



Soil Science Society of Nigeria (SSSN) **PROCEEDINGS OF** **THE 49th ANNUAL CONFERENCE** **“KANO 2025”**

THEME:

**PROMOTING SOIL HEALTH AND RESILIENCE THROUGH RESEARCH
AND INNOVATION FOR SUSTAINABLE DEVELOPMENT**

7TH – 9TH APRIL 2025

Hosted by:
Department of Soil Science, Centre for Dryland Agriculture,
Bayero University Kano

EDITED BY:

Pantami, S. A. | Omar, G. | Abdu, N.

**PROCEEDINGS OF THE
49TH ANNUAL CONFERENCE OF THE SOIL SCIENCE
SOCIETY OF NIGERIA (KANO 2025)
7TH – 11TH APRIL, 2025.**

**DEPARTMENT OF SOIL SCIENCE, FACULTY OF
AGRICULTURE, AND THE
CENTRE FOR DRYLAND AGRICULTURE,
BAYERO UNIVERSITY KANO, NIGERIA.**

**THEME:
PROMOTING SOIL HEALTH AND RESILIENCE
THROUGH RESEARCH AND INNOVATION FOR
SUSTAINABLE FOOD SYSTEMS IN NIGERIA.**

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ISBN: 978-978-699-382-9

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[DOI: https://doi.org/10.67042/sp.SSSN.2025](https://doi.org/10.67042/sp.SSSN.2025)

CITATION

Pantami, S. A., Omar, G., and Abdu, N. (Eds.). (2026). Promoting Soil Health and Resilience Through Research and Innovation for Sustainable Development. Proceedings of the 49th Annual Conference of the Soil Science Society of Nigeria (Kano, 2025). Soil Science Society of Nigeria. ISBN 978-978-699-382-9.

**Soil Science Society of Nigeria (SSSN)
Publishers of the Nigerian Journal of Soil Science**

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Published by:

Soil Science Society of Nigeria (SSSN),
2026.

Edited by:

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Printed by:

Clear Impressions Ltd.
(Printers and Publishers) Kano-Nigeria.
Tel: +234 803 786 1732

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FOREWORD

I sincerely extend my wholehearted and warm greetings to all participants and stakeholders that attended the 49th Annual Conference of the Soil Science Society of Nigeria (SSSN) hosted by the Department of Soil Science, Faculty of Agriculture, Bayero University, Kano and the Centre for Dryland Agriculture, Bayero University, Kano held at the CBN Centre of Excellence, Bayero University, Kano, Nigeria from 7th to 11th April, 2025. Undoubtedly, the conference was a mark of huge commitment of soil scientists as well as stakeholders in ensuring that the agricultural sector in Nigeria thrives through enhanced and sustainable soil management practices and innovative solutions.

This year's conference theme could not have come at a more appropriate time. As we face the dual challenges of climate change and food insecurity, our soils are crying out for attention. Soil degradation is threatening productivity and livelihoods across Nigeria. We are however, optimistic that through innovation, evidence-based research, and a renewed commitment to sustainable practices, we can restore soil health, improve resilience, and secure the future of food in our country.

Our agricultural systems and ecosystems largely depend on the soil. Therefore, ensuring its health and fertility is fundamental in sustaining productive farmlands, improving crop yields and enhancing the livelihoods of our farmers. Hence, the Federal Ministry of Agriculture and Food Security is committed to supporting initiatives that promotes sustainable soil management practices. Along this line, innovations such as the Nigerian Farmers' Soil Health Scheme (NFSHS), offer a promising solution for improving soil fertility, enhancing crop productivity, promoting sustainable agricultural practices and reducing environmental impacts.

I seize this opportunity to commend the leadership as well as the members of the SSSN for their commitment in promoting research in soil science and advancing sustainable land use practices. Your contributions have remained invaluable in guiding policy makers, agricultural practitioners, and development partners toward solutions that ensure improved soil productivity and environmental sustainability.

The proceedings of this conference are expected to provide critical insights, recommendations, and strategies that will shape the future of soil science, enhance sustainable agricultural development, and contribute to Nigeria's food security agenda.

On behalf of the Federal Ministry of Agriculture, I commend all stakeholders for their commitment to improving Nigeria's soil resources and promoting sustainable agriculture.

Sen. Dr. Aliyu Sabi Abdullahi CON

(Baraden Borgu)

***Honorable Minister of State for Agriculture and Food Security,
Federal Republic of Nigeria.***

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COMMUNIQUÉ

49th ANNUAL CONFERENCE OF THE SOIL SCIENCE SOCIETY OF NIGERIA (SSSN)

Theme:

“Promoting Soil Health and Resilience Through Research and Innovation for Sustainable Food Systems in Nigeria”

The 49th Annual Conference of the Soil Science Society of Nigeria (SSSN) was held from 7th to 11th April 2025 at Bayero University, Kano (BUK), Nigeria, and co-hosted by the Department of Soil Science and the Centre for Dryland Agriculture (CDA), BUK.

1. PREAMBLE

The conference brought together over 300 soil scientists, researchers, academics, policymakers, farmers, extension personnel, development partners, industry stakeholders and students from Nigeria and abroad, with both physical and virtual participation. It provided a platform for deliberations on **soil health, land degradation, agricultural productivity and food security**, particularly in the face of climate change and unsustainable land-use practices.

The opening ceremony, held on **8th April 2025 at the CBN Centre of Excellence, BUK**, was chaired by the Hon. Minister of State for Agriculture and Food Security, **Senator Dr. Aliyu Sabi Abdullahi, CON**. The President of SSSN, **Prof. Jibrin M. Jibrin**, and the President and Chairman of the Governing Council of the Nigerian Institute of Soil Science (NISS), **Prof. Abubakar Musa Kundiri**, emphasized the critical importance of soil health to national development and food security and called for stronger collaboration among stakeholders. The Vice Chancellor of BUK, **Prof. Sagir Adamu Abbas**, represented by the Deputy Vice-Chancellor (Academics), **Prof. Haruna Musa**, reaffirmed the University's commitment to advancing soil science. The conference was formally declared open by the Hon. Minister.

2. PARTICIPANTS

Dignitaries at the opening ceremony included the Hon. Minister of State for Agriculture and Food Security, representative of the Executive Governor of Borno State; the President and Chairman Governing Council of NISS, President, International Union of Soil Science (IUSS), representative of the Chairman/CEO, Nigerian Drug Law Enforcement Agency (NDLEA), Executive Director, Institute for Agricultural Research (IAR), Samaru, Zaria, and the Vice Chancellor of the Federal University of Agriculture, Mubi. The event was also attended by fellows and members of SSSN, and other key stakeholders.

3. KEY HIGHLIGHTS

Keynote Presentations:

The Hon. Minister emphasized the messages **“No Farmer, No Nation”** and **“No Soil, No Farmer”**, reaffirming government’s commitment to restoring degraded soils through

the Soil Health Program. He urged soil scientists to translate research into practical, location-specific solutions for farmers and stressed stronger stakeholder collaboration.

The second keynote, delivered on behalf of the NDLEA Chairman/CEO, **Brig. Gen. Mohamed Buba Marwa (Rtd.)**, focused on the Agency's Alternative Development Project, which promotes crop substitution and community-based agricultural livelihoods as alternatives to illicit crop cultivation and associated environmental degradation.

Lead Papers:

Prof. Bitrus Dawi Tarfa presented on OFRA calibration and fertilizer optimization tools, advocating collaboration among SSSN, NISS and policymakers to harmonize soil and fertilizer data and develop updated fertilizer-use recommendations.

Dr. Martin Yemefack, former President of the African Soil Science Society, presented virtually on **Digital Soil Mapping (DSM)**, highlighting its efficiency and accuracy and recommending its wider adoption and integration into soil science curricula in Nigeria.

Conference Proceedings and Fellowship Awards:

The proceedings of the **48th SSSN Conference** were presented and launched by the Hon. Minister of State for Agriculture and Food Security, who also made a personal contribution towards their publication. Fellowship of SSSN was conferred on **Senator Dr. Aliyu Sabi Abdullahi, CON; His Excellency Prof. Babagana Umara Zulum, mni, CON; and Prof. Adam Lawan Ngala.**

Technical Sessions:

A total of **233 scientific papers** were presented, covering land-resource assessment and management, soil health and management, soil physics and conservation, emerging advances in soil science, and capacity building and extension. Major areas of innovation included GIS, remote sensing, digital soil mapping, precision agriculture, machine learning, biofertilizers, carbon sequestration and microbiome engineering.

Field Excursion and AGM:

Participants visited **Tiga Dam, the Kano River Irrigation Scheme and the Teaching and Research Farm of CDA, BUK New Campus**, while the Annual General Meeting deliberated on professional and organizational matters affecting the Society and the advancement of soil science in Nigeria.

4. RESOLUTIONS

The conference recognized ongoing efforts by government, development partners and other stakeholders to improve soil health, including the **ECOWAS Roadmap, Africa's draft Action Plan on Fertilizer and Soil Health, the Soil Values Programme and the Nigeria Farmers' Soil Health Card Scheme.**

To further promote soil health and food security, the conference resolved that SSSN should work closely with the **Federal Ministry of Agriculture and Food Security (FMAFS)** and other relevant stakeholders to:

1. **Promote digital and precision agriculture** for improved fertilizer-use efficiency and stronger collaboration among policymakers, researchers and farmers.
2. **Make relevant soil data accessible to policymakers** to support scientifically based, region-specific fertilizer recommendations.
3. **Translate research into practical farm-level solutions** for soil degradation and improved agricultural productivity.
4. **Support the scaling-up of the Soil Health Program** for restoration of degraded soils, increased resilience and sustainable agriculture.
5. **Promote innovative soil-management practices** that contribute to sustainable and resilient food systems.
6. **Intensify awareness campaigns on soil health** and encourage farmers to undertake soil testing and adopt appropriate soil-management practices.
7. **Resuscitate the National Soil Correlation Committee** to guide the validation and naming of new soil series in accordance with established scientific procedures.
8. **Return the SSSN Annual Conference to October/November** each year to better align with the programmes of FMAFS, FAO and other strategic partners.

5. APPRECIATION

SSSN and the Local Organizing Committee expressed profound appreciation to the **Federal Government of Nigeria, particularly FMAFS**, for its support and commitment to soil conservation and agricultural development. Appreciation was also extended to the **Vice Chancellor and Management of BUK; the Department of Soil Science and CDA, BUK; keynote and lead-paper presenters; session chairs; researchers; participants; and sponsors and partners**, including FMAFS, OCP Africa, Soil Values, Boko Fertilizers, Extension Africa and Afrexia, among others.

6. CONCLUSION

The 49th Annual Conference reaffirmed that **healthy soils are fundamental to Nigeria's food security, agricultural productivity, environmental sustainability and national development**. The Society therefore called on government, academia, the private sector, development partners and farmers to collaborate in implementing the resolutions and translating soil science research and innovation into practical solutions for a resilient and sustainable Nigerian food system.

Signed:

Prof. Jibrin M. Jibrin

President, Soil Science Society of Nigeria

Prof. Jude C. Obi

Secretary, Soil Science Society of Nigeria

Dated: 9th April 2025

**AN ADDRESS BY THE PRESIDENT OF SOIL SCIENCE SOCIETY OF
NIGERIA (SSSN), PROFESSOR JIBRIN MOHAMMED JIBRIN, RSS, FSSSN
DELIVERED AT THE OPENING CEREMONY OF THE 49TH ANNUAL
CONFERENCE OF THE SSSN IN KANO ON 7TH APRIL 2025**

The Executive Governor of Borno State, Prof Babagana Umara Zulum mni CON
The Honourable Minister of State FMAFS, Sen Dr Aliyu Sabi Abdullahi, CON, (Baraden Borgu)
The Vice-Chancellor, Bayero University Kano
The President of the NISS Council
The President of IUSS and Registrar of NISS
Executive committee members of the SSSN
The Dean Faculty of Agriculture
The Head of the Department of Soil Science, my HOD
Keynote and Lead Paper Presenters,
Fellows of SSSN and Members of the SSSN
The Chairman & Members of the Local Organizing Committee
Distinguished Guests
Esteemed Colleagues
Partners in Development
Gentlemen of the Press
Ladies and Gentlemen

It is with great honor and heartfelt joy that I welcome you to the 49th Annual Conference of the Soil Science Society of Nigeria (SSSN). Each year, we gather to share knowledge, renew professional ties, and advance our shared mission—but this year is especially momentous for several reasons. Not only is this a time of increasing global urgency around sustainable agriculture and environmental stewardship, but this conference also returns us to Kano for the first time since 1978. As the current President of SSSN and a proud faculty member of Bayero University, Kano, I find it deeply meaningful to host this conference here at the citadel of knowledge.

This year's theme, *"Promoting Soil Health and Resilience through Research and Innovation for Sustainable Development,"* could not have come at a more appropriate time. As we face the dual challenges of climate change and food insecurity, our soils—silent, yet foundational—are crying out for attention. Soil degradation is threatening productivity and livelihoods across Nigeria. But the good news is that through innovation, evidence-based research, and a renewed commitment to sustainable practices, we can restore soil health, improve resilience, and secure the future of food in our country.

That is why this conference matters. It is more than a gathering of academics—it is a gathering of visionaries. Together, we will share research findings, debate ideas, explore new technologies, and forge new collaborations. We will also strengthen our voice as soil

scientists and demonstrate to policymakers and practitioners alike that healthy soils are the bedrock of national development.

On this note, I would like to express our deep appreciation to the Federal Ministry of Agriculture and Food Security (FMAFS) for its continuous and unwavering support to our Society. This partnership has been pivotal. I am honored to serve as a member of the Ministry's Technical Committee on the Soil Health Card Scheme—an initiative that, when fully implemented, will empower farmers with critical information to manage their soils more sustainably.

The Ministry's role in hosting our 48th Annual Conference, along with its consistent financial, technical, and moral support to our Society, exemplifies the kind of government-academic synergy that drives true transformation. We do not take this support for granted.

Our appreciation also extends to our partners in the private sector and the international community. We acknowledge, in particular, OCP Africa, whose steadfast support has enabled the participation of young scientists and bolstered the quality of our conferences. Likewise, the Soil Values Program, with its innovative focus on improving the productive capacity of African soils and the livelihoods of farmers, has emerged as a critical ally in our mission.

As a Society, we have not rested on our laurels. Over the past year, the SSSN Soil Talk lecture series has continued to provide a vibrant platform for intellectual exchange. These sessions—led by some of our most experienced colleagues—have become a favorite among early-career soil scientists, offering mentorship, fresh perspectives, and a deeper appreciation for the dynamic field of soil science.

We are also proud to report that SSSN continues to sponsor young soil scientists to attend our conferences. Investing in the next generation is not just a noble goal—it is a necessity. These bright minds will carry our legacy forward, and their participation today ensures that soil science in Nigeria has a bright tomorrow.

This year's conference will also feature the conferral of Fellowship Awards on distinguished individuals, including the Honorable Minister of State for Agriculture and Food Security. These awards are not only recognition of service but a celebration of leadership in agricultural transformation, policy, and research. We thank these personalities for their unwavering commitment to the development of Nigeria's agricultural sector.

Let me also take this opportunity to extend my deepest gratitude to the Local Organizing Committee, the Dean, Faculty of Agriculture, Bayero University, the Council of the Nigerian Institute of Soil Science (NISS), and the entire SSSN Executive Committee.

Your tireless efforts, creativity, and teamwork have brought this conference to life. You have made it possible for us to gather, share, and inspire one another.

In conclusion, let us remember that our role as soil scientists extends beyond laboratories and lecture halls. It touches every farm, every family, and every future. Let us leave this conference not only enriched by knowledge but energized by purpose. Together, through research, innovation, and partnership, we can heal our soils, transform our agriculture, and build a resilient and food-secure Nigeria.

I welcome you all once again to this historic conference.

Thank you. God bless you all. God bless the Soil Science Society of Nigeria. God bless Nigeria.

Professor Jibrin Mohammed Jibrin
President, Soil Science Society of Nigeria

ACKNOWLEDGEMENTS

On behalf of the Department of Soil Science and the Centre for Dryland Agriculture, Bayero University, Kano, we express our sincere appreciation to all participants, both individuals and organizations, who contributed to making the 49th Annual Conference of the Soil Science Society of Nigeria (SSSN) a great success. Please allow me to mention that this is one of the best, if not the best, of the conferences ever held by the SSSN.

We commend the EXCO members of the SSSN i.e., Prof. J. M. Jibrin, Prof. O. T. Ande, Prof. J. C. Obi, Prof. A. I. Zata, Dr. A. L. Ngala, Prof. A. Abdulkadir, Prof. N. Abdu, Dr. B. M. Shehu, Prof. B. A. Raji, Prof. A. M. Hassan, Dr. C. M. Jidere, and Prof. S. A. Ibrahim for their total commitment towards the organization of the entire event. Your dedication towards the promotion of soil science research, capacity building, and sustainability of land management practices is deeply appreciated.

Much appreciation also goes to the keynote speakers: Sen. Dr. Aliyu S. Abdullahi CON (Barden Borgu) and Brig. Gen. Mohammed Buba Marwa (rtd) CON, CFR, and the Lead Paper presenters: Prof. B. D. Tarfa and Dr. Martin Yemefack for sharing knowledge and insights throughout the conference. Your contributions are instrumental in advancing knowledge of soil science and developing practical solutions to address challenges in agriculture and environmental sustainability.

Allow us to also express gratitude to our esteemed partners, co-sponsors - Soil Values Program, Federal Ministry of Agriculture and Food Security, Centre for Dryland Agriculture, Bayero University, Kano, OCP Africa, Extension Africa, Sule Lamido University, Kafin Hausa, Yusuf Maitama Sule University, Kano, Katsina State Government, and Federal College of Agricultural Produce Technology, Kano, and other collaborating institutions for their generous support, which has significantly contributed to the success of this conference. We commend your commitment towards fostering scientific exchange and agricultural innovation.

Special gratitude goes to Mr. Olanipekun Oshadiya, the Director, Department of Agricultural Lands and Climate Change Management Services (ALCCMS), Federal Ministry of Agriculture and Food Security, for his immense contributions to the success of the conference.

Finally, we acknowledge the participation of farmers, extension agents, researchers, as well as policymakers who actively participated in this event. Your collaboration is crucial to translating research outcomes into impactful solutions that improve soil productivity and promote sustainable agriculture in Nigeria.

Once again, thank you all for your dedication and invaluable contributions. We are optimistic that the knowledge shared during this conference will inspire meaningful actions toward achieving the much-desired food security, environmental sustainability, and economic growth in our country.

Professor G. Omar
Chairman, LOC

Dr. S. A. Pantami
HOD, Soil Science Department

Professor Amina Mustapha
Co-Chairperson, LOC

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CONFERENCE TECHNICAL PAPERS

SECTION ONE: LAND RESOURCES ASSESSMENT AND MANAGEMENT

SPATIAL VARIABILITY OF SOME SELECTED SOIL PROPERTIES OF RABAH FLOODPLAINS IN SOKOTO STATE, NIGERIA

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ABSTRACT

Soils varied significantly in their soil properties with a landscape, making studies on spatial variability essential for sustainable land management. This study aimed to assess spatial variability of some selected soil chemical properties in the Rabah Floodplains of Sokoto State, Nigeria, using descriptive and Geostatistical analyses. Six soil units were delineated, and two representative soil profiles were excavated in each unit. Soil samples were collected from genetic horizons and analysed following standard laboratory procedures. The results revealed a varying degrees variability in chemical properties. Soil pH exhibited low variability (CV < 15%), indicating relatively uniform soil reaction across the study area. Organic matter and soil texture showed moderate variability (CV 15%–35%), suggesting that land management practices influence soil organic matter, while macro nutrients such as nitrogen, phosphorus, and potassium displayed high variability (CV > 35%), highlighting the effects of fertilization, leaching, and other management practices in the study area. The study underscores the importance of site-specific management strategies to enhance land productivity and sustainability. High nutrient variability suggests the need for precision fertilization approaches to optimize crop yield and soil health.

Keywords: *Spatial Variability, Rabah Floodplain, GIS, Soil Profile*

Introduction

One of the inherent attributes of soil is its spatial heterogeneity (Gallardo *et al.*, 2000), a phenomenon that represents a wide variety of attributes because of interaction of the factors and processes that control soil formation and all aspects of human activities related to land use (Ngailo and Vieira, 2012). Spatial variation may reveal patterns related

to soil attributes, that is, physical and chemical properties of soil that exist within and among fields (Journel and Huijbregts, 1991; Grego *et al.*, 2006). Therefore, as reported by Ngailo and Vieira (2012), spatial variation in soil properties in the field did not exist at random, but rather followed a pattern in which variability decreased as distance between sampling locations shortened. Spatial variability of soil parameters is paramount in the

explanation of the influence of the factors of soil genesis and land use on soils. It permits the use of different tracks of land for different purposes and is the central concept in soil mapping (Samuel *et al.*, 2022). Spatial variability is the combined effect of chemical, physical and biological processes occurring at different spatiotemporal scales coupled with anthropogenic activities (Goovaerts, 1998). It can help to correct nutrient deficiencies (Brevik and Miller, 2015) and to determine production constraints related to soil fertility. Spatial variability of soils can also act as a guide in suggesting variable remedial measures for optimum production and appropriate land use practises sustainable in the long run (Halbac-Cotoara-Zamfir, 2019; Panday *et al.*, 2018). Spatial variability of soil properties is assessed effectively by geostatistical techniques (Emadi *et al.*, 2016; Moosavi and Sepaskhah, 2012; Moradi *et al.*, 2016) which can explain the extent of soil variability. Soil heterogeneity has been studied under different management systems (Behera and Shukla, 2015). Spatio-statistical tools are used to predict the values of soils variables from unsampled locations by factoring in the geographical association between sampled and projected points and reducing variance of assessment error and costs (Behera and Shukla, 2015). Increasing population has been shown to decline agricultural productivity in Nigeria (Buji *et al.*, 2017) therefore there is need to utilize the remaining land appropriately for maximum agricultural production. Blanket application of agricultural inputs is a common practise in the study area, which

led to higher cost of production and low farm output. There is little consideration to soil heterogeneity as a guide to variable fertilizer application. This practice presents a major agricultural challenge, therefore a research need to be conducted to address this issue. Despite the area having favourable climate for production of cereals, vegetables and other crops, coupled with favourable soil conditions for agricultural activities, decline in harvest produce was noticeable due to inappropriate inputs management, as well as failure to understand the nexus between crop nutrient requirements and soil properties. The key objective of this study was to assess the spatial variability of some selected chemical soil parameters in the study area so as to guide decisions on input application.

Materials and Methods

The study was carried out in Rabah District, Rabah Local Government Area of Sokoto State. It is situated about 50km east of Sokoto Metropolis, between latitudes 13° 5' 45" and 13° 8' 45" N and longitudes 5° 28.5' 45" and 5° 33.5' 45" E. Two standard profile pits were sunk in each identified soil unit to a depth of 2.0m, and the profiles were demarcated and described into different horizons in accordance with the pattern of Soil Survey Division (FAO, 2006) soil description procedures. Bulk soil samples were collected inside well labelled plastic containers from each identified genetic horizon starting from the lowest to the topmost horizons to avoid contamination. The samples were processed and subjected to standard laboratory analyses.

Soil pH was determined potentiometrically in water as described by Agbenin, (1995). Organic carbon was determined by the Walkley - Black wet oxidation method (Walkley and Black, 1934) as described by Nelson and Summers (1982) and percent soil organic matter was obtained by multiplying percent soil organic carbon by a factor of 1.724 following the assumptions that organic matter (OM) is composed of 58 % carbon. The micro-Kjeldhal method (Bremner, 1996) was used to determine total Nitrogen. Available phosphorus was determined using the Bray 1 method (Bray and Kurtz, 1965). Exchangeable cations were extracted with 1N, NH₄OAc solution (pH 7). The extract was then read for exchangeable Ca and Mg using Atomic Absorption Spectrophotometer (AAS) while K and Na were read using flame photometer (Black, 1965). Exchange acidity (Al³⁺, H⁺) was determined by titration of soil solution with 1N KCl (Black, 1965). Cation Exchange Capacity (CEC) of the soils was determined with 1M ammonium acetate (NH₄OAc), buffered at pH 7.0 (Chapman, 1965; Rhodes, 1982). Effective CEC was computed by the summation of exchangeable bases (Ca, Mg, K Na) and exchange acidity (Al and H). The exchangeable sodium percentage was calculated as the proportion of the CEC (NH₄OAc) occupied by exchangeable sodium as follows:

$$ESP = \frac{\text{Exchangeable sodium}}{\text{CEC (NH}_4\text{OAc)}}.$$

Exchangeable Acidity was calculated using the Titration method as described by

McLean, (1982). The percentage base saturation was calculated as follows:

$$PBS = \sum \frac{(\text{Ca}^{2+} + \text{Mg}^{2+} + \text{K}^{+} + \text{Na})}{\text{CEC}} \times 100.$$

Descriptive and Geostatistical analyses

Descriptive statistics was done using SPSS to obtain the coefficient of variation (%CV) and other parameters like mean, median, standard error, standard deviation, range, minimum and maximum.

Generation of spatial variability maps

Database for chemical soil properties were created using spread sheet of Microsoft Excel.

The chemical properties were tied together with their geographic coordinate in order to plot each soil point in the ArcGIS 10.3.1 software. Inverse Distance Weighted (IDW) techniques of interpolation were used to predict the values in an unsampled locations through map generation. The IDW lets the user control the significance of known points on the interpolated values, based on their distance from the output point. Ratings of properties were done using standard procedure, where there are single ratings, Jenx (natural breaks) in GIS environment were used to partition such properties into their appropriate rates. The interpolated soil parameters are pH, EC, N, OC, P, Ca, Mg, K, Na, CEC and BS.

Results and Discussion

Extent and Distribution of Mapping Units

The Rabah (RBH) floodplain soil series and their extent of coverage site is presented in (Table 1.) According to Buji *et al.* (2022), the mapped area (about 170ha) was resolved

into six (6) mapping units (soil series) and
were

Table 1. Extent and distribution of Rabah floodplain Mapping Units

S/No.	Soil Series		Hectares (Ha)	Area (%)
1	Tsallaken Diga	(RBH1)	7	4
2	Hauki 1	(RBH2)	32	18
3	Dan Bolo	(RBH3)	17	10
4	Mahijin Riji	(RBH4)	25	15
5	Rabah	(RBH5)	54	32
6	Hauki 2	(RBH6)	35	21
Total			170	100

(Buji *et al.* 2022)

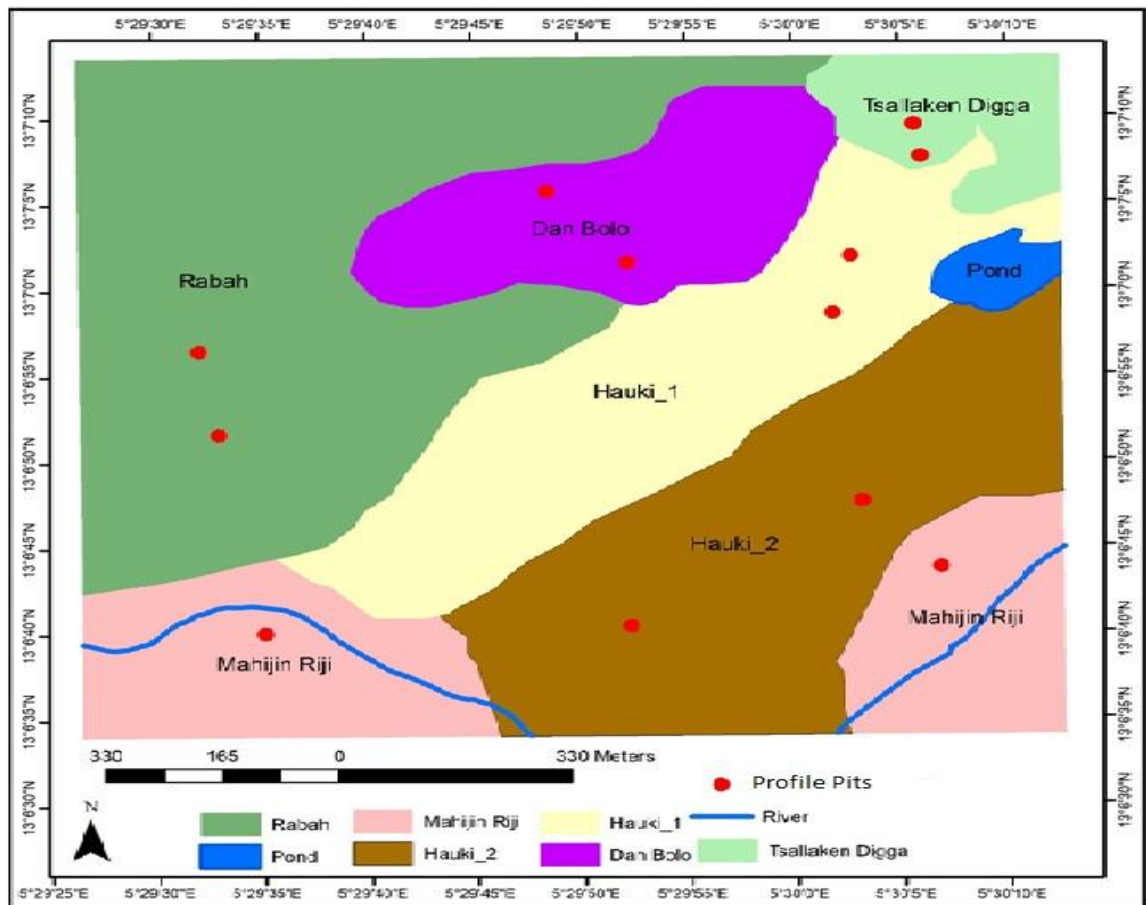


Figure 1. Digitized Map showing distribution of Rabah floodplain Mapping Units as well as location of Profile pits (Buji *et al.* 2022).

named as Tsallaken Diga (RBH1), Hauki 1 (RBH 2), Dan Bolo (RBH 3), Mahijin Riji (RBH 4), Rabah (RBH 5) and Hauki 2 (RBH 6). The land configuration/elevation of the six (6) soil series identified were shown in (Fig. 1). Tsallaken Diga (RBH1) had the least area coverage of 7 ha (4 %), followed by Dan Bolo (RBH3) with 17ha (10 %), Mahijin Riji (RBH4) had 25ha (15 %), Hauki 1 (RBH2) had 32ha (18 %), Hauki 2 (RBH6) with 35ha (21 %) and finally Rabah (RBH5) with 54 ha (32 %) having the largest area coverage.

Variability of the chemical properties

To effectively manage soil, it is crucial to assess its diversity. For effective management, site-specific zones were identified. Not accounting for such variation may result in insufficient input in certain areas. Soil variation was classified based on the coefficient of variation as least (CV < 15%), moderate (CV 15–35%), or high (CV > 35%) as reported by Wilding (1985). The variability of soil properties was presented in table 2. The soil parameters including pH (H₂O), pH (CaCl₂) and available phosphorous (P) have values of CV below 15% indicating least variability across all the soil units, which signifies that soils properties were similar over a large area despite the wide sampling range which would be appropriate in the study area. The standard deviation was used to indicate the shape of distribution in relation to the mean. Most of the values in the study were near zero indicating that the data values are concentrated around the mean.

Total N, Mg and CEC have coefficient of variation (CV) values ranging from 15% to

35%, in most of the soil units indicating moderate variability. Organic carbon and organic matter are key fertility indicators (Liu *et al.*, 2020) and show high variability (>35%), along with EC, K, Al, H and ESP in majority of the soil units (Table 2), which are important indicators of soil fertility. Floodplains carry large amounts of river sediment and soil to low-lying areas, contributing directly to the deposition of organic matter in the soil (Batjes *et al.*, 2020). The topography of the floodplain causes extreme spatial variability during overbank deposition or inundation because of irregular sediment distribution (Talha *et al.*, 2022).

From the findings, it is deduced that most of the properties generally fell into the extremely varied category, and this is because of the nature of the floodplain, where different types of materials are deposited seasonally as a result of the constant flooding that the environment experiences (Buji *et al* 2022). Grego *et al.* (2006) stated that there are many potential causes for the widespread phenomenon of spatial variability in floodplain soils. These may result from changes in lithology, topography, or hydrology. Floodplain soils are inherently variable, with their properties changing horizontally down the soil profile and vertically across the landscape, according to numerous studies on spatial trends (Mulla and McBratney, 2001; Brady and Weil, 2002).

The spatial distribution of soil properties in the Rabah Floodplain, were illustrated in Figure 2 (a–h), highlights the variability of key soil fertility and physical parameters,

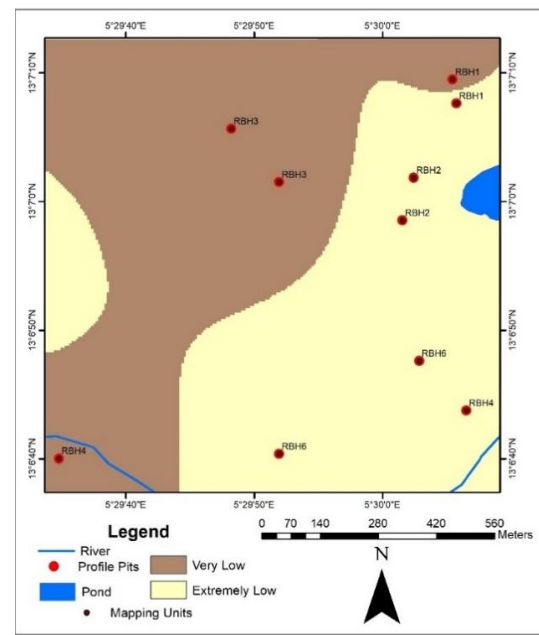
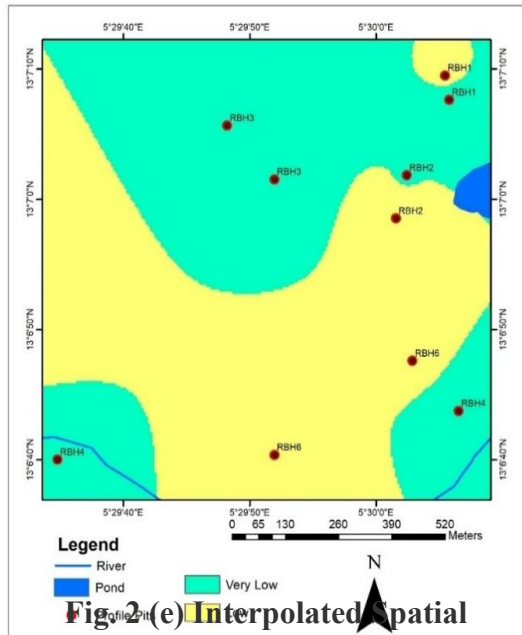
Table 2: Descriptive statistics parameters of chemical properties in the study Area

Parameters	RBH1			RBH2			RBH3			RBH4			RBH5			RBH6		
Chemical properties	Mean	SD	CV (%)	Mean	SD	CV (%)	Mean	SD	CV (%)	Mean	SD	CV (%)	Mean	SD	CV (%)	Mean	SD	CV (%)
pH (H ₂ O)	6.08	0.25	4.1	6.36	0.65	10.22	4.9	0.55	11.22	5.36	0.4	7.45	5.18	0.77	14.9	5.25	0.32	6.06
pH (CaCl ₂)	5.09	0.51	10.06	5.69	0.93	16.4	4.33	0.37	8.49	4.09	0.39	9.42	4.39	0.68	15.4	4.67	0.25	5.42
EC (dS/m)	1.54	0.68	43.93	1.42	1.9	134.0	0.23	0.09	37.97	0.78	0.64	81.68	0.84	0.67	80.2	0.72	0.25	34.94
N (%)	0.54	0.13	24.72	0.54	0.12	21.99	0.42	0.07	17.01	0.37	0.05	14.41	0.55	0.2	35.82	0.62	0.14	22.35
P (mg/kg)	0.58	0.05	9.11	0.61	0.02	4.02	0.58	0.03	5.18	0.56	0.04	6.65	0.58	0.02	3.38	0.59	0.03	5.15
Ca (cmol/kg)	3.48	1.1	31.53	4.84	1.93	39.93	3.25	0.95	29.32	2.74	2.62	95.74	4.32	0.6	13.79	3.25	1.18	36.17
Mg (cmol/kg)	0.5	0.03	6.31	0.61	0.11	17.88	0.49	0.05	10.16	0.81	0.33	41.26	0.58	0.07	12.75	0.47	0.05	11
K (cmol/kg)	0.92	0.27	29.72	0.13	0.05	42.91	0.16	0.09	57.14	0.34	0.17	51.13	0.3	0.23	77.06	0.46	0.21	45.41
Na (cmol/kg)	0.45	0.22	49.32	0.41	0.49	119.2	0.34	0.14	39.85	0.26	0.08	31.17	0.36	0.19	52.97	0.43	0.1	22.03
CEC (cmol/kg)	30.13	1.15	3.83	27.21	9.63	35.37	22.5	7.09	31.51	25.66	4.92	19.19	33.35	7.88	23.62	13.99	0.43	3.1
ECEC (cmol/kg)	4.61	1.53	33.08	6.53	2.3	35.16	4.73	0.83	17.53	7.37	1.44	19.5	6.47	0.71	10.95	5.21	1.26	24.15
BS (%)	17.76	3.27	18.42	25.32	12.99	51.31	21.34	10.35	48.52	56.75	31.48	55.47	17.66	5.04	28.51	32.99	8.73	26.45
Org C (%)	0.49	0.5	100.59	0.55	0.27	48.36	0.26	0.34	131.8	0.43	0.29	68.01	0.62	0.24	38.65	0.67	0.4	59.94
Org M (%)	0.85	0.86	100.6	0.95	0.46	48.45	0.44	0.58	131.99	0.74	0.5	67.78	1.07	0.41	38.67	1.16	0.7	60.03
ESP (%)	1.47	0.7	47.72	1.62	1.62	100.21	1.49	0.22	15	1.01	0.3	29.74	1.02	0.35	34.35	3.09	0.68	21.88

Table. 3 Soil properties and weight influence of the surface samples (0-30cm) used for plotting in GIS environment

Q	pH.w	EC	N	OC	P	Ca	Mg	K	Na	CEC	BS
RBH1	6.67	0.76	0.74	1.54	0.53	4.09	0.49	0.56	0.43	29.8	18.71
RBH1	6.25	0.83	0.42	1.24	0.65	2.13	0.41	0.1	0.48	30.8	13.38
RBH2	5.95	0.18	0.63	0.84	0.59	4.82	0.54	0.13	0.17	19.8	28.59
RBH2	5.45	0.39	0.74	0.78	0.61	4.23	0.72	0.31	0.43	33.8	16.83
RBH3	5.51	0.15	0.53	0.8	0.54	4.56	0.53	0.03	0.22	14.4	37.08
RBH3	4.21	0.35	0.46	0.36	0.54	2.81	0.42	0.1	0.43	29.8	12.62
RBH4	5.21	0.34	0.46	0.8	0.62	3.42	0.53	0.28	0.13	20.4	21.37
RBH4	5.21	0.35	0.44	0.76	0.53	0.65	1.25	0.51	0.41	31.8	8.87
RBH5	4.25	1.49	0.81	0.14	0.59	3.36	0.51	0.57	0.3	30.2	17.28
RBH5	5.05	0.36	0.77	1.02	0.59	4.9	0.66	0.26	0.83	41.6	15.99
RBH6	5.06	0.78	0.88	1.22	0.61	4.67	0.33	0.59	0.39	14.4	41.53
RBH6	5.02	0.98	0.74	1.32	0.62	3.9	0.51	0.72	0.35	14.4	38.06
WEIGHT	0.19	0	0.17	0.07	0.02	0	0	0.03	0	0.04	0.01

Key: S.U = Soil Unit,



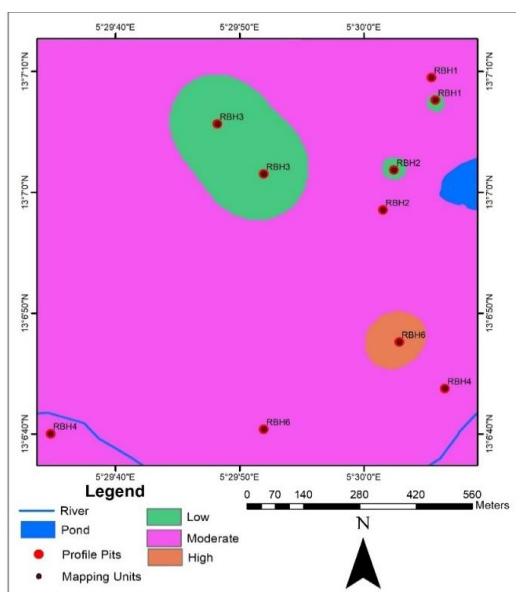


Fig. 2 (c) Interpolated Spatial distribution of Potassium in surface soils of Rabah Floodplain

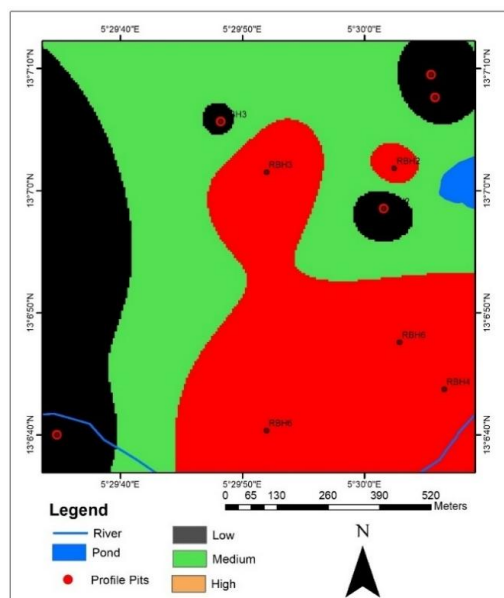


Fig. 2 (d) Interpolated Spatial distribution of CEC in surface soils of Rabah Floodplain

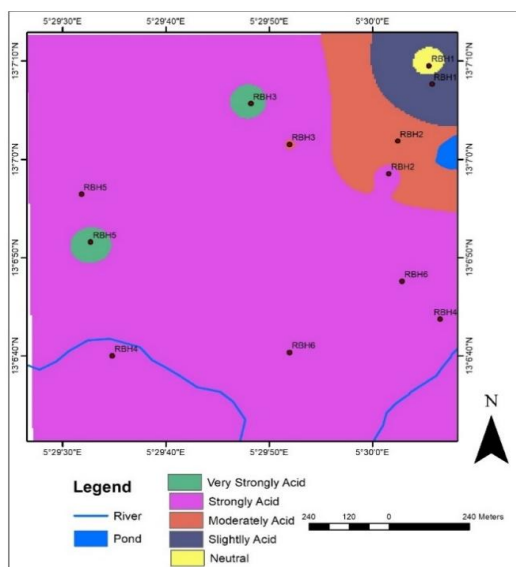


Fig. 2 (e) Interpolated Spatial distribution of Soil pH in surface soils of Rabah Floodplain

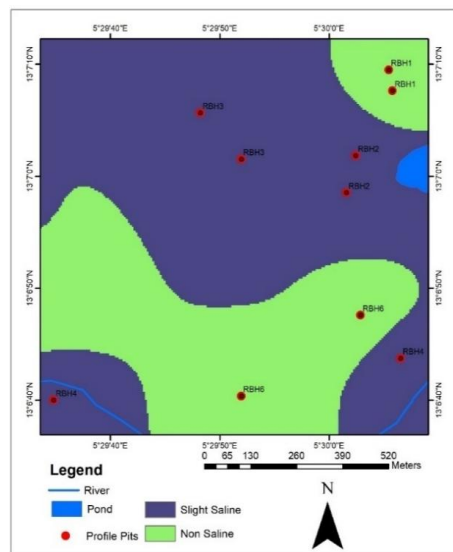
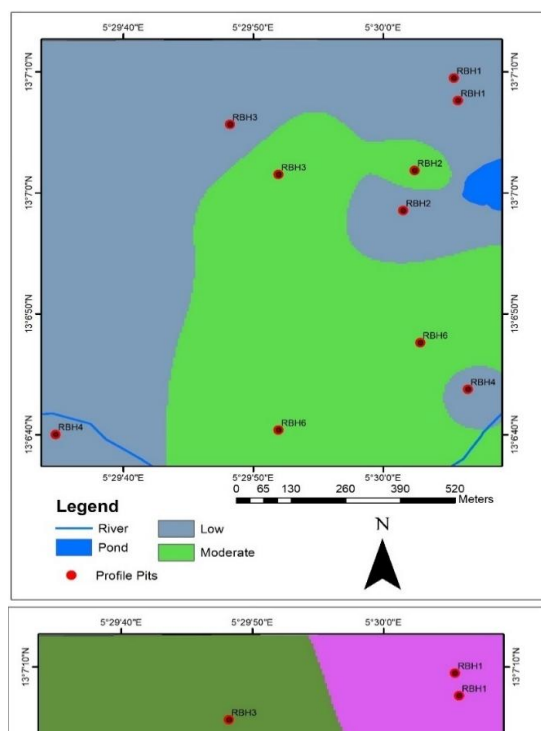


Fig. 2 (f) Interpolated Spatial distribution of Electric conductivity in surface soils



which are essential for land use planning and agricultural productivity.

The interpolated maps for nitrogen (N), phosphorus (P), and potassium (K) (Figures 2a–2c) suggest significant spatial heterogeneity. This variability is likely influenced by soil texture, organic matter content, and past land management practices (Brady & Weil, 2017). Areas with high nitrogen levels may correspond to zones with better organic matter accumulation, whereas phosphorus distribution is often linked to soil mineralogy and past fertilizer applications (Fageria *et al.*, 2011).

Potassium distribution, being highly dependent on clay mineral content and weathering processes, follows a distinct pattern, which could be correlated with soil parent material. Zinc (Zn), manganese (Mn), and iron (Fe) (Figures 2e–2g) show notable spatial differences, which can be attributed

to redox conditions, soil pH, and organic matter interactions (Alloway, 2008). The availability of these micronutrients may be reduced in areas with high pH, as indicated by Figure 2i, due to decreased solubility. Cation exchange capacity (CEC) (Figure 2d) is an essential indicator of soil fertility and buffering capacity. Higher CEC values are generally observed in clay-rich and organic matter-rich zones, supporting the role of soil texture and humus in nutrient retention (Sparks, 2003). The base saturation (BS) map (Figure 2g) complements the CEC data, indicating areas where essential cations (Ca^{2+} , Mg^{2+} , K^+ , Na^+) dominate exchange sites. Higher base saturation typically correlates with better soil fertility and reduced acidity (Sumner & Miller, 1996). The spatial variation in organic carbon (OC) (Figure 2h) is critical for soil fertility, as higher OC content improves soil structure,

moisture retention, and microbial activity. Areas with low organic carbon might require organic amendments to enhance productivity (Lal, 2004).

The Rabah floodplain study assessed the spatial variability of soil properties critical for agricultural productivity. The results underline the importance of addressing soil heterogeneity in management practices. Parameters such as organic matter and cation exchange capacity showed high variability, underscoring the need for tailored input applications to mitigate nutrient deficiencies and enhance productivity. The study contributes to understanding soil variability in floodplains and offers a framework for sustainable land use planning.

Conclusion

The study confirms the existence of substantial spatial variability in the chemical properties of Rabah floodplain soils. Variability is influenced by the nature of sediment deposition, topographic differences, and hydrological regimes. Uniform soil management practices are unsuitable for this region, as each mapping unit exhibits unique characteristics requiring specific interventions. Demarcating the farm into relatively homogeneous physiographic units is crucial for effective and sustainable soil management.

Recommendations

- **Adopt Site-Specific Management Practices:** Tailor input applications based on the spatial variability of soil properties to optimize nutrient use efficiency and agricultural outputs.

- **Regular Monitoring and Mapping:** Conduct periodic soil analyses and update spatial variability maps to track changes over time.
- **Educate Farmers and Stakeholders:** Government should provide training on the implications of soil heterogeneity and the benefits of precision agriculture in floodplain management.
- **Integrate Advanced Technologies:** Use remote sensing and advanced geostatistical tools to refine soil property predictions and management strategies.

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CHARACTERIZATION AND FERTILITY STATUS OF SOILS DEVELOPED ON BASEMENT COMPLEX IN AKAMKPA, CROSS RIVER STATE

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ABSTRACT

The classification and fertility status of soils developed on basement complex in Akamkpa Local Government Area of Cross River State was carried out. Fifteen soil samples were obtained from three profiles dug at Mkpota, Ikpa and Ojok communities for the study. The soils were morphologically described and physico-chemical and mineralogical properties were determined using standard procedures. It was observed that the soils were deep (> 100 cm) having gravelly sandy loam to sandy clay loam texture. The soils had granular and subangular structure with sticky consistence (wet). Bulk density, total porosity and silt/clay had ranges of 1.0 to 1.5 mgm⁻³, 43.4 to 58.0 % and 0.1 to 0.7. pH varied from strongly acid to slightly acid (4.8 to 6.8). Organic carbon varied from low to high, total nitrogen and ECEC were low while base saturation varied moderate to high. BS was higher at Ikpa and Ojok than in Mkpota. The studied micro nutrients were rated medium to high except boron which was low. The minerals identified in the soils were quartz, kaolinite, microcline, muscovite, hornblende and diopside/plagioclase. Quartz and kaolinite were the most abundant while diopside was the least concentrated. The soils fell into typic Kandiodults subgroup, Kandiodults great group, Udults suborder and Ultisols order using USDA Soil Taxonomy (Soil Survey Staff, 2010). Soil fertility management techniques such as mulching, planting of cover crops and adoption of zero tillage should be carried out to reduce leaching of basic nutrients from the soils while liming should be carried out to raise the pH to enhance availability of plant nutrients.

Key word: Classification, fertility, typic kandiodults and Ultisols.

INTRODUCTION

Soils are the most complex and diverse ecosystem in the world (Kopittke *et al.*, 2019) and they perform vital functions to sustain plant and animal life, regulate water flow, filter and buffer pollutants and cycle nutrients. However, the capacity of the soil to support plant growth depends on the extend of its qualities such as nutrient availability, nutrient retention capacity, texture, clay content, rooting conditions, oxygen availability to roots, excess salts, toxicities, and workability (FAO, 2025). Understanding these properties is very important for sustainable land use and

management, and soil productivity, especially now that rapid human population growth coupled with increasing consumption is placing unprecedented pressure on soils through the intensification of agricultural production (Kopittke *et al.*, 2019). The best way to understand and maintain fertile soil is through soil characterization. Soil characterization ensures that soil is put to the most appropriate and sustainable use (Onyekanne *et al.*, 2012). It provides a powerful resource for the benefit of mankind especially in the area of environmental sustainability and food security (Esu, 2004).

Maintaining fertile soils provides continuous supply of mineral nutrients in amounts appropriate for optimal growth and yield of crops (Brady and Weil, 2014). Poor soil management due to lack of information about their properties which are greatly determined by parent materials can result in soil misuse and degradation. Soil degradation reduces the long-term ability of soils to provide the complex multitude of services upon which human survival depends (Kopittke *et al.*, 2019). In order to minimize soil degradation, soil characterization and classification are essential to form the basis for decision making by policy makers on sustainable management of soil resources. They are observational and empirical evidences suggesting that the world's fertile soils are being degraded is capable of worsening the on-going global food crisis (Gebremedhin *et al.*, 2022).

Soils are formed as a result of long-term and complex transformations of parent material. During the first stage of these transformations, parent material, relief, climate, and time played a key role (Mocek and Owczarzak, 2011). Parent material along with climate and biota are the most important factors determining soil physico-chemical characteristics in relationships to its response in agricultural, environmental and geological applications (Wilson, 2019; Jenny, 1941). The capacity of soils to provide plant essential nutrients can be highly variable and depends on several factors, which soil parent material is the most important (Sparks, 2023). Alnaimy *et al.* (2023) found that SOC content was

higher in the soils developed from alluvial deposits compared to the soils formed from other deposits. Variations in parent material also affects soil properties such as clay mineralogy, soil texture, soil structure, soil thickness, erodibility, and shrinkage and swelling potential, cation exchange capacity (CEC), nutrient content, sodicity, salinity, and acidity (Gray and Murphy, 2002).

The soils of Akamkpa Local Government Area are formed from basement complex parent material. Basement complex rock consists of continental crustal rock which has been modified several times through tectonic events including deformation, metamorphism, deposition, partial melting and magmatism (USGS, 2015). The basement complex rocks cover about 50% of Nigeria's land area and extend into neighboring countries like Benin to the west and Cameroun Republic to the east (Opara *et al.*, 2014). Migmatite, gneisses, granite gneisses and granites are the major content of basement complex rock in Nigeria (Okezie, 1974).

Soils formed from basement complex parent material have been reported to have loamy sand to sandy loam texture, low organic carbon, total N and available phosphorus with varying degrees of other properties (Olim *et al.*, 2020; Afu *et al.*, 2022). These reports and other studies elsewhere suggest that basement complex soils are the most dominant soils in Nigeria and have been intensively used for crop production, yet the soils have not been well studied. Obtaining information on soil properties helps land users to sustainably and fully exploit soil productive potentials. Consequently,

characterization and classification of soils formed on basement complex in Akamkpa Local Government Area will provide necessary information about the soils for optimum utilization since soils response to management, use and manipulation can be predicted based on their characteristics. Furthermore, sustainable soil use requires an indebt knowledge of its current state and characteristics which serve as a guide in implementing strategies that can concurrently improve soil physical, biological and chemical conditions and selecting best land use option.

Materials and Methods

Description of the study area

The study location was Akamkpa Local Government Area (Latitude 5°00' and 5°57' N and Longitude 8° 06' and 9°0' E) located in southern Cross River State (Fig. 1). It has tropical humid climatic conditions with a mean annual rainfall range of 2500 to 3000 mm, temperature of 26 to 27 °C and relative humidity of 80 to 90 °C at the peak of the rainy season (Afangide *et al.*, 2010; Aki, 2016). The soils of the area are developed from the basement complex rocks which are redominantly of granite and gneisses (Ekwueme, 2004, Amah *et al.*, 2012).

Field work

A reconnaissance survey of the study area was carried three months ahead of commencement of the study. With the aid of geologic and topographic maps, three villages with basement complex parent materials were selected for this study. The villages are Mkpota, Ikpa and Ojok. One profile pit was dug in each village, properly delineated, described and a total of fifteen

soil samples were collected from horizons of the three profile pits. The soil samples were carefully placed in polythene bags and transported to the soil science laboratory of the University of Calabar for physicochemical and clay mineralogical analyses.

Laboratory studies

In the laboratory, soil samples were airdried, gently crushed with pestle and sieved with 2 mm sieve. Particle size analysis was done using Bouyocous hydrometer method (Gee and Or, 2002). Bulk density was determined by oven-drying the undisturbed sample collected in 100 cm³ metal cylinders to constant weigh at 105°C and dividing the dry weight of the sample by total volume of the sample. pH was obtained potentiometrically in soil: water suspension (1:2.5) as reported by Udo *et al.* (2009) while organic carbon was determined by Walkley-Black wet oxidation method using acid dichromate(K₂Cr₂O₇) method (Nelson and Sommers 1996). Total nitrogen was analyzed with modified micro-kjeldhal method (Udo *et al.*, 2009) while available phosphorus was obtained using Bray P-1 method according to the procedures of Kuo (1996). Exchangeable cations were determined using the extract obtained after leaching samples with one normal neutral ammonium acetate (1 N, NH₄OAC, pH 7.0) solution.

Calcium and magnesium were analyzed using the EDTA titration method while potassium and sodium were estimated by Flame photometer. Aluminum and hydrogen determined by titration using 0.1N NaOH solution (Udo *et al.*, 2009). CEC and

micronutrients were obtained using the method reported by Udo *et al.* (2009). ECEC and base saturation were obtained by computation method.

Clay mineral analysis was done using Xray diffraction method. Ten grams (10 g) of finely ground/powder soil sieved with less than 10 μ m sieves was treated with 30%

H₂O₂. The soil was then heated for about 2 h to digest and remove organic matter after which H₂O₂ was then removed through centrifugation by washing three times with water. 3 ml NaCl was added each time in order to prevent deflocculation of clay particles, and the supernatant solution

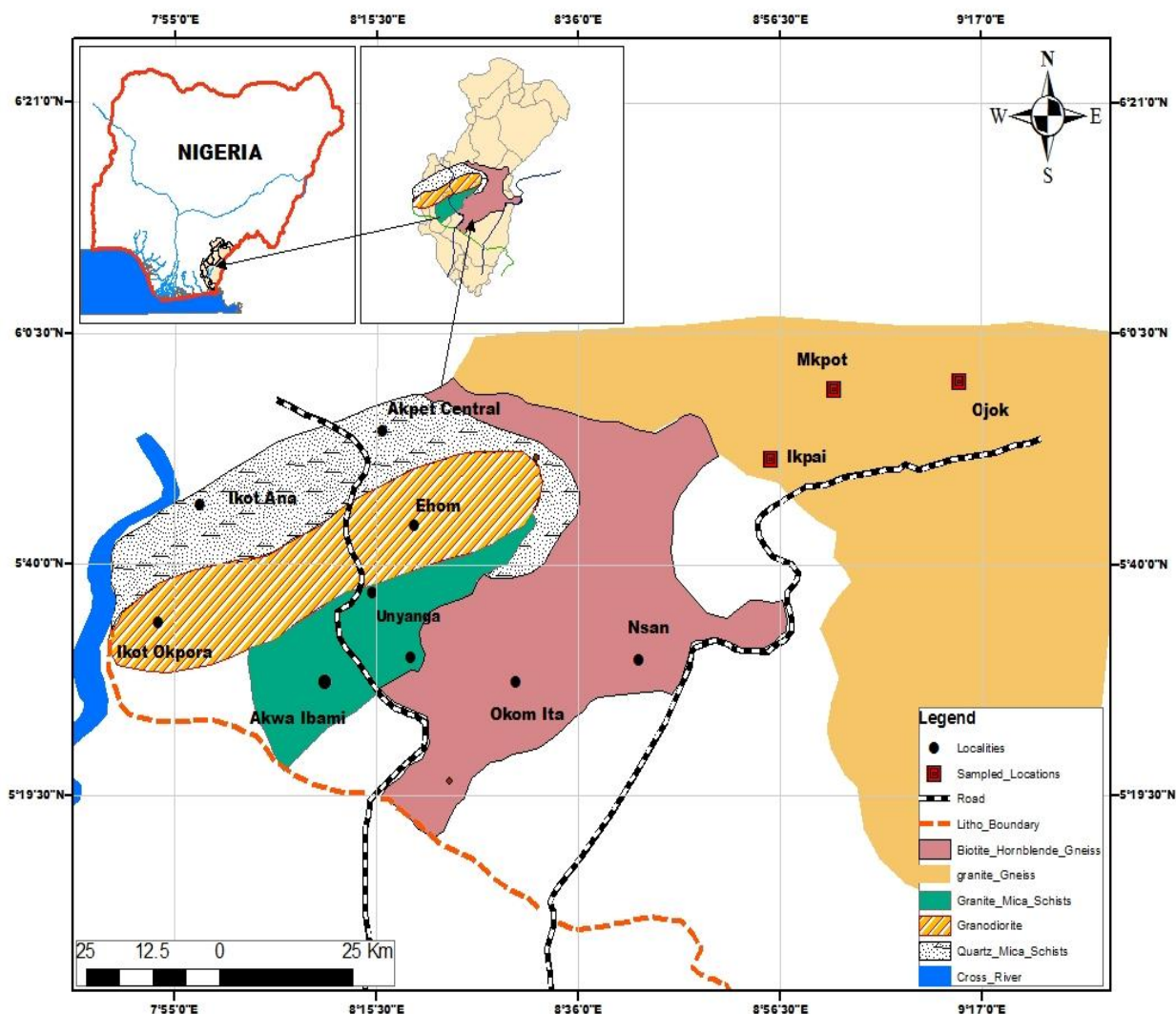


Fig. 1: Geology map of the study area in Akamkpa LGA.

discarded by decantation. Clay fraction (<2 μ m) was separated by repeated sedimentation siphoning method

(Moslehuddin *et al.*, 1998) and prepared into Mg-saturated and glycerol-solvated samples and used for clay mineralogy

analysis. Treated fine ground sample was then placed into a sample holder and smeared uniformly onto a glass slide to ensure a flat upper surface.

Identification and estimation of the mineralogical composition of the clay fractions were carried out using the X-ray diffraction method (XRD) by directing X-rays at the sample and diffracted rays recorded. The approximate mineral content of the silt, clay, and mixed layer clay fractions was estimated based on the relative X-ray peak intensities in the pattern as described by Moocher (2004).

Results and Discussion

Morphological properties

The morphological properties of the are given in Table 1. The color of the soils varied from dark brown (10YR 3/2) to very dark grayish brown (10YR 3/1) at the surface horizons and from yellowish brown (10YR5/6) to strong brown (7.5 YR 5/6) and red (2.5 YR4/8) in the subsurface horizons. All the soils were deep and well developed with depth (> 100 cm). This depth permits crop roots proliferation and elongation. The soils had texture varying from gravelly sandy loam at the surface to gravelly sandy clay and gravelly sandy clay loam at the subsurface, structure varying from medium granular; moderate medium course subangular. Consistency was slightly sticky or sticky and slightly plastic or plastic under wet condition. The soil horizons had clear smooth boundary. These observations are similar to the findings reported for soils developed on gneiss in northern guinea savanna of Nigeria by Shaboyo *et al.*, (2013)

and Aki *et al.*, (2014) on similar soils in Akamkpa.

Physical properties

Table 2 shows the physical properties of the soils. The soils texture varied from sandy loam at the surface to sandy clay loam and sandy clay at the subsurface horizons. The results revealed that sand content decreased while clay amount increased with depth in all the profiles. Sand, silt and clay had means of 690 and 586 g/kg, 227 and 91 g/kg and 570 and 295 g/kg in the surface and subsurface soils accordingly. Higher clay content in subsurface soils may be due to pedogenic process of illuviation (Aki *et al.*, 2014 and Esu, 2010). The soils have relatively higher level of clay which has positive implication in their fertility as clay helps in nutrient and water retention and increase organic matter levels of soils (Brady and Weil, 2014; Afu *et al.*, 2024a; Afu *et al.*, 2024b). Furthermore, bulk density (BD) was found to increase with soil depth, having mean values of 1.2 mg/m⁻³ and 1.4 mg/m⁻³ in surface and subsurface soils which is within optimal limit or range of 1.0 to 1.8 mg/m⁻³ for minerals soils (NPFS, 2009). However, the values of BD in this study slightly differ from the observation of Drewry *et al.* (2001) who stated that for medium to fine textured, soil BD range of 0.9-1.2 mg/m⁻³ is considered optimal for maximal field crop production, while values greater than 1.25-1.30 mg/m⁻³ can potentially cause yield loss due to inadequate soil aeration. BD influences infiltration of water into the soil, water

retention and loss and aeration. BD within
the range obtained in this

Table 1: Morphological properties of soils developed on Granite- Gneiss in Akamkpa

Location	Horizon Designation	Dept(cm)	Munsell Colour	Mottling	Texture	Structure	Consistence	Boundary	Other features
Mkpot	Pedo 1								
	Ap	0-15	10YR3/3 dark brown	-	Gsl	1msbk	Sssp	Cs	Termite, many mica flakes, worm cast; many medium roots; macro and micro pores
	Bt	15-53	10YR5/6 yellowish brown	-	Gl	2msbk	Sssp	Gs	Common fine mica flakes; common fine and medium roots; clay skins in the peds
	B	53-91	10YR6/8 yellowish brown	-	Gl	2msbk	Sp	Ds	Many large quartzite, muscovite, biotite schistose; common medium and fine roots; common macro and fine pores
	BC	91-120	7.5YR5/8 strong brown	-	Gscl	2msbk	Sp	Ds	Many large quartzite, muscovite, biotite schistose and weathered roots; common fine pores
Ikpai	Cr	120-159	7.5YR5/8 Reddish yellow	-	Gscl	2msbk	Sp		Many large quartzite, muscovite, biotite schistose and weathered roots; common fine pores
	Pedon 2								
	Ap	0-23	2.5YR5/8 Red 10YR 3/2 very dark brown	-	Gsl	1msbk	Sssp	Cs	Earthworms cost, Termite and ant activities: many fine roots macro and micro pores.
	Bt	23-43	7.5YR 5/6 strong brown	-	Gsc	2fgr	Sssp	Gs	Many common mica flakes, termite activities; clay skins in the peds
	B	43-74	5YR 5/6 yellowish red	-	Gscl	3mcsbk	Sp	Ds	Many fine mica flakes, many medium weathered rocks, fragments of quartzite schistose; clay skins in the peds
Ojok	BC	74-110	5YR 5/6 yellowish red		Gsc	1msbk	Sp	Ds	Many mica flakes termite activities
	Cr	110-174	2.5YR 4/8 Red		Gsc	1msbk	Sp		Many mica, hematite termite activities
	Pedon 3								
	Ap	0-11	10YR 3/1 very dark grey	-	Gsl	2msbk	Sssp	Cs	Termite, worm casts, human activities; many fine and medium roots; many macro and micro pores
	Bt1	11-30	10YR 6/6 brownish yellow		Gscl	2msbk	Sssp	Gs	Common fine roots; common macro and micro pores; micas flakes; clay skins in the peds
	Bt2	30-65	10YR 5/8 brownish yellow	-	Gscl	2msbk	sp;fi	Ds	Common fine roots; many micro pores; many mica flakes; clay skins in the peds
	Crt	65-116	7.5YR 5/8 Reddish yellow	2.5YRLight red	Gsc	2msbk	sp;fi	Dw	Large quartzite, muscovite schist, biotite schist and weathered; common micro pores Few moderate cutans on peds, common medium pores, many Fe and decay granitic gneisses observed
	Cr	11-120	10YR5/8 yellowish	2.5YRLight red	Gsc	2msbk	sp;fi		

brown

Texture: gls = gravelly loamy sand; gsl = gravelly sandy loam; gsc = gravelly sandy clay

Structure: 1 = Weak, 2 = Moderate, 3 = Strong, f = fine, m=medium, c=coarse, sbk=subangular blocky, gr=granular

Consistency: sssp=slightly slightly plastic; sp=sticky and plastic. Boundary: cs=clear smooth; gs=gradual smooth; gd=gradual diffuse, cw=clear wavy; as=abrupt smooth.

Table 2: Physical properties of soils developed from Granite- Gneiss in Akamkpa Local Government Area

	Horizon	Horizon Depth (cm)	Particle Size			Gravel Cont %	Text. Class	BD Mgm ⁻³	PD Mgm ⁻³	TP (%)	Silt/clay
			Sand gkg ⁻¹	Silt gkg ⁻¹	Clay gkg ⁻¹						
Mkpot	Pedon 1										
	Ap	0-15	810	60	130	16.3	Gsl	1.2	2.58	53.5	0.5
	Bt	15-53	690	40	270	22.3	Gscl	1.3	2.66	51.1	0.1
	B	53-91	630	60	310	55.1	Gscl	1.5	2.65	43.4	0.2
	BC	91-120	570	100	330	44.0	Gscl	-	-	-	0.3
	Cr	120-159	630	80	290	44.2	Gscl	-	-	-	0.3
Ikpai	Pedon 2										
	Ap	0-23	770	80	150	9.80	Gsl	1.4	2.62	46.7	0.5
	Bt	23-43	570	100	330	30.8	Gscl	1.4	2.65	47.2	0.3
	B	43-74	530	80	390	49.7	Gsc	1.3	2.66	51.1	0.2
	BC	74-110	630	100	270	51.8	Gscl	-	-	-	0.3
	Cr	110-174	550	100	350	27.1	Gsc	-	-	-	0.4
Ojok	Pedon 3										
	Ap	0-11	730	120	170	3.1	Gsl	1.2	2.65	56.6	0.5
	Bt1	11-30	570	140	290	42.8	Gscl	1.3	2.65	50.9	0.2
	Bt2	30-65	570	140	490	56.1	Gscl	1.4	2.68	47.7	0.2
	BC	65-116	590	100	310	25.0	Gscl	-	-	-	0.1
	Cr	116-120	570	60	370	18.2	Gscl	-	-	-	0.2
Range			530-810	40-140	130-490	3.1-66.9		1.0-1.5	2.42-2.78	43.4-58.0	0.1-0.5
Surface Mean			690	227	570	53.0		1.2	2.61	52.7	0.4
Sub surface mean			586	91	295	45.0		1.4	2.64	48.2	0.3

Legend: gls=gravelly loamy sand, gl=gravelly loam, gcl=gravelly clay loam, gscl=gravelly sandy clay, gsl=gravelly sandy loam

study allows for root penetration, air and water movement without any impediment. The values of total porosity obtained varied from 43.4 to 58.0% with mean values of 52.7 and 48.2 % in surface and subsurface soils. Higher values of TP obtained in surface than subsurface soils may be due to higher sand content of the surface soils. Soil with TP of 50 % are well granulated and allows for air and water movement. Silt/clay ratio had mean value of 0.4 and 0.3 in the surface and subsurface horizons. Particle density values for the soils ranged from 43.4 to 58.0 mgm^{-3} with mean values of 2.61 and 2.64 mgm^{-3} for surface and subsurface horizons. These values are similar to the critical value of 2.66 mgm^{-3} for mineral soils (Akpan-Idiok, 2012).

Chemical properties

The chemical properties of the studied soils are presented in Table 3. The soils were generally very strongly acid in reaction with mean pH values of 5.6 and 5.3 in surface and subsurface horizons respectively (London, 1991). Strongly acid pH of these soils may be due leaching of bases by high rainfall in the area, aluminum hydrolysis and an indication that the dominant cation in the soil is aluminum (Esu *et al.*, 2008). The ΔpH values were all negative in the soils with means of -1.0 and -0.8 for surface and subsurface respectively. This indicates that the soils possess net negative charged for all the horizons and are capable of retaining soil nutrients for crop growth and against losses through leaching and runoff forces (Aki *et al.*, 2014). Organic carbon was higher in Ikpai than in Mkpote and Ojok, decreased with profile depth and had overall

mean values of 12.17 and 3.7 gkg^{-1} in surface and subsurface soils. Available P was moderate in the surface and low in the subsurface soils while exchangeable bases were low in all the soils according to Landon (1991). Rapid leaching of the basic cations has been reported for soils developed from granite gneiss basement complex in south western Nigeria (Amusan, 2002; Nwaka and Kwari, 2000).

Available P, Ca, Mg and K had surface and subsurface means of 8.98 and 3.59 mg/kg , 2.0 and 1.4 cmol/kg , 0.6 and 0.4 cmol/kg and 0.15 and 0.05 cmol/kg . These properties including CEC (5-15 cmol/kg) and ECEC (10 cmol/kg) were low across the soil while base saturation was moderate (20-60 %) in the subsurface and high (> 60 %) in the surface with overall means of 58 % and 39 % in surface and subsurface soils accordingly. CEC reflects the ability of the soil to hold cations and to exchange these cations and lower CEC indicates that soil nutrient availability is also low (Baja *et al.*, 2021). Low level of basic cation may be due to leaching by intensive rainfall in the study area while deficiency of apatite mineral in the study area and fixation of phosphorus by aluminum and other metallic cations under low pH may have resulted in low level of phosphorus in the studied soil (Kolay, 2000). Like other bases, lower Mg in the studied soils would negatively affect crop growth and yield in the area. Sufficient Mg in soil enhances or brings about high rate of photosynthesis (Tang *et al.*, 2023), enzymes activation (Ahmed *et al.*, 2023) and transportation of carbohydrates from leaves to other developing tissues of plant in the

Table 3: Chemical properties of soils developed from Granite- Gneiss in Akamkpa Local Government Area

Location	Horizon	Depth (Cm)	pH H ₂ O KCl	ΔpH	OC gkg ⁻¹	TN gkg ⁻¹	Av. P. Mg/kg	Ca	Mg	K	Na Cmol/kg	TEB	H+A1	CEC pH7	ECE C pH7	BS %	
Mkpota	Pedon 1																
	Ap	0-15	6.8	4.7	-2.1	15.96	1.12	10.59	2.4	0.6	0.19	0.03	3.22	0.2	5.5	3.4	59
	Bt	15-53	5.1	4.2	-0.9	6.58	0.70	3.27	1.2	0.4	0.09	0.02	1.71	1.2	5.0	2.6	34
	B	53-91	5.2	4.0	-1.2	7.58	-	-	1.0	0.3	0.06	0.01	1.37	2.4	6.1	3.8	26
	BC	91-120	4.8	4.2	-0.6	4.19	-	-	2.0	0.5	0.06	0.05	2.61	3.0	7.2	5.6	36
	Cr	120-159	5.1	4.1	-1.0	1.20	-	-	1.0	0.3	0.04	0.03	1.37	1.6	5.3	2.9	25
Ikpa	Pedon 2																
	Ap	0-23	5.3	4.9	-0.4	24.34	1.68	8.47	3.8	0.9	0.16	0.03	4.89	0.4	5.6	4.9	87
	Bt	23-43	5.5	4.6	-0.9	5.59	0.42	4.24	2.0	0.5	0.05	0.04	2.59	0.4	4.2	2.6	62
	B	43-74	5.4	4.7	-0.7	5.59	-	-	1.2	0.3	0.04	0.03	1.57	0.2	4.8	1.7	33
	BC	74-110	5.3	4.9	-0.4	4.59	-	-	1.4	0.4	0.04	0.03	1.87	0.2	4.5	2.1	42
	Cr	110-174	5.5	4.4	-1.1	2.99	-	-	1.6	0.5	0.03	0.03	2.16	0.4	4.7	2.6	46
Ojok	Pedon 2																
	Ap	0-11	5.4	4.8	-0.6	16.36	1.26	7.89	2.0	0.8	0.33	0.02	3.15	0.4	5.1	3.6	62
	Bt1	11-30	5.7	4.8	-0.9	4.19	0.56	3.27	1.8	0.4	0.09	0.02	2.31	0.2	5.0	2.3	46
	B	30-65	5.2	4.5	-0.7	1.49	-	-	1.4	0.5	0.05	0.02	1.97	1.0	4.2	2.9	46
	Crt	65-116	5.6	4.8	-0.8	2.79	-	-	1.8	0.4	0.05	0.01	2.26	0.2	4.9	2.5	46
	Cr	116-120	5.8	5.0	-0.8	3.19			1.6	0.6	0.05	0.02	2.27	0.2	4.0	2.3	46
Range			4.8-6.8	4.0-5.0	-0.4-2.1	1.2-24.34	0.4-1.68	3.27-10.56	1.0-3.8	0.3-0.9	0.0-0.33	0.01-0.05	1.37-4.89	0.2-3.0	4.0-7.20	1.7-5.6	26-87
	Surf Mean		5.6	4.7	-1.0	12.17	1.35	8.98	2.0	0.6	0.15	0.03	3.75	0.1	5.1	3.2	58
Subsur Mean			5.3	4.5	-0.8	3.7	0.56	3.59	1.4	0.4	0.05	0.03	1.83	0.1	5.8	2.9	39

Table 4: Micronutrients of soils developed on Granite-Gneiss in Akamkpa Local Government Area

Location	Horizon	Depth (cm)	Cu	Mn	Zn	Fe	Bo
			—————→ Mg/kg ←————				
Mkpot	Pedon 1						
	Ap	0-15	1.19	49.10	1022	14.18	0.31
	Bt	15-53	0.09	6.96	6.80	33.78	0.20
Ikpai	Pedon 2						
	Ap	0-23	1.79	72.39	20.91	10.37	0.14
	Bt	23-43	1.77	13.67	8.09	13.28	0.11
Ojok	Pedon 3						
	Ap	0-11	1.39	58.64	10.22	11.19	0.8
	Bt1	11-30	0.45	6.45	7.10	17.04	0.4
Range			1.39-1.79	6.45-72.39	6.8-29.91	11.19-33.78	0.11-0.31
Surf.Mean			1.12	60.04	13.78	19.91	0.26
Subsurf Mean			0.77	9.03	7.33	21.37	0.15

area (Jiao *et al.*, 2023). BS values obtained in this study are within the range that allows for availability of basic nutrients for plant uptake in spite of the low cations reserve in the soils (Akpan-Idiok, 2012).

Micronutrients

The results micronutrient content of the soil is presented in Table 4. All the micronutrients were higher in surface than subsurface soils. Copper, Mn, Zn, Fe and Bo had average values of 1.12 and 0.77 mg/kg, 60.04 and 9.03 mg/kg, 13.78 and 7.33 mg/kg, 19.91 and 21.37 mg/kg and 0.26 and 0.15 mg/kg in surface and subsurface soils respectively. The values of Bo in this present study are quite higher compared with their threshold values of 0.5 to 1.0 mg/kg (Agbede, 2009). The values of micro nutrient concentration in these soils varied from medium to high except boron which was low (Udo *et al.*, 2009).

Mineralogical properties

Figure 2 shows the relative abundance of the minerals identified in the soils while figure shows the diffractograms and peaks at which the minerals were identified. The dominant and the least concentrated minerals in the soils were quartz and diopside/plagioclase accordingly. The minerals identified were quartz (59.13 %), kaolinite (21.72 %), microcline (7.18 %), muscovite (2.91 %), hornblende (2.1 %) and diopside and plagioclase (1.71 %). This findings of are consistent with an earlier work by Amusan (2002) who reported quartz as a dominant mineral in clay fraction of soils derived from granite gneiss of Aberdeen Shire in United Kingdom. The dominance of quartz may be due its high occurrence in highly weathered soils of humid tropical regions due to its high resistance to weathering and chemically

inert nature (Afu *et al.*, 2024a; Afu *et al.*, 2024b). Furthermore, quartz and kaolinite are most dominant minerals in soils in advanced stage of weathering with low percentage of weatherable minerals such as feldspars (Afu *et al.*, 2024a; Chikezie *et al.*, 2010).

The dominance of quartz and kaolinite has serious negative implications in fertility of the soils due their very low CEC (Aki *et al.*, 2014). This implies that loss of nutrients through leaching and other means is very high in the soil.

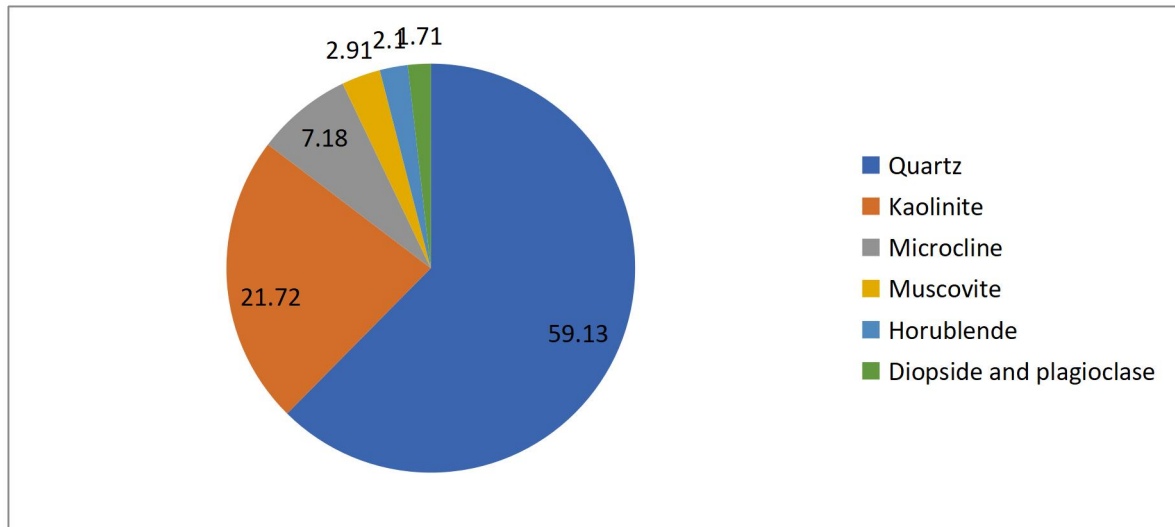


Fig. 2: Percentage Distribution of minerals in clay fractions of soils derived from Granite-Gneiss

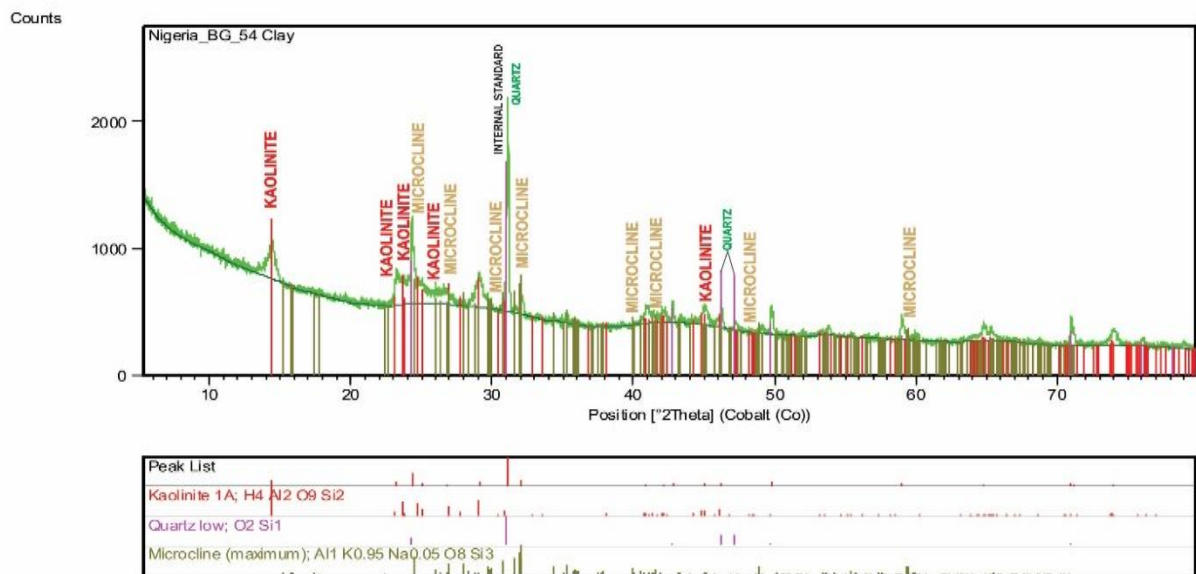


Fig. 3: X-ray diffractogram of clay fractions of soil developed from Granite-Gneiss in Akamkpa Local Government Area

Classification

Using morphological, physicochemical and mineralogical properties, the studied soils were classified under USDA Soil Taxonomy and FAO – World Reference Base for soil Resources. The soils studied had low base saturation, Kandic horizons, ECEC < 12 Cmolkg⁻¹ with umbric epipedon and were therefore fit into the Ultisols order of the USDA Soil Taxonomy (Soil Survey Staff, 2010). The profiles had udic soil moisture regime and brown/brownish yellow argillic or kandic horizons in humid tropical condition and were therefore fit into the suborder of Udults. With kaolinitic horizon, increase in clay content with depth of 150 cm from the mineral soil surface, and irregular decrease of organic carbon with depth, the three profiles were placed in the great group kandiodults and typic kandiodults at the subgroup level and correlated with FAO-WRB as Acrisols. With less than 35 % of clay and rock fragments as well as mixed mineralogy of quartz, microcline (K-feldspars), kaolinite, muscovite, hornblende and plagioclase and diopside, the soil qualify as loamy skeletal, mixed Isohyperthermic Typic kandiodults.

Conclusion

The investigation highlights the morphological properties, physicochemical and mineralogical properties of soil derived from granite gneiss basement complex in Akamkpa Local Government Area of Cross River State, Nigeria. The study found that the soils are well drained and developed with texture varying from sandy loam at the surface to sandy clay loam and sandy clay at the subsurface horizons. The soils were

characterized by strongly acid pH, moderate to high organic carbon and nitrogen as well as low to moderate available P and Low basic cations. Micronutrients (Cu, Mn, Zn, and Fe) were moderate to high except Bo that was low. The minerals identified were quartz, microcline, kaolinite, muscovite, hornblende, plagioclase and diopside with quartz and kaolinite as the most concentrated minerals. The soils were classified as Ultisols and correlated with FAO-WRB as Acrisols. Soil fertility management techniques such as mulching, planting of cover crops, crop rotation, adoption of zero tillage should be carried out to reduce leaching of basic nutrients from the soils. Liming should be carried out to raise the pH to favorable degrees that enhance availability of plant nutrients.

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CHARACTERIZATION AND CLASSIFICATION OF MAJOR SOIL TYPES UNDER VARIOUS LAND USE SYSTEMS IN NORTHERN NIGERIA'S SEMI-ARID ZONE

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ABSTRACT

A semi-detailed fixed grid soil survey of Barema farm Damaturu was conducted in order to obtain comprehensive soil data for characterization and classification. Two soil pedons each were identified on the basis of land use system (acacia and native vegetation, arable, bare land). Morphological properties of the soil reveal that soil in all the land uses is deep, imperfectly drained. The colour of the surface horizons in the study area, varied from brown (7.5YR4/3 moist) to reddish yellow (7.5YR6/6 dry) structure is had moderate to strong, medium to coarse and subangular and angular blocky to subangular blocky, the texture of the surface horizons of all the profiles in the study site are varied from sandy loam, loam to sandy clay loam, while the subsurface horizons were predominantly loam sandy. The soil structure of the surface horizon was moderate, fine to medium sub angular blocky, the surface horizon study area was slightly sticky slightly plastic (wet), friable (moist) and slightly hard (dry). For the subsurface horizons, the wet consistence varied from sticky plastic and slightly sticky slightly plastic with clear, distinctive and smooth boundary. Physical properties of the soils indicate a relative high bulk density and low porosity. Average Mean for hydraulic conductivity (ksat) (cm h⁻¹) for Pedon SU1 P1 (acacia veg), Pedon SU2 P2 (acacia veg), Pedon SU1 P1 (native veg and Pedon SU2 P2 (native veg) were 3.01, 3.21, 2.39 and 1.49 respectively. The dominant exchangeable bases were calcium and magnesium with the soils having high base saturation. The soils were neutral to slightly alkaline in reaction. Organic matter, available P, total N and CEC contents of the soils were generally low. According to USDA Soil Taxonomy System, for the land uses were classified as Typic Plinthustalf, Arenic Paleustalfs, Rhodic Paleustalfs, Typic Haplustalfs, Typic Rhodustalfs and Typic Paleustalf respectively and correlate with Haplic Lixisol, in WRB system of Classification.

Introduction

Soil is a fundamental natural resource that supports agriculture, biodiversity, and ecosystem functions. In northern Nigeria's semi-arid zone, soil properties vary significantly due to differences in climate, vegetation, and land use practices (Odunze *et al* 2006). The classification and characterization of soil types under different

land use systems are essential for understanding soil fertility, productivity, and degradation risks (Fasina *et al* 2007). However, the increasing pressure from agricultural expansion, overgrazing, and deforestation has led to soil degradation, necessitating a scientific approach to soil management.

Land use changes influence soil properties such as organic matter content, texture,

structure, and nutrient availability (Esu, 2005). Understanding these variations across different land use systems, including croplands, grazing lands, and fallow systems, is crucial for sustainable soil management and agricultural planning (Esu, 2005). This study seeks to categorize and characterize major soil types under various land use systems in northern Nigeria's semi-arid zone, providing a foundation for sustainable land use and soil conservation strategies.

Justification

The semi-arid zone of northern Nigeria is characterized by fragile soils that are highly susceptible to degradation due to climatic constraints and unsustainable land use practices (Odunze 2006). The increasing demand for food production has led to extensive land conversion, negatively impacting soil health and fertility. However, there is a limited understanding of how different land use systems influence soil characteristics, making it difficult to implement effective soil management strategies (Odunze 2006). Categorizing and characterizing soil types under various land use systems will provide valuable insights into soil properties, fertility status, and degradation trends. This knowledge is crucial for policymakers, farmers, and land managers in making informed decisions about land use planning, soil conservation, and sustainable agricultural practices. By identifying soil limitations and potentials, this study will contribute to improved soil management, increased productivity, and environmental sustainability in the region.

Problem Statement

Soil degradation is a major challenge in northern Nigeria's semi-arid zone, driven by unsustainable land use practices such as deforestation, overgrazing, and intensive farming (Lekwa *et al* 2004). The continuous alteration of land use without a clear understanding of its impact on soil properties has led to declining soil fertility, reduced agricultural productivity, and increased vulnerability to erosion and desertification (Ogunkunle, 2005). Despite the importance of soil classification in sustainable land management, there is a lack of comprehensive studies that categorize and characterize soils under different land use systems in this region. Without this knowledge, land use planning and soil conservation efforts remain ineffective, further exacerbating land degradation (Ogunkunle, 2005). This study aims to address these gaps by systematically categorizing and characterizing the major soil types under different land use systems in northern Nigeria's semi-arid zone. The findings will provide a scientific basis for improving soil management practices, ensuring sustainable land use, and enhancing agricultural productivity in the region.

MATERIALS AND METHOD

Site description

The study area is Barema farm, established in year 2002 situated some 11 kilometers away from Damaturu, Tarmuwa Geidam road and it cover about 15 square kilometers. The area lies between Latitude 11.8563618°N and Longitude 11.891489° E, with varying altitude varied from 426 to 433 above sea level. the climate of the study area is tropical wet and dry type (Adamu

2012 and Hamza 2018) with annual rainfall of about 500- 760mm all fall withing may-June to October, and mean temperature range 25 to 30⁰ c (Ojanuga, 2006). the soils are mostly moderately deep and well drain sandy loam textured surface and sandy clay loam subsoil (Hamza 2019) the farm is situated in Sudan-Sahel Savannah vegetation type composed of shrubs and grasses with scattered trees. According to the USDA Soil Taxonomy, soils can be classified as Alfisols, this area is dominated by degraded Native vegetation dominated

by grass and shrub species; such as *Piliostigma reticulatum*, *Daniellia oliveri* and *Guera senegalensis* After clear-cutting in some areas of degraded natural forests, about 20 years ago, the area was reforested with acacia species (within 2 × 2 m spaces). The stands were never fertilized. However, some areas were not afforested and are now converted to other land uses/covers (Adamu 2012 and Hamza 2018). A detailed description of each site is reported in Figure 1.

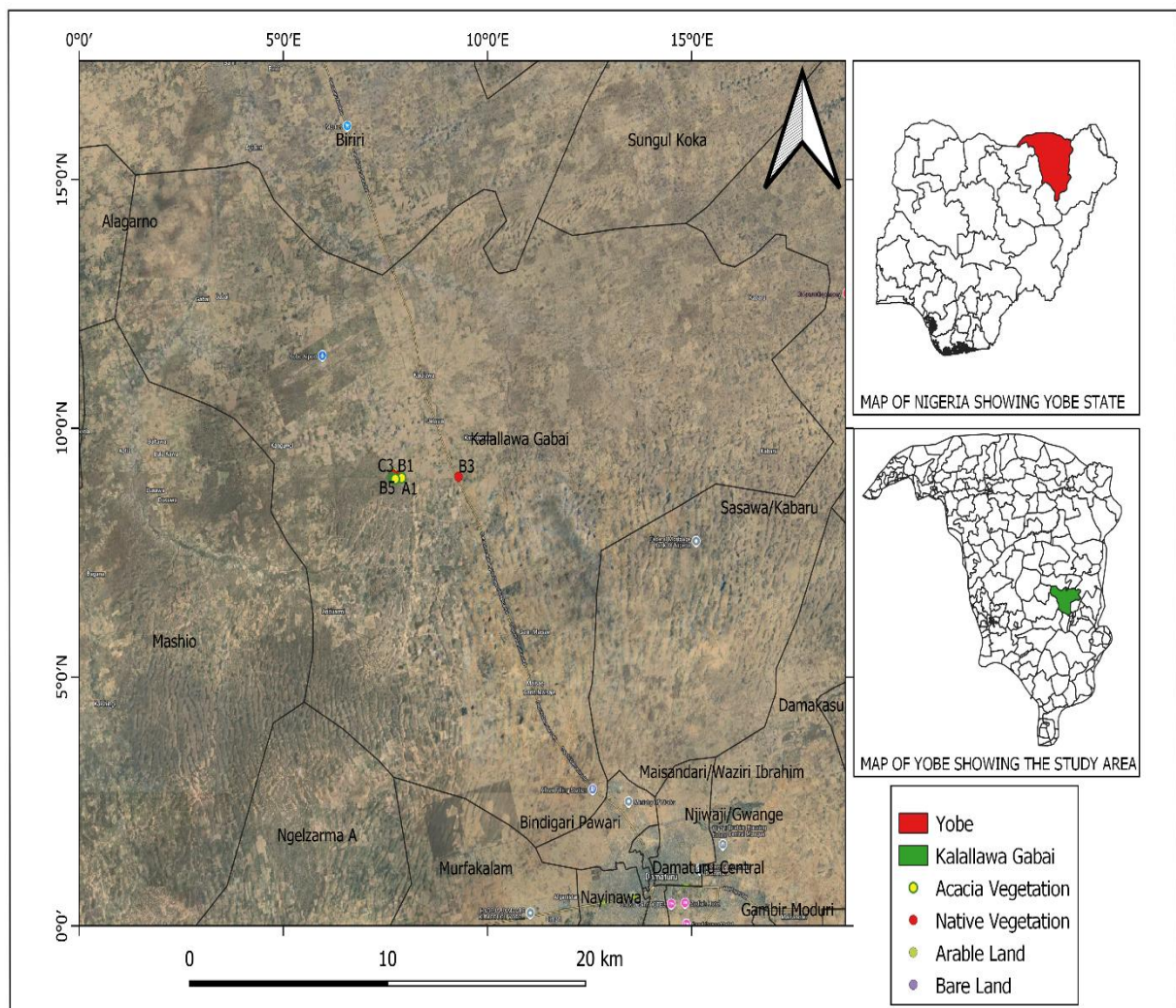


Figure 1: map of Yobe State showing the study area

Field study, sampling and profile description

Field study

A semi-detailed soil survey was conducted in Barema farm at a scale of 1:25,000 following the procedures described in Wilding and Dress (1983), using GPS instruments. Transects at 100 meters intervals were constructed at right angles (900) to the either side of the baseline. This was followed by auger borings to examine and describe the soils consistently at 100 meters interval along each traverse. Observations relating to morphological properties of the soils, colour, were used to establish the soil boundaries. Two modal profile pits were excavated in each identified land use. The soil profiles were described according to FAO (2006) manual while the collection of bulked samples was made from each horizon for laboratory analysis. Samples for bulk density were taken with core samplers (5cm diameter) from the various horizons. carried out beside pedons that are representative of the different soil units. The entire land use was resolved into eight pedons namely acacia 1 and 2, native 1 and 2, arable 1 and 2 and bare land 1 and 2. Based on the data obtained from the soil survey, the soils at Barema farm were subsequently characterized and classified

Laboratory Methods

The samples were air-dried, gently crushed using a wooden mortar and pestle and then sieved through a 2mm mesh. The sieved samples were stored for chemical and physical analyses. Bulk density was

determined by the core sampler method described by Blake and Hartge (1986). Particle size distribution was determined by the hydrometer method (Gee and Bauder, 1986) Particle density was determined by the use of Pycnometer bottle method (Blake, 1965). Total porosity was calculated from particle and bulk densities using the relationship,

$$p = \left(1 - \frac{\rho_b}{\rho_d}\right) \times 100$$

Where;

P =porosity,

Bd = Bulk density,

Pd= Particle density and

100 and 1 are constants.

Soil pH (1:1) in H₂O and CaCl₂ were determined using glass electrode pH meter (Bates, 1954). Organic carbon content of the soils was determined by the modified Walkley-Black method as described by Nelson and Summers (1982). Total nitrogen was determined by the Macro-Kjeldahl digestion and distillation procedures as described by Bremer (1965). Available P was determined by Bray No. 1 Method (Bray and Kurtz, 1954). Exchangeable bases (calcium, magnesium, potassium and sodium) in the soil was determined using the ammonium acetate extract from the CEC determination. Sodium and K were determined using flame photometer and Ca and Mg were determined using atomic absorption spectrometer while Percentage base saturation was calculated by dividing the total exchangeable cations (Ca, Mg, K, and Na) by the cation exchange capacity

(CEC) obtained by the 1M NH₄AOC (pH 7.0) as defined by this relationship;

$$BS\% = \frac{\text{Total exchangeable bases}}{\text{CEC (NH}_4\text{OAC)}} \times 100$$

RESULTS AND DISCUSSION

The morphological, physical, chemical and exchangeable properties of the soils are presented in Tables 1, 2, 3 and 4 respectively.

Morphological Characteristics

Summary of the morphological properties of the soils is presented on Table 1. In pedon 1 and 2, the soils were dark reddish brown (5YR 2/3) at the surface and change to yellow (10YR 4/4) at the subsurface with yellowish red colour mottles (5 YR 4/6) to olive brown colour mottles (2.5 YR 3/6) in the subsurface horizons. In soil of acacia and arable land pedon 1 and 2, reddish and reddish yellow (2.5YR4/6, and 7.5YR7/6) respectively, changing to yellowish red and reddish brown (5YR 5/8 and 7.5YR5/6,) at the subsurface respectively. The soils in native vegetation and bare land pedon 1 and 2 were yellow brown in colour (7YR7/6) and reddish brown (5YR4/4,) in the surface and changed to pel brown (10YR7/3) and reddish yellow (7.5YR6/8), at a depth respectively. An impermeable layer is reached at a depth of less than 50 cm. The soils were generally gravelly sandy loam in texture and were structurally massive. The observations of soil color at the study location agreed with (Wakene, 2001), which reported that variations in soil color are due to the difference in organic matter or the difference in parent material This feature is indicative of the poor drainage status of the soils. The soils were generally deep and

imperfectly drained. Texturally, the soils were loamy sand in the surface changing to sandy clay loam in the subsurface horizons. The structure of the soils was generally weak subangular blocky in the surface and changes to angular blocky in the subsurface According to (Brady N. C. and Weil R. R.,2002), the structure of soil is highly influenced by the amount of clay. According to [Rai 2002], the depth of soil influences both the storage of water and plant nutrients in addition to its effect on root development. . According to the findings of (Wakene 2003) the consistency of soil changes with the depth of soil due to variation in amount of clay and organic matter. Very hard, very firm, and very plastic characteristics of consistency are common in subsurface horizon because of high clay content and low soil organic matter. This supports the result of soil consistency in the study area. the surface horizons had clear smooth boundaries. While in the underlying horizons the boundaries were gradual smooth to clear smooth. In Pedon SU₂ P₂ (native veg), the boundaries of the surface horizons were found to be clear smooth. While in the underlying horizons the boundaries were clear smooth, gradual diffused to smooth. For Pedon SU₁ P₁(acacia veg), the surface horizons had clear smooth boundaries. While, in the underlying horizons had clear smooth to gradual smooth boundaries. According to (FAO, 2006), the presence of difference in horizon boundaries showed that there were different processes and anthropogenic impacts that were involved in soil formation of study area. These may be

due to intensive weathering and cultivation practices

Miscellaneous observations

The pores observed in the entire study sites were generally many, moderate, few to common and coarse, fine to medium, in both surface and subsurface horizons, their pattern of distribution, sizes and quantities were found to be tabular, irregular and vesicular. For the roots, their distribution varied in relation to their sizes and quantities in all the profiles studied, for the surface horizons, the roots were very few, few, moderate, common to many. For the subsurface horizons, root abundance varied from many, few, very few to common and fine to very fine in all the soils (Table 1). Some profiles showed the presence of iron and magnesium (as mottles and/or concretions) which may also be attributed to the parent material (Breuning-Madsen *et al.*, 2007) and temporally reducing conditions due to water stagnation. Worm casts and roots were also found in profiles, therefore, the presence of clay in subsoils could also be as a result of biological activities.

Physical Characteristics

Generally, the soils of the study area have high sand content at surface in both the land uses (Table 2) These soils are formed on aeolian sand cover (Sanda *et al.*, 2007). The silt content of the soils was observed to slightly increase with increasing depth in almost all the profiles. Morbeg and Esu (1991) and Kparmwang (1993) in the studies of soils in the Savanna region of Northern Nigeria mentioned the influence of Harmattan dust in contributing silt to soil. The soils of the study area are found to contain appreciable amount of clay content

in the land uses. The higher clay content often observed in the subsurface horizons of many soils may be attributed to illuviation and pedoturbation processes. The presence of textural B (Bt) in land use and pedons

confirms this. The silt/clay ratio mean averages from 1.47, 1.81, 2.01, 1.29, 1.08, 1.57, 2.31 and 1.17, for acacia 1 and 2, native and 2, arable 1 and 2 and bare land 1 and 2 respectively. Van Wambeke (1962) reported that “old” parent materials usually have a silt/clay ratio below 0.15 while silt/clay ratios above 0.15 are indicative of “young” parent materials. Results of this study show that, all the soils have silt/clay ratio above 0.15 indicating that the soils are relatively young with high degree of weathering potential. Silt/clay ratios are relatively higher in the surface horizons and decrease with increase depth in the pedons. The decrease in silt/clay ratio with depth is an indication that subsoils horizons are more weathered than surface horizons. Yakubu (2006) reported similar results on the soils of Sokoto State. The relative high bulk density values recorded in arable pedon 2 is attributed to compaction caused by machine and grazing animals which is a common activity in the area.

Plant performs best in bulk densities below 1.4Mgm^{-3} and 1.6Mgm^{-3} for loamy and sandy soils respectively (Donahue *et al.*; 1990). Root growth could also be inhibited due to high bulk density because of soil resistance to root penetration, poor aeration, slow movement of nutrients and water and buildup of toxic gases and root exudates (Brady and Weil, 2002; Odunze, 2006).

Consequently, the bulk density values of acacia, arable and native are favourable for crop production, while that of bare land may impair proper root penetration. This present

Table 1: Morphological Properties of the soils under different land use Pedon SU₁ P1 (arable)

Horizon	Depth (cm)	Munsell Colour		Texture	Structure	Consistency			Boundary	Other features
		dry	wet			wet	moist	dry		
AP	0-21	7.5YR5/6,sb		Loamy sand	2f-mp	Ss, Sssp,	frb, frf	sh	cs	Common tubular medium pores, many medium to coarse roots and presence of animal activities
AB₁	21-34	7.5YR7/6, ry		Loamy sand	2f-mp	Sssp,	frf,	sh	Gs	Common irregular fine to medium pores, few very fine to fine roots and presence of animal activities.
AB₂	34-71	7.5YR7/6, ry		Loamy sand	2f-mp	Sssp,	frf ,	sh	cw	Common tubular fine pores, few fine Fe/Mn concretions and few fine faint mottles
BT	71-103	7.5YR7/6, ry		Loamy sand	3f-mabk	Sssp,	frf ,	sh	Cs	Common irregular fine to medium pores & fine Fe/Mn concretions.
BTC	103-180	7.5YR7/6,y		Loamy sand	3f-mabk				Cs	Few tubular fines to medium pores, common fine to medium roots, many fine to medium Fe/Mn concretions and presence of CaCO ₃

Horizon	Depth (cm)	Munsell Colour	Texture	Structure	Consistency			Boundary	Other features
					wet	moist	dry		
Pedon SU ₁ P2 (arable)N11.50323052, E11.54158658and 526m above sea level									
AP	0-19	7.5YR7/6, ry	Loamy sand	2f-mp	Sssp,frf, sh			cs	Many tubular fine to medium pores, many fine roots and presence of vertical and horizontal fine crack
AB ₁	19-31	7.5YR6/8,ry	Loamy sand	2f-mp	Sssp, frf, sh			csm	Many tubular coarse pores, few very fine roots.
AB ₂	31-65	7.5yr7/6,ry	Loamy sand	2fp	Sssp, frf, sh			Csm	Many tubular coarse pores, few very fine roots.
BT	65-98	7.5YR6/8,ry	Loamy sand	2fp	Sssp, frf, sh			csm	Many tubular coarse pores, few very fine roots.
BTC	98-159	7.5yr7/6,ry	Loamy sand	2fp	Ss, frb,	sh		Csm	Many tubular coarse pores, few very fine roots.
BC	159-200	10YR7/4,vpb	Loamy sand	1fsbk	ss	Fr	s	csm	Many tubular fine to medium pores, many very fine roots, and presence of animal activities.

		Munsell	Texture	Structure	Consistency			Boundary	Other features
		Colour							
Horizon	Depth				wet	moist	dry		
	(cm)								
Pedon SU1 P1(bare land) N11.84272, E11.899933 and 494m above sea level									
AP	0-25	5YR4/4, rb	Loamy sand	1-mf- msbk	Ss, frb,	sh	csl	Common tubular fine to medium pores and moderate to few very fine to fine roots.	
AB ₁	25-46	5YR6/8,ry	Loamy sand	1-mf- msbk	Ss, frb,	sh	Csl	Many tubulars very fine pores, few very fine roots and presence animal activities.	
AB ₂	46-88	5YR5/8,yr	Loamy sand	2m-cc	Sssp,frf,	sh	Gdsm	Many tubular fine pores, very few very fine roots and presence of fine crack.	
BT	88-126	5YR5/8,yr	Loamy sand	2mabk	Sssp ,frf,	sh	Csm	Many tubular fine pores and few fine to medium root.	
BTC	120-176	5YR5/8,yr	Loamy sand	2mabk	Ss, frb,	sh	Cs	Common tubular fine pores, few fine to moderate and presence of animal activities.	

		Munsell Colour	Texture	Structure	Consistency			Boundary	Other features
Horizon	Depth (cm)				wet	moist	dry		
Pedon SU ₂ P2 (bare land) N11.843358, E11.899752 and 517m above sea level									
AP	0-22	7.5YR6/6, by	Loamy sand	1f-mabk	Ss, frm	h		csl	Common tubular very fine pores, very few fine roots.
AB ₁	22-37	7.5YR5/6, yb	Loamy sand	1-mf-msbk	Ss, frm	h		Csl-m	Common tubular fine to medium pores, very few very fine roots and presence of illuvial material.
AB ₂	37-55	7.5YR7/6, Y	Loamy sand	2m-fsbk	Ss, frm,	sh		Cs	Common tubular fine pores and presence of illuvial material.
BT	55-76	10YR7/4,vpb	Loamy sand	1-mf-mabk	Ss ,frm	,sh		Cs	Common tubular fine pores, few fine Fe/Mn concretions and few fine faint mottles.
BTC	76-98	7.5YR7/6,ry	Loamy sand	2mf-mabk	Ss, frm,	sh		Csl-m	Common tabular fine pores, common fine Fe/Mn concretions and presence of animals activities.
	98-179	10YR7/4,vpb	Loamy sand	2m-mabk	Ss, frm,	sh		Cs	Few to moderate tabular fine pores, common fine Fe/Mn concretions.

Horizon	Depth (cm)	Munsell Colour	Texture	Structure	Consistency			Boundary	Other features
					wet	moist	dry		
Pedon SU1 P1 (native veg) N11.8441699, E11.89939 and 520m above sea level									
AP	0-20	10YR7/6,y	Loamy sand	1-mf- msbk	Ss, frm,	sh		Cs	Many irregular fine medium pores, many fine to medium roots and few fine Fe concretions
AB ₁	20-35	10YR7/6,y	Loamy sand	1-mf- msbk	Ss,frb	s		Cs	Few tubular fines to medium pores, common fine to medium roots, many fine to medium Fe/Mn concretions and presence of CaCO ₃
AB ₂	35-53	10YR7/3, vpb	Loamy sand	3m-csbk	Ss, frb,	h		Gsm	Few tubular fines to medium pores, common fine to medium roots, many fine to medium Fe/Mn concretions and presence of CaCO ₃ .
BT	53-70	7.5YR7/3,P	Loamy sand	3m-csbk	Ss, frb,	sh		csb	Few tubular fines to medium pores, common fine to medium roots, many fine to medium Fe/Mn concretions and presence of CaCO ₃ .
BTC	70-90	10YR7/4,vpb	Loamy sand	2m-mabk	Ss, frb,	sh		Cs	Few to moderate tabular fine pores, common fine Fe/Mn concretions.
BC	90-200	7.5YR5/3, b	Gc	3f-msbk	Ss frb	sh		sc	Many tubular medium coarse pores, many fine Fe/Mn concretions.

Horizon	Depth (cm)	Munsell Colour	Texture	Structure	Consistency			Boundary	Other features
					wet	moist	dry		
Pedon SU ₂ P2 (native veg) N11.843673, E11.898711 and 520m above sea level									
AP	0-50	7YR7/6,y	Loamy sand	1-mf-msbk	Ss ,frb	,s		Cs	Many irregular fine medium pores, many fine to medium roots and few fine Fe concretions.
AB ₁	50-93	7YR7/6,y	Loamy sand	1-mf-msbk	Ss,frb	s		Cs	Few tubular fines to medium pores, common fine to medium roots, many fine to medium Fe/Mn concretions and presence of CaCo ₃
AB ₂	93-135	10YR7/3, vpb	Loamy sand	3m-csbk	ss, frb,	h		Gsh	Few tubular fines to medium pores, common fine to medium roots, many fine to medium Fe/Mn concretions and presence of CaCo ₃ .
BT	135-140	7.5YR7/3,P	Loamy sand	3m-csbk	Ss, frb,	h		cs	Few tubular fines to medium pores, common fine to medium roots, many fine to medium Fe/Mn concretions and presence of CaCo ₃ .
BC	140-170	10YR7/3,vp b	Loamy sad	tending toward massive	Ss ,frb	h		sc	Few tubular fine pores, few very fine roots, fine Fe concretion and common fine faint of mottle.

		Munsell Colour	Texture	Structure	Consistency			Boundary	Other features
Horizon	Depth (cm				wet	moist	dry		
Pedon SU ₁ P ₁ (acacia veg) N11.841909, E11.900094 and 477m above sea level									
AP	0-25	2.5YR4/6,r	Loamy sand	2m-cabk	Ss, frb,	sh	csm		Common irregular medium pores, few fine to moderate roots and presence of animal activities.
AB ₁	25-52	5YR6/8,ry	Loamy sand	3sg	Ss, frb,	h	gwh		Common irregular medium pores, few fine to medium Fe/Mn concretions and presence of caco ₃ .
AB ₂	52-74	5YR6/8,ry	Loamy sand	1-mfsbk	Ss frb	s	csl		Many tubular medium pores, many fine roots and presence of animal activities.
BT	74-94	5YR7/8,ry	Loamy sand	2f-msbk	Ss frb	sh	Gs		Common tubular fine pores, many very fine roots and presence of fine vertical crack throughout horizon depth.
BTC	94-200	5YR6/8,ry	Loamy sand	3f-mabk	Ss frb	h	Gs		Common tubular fine medium pores, few very fine roots and presence of animal activities.
BC		5YR6/8,ry	Loamy sand	2f-mabk	Ss frb	h	Cs		Few tubular fine medium pores.

Horizon	Depth (cm	Munsell Colour	Texture	Structure	Consistency			Boundary	Other features
					wet	moist	dry		
Pedon SU ₁ P ₂ (acacia veg) N11.842253, E11.900729 and 477m above sea level									
AP	0-19	2.5YR4/6, r	Loamy sand	2m-cabk	Ss, frb,	sh	csm	Common irregular medium pores, few fine to moderate roots and presence of animal activities.	
AB ₁	19-31	5YR6/8,ry	Loamy sand	3sg	Ss, frb,	h	gw	Common irregular medium pores, few fine to medium Fe/Mn concretions and presence of caco ₃ .	
AB ₂	31-65	5YR6/8,ry	Loamy sand	1-mfsbk	Ss frb	s	csl	Many tubular medium pores, many fine roots and presence of animal activities.	
BT	65-98	5YR7/8,ry	Loamy sand	2f-msbk	Ss frb	sh	Gsm-h	Common tubular fine pores, many very fine roots and presence of fine vertical crack throughout horizon depth.	
BTC	98-159	5YR6/8,ry	Loamy sand	3f-mabk	Ss frb	h	sg	Common tubular fine medium pores, few very fine roots and presence of animal activities.	
BC	159-200	5YR6/8,ry	Loamy sand	2f-mabk	Ss frb	h	Cs	Few tubular fine medium pores.	

Sampling location : SU1P1= soil unit 1 p1 and 2= pedon 1 and 2, **Soil colour:** b=brown, ry=reddish yellow, p=pink, dr=dark red, r=red, yr=yellowish red, lrb=light reddish brown, lg=light gray, y=yellow, sb=strong brown, vpb=very pale brown, by=brownish yellow, yb=yellowish brown, rb=reddish brown, g= gray; **Texture:** sl=sandy loam, l=loam, cl=clay loam, gc=gravely clay, s=sandy, gcl=gravely clay loam, scl= sandy clay loam, gls=gravely sandy loam, gs=gravely sand;

Table 2: Average mean values for Physical Characteristic of the Soils of Barema farm Damaturu

Soil unit	mapping	Sand%	Silt %	Clay%	Texture	Silt/clay %	BD gcm ⁻³	Pd (gcm ⁻³	TP %	Ksat cm h ⁻¹
arable Plinthustalf	(Typic	67.78	18.78	13.44	Loamy sand	1.47	1.28	2.33	44.50	9.68
Arable11 (Arenic Paleustalfs)		79.03	13.28	7.69	Loamy sand	1.81	1.62	2.49	35.02	3.01
Acacia1 (Rhodic Paleustalfs)		67.78	19.28	12.94	Sandy loam	2.01	1.50	2.50	45.02	3.21
Acacia 11 (Typic Haplustalfs)		73.03	14.03	12.94	Sandy loam	1.29	1.40	2.40	41.48	2.09
Native1 (Typic Haplustalfs)		72.03	15.78	16.19	Sandy loam	1.08	1.60	2.50	36.17	2.39
Native 11 (Typic Rhodustalfs)		79.57	10.20	10.22	Loamy sand	1.57	1.59	2.39	49.09	1.49
Bare 1 Typic Paleustalf		75.08	14.52	8.6	Loamy sand	2.31	1.57	2.49	35.06	2.75
Bare 11 Typic Paleustalf		73.48	14.08	12.44		1.17	1.53	2.48	38.79	2.5

study reveals an appreciable increase in particle density with depth of soil horizons. Brady (1987) reported that particle density values increase with soil depth. Similar results were also reported by Idoga *et al* (2006) in soils of Samaru area, Nigeria. Porosity average mean values of acacia soil ranges from 41.48 to 45.02% native 36.17 to 49.09%, arable 44.50 to 35.02 and bare 35.06 to 38.79%. Maniyunda and Malgwi (2007) reported similar values in the soils of Zaria, Kaduna State. Fetter (1998), and Riue and Sposito (1991) recommended that soils having porosity of over 50 percent and 45-50 percent of volume are good agricultural soils. Soil porosity is lower in both land uses, this could be attributed to the clayey nature of the soils. hydraulic conductivity ranges from 1.49 to 9.68, The hydraulic conductivity of soils at Barema is moderate and there was no problem of flooding (Table 2). According to Lal *et al* (2004), the textural class, porosity, and the amount of organic matter influence the hydraulic conductivity of soils; thus, such parameters may be favorable for drainage condition.

Chemical Characteristics

Results of the chemical characteristics of the soils of Barema farm are presented in Table 4. The average mean for pH values of the soils is 6.06, 6.64, 6.11 and 6.00 for acacia, native, arable and bare land respectively. The pH was observed to increase or decrease irregularly with increasing depth. Similar trends were observed and reported by Yakubu and Ojanuga (2011). According to Landon (1991), a pH range of 5.5 to 7.0 is the preferred range for most crops. Organic matter is generally very low in the soils according to Landon (1991) ratings (>20 % very high, 10-20 % high, 4-10 % medium, 2-4 % low and < 2 % very low). The low

organic matter content of the soils in yobe State has been attributed to factors such as continuous cultivation, frequent burning of farm residues commonly carried out by farmers in the area which tends to destroy much of the organic materials that could have been added to the soil (Yakubu 2001). This results correspond to , Agbu and Ojanuga (1989) which stated that low organic matter content in soils of Sokoto area could be due to rapid decomposition and mineralization of organic materials contributed by sparse vegetation in the hot semi-arid climate as promoted by radiation Total Nitrogen average mean values for the pedons are 1.49, 1.04, 1.09 and 0.40 gkg⁻¹ for acacia, native arable and bare land respectively. Similar results of low N values were reported by Kparmwang (1996) in Bauchi State. The total nitrogen values of the soils in the area changed irregularly with depth which could be attributed to influence of continuous cultivation, a common practice in the area that is accompanied by nearly crop residue removal (Noma *et al* 2011). Electrical Conductivity (EC) average mean value for the pedons are 0.07, 0.07, 0.04 and 0.06 dsm⁻¹ for acacia native arable and bare land respectively. The average EC value of soil in acacia and native vegetation and bare land indicates salinity status in the soils. The Electrical Conductivity average mean values for arable land were generally low indicating the non-saline status of the soils according to the limits set by Schoeneberger *et al* (2002) and EC value of 0.03 to 0.07 dS/m was rated low based on the rating of Malgwi (2007). The values of exchangeable acidity in all the three soil units are 0.45, 0.36, 1.16 and 1.02

cmol(+)kg⁻¹ for acacia native arable and bare land respectively. There were generally the decrements on the value of exchangeable acidity with the increment of the depth of soils in study area. Soil mapping unit pH (H₂O) average values are 5.84 to 6.81, which was slightly acidic to neutral reaction similar to acacia and native vegetation, the soil mapping unit also had low status of organic carbon (1.06 to 3.42 g/kg), total nitrogen (0.11 to 0.86 g/kg), available

phosphorus (0.98 to 5.19 mg/kg) and carbon nitrogen ratio C/N (1.60 to 3.88). A narrow C/N ratio may give false indication of a good fertility status, if much of the nitrogen was coming from the non-exchangeable NH₄, which may not be readily available for the involved microbes during the short-wet spells in arid zones. The results show that the removal of fixed N from the total N substantially increased C/N ratios in the three profiles. The organic N being naturally small in these soils, will be substantially overestimated by contribution of non-exchangeable NH₄ held by clays. During the short-wet episodes, cyanobacteria and N fixing blue green algae may grow on wet soil crusts (Aranibar *et al*, 2003). Exchangeable acidity (H⁺⁺Al³⁺) average mean values of (0.34 to 1.89 cmol(+) kg⁻¹) were rated as generally low (<1.0 cmol(+)kg⁻¹). This implies that the soils have little or no acidity problems. Raji and Mohammed (2000) reported similar results and submitted that the contribution of exchange acidity to potential acidity is very low in soils of Nigerian savannas.

The soil mapping unit had medium to high exchangeable calcium range of 0.54 to 2.19

cmol(+)kg⁻¹ Calcium values were reported by several researchers (Yaro, 2005; Hussaini, 2011; Singh *et al.*, 2013). The predominance of Ca may be due to calcium bearing parent material in the soil (Nahusenay *et al.*, 2014). Sodium range of 0.37 to 1.17 cmol(+)kg⁻¹ while magnesium range of 0.45 to 1.5 cmol(+)kg⁻¹ was rated medium and potassium range of 0.14 to 0.58 cmol(+)kg⁻¹ was rated low to high (Malgwi, 2007). Exchangeable acidity (H⁺⁺Al³⁺) values of 0.33 to 1.89 cmol(+)kg⁻¹ was rated low (<1.0 cmol(+)kg⁻¹). CEC range of 3.79 to 5.79 cmol(+)kg⁻¹ was rated medium to high while base saturation range of 46.31 to 79.35 % was rated low to high and EC value of 0.04 to 0.09 dS/m was rated low based on the rating of (Malgwi 2007). All the soil mapping units were generally, characterized by slightly acidic to neutral reaction, low OC, TN and Ap but soil mapping units native and acacia recorded higher values in OC and Ap than soil mapping unit arable and bare land which could be attributed to higher rate of erosion as a result of the land clearing and other farming activities which characterize the arable land. These would confirm that soils of the Nigerian Savanna have inherently poor fertility status (Odunze and Kureh 2009). Mapping soil mapping units acacia unit 1 and native unit 2 recorded higher value of exchangeable Ca (1.07 and 2.19 cmol(+)kg⁻¹) and high Na in bare land (1.17 cmol(+)kg⁻¹) while soil mapping unit arable and native unit 2 land recorded the lowest value of K (0.14 cmol(+)kg⁻¹). The generally increasing subsoil exchangeable cation values could imply that nutrient minerals leached from the surface horizons

may have accumulated in the illuvial layers (Bt horizons). Mapping soil mapping unit bare land recorded the highest CEC (5.79 cmol(+) kg⁻¹) while soil mapping unit native recorded the lowest (3.79 cmol(+)kg⁻¹). Based on base saturation, soil mapping unit bare land recorded the highest value (79.35%) which could also be attributed to the lower location of this soil mapping unit which is been enriched with material from depth of the horizon. Generally, the result of variation reveals that there was no significant difference (p>0.05) in the physical and chemical properties within the four soil mapping units (Table 4)

The medium level of the CEC might be a reflection of the intensity of weathering that

produced the soils. The value of CEC indicated good nutrient retention, release and buffering capacity of the soil. Base Saturation (BS) of the soils were rated medium similar result was reported by Atofarati *et al.* (2012). Generally, BS increases down the profile. FAO (1999) reported that soils with base saturation of >50% are regarded as fertile soils while soils with <50% were regarded as not fertile soils. Based on this therefore, the soils are generally fertile. The electrical conductivity (EC) of the soils was rated very low. The EC value of soil was rated very low (< 4 dSm⁻¹), which indicates none saline electrical conductivity class. Similar result was also reported by Maniyunda and Gwari (2014) in Northern Guinea Savanna.

Table 3 average mean value for chemical properties in Barema Farm, Damaturu

Mapping unit	pH	EC dsm ⁻¹	OC gkg ⁻¹	TN gkg ⁻¹	C/N	AP mgkg ⁻¹	E.A cmol(+)kg ⁻¹
Arable (Typic Plinthustalf)	5.84	0.08	2.90	1.12	2.58	3.79	0.56
Arable11 (Arenic PaleustalFs)	6.29	0.06	2.65	1.86	3.11	2.17	0.34
Acacia1 (Rhodic PaleustalFs)	6.81	0.09	2.99	1.16	2.21	5.19	0.37
Acacia 11 (Typic HaplustalFs)	6.48	0.05	2.19	0.93	3.88	2.54	0.35
Native1 (Typic HaplustalFs)	6.11	0.05	3.42	1.11	2.69	3.42	0.43
Native 11 (Typic RhodustalFs)	6.12	0.04	2.53	1.07	2.62	2.27	1.89
Bare 1 Typic Paleustalf	6.00	0.05	1.06	0.69	1.69	0.98	1.70
Bare 11 Typic Paleustalf	6.00	0.07	1.41	0.11	1.60	2.08	0.33

Table 4 show average mean value of chemical properties of barema farm Damaturu.

soil mapping unit	Ca cmol(+)kg ⁻¹	Mg cmol(+)kg ⁻¹	k cmol(+)kg ⁻¹	Na cmol(+)kg ⁻¹	TEB cmol(+)kg ⁻¹	CEC %	BS %
arable (Typic Plinthustalf)	0.55	0.65	0.58	0.43	1.90	4.10	46.47
Arable11 (Arenic PaleustalFs)	0.64	0.96	0.14	0.58	2.33	4.17	54.42
Acacia1 (Rhodic PaleustalFs)	1.07	1.5	0.43	0.92	3.94	5.41	72.97
Acacia 11 (Typic HaplustalFs)	0.79	1.06	0.20	0.48	2.55	4.44	56.24
Native1 (Typic HaplustalFs)	0.54	0.75	0.17	0.37	1.92	3.79	50.65
Native 11 (Typic RhodustalFs)	2.19	0.79	0.14	0.49	1.94	3.88	46.31
Bare 1 Typic Paleustalf	0.68	1.10	0.40	1.17	3.35	5.79	72.26
Bare 11 Typic Paleustalf	0.90	0.45	0.44	0.38	3.02	4.36	79.35

These imply that salinization is not a significant pedogenic process in the soil and the soil does not contain a concentration of soluble salt that may hamper the growth of plant., the unit had low status of organic carbon (1.0 to 1.9 g/kg), total nitrogen (0.07 to 0.14 g/kg). Cation Exchange Capacity of the soils is generally low according to Esu (1991) rating of <6 low, 6-12 medium and >12 high. The low CEC of the soils could be attributed to the nature of clay minerals (kaolinite) Hassan *et al*; 2011). Yakubu *et al* (2011) opined that organic matter content of soils which normally

influences the CEC is generally low and therefore the CEC values may not be attributed to the amount of organic matter.

Soil Classification

The soils identified in the study are Pedon SU₁ P₁ (arable) Pedon SU₂ P₂ (arable), Pedon SU₁ P₁ (acacia veg), SU₂ P₂ (acacia veg), Pedon SU₁ P₁(native veg), Pedon SU₂ P₂(native veg), Pedon SU₁ P₁ (bare land) and Pedon SU₂ P₂(bare land) were classified according to the USDA Soil Taxonomy System (Soil Survey Staff, 1999) and WRB (2014) Soil Taxonomic Classification. The morphological, physical and chemical

properties of the profile were used to classify the soils using the above classification systems.

Soil moisture regime

Soils of the study areas have about six months of the rainy seasons-(May to October) with a mean annual rainfall between 600 to 1000mm. This implies that the soils were moist for less than 180 cumulative days, and are dry for 90 or more cumulative days. A rainy period of less than 180 days, suggest an Ustic Moisture Regime.

Temperature regime

The temperature regime of Pedon SU₁ P₁ (arable) Pedon SU₂ P₂ (arable), Pedon SU₁ P₁ (acacia veg), SU₂ P₂ (acacia veg), Pedon SU₁ P₁(native veg), Pedon SU₂ P₂(native veg), Pedon SU₁ P₁ (bare land) and Pedon SU₂ P₂(bare land) study sites are within the general temperature regime of Yobe State with the diurnal temperature regimes which ranges from 26 - 32⁰C, while the average daily temperature ranges from an average daily maximum of 31.6⁰C to an average daily minimum of 13.1⁰C with a relative humidity of 17-90% (Sowumini and Akintola, 2010). According to Olofin (1987), the temperatures can rise to as high as 38⁰C during the dry season and on the average drops to about 13⁰C in the harmattan season. The mean annual and monthly temperatures are 21 and 26⁰C relatively lower during the wet season and evaporation is never in excess of rainfall (Olofin, 1987). The soil temperature regime is Iso-hyperthermic, which suggests less than 6⁰C difference between mean summer and mean winter soil temperature (Soil Survey Staff, 1999).

Diagnostic surface horizons (epipedon)

Generally, the surface Pedon's of Arable land was slightly thick (21 to 23cm), with color value of 4, 5, 6, 7, 8 (moist), the organic

carbon ranged from 3.39 to 4.59 g/kg, with the percent base saturation by NH₄OAC of 37.06 to 66.30%. Acacia vegetation was slightly thick (19 to 25cm), with color value of 6, 7, 8 (moist), the organic carbon ranged from 2.99 to 4.59 g/kg, with the percent base saturation by NH₄OAC of 45.45% to 70.68%, Native vegetation was too thick (25 to 50cm), with color value of 4, 5, 6, 7, (moist), the organic carbon ranged from 3.12 to 5.39 g/kg, with CEC and the percent base saturation by NH₄OAC of 37.06 to 48.15 %. Bare land surface was slightly thick (20-22cm), color values are 6 and 7 (moist), the organic carbon ranged from 1.12 to 1.39 g/kg with percent base saturation by NH₄OAC of 57.95 to 60.65%. These pedons did not meet the definition for any of the other seven epipedons, in addition to their too little (low) organic carbon, absence of rock structure, color value of 4,5,6,7 and 8 (moist), they are too thin to be considered as either Mollic or Umbric, these epipedons are classified as (Ochric epipedons).

Diagnostic subsurface horizons (endopedon)

The diagnostic subsurface horizons of of Pedon SU₁ P₁ (arable) Pedon SU₂ P₂ (arable), Pedon SU₁ P₁ (acacia veg), SU₂ P₂ (acacia veg), Pedon SU₁ P₁(native veg), Pedon SU₂ P₂(native veg), Pedon SU₁ P₁ (bare land) and Pedon SU₂ P₂(bare land (profile 1-8) have the textural class of loam,

sandy loam, loamy sand, sandy clay loam and silty loam. They show evidence of clay eluviation as indicated by the presences of thin clay films lining the pores and ped surfaces. No densic, lithic, paralithic or petroferic contact within 50cm of the mineral soil, clay contents increased with depth, regular decrease of organic carbon with depth and CEC less than 16cmol (+)/kg by (1N NH₄OAC pH 7). With regard to these properties, all the profiles were qualified as being Kandic and Argillic diagnostic sub surface horizons

Classification according to USDA Soil Taxonomy

The soils of the study area were classified into various classes as shown in Table 5. According to USDA soil taxonomy, soil of acacia (P₁ & P₂), was classified as Rhodic Paleustalfs and Typic Haplustalfs and soil of native (P₁ & P₂), was classified as Typic Haplustalfs and Typic Rhodustalfs soil of arable (P₁ and P₂) was classified as Typic Plinthustalf and Arenic Paleustalfs and soil of bare land (P₁ & P₂) were both classified as Typic Paleustalf respectively.

Classification according to World Reference Base for Soil Resources (WRB, 2006)

The properties that qualify these pedons to be classified as Ochric epipedon are their low Organic carbon, absence of rock fragments too thin to be considered as either Mollic or too thin to be considered as either Mollic or Umbric and their failure to meet the definition of any of the other seven epipedons. According to the World Reference Base for Soil Resources (WRB, 2014), the soils of soil unit 1 profile 1(SU1P1) acacia and soil unit 2 profile 2 (SU2P2) acacia are classified as Haplic Lixisol, while soil unit 1 profile 2 (SU1P2) native and soil unit 2 profile 1(SU2P1) native are classified as Haplic Lixisol and Haplic respectively. In soil unit 3 profile 1 (SU3P1) arable the soil is classified as Haplic Lixisol. Soil unit 3 Profile 2 (SU1P2) arable, soil unit 4 profile 1 and 2 (SU4 P1 & P2) bare and soil unit 1 profile 2 (SU7P2) are classified as Plinthic lixisol respectively, (WRB,2006).

Classification of soils of the study sites based on USDA soil classification system

Soil classification was done employing the international soil classification system for naming soils, the USDA Soil Taxonomy Thirteenth Edition, 2022 and World reference base for soil resources 2014

Table 5 Summary of soil classification (USDA and WRB systems)

Pedon	USDA Soil Taxonomy	WRB 2014
SU ₁ P ₁ AR	Typic Plinthustalf	Haplic Lixisol
SU ₂ P ₂ AR	Arenic Paleustalfs	Haplic Lixisol
SU ₁ P ₁ AC	Rhodic Paleustalfs	Haplic Lixisol
SU ₂ P ₂ AC	Typic Haplustalfs	Haplic Lixisol
SU ₁ P ₁ NV	Typic Haplustalfs	Haplic Lixisol
SU ₂ P ₂ NV	Typic Rhodustalfs	Haplic Lixisol
SU ₁ P ₁ BR	Typic Paleustalf	Haplic Lixisol
SU ₂ P ₂ BR	Typic Paleustalf	Haplic Lixisol

USDA Soil Taxonomy Diagnostic Horizons and Properties

According to the USDA and WRB system the diagnostic horizons, properties and materials were determined prior to classification. The results are presented in Table 5. that have a texture class (fine-earth fraction) of coarse sand, sand, fine sand, loamy coarse sand, loamy sand, or loamy fine sand throughout a layer extending from the mineral soil surface to the top of an argillic horizon at a depth of 50 to 100cm Arenic Paleustalfs, other that have one or more horizons within 150 cm of the mineral soil surface in which plinthite either forms a continuous phase or constitutes one-half or more of the volume (Plinthustalfs). Other profile that has a texture class (fine-earth fraction) of coarse sand, sand, fine sand, loamy coarse sand, loamy sand, or loamy fine sand throughout a layer extending from the mineral soil surface to the top of an argillic horizon at a depth of 50 to 100cm Arenic Paleustalfs. Other profile has a lithic contact within 50 cm of the mineral soil surface Hue of 7.5YR or redder and chroma of 5 or more in 50 percent or more of the matrix; *or* Common or many coarse redox concentrations with hue of 7.5YR or redder or chroma of 6 or more, or both (Haplustalfs)

WRB Reference soil groups of the study area

Based on the classification key, as argic horizon starting ≤ 100 cm from the soil surface was described in all profiles, and the presence of low activity clays in the argic horizon and base status (in half or more of the part between 50 and 100 cm from the mineral soil surface) was confirmed by laboratory analyses, all the 8 soil profiles

were classified as (Haplic Lixisol) according to the World reference base for soil resources (2014).

CONCLUSION

Characterizations of soils of Barema reveal that the soils were medium in inherent fertility though low OC, TN and Ap characterize all the four mapping units. Soil mapping unit arable land was deep, well drained, and texture ranges loam to loamy sand. Soil reaction was slightly acidic to neutral, OC, TN and Ap was rated low while exchangeable bases was rated medium to high. CEC and BS were rated medium. They were classified in the order Alfisol, sub order Ustalfs. At the Great Group and Subgroup as Plinthustalf, at the group level as Typic Plinthustalfs since Sub groups have not been identified for the Great group Plinthustalfs (Soil Survey Staff, 2022). They were classified as Lixisols, and at the lower level, as haplic Lixisols (WRB, 2014). Soil mapping unit acacia was also too deep, well drained, occurring on flat (0-2%) to moderately level landform and texture ranges loam to sand clay loam. Soil reaction was slightly acidic to neutral, OC, TN and Ap was rated very low while exchangeable bases were rated medium to high. CEC was rated medium to high while BS was rated low to high. All land uses was classified into the order alfisols, at the suborder level as Ustalfs The low to medium fertility status of the soils of Barema farm can sustain crop production on a long-term basis under continuous crop production program. Therefore, organic matter has to be substantially increased through effective crop residue management, increased use of leguminous plants as well

as the use of nitrogenous and phosphate fertilizers. For sustainable crop production, there is need for guided inorganic fertilizer use and improved management practices which will enhance and maintain soil quality and productivity in all the soils. This study has brought out clearly relevant soil information that can guide decision on the use and management of soils of the area on a sustainable basis.

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EFFECT OF SLOPE POSITION AND LAND USE ON SOIL CHEMICAL PROPERTIES IN A FOREST-CULTIVATED-FALLOW-GRASSLAND CONTINUUM AT NSUKKA, EASTERN NIGERIA.

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ABSTRACT

For sustainable nutrient management, it is necessary to analyze regional landscapes and soil associations since soil attributes are anisotropic in nature. The research work was conducted on four different land use types in Ugwu Ataba, Onuyi Edem-Nru, in Nsukka, Enugu State to determine the effect of slope position and land use on soil chemical properties in transect of forest-grassland-cultivated-fallow continuum. Soil samples were collected at depths of 0-20cm and 20-40cm on each of the land use types along the transect and were subjected to chemical analyses following standard procedures. Results showed significant differences ($P < 0.05$) among the chemical properties of the different land use types. The soil pH (H_2O) was significantly higher at the grassland (5.54) than at the forestland (4.64). The soil organic carbon was significantly higher at the forestland (1.43 g/kg) than at the fallow land (0.75 g/kg), both exchangeable K and acidity were significantly higher at the forestland than at the grassland but the CEC was significantly higher at the grassland (20.04 Cmol/kg) than at the fallow land (8.12 Cmol/kg). Soil depth significantly ($p < 0.05$) affected the organic carbon, total nitrogen, exchangeable bases and available phosphorus. Organic carbon, exchangeable Ca, Na, and K as well as available P were significantly higher at 0-20cm than at 20-40cm depth. This study clearly demonstrated that land-use type impacted on most soil chemical properties more than slope positions. The study showed that forestland and grassland tended to retain more nutrients and were less likely to lose nutrients through leaching than the other land use types. Irrespective of the topographic positions across the land use types topsoils contained more nutrients than the subsoils.

Key words: slope, land use continuum, soil chemical properties

INTRODUCTION

Soils provide a wide range of ecosystem services that meet human needs such as the supply of food, wood, fibre, raw materials, and physical support for infrastructure; regulating services, which include flood mitigation, nutrient and contaminant filtering, carbon storage and greenhouse gas regulation, detoxification and waste recycling, and population control of pests and diseases; as well as cultural services, which include recreation, aesthetics, heritage values, and cultural identity (Dominati *et al.*, 2014). Soils vary in their physical, chemical, morphological and

mineralogical characteristics and topography happens to be a major factor which controls most surface processes taking place (Esu *et al.*, 2008). Topography plays vital role in bringing about changes in soil properties from the crest position down to the valley bottom (Egbuchua, 2014).

Topography is the dominant factor influencing soil property variation due to its influence on runoff, drainage, microclimate, and soil erosion (Wang *et al.*, 2001). It also affects hydrological and soil processes at the landscape scale which is also reflected in the concept of soil catena. Its geometry; such as slope angle, length and curvature influence

runoff, drainage, and soil erosion (Aandahl, 1948) causing significant differences in soil properties (Brubaker *et al.*, 1993). Slope gradient and slope length have direct and indirect effects on calcification, mineralization and soil physicochemical properties (Nejad and Nejad, 1997). The slope position, i.e. the relative height along the hill slope controls the movement of water and eroded materials, thus contributing to the spatial differences in soil properties along the hill slope (Begum *et al.*, 2010; Khormail *et al.*, 2007). Many soil properties including particle-size distribution, pH, and organic matter content vary substantially with the slope position (Wang *et al.*, 2001). More so, changes in slope inclination have a major impact on soil erosion thereby causing significant loss of finer soil particles (Carroll *et al.*, 2000). Processes of this nature are rarely uniform, and often form a spatial variability along the slope in the topsoil layer.

Similarly, changes in land use and its alterations on the ecosystem can significantly affect soil physical, chemical, and biological properties. The driving agents consist of high population pressure, excessive livestock pressure on grassland areas, changes in land use, inappropriate agricultural practices, massive deforestation of natural forest (farm expansion, fuel, and construction), agricultural expansion (cultivation of steep slopes and marginal areas), and the ruggedness of the landscape. Changing land use from forests to croplands leads to a change in the chemical, physical and biological properties of the soil (Houghton *et al.*, 1999; Zhang *et al.*, 2004; Viollete *et al.*, 2009). With shifting agriculture and livestock production in the twenty-first

century, it is predicted that 25% of the Earth's surface will be covered by cropland, a major change from the twentieth century. Globally the decreasing rate of forests was about 1.7% in the period of 1990 to 2005, especially in Africa where 1.6 million hectares of forest areas were lost per year (FAO and JRC, 2012).

Therefore, it is very important to study the impact of slope position and land use change on chemical properties, which can help policy makers and different stakeholders to have a proper land use planning aiming at replenishing soil fertility, protecting forests and restoring the degraded ecosystem. Hence, this study aimed at examining the effects of slope position and land use on soil chemical properties in transect of forest-cultivated-fallow-grassland continuum at Nru Nsukka, Nigeria.

MATERIALS AND METHODS

Site Description

Location and Background of Study

The study area was at Ugwu Ataba, Onuyi Edem-Nru, in Nsukka, Enugu State on four different land uses. It lies within the latitude 6° 26', 24.72" N and longitude 7° 29', 39.48" E in the humid Savannah zone of South Eastern Nigeria on an elevation of 447.2 m above mean sea level (Okobiom and Asiegbu, 2006).

Climate

These soils experience high temperatures as well as intense, erosive rains, which causes erosion and leaching. In this part of the world, the rainy season and the dry season dominate the climate. The average annual rainfall is approximately 1550 millimeters, with 85 percent of the precipitation occurring between the months of April and October. Average

minimum and maximum temperatures are 22°C and 30°C, respectively. On average, the relative humidity is approximately 60% throughout the years, respectively (Asadu *et al.*, 2002).

Land Use and Vegetation

In a soil-landscape system, the natural vegetation of Nsukka is generated from a Savannah agro-ecological zone with diverse land uses, including forestry, fallow, cultivated areas, and grasslands.

Geology and Soils

Asadu (1990) reported that soil in Nsukka located in the Eastern Nigeria are generally derived from the residual of false-bedded sand-stone or upper-coal measure formations as a result of disintegration of rock. These geological formations give rise to the sandy and clayey soils respectively (Akamigbo and Asadu, 1983). Akamigbo (1984) found that the silt content of the soils of Eastern Nigeria within the study area is low and the soils are generally very low in plant nutrients.

Agriculture

After thorough investigation, it was discovered that the region's principal agricultural method is a traditional, rain-fed, subsistence-based approach. The most common agricultural practices in the research region include continuous cultivation, bush fallowing, mulching, organic manure, and overgrazing. The principal source of income for all residents of the farming community is the production of cassava, maize, yam, pigeon pea, egg plants, oil palm, and pumpkins.

Soil Sampling

Following a reconnaissance visit to the location, a transect cutting across different slope position with fallow plot on the toe

slope, cultivated land on the foot slope, grassland on the middle slope and forestland on the upper slope was established; all the land use types being in a continuum. Triplicate soil samples were collected each of the land use types from 0-20 cm and 20-40 cm depth using an auger. A total of thirty-eight (38) soil samples were collected. They were properly marked and packaged in polythene bags. The soil samples were air-dried, gently crushed, and passed through a 2-mm sieve to obtain fine earth separates for routine analysis. Separate soil core samples from the 0-20cm and 20-40cm depths were collected using a sharp-edged steel cylinder (core sampler) manually inserted into the soil. These samples were used to determine the bulk density and pore-size distribution.

Soil Laboratory Analysis

All the analyses were conducted in the Department of Soil Science laboratory, University of Nigeria, Nsukka following standard laboratory techniques.

Soil Chemical Properties

Total nitrogen (N) was determined using the Kjeldhal digestion, distillation and titration as method described in a study (Bremner, 1996).

Soil pH was determined in 1:2.5 soil-water medium by weighing 10 g of 2 mm sieved soil samples into 50 ml beaker and 25 ml of water was added. The sample solution was stirred up intermittently using a glass rod. The samples were allowed to stand for 30 minutes after which the soil pH was taken using a digital electronic pH meter.

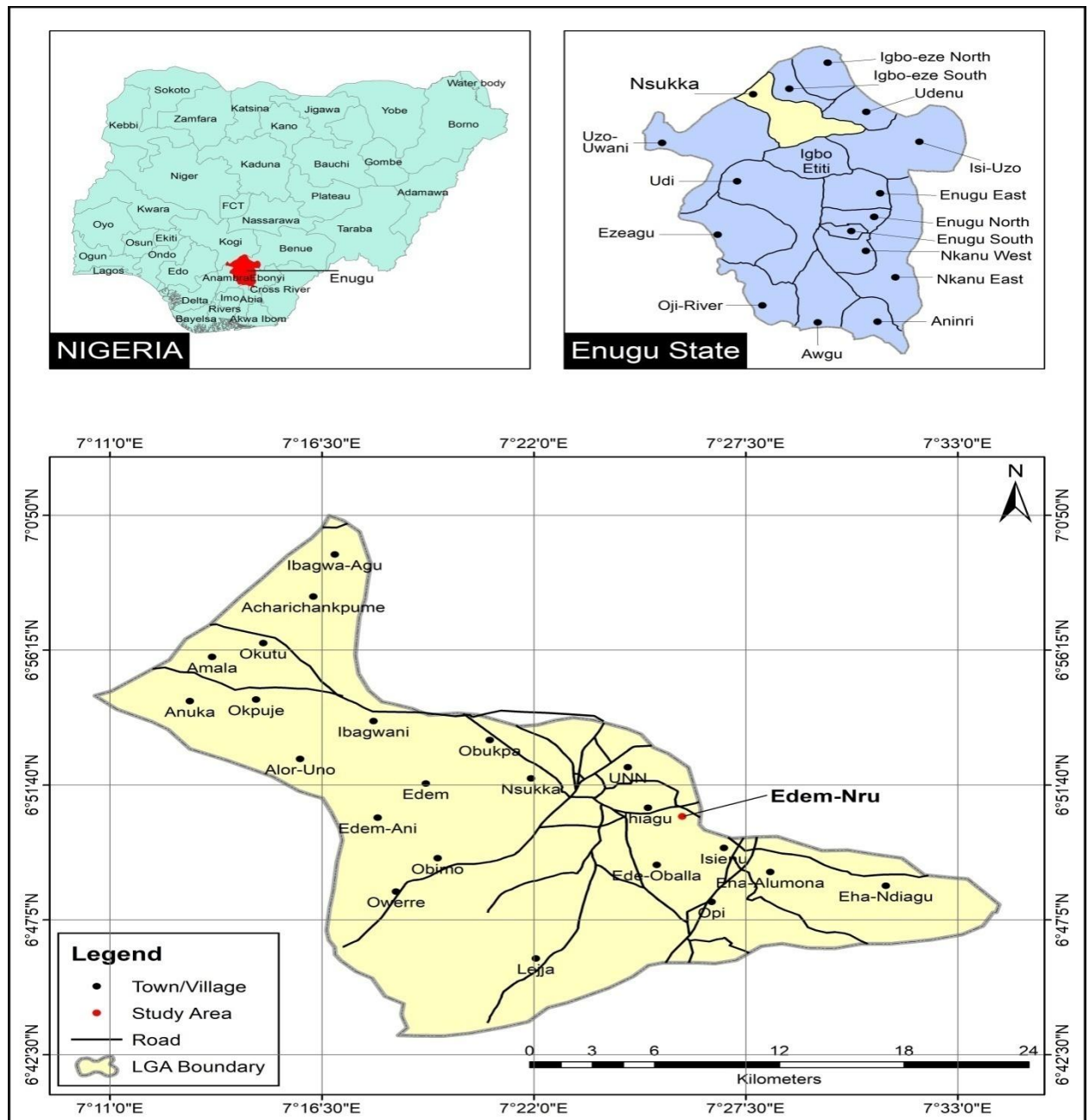


Fig. 1: Map of study area at Edem-Nru Nsukka

The organic carbon content was determined by Walkley-Black method of wet combustion involving oxidation of organic matter with potassium dichromate ($K_2Cr_2O_7$) and sulphuric acid (H_2SO_4) (Nelson and Sommers, 1996). The values of organic carbon were converted to organic matter by multiplying with the factor 1.724.

Available phosphorus (Av. P) was extracted using the Bray (II) method

(Bray and Kurtz, 1945) and the value measured using a colorimeter following the principle of light (Murphy and Riley method).

Exchangeable calcium and magnesium, potassium, sodium and Cation Exchange Capacity were carried out according to (Thomas, 1982).

The exchangeable acidity was determined by extraction with 1.0 M KCl solution and titrated with NaOH and HCl solutions to

measure total acidity (Al^{3+} and H^+) concentrations respectively (McLean, 1965).

Data Analysis

Analysis of variance (ANOVA) was performed on soil data. The GenStat Statistical Package was used to estimate the levels of significance of the parameters

at $P (<0.05)$ using the LSD technique of mean separation.

RESULTS AND DISCUSSION

The Effect of Land use on the Chemical Properties of Soil

The pH values obtained (Table 1) showed that the soils were acidic in nature and ranged from extremely acid to moderately acid, with values ranging from 4.64 to 5.5 (H_2O) and 3.91 to 4.3 (KCL) agreeing with the values reported by Aduayi and Ekong (1981). The mean pH values in H_2O was higher than that in KCl indicating a net negative charge in the soils. In southeastern Nigeria Enwezor *et al.*, (1981) noted that the pH values in H_2O are generally higher than pH in KCl. The soil acidity might be linked to its humid nature of the environment, which is characterized by excessive rainfall that tend to encourage erosion and leaching processes. These processes tend to remove most basic cations, leaving behind hydrogen and aluminum ions that can induce soil acidity. Aluminum ions cause acidity by hydrolysis reaction while hydrogen is by direct dissociation (Brady and Weil, 2007). The pH value of the cultivated land was high due to the intense parent materials weathering, lime application, organic and inorganic fertilizer applications by the farmers. The forest land use recorded the lowest pH

value of (4.64), this could be attributed to the fact that it is on the upper slope and as such prone to intensive erosion and leaching of the basic cations. Enwezor *et al.*, (1981) noted that most soils become acidic due to intensive leaching. In strongly acidic soils, Al^{3+} becomes soluble and increase soil acidity while in alkaline soils; exchangeable basic cations tend to occupy the exchange sites of soils by replacing exchangeable H^+ and Al^{3+} ions (Miller and Donahue, 1995; Eylachew, 1999; Brady and Weil, 2002).

The organic carbon content is often low in most soils of the tropics according to Esu (1991). Land use change is an important factor controlling soil organic carbon (SOC) storage since it affects the quality of litter inputs, the litter decomposition rate and the processes of soil organic matter stabilization (Shepherd *et al.*, 2001). The higher OC in forest land use is in line with the report from Moscatelli *et al.* (2007) which indicated that clearing tropical forests and conversion into farmland lowered by 20-50% in SOM content as cultivation generally aerates the soil and increases OM oxidation rates. The study conducted by Hu *et al.* (2019) revealed that forest land use has higher soil organic carbon (OC). The low OC in cultivated could be attributed to continuous cultivation and inappropriate management according to Majule (2003). According to Isirimah *et al.* (2003), organic matter is significant in many tropical soils for a variety of reasons, including improved fertility status. Asadu *et al.* (2013) concluded that organic matter is significantly important for both storage and release of nutrient ions in tropical soils notably in the ultisols that are dominated by low activity clay.

Land Use	pH	pH	OC	TN	Ca ²⁺	Mg ²⁺	Na ⁺	K ⁺	CEC	EA	P
	in H ₂ O	in KCl	(g/kg)								(mg/kg)
Cultivated	4.82	3.91	1.027	0.227	0.7	0.48	0.1159	0.1168	8.96	2.16	8.11
Fallow	4.93	4.12	0.751	0.251	0.62	0.42	0.1674	0.1598	8.12	2.22	6.99
Forest	4.64	3.92	1.425	0.302	0.6	0.48	0.1674	0.1889	14.24	3.9	6.06
Grassland	5.544	4.305	0.87	0.252	0.7	0.52	0.1747	0.1132	20.04	2.1	3.26
F-LSD	0.19	0.24	0.17	Ns	Ns	Ns	0.03	0.03	1.63	1.32	Ns

Table 1. Effect of land use on the chemical properties of soil

OC: Organic Carbon; TN: Total Nitrogen; Ca²⁺: Exchangeable Calcium; Mg²⁺: Exchangeable Magnesium; Na⁺: Exchangeable Sodium; K⁺: Exchangeable Potassium; CEC: Cation Exchange Capacity; EA: Exchangeable Acidity; P: Available Phosphorus. Organic carbon content (Table 1) was significantly higher in the forest land use than in

Total nitrogen was also significantly higher in forest land use type and lowest in cultivated land use type this supports the work of Hu *et al.* (2019) who found in their study that forest land use has higher total nitrogen (TN) than a cultivated land use system. The total nitrogen values ranged from 0.22 g/kg to 0.30 g/kg (Table 1) and this is considered to be high according to the rating of Esu (1991). When compared to the other land use types, cultivated land had the lowest value, which might be related to the quick mineralization of organic matter from crop residue, leaching, and erosion. Mulugeta (2004) and Gebeyaw (2007) in their investigations got comparable results when comparing cultivated fields to uncultivated fields. However, this difference was statistically non-significant in this study.

Exchangeable Ca²⁺ and Mg²⁺ ranged from 0.6 Cmol/kg to 0.7 Cmol/kg and 0.42 Cmol/kg to 0.52 Cmol/kg respectively (Table 1). The values for Ca²⁺ are considered low and that of Mg²⁺ are

considered medium according to the rating of Esu (1991). These values recorded for both Ca²⁺ and Mg²⁺ could be linked to the dominance of low activity clay, low organic carbon content; the nature of parent material, intense weathering, erosion and leaching effects in the humid region which cause loss of colloidal matters (Isirimah *et al.*, 2003; Egbuchua, 2007). However, the values among the land use types were statistically non-significant (Table 1).

Exchangeable Na⁺ and K⁺ ranged from 0.11 Cmol/kg to 0.16 Cmol/kg and 0.11 Cmol/kg to 0.18 Cmol/kg respectively (Table 1). The exchangeable bases across the land use types were seemingly low (Esu 1991). This could be attributed to the dominance of low activity clay, low organic carbon content; the nature of parent material, intense weathering, erosion and leaching effects in the humid region which cause loss of colloidal matters (Isirimah *et al.*, 2003 and Egbuchua, 2007). The low content of

exchangeable sodium (< 0.3) is an indication that sodicity would not be a problem if proper soils and water management are observed. The low value of exchangeable potassium observed on cultivated land use type corroborates with the findings by Majule (2003) where clearing the natural forest in most parts of the upper zones for cultivation contributed significantly to the reduced level of SOC, N, and K^+ in the soil.

The Cation Exchange Capacity (CEC) values ranged from 8.12 Cmol/kg to 20.04 Cmol/kg with values from grassland and forest land use types statistically higher than those from cultivated and fallow land (Table 1). The mean value from grassland was statically higher than that from the forest land while those from the cultivated and fallow lands were similar statistically. The CEC values of the soils are rated high according to the rating by Esu (1991). High values of CEC is often attributed to the high specific surface area of the clay particles.

The exchangeable acidity was rated medium in all the land use types according to the rating by Esu (1991). The mean values ranged from 2.1 Cmol/kg to 3.9 Cmol/kg (Table 1). These values which are considerable high FMNAR (1996) would have stemmed from the leaching of basic cations by rainfall and the low pH values of the soil (Brady and Weil, 2007).

The highest available P value was reported from the cultivated land use type, while the lowest value was from grassland which is in line with the findings of Beyene (2017) who reported that, in southern Ethiopia, soils of cultivated lands have higher available phosphorus (P) content, whereas exchangeable bases, OC and CEC, were higher in grasslands. This drop, while, was not statistically significant. Low levels of

reserved phosphate minerals in the soil and its parent material are reflected in the figures, which ranged from 3.26 mg/kg to 8.11 mg/kg (Table 1) (Akamigbo and Asadu, 1983). Once more, the soils' acidity and phosphorus fixation by sesquioxides have been cited as contributing causes to the low phosphorus content of soils (Brady and Weil, 2007). However, the differences among the values from the land use types were statistically non-significant (Table 1).

Effect of Soil Depth on the Chemical Properties of Soil

Across the two soil depths (0-20 and 20-40 cm), the mean pH values obtained were in the acid range from 4.949 to 5.018 (H_2O) and 4.04 to 4.088 (KCl) but the differences were statistically non-significant (Table 2). This trend was similar to exchangeable Mg, CEC and exchangeable acidity. However, the mean values OC, TN, exchangeable Ca, Na, K and available P were significantly higher at the 0-20 cm depth than at 20-40 cm depth (Table 2). All these properties are often linked to organic matter content (McAlister *et al.*, 1998) which is often higher in the topsoils than in the subsoils as obtained in this study. Lalissa *et al.* (2010) also reported that OC, TN and P declined with depth for cereal farm. The values obtained were significantly different.

CONCLUSION

This study clearly demonstrated that land use type impacted on most soil chemical properties but along a toposequence of fallow-cultivated-grassland-forest continuum the impact can be influenced by the topographic position. In this study the forest land on the upper slope and the grassland on the middle slope tended to contain more nutrients than cultivated land on foot slope and fallow on the toe slope positions. Thus, forestland and grassland retained more nutrients than the fallow and

cultivated lands probably due to longer the land use types indicated that periods of undisturbed soil cover compared irrespective of the topographic position to fallow and cultivated lands. Comparison topsoils contained more nutrients than the of topsoil and subsoil fertility status across subsoils.

Table 2: The Effect of Soil Depth on the Chemical Properties of Soil

Soil Depth	pH	pH	OC	TN	Ca ²⁺	Mg ²⁺	Na ⁺	K ⁺	CE	E	Av. P
Cm	in	in	(g/kg)								(mg/k
	H ₂ O	KCl									g)
0-20	5.018	4.088	1.136	0.29	0.78	0.53	0.170	0.164	13.18	2.5	7.88
				3			1	4		4	
20-40	4.949	4.04	0.9	0.22	0.53	0.42	0.142	0.125	12.5	2.6	4.34
				3			5			5	
F-LSD	Ns	Ns	0.12	0.05	0.18	Ns	0.02	0.02	Ns	Ns	2.95

OC: Organic Carbon; TN: Total Nitrogen; CEC: Cation Exchange Capacity; EA: Exchangeable Acidity; Av. P: Available Phosphorus; Ns: Not Significant.

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2138-1_19](https://doi.org/10.1007/978-1-4020-2138-1_19)

DIGITAL MAPPING AND USE OF ALGORITHMS FOR QUANTITATIVE PEDOLOGY (AQP) IN VISUALIZING AND INTERPRETING SOIL PROFILE DATA FOR SUSTAINABLE LAND MANAGEMENT IN GURUMPAWO TOPOSEQUENCE

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ABSTRACT

Digital soil mapping plays crucial role in soil surveys now and into the future. Algorithms for Quantitative Pedology (AQP) is a collection of code, ideas, documentation, and examples wrapped up into several R packages. The study was carried out in Gurumpawo, Ganye, Adamawa State, aimed at developing digital soil maps with spatial distribution of soil properties in the study area and generating visual images of profile data using AQP for sustainable management. Desk work was carried out through download of digital elevation model (DEM) and classifying the toposequence into five mapping units using elevation on ArcMap 10.7.1, and basemap generated for field survey from a 26.42 ha toposequence with the largest area of 10.22 ha in the floodplain. Profile pits were dug and soil samples were collected. Digitization was carried out using toggle editing, snapping tool and symbology editing on ArcMap to delineate the boundary of the mapping units. Spatial interpolation was carried out using ordinary kriging method. Visual analysis of the soil profile data was carried out using R Studio 2024.12.0 using AQP package R script on the R console. The toposequence was delineated into crest, upper, middle and lower slopes and, floodplain. Spatial interpolation results revealed the distribution trend of soil properties across the landscape. Soil colour ranged from strong brown (7.5YR 4/6) at the crest to olive and yellowish brown (2.5Y 4/3 to 10YR 5/6) at the floodplain; while soils were well drained at the upper slopes to very poorly and poorly drained at the lower slopes. Soil management by controlling erosion through contour cropping and addition of organic matter by mulching and manuring were recommended at the upper slopes while drainage ditches and establishing crops tolerant to waterlogged conditions at the lower slopes were also recommended.

Keywords: Algorithms for Quantitative Pedology; Digital mapping; Profile data; Toposequence.

Introduction

Traditional soil surveys are cumbersome and time demanding due to their reliance on hand-drawn maps and physical observations which are less accurate. This trend is now replaced with a more data integration and empirically driven digital soil mapping (DSM) that significantly

improves efficiency and accuracy of soil surveys with georeferenced data that could easily be verified. Digital soil mapping plays crucial role in soil surveys now and into the future. The use of geographic information system (GIS) in soil mapping is called digital soil mapping, which

involves creating geographically referenced soil databases from spatially explicit environmental features and field surveys (USDA, 2022).

Digital mapping utilizes technologies like global positioning system (GPS), remote sensing, and GIS to collect and analyze soil data. This enables a more thorough understanding of soil distribution and characteristics by enabling the quick production of spatially explicit soil maps with higher resolution and the integration of multiple environmental layers including; topography, climate, and vegetation. As a result, digital mapping makes it easier to make better decisions about soil management, land-use planning, and environmental modeling, which eventually results in more resource management and sustainable agricultural practices.

Algorithms for Quantitative Pedology (AQP) is a collection of code, ideas, documentation, and examples wrapped up into several R packages (Beaudette *et al.*, 2023). Since its inception in 2009, the AQP project has developed into a suite of related R packages that improve and streamline the quantitative analysis of soil profile data (Beaudette *et al.*, 2022). In addition, Pinheiro *et al.* (2018) stated that AQP contains a collection of algorithms to model soil resources and aid soil classification, soil profile aggregation and visualization. At the heart of the AQP project is a new vocabulary of specialized functions and data structures that can handle the inherent complexity of soil profile information, allowing the scientist to concentrate on ideas rather than repetitive data processing tasks. These functions and data structures have undergone extensive testing and documentation, been applied to projects

involving hundreds of thousands of soil profiles, and have been deeply integrated into popular tools like SoilWeb (O'Geen, 2024).

The AQP project's components (aqp, soilDB, sharpshootR, and soilReports packages) are essential to routine data analysis within the USDA-NRCS Soil Science Division. The AQP suite of R packages offer a convenient platform for bridging the gap between pedometric theory and practice (Beaudette *et al.*, 2022). Soil scientists now favour showing visual results of soil profiles than description alone. Costa *et al.* (2021) used AQP to evaluate dissimilarity between soil profiles on the bases of some key soil properties and landscape relationship and presented their result visually. Peng and Luotto (2021) showed steps in preparing soil profile data for digital soil mapping and script analysis of pedotransfer functions using AQP. Therefore, this study was carried out to delineate the toposequence into identified topographic positions, develop digital soil maps with spatial distribution of soil properties in the study area and generating visual images of profile data using the AQP for sustainable soil management.

Materials and Methods

Study Area

The study was carried out in Gurumpawo, Ganye, Adamawa State, Nigeria. The area is geographically located within the Universal Transverse Mercator (UTM) coordinate reference system (CRS), specifically Zone 32N (EPSG:32632 - WGS 84 / UTM Zone 32N). The extend of the study area lies between longitude 0821700 m to 0822900 m Easting and latitude 934200 m to 934500 m Northing, Figure 1.

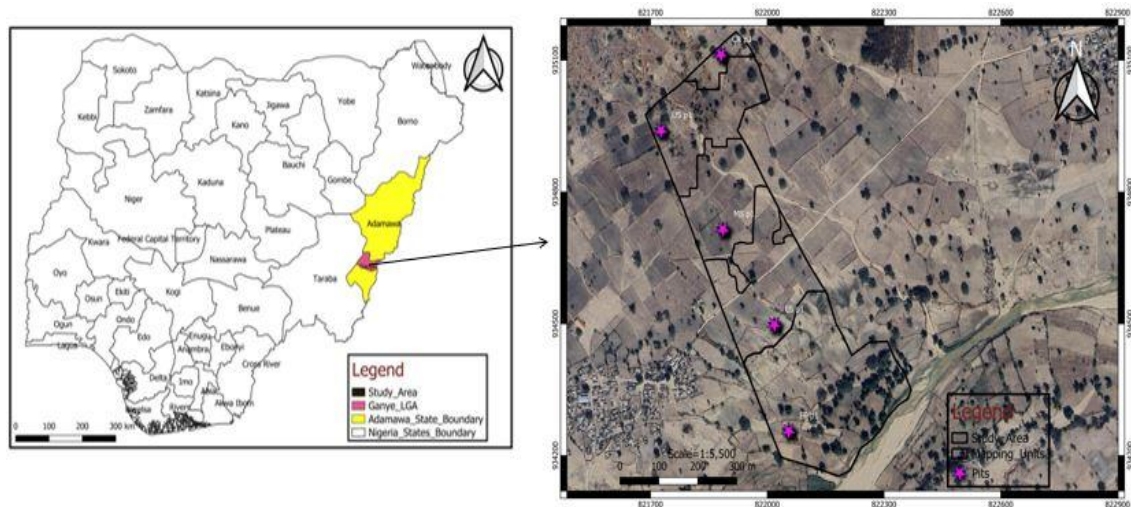


Figure 1: Location Map of the Study Area

Geology and Climate of the Study Area

The study area in Gurumpawo, Ganye, Adamawa State and it is part of the Nigerian subterranean basement complex. This region is characterized by precambrian rocks, such as granites, gneisses, and migmatites, which are found in the larger Adamawa Massif region (Ahmed *et al.*, 2017). The region is predominated by biotite, quartz, muscovite, feldspar, plagioclase minerals of the granitic rocks exposed in the region from petrographic analysis carried out by Obiefuna *et al.* (2012).

The climate of the area exhibits a West African Savannah climate characterized by consistently high temperatures influenced by intense solar radiation and its continental location. Temperatures peak between January and April (30-35°C), with brief reductions during the onset of the rainy season and the Harmattan period (October-February). Rainfall, critical for the region's rainfed agriculture-dependent economy, ranges from 1500 to 1800 mm annually, concentrated between May and October, with August and September experiencing

the highest precipitation. This bimodal seasonal pattern is driven by the interplay of dry, desert-derived Harmattan winds and moisture-laden Atlantic Ocean air masses.

Desk work

Digital elevation model (DEM) was downloaded from the United States Geological Survey (<https://earthexplorer.usgs.gov/>) using the Shuttle Radar Topography Mission/ Arc-Second Digital Terrain Elevation Data-Global (SRTM/Arc-Second Global) at 30 m resolution. The DEM was used to classify the toposequence into crest, upper, middle and lower slopes and, floodplain as described by Soil Science Division Staff (2017) using elevation on ArcGIS 10.71. Basemap was generated for field survey from a 26.42 ha with the largest area of 10.22 ha at the floodplain and proposed sites were placed on the maps on each mapping unit using the satellite imagery on ArcGIS.

Field Survey

The basemap was loaded on Avenza Map App and ground-truthing of the study area was carried out to identify the location of

the pits and adjustments made where necessary. Profile pits were dug using the standard dimensions of 2 x 1.5 x 2 meters or to a depth of impenetrable layer or water table and soil samples were collected from each of the diagnostic horizons of the pits as described by Soil Survey Staff (2014) guidelines.

Post-Field Desk Work

After the field survey, map digitization was carried out using toggle editing, snapping tool and symbology editing on ArcGIS to delineate the boundary of the mapping units. Different colour symbology and inversions were used to identify the different mapping units. The field calculator function on ArcGIS was used to calculate the total area of each mapping unit in hectares.

Laboratory Analysis

Soil samples were air dried at room temperature, gently crushed and passed through a 2mm sieve for the analysis. Particle size analysis was carried out using the Bouyoucos hydrometric method as described by Soil Survey Staff (2014). Soil bulk density was determined by the undisturbed core sampler method after drying the soil samples in an oven at 105°C to constant weights as described by Jaiswal (2004). Also, Particle density was determined by using the pycnometer method (Blake and Hartge, 1986). Soil total porosity was also calculated using the following formula;

$$F = 1 - (Db/Dp) \times 100$$

Where:

F = Total Porosity

Db = Bulk density

Dp = Particle density

The gravimeter technique of soil moisture content determination by weight was used as described by Gardner (1986). Soil pH

was determined using a 1:2.5 soil to water ratio using a glass rod and an electrode pH Meter. Soil organic carbon was determined using the dichromate wet combustion method by Walkley-Black as described by Nelson and Sommers (1982).

Spatial Analysis on ArcGIS

Spatial interpolation was carried out using ordinary kriging method. The kriging process involves several steps: first, constructing a semi-variogram to model spatial dependence; second, using the semi-variogram model to estimate the kriging weights; and finally applying these weights to predict unsampled points (Douzouné *et al.*, 2024).

$Z'(x_0)$, the predicted soil property at unsampled location x_0 , and by $\sigma^2(x_0)$, the error variance of the prediction computed at each sampled location using measured values,

$Z(x_i)$ ($i = 1; 2; n$), by means of the following equation:

$$Z'(x_0) = \sum_{i=1}^n \lambda_i Z(x_i) \quad \text{eq. 1}$$

Where:

$Z'(x_0)$ this is the estimated value of the soil properties at location x_0 .

λ_i this is the kriging weights for the sampled locations i .

$Z(x_i)$ this is the measured values of the soil properties at the sampled locations i .

n this is the number of sampled locations.

$$\sigma^2(x_0) = \mu + \sum_{i=1}^n \lambda_i \gamma(x_0 + x_i) \quad \text{eq. 2}$$

Where:

μ this is the range constant in the process.

λ_i this is the kriging weight.

γ this is the semi-variogram values corresponding to the distance between $x_0 + x_i$.

AQP Analysis

Visual analysis of the soil profile data was carried out using R Studio 2024.12.0 using AQP package R script on the R console. Twelve (12) steps where scripts were written for the profile data analysis;

i. The working directory on the R console was Set. This function was used to located the .csv file in the folder `{setwd()}`.

ii. All necessary library were loaded and these packages were installed from the installation passages responsible for librarying and analyzing soil profile data.

```
library(readr); library(aqp);  
library(sharpsheetR).
```

iii. The soil profile data was read on the R console using `data <- read.csv("solo_poksmen.csv", header = TRUE)`.

iv. Data formatting was carried out using R codes which arranged the data in a readable and suitable format;

```
data$Id <- as.factor(data$Id)  
data$Top <- as.numeric(data$Top)  
data$bottom <-  
as.numeric(data$bottom)
```

v. Then, the data was ordered by the 'id' and 'depth' from the profiles using script; `data <- data[order(data$Id, data$Top),]`

vi. A script for SoilProfileCollection object was written which is a specialized data structure for soil profile on the .aqp package on R.

```
depths(data) <- id ~ top + bottom.
```

vii. Soil colour information was then extracted using R script `munsell2rgb()` which converted Munsell colour

notations (hue, value, chroma) to RGB (red, green, blue).

viii. Site level data was added and this function from .aqp added site level

information to the SoilProfileCollection on the R console `{site(data) <- ~ Soil_unit}`.

ix. Various scripts were then written to plot the soil profiles and adjust the profile data. Some scripts are;

```
op <- par(mar = c(0)) # Adjust  
margins for plotting
```

```
plotSPC(data, name = 'name',  
name.style = 'center-center', width = 0,  
cex.names = 0, cex.id = 0,  
cex.depth.axis = 0, max.depth = 0)
```

x. Then next, grouped profile plot script was added on the R console using various codes from .aqp function to plots soil profiles grouped by specific factor.

```
groupedProfilePlot()  
groups = 'Soil_unit'  
color = 'slope'
```

xi. Volume fraction script was then added and this code from .aqp added a visual representation of volume fraction to the `{plotsaddVolumeFraction()}` function.

xii. Finally, the boundary visualization function of the .aqp script was added and this script converted horizon boundary distinctness codes to offsets for plotting `{hzDistinctnessCodeToOffset()}`.

Results and Discussion

The result of classification of DEM (Figure 2) and digitization of the map showed that the toposequence was delineated into crest, upper, middle and lower slopes and, floodplain (Figure 3). The result of the calculated total area was 26.42 ha and each mapping unit showed

that crest was 0.86 ha, upper slope 4.68 ha, middle slope 4.75 ha, lower slope 5.91 ha and floodplain 10.22 ha respectfully. The results of spatial interpolation maps (Figure 4) showed that sandy loam dominated the soils in parts of the crest, lower slope and floodplain while silty loam dominated in parts of the upper, middle and floodplain soils. Loam texture was only recorded at the upper and middle slope. This suggest low nutrient retention capacity of the soils and require management to reduce the risk of leaching by adding organic matter. Shobayo and

Ya'u (2020) reported that sandy soil fractions were predominant in the soils and were highest especially at the surfacesoils due to the basement complex parent materials in Northwest Nigeria. Maniyunda *et al.* (2019) also reported sand as the dominant soil fraction and attributed it to development on sandstone parent material in the Savannah Region, Nigeria. The Silty loam and loam texture could support arable crop cultivation with fertility management strategies like addition of fertilizers.

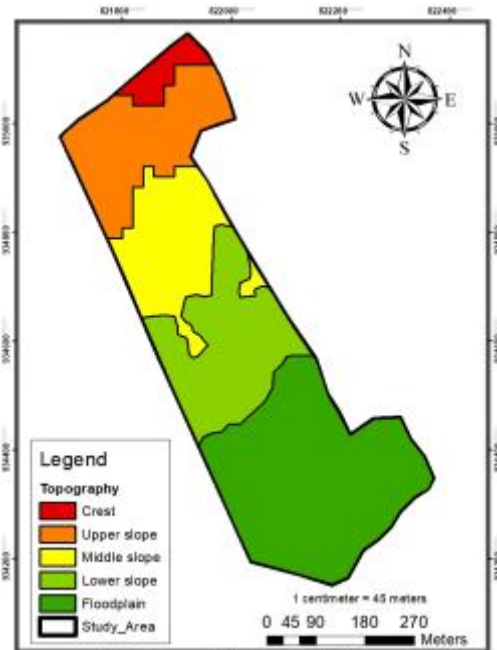
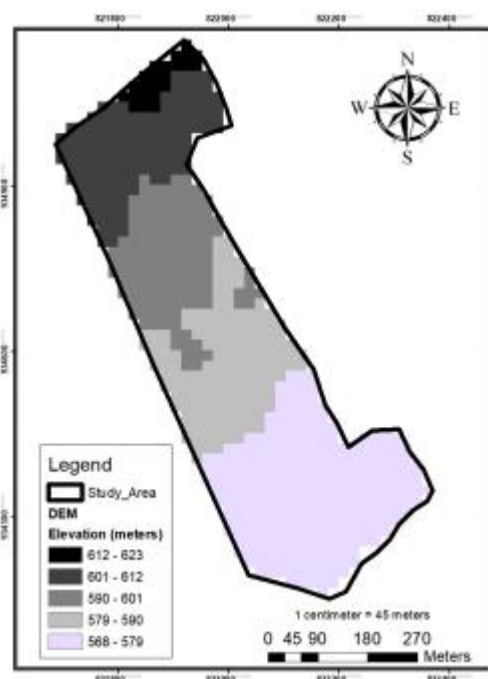


Figure 2: DEM of the Study Area

Figure 3: Topographic Map of the Study Area

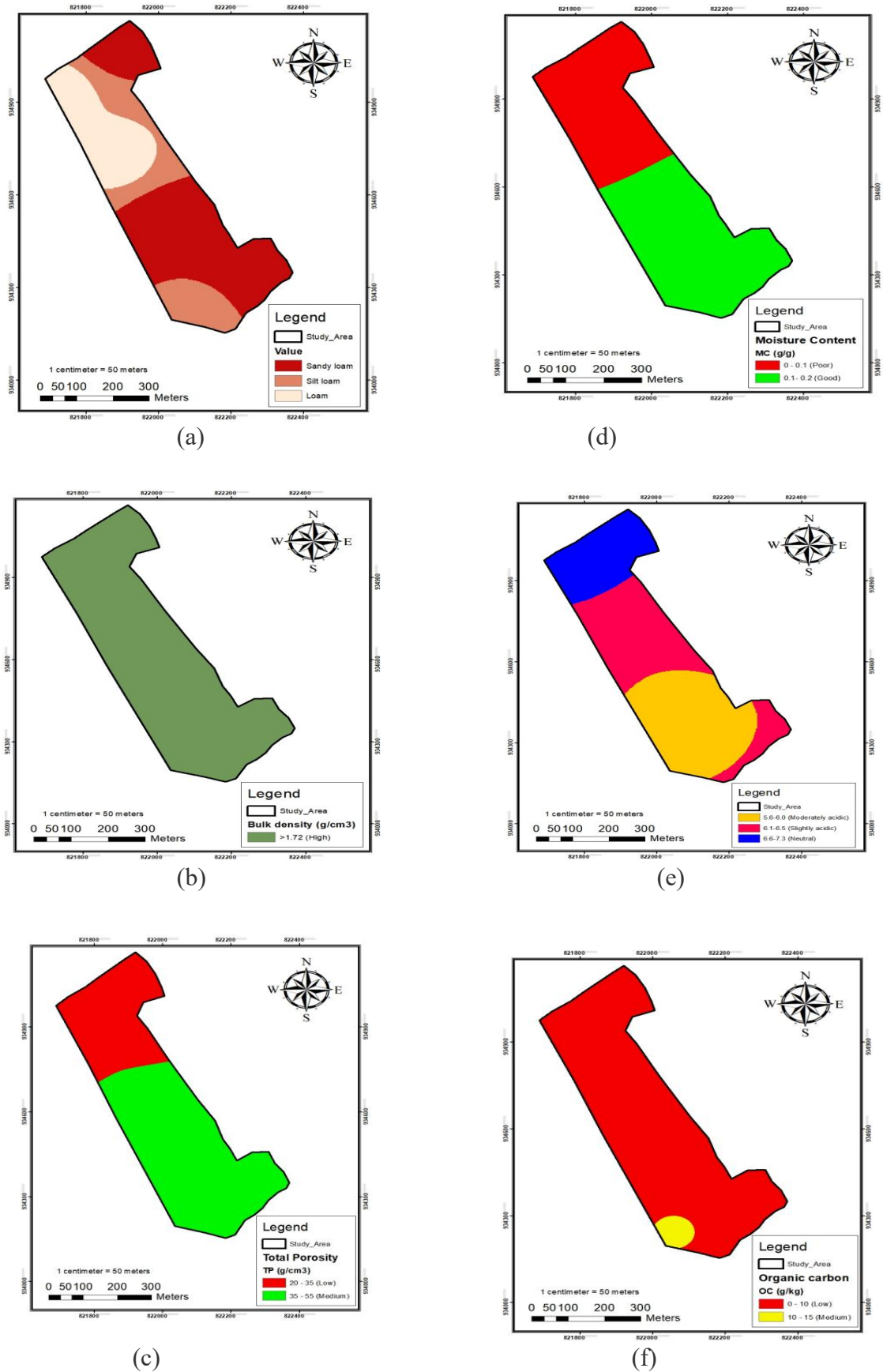


Figure 4: Spatial Distribution Map of the Study Area: (a) Soil Textural Map (b) Bulk Density Map (C) Total Porosity Map (D) Soil Moisture Content Map (E) Soil pH Map (F) Soil Organic Carbon Map

The result indicated high bulk density $>1.72 \text{ g/cm}^3$ across the landscape. This result indicated compacted soils that could reduce pore space, which is essential for root penetration, moisture availability for plant roots and aeration. The high bulk density might be due to the sandy nature of the soils and restriction to root penetration could result in lower yields in the area. Planting cover crops and reduced tillage might be helpful to the soils. Blanco-Canqui and Ruis (2020) stated that sandy soils tend to have higher bulk density and soils with $>1.6 \text{ g/cm}^3$ tends to restrict root growth and development. The results also showed low ($20\text{-}35 \text{ g/cm}^3$) to medium ($35\text{-}55 \text{ g/cm}^3$) soil total porosity collaborate the high bulk density sandy soil nature of the environment and this result might reduce root growth, water infiltration and aeration. This might restrict nutrient movement in the soil and result in poor yields. Bowen (2023) aligns with this result in his finding that if particle size remains constant, as bulk density increases, porosity decreases.

Generally, soil moisture content was poor at the crest, upper and middle slopes that could restrict plant growth and establishment. This result could be attributed to the rainfall that erodes the surface soils and moves with increase slope. Therefore, this could have led to increase in erosion hazards and resulted to leaching of nutrient minerals by any water that remains in the soils. Oklo *et al.* (2021) reported low soil nutrients in Benue soils and partly attributed it to leaching. Contour farming, terracing, mulching and cover cropping could be adopted to reduce excessive erosion across the slope. This result is consistent with the findings from Simelane *et al.* (2024) who reported that

steeper slopes such as those with 8° gradient, generally led to reduced infiltration rates and increased runoff. Xu *et al.* (2010) also reported that steeper slopes decrease infiltration rates, thereby encourages surface runoff, erosion activities, and nutrient loss. Moisture content was reported as good at the lower slopes and this might be due to transportation, deposition and accumulation of water by gravitational forces. Moisture was retained at the slower slopes which might be good and support crop cultivation. However, excess moisture that could affect crop growth and development could be drained using ditches, drain pits or channels and cropping on raised beds in the area.

The results also indicated that the soils were neutral at the crest and upper slope ($6.6\text{-}7.3$), slightly acidic ($6.1\text{-}6.6$) at the upper to middle slope and parts of the floodplain while the soils were moderately acid ($5.6\text{-}6.0$) at parts of the lower slope and floodplain. The neutral soils might be ideal for macronutrients uptake like nitrogen, potassium and sulphur. These results might be due to leaching activities and erosion which washed the mineral surface and increased the soil acidity. This result might affect essential nutrients such as phosphorus, calcium and magnesium, making them less available for crop uptake especially in acidic medium. Khaidem *et al.* (2018) agrees with this findings and state that availability of essential plant nutrients is highly correlated with the function of pH and low pH results in less availability of essential elements like phosphorus and calcium. These results are supported by findings of McCauley *et al.* (2009) which stated that macronutrients like nitrogen, potassium

and sulphur are more readily available in a pH range of 6.5 to 8.

Crops that have tolerance to acidic medium could be selected for cultivation in areas with low acidity like corn and potatoes. Liming could reduce hydrogen ions in the soils while addition of organic matter can improve soil buffering capacity and mitigate the effect of acidity.

The soils were low (<10 g/kg) in organic carbon across the landscape except for a portion of the floodplain that was medium (10-15 g/kg). This result might be due to high bulk density and low porosity which lead to compacted soils that limited aeration and root penetration. This might have resulted in reduced root growth and microbial activities which contributed to organic matter accumulation in the soils. The reduction in microbial activities might have resulted in reduced microbial decomposition of organic matter in the soils, but also could have reduced the creation of new organic matter in the soils. This finding is supported by Magdoff and Harold (2021) who reported that organic matter is the food source of soil microorganisms and low organic carbon lowers their activities, affecting the nutrient circle. Additionally, the dominance of sandy loam and silty loam might have resulted in low organic carbon content in the soils. This result agrees with reports by Omara *et al.* (2023) that sandy soils reduced microbial activities hence, reduced organic matter. The medium organic carbon at the floodplain could be as a result of water runoff, transportation and deposition, leading to increased organic carbon.

The results of the R code showed visual images of the soil profile data analysis on

the R console and plots environment. The visual result showed that the soils were all deep (>100 cm) across the landscape, Figure 5. This result suggests that the soils could support variety of crops due to its ability to accommodate deep rooted crops. This finding is supported by the report of Shobayo *et al.* (2021) who reported deep soils at the floodplain and the middle slope, suggesting that even moderate slopes can support deeper soil profiles. Jimoh *et al.* (2020) also found generally deep soils on crests, upper slopes, and valley bottoms, with the middle slope exhibiting a very deep profile.

Figure 6 revealed various colour across the landscape due to organic matter, moisture, weathering and decomposition rates in the study area. brown (7.5YR 2.5/2) colour while, the Btv2 was light brown (7.5YR 6/4) colour. The lower slope recorded a dark grayish brown (10YR 4/2) colour at the Ap horizon while light olive brown (2.5Y 5/3) was observed at the Cg horizon. The colour change from dark brown at the upper slopes to grayish colour at the lower slopes might be due to low organic matter decomposition at the upper slopes and poor drainage might have resulted to the grayish colour at the lower slopes. This is a contrast from reports by Imadojemu *et al.* (2022) who observed darker brown color at the lower slope, transitioning to progressively lighter browns, and a dramatic color change, with dark reddish brown transitioning through strong brown at the upper slope.

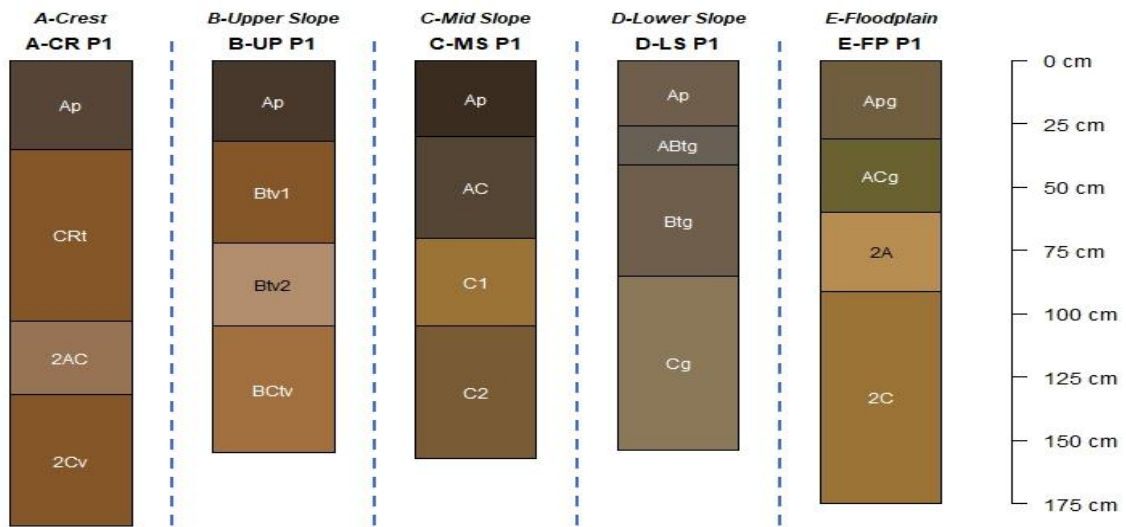


Figure 5: Depth Profile of the Study Area

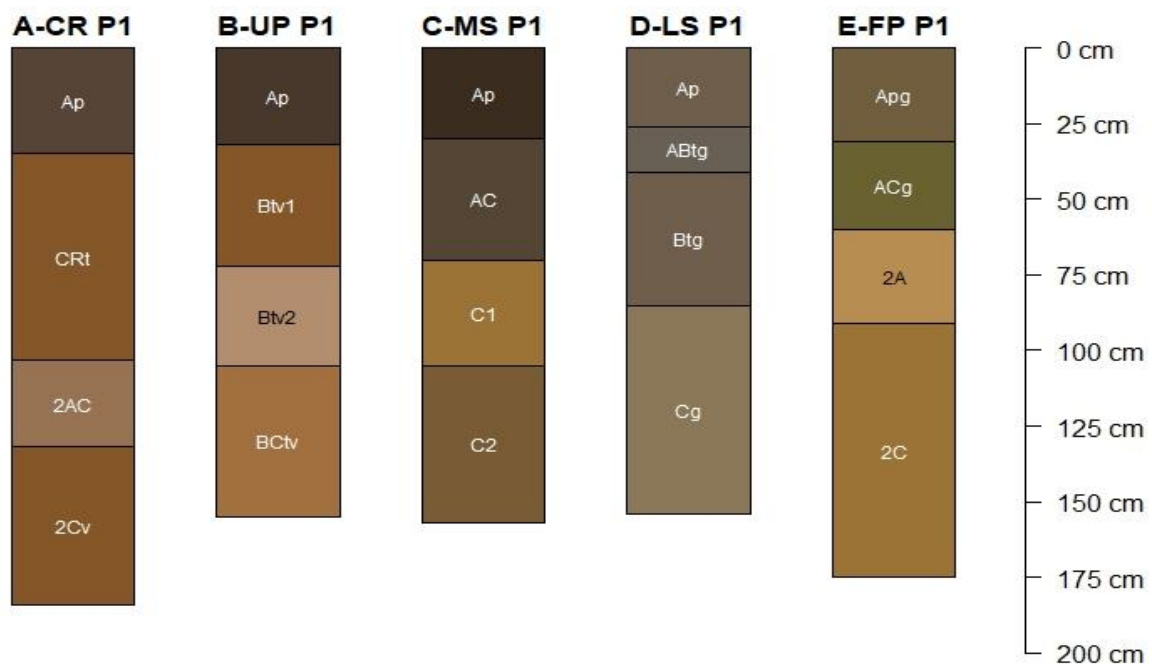


Figure 6: Colour Profile of the Study Area

The visual analysis of slop of the study area revealed that the soils were level to nearly leveled (0-2%) at the lower slope and floodplain while the crest, upper and middle slopes where moderately to strongly sloping (4-7%), Figure 7. This result suggests that the soils at lower slope

could support variety of crops due to good soil fertility owing to less erosion and good infiltration. However, the soils might have problems in waterlogged conditions. While upper slopes could be cultivated with management strategies for areas that are sloppy. Wang *et al.* (2023) showed

that slope gradient had a significant positive correlation with the slope surface runoff and nutrient loss.

Figure 8 shows the visual analysis of drainage of the study area. The analysis

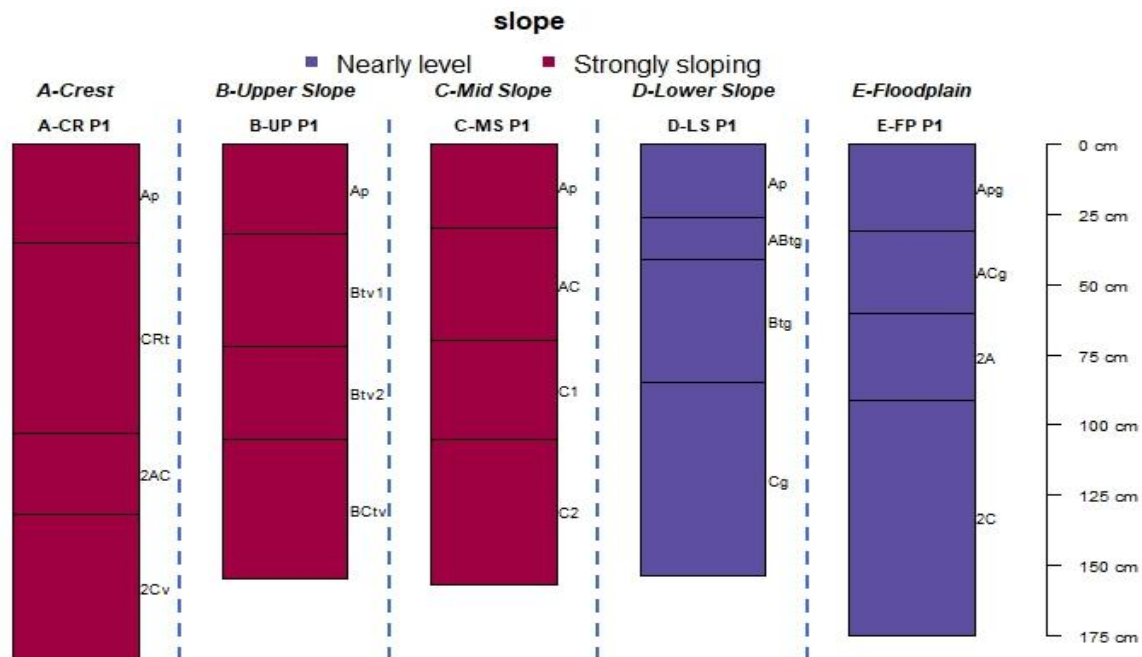
Figure 8: Drainage Profile of the Study Area

was poorly drained (mottles within 25-50

revealed that crest, upper and middle slopes were all well drained (no mottles within 100-150 cm depth), lower slope

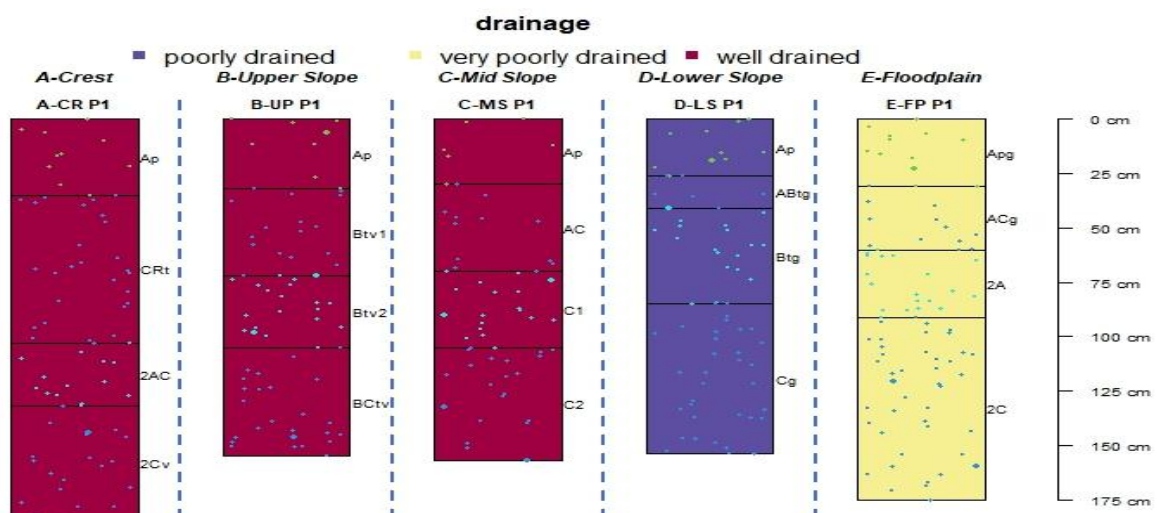
Figure 7: Slope Profile of the Study Area

presence of mottles at the lower slopes



cm depth) and the floodplain soils were very poorly drained (mottles within 0-25

was an indication of the poor drainage and accumulation of water transported and



cm depth) respectively. The well drained conditions at the upper slopes might be due to soil texture, low organic matter, poor water holding capacity slope gradient which moved water downslope. The

deposited with decrease in slope. Sharu *et al.* (2013) found the upper and middle slopes were well drained while the lower slope soils were imperfectly drained. This finding is supported by Shobayo *et al.*

(2019) and Osinuga *et al.* (2020) who also documented a pattern of well-drained upper and middle slopes contrasting with poorly drained soils at the lower slopes. The AQP analysis for soil horizon boundary is presented in Figure 9. The results indicated that there were variations of boundaries from each pedon across the landscape. The results showed boundaries of abrupt and smooth, clear and smooth, clear and wavy, diffuse and smooth and lastly, nil for the last horizon. All the Ap horizons had a clear and wavy Observed at the middle slope between Ap and AC, could be due to some degree of bioturbation or uneven deposition. The abrupt boundary as seen at the lower slope from a sandy Ap horizon to a Btg horizon might restrict soil water movement with

the soil and result in a patched water table or limit nutrient uptake by plant roots hairs. This could have fertility implications due to nutrient availability for the soils which might result in poor yields. Similar variability in horizon boundary were reported by Chengpeng *et al.* (2021) that textural layered soils displayed large variability in the sampled landscape. Fawole *et al.* (2016) observed a shift from clear transitions in the upper slope's Ap horizon to diffused boundaries deeper down the BC1. Diffuse boundaries indicated a gradual transition between two horizons and this suggests the soils promote better water infiltration and nutrient movement within the soils which could enhance soil fertility and optimum crop yield.

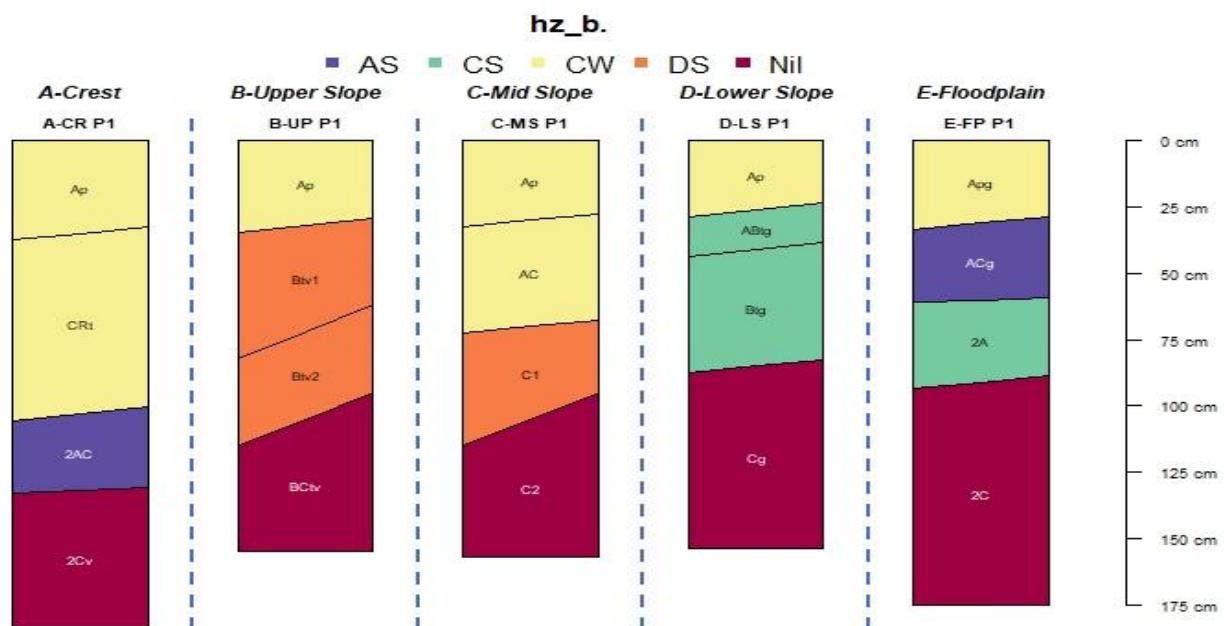


Figure 9: Horizon Boundary Profile of the Study Area

Conclusion

Digital soil mapping is fast, accurate and not expensive. The toposquence is delineated into crest, upper, middle, and lower slopes and, the floodplain and correspondent the DEM of the study area.

The visual AQP analysis clearly showed that it is an alternative to the conventional profile data analysis and result presentation with visuals rather than tables

alone. The soils are generally low in fertility due to rainfall intensity which resulted in erosion hazards especially at the upper slopes while the lower slope and floodplain soils poses drainage challenges. The soil fertility challenges could be ameliorated due to the potential of the soils for crop cultivation with management strategies like reduced tillage at the upper slope, contour cultivation and addition of organic matter to improve soil texture and structure. Liming and use of farm yard manure could improve soil pH and use of acid tolerant crops like potatoes. Making channels, ditches and drains could improve aeration at the lower slope and encourage microbial activities that will improve fertility and crop yields. By understanding and implementing of these site-specific soil attributes, land managers can establish sustainable methods that improve soil health and guarantee sustained agricultural output throughout the landscape in the study area.

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CHARACTERIZATION AND CLASSIFICATION OF SOILS DERIVED FROM TWO DIFFERENT PARENT MATERIALS IN NIGER STATE.

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ABSTRACT

The aim of this study was to characterize and classify soils developed under two geological formations (that is, basement complex rocks and the sedimentary rocks) in Niger State. Four sites, two each under the formations were selected for the study. Gidan Mangoro (GDM) and Nubwa Koyi (NBK) represented the basement complex while Patita (PTA) and Ndayako (NDY) represented the sedimentary rocks. In each site, a mini profile pit (1m x 1m x 1m) was dug, described and sampled according to FAO guidelines. The samples were analyzed in the laboratory following the standard analytical procedures. The soils were classified according to USDA Soil Taxonomy system and correlated with the WRB System. The texture of GDM, was loamy sand at topmost horizon (Ap), underlain by sandy clay loam at Bt horizon over sandy loam texture at Btv horizon. The NBK was sandy loam at Ap horizon over sandy clay loam at Btv1 and Btv2 horizons. PTA, and NYK were sandy loam all through. Soil pH was moderately acid to neutral in all the study sites. Total nitrogen was low (0.3 g kg⁻¹), (> available phosphorus was moderate to high (9.33 to 29 mg/kg⁻¹) Exchangeable potassium (K) was low to very low (0.05 to 0.11 cmol kg⁻¹), while cation exchange capacity (CEC) ranged from 5.02 to 10.40 cmol kg⁻¹ and was low to moderate. The soils were classified as Typic Plinthustalf (GDM), Plinthic Kanhaplustult (NBK), Oxic Haplustept (PTA) and Rhodic Kanhaplustults (NDY). The soils developed under basement complex rocks were shallow to deep soils while the soils from sedimentary rocks formations were deep to very deep.

Key words: Basement complex, Characterization, Classification, parent materials, Sedimentary.

INTRODUCTION

Soil characterization presents a potent resource for benefits to man in this regard, essentially in the theme of food sustainability and environmental protection (Esu, 2004). It is also concerned

with the determination of soil morphological properties, as well as their fitting into generally accepted soil classification system. Characterization provides the building block for understanding and appreciating the soil, and further classification of it. Soil characterization is the separation of soils

into groups of similar morphological properties such as colour, texture, structure, consistency, roots; physical properties such as sand, silt, clay, bulk density, porosity; chemical properties such as pH, organic matter content, total nitrogen, available phosphorus and exchangeable cations (Ukut *et al.*, 2014). Soil characterization provides the fundamental information necessary to create functional soil classification schemes, and assess soil fertility to resolve some unique soil problems in an ecosystem (Lekwa *et al.*, 2004).

Soil classification is the systematic grouping or separation of soils base on their properties. There is an increasing demand for information on soils as a means to produce food (Fasina *et al* 2007). Soil characterization, classification and evaluation are the first or primary indicators for establishing soil database, as proper understanding of soil resources for a judicious uses of land resources (Jagdish *et al.* 2009). Parent materials have an influence on soil morphological, physical and chemical properties and also affects the pattern of soil distribution over landscape even when the soils are formed from the same parent material Lawal *et al.*, (2014). Productivity of a soil is a function of its physical and chemical properties. These properties are as a result of the interaction among the soil forming factors and processes, hence, making soil to be heterogeneous (Lawal *et al.*, 2014). The objective of this study was to characterize and classify soils developed under two geological formations (that is, basement complex rocks and the sedimentary rocks) in Niger State, Nigeria, for proper utilization.

MATERIALS AND METHODS

Niger State is underlain by two geological terrains namely the Basement complex rocks and the sedimentary rock formations. The study covered the four sites, two from the basement complex and two from sedimentary rock geological formation. The site were Gidan Mangoro (Longitude: 6° 29' 30.570" E and Latitude: 9° 34' 29.652" N), Nubwa koyi (Longitude: 7° 08' 43.428" E and Latitude: 9° 15' 08.826" N), Patita (Longitude: 5° 53' 10.835" E and Latitude: 9° 12' 22.716" N), Ndayako (Longitude: 5° 00' 49.440" E and Latitude: 9° 22' 19.002" N), all within the southern Guinea savanna agroecological zone of Nigeria. Niger State is sub-humid tropical and experiences two distinct wet season and dry seasons. Rainfall is bi-modal with mean total annual rainfall of 1,600 mm in the southern part and decreased to 1,200 mm in the northern part of the state, distributed from the months of May to October. The dry season is about 5 month's duration from November to March. The mean annual maximum rainfall is about 1600 mm. The average minimum and maximum temperatures are 20 °C and 37 °C respectively while the mean annual relative humidity is between 39% to 70%. Geomorphologically, Niger State was characterized by undulating landscape, upland, lowland, plains, flood plains, and rolling dissected plains (Alabi 2011).

Field work and soil sampling.

One profile pit measuring 1 m × 1 m × 1 m (or to permissible depth), was dug in each of the locations and were described according to FAO guidelines (FAO, 2006). Soil samples were collected from the identified genetic horizons, from bottom to the top of the profile. The following

materials were used for the field study; handheld GPS device, Munsell Colour Chart (2009 version), a plastic bucket, zip-lock bags, digger, shovel, hand-trowel, hand note book, writing pen, permanent marker, stapler, and masking tape. The well-labelled soil samples were taken to the laboratory for processing and routine analysis.

Laboratory Analysis

The air-dried soil samples were passed through a 2 mm mesh and analysed according to standard laboratory procedures (IITA, 2015). Briefly, particle size distribution was determined by Bouyoucos hydrometer method, using sodium hexametaphosphate as the soil dispersing agent. The textural classes of the soils were determined using IUSS soil textural triangle. Soil pH was determined in a 1:2.5 soil / water suspension using a standard pH meter and electrodes. Exchangeable acidity (H^+ and Al^{3+}) was determined by titrimetric method, while organic carbon (C) was determined by Walkley-Black method of wet combustion involving oxidation of organic matter with potassium dichromate ($K_2Cr_2O_7$) and sulphuric acid (H_2SO_4). Exchangeable bases (Ca, Mg, K and Na) were extracted with 1N NH_4OAc . Calcium and Mg in the soil extract were determined using atomic absorption spectrophotometer while K and Na were determined by flame photometry. Cation exchange capacity (CEC) was determined by the neutral 1N NH_4OAc saturation method. Base saturation was determined by calculation, dividing the sum of exchangeable bases by their CEC and then multiplied by 100.

Soil Taxonomic Classification

Based on the results obtained from the field and laboratory analysis, soils of the study areas will be classified up to the

Subgroup level following the United State Development of Agriculture (USDA) Soil Taxonomy (Soil Survey Staff, 2022), correlated with World Reference Base (WRB, working group 2022) for Soil resources.

RESULTS AND DISCUSSIONS

Morphological Properties of the Soils

The study showed that the soils from GDM and NBK were moderately-deep to deep, having 70-100 cm effective soil depth, with coarse fragments. The dominant colour spectral of the soils indicated a range of 7.5YR and 10YR hues which impacted the soils with colour variations such as dark yellowish brown, strong brown, brown, pale brown. According to Brady and Weil (1999) and Aki *et al.* (2014), these group of colours may be indicative of the presence of migmatite, gibbsite, goethite and haematite minerals in the soils. The presence of mottle colouration in the subsoils may be an indication of internal drainage problem due to presence of plinthic layers which restricted free movement of water within the soil body, during the rainy season. This causes the soils to be imperfectly to poorly drained during the rainy season.

The soils from PTA and NDY were deep to very deep effective soil depth of 75-105 cm and were relatively free from coarse fragments and were well-drained. Similar to soils described under the basement complex, the colour features of soils of PTA and NDY indicated a range of 2.5YR to 10YR which impacted them with red, dark yellowish brown, dark red, dark yellow brown and dark reddish brown.

Physical Properties.

The physical properties of the soils of the four sites are presented in Table 1. The soils from GDM and NBK developed

from basement complex, which have their textures to be loamy sand in surface horizons while sandy clay loam in sub-surface horizons respectively. The sand content follow the same pattern in all the soils of these sites, it decreased with soil depth. The silt content of these sites decreased and increased with soils depth. The clay content of GDM and NBK increased with soil depth. The high sand fraction in surface horizon was also influenced by the parent material from which the soils are formed (Akpan-Idiok (2012); Peter and Umweni, 2021). The texture of PTA and NDY were sandy loam both in surface and sub-surface horizons. The sand content follow a particular pattern in all the soils, it decreased and increased with depth. Silt fraction from PTA and NDY were less in the topsoils than in the sub soils, while clay content increased with depth. The relative high sand content in the area was the reflection of the effect of parent material such as Nupe sandstones. According to (Akamigbo and Asadu, 1983), the parent materials have been noted to influence the texture of the soils derived from them. The lower silt content in the soils may also be attributed to the effect of parent materials on the soils, as it has been reported by Akamigbo, (1984) that silt content is low in most soils of Guinea savanna of Nigeria.

Chemical properties

The chemical properties of the soils of study areas are presented in Table 2. Soil reaction was slightly acid to neutral with pH values of the surface soil as 6.3, 6.3, 6.3 and 6.5 for GDM, NBK, PTA and NDY respectively and were classified as slightly acid in all the sites. Organic carbon (OC) in GDM ranged from 1.46 to 2.33 g kg⁻¹ and was high. OC in NBK

ranged from 2.13 to 3.11 g kg⁻¹, and was very high. OC in PTA ranged from 0.67 to 2.50 g kg⁻¹, and was low to high. OC in NDY ranged from 6.72 to 9.01 g kg⁻¹, and was very high. Organic carbon is an essential component of soil chemical parameter for tropical soils, contributing to aggregate stability, permeability, water holding capacity, nutrient retention, and other desirable soil properties. (Ravindra. *et al.*2017). Total N in the soils of all sites was very high (> 0.3 g.g⁻¹). While available phosphorus was low, other sites had moderate to high values. The cation exchange capacity (CEC) values for all sites were generally low, except for PTA that was

Very low. According to (Chude, *et al.* 2011) rating, the concentration of exchangeable Ca²⁺ in NBK and NDY were very low, and exhibited the pattern of increased and decreased with the profile depth. While it concentration in GDM and PTA was low and increased and decreased with soil depth. The concentration of exchangeable Mg was generally low in all the study sites and also exhibited increased and decreased pattern with soil depth. The concentration of exchangeable K in GDM, PTA, and NDY was very low, while in NBK was low both in surface and sub-surface horizons, and exhibited increased and decreased pattern with soil depth. The concentration of exchangeable Na in GDM and NBK was high in both surface and sub-surface horizons, and exhibited increased and decreased with soil depth. While the concentration of Na in PTA and NDY was moderate, both in the surface and sub-surface horizons, and also exhibited the pattern of increased and decreased with soil depth.

Table 1: Physical properties of the soils

Site	Horizon	Soil Depth (cm)	Sand	Silt (g kg ⁻¹)	Clay	Textural Class	Bulk density (g cm ⁻³)	Total porosity (%)
GDM	Ap	0 – 30	774	160	66	LS	1.45	45
	Bt	30 – 46	614	140	246	SCL	1.50	43
	Btv	46 – 75	674	200	126	SL	1.67	37
NBK	Ap	0 - 33	721	180	99	SL	1.46	45
	Bt2	45 - 78	641	80	279	SCL	1.52	43
	Btvg	78 - 100	541	160	299	SCL	1.68	37
PTA	Ap	0 - 8	794	120	86	SL	1.38	43
	AB	8 - 50	774	140	86	SL	1.46	45
	Bt	50 - 100	614	220	166	SL	1.48	44
NDY	Ap	0 – 20	721	180	99	SL	1.32	50
	Bt1	20 – 75	761	120	119	SL	1.47	45
	Bt2	75 - 100	721	160	119	SL	1.48	44

LS=loamy sand, SL= sandy loam, SCL= sandy clay loam

Nubwa Koyi

Nubwa Koyi had 1.2 times higher clay content at Bt1 than Ap confirming presence of a well-developed argillic horizon. Base saturation was low, hence placed under Ultisols at the USDA's Soil Taxonomy's Order level. The soil was formed under ustic moisture regime and therefore further placed under Ustults at Suborder level. This site had kandic horizon but lacked further diagnostic features that will require it placement perfectly into any class. As such it was classified as Kanhaplustults at Great Group level. The soil was classified as Plinthic Kanhaplustult at Subgroup level due to presence of plinthic horizon within 150 cm (in this case, starting from 78 cm depth). Under WRB classification, the soil of Nubwa Koyi was classified to be Haplic Kandisol Plinthic.

Patita

Patita showed no evidence of clay illuviation between AB and Ap horizon

and therefore placed under Inceptisols at the USDA's Soil Taxonomy's Order level. The soil was formed under ustic moisture regime and therefore further placed under Ustepts at Suborder level and Haplustepts at Great Group level due to insufficient diagnostic criteria to qualify it to fit into other class at this taxon. It was further classified at Subgroup as Oxic Haplustept for having CEC < 24 cmol kg⁻¹ clay at depth of 25 cm from mineral surface up to 100 cm depth. Under WRB classification, Patita had sub-layers that are not properly undergone significant pedogenic alteration and surface layer that had been altered by human activity (cultivation), this qualifies the soil Eutric Cambisol (Oxyaquic).

Ndayako

Ndayako showed 1.2 times higher clay content at Bt1 than Ap confirming presence of a well-developed argillic horizon. Base saturation was low and irregularly decreased with increasing soil depth.

Table 2: Chemical properties of soils

Sites	Soil Depth (cm)	Ph (H ₂ O)	OC (g/kg ⁻¹)	N	P (mg/kg ⁻¹)	Ca ←	Mg	K (cmol/kg ⁻¹)	Na →	EA	CEC	BS (%)	ESP (%)
Gidan Mangoro	0 – 30	6.3	1.46	0.46	13	2.88	0.96	0.07	0.83	0.04	8.40	56	9.88
	30 – 46	6.1	2.33	0.48	7	3.20	2.08	0.08	0.67	0.03	9.01	67	7.44
	46 – 75	6.2	1.46	0.36	10	2.40	1.12	0.07	0.58	0.04	7.11	59	8.16
Nubwakoyi	0 – 33	6.3	2.46	0.59	16	1.44	0.48	0.11	0.93	0.07	9.31	32	9.99
	33 – 45	6.0	3.11	0.53	17	1.28	1.44	0.11	0.54	0.09	9.03	37	5.98
	45 – 78	5.8	2.62	0.56	29	3.04	0.96	0.13	0.60	0.23	7.80	61	7.69
	78 – 100	6.1	2.13	0.84	23	3.20	1.76	0.15	0.56	0.30	8.20	69	6.83
Patita	0 – 8	6.3	2.50	0.42	10	2.24	0.96	0.06	0.62	0.05	5.02	77	12.35
	8 – 50	6.5	0.49	0.41	8	2.38	1.60	0.07	0.67	0.05	6.00	79	11.17
	50 – 100	6.3	0.67	0.48	8	2.08	1.44	0.05	0.54	0.05	9.58	43	5.64
Ndayako	0 – 20	6.5	6.72	0.36	9	1.60	0.96	0.05	0.50	0.11	10.40	30	4.81
	20 – 75	6.5	7.70	0.46	7	2.08	0.80	0.09	0.56	0.13	13.86	25	4.04
	75 – 100	6.6	9.01	0.42	3	1.92	0.96	0.05	0.53	0.15	11.88	29	4.46

Table: 3 Summary classification of the soils of the study sites.

SITES	USDA			WRB	
	ORDER	SUB ORDER	GREAT GROUP	SUB GROUP	
Gidan Mangoro	Alfisol	Ustalf	Plinthustalf	Typic plinthustalf	Haplic Plinthosols (Loamic)
Nubwakoyi	Ultisol	Ustult	Kanhaplustult	Plinthic Kanhaplustult	Haplic Kandisols Plinthic
Patita	Inceptisol	Ustept	Haplustept	Oxic Haplustept	Eutric Cambisol (Oxyaquic)
Ndayako	Ultisol	Ustult	Kanhaplustult	Rhodic Kanhaplustult	Haplic Alisols (Loamic)

On this basis, the soil was placed under Ultisols at the USDA's Soil Taxonomy's Order level. The soil was formed under aquatic moisture regime and therefore further placed under Ustults at Suborder level. Inadequate diagnostic features at Great Group level allowed its placement under Kanhaplustults. At Subgroup level, it was further classified as Rhodic Kanhaplustults for having colour of matrix with Hue of 2.5 and value of 3 (moist) and dry value not higher than 1. Under WRB classification, the soils of Ndayako were classified to be Haplic Alisols (Loamic).

Conclusion

The soils developed under basement complex rocks were shallow to deep soils while the soils from sedimentary rocks formations were deep to very deep.

The soils of the study areas generally have favorable pH, high base status, but low to medium fertility. However, with adequate application of mineral fertilizers and organic inputs, the soils can be more productive.

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**VARIABILITY IN SOIL MICRONUTRIENTS STATUS ALONG A
TOPOSEQUENCE AT KUFAYI-BILLE FARMING COMMUNITY, AKKO
LOCAL GOVERNMENT AREA, GOMBE STATE**

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ABSTRACT

The study was carried out at Kufayi-Bille Farming Community, Akko local Government Area, Gombe state with the aim of determining the variability in soil micronutrients status along a Toposequence. Three profile pits were dug in upper, middle and lower slope positions and soil samples were collected from each identified genetic horizon and used for laboratory analysis. The result indicated that particle size distribution across the pedons was dominated by sand which ranged from 66.46-69.66% with an overall mean value of 68.16%, followed by clay 17.08-21.20% with an overall mean value 19.01% and silt 10.08-14.66% with an overall mean 12.09%, while bulk density, particle density and total porosity values ranged from 1.36-1.51g/cm³ with an overall mean value 1.43 g/cm³, 2.23-2.55 g/cm³ with an overall mean value 2.38 g/cm³ and 36.55-43.92% with an overall mean value 39.97% respectively and were all rated low across the location. However, textural class in all the pedons ranges from sandy loam to sandy clay loam. The values of manganese, iron, copper and zinc obtained in this study ranged from 0.40 to 10.00 mg/kg, 4.81 to 14.62 mg/kg, 1.40 to 18.40 mg/kg and 0.47 to 12.15mg/kg respectively. The study further revealed that the coefficient of variation showed low variability in all the physical properties of the soils except silt which is moderate, while Cu recorded low to high, Fe moderate, Zn and Mn high variability across the study area. The low variability in most of the physical properties indicated that the soils developed from the same parent materials. Agronomic practices such as Strip-cropping, use of vegetative barriers, alley cropping, mulching and effective soil management practices such as application of organic manure, and systematic grazing should be adopted for suitable agricultural production.

Keywords: Genetic Horizon, Micronutrients, Mulching, Status, Variability

INTRODUCTION

Soils are that portion of the earth's crust in which plants can grow, if water and temperature are adequate, at least the minimum nutrients are available, and toxic substances are in low concentration. It is an important natural resource for agricultural and industrial development of a nation. It has numerous functions some of which are provision of anchorage to growing plants, provision or supply of nutrients and water to crops (Tripathi 2015). Bell and Bernard 2008 asserted that the Plant growth is determined by the fertility of the soil and it is determined by the presence or absence of macro or micronutrients optimum

utilization of the soil for agricultural production is possible as long as the soil is stable and well supplied with nutrients, air and water. The nutrients in the soil are broadly classified in to two; they are macro and micro nutrients. The former is required in a large quantity while the later is required in a small quantity. Both the two forms of nutrients are term as essential nutrients. An essential nutrient is the nutrient without which the plant cannot complete its life cycle.

Micronutrients are part of these essential nutrients. Although they are needed in trace quantities, it does not affect their significance in plant nutrition (Mathayo, et

al., 2016). Eight of the eighteen elements that are essential for plant growth are micronutrients. They are Boron (B), Chlorine (Cl), Copper (Cu), Iron (Fe), Manganese (Mn), Molybdenum (Mo), Zinc (Zn) and Nickel (Ni) plus others that are considered to be beneficial (Cobalt (Co), Sodium (Na), Silicon (Si) and Vanadium. Fertilizer applications in Nigeria involves only the macronutrients even though cropping, erosion and leaching deplete soil of micronutrients which should be replenished by the return of organic materials such as crop residues, farm yard manure and compost (Chaudhari, and Vidya 2012).

Deficiencies of Copper and Zinc are more common than those of Fe and Mn in many coarse textured and acid soils in Africa, particularly in Nigeria. Research on micronutrients in recent time shows that, areas where intensive agriculture is practice bring up the deficiencies, the soils with micronutrient deficiencies will recover its nutrient through application of small quantities of these nutrients (mostly found in organic matter) to enhance crop production while large quantities added to the soil may be harmful (toxic) to the plants and animal consuming the forage (Chaudhari, and Vidya, 2012). This is unlike countries where shifting cultivation is a dominant practice and micronutrient deficiency problems have not been given much attention. This is probably because nutrient recycling through leaf litter decomposition maintains the required level of the micronutrients. Therefore, it is important to know the original concentration of micronutrients in the soils and add only as much of the micronutrients as is beneficial to plants and foraging animals. The replenishment of

micronutrients through fertilizer is still in its infancy stage in Nigeria.

Variability of soil properties occurs as a result of interaction of various ongoing soil forming processes and management practices. Parent material and pedogenic processes are the main factors governing the variation in total micronutrient content of soils. Micronutrients content of parent materials widely differs, and diversity in the weathering regimes boosts variability in distribution and availability of micronutrient contents of soils. The variability in soil micronutrient status presents a significant challenge to agricultural productivity and sustainability (Mathayo, *et al.*, 2016). Micronutrients are essential for plant growth and development, and their heterogeneous distribution within agricultural soils can lead to uneven crop yields and quality. This variability can be influenced by factors such as soil type, land management practices, and environmental conditions (Joel *et al.*, 2015). In order to enhance the micronutrient status of the soils, there is need for assessment of their initial status in order to integrate the appropriate soil fertility management that involves judicious use of combined organic and inorganic fertilizers. This is a feasible approach which has been employed in overcoming soil fertility constraints (Ibrahim, *et al.*, 2011).

Materials and Methods

The study area

The study area is in Gombe State which lies between longitudes and latitudes 10°30'20.281"E, 9°31'45.113"N and 11°59'32.66"E, 11°18'19.903"N of the Greenwich meridian within the Savannah ecological zone of Nigeria (Klinkenberg and Higgins, 1968). While the experiment was carried out at Kufayi-Bille Farming Community of Kashere, which lies

between longitudes and latitudes 10°56'19.564"E, 9°53'4.604"N, in Akko local government area of the State. The climate of the area is that of the semi-arid type characterized by wide seasonal and diurnal temperature ranges with two main seasons: rainy season (April-October) and dry season (November to March) (Abubakar, 2013). The average annual rainfall is put at 1000mm with the greater part falling between July and October (UBRDA, 2018). April is usually the hottest month (maximum temperature being 39°C), while December and January have the lowest temperature averaging 16°C (UBRDA, 2018).

Soil sampling and handling

One (1) soil profile pit each with dimensions 2m long, 1.5m wide 2m deep was dug in the upper, middle and lower slope portions of the toposequence respectively, making total number of three (3) pits. Soil samples were collected from each recognized pedogenic horizons and used for determination of soil physical and micro nutrients properties following a standard laboratory procedure as described by the Soil Survey Field and laboratory methods manual (Burt, 2014). For the determination of soil physical and micronutrients properties, two sets of soil samples were collected from each pedon; the first was bulk samples of each genetic horizon used for routine analysis, the second was the core samples of each horizon for bulk density determination.

Preparation and Laboratory Analysis of Soil Samples

The collected soil samples were then air-dried in the laboratory and ground using wooden pestle and mortar and sieved to pass through 2mm mesh sieve. Properly labeled samples were kept in clean and fresh plastic bags for laboratory analysis. The

particle size distribution was determined by the Bouyoucos hydrometer method after dispersing the soil samples with 5% Sodium hexametaphosphate as described by Gee and Bauder (1986). Bulk density was determined by the clod method using the procedure described by Blake and Hartge (1986). Particle density was determined after the removal of entrapped air in soils using the pycnometer method as described by Blake and Hartge (1986). Total porosity of the soil was calculated mathematically from the results of bulk density and particle density (Agbenin, 1995). Soil micro nutrients (Zn, Fe, Cu, Mn) were determined by wet digestion method.

Data Analysis

Descriptive statistics was used to assess the mean distribution of data for parameters analyzed in the laboratory (Agbenin, 1995), while Coefficient of Variation (CV) was used to determine the degree of variability of the physical and micro nutrients properties studied across the study area (Welding, 1985).

RESULTS AND DISCUSSION

Physical Properties of the Study Area

Sand fraction dominated the particle size distribution which ranged from 67.35 to 69.66%, 66.56 to 69.12% and 66.46 to 69.46% with mean value of 68.16% in the upper, middle and lower slope respectively, with the upper slope recorded the highest sand content of 69.66% at the depth of 74-87cm while the lower slope recorded the lowest sand content of 66.46% (Table 1). Sand content had irregular pattern of increase with depth as shown from the result in (Table 1). The high sand content could be associated with the parent material and climatic condition that encourage the sorting of the soil particles (Onweremadu *et al.*, 2011). The percentage of silt values ranged from 10.08

to 12.61%, 13.20 to 14.66% and 12.94 to 13.46% with mean value of 12.09% in the upper, middle and lower slope respectively (Table 1), with the middle slope recording the highest silt values of 14.66% at the AP horizon while the least value of 10.08%

was obtained at the upper slope (Table 4.1) as shown from the result in Table 1. Nsor and Uhie (2016); Askira *et al.* (2019a) also reported high silt content in their various studies.

Table 1: Soil Physical Properties of the Study Area

Horizon	Depth (cm)	Sand (%)	Silt (%)	Clay (%)	Texture	BD (g/cm ³)	PD (g/cm ³)	TP (%)
Upper Slope								
AP	0-19	68.94	12.61	18.45	SL	1.36	2.27	40.26
AB	19-40	68.91	11.23	19.86	SL	1.40	2.32	39.66
Bw	40-56	68.72	10.08	21.20	SCL	1.42	2.36	39.83
Bt	56-74	67.35	12.09	20.56	SCL	1.42	2.41	41.08
Bc	74-87	69.66	10.80	19.54	SCL	1.50	2.38	36.97
	Mean	68.72	9.20	19.92		1.42	2.35	39.56
CV%		1.23	8.87	5.24		3.59	2.32	3.91
Middle Slope								
AP	0-11	67.66	14.66	17.68	SL	1.42	2.33	39.01
Bt	11-23	69.12	13.20	17.68	SCL	1.45	2.36	38.56
Bt2	23-49	69.12	14.02	16.86	SL	1.43	2.41	40.66
Bt3	49-75	66.50	13.90	19.60	SCL	1.51	2.38	36.55
	Mean	68.10	13.95	17.96		1.45	2.37	38.69
CV%		1.86	4.29	6.48		2.78	1.42	4.37
Lower Slope								
AP	0-19	66.94	13.20	19.86	SL	1.41	2.23	38.64
Bw	19-35	69.46	13.46	17.08	SCL	1.43	2.55	43.92
Bw2	35-60	66.46	12.94	20.60	SCL	1.39	2.45	43.26
Bc	60-84	67.80	13.10	19.10	SCL	1.48	2.50	40.80
	Mean	67.67	13.11	19.16		1.43	2.43	41.66
CV%		1.95	1.66	7.91		2.71	5.80	5.80

Key: BD= bulk density, PD= particle density, TP= total porosity, SL= sandy loam and SCL= sandy clay loam, CV= coefficient of variation

This high silt content obtained in this study could be attributed to the nature of parent material and soil development (Maniyunda and Gwari, 2014). The clay content ranges from 18.45% to 21.20%, 16.86 to 19.60.% and 17.08 to 20.60% with mean value of 19.01 in the upper, middle and lower slope respectively (Table 1), with the B- horizon

of the lower slope recorded both the highest and the lowest values of 2.60% and 17.08 respectively (Table 1). The clay content of the soils studied has irregular increase with depth. Brady and Weil (2017) attributed this occurrence to the nature of the parent material from which the soil is formed. Similarly, the clay content tends to

increase with soil depth in most of the profiles indicating possible clay migration by eluviation-illuviation process. This finding agreed with the works of Chikezie *et al.* (2009) and Malgwi *et al.* (2000). The higher clay content often observed in subsurface horizons of many soils may be attributed to illuviation and pedoturbation processes (Malgwi, 2001). This indicates the presence of argillic horizons (accumulation of clay in B-horizon) in most of the pedons studied. The result of bulk density ranged from 1.36 to 1.50 g/cm³, 1.42 to 1.51 g/cm³ and 1.39 to 1.48 g/cm³ (Table 1) with mean value of 1.43 g/cm³. Middle lower slope recorded the highest bulk density value of 1.51 g/cm³ while the upper slope recorded the least value of 1.36 (Table 1). This range of values is regarded as low (Malgwi, 2007). The finding also showed that bulk density obtained in this study is not expected to cause root and water movement restriction (Ekwoanya and Ojanuga, 2001). It also showed an apparent increase with depth, this could be attributed to OC distribution down the profile. The particle density values ranged from 2.27-2.41 g/cm³, 2.33-2.41 g/cm³ and 2.23-2.55 g/cm³ with mean value of 2.38 g/cm³ in the upper, middle and lower slope respectively (Table 1) with the lower slope recorded the highest value of 2.55 g/cm³ while the upper slope recorded the least value of 2.27 g/cm³ (Table 1). This range of values is rated low as per Malgwi (2007) rating scale. Ayolagha and Opene, (2012) reported that particle density values recorded in this study indicates that perhaps quartz, feldspars, mica, and other colloidal silicate clays which have densities between the range of 2.50-2.70 g/cm³ make-up the major portion of the materials

in the studied soils. The values of porosity on the other hand ranged from 36.79 to 41.08%, 36.55 to 40.66% and 38.64 to 43.92% with mean value of 39.97% in the upper, middle lower slope (Table 1) with the lower slope recorded higher value of 43.92% while middle slope has the lower value of 36.55%. The recorded range of total porosity values across the location are regarded as low (Malgwi, 2007). Also Kachinskii, (1956) reported that soil having TP 40-45% is regarded as satisfactory. Zata, *et al.* (2020) also reported low total porosity in their study. Similarly, the coefficient of variability of all the physical properties studied across the location indicated low variability (CV <15%) as per Wilding rating (1985) (Table 1)

Micronutrients Properties of the Study Area

Manganese (Mn) content of the studied soils ranged from 2.20 mg/kg - 10.00 mg/kg, 0.60-4.40 mg/kg, and 0.40-8.80 mg/kg in the upper, middle and lower slope respectively (Table 2). Manganese content of the soils was rated low to high as per Malgwi (2007) rating scale. This result is in line with the report of Abay *et al.* (2015). It's also in agreement with the report of Maniyunda *et al.* (2017) when working on three ecological zones of Nigeria. The values observed for iron (Fe) content ranged from 6.23-11.48 mg/kg, 10.37-14.62 mg/kg and 4.81-11.60 mg/kg in the upper, middle and lower slope respectively (Table 2). The iron values of the studied soils across the locations were generally rated low to high in accordance with Malgwi (2007) ratings. This result is in line with the report of Okoli *et al.* (2017) who reported low to high available iron.

Table 2: Soil Micronutrient Distribution of the Study area

Horizon	Depth (cm)	Mn (mg/kg)	Fe (mg/kg)	Cu (mg/kg)	Zn (mg/kg)
Upper Slope					
AP	0-19	10.00	6.23	1.40	1.64
AB	19-40	2.80	7.09	4.40	2.27
Bw	40-56	2.20	11.48	4.60	2.03
Bt	56-74	3.50	11.11	18.40	1.09
Bc	74-87	8.20	10.61	6.60	2.58
	Mean	5.34	8.06	7.08	1.92
CV%		65.94	26.36	93.15	30.09
Middle Slope					
AP	0-11	2.60	14.62	3.40	2.43
Bt	11-23	0.60	10.61	3.40	3.76
Bt2	23-49	4.40	10.37	3.20	0.86
Bt3	49-75	0.60	11.17	3.80	2.50
	Mean	2.05	11.69	3.45	2.39
CV%		89.19	16.94	7.29	49.74
Lower Slope					
AP	0-19	1.80	10.00	4.00	2.43
Bw	19-35	0.40	10.86	5.60	3.21
Bw2	35-60	5.40	4.81	3.60	0.47
Bc	60-84	8.80	11.60	5.00	12.15
	Mean	4.10	9.31	4.55	4.57
CV%		92.08	33.01	20.10	94.61

Key: Mn= manganese, Fe=iron, Cu= copper and Zn= zinc, CV= coefficient of variation

However, Dan'azumi *et al.* (2017) reported moderate iron content while working on assessment of extractable micronutrients in Kano State. Irregular increase with depth of Fe content was observed across the studied soils. There was an observed apparent increase in iron content with increase in soil depth. This could be attributed to higher clay content of the soils in the lower horizons. Hardy and Cornu (2006) stated concisely that micronutrients contents increases as clay decreases. The values for Cupper (Cu) ranged from 1.40-18.40mg/kg, 3.20-3.80mg/kg and 3.60-5.60mg/kg in the upper, middle and lower

slope respectively (Table 2). Generally, the copper values across the locations were rated low to high (Malgwi, 2007). Raji (2017) obtained similar result of moderate to high Cu content when working on basement complex soils in Kwara State. It's also in line with the report of several researchers such as Abay *et al.* (2015); Adiele *et al.* (2015); Dan'azumi, (2017) and Maniyunda *et al.* (2017). This low to high values of available copper content could probably be attributed to the acidic nature of the soils of the study areas (Dan'azumi, 2017). Okoli *et al.* (2017) indicated that plant growing in soils with

medium copper content will not suffer copper deficiency. Zinc values ranged from 1.09 to 2.58 mg/kg, 0.86 to 3.76mg/kg and 0.47 to 12.15mg/kg in the upper, middle and lower slope respectively (Table 2). Generally, the Zn values of the soils under study were rated low to high as per the rating of Malgwi (2007). Okoli *et al.* (2017) and Eleng *et al.* (2014) also obtained low available form of Zn in soils of southeastern Nigeria, while Raji (2017) reported moderate Zn values when working on basement complex soils in Kwara State. According to Alloway, (2008), sandy soils and acid highly leached soils with total and plant-available zinc concentrates are highly prone to zinc deficiency. Havlin *et al.* (2012) noted that zinc availability decreases with increase in soil pH.

Across the location, the coefficient of variation for all the soil micronutrients studied indicated high variation with the exception of Fe which recorded moderate variation (Wilding, 1985)

Conclusion

In view of the above findings, it can be concluded that the soils of the study area are generally predominantly sandy clay loam to sandy loam. The results further indicated that almost all the soil fertility indicators most especially the extractable micronutrients were low. The coefficient of variation showed low variability in all the soil physical properties considered in this study, which is an indication that the soils are similar in physical properties and could be related to the nature of the parent material, climate and soil management practices.

Recommendations

Based on the findings of this study, the major limitation against sustainable productivity of the soils is low soil fertility.

Therefore, farmers should embark on agronomic practices such as application of manures, afforestation, cover cropping, systematic grazing etc to check erosion and improve the organic matter status of soils of the study area. These practices will improve soil fertility, soil structure, soil porosity and aeration. Hence more research should be conducted on the soil fertility status and appropriate management systems.

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SUITABILITY ASSESSMENT FOR IRRIGATED PEPPER CULTIVATION USING GIS AND AHP-BASED TECHNIQUE IN HUNKUYI, NORTHERN NIGERIA

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ABSTRACT

*This study assessed land suitability for irrigated pepper (*Capsicum annum L.*) cultivation in Hunkuyi, Northern Nigeria using an integrated Geographic Information System (GIS) and Analytic Hierarchy Process (AHP) approach. Nine biophysical criteria including available water holding capacity (AWHC), effective rooting depth, soil texture, drainage, pH, cation exchange capacity (CEC), base saturation, electrical conductivity (EC), and slope were evaluated using the FAO land evaluation framework with modified suitability ratings. Field data were collected from six soil profile pits across delineated land units, and laboratory analyses were conducted to determine key soil properties. The AHP method was used to assign relative weights to the criteria, and weighted overlay analysis in ArcGIS 10.7 was applied to generate the final suitability map. Results showed that AWHC (0.192) and rooting depth (0.189) were the most influential factors affecting irrigation suitability for pepper, followed by soil texture and drainage (0.147 each). The consistency ratio (0.024) confirmed reliable and consistent expert judgments. Spatial analysis revealed that 64.9% (116.82 ha) of the study area was moderately suitable (S2) while 35.1% (63.18 ha) was marginally suitable (S3) for irrigated pepper cultivation. Major limiting factors included low water retention capacity, moderate soil fertility constraints, drainage limitations, and slope variability. The study demonstrates that GIS-AHP is an effective decision-support tool for irrigated agriculture, highlighting the need for targeted soil fertility improvement and drainage management in moderately and marginally suitable areas to enhance productivity.*

Key words: GIS; AHP; Crop Suitability; Irrigated Pepper Cultivation

Introduction

Agricultural productivity in many developing countries is strongly influenced by the suitability of land resources for specific crops (Anabaraonye *et al.*, 2021). Soil and environmental conditions determine the availability of water, nutrients, aeration, and rooting conditions required for optimum crop growth (Maniyunda *et al.*, 2023; Sadiq *et al.*, 2023; Sadiq *et al.*, 2025; Naidu *et al.*, 2006). Where crops are cultivated without

adequate consideration of soil and site characteristics, productivity often declines due to poor nutrient availability, erosion risk, water stress, or unsuitable physical conditions. Consequently, land suitability assessment has become an important component of sustainable agricultural planning because it provides a scientific basis for matching land characteristics with crop requirements (Shah & Wu, 2019; Maniyunda *et al.*, 2023; Sadiq *et al.*, 2025). In irrigated agriculture particularly, the

suitability of land is critical since irrigation performance and crop yield are closely linked to soil texture, drainage conditions, slope, salinity status, and water-holding capacity. Proper evaluation of these factors therefore contributes to efficient land and water resource management and reduces the risk of land degradation.

Conventional land evaluation methods have long been used to determine the suitability of land for agricultural production. The framework proposed by the Food and Agriculture Organization (FAO, 1976) remains one of the most widely adopted approaches because it systematically relates land qualities to crop requirements. However, land suitability assessment involves the integration of numerous biophysical factors that vary spatially and differ in relative importance (Günel *et al.*, 2022; Gani & Awwal, 2026). The development of Geographic Information Systems (GIS) has greatly improved the efficiency and accuracy of land evaluation by enabling the acquisition, management, analysis, and visualization of spatial data. GIS also supports Multi-Criteria Decision-Making (MCDM) techniques, which are useful for combining several environmental variables into a single suitability model. Among the various MCDM techniques, the Analytic Hierarchy Process (AHP) is widely applied because it allows the relative importance of suitability factors to be determined through pairwise comparison and weighted analysis (Mallick *et al.*, 2018; Montgomery, *et al.*, 2016; Sadiq *et al.*, 2025). The integration of GIS and AHP has therefore become increasingly popular in agricultural suitability studies due to its ability to provide spatially explicit and decision-oriented outputs for land-use planning.

Several studies have applied GIS-based suitability assessment techniques for evaluating agricultural land for different crops under varying environmental conditions. These studies have demonstrated the importance of integrating soil, terrain, hydrological, and climatic variables in identifying suitable areas for crop cultivation (Sadiq *et al.*, 2023, Sadiq *et al.*, 2025; Gani & Awwal, 2026). In irrigated agriculture, GIS-AHP approaches have proven particularly effective because they support the evaluation of both soil and irrigation-related factors simultaneously. Despite the growing application of these techniques, information on irrigated land suitability for vegetable production in many parts of Northern Nigeria remains inadequate. Existing agricultural practices in several areas are often based on traditional knowledge with limited scientific evaluation of land capability, resulting in inefficient use of land and water resources (Fatihu *et al.*, 2020).

Pepper (*Capsicum annuum* L.) is an important vegetable and spice crop widely cultivated and consumed in Nigeria due to its nutritional, culinary, and economic value (Olutumise, 2022; Zohoungbogbo *et al.*, 2024). The crop serves as a major source of income for many smallholder farmers and contributes significantly to local food systems. Although Northern Nigeria possesses favourable climatic conditions for pepper production, productivity is frequently constrained by poor irrigation management and inadequate information on the suitability of available land resources (Ajayi *et al.*, 2022). In Hunkuyi, where irrigation farming plays an important role in dry-season agriculture, the absence of detailed suitability information limits effective agricultural planning and sustainable land utilization

(Sadiq *et al.*, 2023). Assessing the suitability of land for irrigated pepper cultivation is therefore necessary to support informed decision-making, improve resource-use efficiency, and enhance agricultural productivity. Therefore, this study aimed to assess land suitability for irrigated pepper cultivation in Hunkuyi, Northern Nigeria, using GIS and AHP-based techniques.

Materials and Methods

Study Area

The study was conducted in Hunkuyi District, Kudan Local Government Area of Kaduna State, Nigeria, within the Northern Guinea Savanna agro-ecological zone. The study area lies between latitudes 11° 14' 55.22" and 11° 15' 06.5" N, and longitudes 7° 38' 56.7" and 7° 39' 17.0" E, covering

approximately 180 ha (Fig. 1). Geologically, the area is underlain by Basement Complex rocks dominated by high-grade metamorphic materials, particularly quartzites. The terrain is characterized by gently undulating plains with elevations ranging from 637 to 665 m above sea level. Drainage within the area is mainly controlled by tributaries that discharge into the Galma River system (Sadiq *et al.*, 2025). The area experiences a tropical savanna climate with distinct wet and dry seasons. Mean annual rainfall is approximately 1071 mm, while the mean annual temperature is about 27 °C. The soil temperature regime is iso-hyperthermic and the moisture regime is ustic. Relative humidity varies considerably between the rainy and dry seasons.

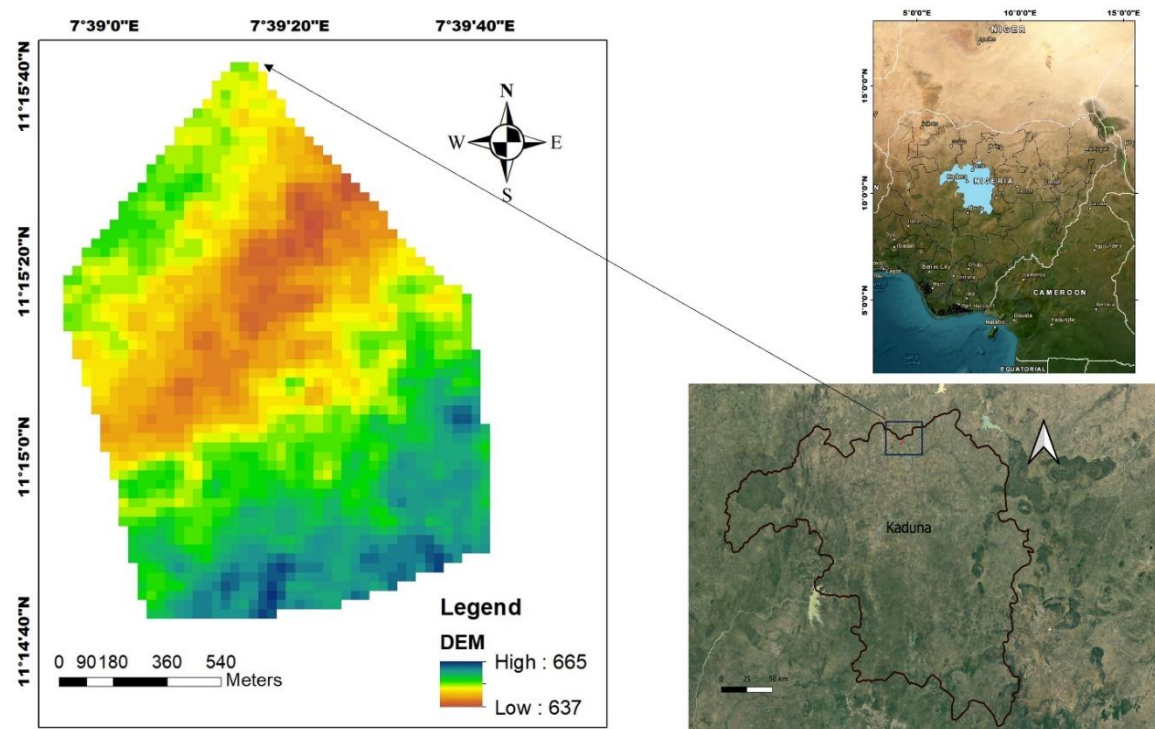


Fig. 1: Map showing location and digital elevation of the study area in Hunkuyi District, Nigeria

Reconnaissance Survey and Delineation of Land Units

A preliminary reconnaissance survey was conducted to understand the physiographic

characteristics, land use patterns, and slope variations within the study area. Field observations were used to delineate the area into three land use units designated as

HK1, HK2, and HK3. HK1 represents the floodplain area characterized by combined irrigated and rain-fed cultivation. HK2 occupies the middle slope position where both irrigation and rain-fed farming are practiced, while HK3 represents the upper slope area predominantly used for rain-fed agriculture. The delineation of these land units provided the basis for detailed soil investigation and sampling.

Field Characterization, Sampling Collection and Preparation

Detailed soil investigations were carried out across the three land units using six pedons, with two profile pits excavated within each unit. Morphological properties of the soil horizons were described in the field following standard soil profile description procedures (Soil Survey Staff, 2014). Observations included soil colour, texture, structure, consistence, drainage condition, and horizon boundaries. Disturbed soil samples were collected from identified genetic horizons for laboratory analysis, while undisturbed core samples were obtained for bulk density determination. The disturbed samples were air-dried, gently crushed, and passed through a 2-mm sieve prior to laboratory analysis.

Laboratory Analysis

Physical and chemical analyses of the soil samples were conducted using standard laboratory procedures. Soil pH and electrical conductivity (EC) were determined in a 1:2.5 soil-to-water suspension. Available water holding capacity (AWHC) was computed as the

difference between moisture content at field capacity (-33 kPa) and permanent wilting point (-1,500 kPa), both determined using the pressure plate apparatus method (Klute, 1986). Cation exchange capacity (CEC) and exchangeable bases (Ca, Mg, K, and Na) were determined using the neutral ammonium acetate (NH₄OAc) extraction method (Rhoades, 1983; Thomas & Hargrove, 1984). Base saturation (BS) was subsequently calculated from the analytical results as the proportion of exchangeable bases to total CEC of the soils.

Topographic Data and Slope Analysis

Topographic information for the study area was derived from the ASTER Digital Elevation Model (DEM) obtained from the United States Geological Survey (USGS). The DEM was processed in ArcGIS 10.7 to generate slope data for the study area. Slope information was incorporated into the suitability evaluation because of its influence on irrigation efficiency, runoff, erosion, and soil management.

Land Suitability Evaluation for Irrigated Pepper Cultivation

Land suitability for irrigated pepper cultivation was evaluated using the FAO land evaluation framework (FAO, 1976), with modifications based on the criteria proposed by Sys *et al.* (1991) and Naidu *et al.* (2006). The evaluation considered major soil and site characteristics relevant to irrigated pepper production, including available water capacity, effective soil depth, texture, drainage, soil pH, cation exchange capacity, base saturation, salinity, and slope (Table 1).

Table 1: Factor Ratings of Land Use Requirements for Irrigated Pepper (Sprinkler/Drip)

Qualities/ Characteristics	Unit	S1	S2	S3	N
AWHC	cm 120 cm ⁻¹	>12	9 – 12	6 - 9	<6
	cm 30 cm ⁻¹	>4	3 - 4	2 - 3	<2
Effective soil depth	cm	>50	30 - 50	20 - 30	<20
Texture	Class	SL, L, CL, SCL, SC, SiL	C, SiCL, S	SiC, hC, LS	S
Drainage	Class	WD	MD, ID	PD	VPD, ED
pH	--	6.1-8.0	8.1 – 9.0, 5.1 – 6.0	9.1 – 9.5, 4.1 – 5.0	> 9.5, <4.0
CEC	cmol kg ⁻¹	>12	8 - 12	4 - 8	<4
Base Saturation	%	>35	25 - 35	20 - 25	< 20
Salinity (EC)	dS m ⁻¹	<6	6-12	12-24	>24
Slope	%	0 - 2	2 – 4	4 - 6	> 6

Note: AWHC – available water holding capacity; SL – sandy loam; L – loam; CL – clay loam; SCL – sandy clay loam; SC – sandy clay; SiL – silt loam; C – clay; SiCL – silty clay loam; S – sand; SiC – silty clay; hC – heavy clay ($\geq 60\%$ clay content); WD – well drained; MD – moderately drained; ID – imperfectly drained; PD – poorly drained; VPD – very poorly drained; ED – excessively drained; CEC – cation exchange capacity; EC – electrical conductivity of saturated soil extract; S1 – highly suitable; S2 – moderately suitable; S3 – marginally suitable; N – not suitable.

Each land characteristic was classified into suitability classes comprising highly suitable (S1), moderately suitable (S2), marginally suitable (S3), and not suitable (N), based on the requirements for irrigated pepper cultivation.

Analytic Hierarchy Process (AHP)

The relative importance of the suitability criteria was determined using the Analytic Hierarchy Process (AHP) developed by

Saaty (1980). Pairwise comparisons among the criteria were conducted using Saaty's fundamental scale ranging from 1 to 9, where higher values indicate greater relative importance of one criterion over another (Table 2). The pairwise comparison matrix was used to derive normalized weights for each suitability factor.

Table 2: The fundamental score for pairwise comparison in AHP

Scores	Score representation
1	represents equal importance
3	represents moderate importance
5	represents strong importance
7	represents very strong importance
9	represents extreme importance
2, 4, 6 and 8	Intermediate values between the two options

The consistency of the pairwise comparison matrix was evaluated using the Consistency Index (CI) and Consistency Ratio (CR). The Consistency Index was computed using Eq. (1), defined as:

$$CI = \frac{\lambda_{max} - n}{n - 1} \quad \text{Eq. (1)}$$

where λ_{max} is the maximum eigenvalue of the comparison matrix and (n) is the number of criteria considered.

The Consistency Ratio was then calculated as:

$$CR = \frac{CI}{RI} \quad \text{Eq. (2)}$$

where RI represents the Random Index proposed by Saaty (2004). A CR value less than 0.10 was considered acceptable, indicating satisfactory consistency in the pairwise comparisons.

GIS-Based Multi-Criteria Evaluation and Suitability Mapping

The weighted suitability factors derived from the AHP analysis were integrated in ArcGIS 10.7 using the weighted overlay technique to produce the land suitability map for irrigated pepper cultivation. Spatial layers representing the evaluated soil and terrain properties were generated and reclassified according to their suitability ratings. The weighted overlay analysis

combined the standardized criteria and their corresponding weights to produce the final suitability map. The resulting map classified the study area into different

suitability categories, thereby identifying areas suitable for irrigated pepper cultivation within the study area.

Results and Discussion

Criteria Weighting and AHP Consistency Analysis

Table 3 shows the pairwise comparison of suitability criteria considered for irrigated pepper suitability in the study area, while Table 4 shows the final derived weights and consistency metrics.

Among the evaluated criteria, AWHC and effective rooting depth were assigned the highest weights of 0.192 (19.2%) and 0.189 (18.9%), respectively (Table 4). Their high ranking highlights the importance of adequate soil moisture storage and rooting conditions for irrigated pepper cultivation. Available water holding capacity determines the quantity of water retained within the soil for plant uptake between irrigation intervals. Low AWHC increases susceptibility to moisture stress, even under irrigation, particularly during flowering and fruit development stages (Chen *et al.*, 2023). Similar observations were reported by Hussien *et al.* (2019) in irrigated agricultural lands along the Erer Watershed, Ethiopia. Effective rooting depth also plays a major role in crop performance because shallow or compacted soils restrict root penetration, thereby limiting access to water and

nutrients. Consequently, soils with greater rooting depth and higher moisture

Table 3: Pairwise comparison matrix of suitability criteria for irrigated pepper cultivation

Criteria	AWC	Depth	Texture	Drainage	pH	CEC	BS	EC	Slope
AWHC	1	1	2	2	3	3	3	4	2
Depth	1	1	2	2	3	3	3	4	2
Texture	1/2	1/2	1	1	3	3	3	4	2
Drainage	1/2	1/2	1	1	3	3	3	4	2
pH	1/3	1/3	1/3	1/3	1	1	1	2	1/2
CEC	1/3	1/3	1/3	1/3	1	1	1	2	1/2
BS	1/3	1/3	1/3	1/3	1	1	1	1	1/2
EC	1/4	1/4	1/4	1/4	1/2	1/2	1	1	1/2
Slope	1/2	1/2	1/2	1/2	2	2	2	1	1

Note: AWHC – available water holding capacity; CEC – cation exchange capacity; BS – base saturation percentage; EC – electrical conductivity.

Table 4: AHP-derived weights of suitability criteria and consistency metrics

Criterion	Weight (CWI)
AWC	0.192
Root depth	0.189
Texture	0.147
Drainage	0.147
pH	0.059
CEC	0.059
BS	0.055
EC	0.027
Slope	0.125
Consistency Index (CI)	0.035
Random Index (RI)	1.450
Consistency Ratio (CR)	0.024

Note: AWHC – available water holding capacity; CEC – cation exchange capacity; BS – base saturation percentage; EC – electrical conductivity.

retention capacity are generally more favourable for sustainable pepper production (Abdelkhalik *et al.*, 2020). Soil texture and drainage were the next most important factors, each receiving a weight of 0.147 (14.7%). These properties strongly influence water movement, aeration, and nutrient retention within the soil profile. Pepper performs best under well-drained soils with moderate moisture

retention, as the crop is sensitive to both drought and prolonged waterlogging (Sadiq *et al.*, 2021; Aluvihara *et al.*, 2024). Previous studies have similarly identified soil texture and drainage as critical determinants of pepper productivity (Jung *et al.*, 2004; Rusmin *et al.*, 2021; Addharu *et al.*, 2021). Fine-textured soils may retain excessive water and predispose crops to root diseases, whereas excessively sandy

soils may lose water rapidly through drainage. Proper drainage is therefore essential for maintaining favourable root-zone conditions under irrigation (Osman, 2018).

Slope was assigned a weight of 0.125 (12.5%), indicating its moderate importance in the suitability analysis. Slope influences runoff, erosion risk, irrigation efficiency, and ease of field management (Sadiq *et al.*, 2021). Areas with gentle slopes are generally more suitable for irrigated agriculture because they minimize runoff losses and facilitate efficient water distribution.

Chemical properties including pH, CEC, BS, and EC received comparatively lower weights ranging from 0.027 to 0.059. Although these properties are important for crop growth and nutrient availability, they are often considered manageable through appropriate soil amendments and fertilizer application (Jung *et al.*, 2004; Addharu *et al.*, 2021). For instance, soil acidity can be corrected through liming, while nutrient deficiencies may be improved through fertilizer and organic matter application. Nevertheless, these chemical properties remain important for sustaining long-term soil fertility and crop productivity under irrigation. Similar findings were reported by Yusra *et al.* (2022), who identified pH, CEC, and BS as limiting factors for pepper cultivation in Bireuen Regency, while Olajide *et al.* (2020) reported soil acidity as a major limitation to pepper production in southwestern Nigeria.

The reliability of the pairwise comparison matrix was evaluated using the Consistency Index (CI), Random Index (RI), and Consistency Ratio (CR). The analysis produced a CI value of 0.035, an RI value of 1.45, and a CR value of 0.024 (Table 4). According to Saaty (1980) and

Sarkar *et al.* (2021), a CR value below 0.10 indicates acceptable consistency in pairwise judgments. The CR obtained in this study therefore confirms that the weighting process was highly consistent and reliable. This validates the suitability of the AHP method for assigning weights to the evaluated criteria and supports its application in GIS-based land suitability assessment (Sadiq *et al.*, 2023; Sadiq *et al.*, 2025).

Spatial Distribution of Soil and Site Suitability Parameters

The suitability assessment based on individual soil and terrain parameters revealed varying levels of suitability across the study area (Fig. 2a–i). Available water holding capacity was generally classified as marginally suitable (S3) throughout most of the study area (Fig. 2a). This suggests that the soils possess limited capacity to retain plant-available water, thereby increasing the frequency of irrigation required for optimum pepper production. Similar observations were reported by Pérez-Gutiérrez *et al.* (2017), who emphasized the importance of adequate soil moisture retention for irrigated crops. Improving soil organic matter content through compost or manure application may therefore enhance water retention and improve crop performance (Sadiq *et al.*, 2025).

The study area was found to be highly suitable (S1) with respect to soil texture, effective rooting depth, base saturation, and electrical conductivity (Fig. 2b–e). These favourable conditions indicate that the soils possess adequate physical characteristics for root development and nutrient uptake, while salinity levels remain within acceptable limits for pepper cultivation.

Soil texture and rooting depth are particularly important because they influence root penetration, water movement, and nutrient availability within the soil profile.

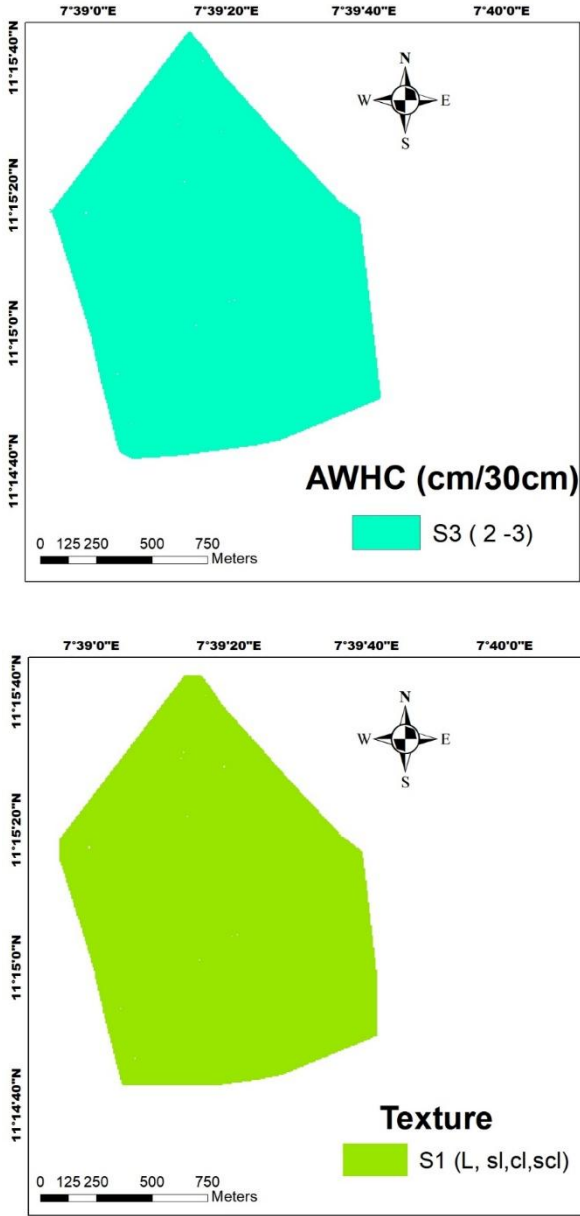


Fig. 2a: Spatial Distribution of AWHC
Fig. 2b: Textural Class
Distribution

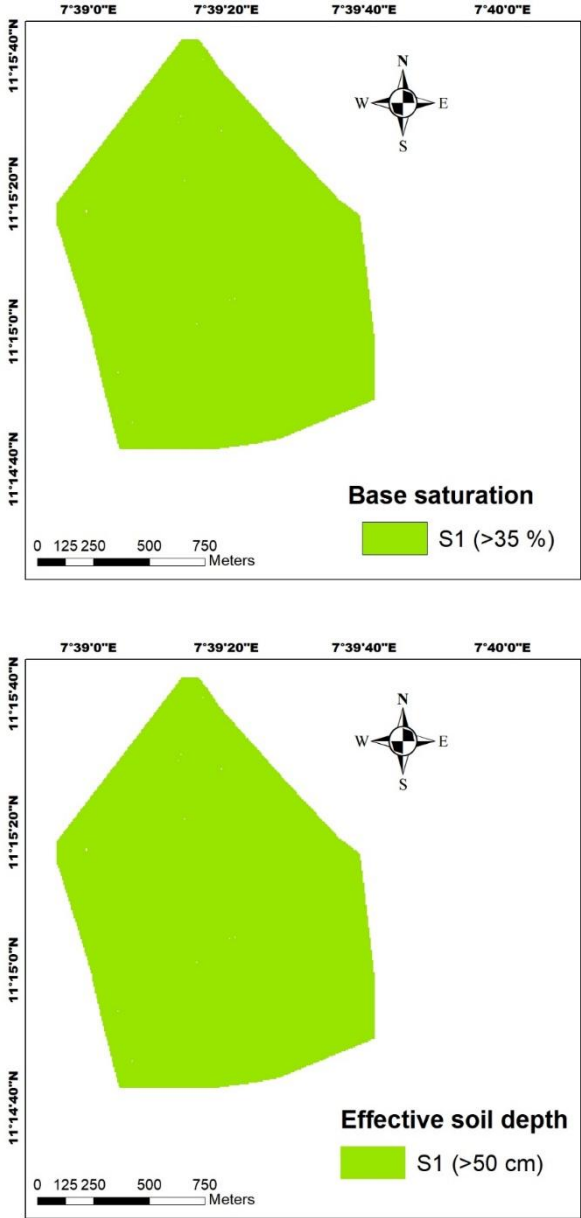


Fig. 2c: Base Saturation Distribution
Fig. 2d: Effective Depth
Distribution

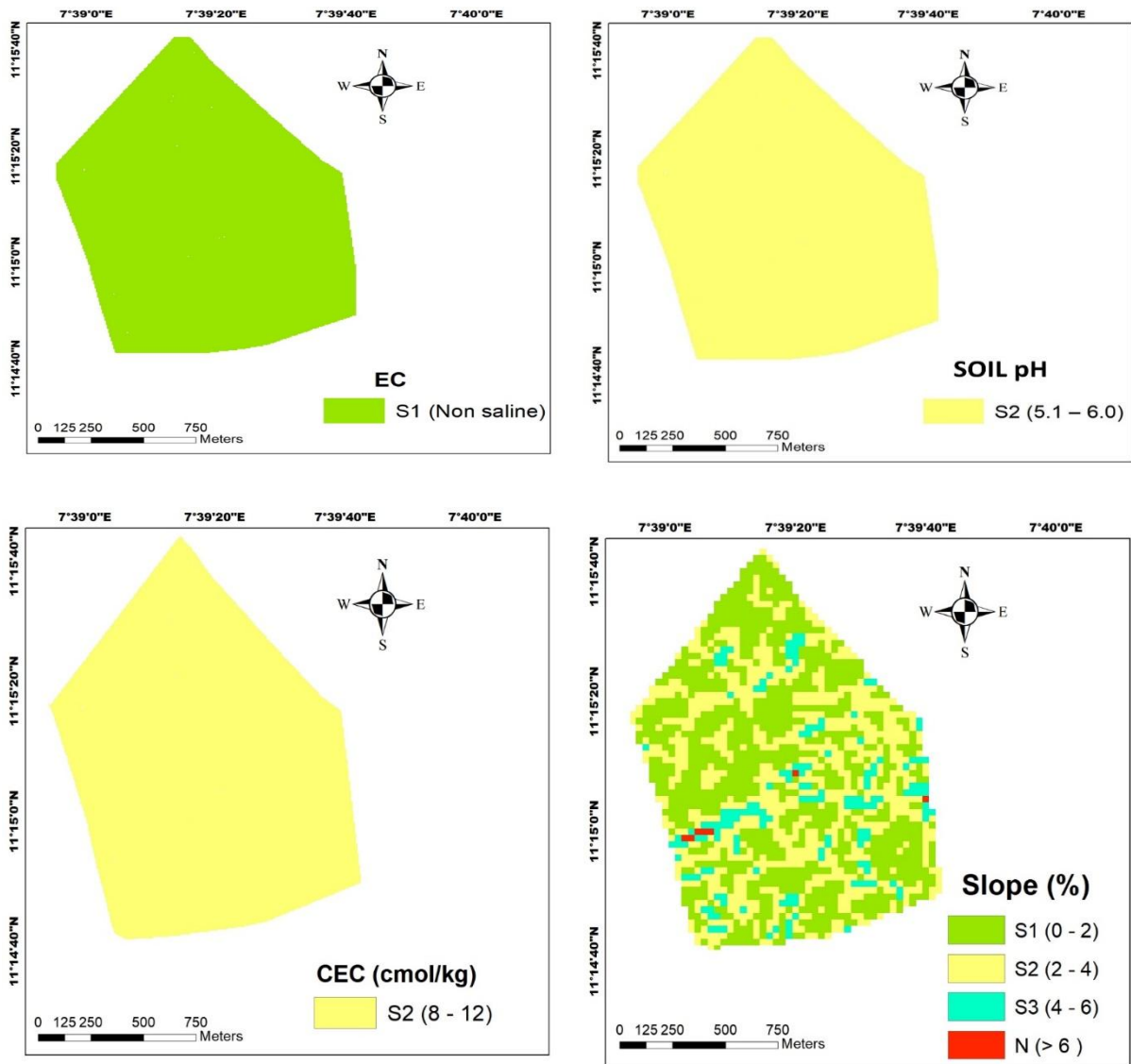


Fig. 2e: Electrical Conductivity Distribution
Fig. 2f: CEC Distribution

Fig. 2g: Soil pH Distribution
Fig. 2h: Slope Distribution

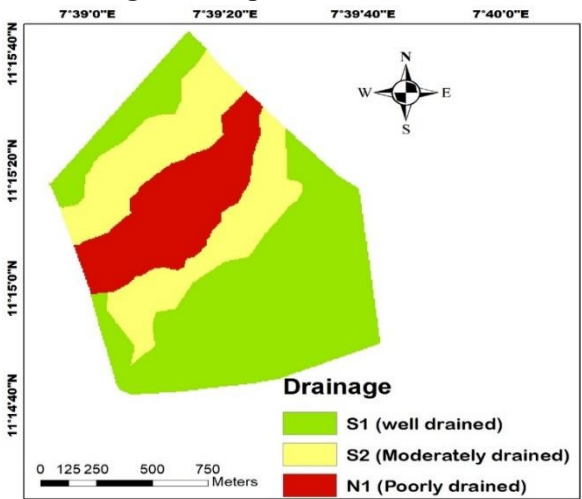


Fig. 2i: Drainage Class Distribution
In contrast, soil pH and cation exchange capacity were classified as moderately

suitable (S2) across much of the study area (Fig. 2f–g). Soil pH directly affects nutrient solubility and availability, while CEC reflects the soil's ability to retain and exchange essential nutrients. Moderate suitability of these properties indicates the need for soil fertility management practices, including liming and organic matter application, to optimize nutrient availability for pepper production. These findings agree with those of Ogechi and Blessing (2024), who reported similar fertility-related limitations in the region.

Topographic analysis showed that 50.4% of the study area was highly suitable (S1) for slope, while 40.75%, 8.46%, and 0.37% were classified as moderately suitable (S2), marginally suitable (S3), and not suitable (N), respectively (Fig. 2h). Gentle slopes favour irrigation management and reduce erosion hazards, whereas steeper slopes increase runoff and nutrient losses (Awwal, 2021; Wange *et al.*, 2022). Drainage suitability analysis indicated that 52.2% of the area was highly suitable (S1), 28.56% marginally suitable (S3), and 19.3% not suitable (N) for irrigated pepper cultivation (Fig. 2i). Poor drainage conditions may result in waterlogging, reduced oxygen supply to roots, and increased incidence of root diseases. These findings support earlier reports emphasizing the importance of adequate drainage for irrigated pepper production (Magaji & Pantami, 2024; Sadiq *et al.*, 2023).

Overall Land Suitability for Irrigated Pepper Cultivation

The overall suitability map generated through the GIS-AHP weighted overlay analysis revealed that the study area is predominantly moderately suitable for

irrigated pepper cultivation (Fig. 3). Approximately 64.9% (116.82 ha) of the total area was classified as moderately suitable (S2), while 35.1% (63.18 ha) was classified as marginally suitable (S3). No areas were classified as highly suitable at the overall level, indicating the presence of certain limitations affecting land performance for irrigated pepper cultivation.

The major limiting factors identified in the study area were available water holding capacity, cation exchange capacity, soil pH, drainage, and slope. Low AWHC reduces the soil's ability to retain sufficient moisture between irrigation intervals, thereby increasing the risk of drought stress during critical growth stages. Similarly, low CEC limits nutrient retention and fertilizer-use efficiency, while unfavourable pH conditions may restrict nutrient availability and uptake by pepper plants.

Drainage and slope also constituted important physical constraints in some parts of the landscape. Poor drainage conditions may lead to waterlogging and root diseases, whereas steeper slopes increase the risk of runoff, erosion, and nutrient loss. These factors can reduce crop productivity and complicate irrigation management if appropriate conservation measures are not implemented.

To improve land suitability for irrigated pepper cultivation, several management interventions are recommended. The incorporation of organic amendments such as compost and manure can improve soil structure, increase AWHC, enhance CEC, and buffer soil pH. In sloping areas, erosion control measures including contour

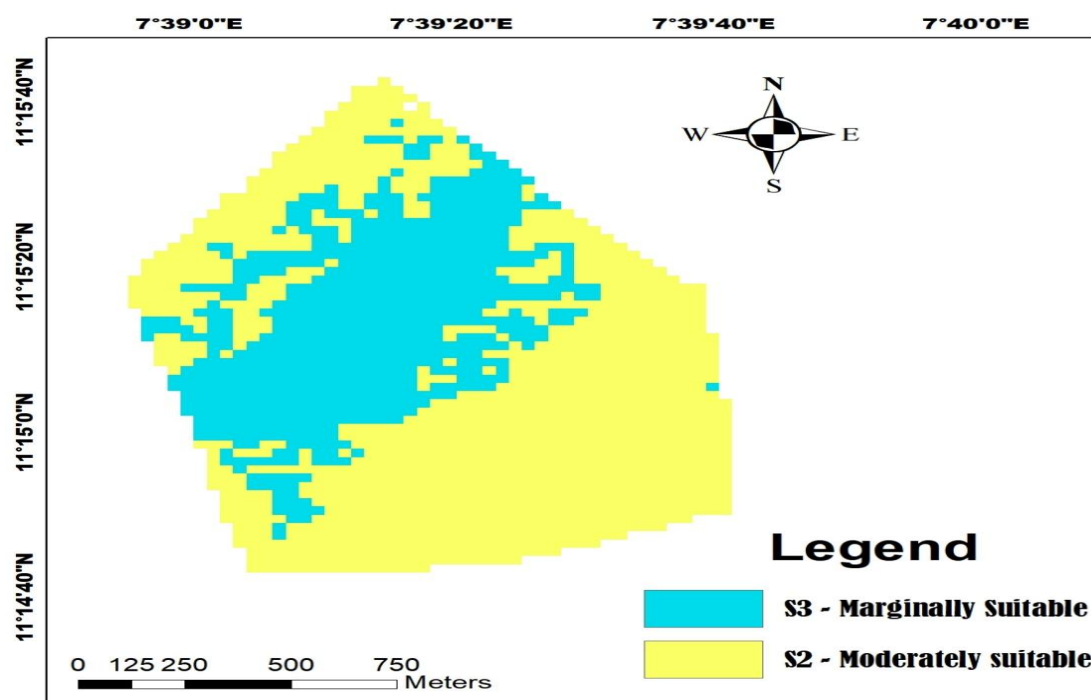


Figure 3: Land suitability map for irrigated pepper cultivation in the study area

farming, cover cropping, and terracing should be adopted to minimize soil loss. Areas affected by poor drainage may require improved drainage systems such as raised beds or field drains to prevent water stagnation. In addition, efficient irrigation practices should be implemented to optimize water use and maintain favourable soil moisture conditions.

Conclusion

This study evaluated the suitability of land for irrigated pepper cultivation in Hunkuyi, Northern Nigeria using an integrated GIS and Analytic Hierarchy Process (AHP) approach. The integration of soil physical, chemical, and topographic parameters provided a comprehensive framework for assessing land capability under irrigated agricultural conditions. The AHP analysis revealed that available water holding capacity and effective rooting depth were the most influential factors controlling suitability, followed by soil texture, drainage, and slope, while chemical properties such as pH, CEC, base

saturation, and electrical conductivity played comparatively lower but still important roles. The consistency ratio confirmed that the pairwise comparisons were reliable, strengthening the validity of the derived weights.

Spatial analysis indicated that most of the study area is moderately suitable for irrigated pepper cultivation, with the remaining portion classified as marginally suitable. No area attained a predominantly highly suitable classification, largely due to constraints such as low water-holding capacity, moderate limitations in soil chemical fertility, drainage issues, and slope variability. These limitations suggest that while the area has potential for pepper production under irrigation, productivity may be constrained without targeted soil and water management interventions.

The study demonstrates that GIS-AHP is an effective decision-support tool for land evaluation in irrigated agriculture. It provides spatially explicit information that can guide sustainable land-use planning

and improve crop productivity. Addressing the identified constraints through soil amendment, improved drainage, and efficient irrigation practices will significantly enhance the suitability and productivity of the area for pepper cultivation.

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LAND EVALUATION FOR SUGARCANE CULTIVATION USING GIS AND MULTI-CRITERIA DECISION ANALYSIS IN MOKWA, NIGER STATE, NIGERIA

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ABSTRACT

This study assessed the suitability of soils for sugarcane production in Mokwa, Niger State, Nigeria, using Geographic Information Systems (GIS) and Multi-Criteria Decision Analysis (MCDA). The research utilized a legacy soil map, which was georeferenced and digitized to create a basemap. The study area was systematically divided into grids at 2.5 km intervals and mapped at a scale of 1:100,000. To enhance accuracy, soil data were harmonized with the FAO Harmonized World Soil Database V2.0 for extracting pH and depth values. Additionally, percentage slope was derived from LiDAR point cloud data collected in the field, while rainfall and temperature data were sourced from the NASA Langley Research Center. Economic feasibility was incorporated by analyzing distance buffers from a sugar mill. All spatial analyses and data processing were conducted using ArcMap 10.8, with the Analytical Hierarchy Process (AHP) applied to weigh the factors influencing sugarcane production and the final suitability assessment was determined through a weighted overlay analysis. The results indicated that soil depth, pH, slope, and temperature were highly suitable (S1) for sugarcane cultivation, while rainfall was moderately suitable (S2). The soil pH, ranged from slightly acidic to neutral which created an optimal environment for sugarcane growth by ensuring nutrient availability and supporting root development. The study area's deep soils (100-150 cm) facilitated extensive root growth, enhanced water and nutrient uptake; critical for sugarcane's high water and nutrient requirements. The gentle slopes observed minimized soil erosion, improve water retention and drainage, reducing the risk of waterlogging while maintaining adequate moisture. Additionally, the region's temperature ranged between 25–30°C is well-suited for sugarcane cultivation, promotes photosynthesis and crop development. While the annual rainfall (1000–1200 mm) was slightly below the optimal range (1200–1800 mm), proper irrigation strategies that will compensate for the deficit, and ensure sustainable sugarcane production is recommended.

Keywords: Land suitability, sugarcane, GIS, Multi-Criteria Decision Analysis (MCDA), Analytical Hierarchy Process (AHP), Sunti, Mokwa.

Introduction

The agriculture sector plays a crucial role in the economic and social development of a nation (Giannakis & Zittis, 2021). Competition for land is increasing as demand for multiple land uses and ecosystem services rise; food security issues, renewable energy, and emerging carbon

markets are creating price signals for the conversion of agricultural land to other uses, such as reforestation and biofuels (Metternicht, 2018). Sugarcane (*Saccharum officinarum*) is a critical agricultural commodity, serving as a primary source of sugar, biofuel, and industrial materials worldwide. It is one of the main crops earning foreign exchange. The sustainable

expansion of sugarcane production is paramount in meeting increasing global demand while minimizing environmental impact and optimizing land use efficiency.

In Nigeria, sugarcane production is critical for reducing the country's reliance on sugar imports. Despite favorable ecological conditions, national self-sufficiency in sugar consumption is hanging, highlighting the need for improved land evaluation to enhance productivity. There is lack of land evaluation and associated information in Sunti because land evaluation and mapping have followed the traditional approach and also time-consuming and costly (Behrens & Schloten, 2006).

Deficit in spatial knowledge directly threatens food security objectives. Regional and national food security planning requires granular understanding of crop production potential across diverse landscapes. Mokwa LGA, with a functional sugar mill faces challenges of spatial knowledge. Without knowing where specific crops can thrive at a field level, we are essentially operating on educated guesses rather than science. However, identifying suitable land for sugarcane cultivation presents a complex challenge, requiring sophisticated spatial analysis and comprehensive evaluation methodologies. Therefore, this study provides evidence-based spatial planning for sustainable agricultural intensification.

Land suitability analysis is essential for informed farming decisions, revealing an area's natural potential and limitations (Halder, 2013). Agricultural land evaluation for crop cultivation plays a vital role in developing a sustainable and productive agricultural system. It is one of the important processes employed towards the reduction of human influence on natural

resources' degradation and in the identification of sustainable land use options. A widely used and crucial stage in resource management is the land suitability assessment, which is a central part of the land-use evaluation (FAO, 1996). Such kind of analysis allows decision-makers to implement the best land management strategies hence increasing land productivity by identifying the main limiting factors for the specified agricultural practice (Alhammad *et al.*, 2023; Seleiman *et al.*, 2022).

Materials and methods

Study area

Sunti is located in Mokwa LGA of Niger State, a region of southern guinea savanna geographically between latitudes 8°59'48.732"N and 9°7'22.71"N and longitudes 5°12'50.423"E and 5°25'47.778"E. The study area covers approximately 15,160 hectares and is characterized by a semi-arid to semi-humid subtropical climate, with an average maximum annual temperature of 32 °C and distinct wet (April–October) and dry (November–March) seasons. The mean annual rainfall varies from 1000 mm to 1200 mm. Sunti, is a significant agricultural hub in the region, thanks to its proximity to Sunti Golden Sugar Estate and the River Niger, which provides irrigation opportunities. The area primarily focusing on both rain-fed and irrigated agriculture.

Office (desk) work

Soil is a key factor in determining the suitability of an area generally for agriculture. Soil mapping units (SMU) of the study area was acquired from the soil map of Nigeria as described by Sonneveld B.G.J.S (1996). The SMU were georeferenced, clipped, and digitized in ArcMap 10.8.

The soil depth and pH of the study area was accessed from the FAO Harmonized World Soil Database in an Environmental System

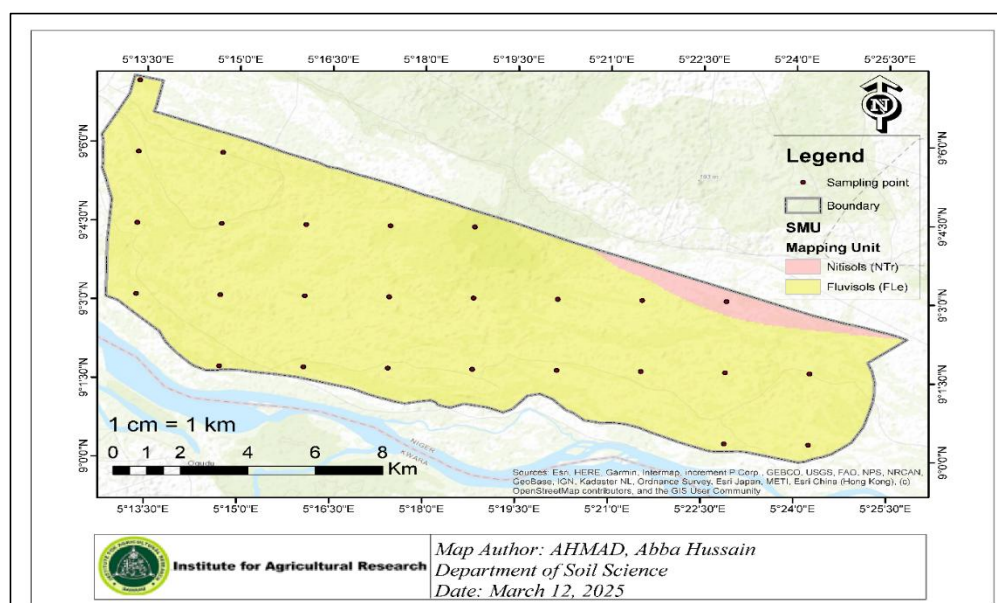


Figure 1: Study area map

Research Institute (ESRI) software (version 2.0). at 2.5 Km intervals across the study area (Fig. 1), interpolated and a soil depth and pH raster generated. The maps were produced at a scale of 1:100, 000. LiDAR point cloud survey data of the study area was converted into a raster surface using a Triangulated Irregular Network (TIN) producing an elevation data which was further converted to a raster using TIN to Raster conversion of 3D Analyst Tools of ArcMap 10.8. The resulting raster, a digital elevation model was then used to create percentage slope map of the study area under Raster Surface of same 3D Analyst Tools of ArcMap Toolbox.

Average rainfall and temperature data over a 30-year period was sought from NASA Langley Research Centre (LaRC) portal where point or area rainfall information could be derived. The point data imported into ArcMap, interpolated and raster surface generated. All data were resampled to have same 30 by 30-meter spatial resolution.

Results

Spatial distribution of parameters

The required soil data were assembled from different sources, rated using rating for soil

data interpretation as shown in Table 1 below;

Discussion

Given the deep soils (100–150 cm) indicated by spatial distribution, research indicates that sugarcane roots predominantly occupy the upper 50 cm of the soil profile, with significant root concentration near the cane rows. For instance, a study in Brazil found that most roots were concentrated within 0 to 18 cm from the cane rows and in the upper 54 cm of the soil (Silva *et al.*, 2018). This suggests that while sugarcane roots can extend deeper, the majority of root activity occurs in the upper soil layers. (Mirian, Jairo, Godofredo, & Lucio, 2007).

Deep soils enhance water and nutrient retention, which is beneficial for sugarcane growth. A study in Sudan found that sugarcane yields were positively correlated with clay content and exchangeable potassium, indicating that soil properties significantly influence productivity. Therefore, deep soils with higher clay content can improve water and nutrient availability, supporting robust sugarcane growth (Ibrahim, 1978).

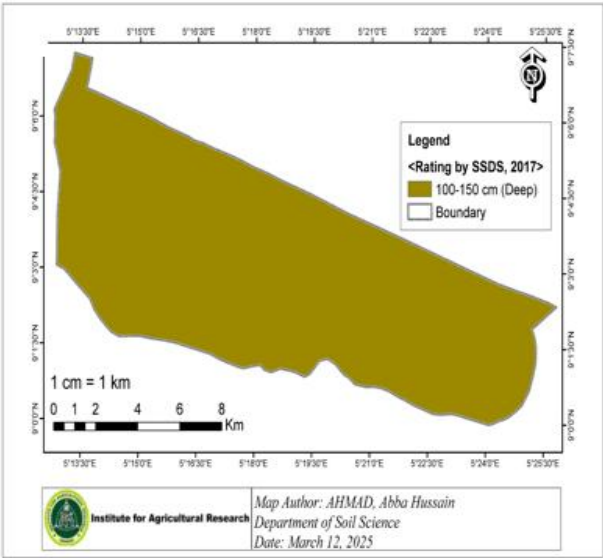
The relationship between soil properties and sugarcane yield has been observed in various studies. For example, research conducted at the Bacita Sugar Estate in

Nigeria found that soil acidity adversely affected sugarcane yield, while adequate levels of potassium and other nutrients were associated with better growth.

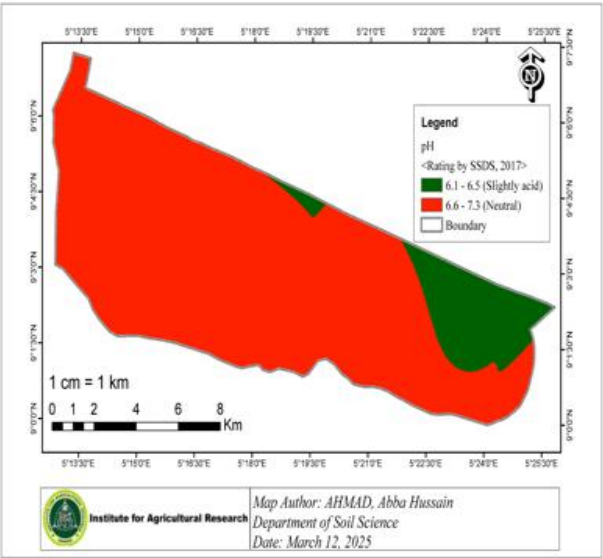
Table 1: Ratings for soil data interpretation

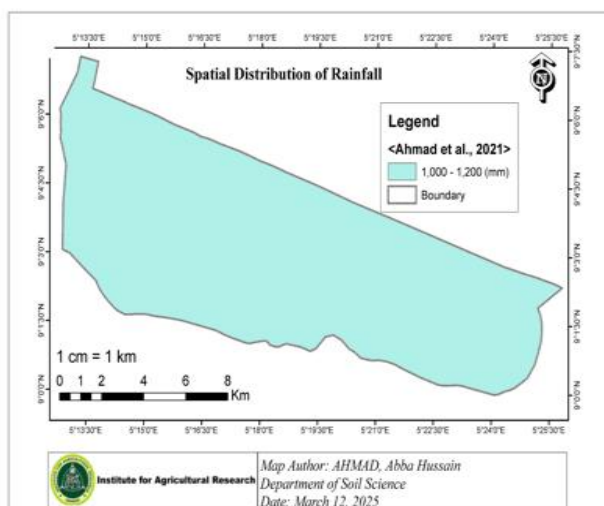
Parameter	Classes	Reference
Rooting condition (Soil depth (cm))	<25 - Very shallow 25-50 – Shallow 50-100 – Moderately deep 100-150 – Deep >150 – Very deep	Soil Science Division Staff (2017)
Nutrient availability (pH)	<4.5 Extremely acid 4.5-5.0 Very strongly acid 5.1-5.5 Strongly acid 5.6-6.0 Moderately acid 6.1-6.5 Slightly acid 6.6-7.3 Neutral 7.4-7.8 Slightly alkaline 7.9-8.4 Moderately alkaline 8.5-9.0 Strongly alkaline >9.0 Very strongly alkaline	
Slope (%)	0-2 level to nearly level 2-4 Gently sloping (Undulating) 4-7 Moderately to strongly sloping 7-12 Very strongly sloping 12-18 Steeply sloping and hilly 18-30 Very steep or hilly	Esu (1991)

a. Soil depth

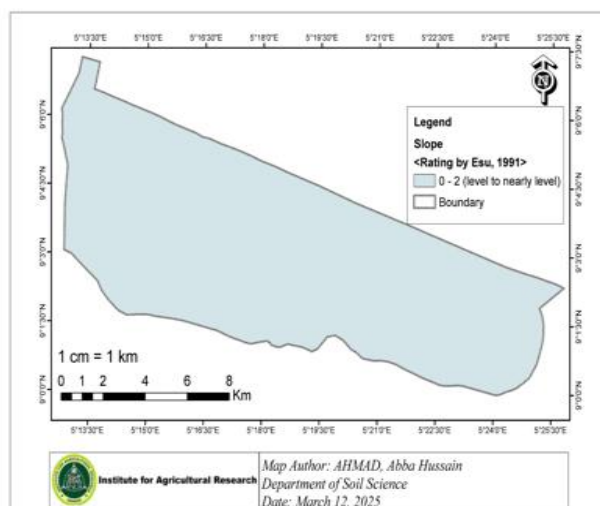


b. pH

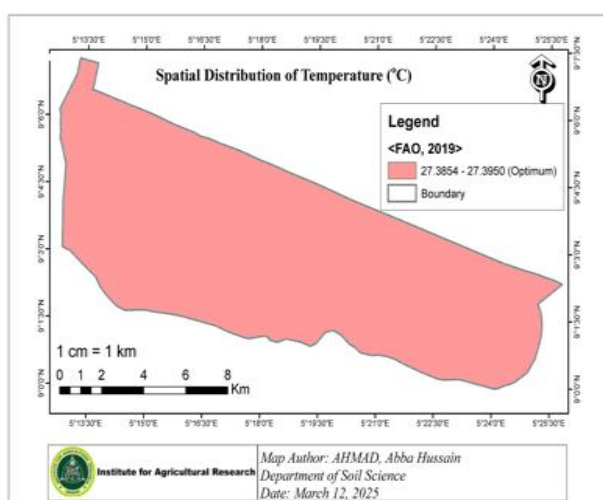




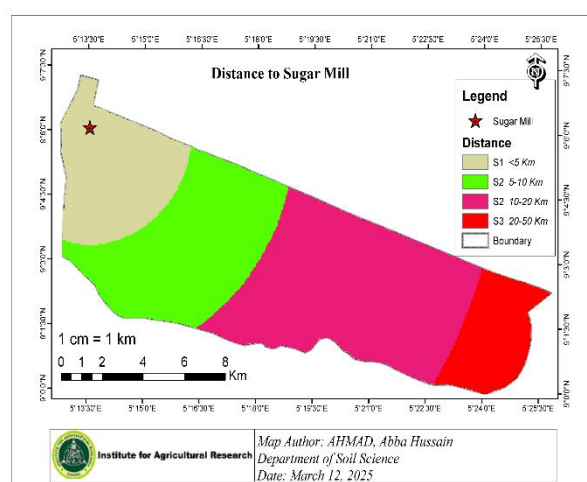
c. Rainfall



d. Slope



e. Temperature



f. Distance to mill

Table 2: Land characteristics suitability ratings

Land characteristics	Highly Suitable	Moderately Suitable	Marginally Suitable	Not Suitable
Precipitation (mm)	1200-1800	1000-1200	900-1000	<900
Mean temperature (°C)	20-38	15-20	11-15	<11
Slope (%)	<3	3-5	5-8	>8
Depth (cm)	>100	100-75	75-50	<50
pH (H ₂ O)	6.0-7.3	7.3-7.8	7.8-8.4	>8.4
		5.0-6.0	5.0	<5
Distance to sugar mill (km)	<5	5-10	10-20	>20

Source: FAO, 2019; Jamil *et al.*, 2017; Naidu *et al.*, 2006

This underscores the importance of managing soil properties to optimize yield potential (Ogunwale & Ashaye, 2014; Afolabi, 1996).

Studies in floodplain areas have identified poor drainage and soil acidity as constraints for sugarcane growth, necessitating appropriate land management strategies (Akinbola *et al.*, 2020). Proper drainage is crucial to prevent waterlogging, which can hinder root function. Implementing drainage and flood control measures, along with soil amendments, was recommended to mitigate these limitations for sugarcane cultivation. This highlights the need for effective water management strategies in deep soils.

To maintain and enhance soil structure and fertility in deep soils, practices such as deep plowing, organic matter incorporation, and proper fertilization are recommended. For example, in sugarcane cultivation, deep plowing to a depth of 20–25 cm, followed by harrowing and weed control, has been suggested to prepare the soil effectively. Additionally, addressing soil acidity through liming and ensuring balanced nutrient application can further support optimal sugarcane growth (EOS Data Analytics, 2023).

Sugarcane can tolerate considerable degree of soil acidity and alkalinity. It is cultivated in soils with slight acidic and alkaline reaction. However, soil pH ranging from 6.5 to 8.5 is considered best for sugarcane cultivation (Jamil *et al.*, 2017). Given that the majority (88.1%) of the area is neutral, it is highly suitable for sugarcane cultivation with minimal pH-related constraints. However, the 11.9% slightly acidic zones may require site-specific soil management to prevent acidification and sustain high crop productivity (FAO, 2020a). The dominance of neutral soils in

the area is advantageous for nutrient availability, root development, and microbial activity (Kumar *et al.*, 2018). This neutral range enhances the solubility and availability of essential macronutrients such as nitrogen (N), phosphorus (P), and potassium (K), which are critical for sugarcane growth and yield (Rashid *et al.*, 2021). Slightly acidic soils (6.1–6.5) while still within the acceptable range, phosphorus (P) availability may slightly decrease due to increased fixation by iron and aluminum oxides (Havlin *et al.*, 2014). If acidification progresses to pH < 5.5, the soil could experience aluminum (Al) and manganese (Mn) toxicity, leading to root damage and poor sugarcane performance (Fageria & Baligar, 2008).

To optimize soil conditions for sugarcane in the study area, management strategies are recommended:

- **Lime Application:** The slightly acidic soils (11.9%) may require periodic liming (e.g., dolomitic limestone) to maintain pH above 6.0 and prevent nutrient imbalances (Okon *et al.*, 2019).
- **Organic Matter Amendment:** The addition of organic materials (e.g., compost, manure, crop residues) can buffer soil pH changes and improve nutrient retention (Pathak *et al.*, 2021).
- **Phosphorus Fertilization:** In slightly acidic areas, band placement of phosphorus fertilizers (e.g., single super phosphate) can enhance P availability and reduce fixation (Brady & Weil, 2016).

The pH status of the soils in Sunti is highly suitable for sugarcane production, with only minor concerns in the slightly acidic areas. Long-term soil monitoring, site-specific

liming, organic amendments, and proper fertilization strategies will help maintain soil productivity and sustain high sugarcane yields in the region.

The spatial analysis of the study area shows that the land has a slope between 0-2%, indicating a nearly flat terrain. This slope condition is highly suitable for sugarcane cultivation, as sugarcane prefers gentle to flat slopes (0-3%) for optimal growth and mechanized farming (FAO, 2020b; Lal, 2018). Flat land facilitates uniform water distribution, reducing runoff and ensuring better moisture availability for sugarcane growth (Singh *et al.*, 2021); suitable for both flood irrigation and furrow irrigation systems, which are commonly used in large-scale sugarcane plantations. Steeper slopes (>3%) can lead to erosion and nutrient loss, which negatively affects sugarcane productivity (Brady & Weil, 2016). With a 0-2% slope, the risk of soil erosion is minimal, ensuring long-term soil fertility sustainability.

While a flat slope is beneficial, poor drainage and waterlogging can become a concern, especially in heavy rainfall periods (Ratoon *et al.*, 2021). Proper drainage channels or raised beds may be required to prevent stagnant water, which could affect root development. Sugarcane farming requires intensive land preparation, planting, and harvesting. With flat lands, mechanized operations are enhanced, improving efficiency and reducing production costs (Pathak *et al.*, 2022); facilitating large-scale sugarcane production, particularly for commercial farming. Prolonged mechanization on flat land can lead to soil compaction, affecting root penetration and nutrient uptake (Okon *et al.*, 2019). Periodic deep tillage and organic matter addition can mitigate compaction issues.

In evaluating the economic suitability of land for sugarcane production in Sunti, the distance to the nearest sugar mill is a crucial factor. Proximity influences transportation costs, which directly affect the profitability and feasibility of sugarcane farming. According to the Food and Agriculture Organization (FAO) land suitability classification, distance to processing facilities like sugar mills is integral to determining the economic viability of agricultural land. Correlating with Jamil *et al.*, (2017), in their land suitability assessment for sugarcane cultivation in Bijnor District, India, they incorporated the distance to the nearest sugar mill as a critical criterion. They categorized suitability based on distance as follows:

- 0–5 km: Highly suitable (S1)
- 5–10 km: Moderately suitable (S2)
- 10–20 km: Marginally suitable (S3)
- >20 km: Unsuitable (N)

Applying this framework to the Sunti area

- 18.92% of the land (<5 km) is highly suitable.
- 29.01% (5–10 km) is moderately suitable.
- 41.2% (10–20 km) is marginally suitable.
- 10.87% (>20 km) is deemed unsuitable due to excessive transportation costs.

The spatial distribution of land in relation to the existing sugar mill in Sunti indicates that a substantial portion of the area is suitable for sugarcane production when considering economic factors. However, as distance increases, transportation costs become a limiting factor, reducing the economic viability of cultivation. Strategic planning, including potential infrastructure

improvements or the establishment of additional processing facilities, could enhance the suitability of more distant areas. The spatial analysis shows that total of the study area is highly suitable (S1) in terms of temperature for sugarcane production. This indicates that the region experiences optimal temperature conditions, which significantly enhance sugarcane growth and yield. Sugarcane thrives best at temperatures between 25°C and 35°C for optimal photosynthesis and sucrose accumulation (FAO, 2020a). Sunti falls within this range, making the region ideal for sugarcane growth throughout the growing season. Singh *et al.*, (2019) highlighted that high temperatures promote rapid tillering, stem elongation, and leaf expansion, leading to increased biomass production. Warm temperatures during the ripening phase increase sugar concentration, improving the quality of cane for processing (Lal *et al.*, 2021).

In terms of rainfall, the analysis indicates that 100% of the study area falls under moderately suitable (S2) conditions, implying that while rainfall is sufficient for sugarcane growth, it may require supplementary irrigation for optimal yield. Sugarcane requires 1200–1800 mm of annual rainfall, well-distributed throughout the growing cycle (FAO, 2020a). The Sunti region receives 1000–1200 mm of annual rainfall, which falls within the moderately suitable range but may have uneven distribution. Rainfall distribution in the region may not always align with critical growth stages such as germination, tillering, and elongation, leading to moisture stress (Oke *et al.*, 2021). Supplemental irrigation during dry periods will be essential to prevent yield reductions, particularly in prolonged dry spells (Ali *et al.*, 2018).

Sugarcane ripening benefits from mild water stress, as excess moisture at this stage reduces sucrose accumulation. The moderate suitability of rainfall in Sunti may actually be beneficial during this phase (Shukla *et al.*, 2020).

Land Suitability Map

Standardizing criteria layers is a fundamental prerequisite for conducting weighted overlay analysis in land suitability assessments. To facilitate this process, all vector-based criteria layers were converted into raster format within a GIS environment. The standardization framework applied for sugarcane suitability classification is outlined in Table 2.

This study adheres to the FAO land suitability guidelines, which classify land into four distinct categories: highly suitable (S1), moderately suitable (S2), marginally suitable (S3), and not suitable (N).

- Highly suitable (S1): Land within this category has minimal to no significant limitations for the intended land use. Any existing constraints are minor and do not substantially affect productivity, nor do they require excessive additional inputs.
- Moderately suitable (S2): This classification includes land with moderate limitations, which, if unaddressed, can lead to reduced productivity. However, the required interventions remain economically viable, ensuring that the overall benefits are still attractive, albeit lower than in highly suitable areas.
- Marginally suitable (S3): Land under this category exhibits severe limitations that significantly impact productivity and economic returns, making sugarcane cultivation less

- profitable unless substantial modifications are implemented.
- Not suitable (N): This category represents land with constraints too severe to support sustainable sugarcane cultivation.

To facilitate the weighted overlay analysis, suitability categories were assigned numerical scores on a scale of 1 to 4, where 4 represents highly suitable (S1), 3 represents moderately suitable (S2), 2 represents marginally suitable (S3), and 1 represents not suitable (N). This standardized scoring system ensures quantitative comparability across different land attributes, enabling a more robust and objective suitability evaluation.

To evaluate the degree of influence of selected parameters on the growth rate of the target crops, the Analytic Hierarchy Process (AHP), as proposed by Saaty (2002), was employed as a strategic approach for assigning relative weights to these heterogeneous and influential factors. The AHP methodology involves structuring multiple influential parameters into a hierarchical framework and determining their relative importance through pairwise comparisons. Expert opinions from crop specialists were incorporated to conduct these comparisons, using a scale ranging from 1 to 9 (Table 3).

Table 3: Rating measures for pairwise comparison of criteria

1/9	1/7	1/5	1/3	1	3	5	7	9
Extreme less important	Very strong	Strong	Moderate	Equal importance	Moderate more importance	Strong	Very strong	Extreme

Following the pairwise comparisons, a comparison matrix was generated and subsequently normalized by dividing each parameter's weight value by the column sum. The mean value of each row in the normalized matrix represents the primary eigenvector, which determines the final weight of each parameter. To ensure the consistency of the comparison matrix, the consistency ratio (CR) is calculated using Equation (1). Since random variations can introduce inconsistency, the CR must not exceed 10% for the matrix to be considered reliable.

$$CR = \frac{CI}{RI} \tag{1}$$

The consistency index (CI) and random index (RI) are key components of this

calculation, with CI computed using Equation (2).

$$CI = \frac{\lambda_{max}-n}{n-1} \tag{2}$$

λ_{max} represent the largest eigenvalue of the comparison matrix of order n .

Tables 4 represent the pairwise comparison matrix for sugarcane suitability. The significant finding of the AHP process was that the obtained CR was 0.040789, which was below the threshold level of 0.1. Therefore, the obtained weights were acceptable. The outcome of the AHP process from Table 4 also reveals that the most limiting factor concerning land evaluation for sugarcane crops is rainfall, which has the highest weightage of 0.46, and slope is the least limiting factor due to the flat terrain of the study area.

Table 4: A pairwise comparison matrix for assessing the parameter weights (relative influence) concerning sugarcane crop suitability

OID	Layer name	Depth	pH	Slope	Temperature	Rainfall	Distance	weight	CI	RI	CR
1	Depth	1	3	5	1/3	1/5	3	0.133001	0.051394	1.26	0.040789
2	pH	1/3	1	3	1/2	1/7	1	0.061886	0.051394	1.26	0.040789
3	Slope	1/5	1/3	1	1/7	1/9	1/3	0.030215	0.051394	1.26	0.040789
4	Temperature	3	5	7	1	1/3	5	0.251463	0.051394	1.26	0.040789
5	Rainfall	5	7	9	3	1	7	0.46155	0.051394	1.26	0.040789
6	Distance	1/3	1	3	1/5	1/7	1	0.061886	0.051394	1.26	0.040789

The suitability index evaluation is performed after collecting crop-specific parameters, obtaining their degree of influence using the AHP process, and standardization of the parameters. The weighted aggregation model was used to generate the suitability indexes of the land units for sugarcane (Eq. (3)). The reclassified parameter values are aggregated using the measured AHP weights.

$$S_i = \sum_{j=1}^n w_j x_{ij} \quad (3)$$

where, S_i denotes the land suitability index of i^{th} land unit, w_j denotes the weight of the j^{th} parameter, x_{ij} represent the substituted range value of the j^{th} parameter concerning i^{th} land unit, and n represents the total number of considered criteria

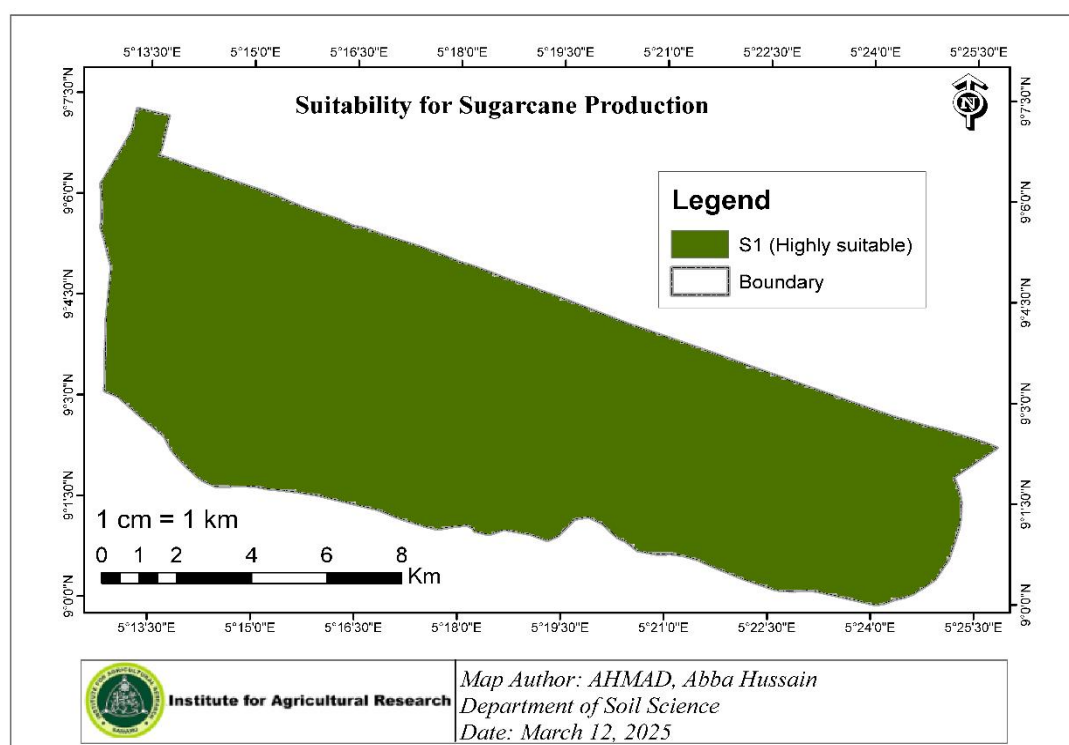


Figure 2: Suitability map for sugarcane production of Sunti

Discussion

The spatial analysis of land suitability for sugarcane cultivation in the study area indicates that the entire region is classified

as highly suitable. This classification is a result of multiple environmental and economic factors aligning favorably with the growth requirements of sugarcane. The

assessment incorporated various land evaluation criteria, including soil pH, slope, distance to the sugar mill, rainfall, and temperature, following FAO land suitability guidelines.

The soil pH analysis revealed that a significant portion of the study area falls within the neutral to slightly acidic range, which is optimal for sugarcane growth. Given that sugarcane thrives in pH levels between 5.5 and 7.0, the minimal acidity in some areas does not pose a significant limitation. Similarly, the terrain analysis showed that the entire study area has a slope range of 0-2%, which is ideal for mechanized farming and irrigation management. The gentle slope minimizes erosion and ensures even distribution of water and nutrients.

Economic considerations, particularly distance to the sugar mill, play a vital role in land suitability classification. The spatial analysis showed that 18.92% of the land is within 5 km of the mill, while 29.01% falls within the 5-10 km range. These zones are highly favorable due to reduced transportation costs and minimal post-harvest losses. Even areas within the 10-20 km range (41.2%) remain economically viable, although they may incur slightly higher operational costs. The 10.87% of the land located more than 20 km from the mill presents logistical challenges, requiring additional investments in infrastructure and transportation.

Climatic factors such as rainfall and temperature also support the classification of the area as highly suitable. The study area exhibits a moderate suitability for rainfall, indicating that supplementary irrigation might be necessary during dry periods. However, the temperature conditions are highly favorable, ensuring

optimal growth rates and sucrose accumulation in the crop.

Conclusion

The study's findings indicate that the entire study area is highly suitable for sugarcane cultivation, considering the integrated evaluation of soil properties, topography, economic factors, and climatic conditions. The combination of neutral soil pH, minimal slope, reasonable proximity to the sugar mill, and favorable temperature conditions contributes to the overall classification. While moderate suitability for rainfall suggests some limitations, these can be mitigated through strategic water management practices.

Recommendations for Future Research

- i. **Irrigation Management:** Given the moderate suitability of rainfall, investments in irrigation infrastructure should be considered to ensure consistent water availability, particularly during dry seasons.
- ii. **Infrastructure Development:** Enhancing transportation networks, especially for areas beyond 20 km from the sugar mill, would improve economic feasibility and reduce production costs.
- iii. **Soil Fertility Management:** While soil pH is generally within a favorable range, continuous monitoring and amendment strategies, such as lime application in slightly acidic areas, should be adopted.
- iv. **Remote Sensing and Precision Agriculture:** Future research should incorporate advanced remote sensing techniques and precision agriculture to further refine land suitability assessments and optimize resource allocation.

- v. Long-Term Climate Impact Studies:
Given the changing climate patterns, further research should explore long-term projections on temperature and rainfall trends to ensure sustainable sugarcane production in the region.

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CHARACTERIZATION AND CLASSIFICATION OF SOILS IN BOKI, CROSS RIVER STATE – NIGERIA

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ABSTRACT

Soil characterization and classification provide valuable information for agricultural land use decisions and offer a universal language for soil prediction. This study aimed to characterize and classify soils adjoining two landscape positions in the Boki area of Cross River State. One soil profile pit was sited on each of the middle slope and valley bottom positions of Boje, Bamba and Borum communities in Boki, resulting in six profile pits. Dark reddish brown (5YR 3/3) to dark brown (7.5YR 3/3) colours in the middle slope with an expression of yellowish red and dark red colours in the subsurface soils, against very dark grey (7.5YR 3/1), dark brown (5YR 3/2) to dark reddish grey (5YR 4/2) colours were common in the surface soils of the valley bottom. Fe nodules, mica flakes, quartz grains and animal activities characterized the soils. Clay, clay loam and loam textures characterized the subsurface horizons of the middle slope with obvious expression of argillation, against sandy loam, sandy clay loam and clay loam textures in the valley bottom. Bulk density values favoured root proliferation and were less than 1.70 Mg/m³, soil pH was less than 5.5, while soil organic carbon exceeded 1.0 % in the Ap horizons. Exchangeable base complex was dominated by Ca²⁺ but with concentration below 6.0 cmol/kg, while exchangeable Mg²⁺, K⁺ and Na⁺ were less than 1.0 cmol/kg in all the soils. On the middle slope, the soils were classified as Typic Paleudult and Humic Hapludult by the USDA System and as Luvic Umbrisol (Eutric, Loamic) and Luvic Umbrisol (Eutric, Humic, Loamic) in World Reference Base System. On the valley bottom, the soils were Fluventic Endoaquepts by the USDA System and Fluvisol Cambisol (Humic, Loamic) by the World Reference Base for Soil Resources System (WRB). The results indicate comparatively more suitable middle slope soils for regular crop production with limitations in the valley bottom posed by soil texture and high-water table.

Keywords: Basement-complex, Tropical rainforest, Ultisols, Inceptisols, soil properties

INTRODUCTION

Soil characterization, mapping and interpretation is of great significance in agricultural development as the production systems rely on it for its properties, extent and spatial distribution. Hence the need for baseline information on the characteristics of soils (Laake, 2000). Knowledge on the characteristics and classification of soils is a

prerequisite for agricultural practices as soil resource inventory provides an insight into the potentialities & limitation of soil for its effective exploitation (Thilagam and Sivasamy, 2013).

A major factor limiting the growth and development of agriculture in the tropics, particularly in Nigeria is the inadequacy of detailed information and knowledge of the

soil resources. By evaluating the soil resource, inventory is made available for analysis and categorization which makes the data relevant and applicable to any pending problems emanating from land use planning. This way, the farmer identifies a more profitable tract of land to grow crops. This is the essence of pedological characterization which employs soil physical, chemical, mineralogical and micromorphological data for studies (Esu, 2010).

In recent times, a number of attempts have been made for global data utilization, amalgamation and sharing in order to identify the problems, prospects and fertility status of soils in areas different from one's jurisdiction for potential investment needs. One major attempt in this direction is the Taxonomic soil classification which categorizes soils based on their characteristics. The system was designed to group soils having similar characteristics for a common universal language, organization and categorization, predictive purposes, simplification of complex soil data and ease in data sharing.

Soils in the Boki area have been studied and reported to have pH of 4.9 - 6.10, total nitrogen of 0.9 g/kg, and available P of 10 mg/kg whereas exchangeable Ca^{2+} was reported to be adequate while Mg^{2+} content exceeded the critical limit of 0.9 cmol/kg-1, and exchangeable K content was limiting (Kekong and Udie, 2020; Kekong and Ndifon 2020). The soils have largely been utilized for cocoa production ((Ajiboye *et al.* 2015) and reported as moderately and highly suitable for cocoa production (Ojie *et al.*, 2024). Earlier studies by Kekong and Udie (2020), Kekong and Ndifon (2020) and Ojie *et al.* (2024) focused on soil characterization and technical soil classification without due consideration of

the Taxonomic soil classification. This gap tends to shrink the agricultural potentials and gives little consideration to the soils of Boki in the global rating and management.

This study seeks to provide soil resource base for characterization and Taxonomic classification of some soils in Boki LGA for site-specific management measures. The study is aimed at characterizing the soils based on morphological, physical and chemical properties, and classifying them based on the criteria of the USDA Soil Taxonomy and World Reference Base for Soil Resources Systems.

MATERIALS AND METHODS

Study Area

The study was conducted in Boki Local Government Area, located in the central agricultural zone of Cross River State, Nigeria. Geographically, the area lies between latitudes 5°51'0" and 6°36'0" N, and longitudes 8°46'0" and 9°14'0" E. The location is bounded by Obudu to the north, Ogoja to the west, Ikom and Etung to the south, and the Republic of Cameroon to the east (FIG. 1).

Geology

The geology of Boki Local Government Area consists of Sedimentary Basin and Basement Complex formations. In the low-lying areas, the Sedimentary formations comprise recent alluvium, while the uplands are dominated by shale and limestone with sandstone intercalations. The Basement Complex areas, which form the dominant geology in the region, are an admixture of igneous and metamorphic rocks (FIG. 1). Specifically, the Basement Complex comprises porphyritic granite, biotite hornblende granite, and hornblende granite gneiss. Notably, some areas supporting cocoa production are underlain by shale-basalt (Amajor, 1989).

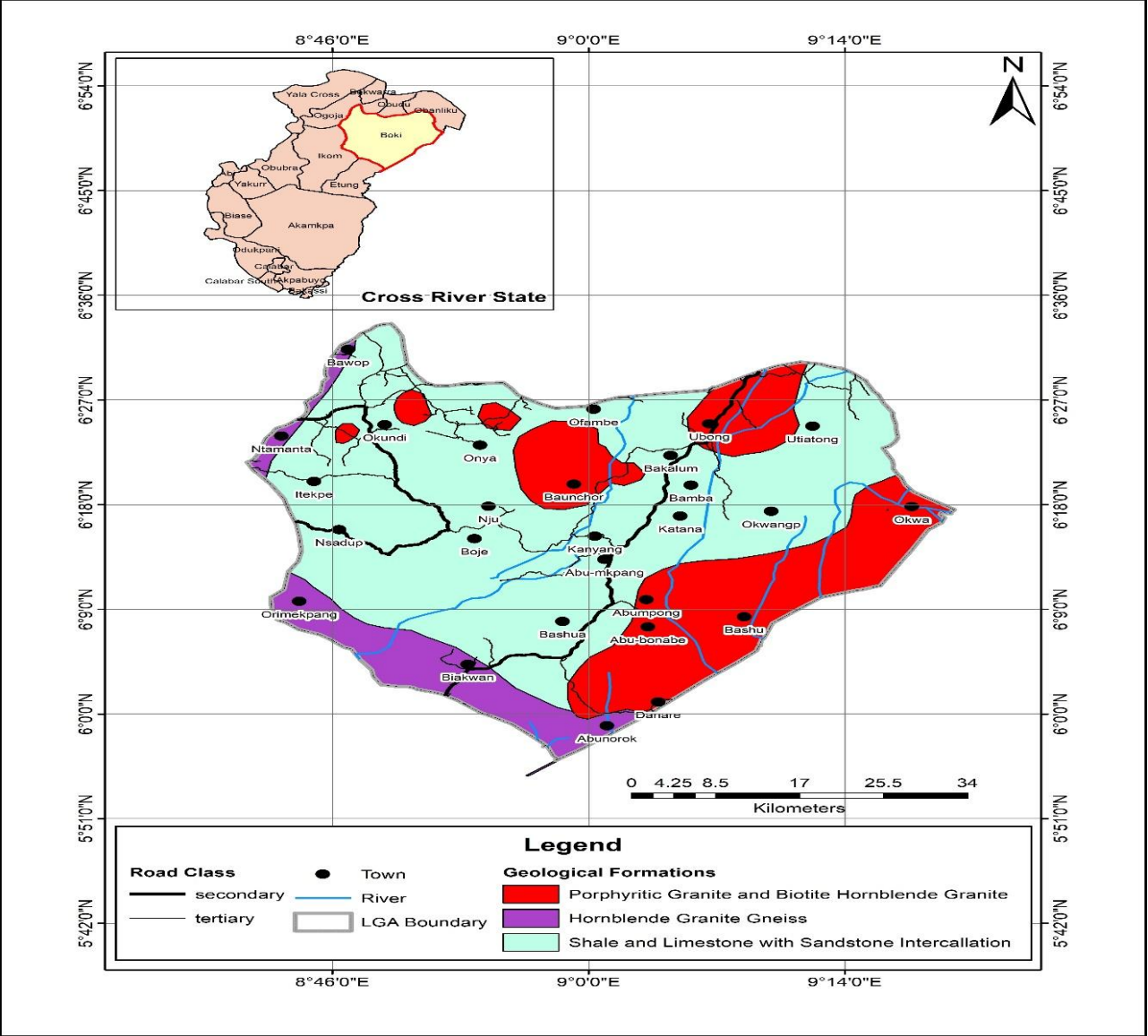


Fig. 1: Study location showing Geology of the area
Source: GIS Unit, 2024

Climate

Boki Local Government Area has a humid tropical climate characterized by distinct wet and dry seasons. According to the Koppen climate system, the area is classified as tropical moist, with temperatures consistently above 18°C throughout the year and precipitation exceeding 1500 mm/year. The rainfall distribution in Boki is bimodal, ranging from 1200 to 3000 mm, with an average annual rainfall of 2248.8 mm. The

rainfall peaks between June and September, with an average of 3000 mm, while the lowest rainfall occurs in December, averaging 12 mm per annum. Temperature fluctuations in the area are moderate, ranging from 22.56°C to 31.95°C, with a mean annual temperature of 26.9°C. Additionally, the area is characterized by a mean daily relative humidity of 81.7% and an average daily evaporation rate of 2.24 mm/day (Sambo *et al.*, 2016).

Vegetation and Land Use

The vegetation in Boki is typically tropical rainforest, dominated by dense forests with tall, luxuriant trees covering more than half of the land area.

Field study

Preliminary field reconnaissance visits were conducted in Boje, Bamba, and Borum in Boki LGA to verify the geology and identify suitable locations for soil profile pits. These areas had previously been mapped by the Nigerian Geological Survey Agency, revealing underlying shale, limestone, sandstone, porphyritic granite, biotite hornblende granite, and hornblende granite gneiss (FIG. 1).

Soil profile pits were strategically located in the middle slope and valley bottom to represent soils on stable and seasonally influenced landscapes, respectively. The middle slope was chosen for its ease of accessibility for arable and tree crop establishment. A total of six soil profile pits were sunk across three communities: Boje, Bamba, and Borum.

Each soil profile pit was georeferenced using a geographical positioning system, and general site information was recorded. The profile pits were described according to the guidelines of Schoeneberger *et al.* (2012). Soil samples were collected from multiple sections of the diagnostic horizons, bulked in composite, labeled, and transported to the laboratory for air-drying. The samples were then grinded and sieved using a 2 mm mesh-sized sieve. Undisturbed core samples were also collected from the soil horizons for determination of bulk density, total, and air-filled porosities.

Laboratory studies

The fine-earth fraction was subjected to various laboratory analyses, following the procedures outlined by the Soil Survey Staff (2014). To determine the particle size

distribution, the Bouyoucous hydrometer method was employed. Meanwhile, soil bulk density was measured using the core method, where undisturbed core soil samples were oven-dried at 105°C to a constant weight.

Total porosity was subsequently calculated using the expression $\{1 - (\text{bulk density/particle density})\}$ and expressed as a percentage, assuming a particle density of 2.65 Mg/m³. Soil pH was determined electrometrically using a pH meter, with a soil-water ratio of 1:2.5. Additionally, soil organic carbon content was determined using the modified Walkley-Black wet digestion and combustion method, while total nitrogen was analyzed via the macro Kjeldahl method. The titrimetric method was employed to determine basic cations (K⁺, Ca²⁺, Mg²⁺, Na⁺), and cation exchange capacity (CEC) was assessed using the ammonium acetate displacement method. Available phosphorus was measured using the Bray-1 method. Furthermore, exchangeable Al³⁺ and H⁺ were determined by titration with 1 M KCl as the extracting agent, following the addition of 5 drops of phenolphthalein indicator. The extract was then titrated against 0.01 M NaOH until a colorless solution was obtained. Finally, base saturation was calculated by expressing the sum of exchangeable basic cations (Ca²⁺, Mg²⁺, K⁺, and Na⁺) as a percentage of CEC.

RESULTS AND DISCUSSION

Morphological properties of soils

Morphological properties of the soils are presented on Tables 1 a and b. Bt and Crt horizons characterized soils in the middle slope with pronounce argillation depicted by clay cutans and significant deposition of clay in the B horizon, leading to the sequences Ap-BA-Bt1-Bt2, Ap-Bt1-Bt2-Crt

and Ap-BC-Bt-Cr, in Borum, Bamba and Boje, respectively, just as transition BA horizon defined the subsurface soils of the valley bottom resulting in Ap-BA horizon sequence with indications of cambic B horizons. The sequences indicate that the soils may have had more periods of pedogenesis leading to the development of Bt and even Crt horizons. The presence of clay-deposited horizons (Bt and Crt) designates soil maturity. Increase in the rate of weathering of soil minerals and decomposition of rocks result in pronounce soil horizons in the tropics (Krishna and Mohan, 2017). The findings in the current study align with those of Nwaka (1990) and Ayolagha (2001) who reported that soil development can be deduced from kinds and sequences of horizons in soil profiles.

Matrix soil colour in the middle slope was dark brown (7.5YR 3/3) to dark reddish brown (5YR 3/2) in the surface soils with redder hues in the subsurface soils. Colours in the valley bottom ranged from very dark grey (7.5YR 3/1) and dark brown (5YR 3/2) to dark reddish grey (5YR 4/2) in the surface soils, while strong brown (7.5YR 4/6) and brown (7.5YR 5/3) colours were observed in the subsurface soils.

oxide in a well-drained soil to hydrated Fe oxide in a somewhat moister soil condition. Also, the iron released during intense weathering in the dry season may have precipitated and given rise to pedogenic hematite (Yaalon, 1997). The greyish colouration in the valley bottom is explained by filled-in macro pores as the soils have been inundated for a long period leading to the dominance of reduction processes over oxidation. Dark or brown colours are attributed to the accumulation of decayed organic matter or humus (Esu (2010). However, in the subsurface soils, brownish colourations may be due to

translocated organic matter. Akpan-Idiok *et al.* (2016) attributed reddish-brown colouration to the presence of Fe^{3+} oxides with the brown and dark colours depicting large amounts of soil-humus. Few, fine and distinct dark grey (5YR 4/1) mottles in the subsurface soils of the valley bottom are attributed to the wetness condition of the soils.

Soil pores decreased in size to number from the middle slope to common - many, fine - medium, and many coarse pores in the surface horizons, and common, fine - medium and few, fine pores in the subsurface soils of the valley bottom. The poorly-aerated soil condition if prolonged may lead to gleization. Plant roots proliferated in the surface and subsurface soils and ranged from common, coarse to many, medium to coarse roots in the surface soils to medium and coarse roots in the subsurface of the entire soils.

The presence of roots, especially in the subsurface soils indicate the absence of root restrictive impediments such as hard pans, saline layers, stone-line etc. Animal activities were dominantly represented by crabs, worms, ants and termites. The presence of these organisms in their numbers is an indication that they may have significantly contributed to soil mixing.

Soil physical properties

Physical properties of the studied soils are presented in Tables 2a and b. In the middle slope soils, bulk density had ranges of 1.19 – 1.39 and 1.37 – 1.69 Mg/m^3 in the surface and subsurface soils, Yellowish red colour in the subsurface soils may be explained by a transition from unhydrated Fe respectively, whereas 1.01 - 1.26 Mg/m^3 was obtained in the surface soils of the valley bottom which had mean of 1.14 Mg/m^3 , while the subsurface soils had range of 1.29 - 1.4

Mg/m³ with mean of 1.33 Mg/m³. Higher values in the subsurface soils are due to the relatively higher organic matter accumulation in the top soils and overburden from the surface soils.

Table 1a: Morphological properties

of the middle slope Soils

Horizon	Depth (cm)	Munsell colour (moist)	Mottles	Tex	Struc.	Consist.	Bound.	Other characteristics
BOJE: N 0492677, E0692265; 158m asl; Typic Paleudult; Luvic Umbrisol (Eutric, Loamic)								
Ap	0-30	Dark brown (7.5YR 3/3)		SL	1m gr	wss; mvfri.	Cw	Many fine medium pores; many fine medium roots; many ants.
BC	30-95	Red (2.5YR 4/8)		CL	2m sbk	ws; mfri.	Gw	Common fine pores; fine roots.
Bt	95-140	Dark red (2.5YR 3/6)		L	2m sbk	ws; mfri.	Cw	Few fine pores; common fine roots; very few clay cutans thin.
Cr	140-158	Reddish brown (2.5YR 3/4)		L	2m sbk	ws; mfri		few very fine pores; few fine roots, very few clay cutans thin.
BAMBA: N 0513921; E0693958; 140m asl; Humic Hapludult; Luvic Umbrisol (Eutric, Humic, Loamic)								
Ap	0-20	Dark reddish brown (5YR 3/2)		SL	1m gr	wss; mvfri.	Cs	Many medium pores; few roots seen; Ants and worms seen.
Bt1	20-57	Yellowish red (5YR 5/6)		L	2m sbk	ws; mfri.	Gs	Few very fine pores; few very fine roots; few ants; quartz seen
Bt2	57-88	Yellowish red (5YR 5/6)	c.m.d (Dark Red (7.5R 3/8)	CL	2m sbk	ws; mfr.	Gs	Few very fine pores; few very fine roots; Granites sighted; Ants and termites seen.
Crt	88-180	Yellowish red (5YR 5/6)	c.m.d (Dark grey) (7.5R 3/8)	L	2m sbk	ws; mfri	Gs	Few fine pores; few very fine roots, quartz seen.
BORUM: N 0489227, E0709193; 138m asl; Typic Paleudult; Luvic Umbrisol (Eutric, Humic, Loamic)								
Ap	0-28	Dark reddish brown (5YR 3/3)		SL	1m gr	wss; mvfr,	Cs	Many medium coarse pores; many medium roots; ants and termites seen.
BA	28-75	Yellowish red (5 YR 5/6)		C	2m sbk	wss; mfr.	Gs	Common medium pores; common fine medium roots; charcoal, ermites and ants seen
Bt1	75-130	Yellowish red (2.5YR 5/6)		CL	2m sbk	wss; mfr.	Dw	Few very fine pores; few fine roots; fe, clay,

Bt2	130-200	Yellowish red (5YR 5/6)	c.m.f.(Brown) (7.5 YR 5/4)	L	2m sbk	wss; mfr.	-	mica and few ants slighted. Few very fine pores; few very fine roots; fe and mica sighted.

Table 1b: Morphological properties of Valley bottom Soils

Horizon	Depth (cm)	Munsell (moist)	colour	Mottles	Tex	Struc.	Consist.	Bound.	Other characteristics
BOJE: N 0495729; EO689058; 105m asl; Fluventic Endoaquepts; Fluvic Cambisol (Humic, Loamic)									
Ap	0-14	Very dark grey (7.5YR 3/1)			SL	1m Cr	wss; mvfri.	cs	Common fine Medium pores; common coarse roots; many ants
BA	14-45	Strong brown (7.5YR 4/6)			SCL	2m sbk	wss; mvfri.		Common fine pores; common medium and coarse roots; few crabs.
BAMBA: N 0512836, E0701362; 45m asl; Fluventic Endoaquepts; Fluvic Cambisol (Humic, Loamic)									
Ap	0-15	Dark brown (5YR 3/2)			SL	1m gr	wss; mvfr.	Cs	Many fine medium pores; many medium coarse roots; worms, ants and termites seen
BA	0-47	Strong brown (7.5YR 5/6)		f.f.d (Dark grey) (5YR 4/1)	CL	1m sbk	wss; mvfri		Common fine medium pores; few very fine roots.
BORUM: N 0487355, E0708978, 125m asl; Fluventic Endoaquepts; Fluvic Cambisol (Humic, Loamic)									
Ap	0-15	Dark reddish grey (5YR 4/2)			SL	1gr	wss; mrfr	Cs	Common medium pores, many medium roots
BA	15-40	Brown (7.5YR 5/3)		f, f, f (dark grey) 5YR 4/1)	SL	1m sbk	wss; mvfr	-	Few fine pores; few fine medium roots

Mottles: ffd= few, fine, distinct; fff= few, fine, faint, cmf= common, medium, faint; cmd= common, medium, distinct; mcp= moderate, coarse, prominent; mcd= moderate, coarse, distinct; Text. = texture, gr = gravel, co = cobbles, l = loam, s = sand, c = clay; struc.= structure: 1,2,3 = weak, moderate, m, c = medium, coarse; gr, cr, sbk = granular, crumbly and sub-angular blocky structure; consist.= consistence: w = wet, m = moist, ss = slightly sticky, fr = friable, fi = firm, v = very; bound.= boundary: cs = clear smooth, cw = clear wavy, gw = gradual wavy; gi = gradual irregular, ASL: above sea level

Table 2a: Physical properties of middle slope soils

Profile pits and soil depth	BD Mg/m ³	%TP	%MaP	% Clay	% Silt	% Sand	Textural class
Boje							
0-14	1.1	58.5	41.4	12.8	30	57.2	SL
14-45	1.3	21.1	21.6	20.8	28	51.2	SCL
Bamba							
0-15	1.26	52.5	27.6	12.8	20	69.2	SL
15-47	1.29	51.3	24.7	20.8	24	55.2	SCL
Borum							
0-15	1.06	60	37.4	16.8	24	59.2	SL
15-40	1.4	47.2	30.4	14.8	30	55.2	SL
Mean Sur	1.14	57.0	35.5	14.1	24.7	61.2	
Range Sur	1.06-1.26	52.5-60.0	27.6-41.4	12.8-16.8	20-30	57.2-69.2	
Mean Sub	1.33	39.9	25.6	18.3	27.3	54.4	
Range Sub	1.29-1.4	21.1-51.3	21.6-30.4	14.8-20.8	24-28	51.2-55.2	

Table 2a: Physical properties of Valley bottom soils

Profile pits and soil depth	BD Mg/m ³	%TP	%MaP	% Clay	% Silt	% Sand	Textural class
Boje							
0-30	1.39	47.5	33.0	16.8	30	53.2	SL
30-95	1.4	47.2	32.0	28.8	38	33.2	CL
95-140	1.4	47.2	31.6	22.8	42	35.2	L
140-158	1.47	44.5	25.5	20.8	34	45.2	L
Bamba							
0-20	1.36	48.7	29.4	12.8	32	55.2	SL
20-57	1.56	41.1	26.1	20.8	32	27.2	L
57-88	1.37	48.3	28.2	34.8	38	27.2	CL
88-130	1.4	47.2	26.7	20.8	40	39.2	L
Borum							
0-28	1.19	55.1	32.4	16.8	24	59.2	SL
28-75	1.69	36.2	20.5	42.8	26	31.2	C
75-130	1.4	47.2	25.9	36.8	32	31.2	CL
130-200	1.38	47.9	24.1	24.8	34	41.2	L
Mean Surface	1.31	50.4	31.6	19.8	28.7	51.5	
Range Surface	1.19-1.39	47.5-55.1	29.4-33	12.8-16.8	24-32	53.2-59.2	
Mean Subsurface	1.45	45.2	26.7	28.10	35.1	36.8	
Range Subsurface	1.37-1.69	36.2-48.3	20.5-32.0	20.8-42.8	26-68	27.2-45.2	

BD=Bulk density, TP = Total porosity, MaP = Macro Porosity

These values agree with 1.2 - 1.8 Mg/m³ for sand dominated soils (Brady and Weil, 2022) and will encourage aeration, roots proliferation and water movement for optimum crop growth (Esu, 2010). Bulk density values exceeding 1.6 Mg/m³ may be a threat to optimal air and water movement as in the case of the subsurface soils in the middle slope of Borum. Ajiboye *et al.* (2015) reported 0.91 - 1.84 Mg/m³ for the Etung area while, Ofem and Esu (2015) reported 1.01 - 1.67 Mg/m³ for the schistose soils of Biase.

Irrespective of landscape position, soil total porosity exceeded 45 % in the surface soils, while subsurface soil values were greater than 20 %. Values in the surface soils approached 50 % that is recommended for a silt-loam surface soil (Brady, 1974). Such values may encourage the free movement of air and water in the soils (Pagliai, 1988) which may be an avenue for nutrient loss. In a related study by Ajiboye *et al.* (2015), total porosity in the Etung area had range of 25.96 - 59.78 %, whereas Fetter (1998) and, Rieu and Sposito (1991) reported that when total porosity exceeds 45.50 % of the total volume of soil, such a soil is good for agricultural purposes.

Air-filled (macro) porosity exceeded 25 % in the entire surface soils with values that decreased with increasing soil depth. Silva (2004) recommended that air-filled porosity values that exceed 10 % is good for agricultural crop production, further indicating that the soils under study have good air-filled porosity that allows for good aeration, water movement and solubility of nutrients. Total air-filled porosity below 10% indicates inhibited soil oxygen diffusion rate, causing injury to roots and their inability to function (Engalaar and Yoneyama, (2004), and may be detrimental to plants growth (Grichko and Glick, 2001).

In the middle slope soils, clay content exceeded 20 % at all subsurface depths resulting in obvious clay bulges in the B and somewhat C horizons, while values in the valley bottom were below 25 % at all depths. Clay increase with soil depth in the middle slope indicate argillation and imply that the soils are developed. Akpan-Idiok *et al.* (2016) made similar report of increased clay content with increasing soil depth in the Ikom area, while Ofem and Esu (2015) reported amounts within 7.0 – 57.0 % in the schistose soils of Biase with the development of distinct clay bulges in the B horizons, whereas Ajiboye *et al.* (2015) obtained 9.6 – 68.8 % in the Etung area.

Silt content in the middle slope had ranges of 24 - 32 and 26 – 68 % in the surface and subsurface soils, respectively and partly exceeding ranges of 20 – 30 and 24 – 28 % in the surface and subsurface soils, respectively in the valley bottom. According to Birkeland (1984), soil weathering is the main factor for the decreasing particle size and support the fact that larger particles weathered physically to smaller particular sizes like silt and clay with soil age. Cowie (1968) and Thompson (1981) indicate that total silt and clay in soil profiles show straight line relationships with soil age. Thus, the comparatively higher silt content in the middle slope soils indicate relative soil maturity as straight-line relationships have been established between total silt and soil age, and further explains that soil age is a contributor to increasing silt content (VandenBygaart and Protz, 1994). Soils with finer particles have larger surface areas with a wider capacity for the adsorption of cations on the soil exchange complex. In Etung, Ajiboye *et al.* (2015) reported 2.5 - 18.8 %, while Akpan-Idiok *et al.* (2016) presented 11.5 – 17.2 % for the Ikom area.

Sand content in the middle slope had ranges of 53.2 – 59.2 and 27.2 – 45.2 % compared to ranges of 57.2 - 69.2 and 51.2 – 55.2 % in the valley bottom for the surface and subsurface soils, respectively. The comparatively low sand amount, particularly in the subsurface soils of the middle slope indicates that sand-sized particles may have weathered into clay and silt over time (Aksoy *et al.* 2009; Birkeland, 1984). Comparatively higher values were obtained in the Etung area by Ajiboye *et al.* (2015) with values reaching 87 %. Sand dominated soils are loose and likely to experience ion leaching and impoverishment.

Soil chemical properties

Chemical properties of the soils are presented in Tables 3a and b. The middle slope soils had soil pH (H₂O) range of 4.9 – 5.3 with mean of 5.1, and values that fluctuated irregularly with soil depth, while in the valley bottom, range of 4.8 - 4.9 and mean of 4.8 were obtained in the surface soils. In all cases, pH (KCl) was lower than pH (H₂O) by about 1 pH unit. Soil pH (H₂O) is rated as very strongly to strongly acid on the scale of Holland *et al.* (1989), and indicates that exchangeable Al³⁺ and H⁺ are present in the soil solution to affect plant growth. In related studies, Kekong and Ndifon (2020) obtained 4.9 - 5.1 in the Boki area, while Ofem and Esu (2015) obtained 4.1 – 5.2 in the Biase area. Soils with pH of 4.5 – 5.5 as in the current study, have significant amounts of exchangeable Al³⁺ in the soil solution which may affect crop production (Udo *et al.*, 2009). Such strongly acid soils result in the leaching of more soluble silica and formation of kaolinite, gibbsite and bauxite (Ollier, 1975). Soil pH is an important soil regulator, controlling crop performance (Agbede, 1984), organic matter

decomposition rate, microorganisms' activities, nutrient availability and uptake by crops (Agbede, 2009).

Soil organic carbon (SOC) in the middle slope has range of 1.08 - 2.03 with mean of 1.57 % in the surface soils, whereas values in the valley bottom ranged from 1.55 to 1.72 with mean of 1.62 %. On the scale of Holland *et al.* (1989), the entire surface soils were high in organic carbon content as values exceeded 1.5 % and decreased regularly with soil depth. High organic carbon may be due to periodic leaf fall in the densely forested area of Boki as well as delayed mineralization process against humification (Haynes, 2005). Comparatively higher clay amount in the middle slope soils may be responsible for higher SOC content as organic matter may have been held in soil aggregates.

The current results align with 0.04 – 3.5 % measured by Ajiboye *et al.* (2015) for soil organic carbon content in the surface soils of Etung.

Total N in the middle slope soils had range of 0.09 – 0.17 and mean of 0.13 %, while in the valley bottom, range of 0.13 - 0.15 % and mean of 0.14 % were determined, all in the surface soils. Total N decreased with soil depth and was rated low on the scale of Holland *et al.* (1989) as values were less than 0.2 % in the studied soils. Soil total nitrogen is a product and function of organic matter mineralization (Esu, 2010), but does not seem to reflect the high organic carbon status of the soils. Nitrogen in the soil may have been immobilized, reducing its availability or it may have been affected by

Table 3a: Chemical properties of Middle slope soils

Soil depth (cm)	Horizon	pH		% Org C	%T.N	Avail. P mg/kg	Ca ² +	Mg ² +	K ⁺	Na ⁺	Al ³⁺	H ⁺	CEC	%B S
		H ₂ O	KCl				←————→			cmol/kg				
Boje														
0-30	Ap	5.3	4.2	1.08	0.09	6.87	2.2	0.2	0.09	0.07	2.0	0.4	9	28
30-95	BC	4.9	4.2	0.50	0.04	6.50	2.2	1.8	0.08	0.06	1.92	0.48	18	23
95-140	Bt	4.9	4.2	0.42	0.03	4.87	3.6	0.8	0.1	0.08	0.76	0.36	20	23
140-158	Cr	5.1	4.2	0.32	0.02	4.12	2.4	0.4	0.1	0.09	1.72	0.48	13	23
Bamba														
0-20	Ap	4.9	4.4	2.03	0.17	4.12	5.6	0.4	0.09	0.07	0.32	0.64	18	34
20-57	Bt1	5.2	4.6	0.48	0.03	1.5	4.2	0.6	0.10	0.08	0.0	0.92	23	22
57-88	Bt2	5.0	4.6	0.66	0.05	2.37	4.0	0.4	0.09	0.07	0.16	0.86	15	30
88-180	Crt	5.1	4.5	0.28	0.01	2.87	3.6	0.2	0.10	0.08	0.2	0.76	20	20
Borum														
0-28	Ap	5.0	4.2	1.6	0.14	2.75	5.0	1.0	0.09	0.08	0.48	0.76	17	36
28-75	BA	5.0	4.1	0.7	0.06	1.5	3.8	0.4	0.10	0.08	1.84	0.68	19	23
75-130	Bt1	5.2	4.1	0.5	0.04	1.5	4.0	0.6	0.11	0.09	1.40	0.12	21	23
130-200	Bt2	5.2	4.0	0.44	0.03	2.25	3.8	0.4	0.11	0.08	1.76	1.0	23	19
Mean Sur		5.1	4.3	1.57	0.13	4.58	4.3	0.53	0.09	0.07	0.93	0.6	14.7	33
Range		4.9-	4.2-	1.08-2.03	0.09-	2.75-	2.2-	0.2-	-	0.07-	0.32-	0.4-	9.0-18	28-
Sub		5.3	4.4		0.17	6.87	5.6	1.0		0.08	2.0	0.76		36
Mean Sub		5.1	4.3	0.48	0.03	3.05	3.5	0.51	0.10	0.08	1.08	0.63	19.1	23
Range		4.9-	4.0-	0.32-0.70	0.01-	1.5-6.5	2.2-	0.2-	0.08-	0.06-	0.0-	0.12-	13-23	19-
Sub		5.2	4.6		0.06		4.2	1.8	0.11	0.09	1.92	0.92		30

Table 3b: Chemical properties of Valley bottom soils

Soil depth (cm)	pH		% Org C	%T.N	Avail. P	Ca ²⁺	Mg ²⁺	K ⁺	Na ⁺	Al ³⁺	H ⁺	CEC	%BS
	H ₂ O	KCl											
mg/kg ←————— cmol/kg —————→													
Boje													
0-14	4.8	4.1	1.72	0.15	3.52	5.4	0.8	0.09	0.07	1.2	0.44	14	45
14-45	4.9	4.2	0.46	0.03	1.75	4.0	0.4	0.10	0.08	1.28	0.48	9	51
Bamba													
0-15	4.8	4.1	1.55	0.13	3.87	5.4	0.4	0.08	0.06	0.48	0.88	13	46
15-47	4.9	4.3	0.58	0.04	4.37	3.8	0.2	0.09	0.07	0.72	0.64	8	52
Borum													
0-15	4.9	4.4	1.58	0.14	3	4.6	0.2	0.09	0.06	0.80	0.44	12	41
15-40	5.0	4.8	0.68	0.05	3	3.8	0.4	0.10	0.08	0.68	0.38	13	34
Mean Sur	4.8	4.2	1.62	0.14	3.46	5.13	0.47	0.09	0.06	0.83	0.59	13	44
Range Sub	4.8- 4.9	4.1- 4.7	1.55-1.72	0.13-0.15	3.0-3.87	4.6-5.4	0.2-0.8	0.08-0.09	0.06-0.07	0.48-1.2	0.44-0.88	12- 14	41-46
Mean Sub	4.8	4.4	0.57	0.04	3.04	3.87	0.33	0.10	0.08	0.89	0.5	10	46
Range Sub	4.9- 5.	4.2- 4.8	0.46-0.68	0.03-0.05	1.75-4.37	3.8-4.0	0.2-0.4	0.09-0.10	0.07-0.08	0.68-1.28	0.38-0.64	8-13	34-52
NB: Org C = Organic carbon, T. N. = Total nitrogen, avail P = available P, CEC = cation exchange capacity, BS= Base saturation													

the 4.5 – 5.5 range of soil pH. Kekong and Ndifon (2020) reported 0.09 % in the surface soils of Boki, while Akpan-Idiok *et al.* (2016) reported range of 0.039 - 0.14 % in the Ikom area, whereas Ajiboye *et al.* (2015) reported 0.11 – 0.267 % in Etung.

In the middle slope, means of 4.58 and 3.05 mg/kg were obtained in the surface and subsurface soils, respectively. The valley bottom soils had available P values of 3.0 – 3.87 mg/kg with mean of 3.46 mg/kg in the surface soils, while the subsurface soils had range of 1.75 - 4.37 mg/kg and mean of 3.04 mg/kg. The distribution of available P was somewhat irregular in most of the soil profiles, with values found below 8.0 mg/kg and qualifying in the low category on the scale of Holland *et al.* (1989). This indicates that available P may either have been leached due to intense weathering condition or fixed in the soils. Ajiboye *et al.* (2015) reported variable results ranging from low (1.28) to high (21.88 mg/kg), while Kekong and Ndifon (2020) reported that Boki soils have available P occurring in below critical limit concentration of 10 mg/kg.

Exchangeable Ca in the middle slope soils had means of 4.3 and 3.5 cmol/kg in the surface and subsurface soils. In the valley bottom soils, range of 4.6 – 5.4 cmol/kg at all depths with means of 5.13 and 3.87 cmol/kg in the surface and subsurface soils, respectively were measured. Exchangeable Ca dominated the soils' exchange complex and decreased with soil depth qualifying as low to moderate in the soils as the values were within 5.0 – 10.0 cmol/kg on the scale of Holland *et al.* (1989), and indicate that the tropical soils are weathered and may have lost most of its mobile cations to

leaching, particularly as a result of the high rainfall and sandy textures in the area. Ajiboye *et al.* (2015) indicated low values in Etung with Ca^{2+} dominance and concentration of 0.05 - 9.48 cmol/kg, whereas Kekong and Ndifon (2020) stated the adequacy of Ca^{2+} in the Boki area, while 1.6 - 3.4 cmol/kg was reported by Ofem and Esu (2015) in the Biase area of Cross River State.

In the middle slope soils, exchangeable Mg range of 0.2 - 1.0 cmol/kg with mean of 0.53 cmol/kg was obtained in the surface soils, while the subsurface soils had 0.2 - 1.8 cmol/kg and 0.51 cmol/kg as range and mean, respectively. In the soils of the valley bottom, exchangeable Mg had means of 0.47 and 0.33 cmol/kg in the surface and subsurface soils, respectively with range of 0.2 - 0.8 cmol/kg in the surface soils. The values are less than 1.0 cmol/kg and are low on the scale of Holland *et al.* (1989). Low values of Mg^{2+} may be due to the high rainfall as well as the sand dominated particle size distribution in the area which may have led to leaching of the cation. Ajiboye *et al.* (2015) reported 0.08 - 0.76 cmol/kg in Etung, while Kekong and Ndifon (2020), and Akpan-Idiok *et al.* (2016) recorded values that exceeded the critical limit of 1.0 cmol/kg in the Boki soils and basaltic soils of Ikom, whereas Ofem and Esu (2015), reported similar range of 0.4 - 1.14 cmol/kg in the Biase area.

Exchangeable potassium and sodium were less than 0.2 cmol/kg in all the studied soils, and qualified as low on the rating scale of Holland *et al.* (1989). This may be because K is less attached and easily

leached from plant root zone and soil exchange complex (Markoski *et al.*, 2018). Kekong and Ndifon (2020), Akpan-Idiok *et al.* (2016) and Ofem and Esu (2015) reported concentrations of below 0.30 cmol/kg in similar soils. Soils with low total K are highly weathered and have low mineral reserve, while soils of high K are only slightly weathered and have high mineral reserve (Yakubu and Ojanuga, 2013). Also, when exchangeable Na^+ is less than 1.0 cmol/kg, it cannot be harmful to plant roots (Olasoji *et al.* 2022; Uwitonze *et al.* 2016), and reflects a good soil quality for agricultural purposes. The low amount of Na in the adsorption complex of most soils is due to the ease of leaching of the cation (Markoski *et al.*, 2018).

Exchangeable Al had values below 2.0 cmol/kg in the studied soils. The concentration of exchangeable Al^{3+} does not indicate toxicity (Ajiboye *et al.*, 2015). However, as Al ions are released during acidification or weathering processes, they become more accessible on cation exchange sites; in solution or simply on exposed surfaces, and identifies Al toxicity as a major crop limiting factor in acid, highly weathered tropical soils.

In the middle slope, CEC had range of 9.0 - 18.0 cmol/kg at all depths with means of 14.7 and 19.1 cmol/kg in the surface and subsurface soils, respectively. In the valley bottom soils, CEC had range of 12.0 - 14.0 cmol/kg with mean of 13 cmol/kg in the surface soils, while values in the subsurface soils had range of 8.0 - 13.0 cmol/kg with mean of 10 cmol/kg. These values are moderate on the scale of

Holland *et al.* (1989). The moderate level of CEC seems to have aligned with the moderate to high SOC content, while its distribution with soil depth followed clay amount. This could indicate that organic matter defined CEC in the surface soils, while clay amount influenced its distribution in the subsurface soils.

Base saturation of soils in the middle slope had range of 28.0 - 36.0 % with mean of 33 % in the surface soils, while in the subsurface soils, range of 19.0 - 30.0 % and mean of 23 % were estimated. In the valley bottom soils, range of 41.0 - 46.0 % and mean of 44.0 % were measured in the surface soils, while values in the subsurface soils had range of 34.0 - 52.0 % with mean of 46 %. The base saturation of the soils was less than 60 %, and qualified as moderate on the scale of Holland *et al.* (1989) with a possible Taxonomic classification as Ultisol. The moderate rating is an indication that either basic nutrients may not have occurred in available forms in soil solution for plant uptake or the soils may have been highly weathered and lost its basic-mobile cations to leaching. Kekong and Ndifon (2020), and Akpan-Idiok *et al.* (2016) reported values that exceeded 60 %, whereas Olasoji (2022) showed that similar soils in Northern Ogun state - Nigeria are characterized by high base saturation with values exceeding 60 %. The disparity in base saturation may be attributed to a regional rainfall distribution.

Taxonomic classification

USDA Soil Taxonomy System

In the middle slope, the soils had argillic horizons beginning at 75, 20 and 95 cm

depths for Borum, Bamba and Boje, respectively with base saturation by NH_4OAc exceeding 35 % and qualify as Ultisols. Udic soil moisture regime which characterized the soils qualify them as Udults. In Borum and Boje, with increasing soil depth, the soils do not have a clay decrease of 20 % or more from the maximum clay content and qualify as Paleudults in the great group, and as **Typic Paleudults** in the subgroup category. In Bamba, the soil failed to meet other criteria and qualify as Hapludult in the great group. The soils have Ap horizons that exceed 18 cm thickness with colour value (moist) of 3, and qualify as **Humic Hapludult**.

Soils in the valley bottom have cambic horizons with thicknesses that exceed 15 cm as well as sandy clay loam and sandy loam textures within 100 cm of mineral soil surface. They have lower boundary that exceed 25 cm, and qualify as Inceptisols. Aquic conditions at 40, 45 and 47 cm with chroma of 1 and 2 in the epipedons qualify the soils as Aquepts and as Endoaquepts in the great group category. A total thickness of less than 50 cm, hue of 7.5YR and redder, and chroma equalling or exceeding 2 at all depths qualify the soil as **Fluventic Endoaquepts** in the subgroup category.

World Reference Base for Soil Resources System

In the middle slope, the soils had > 0.6 % SOC, umbric epipedon (>20 cm thick, <50 % base saturation by NH_4OAc) and qualify as Umbrisol. With argic horizon starting < 100 cm from the mineral soil surface, CEC by NH_4OAc of > 24 cmol/kg clay within 150 cm of the mineral soil

surface, and exchangeable $\text{Al} < \text{exchangeable (Ca + Mg + K + Na)}$ throughout the depth qualify the soils in the Luvic Principal qualifier. Clay loam and loam textural classes with thicknesses ≥ 30 cm within 100 cm depth of mineral soil surface qualify the soils in the Loamic Supplementary qualifier. Also, at 20 – 50 cm depth of the mineral soil surface, exchangeable $(\text{Ca} + \text{Mg} + \text{K} + \text{Na}) > \text{exchangeable Al}$ at all depths of the profile qualify the soils for Eutric supplementary qualifier. Therefore, Boje soils qualify as **Luvic Umbrisol (Eutric, Loamic)**. In Bamba and Borum, >1% SOC as a weighted average to a depth of 50 cm from the mineral soil surface qualify the soils in the Humic Supplementary qualifier. The middle slope soils in Bamba and Borum qualify as **Luvic Umbrisol (Eutric, Humic, Loamic)**.

Soils in the valley bottom have cambic B horizons starting at less than 50 cm from the mineral soil surface and having its lower limit greater than 25 cm from the mineral soil surface and qualify as Cambisols. Soil organic carbon (SOC) exceeds 0.2 % throughout its depth without a natric horizon and qualify as Fluvic Principal qualifier. Textural class of sandy loam and sandy clay loam throughout the thickness of less than 100 cm of the mineral soil surface as well as > 1 % soil organic carbon (SOC) of weighted average to a depth of 50 cm from the mineral soil surface qualify the soils in the Loamic and Humic supplementary qualifier. The soils are classified as **Fluvic Cambisol (Humic, Loamic)**.

Summary and Conclusion

Middle slope and valley bottom soils were studied in Boje, Bamba and Borum communities in Boki Local Government Area. Middle slope soils were characterized by pronounce accumulation of clay depicted by cutans in the B and C horizons, whereas soils at the valley bottom were poorly-drained, with transition BA horizon dominating the subsurface horizons. Variations in loamy textural classes were observed in the valley bottom, whereas loamy and clayey textural classes characterized the middle slope with evidences of clay accumulation in the subsurface layers. Bulk density was less than 1.70 Mg/m^3 in all the studied soils. Soil pH (H_2O) was less than 5.5 in the entire soils, soil organic carbon exceeded 1.5 % in the surface soils, while available P appear to be less than 8.0 mg/kg in majority of the soils. Exchangeable Ca^{2+} showed dominance over other exchangeable basic cations with concentration below 6.0 cmol/kg in the soils, while exchangeable Mg^{2+} was less than 1.0 cmol/kg in most of the soils resulting in low to moderate base saturation. The soils were classified as Humic Hapludult and Typic Paleudults (middle slope), and Fluventic Endoaquept (valley bottom) by the USDA System. By the World Reference Base for Soil Resources System, the soils qualified as Luvic Umbrisol (Eutric, Humic, Loamic) (middle slope) and Fluvic Cambisol (Humic, Loamic) (valley bottom). Overall, the characteristics of soils in Boje, Borum and Bamba are adapted for regular crop production with easy-to-manage

limiting soil properties. Furthermore, the soils of valley bottom being poorly-drained could be put to sugarcane or rice production.

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LAND SUITABILITY EVALUATION FOR ARABLE CROPS PRODUCTION ON HILLY SOILS DEVELOPED ON SEDIMENTARY TERRAIN IN BIDA, NIGER STATE

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ABSTRACT

The study covered the immediate surrounding of hilly terrain of Bida, Niger State of Nigeria. The site was demarcated into three physiographic positions and designated as summit, shoulder and footslope. Two modal profile pits were sunk in each unit to permissible depth, giving a total of six (6) profile pits. Soil samples collected from genetic horizons were analysed for physical and chemical properties. The soils were evaluated and classified using USDA Soil Taxonomy System and World Reference Base for Soil Resources. Its agricultural potentials were assessed using land suitability methods. Most epipedons had weak to moderate crumb structure on surface over massive subsoils. Particle size analysis showed dominance of sand over other mineral fractions. Soil reaction (pH) was moderately acid in the study site. Organic carbon, total nitrogen and available phosphorus were low. Calcium was the dominant exchangeable base in the study site. The summit soils were classified as Rhodic Ustipsamments while Shoulder soils were classified as Lithic Dystrustepts; Footslope soils were classified as Lithic Rhodustults under USDA Soil Taxonomy; and correlated with WRB^s, Dystric Arenosols (Rhodic), Leptic Cambisols (Arenic) and Rhodic Acrisols (Clayic) respectively. In suitability classification, the soils were classified as permanently not suitable (N2sfn) for sorghum and cowpea production. The soils need to be improved through erosional control measures and applications of both organic and inorganic fertilizers.

Keywords: Classification, footslope, physical and chemical properties, shoulder, summit.

INTRODUCTION

One of the major challenges militating against agricultural productivity in developing countries in which Nigeria is inclusive is inadequate knowledge of soil resources and unplanned land use (Fajobi *et al.*, 2023). It is very pertinent that this reoccurring challenge of inadequate knowledge of soil resources over the decades

be addressed urgently with immediate effect in order to mitigate food insecurity and, to safeguard and preserve land resources from deterioration. Humanity's most valuable resource is soil, which is readily damaged due to misuse and poor management, thereby lowering the land's ability to provide food. Nigeria as one of the developing countries must deal with

inefficient and haphazard land usage, inadequate understanding and evaluation of the soil's potential for crop growth, and other issues that are related to land (Fajobi *et al.*, 2023).

Hilly soils have long performed a host of vital ecosystem services that help to ensure food security and nutrition to many people around the world. Hilly terrains are areas with clusters of contours and also the areas in which the elevation is higher than its surrounding environment (Okoli, 2024). Soils of hilly terrain have the potential to generate a significant diversity and magnitude and ecosystem services, including those that are life supporting, regulating, provisioning or cultural (Bhadouria *et al.*, 2023).

Agricultural produce is at risk due to minimized matching of the necessities of land use to land qualities which are the basic requirements for land evaluation (Singha and Swain, 2016). Studying the physical-chemical properties of the soil as well as its economic situation is necessary for land appraisal, which aims to maximize the utilization of natural resources without compromising their quality (Ogwu *et al.*, 2024). Allocation of land to those who can maximize its potential, is the most effective and efficient way to maximize returns on agricultural land.

Hilly terrains in Bida Niger state covering expanse area of land have been regarded as marginal lands and have not been adequately put to use. With the increasing population, there is need to explore this type of land (hilly terrains) for arable crops (cowpea and sorghum) production. To achieve this goal, proper agricultural planning must be done.

The objective of this paper was to conduct land suitability evaluation for cowpea and sorghum production from hilly soils developed on sedimentary terrain area of Bida, Niger state.

MATERIALS AND METHODS

Description of the Study Site

The study was carried out in suburb of Bida, Niger state of Nigeria. The site as identified on the satellite imagery lies between latitude 09°10'55N and longitude 005°06'38" E. The climate of the study area is sub-humid tropical which experiences a monomodal annual rain fall of about 1200 mm (90 % of the rain is between June and August). The highest and daily temperatures rarely fall below 22° C and 40° C between February to March (Adeboye *et al.*, 2011). Sedimentary areas of Niger state comprise of basin of the River Niger. The rocks are stratified formations of late Cretaceous to recent time and consist of sandstone, shale, mudstone and siltstones (Awe, 2023). The major crops grown in the area are cereals (maize, upland rice and sorghum), legumes (groundnut and soybeans) and tubers (yam).

Fieldwork

To comprehend the vegetation, cropping systems, and rural topography of the research region, information on geology, vegetation, and land use pattern were collected both from the field and from the available literature. Satellite imagery and topographic map information were integrated to prepare the base map for the study (Figure 1). With the aid of satellite imagery of the study site and computer software, Sulfer II (Golden Software Inc., 2012), contour map of the study site was plotted to facilitate ground-truthing and

subsequent interpretation of results (Figure.2). Two modal profile pits were sunk in the summit, shoulder and footslope to permissible depths giving a total of six (6) profiles. Three profile (3) were described *in*

situ for morphological properties, while bulk soil samples were taken from the genetic horizons for laboratory analyses, following the procedures described by (FAO, 2014).

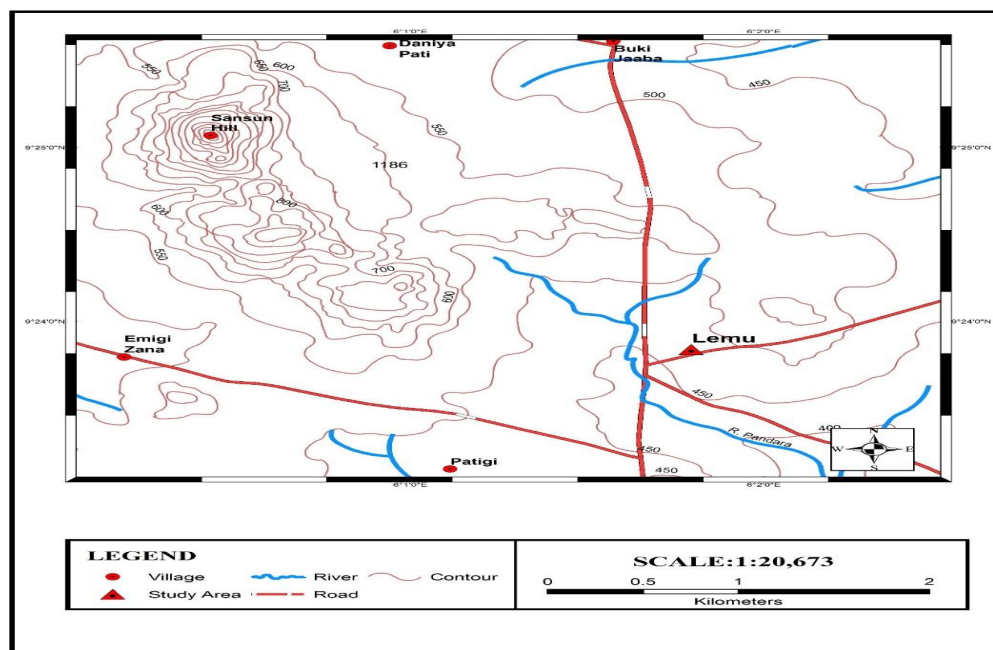


Figure 1: The study site as extracted from topographical map of Bida sheet 184 N.

Sample preparation and laboratory analysis

The soil samples collected from the soil profiles were air-dried, gently crushed using porcelain pestle and mortar and passed through a 2 mm sieve to obtain fine earth separates, while subsamples were further passed through 0.5 mm sieve for total nitrogen and organic carbon determinations. The particle size distribution was determined by the hydrometer method as described by Gee

and Or (2002). Bulk density (B-d) was determined by clod method (Grossman and Reinsch, 2002). Porosity was calculated as function of the total volume not occupied by soil solids from bulk density. Soil pH was determined in water solution at a 1:1 soil/water or solution ratios (Thomas, 1996). The organic carbon was determined by the Walkley-Black dichromate wet oxidation method as described by Nelson and Sommers (1982).

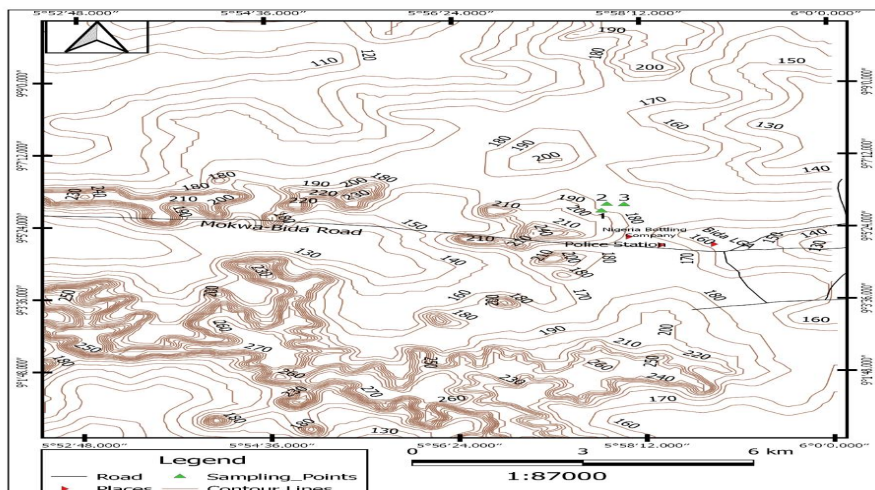


Figure 2: Topographical map of Bida study site.

Taxonomic Classification

Soil morphological properties and laboratory analytical (physical and chemical) data were used to classify the soils according to USDA Soil Taxonomical System (Soil Survey Staff, 2014) up to the subgroup level and were correlated with World Reference Base for Soil Resources Classification Method (IUSS WRB Soil Working Group, 2022) up to third level soil unit names.

Land Suitability Evaluation of the Soils for Cowpea and Sorghum

Simple limitation method

Qualitative land suitability evaluation study was carried out using the methods of the Food and Agricultural Organization (FAO) Framework for Land evaluation (FAO, 2007) and the FAO Guidelines on Land Evaluation for rain-fed agriculture (FAO, 1984). Field and laboratory generated data, also known as land quality/ characteristics

were matched with the ecological requirements of cowpea and sorghum. The overall land suitability class for each identified soil in the given area was determined by using the limitation method as the final class of the land ratings following the guidelines described by Sys *et al.* (1993).

Parametric method (Storie index)

The parametric land evaluation consists of numerical rating of different levels of land characteristics and qualities according to numerical scale between a maximum (normally 100) to a minimum value (Sys *et al.*, 1993; Van Ranst and Verdoot, 2005; O'geen *et al.*, 2008). The rating for the soils were carried out by matching the land qualities with the requirements of cowpea and sorghum to arrive at the numerical values (Sys *et al.*, 1993). Thereafter, soil/land indices were calculated using:

- i. Storie Index equation (Storie, 1933):

$$= A \times \frac{B}{100} \times \frac{C}{100} \times \dots \times n$$

Where: I = the index (%) of suitability, A = index of the most limiting factor, B, C... are indexes of other rating besides the minimum rating.

ii. Square root method (Khiddir, 1986):

$$I = R_{\min} \times \sqrt{\frac{A}{100} \times \frac{B}{100} \times \frac{C}{100} \times \dots}$$

Classification of the Soils using Soil Taxonomy

The soils of the summit had no profile differentiation, that is they have sandy loam occurring from surface soils to subsoils in all the profiles. These characteristics qualified the soils as Entisol in the soil order level. The soils were classified as Psamments as the sub-order level because of rock fragments and a texture of sandy in entire profiles. The soils were classified as Ustipsamments at the great group level as a result soil moisture regime of the agroecological zone in which Niger state belong to. The soils of the shoulder were classified as Inceptisols at order level because of their poorly developed profiles. There were however, evidences of alteration and horizon differentiation, but no horizon the meets the requirements of the argillic, kandic, oxic or spodic horizons. The ustic moisture regime of the area qualified soils as Ustepts in the sub-order level. The soils were classified as Dystrustepts at great group level due to their possession of base saturation (by NH_4OAc) of less than 60 percent in most of the horizons at the depth between 25 and 75

cm from mineral soils. The soils were classified as Rhodic Dystrustepts because they had in all the horizons from depth of 25-100 cm, more 50 percent YR or redder. The soils of footslope possess ochric epipedon, base saturation less than 35 % in some subsoils and the evidence of increasing clay content with increasing depth, thus classified as Ultisols at order category. The ustic moisture regime of the area qualified the soils as Ustults in sub-order level. The soil had epipedons with colour value, moist 3 in subsoil horizons, thus qualified the soils as Rhodustults in the great group level of soil classification. The soil had lithic contact (gravels and stone boulders) within 50 cm of the mineral soil surface, thus classified as Lithic Rhodustults in sub-group of classification.

Classification of the Soils using World Reference Base (WRB)

In the summit soils, the mineral soils lacked developed horizons, thus classified as Arenosols at Reference Soil Groups (RSG) level of WRB classification system (IUSS WRB Working Group, 2022). The soils had base saturation less than 60 percent in the part of the mineral soil surface, thus ascribed Dystric Arenosols. The soils were classified as Dystric Arenosols (Rhodic) due to red colour of the soil at supplementary qualifier level. The shoulder soils had weak structural development in all the horizon, thus classified as Cambisols. The soil had gravels and stone boulder (lithic contact) at 50 cm, thus ascribed Leptic Cambisols. The soils were further classified as Leptic Cambisols (Arenic) at supplementary qualifier since they showed greater proportion of sand in their particle

size distribution. The footslope soils possessed 35-45 cm thick epipedon over argillic horizon which had less than 35 percent base saturation in part of the mineral soils, thus classified as Acrisols. As a result of red colour of the was classified as Rhodic Acrisols. The soils were classified as Rhodic Acrisols (clayic) at supplementary qualifier level due to high clay content in the sub soil horizon.

RESULTS AND DISCUSSION

The site was delineated into three physiographic units (positions) and designated as summit, shoulder and footslope. The study revealed that the site is found on high elevation as shown on Digital Elevation Terrain (DET) and Physical Terrain (Figure 3 and Plate 1), while the cross-sectional profile of the study site is shown on Figure 4. The major rock materials identified in study site include ironstone, siltstone, claystone and ironstone (Plate II-I) and they were mostly weak and soft. The weak structure of the soils could be as a result of the geology of the Nupe environment in which the soils are formed. Soils on summit landform have the least depth among the three landforms of the study site. Libohava *et al.* (2016) opined that position of landform affects the depth of soil. The soil colour was predominantly light red (2.5YR6/8) in surface and subsoil horizons. Ukaegbu *et al.* (2023) opined that soils of sedimentary

generally possess red colours. Particle size distribution showed that sand dominated the soil particle size fraction in all the profiles. High sand content recorded could may be attributed to the nature of parent materials from which the soils were developed (Lawal *et al.*, 2012). The pH values of the soil ranged from 4.4 to 5.7 and rated extremely acid to moderately acid. The drop in pH could be caused by the effect of cultivation and leaching of nutrients in the profiles, therefore readily available at pH below 6 makes phosphorous and other essential nutrients less available to plants, limiting the amount of nutrient uptake. These soils may need some liming due to their high acidic nature for better crop productivity. The low organic carbon in the soils could be attributed to effects of high temperatures and high relative humidity, which favor rapid mineralization of organic matter, and differential land use could also account for low OC levels and poor soil management practices such as crop residue incineration, intensive cultivation, and seasonal bush burning, which is common practices in the study area. Farmers in the study area should employ cultural practices that encourage recycling and incorporation of plan/crop residues into the soil to increase soil organic matter content.

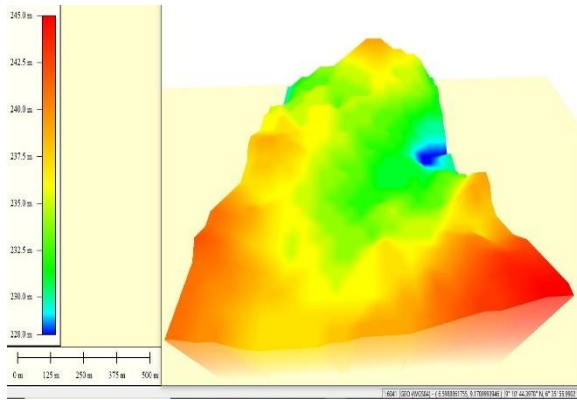


Figure 3: Digital Elevation Terrain (DET) Plate 1: Physical terrain of the study site
of the study site.

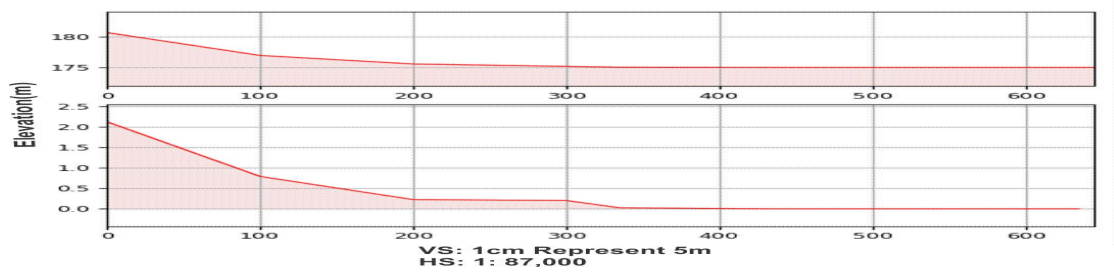


Figure 4: Cross sectional profile of the study site.



Plate II: Sampled ironstone (left) and claystone (right) rock materials showing cleavages and evidence of rocks undergoing weathering on the study site and also believed to have weathered to form the soil.



Plate III: Sampled siltstone (left) and sandstone (right) rock materials showing cleavages and evidence of rocks undergoing weathering on the study site and also believed to have weathered to form the soil.

The total nitrogen content of the soils was low compared to the critical value of 2 g kg⁻¹ recommended by (Ahukaemere, 2018). The low nitrogen in the soil could be as a

result of low organic matter content of the soil. The available phosphorous was generally low compared to the critical value of 10 mg kg⁻¹ (Ajiboye, and Olaniyan, 2016). Nigerian soils have been reported to be phosphorous deficient due to the high P-fixing capacity of these soils (Ahukaemere, 2018). The low levels of available phosphorous in the soils can be attributed to the kaolinitic clay type observed as low activity (low CEC) clay in the soils of the study area, which binds more available phosphorous than other clays. Another factor for low available P in soils could be attributed to the fixation of phosphorous to iron (Fe) in soils (Gupta *et al.*, 2021). Calcium (Ca²⁺) and magnesium (Mg⁺²) in Nigerian soils are between 2.00 and 1.2 cmol kg⁻¹ respectively. Exchangeable calcium (Ca⁺²) and magnesium (Mg⁺²) levels for the soils were rated low to

medium. The exchangeable K ranged from 0.65 to 1.45 cmol kg⁻¹ and rated high in all the landforms.

Land Suitability Evaluation

The suitability of the soils for cowpea and sorghum production were carried out in order to ascertain the productivity and management practices of the soil. The suitability of cowpea and sorghum was evaluated by matching the area's soil properties with the agronomic requirements of the test crops. The land use requirements for cowpea and sorghum are shown in Table 1 and 2. Therefore, the evaluation (particularly the parametric methods), was taken in two phases: actual and potential suitability. The actual suitability implies the suitability of the soil for the crop production in its present condition when correctable

Table 1: Land and environmental requirements for Cowpea

S1=highly suitable, S2 moderately suitable, S3 marginally suitable, N1 currently not suitable, N2 permanently not suitable.

Land Qualities	S1₁ 85-95%	S1₂ 60-85%	S2 40-60%	S3 25-40%	N1 25-40%	N2 0-25%
Climate (C)						
Annual rainfall (mm)	>1200	1000-1200	800-1000	600-800	-	>600
Length of dry season (months)	>5	4-5	3-4	2-3	-	>2
Mean annual maxi. T (°C)	29	27-29	24-27	22-24	-	>22
Average daily min. T (°C)	>25	18-20	16-18	14-16	-	>14
Mean annual T (°C)	>25	22-25	20-22	18-20	-	>18
Relative humidity (%)	>75	70-75	65-70	60-65	-	>60
Topography (t)						
Slope (%)	0-4	4-8	8-12	12-16	>16	-
Wetness (w)						
Flooding	F ₀	F ₀	F ₁	F ₂	-	F ₂
Drainage	WD	WD	WD	IWD	PD	VPD
Soil physical properties						
Texture	LS	SL	SC	SCL	Any	C, CL
Soil structure	Crumb	Crumb	S.A. Blocky	S.A. Blocky	Column ar	Column ar
Coarse fragment (Vol. %)	3-10	10-15	15-35	35-55	-	>55
Depth (cm)	>100	90-100	50-90	25-50	-	>25
Fertility (f)						
CEC (Cmol/kg)	>10	8-10	6-8	4-6	2-4	<2
Base saturation (%)	>70	60-70	40-60	20-40	-	0
pH	>6.0-6.5	6.0-7.0	5.5-6.0	5.0-5.5	4.5-5.0	<4.5-7.5
Organic carbon (%)	>1.5-2.0	1.5-2.0	1.25-1.5	1.0-1.25	<1.0	<1.00
Ca (Cmol/kg)	0.8-0.9	0.7-0.8	0.6-0.7	0.4-0.6	0.2-0.4	<1.00
Avail. P (mg/kg)	>20	16-20	12-16	8-12	4-8	<4.0
Ec (ds/m ⁻¹)	<1	1-2	2-3	3-4	4-8	>8

Source: FAO, (2007).

Table 2: Land and environmental requirements for Sorghum

Criteria factors	Unit	Factors rating			
		(S1)	(S2)	(S3)	N
Soil Reaction	pH	6.0 -8.9	5.5-5.9 &8.1-8.5	>5.5 & 8.6 -9.0	> 9.0
Total Nitrogen	%	>0.2	0.1-0.2	0.02 -0.1	< 0.02
Available P.	Mg/kg	> 8.0	5-7	4 -5	< 4.0
Organic matter (Om)	%	>1.5	1.0-1.5	0.5 – 1.0	< 0.5
Exchangeable Ca	Cmol/kg ⁻¹	>10	8-10	4 -8	< 4.0
Exchangeable Mg	Cmol/kg ⁻¹	>4	2-4	0.5 -2.0	<0.5
Exchangeable K	Cmol/kg ⁻¹	>0.40	0.20-0.40	0.15 -0.20	< 0.15
Exchangeable Na	Cmol/kg ⁻¹	0.01-0.03	0.03-0.05	0.05 – 0.10	< 0.10
CEC	Cmol/kg	>16	8-16	5 -8	<5
EC	dsm	0-6.8	6.8 -8.4	8.4 -10	>10
Rainfall	Mm	>600	3 00 -600	150 – 300	,150
Temperature	°C	24-32	20-24	15 – 20	>15, >32
Slope	%	0 -3	3 -8	8 -16	>16
Soil depth	cm	>90	50 -90	20 -50	20

S1=highly suitable, S2 moderately suitable, S3 marginally suitable, N1 currently not suitable, N2 permanently not suitable

Source: Ahmed and Jeb (2014).

Table 3: Land qualities/ characteristics of the study site

Land Quality/Characteristics	Summit	Shoulder	Footslope
Climatic data:			
Mean Annual Rainfall (mm)*	1200	1200	1200
Average Length of dry season (months)*	95	95	95
Temperature (°C)*	34	34	34
Land/Soil Physical Properties:			
Slope	4	1-4	1-3
Drainage	Well drained	Well drained	Well drained
Soil depth	162	163	170
Texture (surface)+	SL	S	LS
Structure (surface)++	Cr	SG	Cr
Nutrient availability (surface soil)			
Soil reaction (pH)	6.4	6.1	6.3
Total N (g kg ⁻¹)	0.32	0.46	0.36
Exchangeable Ca (cmol kg ⁻¹)	0.64	1.92	1.92
Exchangeable Na (cmol kg ⁻¹)	0.17	0.17	0.20
Available P (mg kg ⁻¹)	1.10	5.28	1.51
Exchangeable K (cmol)	0.37	0.35	0.65
Organic C (g kg ⁻¹)	0.41	3.00	1.06
CEC (cmol kg ⁻¹)	10.96	10.96	4.62
Base saturation (%)	12.22	30.66	96.32
Exchangeable sodium percentage (%)	1.55	1.69	4.33
Electrical conductivity (dS m ⁻¹)	0.053	0.098	0.049

+Sandy loam, Loamy sand, ++ Crumb

Table 4: Suitability evaluation of the study site for Cowpea and Sorghum using FAO simple limitation method

Land factor rating	Cowpea	Sorghum

	Summit		Footslope	Summit	Shoulder	Footslope
	Shoulder					
Slope	S1	S1	S1	S1	S1	S1
Drainage	S1	S1	S3	-	-	-
Rainfall	S1	S1	S1	S1	S1	S1
Temperature	S1	S1	S1	S1	S1	S1
Texture	S1	S1	S1	-	-	-
Structure	S1	S1	S1	-	-	-
Soil depth	S1	S1	S1	S1	S1	S1
Nutrient availability (f)						
Soil reaction (pH)	S1	S1	S1	S1	S1	S1
Total Nitrogen (g kg ⁻¹)	-	-	-	N2	N2	N2
Avail. P (mg kg ⁻¹)	N2	N1	N2	N1	S3	N1
Exchangeable Ca	S2	S1	S3	S2	S2	N1
(cmol kg ⁻¹)	-	-	-	S1	S1	S1
Exchangeable Mg	-	-	-		S1	S1
(cmol kg ⁻¹)						
Exchangeable Na						
(cmol kg ⁻¹)						
Nutrient retention (n)						
Organic matter (g kg ⁻¹)	N2	N2	N2	N1	N1	N1
CEC (cmol kg ⁻¹)	S1	S1	S3	S2	S2	N1
Base saturation (%)	N1	S3	S1	-	-	-
EC (dS/m ⁻¹)	S1	S1	S1	S1	S1	S1
Aggregate suitability	N2sfn	N2sfn	N2sfn	N2sfn	N2sfn	N2sfn

*Limitations (restrictive features): s = soil physical characteristics, f = fertility, t = topography, w = wetness (drainage)
 limitation, S1(100-75) = highly suitable, S2(75-50) = moderately suitable, S3 (50-25) = marginally suitable, N1(25-2.5) = currently not suitable, N2 (12.5-0) = permanently not suitable.

Table 5: Suitability evaluation of the study site for Cowpea using square root method

Land factor ratings	Summit		Shoulder		Footslope	
Climatic data:	Actual	Potential	Actual	Potential	Actual	Potential
Topography (t)						
Slope	95	95	95	95	95	95
Drainage (w):						
Wetness	95	95	95	95	95	95
Climate (c)						
Rainfall	100	100	100	100	100	100
Temperature	100	100	100	100	100	100
Soil physical characteristics (s):						
Texture	95	95	95	95	95	95
Structure	95	95	95	95	95	95
Soil depth	95	95	95	95	95	95
Nutrient availability (f):						
Soil reaction (pH)	95	-	95	-	95	-
Total Nitrogen (g kg ⁻¹)	-	-	-	-	-	-
Available P (mg kg ⁻¹)	25	-	40	-	25	-
Exchangeable Ca (cmol kg ⁻¹)	85	-	95	-	95	-
Exchangeable Mg (cmol kg ⁻¹)	-	-	-	-	-	-
Exchangeable Na (cmol kg ⁻¹)	-	-	-	-	-	-
Nutrient retention (n)						
Organic matter (g kg ⁻¹)	25	25	25	25	25	25
CEC (cmol kg ⁻¹)	95	95	95	95	85	85
Base saturation (%)	40	40	60	60	95	95
EC (dS m ⁻¹)	95	95	95	95	95	95
Suitability index	3.85	8.57	7.35	12.86	4.69	9.88
Suitability class	N2sfn	N2sn	N2sfn	N1sn	N2sfn	N2sn

*S1 = highly suitable, S2 = moderately suitable, S3 = marginally suitable, N1 = currently not suitable, N2 = permanently not suitable,

+ Limitations (restrictive features): s = soil physical characteristics, f = fertility, t = topography, w = wetness (drainage) limitation

Table 6: Suitability evaluation of the study site for Sorghum using square root method

Land factor ratings	Summit		Shoulder		Footslope	
Climatic data:	Actual	Potential	Actual	Potential	Actual	Potential
Topography (t)						
Slope	95	95	95	95	95	95
Drainage (w):						
Wetness	-	-	-	-	-	-
Climate (c)						
Rainfall	100	100	100	100	100	100
Temperature	100	100	100	100	100	100
Soil physical characteristics (s):						
Texture	-	-	-	-	-	-
Structure	-	-	-	-	-	-
Soil depth	95	95	95	95	95	95
Nutrient availability (f):						
Soil reaction (pH)	95	-	95	-	95	-
Total Nitrogen (g kg ⁻¹)	25	-	25	-	25	-
Available P (mg kg ⁻¹)	40	-	60	-	40	-
Exchangeable Ca (cmol kg ⁻¹)	40	-	40	-	40	-
Exchangeable Mg (g kg ⁻¹)	85	-	60	-	60	-
Exchangeable Na (g kg ⁻¹)	95	-	95	-	95	-
Nutrient retention (n)						
Organic matter (g kg ⁻¹)	40	40	40	40	40	40
CEC (cmol kg ⁻¹)	85	85	85	85	40	40
Base saturation (%)	-	-	-	-	-	-
EC (dS m ⁻¹)	95	95	95	95	95	95
Suitability index	3.86	27.14	3.87	27.14	1.77	15.20
Suitability class	N2sfn	S3sn	N2sfn	S3sn	N2sn	N1sn

*S1 = highly suitable, S2 = moderately suitable, S3 = marginally suitable, N1 = currently not suitable, N2 = permanently not suitable,

9+ Limitations (restrictive features): s = soil physical characteristics f = fertility, t = topography, w = wetness (drainage) limitation

limitations, that is chemical fertility (pH, N, P, Ca, Mg and Na) are not corrected. Potential fertility on the other hand was assessment made on the basis that nutrient availability limitations are corrected (Faturoti *et al.*, 2015). The results of land characteristics/qualities of the study site are presented in (Table 3). The climatic condition of the study area in terms of amount of rainfall distribution and temperature are highly suitable for the cultivation of the two crops when compared to cowpea and sorghum land use requirements.

The slope, drainage, texture and structure, soil reaction, CEC and EC were highly suitable for the two crops in all the landforms while Texture and structure were not put into consideration for the suitability of sorghum (Tables 4-6). Fertility characteristics were the main limiting factors for the production of the two crops. The aggregate suitability has shown that the soils are permanently not suitable (N2sfn) for the production of cowpea and sorghum.

Conclusion and Recommendations

The study revealed that landscape position in relation to geological material to a large extent has great influences on the inherent morphological, physical and chemical properties of soil and their potential for agricultural production. The soil colour was characterized with reddish colour. Sand dominated the particle size fraction of fine earth (< 2 mm) portion in all the landforms. Organic matter content was found to be generally low in the study site. The soils

had low pH level. The soils were characterized and classified according to Soil Taxonomy and WRB for Soil Resources. The summit soils were classified as Rhodic Ustipsamments, shoulder as Lithic Dystrustepts while the footslope soils were classified as Lithic Rhodustults (Soil Survey Staff, 2014). With the WRB system, the summit soils were classified as Dystric Arenasols (Rhodic), the shoulder soils were classified as Leptic Cambisols while the footslope soils were classified as Rhodic Acrisols (clayic). The suitability evaluation of the soil was carried out by means of simple limitation and parametric method and the results showed that the soils are currently not suitable (N2sfn) for the production of cowpea and sorghum. According to the results, the biggest limiting factor is soil fertility. It is important to employ management practices such as conservation tillage and fertilization that improve the soil's physical and fertile conditions. The incorporation of organic fertilizer and legumes into the site's cultivation pattern is suggested.

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EVALUATION OF SOIL CHARACTERISTICS AND LEAD CONCENTRATION IN AGRICULTURAL SOILS OF ABARE, ANKA LOCAL GOVERNMENT AREA, ZAMFARA STATE.

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ABSTRACT

This study sought to evaluate the soil characteristics and lead (Pb) concentration in the agricultural soils of Abare, situated in the Anka Local Government Area of Zamfara State, Nigeria. Soil samples were obtained from four specific locations: East, West, North, and South. The research examined the textural classifications, chemical characteristics, and levels of total and extractable Pb in several soil fractions (sand, silt, and clay). The results indicated that the soils in Abare exhibit varying degrees of Pb contamination, with the clay fractions showing the highest Pb concentrations. The soil characteristics in the region varied from sandy clay loam to clay loam and loam, exhibiting moderate pH levels and organic carbon content. This study offers insights into the environmental quality of agricultural soils in Abare and underscores the potential hazards of lead pollution to agricultural productivity and human health.

Keywords: soil characteristics, lead pollution, soil components.

INTRODUCTION

The presence of heavy metals, such as lead (Pb), in soils poses a considerable environmental issue, especially in agricultural regions where crops are cultivated for human consumption. Lead exposure can result in soil degradation, diminished crop productivity, and prolonged health hazards via the food chain. This study examines the soil characteristics and lead contamination levels in the agricultural soils of Abare, located in the Anka LGA of Zamfara State, Nigeria. Soil characteristics like texture, pH, organic carbon (O.C.), total nitrogen (T.N.), and cation exchange capacity (CEC) are pivotal in determining the mobility and bioavailability of heavy metals in soils (Ojo,

2020). The soil's chemical composition affects the absorption of harmful metals by plants (Sani *et al.*, 2018). In areas where human activities, like mining, agriculture, and urbanisation, affect soil composition, it is essential to monitor pollutant levels (Ogundiran *et al.*, 2022). This study seeks to ascertain the soil textural characteristics, chemical composition, and lead concentrations in several soil fractions (sand, silt, and clay) to assess lead contamination levels across different locations in Abare.

MATERIALS AND METHODS

Description of the Study Area

Abare is located in the Anka Local Government Area of Zamfara State, Nigeria. The state is situated in Nigeria's savanna region. Abare is located at latitudes 12° 04' 41.56" N to 11° 30' 41.56"

N and longitudes 5° 57' 25.64"E to 6° 15' 41.56"E (Anon, 2022). The area is characterized by farming activities, which include the cultivation of various crops. The region's climatic conditions and soil characteristics make it suitable for agricultural activities, but the presence of heavy metals like Pb poses a risk to both the environment and public health. The research region is characterized by a mild tropical environment, featuring two distinct seasons: the rainy season from late May to September and the dry season from November to April. The annual precipitation ranges from 579 mm to 1,020 mm, with a mean maximum temperature of

approximately 36°C and a mean minimum temperature of 17.7°C (People, Population and Settlement, 2013). The soils of Zamfara are ferruginous tropical lithosols originating from Basement Complex rocks. The soils include a sandy surface horizon and clayey sub soils, both of which are conducive to agricultural productivity (PPS, 2013). Zamfara State comprises two principal agro-ecological zones: Northern Guinea Savanna and Sudan Savanna. The study region is located within the Northern Guinea savanna, characterized by forests where grasses are present either exclusively or in combination with other herbaceous or shrubby flora (PPS, 2013).

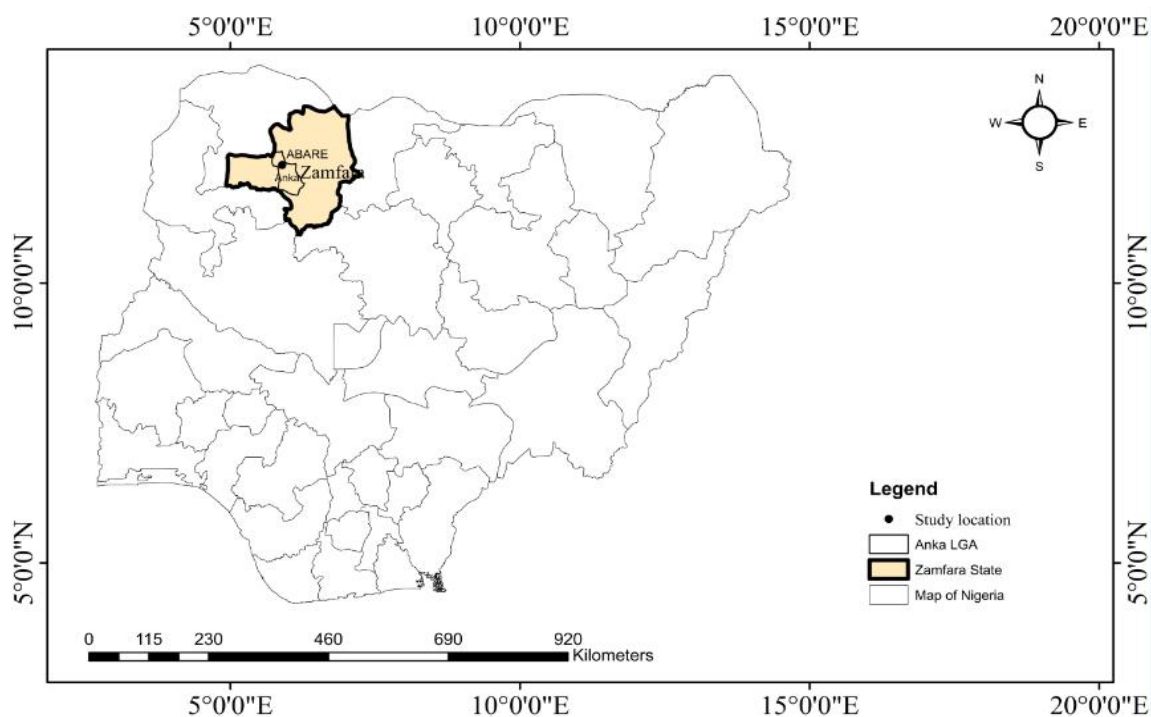


Figure1: Map of the study area

Field Studies

Soil collection and preparation:

Soil samples were collected from four locations in Abare, (East, West, North, and South). At each location, soil samples were taken from the top 20 cm of the soil profile, representing the uppermost layer where most agricultural activities occur. A total of 16 soil samples (4 from each location) were analyzed for both physical and chemical properties. The selection of locations and farmlands, along with soil sampling from each site, aimed to accurately portray the characteristics of Pb pollution in the village of Abare. The materials were air-dried, pulverized, and sieved through a 2-mm mesh before being stored for examination.

Laboratory Analyses

The soil samples were desiccated, sieved, and preserved in an airtight container prior to laboratory analysis. The soil's particle size distribution was ascertained using the hydrometer method, as described by Gee and Bauder (1986). The cation exchange capacity of the soil was assessed using the 1N ammonium acetate (NH₄OAc) saturation method as outlined by Rhoades (1982). Soil pH was assessed in both water and a calcium chloride (0.01M CaCl₂) solution; use a 1:2.5 soil/water suspension and a soil/CaCl₂ suspension (IITA, 1979). The organic carbon (OC) content of the soil was assessed using the dichromate oxidation method established by Walkley and Black, as outlined by Nelson and Sommers (1986). The soil's total nitrogen was assessed with the Kjeldahl method as outlined by Agbenin (1995). Available phosphorus was removed utilising the Bray 1 technique (Bray and Kurtz, 1945).

Table 1: Physical Properties of the Soils

The exchangeable bases (Ca, Mg, K, and Na) were extracted using a buffered ammonium acetate (1N NH₄OAc) solution at pH 7.0, as noted by Agbenin (1995). The total lead concentration was ascertained from the isolated soil fractions (sand, silt, and clay). The soil was treated with a combination of HCl, HNO₃, and HF according to the method outlined by Lim and Jackson (1986). The concentration of extractable lead was quantified from the segregated soil fractions (sand, silt, and clay) as outlined by Baker and Amacher (1982).

Statistical Analysis:

The data acquired on the analysed soil qualities underwent basic descriptive statistics, utilising range and means to compare the averages of the investigated areas.

Results and Discussion

Soil Texture and Chemical Properties

The soil texture in Abare varies across the different locations, with the East and West locations exhibiting sandy clay loam, the North location displaying clay loam, and the South location classified as loam (Table 1). This variation in texture plays a significant role in water retention, nutrient availability, and the potential for heavy metal mobility within the soil profile. Sandy soils generally have a lower capacity to retain water and nutrients, which can affect plant growth (Pierzynski *et al.*, 2000). In contrast, loamy and clay loam soils, which are more common in the North and South locations, offer a better balance between drainage and

Locations	Sand	Silt	Clay	Textural Class
East	516.8	212.8	270.4	Sandy clay loam
West	556.8	252.8	190.4	Sandy clay loam
North	376.8	272.8	350.4	Clay loam
South	456.8	332.8	210.4	Loam

retention, making them more suitable for agriculture (Singh *et al.*, 2015).

The pH of soils

The pH of soils in Abare ranged from 6.0 to 6.7 in water, which is slightly acidic to neutral (Table 2). This is consistent with the findings of Usman *et al.* (2017) who observed similar pH values in soils from agricultural areas in Nigeria. Soils with pH values in this range are generally suitable for plant growth, as most crops prefer a slightly acidic to neutral pH (Brady & Weil, 2008).

The organic carbon content ranged from 4.5 to 9.7 g/kg with an average of 7.1 g/kg, which is comparable to findings by Oyedele *et al.* (2017) in the same agro-ecological zone, indicating a moderate level of soil organic matter. Organic matter plays a critical role in improving soil structure, water retention, and nutrient supply, which are essential for healthy plant growth (Berg *et al.*, 2009).

Table 2: Chemical Properties of the Soils across the Locations

Properties	Minimum	Maximum	Mean
pH (Water)	6.0	6.7	6.35
CaCl ₂	5.2	5.8	5.50
O.C (gkg ⁻¹)	4.50	9.70	7.10
T.N (gkg ⁻¹)	0.40	0.90	0.65
Avail. P (mgkg ⁻¹)	2.80	68.43	35.62
CEC (cmolkg ⁻¹)	3.95	10.91	7.43
Ca (cmolkg ⁻¹)	2.64	8.75	5.70
Mg (cmolkg ⁻¹)	0.59	0.71	0.65
Na (cmolkg ⁻¹)	0.26	0.61	0.44
K (cmolkg ⁻¹)	0.26	0.87	0.57

The CEC

The CEC in Abare ranged from 3.95 to 10.91 cmol/kg, with a mean of 7.43 cmol/kg (Table 2). CEC is an important property that indicates the soil's ability to retain cations,

including essential nutrients like potassium, calcium, and magnesium (Akpan *et al.*, 2014). This range is typical for agricultural soils, suggesting that the soils in Abare have moderate fertility. However, studies by Ojo *et al.* (2021) in neighboring areas showed

slightly higher CEC values, which could indicate differences in organic matter content or clay content, factors that influence CEC.

Lead Concentrations in Soil Fractions

The concentration of total Pb was highest in the clay fraction (157.90 mg/kg) and lowest in the sand fraction (135.95 mg/kg), with silt falling in between (141.45 mg/kg) (Table 3). This trend is consistent with the findings of Akinremi *et al.* (2000), who reported that finer soil fractions, especially clay, have higher capacities to retain heavy metals due to their larger surface area and greater CEC. The study also found that the clay fraction exhibited the highest extractable Pb concentration (86.14 mg/kg), which further supports the hypothesis that Pb is more bioavailable in finer soil fractions due to their higher binding affinity (Liu *et al.*, 2019).

In a comparative analysis, studies conducted in other agricultural regions,

such as by Zhang *et al.* (2016) in northern China, also found that clay and silt fractions accumulate higher concentrations of Pb compared to sand. This is particularly relevant in areas affected by industrial activities or mining, where heavy metal deposition is more pronounced in fine soil particles (Jiang *et al.*, 2015). Similarly, a study by Anwar *et al.* (2018) in Pakistan observed that heavy metals, including Pb, were more concentrated in the clay and silt fractions of farm soils, which emphasizes the importance of monitoring these fractions for potential contamination risks.

Extractable Pb concentrations

Extractable Pb concentrations in Abare were found to range from 9.71 to 194.00 mg/kg, with a mean of 62.21 mg/kg in sand, 9.71 to 215.43 mg/kg, with a mean of 68.29 mg/kg in silt, and 9.71 to 279.71 mg/kg, with a mean of 86.14 mg/kg in clay (Table 3).

Table 3: Concentration of total and extricable Pb in the different soil fractions

Soil Fraction	Minimum (mgkg)	Maximum (mgkg)	Mean (mgkg)
Concentration of total Pb			
Sand	59.21	289.48	135.95
Silt	59.21	355.26	141.45
Clay	59.21	388.16	157.90
Extricable Pb			
Sand	9.71	194.00	62.21
Silt	9.71	215.43	68.29
Clay	9.71	279.71	86.14

The higher levels of extractable Pb in the clay fractions are of particular concern, as they indicate a potential for higher bioavailability and a greater likelihood of Pb uptake by crops (Wei *et al.*, 2017). This trend suggests that crops grown in soils with high clay content are at a greater risk of Pb contamination, which could negatively impact food safety and human health (Singh *et al.*, 2020).

Environmental Implications and Health Risks

The elevated concentrations of Pb in the farm soils of Abare, particularly in the clay and silt fractions, suggest a potential environmental and health risk. Pb is a highly toxic metal that can adversely affect plant growth by inhibiting root development, reducing nutrient uptake, and affecting chlorophyll synthesis (Ali *et al.*, 2019). Furthermore, Pb can enter the human food chain through contaminated crops, especially root vegetables and leafy greens, which are more likely to absorb heavy metals from the soil (Nayyar & Shaukat, 2017). The potential for Pb accumulation in edible crops poses a serious risk to human health, as Pb is known to cause neurological and developmental disorders, particularly in children (Hernandez *et al.*, 2020).

The levels of Pb observed in the soils of Abare are comparable to those reported in other parts of Nigeria and Africa. For instance, studies by Akinola *et al.* (2019) and Olayinka *et al.* (2018) reported similar Pb concentrations in agricultural soils in southwestern Nigeria, indicating that Pb contamination is a widespread issue in Nigerian farm soils. These findings are also supported by studies conducted in other

parts of Africa, such as in Ghana, where Pb contamination in soils used for food production was found to be a growing concern (Antwi-Agyei *et al.*, 2017).

Comparison with Other Studies

A comparison of Pb concentrations in this study with those from other regions reveals significant variation in soil contamination levels. For example, a study by Li *et al.* (2014) in a mining-affected area in China found much higher Pb concentrations, particularly in soils with high clay content. Similarly, in mining regions in Zambia, Pb concentrations were reported to be significantly higher in the soil compared to the Abare soils (Mwansa *et al.*, 2016). In contrast, studies in non-mining regions, such as in agricultural zones of Europe and North America, often report lower Pb concentrations due to better soil management practices and regulations on the use of Pb-based fertilizers (Sampson *et al.*, 2015).

The Pb concentrations in Abare, while concerning, are not alarmingly high when compared to contaminated mining areas, but they still present a potential threat to food safety, especially in areas with limited agricultural monitoring and remediation efforts. This highlights the need for continuous monitoring and the implementation of soil remediation strategies in agricultural zones where Pb contamination is detected.

Conclusion

The study of soil properties and Pb contamination in the farm soils of Abare, Anka Local Government Area, revealed moderate fertility and varying degrees of Pb contamination. The highest Pb

concentrations were found in the clay fractions, indicating a potential risk for crop contamination, particularly in locations with fine-textured soils. While the Pb concentrations in Abare were not as high as those found in mining-affected areas, they still pose a risk to agricultural productivity and human health.

The findings underscore the importance of monitoring heavy metal concentrations in soils, particularly in agricultural areas, to mitigate potential risks associated with food safety. Future studies should explore the impact of Pb contamination on crop yield and human health in Abare, as well as potential soil remediation strategies to reduce Pb bioavailability.

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SECTION TWO: SOIL HEALTH AND NUTRIENT MANAGEMENT

CLUSTERING SOIL PROPERTIES FOR SUSTAINABLE AND EFFICIENT RICE PRODUCTION MANAGEMENT PRACTICES IN BURSARI LGA OF YOBE STATE

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ABSTRACT

This study investigates the soil properties of rice farms in Bursari LGA, Yobe State. Principal component (PCA) and hierarchical clustering analyses were employed to identify key factors contributing to soil variability and to aid in the development of site-specific management practices. A total of 36 soil samples were randomly collected at 0–20 cm depth from 6 rice production villages (Daskum, Dumbiri, Gadine, Gangawa, Masaba, and Tabawa) in the Bursari Local Government Area, Yobe State, Nigeria. Samples were analyzed for physico-chemical properties. Results revealed variations in soil texture, with loam and sandy clay loam being predominant, saturated hydraulic conductivity (Ks), OC, and Zn showed high coefficients of variability (> 35%) within the villages; all other soil properties had moderate variability. Most of the chemical properties were rated medium, except for OC, TN, and CEC in all the sampled villages. The first three principal components (PC1, PC2, and PC3) explain 97.76% of the total variance in the dataset, with PC1 alone accounting for 57.15% of the variance. Key soil properties influencing PC1 include silt, available water (AW), phosphorus (P), cation exchange capacity (CEC), calcium (Ca), and magnesium (Mg). PC2 is primarily influenced by field capacity (FC), porosity, copper (Cu), and bulk density (BD). PC3 is driven by sodium (Na), iron (Fe), magnesium (Mg), copper (Cu), and cation exchange capacity (CEC). Daskum and Gangawa formed a distinct cluster, while Gadine and Tabawa are in a separate cluster, and Dumbiri and Masaba are in another, but at a higher level they share similar characteristics. Implementation of site-specific management practices in terms of limiting soil properties to optimize rice farming production in Bursari LGA, Yobe State, is highly recommended in place of the usual blanket recommendation.

Keywords: Bursari, dendrogram, soil, variability, Yobe

INTRODUCTION

Rice (*Oryza sativa* L.) is a major staple food for over half of the world's population, including Nigeria, where it is a crucial component of the diet and a significant contributor to the agricultural economy (IRRI, 2022). In recent years, the demand for rice has increased due to population growth and changing dietary preferences.

However, rice production in Nigeria faces several challenges, including soil degradation, nutrient depletion, and inefficient water use, which threaten sustainability and productivity (Mohammed, 2019). Bursari Local Government Area (LGA) in Yobe State is one of the regions in Nigeria where rice farming is predominant. The Savanna area is characterized by diverse soil types,

ranging from sandy to clayey soils, which influence the productivity of rice (Mustapha *et al.*, 2020). Understanding the spatial variability of soil properties is essential for developing effective and sustainable rice production management practices. Soil properties such as texture, pH, organic matter content, and nutrient levels play a significant role in determining soil fertility and crop performance (Delgado and Gomez, 2016). Clustering soil properties is an effective approach to identify distinct soil management zones, which can be used to tailor agricultural practices to the specific needs of each zone. This method allows for precision agriculture, where inputs such as fertilizers, water, and amendments are applied more efficiently, reducing waste and environmental impact (Shelia and Hoogenboom, 2020).

In Bursari LGA, clustering soil properties involves grouping soils with similar characteristics into distinct clusters or zones. This process can be achieved using statistical techniques such as hierarchical clustering, or principal component analysis (PCA) and the PCs with eigenvalues of more than 1 are selected by considered to be the best to represent the input variables (Metwally *et al.*, 2019). Once the soil clusters are identified, management practices can be tailored to the specific needs of each cluster, optimizing resource use and improving rice yields.

Implementing clustered soil management practices has several benefits. Including enhancement of soil fertility by ensuring that nutrients are applied where they are most needed, reducing the risk of nutrient imbalances and deficiencies and it also improves water use efficiency by tailoring

irrigation practices to the soil's water-holding capacity, minimizing water wastage. It equally supports sustainable agriculture by promoting practices that maintain soil health and prevent degradation (Tang, 2025). This study aims to analyze the soil physico-chemical properties of rice farms in six villages within the Bursari Local Government Area of Yobe State, Nigeria, in order to provide insights into the fertility status of these soils and determine different management zones using PC and Clustering Analysis.

MATERIALS AND METHODS

Study Area

The study was conducted in six villages within the Bursari LGA of Yobe State, Nigeria, namely Daskum, Dumbiri, Gadine, Gangawa, Masaba, and Tabawa. The LGA has an area 3818km² and is located between latitudes 12.250 ° to 13.000 ° N and longitudes 11.000 ° to 11.500 ° E on an elevation of 334masl (Figure 1).

Generally, the soils are characterized by sand to sandy loam texture. The Yobe river and ground water is the main irrigation source in the area. The climate during the dry season has an air temperature ranging between 29 to 43°C (The warmest months with the highest average high temperature are usually between April - June. While the cold/harmattan period is with air temperatures between 16 to 32°C. The coldest months are November to February. The rainfall period is between July to early October with an average annual rainfall of about 255.88 mm (World Weather Online,

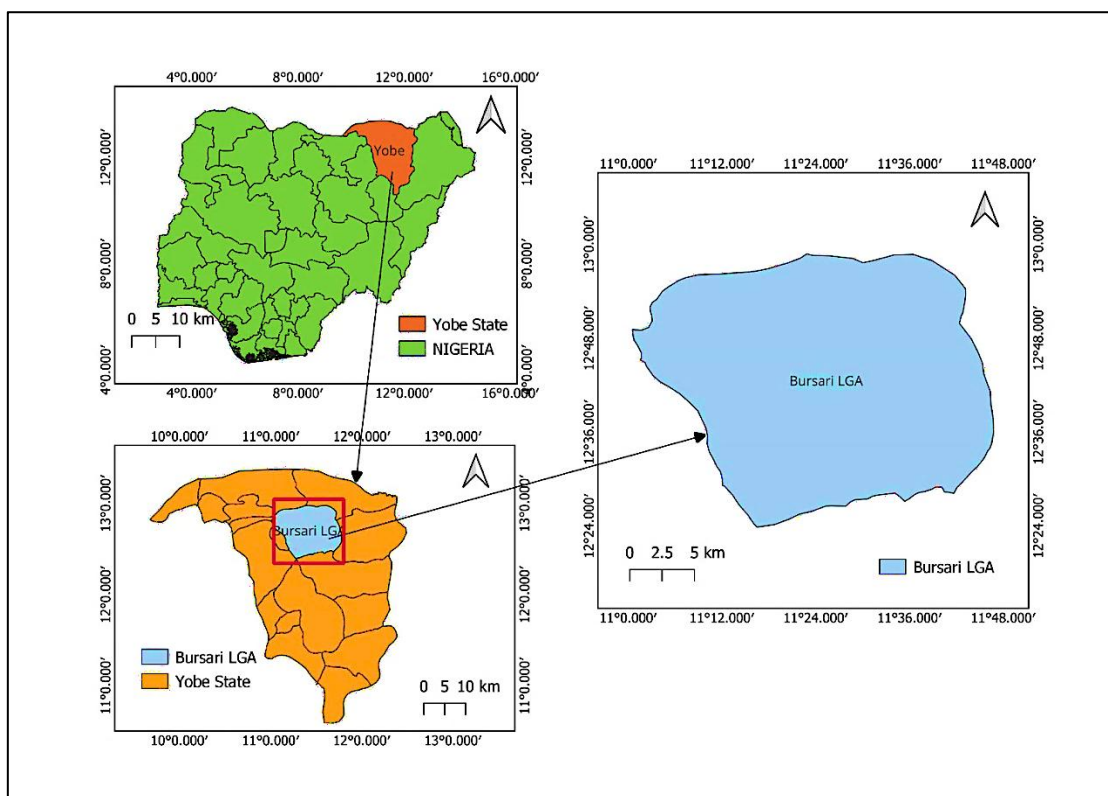


Figure 1. Study area map (Bursari LGA)

n.d.). Millet, sorghum, rice, wheat, cowpea, sesame and a few vegetables are cultivated in some of the areas in the LGA.

Soil Samples Collection

A total of 36 soil samples were randomly collected at 0–20 cm depth from 6 rice production villages (Daskum, Dumbiri, Gadine, Gangawa, Masaba, and Tabawa) in the Bursari Local Government Area (Table 1). Purposive random sampling techniques were adopted in the collection of soil samples (from irrigated rice farms only). Six (6) rice farms were selected for soil sampling from each location and five (5) sampling points from each farm were chosen randomly and then samples taken using soil auger at the depth of 0-20cm which were composite to represent the farm.

Total of 36 samples (6 farms x 6 locations) were then taken to laboratory for analysis.

Laboratory Analysis

Particle size distribution was determined by the hydrometer method, as described by Gee and Bauder (1986). Bulk density was measured using core method (Grossman and Reinsch, 2002). Soil porosity was calculated using a mathematical relationship between bulk density and particle density (Foth, 1984) using the expression:

$$P (\%) = 1 - (BD/PD) \times 100 \quad (1)$$

Where,

P=Porosity (%), BD=Bulk density (g/m^3), PD=Particle density (2.65 g/m^3).

Table 1. Geographical Locations of the Sampling Villages

S/N	VILLAGES	COORDINATE
1.	Gadine	12°54'14"N, 11°7'2"E
2.	Gangawa	12°12'14"N, 11°7'3"E
3.	Tabawa	12°53'39"N, 11°4'18"E
4.	Masaba	12°52'10"N, 11°15'2"E
5.	Daskum	12°53'25"N, 11°2'33"E
6.	Dumbiri	12°53'26"N, 11°4'18"E

The soil total nitrogen was determined by the Kjeldahl digestion method, as described by Bremner and Mulvaney (1982). Soil organic carbon was measured using the method described by Nelson and Sommers (1982). Exchangeable Ca and Mg were determined using Atomic Absorption Spectrophotometer (AAS), while exchangeable K and Na were estimated using Flame Photometry (FP) (Jackson, 1958). The Cation Exchange Capacity (CEC) was estimated using a summation method. Saxton, *et al.* (1986) model was used in estimating soil water retention capacities (FC, PWP and Ks)

Statistical analysis

Data collected were subjected to analysis of variance (ANOVA) using R Package 'doebioresearch'. Tukey's HSD was used to separate means when significant difference was realized at 5% level of probability. Principal component analysis (PCA) and Agglomerative Hierarchical Clustering was performed on the soil properties to evaluate their respective contribution to soil variability and grouping of sampled locations according to management zones (R, 2024).

RESULTS AND DISCUSSION

Mean values of soil physical properties of the rice farms in Bursari LGA of Yobe State

Table 2 presents the mean values of some soil physical properties from the selected rice farms in LGA. Analyzing soil physical properties across different locations provides valuable insights into soil behavior and suitability for various land uses. The data presented in Table 2 include percentages of sand, silt, and clay; textural class (TC); bulk density (BD); porosity; field capacity (FC); permanent wilting point (PWP); available water (AW); and saturated hydraulic conductivity (Ks).

The physical properties did not show significant differences across the sites but a vital information can be deduced such that the soil texture varies among locations, with Daskum, Dumbiri, Gangawa, and Tabawa classified as loam (L), and Gadine and Masaba as sandy clay loam (SCL). Bulk density (BD) values range from 1.41 to 1.44 g/cm³, while porosity ranges from 45.68% to 46.84%. The observed values suggest well-structured soils with adequate pore space, facilitating root growth and water movement. FC values range from 24.30% to 25.32%, PWP from 11.90% to 14.23%, and AW from 11.07% to 13.14%. AW, calculated as the difference between FC and PWP, indicates the water available to plants. Loam soils

generally have higher AW compared to sandy clay loam soils, aligning with the presented data (Hohenbrink *et al.*, 2023). Ks values vary significantly across locations, from 0.54 to 1.08 cm/day. Higher Ks values indicate better soil permeability, which is essential for drainage and reducing erosion risks. The

variability in Ks reflects differences in soil structure and texture among the locations (Hohenbrink *et al.*, 2023). High CV% values for certain properties, such as Ks (42.46%) and silt (37.42%) suggest considerable variability, which could impact soil management practices (Table 2).

Table 2: Mean values of soil physical properties of the rice farms in Bursari LGA of Yobe State

Locations	Sand	Silt	Clay	TC	DB	Porosity	FC	PWP	AW	Ks
	%	%			gcm ⁻³		%			cm day ⁻¹
Daskum	53.04	27.13	19.83	L	1.44	45.81	24.30	12.81	11.49	0.88
Dumbiri	44.51	37.45	18.04	L	1.43	45.94	25.04	11.90	13.14	1.08
Gadine	53.48	23.77	22.75	SCL	1.41	46.63	25.02	13.95	11.07	0.57
Gangawa	51.37	29.67	18.95	L	1.44	45.68	24.35	12.44	11.90	0.98
Masaba	52.83	23.73	23.43	SCL	1.41	46.84	25.32	14.23	11.09	0.54
Tabawa	45.55	35.09	19.36	L	1.43	46.24	25.23	12.44	12.79	0.95
CV (%)	17.10	37.42	15.82		1.34	1.49	3.65	10.82	14.65	42.46
LSD (0.05)	NS	NS	NS		NS	NS	NS	NS	NS	NS

Mean values of some soil chemical properties of rice farms in Bursari LGA of Yobe State

The soil chemical properties such as pH, electrical conductivity (EC), organic carbon (OC), total nitrogen (TN), available phosphorus (AvP), cation exchange capacity (CEC), and essential cations (Ca, Mg, K, Na) were analyzed and presented in Table 3. A slightly acidic to neutral pH range is optimal for most crops, as it facilitates nutrient availability. The highest pH value observed is 7.34, which is within this optimal range (Brady and Weil, 2022). EC values around 2.5 to 2.6 dS/m suggest moderate salinity levels; it was reported for soils in KRIP which are along same floodplain and agro-ecological zones to be predominantly slightly to moderately saline (Garba *et al.*, 2022). While some crops can tolerate these levels, others may experience reduced growth. It's essential to consider

crop selection and management practices to mitigate potential salinity effects. OC content is a key indicator of soil organic matter, influencing soil structure, water retention, and nutrient supply. Values ranging from 0.40% to 0.65% indicate varying levels of organic matter, considered to be low. The highest TN value observed is 0.055%, which is relatively low. This suggests that nitrogen fertilization may be necessary to support optimal crop yields. An AvP content of 11.49 mg/kg is considered moderate, supporting adequate crop growth. Low CEC values (Esu, 1991), along with varying levels of essential cations like Ca, Mg, and K, suggest better nutrient retention and ability to respond to fertilization. (Table 3). A high coefficient of variation (CV) in soil nutrients indicates significant spatial variability in nutrient availability across the selected locations.

This variability can have implications such as that some locations may have nutrient deficiencies while others have excess levels, leading to inconsistent crop growth and yield; can cause nutrient imbalances, may suffer from soil degradation and affect plant uptake and productivity. This area may require site-specific nutrient

management rather than a uniform fertilization strategy (Aggag and Alharbi, 2022). It also related that spatial variability of farmland soil nutrients on different scales is important for farming as it forms the basis for the efficient utilization of soil nutrients and precision fertilization (Zhao *et al.*, 2019).

Table 3: Mean values of some soil chemical properties of rice farms in Bursari LGA of Yobe State

Locations	pH	EC (dS/m)	OC (%)	TN	AvP mg/kg	Ca Cmol/kg (+)	Mg	K	Na	CEC
Daskum	6.96cd	2.59	0.43	0.045ab	9.12	2.88ab	0.62	0.25	0.23	3.97ab
Dumbiri	7.34a	2.66	0.40	0.035b	10.23	3.60ab	0.78	0.18	0.25	4.83ab
Gadine	6.88cd	2.50	0.65	0.055a	7.59	2.94ab	0.70	0.29	0.26	4.18ab
Gangawa	6.83d	2.48	0.48	0.050ab	10.25	3.23ab	0.70	0.28	0.28	4.49ab
Masaba	7.03bc	2.62	0.58	0.045ab	6.75	2.62b	0.62	0.26	0.24	3.73b
Tabawa	7.20ab	2.55	0.44	0.040ab	11.49	3.92a	0.88	0.21	0.27	5.27a
CV (%)	1.09	4.12	37.94	18.14	30.55	17.74	19.52	30.99	15.65	14.64
HSD (0.05)	0.1718	NS	NS	0.0183	NS	1.2754	NS	NS	NS	1.4511

Principal Component Analysis

Principal Component Analysis (PCA) is a statistical technique used to reduce the dimensionality of datasets while preserving as much variability as possible. PCA helps identify patterns and relationships among various soil properties. The findings are presented in Tables 4 -6.

Table 4 showed that Principal Component 1 (PC1) Positive loadings were in Silt (0.2686), Available Water (AW) (0.2654), Saturated Hydraulic Conductivity (Ks) (0.2607), Phosphorus (P) (0.2538), and Calcium (Ca) (0.2411), while the negative loadings were recorded with Permanent Wilting Point (PWP) (-0.2647), Organic Carbon (OC) (-0.2488), Sand (-0.2445), and Nitrogen (N) (-0.2439). This indicated that PC1 captures variations related to soil texture and essential nutrients. A study in the Northern Guinea Savanna agro-ecology

of Nigeria found that Effective Cation Exchange Capacity (ECEC), Cation Exchange Capacity (CEC), Ca, Magnesium (Mg), OC, Total Nitrogen (TN), and pH dominated PC1, cumulatively contributing 55.38% to soil productivity variation (Omeke *et al.*, 2022).

PC2 positive loadings were in Field Capacity (FC) (0.3997), Porosity (0.2933), Zinc (Zn) (0.3836), and Copper (Cu) (0.2771) and the negative loading was with Bulk Density (BD) (-0.2878). PC2 highlights factors related to soil moisture and porosity. In the same Nigerian study, PC2 was dominated by negative BD and positive porosity, explaining 12% of the total variance (Omeke *et al.*, 2022).

PC3 positive loading was with Sodium (Na) (0.4901) and the negative loading was with electrical conductivity (EC) (-0.4859). PC3 captures the salinity aspects of the soil. A

study in the El-Fayoum Depression, Egypt, found that soil EC had significant positive correlations with N, P, Exchangeable Sodium Percentage (ESP), and clay content, indicating that EC is a crucial factor in soil salinity (Abdel-Fattah *et al.*, 2021). PC4 positive loadings was with Clay (0.2725), P (0.3194), and PWP (0.2691) and negative loading with N (-0.3850). PC4 reflects the interplay between certain soil nutrients and clay content. The Iranian Forest study using PCA found that soils with high clay content occupied different areas in the forest, indicating that clay content significantly influences soil properties and nutrient availability (Salehi and Zahedi, 2005).

PC5 positive loading was with N (0.4839) and negative with Na (-0.6399). PC5 indicates the relationship between nitrogen content and sodium presence in the soil. High Na content can adversely affect soil structure and nutrient availability, impacting N dynamics.

PC6 positive loadings was with BD (0.6186) and FC (0.5020) and negatively with: Porosity (-0.3378). PC6 emphasizes factors associated with bulk density and field capacity. The Nigerian study found that BD and porosity are critical physical properties influencing soil productivity (Omeke *et al.*, 2022).

Table 4: PC Loadings for the variables

Variables	PC1	PC2	PC3	PC4	PC5	PC6
Sand	-0.2445	-0.1861	-0.0089	0.1233	0.0837	0.1392
Silt	0.2686	0.0822	0.0186	-0.1896	-0.0312	-0.0184
Clay	-0.2585	0.1272	-0.0323	0.2725	-0.0697	0.0019
BD	0.1926	-0.2878	0.0090	0.2313	0.0281	0.6186
Porosity	-0.1867	0.2933	-0.0327	0.2639	-0.1099	-0.3378
FC	-0.0275	0.3997	-0.0263	0.1744	-0.2773	0.5020
PWP	-0.2647	0.0956	-0.0317	0.2691	-0.0782	0.0874
AW	0.2654	0.1015	0.0201	-0.1947	-0.0561	0.0537
Ks	0.2607	-0.1235	0.0215	-0.2273	-0.0287	-0.0264
pH	0.1902	0.2432	-0.2233	-0.0814	0.0714	0.1111
EC	0.0777	0.1434	-0.4859	-0.1622	-0.1280	0.2735
OC	-0.2488	0.1173	0.1685	-0.1807	0.0443	0.1125
N	-0.2439	-0.1039	0.1286	-0.3850	0.4839	0.2143
P	0.2538	-0.0481	0.1817	0.3194	0.0985	-0.0350
Ca	0.2411	0.1214	0.2000	0.1473	0.1831	-0.0496
Mg	0.2004	0.2072	0.2406	0.1818	0.2228	0.1055
K	-0.2269	-0.1682	0.2127	0.0128	-0.0969	0.1089
Na	0.0634	0.0626	0.4901	-0.2805	-0.6399	0.0299
CEC	0.2287	0.1277	0.2466	0.1410	0.1644	-0.0808

The provided Principal Component Analysis (PCA) results offer insights into the data's structure and variability distribution. The eigenvalues represent the amount of variance each principal component (PC) captures from the data. A higher eigenvalue indicates that the corresponding PC accounts for a more

significant portion of the total variance. PC1 proportion of variance = 0.5715 (57.15%) with cumulative proportion = 0.5715 (57.15%); PC2 proportion of variance = 0.2614 (26.14%) making the cumulative proportion to be 0.8328 (83.28%); PC3 proportion of variance = 0.1447 (14.47%), cumulative proportion was raised to 0.9776 (97.76%); PC4: proportion of variance = 0.0114 (1.14%), cumulative proportion became 0.9890 (98.90%); PC5 proportion of variance = 0.0110 (1.10%), cumulative proportion = 1.0000 (100%); PC6 proportion of variance = 0 (0%), cumulative proportion was still 1.0000 (100%) (Table 5).

PC1 accounts for 57.15% of the total variance, suggesting that this component captures the most significant variability in the dataset. This dominance implies that the data may be effectively represented along this single dimension, potentially simplifying analyses and interpretations. PC2 and PC3 explain 26.14% and 14.47%

of the variance, respectively. Combined with PC1, these three components account for approximately 97.76% of the total variance. This indicates that a three-dimensional representation of the data would retain most of its variability, making it suitable for further analysis. The remaining components (PC4 to PC6) contribute minimally to the total variance, with each explaining around or less than 1.14%. This minimal contribution suggests that these components may represent noise or insignificant variability in the data and could potentially be excluded from further analysis without substantial information loss. The PCA results suggest that the dataset's intrinsic dimensionality is lower than its original feature space, with the first three principal components capturing the most significant variability. This insight allows for more efficient data processing and analysis strategies (GeeksforGeeks, n.d.).

Table 5: Principal component analysis of soil properties and loading coefficient for first six principal components.

Statistics	PC1	PC2	PC3	PC4	PC5	PC6
Standard Deviation	3.6254	2.4519	1.8246	0.5133	0.5020	0
Proportion of Variance	0.5715	0.2614	0.1447	0.0114	0.0110	0
Cumulative Proportion	0.5715	0.8328	0.9776	0.9890	1.0000	1
EigenValues	13.1435	6.0118	3.3292	0.2635	0.2520	0

Scree Plot

A scree plot is a graphical representation of the eigenvalues of the covariance matrix of the original variables. The plot (Figure 2) shows a sharp drop from PC1 to PC2 and then a more gradual decline from PC3 to PC6. The "elbow" is around PC3 or PC4, meaning these components start

contributing less significant variance beyond this point.

PC1 and PC2 dominate: with PC1 having the highest eigenvalue (~12), indicating it explains the most variance in the soil properties and then PC2 with a significant eigenvalue (~6), meaning it captures additional but less variance than PC1. PC1

and PC2 should definitely be retained because they explain the majority of variance. PC3 was also considered, and can likely be discarded (Figure 2). because of the threshold of retaining components with eigenvalues >1 . PC4, PC5, and PC6 contribute minimal variance.

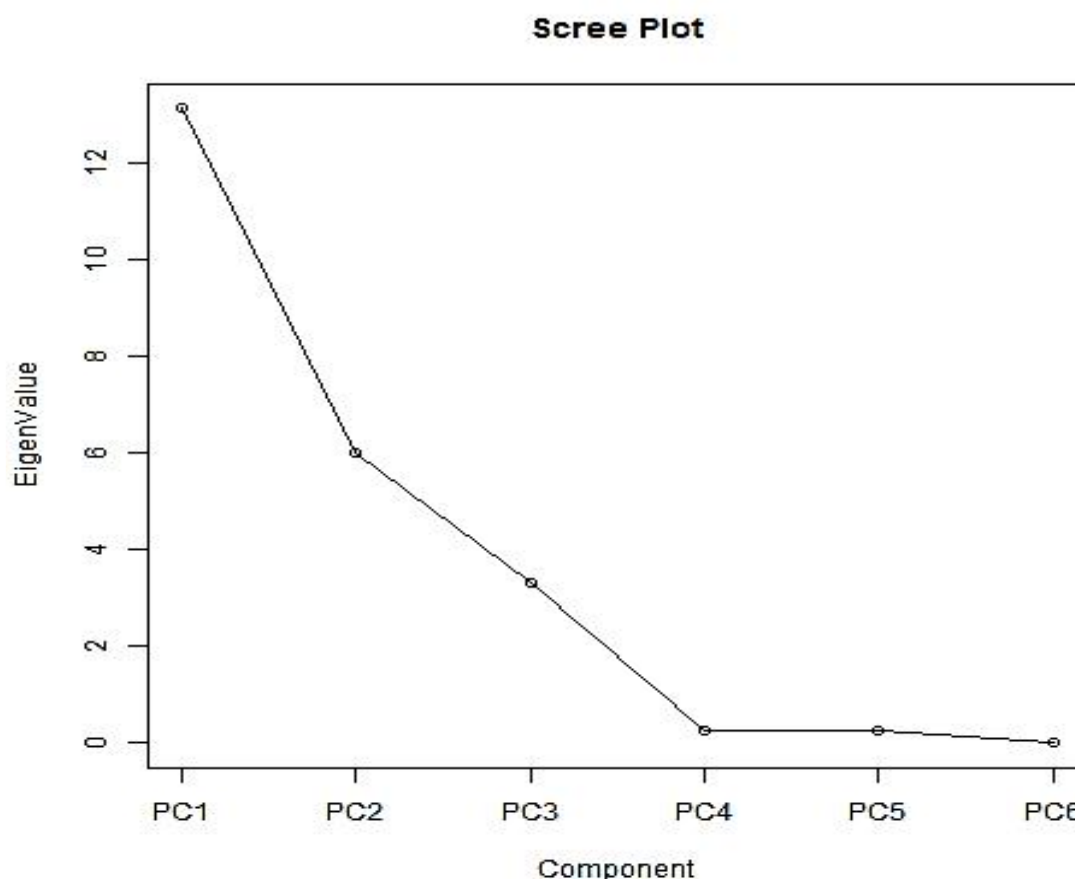


Figure 2. Scree plot of the principal components

Clustering analysis

The combined clusters of Gadine, Tabawa, Dumbiri, and Masaba is grouped with the cluster of Daskum and Gangawa at a height of about 70, indicating some slightly shared similarities. The cluster of Gadine and Tabawa is combined with the cluster of Dumbiri and Masaba at a height of approximately 50, showing that these four locations are relatively similar to each other. Daskum and Gangawa on the one hand (Figure 3). Cluster 1 comprise of Daskum and Gangwa with relatively similar pH (6.96 and 6.83), both slightly

acidic; low EC (~ 2.5 dS/m), indicating moderate salinity; moderate OC% (0.43 and 0.48), suggesting medium organic matter; similar TN and CEC values and relatively high available phosphorus (AvP) (~ 10 mg/kg) (Table 3). The management strategy for these areas will require maintenance of soil organic matter, application of phosphorus fertilizers efficiently to sustain its availability and consider gypsum application if salinity issues arise.

Cluster 2 has Gadine and Tabawa with these key soil characteristics at Gadine has the pH (6.88), while Tabawa is slightly

more alkaline (7.20), highest organic carbon (0.65%) in Gadine, indicating better soil structure and Tabawa has higher Ca and Mg content, contributing to better soil fertility and Tabawa has the highest CEC (5.27), making it more nutrient-retentive (Table 3). The management strategy for this cluster should include organic matter retention to maintain Gadine's high OC%, monitoring pH changes and ensure balanced liming to maintain optimal soil health and Tabawa's high Ca and CEC indicates good nutrient-holding capacity, so moderate fertilizer applications should be considered.

Cluster 3 comprise of Dumbiri and Masaba, both have slightly alkaline pH (7.34 and 7.03), indicating minimal acidity issues, lower organic carbon (0.40–0.58%), meaning reduced microbial activity, Masaba has the lowest available phosphorus (6.75 mg/kg), which may affect plant growth and moderate cation exchange capacity (CEC ~4.8 and 3.73), meaning fair nutrient retention (Table 3). Increase application of organic matter and phosphorus-based fertilizers in Masaba to address deficiency.

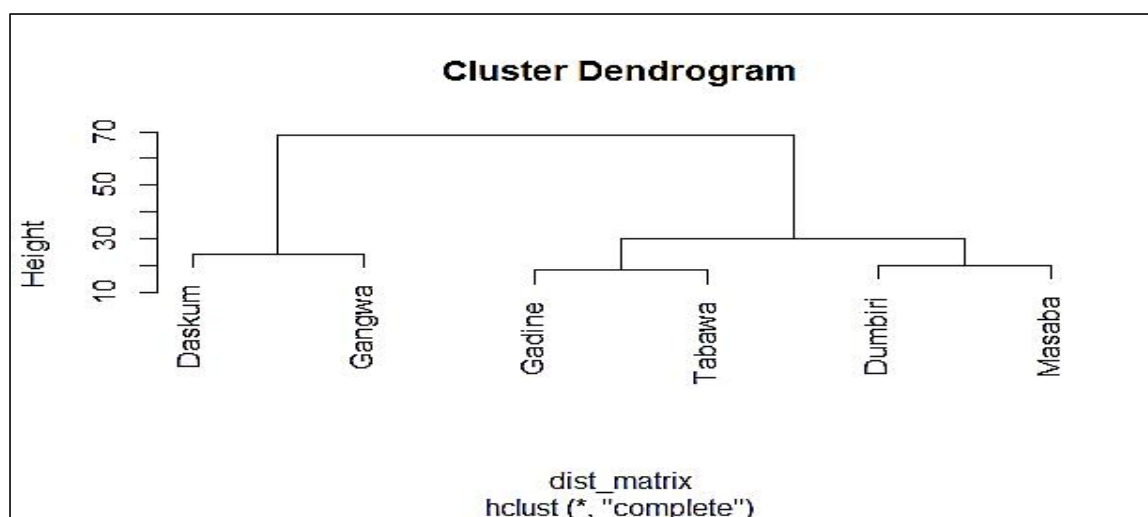


Figure 3: Dendrogram of 6 locations grouping based on 36 soil samples physico-chemical parameters measured at 0-20cm soil depth.

CONCLUSION

This study provides valuable insights into the spatial variability of soil properties in Bursari LGA, emphasizing the need for tailored soil management practices. The identification of management zones through PCA and clustering enables more efficient resource allocation, reducing input waste while enhancing soil fertility and crop productivity. The observed variability in soil texture, nutrient levels, and water retention capacity suggests that a uniform

approach to soil management may not be effective. Instead, site-specific strategies, such as targeted fertilization and irrigation, can improve rice yields and promote sustainable agricultural practices. Future research should focus on integrating remote sensing and geographic information systems (GIS) for more detailed soil mapping, ensuring precise decision-making for improved rice production in the region.

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EFFECT OF C O-INCORPORATION OF BIOCHAR AND UREA INHIBITOR FERTILIZER ON PERFORMANCE AND NUTRIENT COMPOSITION OF CUCUMBER (*Cucumis Sativus* L.) IN MALETE, KWARA STATE.

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ABSTRACT

A pot trial was conducted in the screen-house of Kwara State University, Malete, to evaluate the effect of co-incorporating biochar and urea inhibitor fertilizer on the performance, and nutrient composition of cucumber (*Cucumis sativus* L) in Malete. The study comprised of 6 treatments viz; control, NPK at 100 kgN/ha, biochar 10 t/ha supplemented with slow-release fertilizer (urea inhibitor (UI) at varying rates 70, 80, 90 and 100 Kg N/ha. Each treatment was replicated three times and arranged in a completely randomized design (CRD). Agronomic parameters taken were; vine length, stem girth, number of leaves, days to 50% flowering, and fruit weight per plant. The results showed that application of biochar 10 t/ha + UI at 100 kgN /ha significantly improved cucumber growth and yield compared to the application of NPK. Proximate study of cucumber fruit showed that after comparison with cucumber pots treated with NPK and control, the cucumber cultivated with biochar 10 t/ha + UI at 100 kgN /ha differed significantly at $P < 0.05$ in crude fiber, moisture, ash, protein, fat and carbohydrate content. Therefore, the co-incorporation of biochar 10 t/ha + UI at 100 kgN /ha was the most effective in improving the production and quality of cucumber production based on these findings.

Keywords: Biochar; cucumber, slow-release fertilizer, yield

Introduction

Cucumber (*Cucumis sativus* L.) is one of the most extensively cultivated and consumed vegetable crops worldwide (Samba, *et al.*, 2024). It is the fourth most cultivated vegetable in the world, following tomatoes, brassicas, and onions (Wehner. 2007). The rising demand of the crop is due to the awareness of its health benefits. Various scientific approaches adopted to sustain and enhance the availability of the crop. (Munir *et al.*, 2020). Cucumber (*Cucumis sativus*) is an important vegetable fruit eaten raw, grilled, or used in salads. Cucumber is a very good source of vitamins A, C, K, B6, potassium, pantothenic acid, magnesium,

phosphorus, copper and manganese (Singh *et al.*, 2020). The crop serves as the main source of vitamins; due to several factors, this crop is still poor in productivity in Nigeria (Olowoake *et al.*, 2021). Cucumber is a very useful ingredient in the preparation of salad and liquor drinks in canteens, hotels and homes as well as for its medicinal and cosmetic value (Muhammad *et al.*, 2023). Soil productivity in sub-Saharan Africa is severely constrained, with 65% of agricultural land degraded due to low nutrient application, soil erosion, and acidification. Fragile soils with low organic

matter, low pH, and high phosphorus fixation are exacerbated by unsustainable practices like overgrazing, deforestation, and lack of fertilizer use (Zingore *et al.*, 2015). The use of organic fertilizers as a cultural means of solving soil fertility problems over the years has the potential of reducing the use of chemical fertilizers which is often limited in many developing countries by its high cost and scarcity (AdeOluwa *et al.*, 2021).

Sustainable practices are imperative, leading to the exploration of innovative approaches that optimize crop production. One such approach involves the synergistic use of biochar and slow-release fertilizers, which has shown promise in enhancing soil fertility and nutrient availability (Cayuela *et al.*, 2014). Biochar, a carbon-rich material derived from the pyrolysis of organic matter, has gained attention for its ability to improve soil structure, water retention, and nutrient availability (Jeffery *et al.*, 2011). The porous structure of biochar not only provides a habitat for beneficial microorganisms but also acts as a reservoir for water and nutrients, facilitating their slow release into the soil (Lehmann *et al.*, 2011). Biochar addition to the soil may improve the physicochemical properties of soil like bulk density, water holding capacity, nutrient retention, soil pH, and cation exchange capacity resulting in beneficial effects on plant growth (Olowoake and Akinriola, 2024). Another slow-release fertilizer that is known to be very effective in supplying nutrients is urea

inhibitor. N-(n-butyl) thiophosphoric triamide (NBPT) is a urease inhibitor which can reduce nitrogen loss via ammonia volatilization from urea and dicyandiamide. Urease diffusion time and decrease the concentration of ammonia present near the soil surface. It is used as a fertilizer additive in agricultural applications. Once applied to the soil, NBPT can reduce urease activity, slow down the hydrolysis process of urease decomposition, prolong urease diffusion time and decrease the concentration of ammonia present near the soil surface (Olowoake *et al.*, 2024). Studies focusing on improving the yield of cucumber and restoring the fertility status of soils in Nigeria with biochar and slow-release fertilizer are limited. Thus, this study aims to investigate the effect of co-incorporation of biochar and slow-release fertilizer on the growth, yield, and nutrient composition of cucumber.

MATERIALS AND METHODS

Pot experiment was carried out at Kwara State University, faculty of Agriculture Screen House, (Latitude 8° 71'N and Longitude 4° 44'E) Malete. Eighteen pots were filled with 25 kg of soil. The treatments used were control, Biochar10t/ha + Urea Inhibitor at 70, 80, 90, 100 kgN/ha and NPK fertilizer was applied at the rate of 100 kgN/ha. The chemical composition of biochar made from bamboo used in the study is summarized in Table 1.

Table 1: Chemical composition of Biochar

Treatment	Nutrient (%)						
	N	P	K	Org C	Ca	Mg	Na
Biochar	0.15	0.06	0.10	5.1	0.40	0.20	0.50
Urea Inhibitor	42.0	Nd	Nd	Nd	Nd	Nd	Nd

Legend: Nd- not determine

The biochar was applied two weeks before planting while urea inhibitor was applied two weeks after planting. Cucumber seed were sown in a pot and was watered immediately. The treatments were arranged in a completely randomized design (CRD) with four replicates. The cucumber plants were staked on reaching a height of about 50 cm. Watering and weeding were carried out throughout the experimental period.

Soil Sampling and Analytical Methods

Before the experiment and again after harvest, a pre-cropping chemical analysis of the experimental soil utilized in the screen-house was conducted to ascertain the soil's residual effects. Soil samples from the top soil (0-15cm) were collected from the experimental site, bulked, air dried and screened with a 2mm sieve. using a soil auger. The samples were air-dried and sieved with a 2mm sieve, then analyzed to determine the physical and chemical properties of the samples before and after the experiment. Soil pH was measured in 0.01M CaCl₂, and the particle size distribution was ascertained using the hydrometer method (Bouyoucos, 1962). The Walkey and Black methods, as outlined by Sholeye *et al.* (2021), and the micro-Kjeldahl digestion method (Ever and Hughes, 2002) were used to assess the soil organic carbon and total N, respectively. The method of Bray and Kurtz, (1945) was used to extract the available P, and flame photometry was used to measure the concentrations of exchangeable bases (Ca, Mg, K, and Na) using neutral 1M NH₄OAc at a soil solution ratio of 10. Magnesium and other micronutrients were determined using an atomic absorption spectrophotometer (AAS). An atomic absorption spectrophotometer was used to

assess the micronutrients after they were extracted using 0.1 EDTA (Table 2).

Proximate Analysis

Proximate analysis was conducted on cucumber after harvest. After harvesting, cucumber samples were taken from each treatment plant and the control. In an oven set at 65°C, the samples were dried until their weight remained constant. A 0.5 mm sieve was used to filter the dried samples before they were ground separately using a Wiley mill for tissue analysis. The following proximate analysis were determined; Ash (%), crude protein (%), crude fiber (%), Fat(%), Moisture (%) and Carbohydrate (%) using the technique mentioned in Chihoub *et al.* (2019).

Data Collection and Analysis

Data on growth and yield parameters collected include; vine length, vine girth, number of leaves, number of branches, number of days to 50% flowering, fruit diameter and weight of fruit/plant. The data were subjected to analysis of variance and differences among means separated using Duncan's Multiple Range Test.

Results and Discussion

The results of the physical and chemical properties of the soil used for the experiment are presented in Table 2. The soil was slightly acidic and low in total N, P, Ca, Mg and adequate in K. (Aduloju, (2004), Adeoye, (1986) and Olowoake *et al.*, 2021) The low soil contents for the major nutrients signify the need for improvement for optimal cucumber performance.

Cucumber Growth Parameters as affected by biochar and urea inhibitor fertilizer

The length of the vine, vine girth and the number of leaves of the cucumber plants

increased significantly ($P<0.05$) when biochar and urea inhibitor fertilizer were applied. The length of the cucumber vine increased significantly ($P<0.05$) when NPK was applied at 100 kgN/ha. Application of NPK at 100 kg N/ha produced the longest vine (210.3 cm) and the control produced the shortest vine (59.0 cm). In the pot treated with NPK, biochar and urea inhibitor the maximum vine girth of 11.4 cm was observed at biochar 10t/ha +UI at 100 kgN/ha and the control had the shortest vine girth of 9.60 cm. The difference in vine girth between NPK, biochar 10t/ha +UI at 70, 80 and 90 kgN/ha was not significant. Among the treatments, the number of leaves per plant was significantly different ($P<0.05$). Application of biochar 10t/ha +UI at 100 kgN/ha produced

Table 2: Physico-chemical properties of experimental soil

Parameters	Soil test value
pH (H ₂ O)	6.7
Org.C (%)	7.9
Total N (%)	0.82
P (mg/kg)	2.77
Exchangeable bases (cmol/kg)	
Mg	0.78
Ca	0.58
Na	0.43
K	0.28
Extractable micronutrients (mg/kg)	
Cu	0.90
Fe	107
Mn	106
Zn	7.0
Sand (%)	82.0
Silt (%)	15.0
Clay (%)	3.0
Textural class	Loamy sand

the highest number of leaves (22.0) followed by NPK (20.5), the control resulted in the lowest number of leaves per plant (17.5). The high values of vine length of cucumber grown in the pot treated with NPK over biochar and urea inhibitor might be as a result of its quicker release of N, P and K which are the major nutrients required by crop for vegetative growth, seed and root development. This observation is in line with the findings of Olowoake, (2014), that mineral fertilizers quickly release their nutrients to the soil.

Similar findings were reported by Kuranga. (2014), who observed that the application of NPK increased the vine length of cucumber which is an indication that the nutrients taken up by the plants were well utilized in cell multiplication, amino acid synthesis and energy formation hence increase in photosynthesis. Biochar 10t/ha +UI at 100 kgN/ha provided the paramount results with regard to number of leaves, and vine girth. The high values of vine girth and number of leaves of cucumber in

pots treated with biochar and a urea inhibitor are likely due to improved nitrogen use efficiency, enhanced nutrient retention in the potting medium, reduced nitrogen loss (leaching/volatilization), and access nitrogen throughout the growing season (Shofiati *et al.*, 2025).

Treatment	Days to 50% flowering	Fruit weight (g)	biochar with urea inhibitor enables plants to
Control	29.0c	104.1c	
Biochar 10 t/ha +UI @ 70 kgN/ha	27.0b	110.8b	
retention in the potting medium, reduced nitrogen loss (leaching/volatilization), and access nitrogen throughout the growing season (Shofiati <i>et al.</i> , 2025).			
Treatment	Vine length (cm)	Vine girth (cm)	Number of leaves
Control	59.0b	9.60c	17.5c
Biochar 10 t/ha +UI @ 70 kgN/ha	132.0ab	10.4b	18.5bc
Biochar 10 t/ha +UI @ 80 kgN/ha	127.7b	10.4b	18.0bc
Biochar 10 t/ha +UI @ 90 kgN/ha	137.3ab	10.2b	20.0b
Biochar 10 t/ha +UI @ 100 kgN/ha	135.0ab	11.4a	22.0a
NPK @ 100 kgN/ha	210.3a	10.6b	20.5b
improved soil structure providing a better			

Table 3. Effect of biochar and urea inhibitor on growth parameters of *Cucumis sativus*

Means having the same letter along the columns indicate no significant difference using Duncan Multiple Range Test at 5% probability level

Legend

UI – Urea Inhibitor

Cucumber yield parameters as affected by biochar and urea inhibitor fertilizer

Table 4 shows the results of number of days prior to 50 percent flowering and fruit weight. The study indicated that the effects of biochar and urea inhibitor fertilizer varied significantly ($p<0.05$) between the treatments. The yield component values obtained from biochar 10t/ha +UI at 100 kgN/ha were significantly higher than the control, NPK, and biochar 10t/ha +UI at 70, 80 and 90 kgN/ha in number of days before 50 percent flowering and fruit weight. The significant effect of biochar and urea inhibitor on cucumber yield components is primarily due to improved nutrient use efficiency, reduced nitrogen leaching, and enhanced soil physical properties. Biochar increases nutrient retention and improves pH, while urea inhibitors slow the conversion of nitrogen, ensuring a sustained supply for crop uptake (Osaji *et al.*, 2017; Ayito *et al.*, 2024). These findings align with those of Zhang *et al.* (2025) who reported that biochar coated urea treatments led to increased nitrogen absorption by plants, improving growth and yield.

Table 4. Effect of biochar and urea inhibitor on yield parameters of *Cucumis sativus*

Biochar 10 t/ha +UI @ 80 kgN/ha	26.0b	110.2b
Biochar 10 t/ha +UI @ 90 kgN/ha	26.0b	118.9b
Biochar 10 t/ha +UI @ 100 kgN/ha	25.0a	280.3a
NPK @ 100 kgN/ha	28.0b	145.5b

Means having the same letter along the columns indicate no significant difference using Duncan Multiple Range Test at 5% probability level

UI – Urea Inhibitor

Table 5. Proximate results of *Cucumis sativus* grown with biochar and urea inhibitor

Treatment	% -----						
	Ash	Moisture content	Crude protein	Crude fibre	Crude fat	Dry matter	Carbohydrate
Control	1.03e	91.7d	1.5d	1.1e	0.4e	5.24e	0.75e
Biochar 10 t/ha +UI @ 70 kgN/ha	1.06d	94.6b	1.88b	1.05e	0.46d	5.4d	1.01b
Biochar 10 t/ha +UI @ 80 kgN/ha	1.17b	94.1b	1.53d	1.25d	0.5c	5.9b	0.92c
Biochar 10 t/ha +UI @ 90 kgN/ha	1.12c	94.3b	1.7c	1.34c	0.51c	5.0f	0.43f
Biochar 10 t/ha +UI @ 100 kgN/ha	1.21a	95.1a	2.4a	1.82a	0.84a	8.7a	1.49a
NPK @ 100 kgN/ha	1.1c	93.3c	1.53d	1.59b	0.55b	5.67c	0.82d

Means having the same letter along the columns indicate no significant difference using Duncan Multiple Range Test at 5% probability level

UI – Urea Inhibitor

Proximate Analysis

Table 5 shows the proximate values of cucumber plants grown with biochar and urea inhibitor. In the cucumber plant grown with all the treatments, it showed that moisture content had the highest proximate content compared to ash, protein, crude fiber, fat, dry matter and carbohydrate. Moisture is very similar among all treatments except control and

NPK. The application of biochar 10t/ha + UI at 100 kgN/ha holds a positive impact on proximate cucumber analysis. Compared to control and NPK, biochar 10t/ha +UI at 100 kgN/ha application improves cucumber nutrient composition, including increased protein, fat, and fiber, by enhancing nutrient availability and reducing nitrogen loss. This finding aligns with studies demonstrating that biochar,

particularly when combined with fertilizers or organic amendments,
Conclusion

The application of biochar 10t/ha +urea inhibitor at 100 kgN/ha fertilizer is an effective agronomic practice for improving cucumber growth, yield, and nutrient quality than NPK. Adoption of this integrated soil fertility management approach is recommended for sustainable cucumber production, particularly in soils with low fertility status. This study suggest that integrating biochar with slow-release fertilizer is capable of improving productivity while potentially reducing excessive fertilizer application and environmental degradation. Further studies under different agro-ecological zones and field conditions are recommended to validate these findings and optimize application rates for maximum economic returns.

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EFFECT OF AGROFORESTRY SYSTEMS ON SOIL PROPERTIES AND CARBON SEQUESTRATION IN SUB-HUMID SAVANNAH AGRO-ECOLOGICAL ZONE OF ZARIA, KADUNA STATE, NIGERIA

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ABSTRACT

Soil carbon sequestration (SOC) is a vital process for mitigating climate change and enhancing soil fertility. This study assessed the effects of three agroforestry systems on SOC and soil properties in Zaria, Nigeria, across two soil depths (0–15 cm and 15–30 cm). Soil samples were analysed for physical and chemical properties. Data were analysed for ANOVA to determine the influence of agroforestry systems on soil properties and carbon stock and Multiple regression models were applied to evaluate the significance and influence of each variable on CS. The apiculture system demonstrated the highest SOC content (11.57 g/kg) and AvP levels (5.94 mg/kg), attributed to organic matter recycling and nutrient cycling. Agrosilviculture recorded the highest clay (195 g/kg) and silt (517.5 g/kg) contents, promoting better soil structure and water retention, while silvopastoral systems had higher sand content (607.5 g/kg). Surface soils had significantly higher SOC, AvP, magnesium, and calcium compared to subsoils, reflecting greater organic matter accumulation and reduced leaching. Bulk density, TN, and pH were not significantly influenced by agroforestry systems or soil depth. These results highlight the effectiveness of agroforestry systems, particularly apiculture, in enhancing SOC sequestration and improving soil health in semi-arid regions. This study recommended the adoption of Apiculture Systems for their high potential in SOC sequestration and nutrient recycling and the implementation of erosion control and soil conservation practices in silvopastoral systems to mitigate the effects of high sand content.

Keyword: Soil Carbon Sequestration, Agroforestry Systems, Water Conservation, Nutrient Cycling, Sustainable Agriculture

Introduction

Soil carbon refers to the carbon stored in global soils, encompassing both organic and inorganic forms. It plays a pivotal role in the global carbon cycle, acting as a major carbon sink critical for biogeochemistry, climate change

mitigation, and climate modelling. Soils store approximately three

times more carbon than the atmosphere, making them indispensable for a healthy global carbon cycle. Soil carbon sequestration, as defined by Lal (2010), involves the long-term storage of carbon

dioxide (CO₂) or other carbon forms in soils, vegetation, oceans, and geologic formations. This process mitigates greenhouse gas accumulation and combats global warming. Soil organic carbon (SOC), a key component of soil organic matter (SOM), is integral to soil fertility and ecosystem functioning. SOC storage is influenced by climatic factors, vegetation, soil texture, and management practices. High soil temperatures, for instance, accelerate organic matter decomposition, reducing SOC levels (Conant *et al.*, 2011). Agroforestry, the integration of trees and shrubs within agricultural landscapes, emerges as a viable strategy for enhancing SOC sequestration. It balances productivity with sustainable ecosystem services, including improved soil health, biodiversity, and carbon storage. Trees act as carbon sinks, sequestering atmospheric CO₂ through photosynthesis and storing it in biomass and soil (Nair *et al.*, 2009; Chauhan *et al.*, 2012).

SOC forms a critical link between soil health and climate regulation. It influences microbial activity, water retention, and nutrient cycling. Factors such as soil temperature and moisture govern SOC storage, while decomposition releases carbon back into the atmosphere. Kell (2011) emphasized that plant-derived carbon from photosynthesis is retained in plant tissues or transferred to the soil as litter. SOM, comprising a mix of organic compounds and microorganisms, dictates the duration and stability of SOC in the soil. Healthy soils underpin local food production, biodiversity, and ecosystem services, aligning with the Sustainable Development Goals (SDGs). Unsustainable practices have degraded nearly half of global soils, depleting their organic carbon stocks (FAO, 2015). Restoring SOM

content is critical for reversing this trend. Agroforestry aligns with the Convention on Biological Diversity and the One Health concept by promoting sustainable land management practices.

Agroforestry offers a sustainable pathway to enhance SOC sequestration, mitigate climate change, and promote land restoration. While studies across Africa underscore its potential, further research in Zaria is essential to harness its full benefits. By leveraging agroforestry practices, Zaria can build resilient agricultural systems that support both environmental and socio-economic sustainability. Thus, this study aims to evaluate the SOC sequestration potential of various agroforestry systems in Zaria.

Methodology

Study Area

The research was carried out at National Animal Production Research Institute (NAPRI) Shika, Giwa local government area of Kaduna, Nigeria on Latitude 11° 09'525''N; Longitude 7° 38'133'' and 7°38'164''E at an elevation of 667.4m above sea level and Savanna Forestry Research station, Samaru. The areas are situated in the Northern Guinea Savannah zone of Nigeria with unimodal annual rainfall of about 1011±161mm for long time average, concentrated almost entirely in 6-7 months (April/May to September/October) and mean daily minimum and maximum temperatures of between 15 °C and 38°C.

Experimental Treatments

Two agroforestry systems namely Agrosilviculture and sivilpastoral from NAPRI and one (Apiculture) from Forestry Research Station Samaru, were used for the study. The Agrosilviculture consist of *Leucena leucephala* and *Gliricidia sepium*. In the site for Silvipastoral, tress such as

Gmelina arborea and *Parkia biglobosa* and pasture such as *Arachis pintoi* and *Cynodon dactylon* are grown. In the area where Apicultural practices are carried in addition to bee Keeping, trees such as *Azadirachta indica* and *Adansonia digitata* are found there.

Soil Sampling and Measurements

Soil samples was collected from each location by simple random technique (Petersen and Calvin, 1986). Soil samples was collected from two depths: 0-15 cm and 15-30 cm using a soil auger. Three soil samples per plot was collected. The samples collected was oven dried, sieved through 2 mm mesh for soil properties determination. Also, undisturbed soil cores were also collected from each location. The soil cores were kept air-tight and taken to the laboratory for determinations.

Soil bulk density was determined as the ratio of oven-dry soil mass to its volume, following the method described by Blake and Hartge (1986). Soil texture was determined using the hydrometer method (Gee and Or, 2002) by dispersing the soil with sodium hexametaphosphate (NaPO_3). Soil pH was measured in a soil suspension prepared in a 1:2.5 (w/v) soil-to-water ratio using a pH meter. Organic matter content was determined using the Walkley and Black (1934) wet oxidation method, and total nitrogen was measured using the Kjeldahl procedure as described by Bremner and Mulvaney (1982). Available phosphorus was extracted using the method described by Brady and Weil (2010). Cation exchange capacity (CEC) and exchangeable bases (Ca, Mg, K, and Na) were determined by leaching the soil with 1N ammonium acetate (NH_4OAc) at pH 7.0. Exchangeable Ca and Mg were

measured using an atomic absorption spectrophotometer, while Na and K were analysed using a flame photometer (Chapman, 1965). Cation exchange capacity was estimated titrimetrically by distilling ammonium displaced by sodium from a NaCl solution (Chapman, 1965).

Statistical Analysis

The results from the laboratory analyses were subjected to Analysis of Variance (ANOVA), and significant differences among treatments were separated using Tukey's post hoc test at a 0.05 probability level. Additionally, the relationships between soil properties with carbon stock were evaluated using a multiple liner regression. All analyses were conducted using the R statistical software package.

Results and Discussion

Impact of Agroforestry Systems on Soil Physical Properties in Zaria

The findings in Table 1 highlight how various agroforestry systems influence soil physical properties differently in the Zaria region.

Bulk Density (BD)

Bulk density, a measure of soil compaction, was not significantly influenced by either the agroforestry system or soil depth ($\text{Pr}(> F) = \text{NS}$). However, Agrisilviculture showed slightly lower BD, indicating potentially better soil structure and porosity, likely due to the inclusion of deep-rooted species such as *Leucaena leucocephala* and *Gliricidia sepium*. These species are known to improve soil structure by breaking up compacted layers and enhancing organic matter. Depth did not significantly affect bulk density ($\text{Pr}(> F) = \text{NS}$), although surface soils showed slightly higher bulk density (1.54 g/cm^3) compared to sub-

Table 1: Impact different agroforestry systems within Zaria on soil physical properties

	BD (g/cm ³)	Clay (g/kg)	Silt (g/kg)	Sand (g/kg)
Agroforestry				
Apiculture	1.51	147.50 ^{ab}	367.50 ^b	485.00 ^a
Silvipastoral	1.50	125.00 ^b	267.50 ^b	607.50 ^a
Agrisilviculture	1.42	195.00 ^a	517.50 ^a	287.50 ^b
Pr(>F)	NS	***	***	***
Depth				
Surface	1.54	140.00	395.00	465.00
Sub surface	1.42	171.67	373.33	455.00
Pr(>F)	NS	NS	NS	NS

BD: Bulk density, NS: Nonsignificant, ***: highly Significant

surface soils (1.42 g/cm³), which might result from compaction due to human and livestock activity.

Clay Content

Clay content varied significantly among systems (Pr(>F) = ***), agrisilviculture recorded the highest clay content (195 g/kg), suggesting that its tree species might contribute to better soil aggregation and reduced erosion, helping retain fine soil particles. Higher clay content in agrisilviculture may also be attributed to operation such as tillage, which can enhance soil aggregation and promote finer particles such as clay moving downward in the soil profile. This is because regular cultivation has been reported to help retain finer particles in the topsoil, increasing clay concentration (Ya'u *et al.*, 2022). Silvopastoral systems, with species such as *Gmelina arborea* and *Parkia biglobosa*, showed the lowest clay content (125 g/kg), likely due to pasture components (*Arachis pintoii* and *Cynodon dactylon*) that may not protect the soil surface as effectively. More so, lower clay content observed in Silvopastoral systems may be due to animal trampling exposing the soil surface to more disturbance, leading to soil compaction and reduced organic matter, making finer particles like clay more prone to erosion. The physical activity of grazing animals

has also been reported to facilitate the movement of clay particles away from the surface, resulting in lower clay content (Donovan and Monaghan, 2021). Depth did not significantly affect clay content of the soil. However, sub-surface soils had marginally higher clay content (171.67 g/kg) compared to surface soils (140 g/kg), consistent with clay leaching processes in soil profiles.

Silt Content

Silt content was also significantly different across systems (Pr(>F) = ***). Agrosilviculture had the highest silt content (517.5 g/kg), which might contribute to improved water retention and nutrient availability, supporting plant growth. Both apiculture and silvopastoral systems showed lower silt content (367.5 g/kg and 267.5 g/kg, respectively), possibly due to higher sand proportions that could indicate more weathered soils or limited protection against erosion. Higher vegetation cover in agrisilviculture may have reduced the impact of rain and wind on the soil surface, thereby protecting silt particles from being washed or blown away (Arrington, 2021). There was no significant difference in silt content with depth. However, surface soils had marginally higher silt content (395.00 g/kg) compared to sub-surface soils (373.33

g/kg), reflect the composition of the underlying parent material.

Sand Content

Sand content was significantly influenced by the agroforestry system ($\text{Pr(>F)} = ***$). Silvopastoral systems showed the highest sand content (607.5 g/kg), suggesting that these systems may result in coarser soils with lower water-holding capacity. This could be attributed to less effective litter cover or higher susceptibility to soil erosion. Conversely, agrisilviculture recorded the lowest sand content (287.5 g/kg), indicative of better soil texture

balance, likely due to increased organic matter inputs from tree litter and root activity. The higher sand content in Silvopastoral systems could be due to the combination of grazing-induced soil disturbance and reduced vegetation cover leading to erosion, lower organic matter, and the natural preference for coarser soils in pastures (Yang *et al.*, 2023).

Impact of Agroforestry Systems on Soil Chemical Properties in Zaria

Table 2 outlines the effects of different agroforestry systems and soil depth on key soil chemical properties

Table 2: Impact different agroforestry systems within Zaria on soil chemical properties

	TN	pH	OC	Na	Mg	K	EA	CEC	Ca	AvP
Agroforestry System										
Apiculture	1.74	6.09	11.57	0.49	1.39	0.48	1.93	6.68	4.78	5.94 ^a
Agrisilviculture	1.37	6.02	7.54	0.53	1.55	0.32	1.75	6.71	5.38	3.52 ^b
Silvipastoral	0.75	5.93	9.31	0.50	1.66	0.51	1.43	6.96	5.71	3.64 ^b
Pr(>F)	NS	NS	NS	NS	NS	NS	NS	NS	NS	**
Depth										
Surface Soil	0.75	6.09	11.75 ^a	0.51	1.64 ^a	0.52	1.77	7.18	5.67 ^a	5.20 ^a
Sub soil	1.82	5.94	7.20 ^b	0.50	1.43 ^b	0.36	1.63	6.38	4.91 ^b	3.53 ^b
Pr(>F)	NS	NS	*	NS	*	NS	NS	NS	*	*

NS: non-significant, * Significant difference

TN: total nitrogen, OC: organic carbon, Na: sodium, Mg: magnesium, K: potassium, EA: exchangeable acidity, CEC: cation exchange capacity, Ca: calcium, AvP: available phosphorus.

Available phosphorus

Among the agroforestry systems, Apiculture had the highest available phosphorus (AvP) content (5.94 mg/kg, $\text{Pr(>F)} = **$), significantly higher than that of Agrisilviculture (3.52 mg/kg) and Silvopastoral (3.64 mg/kg). This could be attributed to the presence of *Azadirachta indica* and *Adansonia digitata*, which might promote phosphorus availability through organic matter decomposition and nutrient cycling. In contrast,

agrosilviculture and silvipastoral systems showed relatively lower AvP, possibly due to competition between trees and crops for phosphorus. The phosphorus availability in Apiculture may be attributed to the management of organic matter and nutrient recycling from beekeeping activities (Leakey, 2012). In contrast, the lower AvP in Agrosilviculture and Silvopastoral may limit nutrient availability and, consequently, plant productivity (Rutto *et al.*, 2009). Similarly, AvP was significantly higher in

surface soils (5.20 mg/kg, $\text{Pr}(> F) = *$) than sub-soils (3.53 mg/kg). This is likely due to limited phosphorus mobility in soil, resulting in higher concentrations near the surface. Higher AvP in the surface soils could be due to the availability of more organic matter from accumulation of plant litter, decomposing roots, and microbial activity (Aliyu 2023). This is because as organic matter decomposes, it releases phosphorus, which increases the availability of phosphorus in the surface layer (Jindo *et al.*, 2023). More so, in agricultural systems, phosphorus fertilizers and organic amendments (such as manure) are generally applied to the soil surface. This practice leads to a buildup of available phosphorus in the topsoil, while subsoils remain relatively deficient (Johan *et al.*, 2021).

Organic Carbon (OC)

There was no significance difference in organic carbon between the agroforestry systems, however, apiculture systems has the highest organic carbon content (11.57 g/kg), reflecting higher organic matter inputs, likely from tree litter and the protective canopy of *Azadirachta indica* and *Adansonia digitata*, while Agrisilviculture had the lowest OC (7.54 g/kg), potentially due to lower organic matter input or faster decomposition rates in this system. OC content was significantly higher in surface soil (11.75 g/kg) compared to sub-soil (7.20 g/kg, $\text{Pr}(> F) = *$). This result aligns with typical soil profiles, where organic matter accumulates at the surface due to litterfall and microbial activity. The higher organic carbon in the surface soil could be attributed to the accumulation of plant litter and root biomass, which decompose and contribute to organic matter formation (Lal, 2004). This supports the conclusion that

surface soils in agroforestry systems play a key role in carbon sequestration and nutrient cycling (Mutuo *et al.*, 2005).

Total nitrogen and pH

There was no significance difference ($P > 0.05$) in total nitrogen between the agroforestry systems and soil depth, however, Apiculture has the highest total nitrogen while silvipastoral had the least. More so, sub soil had higher total nitrogen compared to surface soils. Similarly, There was no significance difference in soil pH between the agroforestry systems and between soil depth. The agroforestry systems are located on soils derived from the same parent material and subject to similar climatic conditions, intrinsic pH levels are less likely to vary significantly.

Exchangeable bases

There was no significance difference in exchangeable bases; sodium (Na), magnesium (Mg), potassium (K) and calcium (Ca) between the agroforestry systems and between soil depth except Mg and Ca which were higher in surface soil and lower in sub soil. Surface soil had significantly higher values for Mg (1.64 cmol/kg) and Ca (5.67 cmol/kg) compared to the subsoil, where Mg (1.43 cmol/kg) and Ca (4.91 cmol/kg) contents were lower. The higher magnesium and calcium content reported in the surface soil compared to the sub soil shows that agroforestry systems helps to reduce nutrient leaching compared to monocropping systems, thereby maintaining higher nutrient availability in the upper soil layers (Nair *et al.*, 2009). Additionally Jimoh and Aliyu (2021) reported high calcium in the surface soil could be due to calcium deposition from plant residues or higher microbial activity facilitating nutrient release in the topsoil.

Cation exchange capacity

There was no significance difference in cation exchange capacity (CEC) between the agro forestry systems and between soil depth. However, silvopastoral systems showed the highest CEC (6.96 cmol/kg), indicating improved nutrient retention capacity, possibly due to the interplay between tree roots of *Gmelina arborea*, *Parkia biglobosa*, and pasture components from *Arachis pintoi* and *Cynodon dactylon*. This system may benefit from additional organic matter inputs to enhance phosphorus availability.

Impact Different Agroforestry Systems within Zaria on Soil Carbon Sequestration

The carbon sequestration (carbon stock) of different agroforestry systems within two soil depths is shown in Figure 1. The results showed that apiculture (36, 036.98 g/ha) showed higher carbon stock compared to silvopastoral (28, 102.36 g/ha) and agrisilviculture (24, 298.86 g/ha) which had lower carbon stock. Higher carbon stock in Apiculture agroforestry system may be attributed to the management of organic matter and nutrient recycling from beekeeping activities (Leakey, 2012) resulting into higher organic element availability.

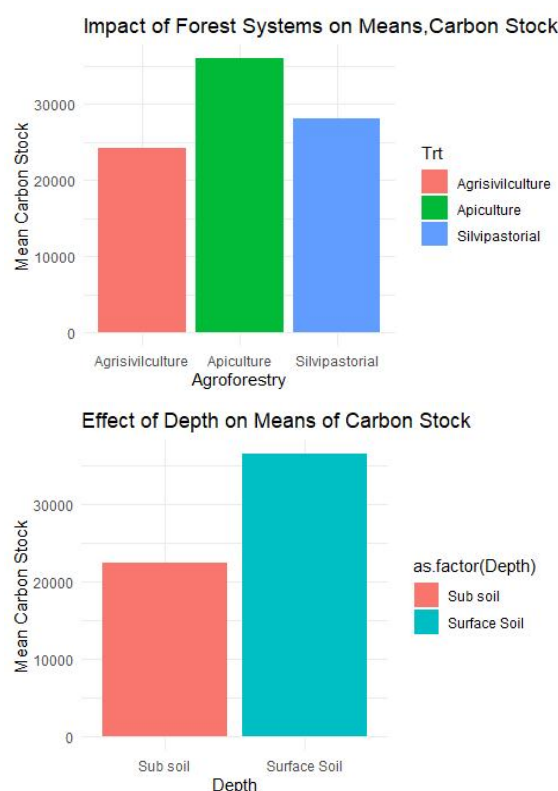


Figure 1: Impact of (a) agroforestry systems and (b) soil depths on soil carbon stock

The results on depth showed that surface soil has a significantly higher mean carbon stock, approximately 36,559.69 kg/ha, compared to subsoil, which has a mean carbon stock of around 22,399.11 kg/ha. This suggests that carbon accumulation is

more pronounced in the surface layer of the soil, likely due to higher organic matter input and microbial activity associated with the upper soil layer. Several research have shown that surface soils are often enriched with organic carbon because they receive

most organic matter inputs from decaying plant material, root biomass, and microbial activity (Lal, 2004; Paustian *et al.*, 2016). This is because the concentration of organic matter in the top layer of soil is essential for promoting soil structure and fertility (Lehmann and Kleber, 2015). Furthermore, the microbial community is more active in the surface layer, facilitating the decomposition of organic matter and subsequent carbon sequestration (Six *et al.*, 2006). The observed decline in carbon stock in the subsoil can be attributed to

several factors, including lower organic matter inputs and reduced microbial activity compared to surface soils (Kätterer *et al.*, 2011). This is because strategies such as cover cropping, reduced tillage, and the application of organic amendments can significantly improve soil carbon stocks and enhance overall soil health (Jimoh and Aliyu, 2024).

Influence of Soil Physical and Chemical Properties on Carbon Sequestration

The relationship between CS and soil properties is presented in Table 3.

Table 3: Influence of Soil Physical and Chemical Properties on Carbon Sequestration

term	estimate	std.error	statistic	p.value
(Intercept)	-40970.770	18709.569	-2.190	0.045
TN	892.765	411.805	2.168	0.047
BD	25040.488	5516.429	4.539	0.000
OC	2947.379	214.298	13.754	0.000
AvP	-478.341	396.570	-1.206	0.246
Silt	5.408	5.429	0.996	0.335
pH	1180.728	3806.254	0.310	0.761
Na	6886.296	8200.171	0.840	0.414
CEC	-910.872	762.112	-1.195	0.251

Total Nitrogen has a positive and statistically significant ($p = 0.0467$) effect on CS. The significance of nitrogen in soil carbon dynamics is demonstrated by the fact that CS rises by about 892.76 units for every unit increase in TN. Nitrogen promotes microbial activity and accelerates the breakdown of organic matter into stable carbon molecules, which is consistent with other research (Lal, 2010; Bossio *et al.*, 2020). There was a large and statistically significant positive correlation. There was a strong and highly significant positive relationship with CS ($p = 0.0004$). A unit increase in BD resulted in an estimated 25,040.49-unit increase in CS. By decreasing oxygen availability and delaying the breakdown of organic matter, BD can improve carbon storage (Six *et al.*, 2002). However, too much BD might negatively impact root penetration and soil aeration. With an estimate of 2,947.38, Organic Carbon was the most significant predictor of CS ($p = 6.56 \times 10^{-10}$). Many studies have found that soil organic carbon is the primary driver of carbon sequestration, and this conclusion is in line with those findings (Lehmann & Kleber, 2015).

Available Phosphorus exhibited a negative but non-significant relationship with CS ($p = 0.2464$). Despite being essential for plant growth, available phosphorus may not have a direct influence on CS. This result supports findings by Conant *et al.* (2011) that

phosphorus effects on CS are indirect, mostly through enhanced litter input and vegetation growth. The effect of silt on CS was positive but non-significant effect on CS ($p = 0.3350$). This suggests that soil texture, particularly the silt fraction, may not directly influence CS, as also reported by Bronick and Lal (2005). The role of silt in stabilizing organic matter may depend on interactions with other soil fractions and management practices. The fact that pH and CS have a positive but non-significant association ($p = 0.7607$) suggests that soil pH may not have a direct impact on carbon sequestration. This result is consistent with Powlson *et al.* (2011), who propose that rather than directly contributing to CS, pH's effects are mediated by microbial activity and nutrient availability. Sodium (Na) exhibited a positive but non-significant effect on CS ($p = 0.4142$). The impacts of high soil salinity on CS may be offset by lower plant production, which is typically linked to high soil salinity as indicated by Na content (Rengasamy, 2006). Cation Exchange Capacity showed a negative but non-significant effect on CS ($p = 0.2506$). Despite being essential for soil fertility and nutrient retention, CEC seems to have an indirect impact on CS. This is consistent with research by Angst *et al.* (2018), who reported that CEC alone does not strongly predict soil carbon dynamics.

Summary and Recommendation

This study evaluated the effects of apiculture, agrisilviculture, and silvopastoral on soil organic carbon (SOC) sequestration and associated soil properties in Zaria, Nigeria. Soil samples were collected from two depths and analysed for bulk density, texture, SOC, total nitrogen (TN), available phosphorus (AvP), pH, and exchangeable bases. The findings revealed that apiculture had the highest SOC (11.57 g/kg) and AvP (5.94 mg/kg), reflecting efficient organic matter recycling and nutrient cycling. Agrisilviculture exhibited the highest clay (195 g/kg) and silt (517.5 g/kg) contents, which improved soil structure and water retention. In contrast, silvopastoral systems recorded the highest sand content (607.5 g/kg), indicative of lower water-holding capacity and vulnerability to erosion. Surface soils contained significantly higher SOC, AvP, magnesium, and calcium compared to subsoils, likely due to organic matter accumulation and reduced nutrient leaching. While bulk density, TN, and pH showed no significant differences across systems or depths. The results highlighted significant positive associations between CS and TN, BD, and OC. Organic carbon was identified as the most critical factor influencing carbon sequestration, emphasizing its importance in agroforestry practices. Variables such as pH, Na, AvP, and CEC showed weak or non-significant effects on CS, suggesting that their roles in carbon sequestration may be minimal in the studied context. The study therefore recommends the adopt Apiculture Systems for their high potential in SOC sequestration and nutrient recycling. It also recommends incorporation of organic matter through mulching and composting to further improve SOC levels across all agroforestry systems and Implement erosion control and soil conservation practices in silvopastoral systems to mitigate the effects of high sand content.

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EVALUATION OF ORGANIC NPK 5:3:5 AND NPK 20:10:10 ON SELECTED SOIL PROPERTIES AND YIELD OF OKRA (*Abelmoschus esculentus*) IN MAKURDI, NIGERIA

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ABSTRACT

A field experiment was conducted at the Teaching and Research Farm of Joseph Sarwuan Tarka University, Makurdi, during the 2024 cropping season to evaluate the effects of organic NPK[®] 5:3:5 and NPK 20:10:10 on soil properties and yield of okra (*Abelmoschus esculentus*). The study comprised six treatments: T_1 = Control, T_2 = 77 kgN, 46 kg P_2O_5 , 77kg K_2O /ha organic NPK, T_3 = 96 kgN, 58kg P_2O_5 , 96kg K_2O /ha organic NPK, T_4 = 77 kgN, 46 kg P_2O_5 , 77kg K_2O /ha organic NPK + 1.5 bag of NPK 20:10:10. T_5 = 96kgN, 58 kg P_2O_5 , 96 kg K_2O /ha organic NPK + 1.5 bag of NPK 20:10:10 and T_6 = 3 bags of NPK20:10:10. The treatments were arranged in a Randomized Complete Block Design with three replications. Data collected included the number of pods per plant, pod weight per plant, and pods weight per hectare. Results indicated that yields significantly increased with the application of organic NPK[®] 5:3:5 and NPK 20:10:10. The highest number of pods per plant (12.6) and the highest yield per hectare (3.68 t/ha) were obtained from T_5 . This was closely followed by treatment six. The lowest yield was obtained in the control treatment. Soil analyses showed improvements in pH, organic matter, and nutrient concentrations with organic NPK fertilizer application. Thus, applying 96kgN, 58 kg P_2O_5 , 96 kg K_2O /ha organic NPK + 1.5 bag of NPK 20:10:10 is recommended for optimal okra production in Makurdi.

Key words: organic matter, soil nutrients, organic NPK[®] and okra

Introduction

Okra (*Abelmoschus esculentus*) is widely cultivated in Nigeria for its mucilaginous fruits, which are rich in vitamins, minerals, and antioxidants (Schipper, 2000). Ibeawuchi, (2007) reported that okra ranks third in consumption and production area in Nigeria, following tomatoes and peppers. The crop has varying uses; the immature pods are commonly used as a boiled vegetable, while the dried pods serve as a thickener for soups. In addition, the green pods are rich in vitamins, calcium, potassium, and various other minerals (Yadev, *et al.*, 2002). The soil is a critical

component of agriculture, and its fertility is vital for plant growth and development. However, as much as 55% of the land in tropical Africa is adjudging to be inherently low in fertility, chemically fragile and easily degradable under continuous cultivation (Mokwunye and Bationo, 2011). This implies adoption of proper land conservation strategies to overcome these challenges. The use of fertilizers to correct nutrient deficiencies and increase crop yield is an age long practice (Plaster, 1997). However, the choice of fertilizer type and application rate can impact soil physical, chemical, and biological properties (Brady and Weil, 2017). Inorganic fertilizers are widely used

in Nigeria for crop production. They contain a balanced mix of nitrogen (N), phosphorus (P), and potassium (K) essential for plant growth. The NPK ratio varies depending on the fertilizer type, with NPK 20:10:10, NPK 27:13:13, NPK 15:15:15, being a common formulation used in Nigeria (Aduayi, *et al*,2002). However, the use of organic NPK 5:3:5, which is improved organic manure with high N and P contents, has not been adequately adopted in Makurdi. Therefore, this study was designed to: assess the efficiency of NPK 5:3:5 plus NPK 20:10:10 in improving soil fertility (pH, organic matter content, N, available P, and exchangeable cations) and to assess the impact of this fertilizer on the yield of okra (*Abelmoschus esculentus*) in Makurdi.

Materials and Methods

The study was conducted in Teaching and Research Farm, Joseph Sarwuan Tarka University, Makurdi, in 2024 cropping season.

Experimental Design

The study comprised six treatments: T₁= Control, T₂=77 kgN,46 kg P₂O₅, 77kg K₂O/ha organic NPK, T₃=96 kgN,58kg P₂O₅, 96kg K₂O/ha organic NPK , T₄= 77 kgN,46 kg P₂O₅, 77kg K₂O/ha organic NPK +1.5 bag of NPK 20:10:10. T₅= 96kgN,58 kg P₂O₅, 96 kg K₂O/ha organic NPK +1.5 bag of NPK 20:10:10 and T₆ = 3 bags of NPK20:10:10. The treatments were arranged in a Randomized Complete Block Design with three replications.

Data Collection

The data collected included: the number of pods per plant, pod weight per plant, and pods weight per hectare. The data was analyzed using analysis of variance (ANOVA), and mean separation was done

using Fisher's Least Significant Difference (Obi,2001)

Soil samples were collected from each plot at the beginning and end of the growing season, and analyzed using standard procedure in the laboratory to determine soil properties as affected by fertilizers application.

RESULTS AND DISCUSSION

The soil analysis results for the study area, as presented in Table 1, revealed that the particle size distribution (PSD) is composed of 78.4% sand, 12.6% silt, and 9.0% clay. This categorization classifies the soil as sandy loam according to the Food and Agriculture Organization (FAO, 2015). The soil pH measured at 6.7, indicating a slightly acidic condition. The organic matter content was recorded at 1.22%, while total nitrogen was found to be 0.05%. Available phosphorus levels stood at 11.7 mg/kg. The exchangeable cations, including calcium (Ca), magnesium (Mg), potassium (K), and sodium (Na), were measured at 5.1, 0.30, 0.21, and 0.15 cmol/kg, respectively. The soil's cation exchange capacity (CEC) was determined to be 5.76 cmol/kg. The soil fertility status of the study area could hinder sustainable crop yield due to the low concentrations of organic matter, total nitrogen, and available phosphorus, as outlined by the Food and Agriculture Organization (FAO, 2014). This deficiency could be attributed to intensive farming and inefficient agronomic practices within the study area, a scenario which has been documented as a primary cause of soil nutrient depletion in sub Saharan regions (Agbede, and Adekiya,2012; Asungre *et al.*, 2021).

Table1: Soil Properties of the study Area

Soil Properties (0 -15cm)	Value
Chemical properties	
pH (H ₂ O)	6.7
Organic carbon (%)	0.70
Organic Matter (%)	1.22
Total Nitrogen (%)	0.05
Available P (mg/kg)	11.70
Exchangeable cations (cmolkg⁻¹)	
Ca	5.10
Mg	0.30
K	0.21
Na	0.15
CEC	5.76
Particle Size Distribution (%)	
Sand	78.4
Silt	11.6
Clay	9.0
Textural class	Sandy loam

Effect of Organic NPK[®] and Mineral Fertilizer on Soil Properties

The analysis of soil samples obtained after harvest (Table 2) indicated an increase in soil pH and nutrient levels following the application of organic NPK[®], either as a sole nutrient source or plus mineral fertilizer. This treatment resulted in a notable increase in soil pH, ranging from 6.7 to 7.2. Additionally, the total nitrogen, available phosphorus, and potassium levels also increased with the application of organic NPK[®] either as sole fertilizer or in combination with mineral fertilizer. The highest levels of these nutrients were observed when organic NPK[®] was applied at 96kgN, 58 kg P₂O₅, 96 kg K₂O/ha organic NPK +1.5 bag of NPK 20:10:10. In contrast, non-fertilizer treatments and

the application of mineral fertilizer alone resulted in a decrease in soil pH, depletion in soil organic matter (SOM) and exchangeable cations. The lowest soil pH (6.3) and SOM (1.01%) were recorded in the non-fertilizer treatments. These findings demonstrate the positive impact of organic fertilizers in sustainable cropping systems, as reported by previous researchers (Agbede and Adekiya, 2012; Mokuwunye and Batiano, 2021). The availability of organic matter in the soil is essential for nutrient retention, improved soil structure, and overall soil health (Brady and Weil, 2017). This can only be achieved through the incorporation of organic fertilizers, such as animal manure, compost, and organic NPK.

Table 2: Effect of treatment on soil Properties

Treatment	pH	OM (%)	N(%)	P(mg/kg)	Ca	Mg	K	Na	CEC
							(Cmolkg ⁻¹)		
T ₁	6.3	1.01	0.02	11.1	4.2	0.22	0.17	0.11	4.70
T ₂	6.7	1.31	0.05	11.1	4.2	0.22	0.20	0.10	4.74
T ₃	6.8	1.33	0.10	11.7	5.1	0.30	0.27	0.15	5.82
T ₄	6.8	1.50	0.10	11.7	5.4	0.32	0.33	0.15	6.25
T ₅	7.2	1.56	0.13	11.9	5.4	0.35	0.33	0.18	6.26
T ₆	6.3	1.01	0.04	11.3	4.0	0.24	0.20	0.11	4.58

Key: T₁= Control, T₂=77 kgN,46 kg P₂O₅, 77kg K₂O/ha organic NPK 5:3:5, T₃=96 kgN,58kg P₂O₅, 96kg K₂O/ha organic NPK 5:3:5, T₄= 77 kgN,46 kg P₂O₅, 77kg K₂O/ha organic NPK +1.5 bag of NPK 20:10:10. T₅= 96kgN,58 kg P₂O₅, 96 kg K₂O/ha organic NPK +1.5 bag of NPK 20:10:10 and T₆ = 3 bags of NPK20:10:10

formulations, as demonstrated in this study. The results of this study are consistent with those of Akinrinde *et al.* (2013) and Nweke *et al.* (2019), who found that the application of organic fertilizer alone or in combination with mineral fertilizer enhanced concentration of plant nutrients in the soil in south west Nigeria and Minna, Niger State, respectively.

Effect of Organic NPK® and Mineral Fertilizer on Pods Yield

Table 3 presents the effects of fertilizer treatments on okra pod yield. While fertilizer application showed marginal increases in the number of pods per plant, this effect was not statistically significant. However, both the weight yield of pods per plant and yield per hectare were significantly affected by fertilizer treatments. The highest yield, 3.68 t/ha, was achieved with a combination of 96kgN,58 kg P₂O₅, 96 kg K₂O/ha organic NPK +1.5 bag of NPK 20:10:10. This was followed by the yield from a sole application of mineral fertilizer at 150 kg/ha (or three bags) NPK 20:10:10. The lowest yield, 1.05 t/ha, was observed in the non-fertilizer treatment, which was statistically similar to the yield from the

application of 77 kgN,46 kg P₂O₅, 77kg K₂O/ha organic NPK (i.e T₂). These results highlight the importance of fertilizer, whether organic or inorganic, in crop production. This finding is supported by other studies (Doran, *et al.*, 2002; Kamara, *et al.*, 2005; Omotoso and Johnson,2015 Zang *et al.*, 2022).

CONCLUSION AND RECOMMENDATIONS

Fertilizer application, as sole nutrient source or in combination with mineral fertilizer, improved soil pH, increased total nitrogen, available phosphorus, and potassium levels, and enhanced soil organic matter. Also, the study highlights the efficacy of organic and mineral fertilizers, in boosting okra production, specifically influencing the weight yield per plant and the yield per hectare. Therefore, it is recommended that Farmers should consider implementing a fertilization strategy that combines organic and mineral fertilizers for sustainable agriculture. The specific combination of 96kgN,58 kg P₂O₅, 96 kg K₂O/ha organic NPK +1.5 bag of NPK 20:10:10, as used in this study, could be adopted for sustainable crop yield in the study area.

Table 3: Effect of Fertilizer Treatments on pod Yield

Treatment	No. of Pod/plant	weight of pod/plant (g)	Yield of pod/ha (t / ha)
T ₁	7.0	213.02a	1.05a
T ₂	7.7	218.10ab	1.21ab
T ₃	8.7	224.5b	1.77b
T ₄	10.3	314.7c	2.8bc
T ₅	11.1	323.5d	3.68c
T ₆	12.6	323.1d	3.63c
LSD (0.05)	NS	8.06	1.53

Key: T₁= Control, T₂=77 kgN,46 kg P₂O₅, 77kg K₂O/ha organic NPK 5:3:5, T₃=96 kgN,58kg P₂O₅, 96kg K₂O/ha organic NPK 5:3:5, T₄= 77 kgN,46 kg P₂O₅, 77kg K₂O/ha organic NPK +1.5 bag of NPK 20:10:10. T₅= 96kgN,58 kg P₂O₅, 96 kg K₂O/ha organic NPK +1.5 bag of NPK 20:10:10 and T₆= 3 bags of NPK20:10:10

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GROWTH AND YIELD RESPONSE OF GROUNDNUT (*ARACHIS HYPOGAEA*) TO POULTRY MANURE AND NPK FERTILIZER IN CALABAR, NIGERIA

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ABSTRACT

*The use of organic amendment and inorganic fertilizer to increase plants productivities is increasing. Understanding the effects of different fertilizers on chemical properties of the soil is essential for optimizing agricultural practices. The study was a field experiment conducted at the University of Calabar Teaching and Research Farm to evaluate the combined and individual effects of poultry manure and NPK fertilizer on plant growth, and yield of groundnut (*Arachis hypogaea*) and to determine the best nutrient management practice for enhancing its productivity. The treatments consisted of NPK, poultry manure, studied sole and in combination with a control making a total of four treatments. The field experiment was laid out in a Randomized Complete Block Design with three replications of 2 m x 3 m plot size. The results revealed that the soil organic carbon (0.89 %), total nitrogen content (0.10 %) as well as exchangeable bases and effective cation exchange capacity (ECEC) (7.46 cmol kg⁻¹) were low, while the available phosphorus content (16.3 mg kg⁻¹) was moderate. The results of the effects of the amendments on the chemical properties, growth and yield of groundnut showed that there were significant ($p < 0.05$) increases in the soil pH, and the concentration of SOC, TN, Av. P, exchangeable Ca, Mg, K, Na and ECEC. The application of 2.5 t PM ha⁻¹ + 50 kg NPK ha⁻¹ (T₄) resulted in significantly ($p < 0.05$) higher plant height, number of branches and number of leaves than the other treatments. Higher number of pods plant⁻¹ (24.45), number of seeds pod⁻¹ (2.94), 100 seed weight (265.23 g) and seed yield of groundnut (2734 kg ha⁻¹) were also obtained from the T₄ plots. Generally, the application of T₄ improved the soil chemical properties, enhanced optimum groundnut growth and increased the yield of groundnut.*

Key words: Amendments, soil chemical properties, management practices, combination, plants productivities

Introduction

Groundnut (*Arachis hypogea* L.) belongs to Family: Fabaceae, Sub-Family: Papilionaceae, Genus: *Arachis* and Species: *hypogaea*. *Arachis hypogaea*, is native to South America, Mexico and Central America (El-Habbasha *et al.*, 2009). It is an annual herbaceous plant growing to 30 to 50cm tall. The leaves are opposite, pinnate with four leaflets (two opposite pairs; no terminal leaflet), each leaflet 1 to 7 cm long and 1 to 3 cm broad. The flowers are a typical pea flower in shape, 2 to 4cm (3/4 to 1 1/2 inch) across, yellow with reddish veining. It fixes atmospheric nitrogen, and hence improves the soil nitrogen that plays its role as a restorative crop (Mukurumbia, 1985). Since the nitrogen requirement for the other crop (intercropped) is met through nitrogen fixation, therefore the interest has been developed in cultivation of groundnut for its tremendous potentials both as food and in soil fertility maintenance (Somasegaran *et al.*, 1990).

Crop production in Nigeria is hindered by several factors such as low soil fertility as well as restricted access to mineral fertilizer (Nyanabgara and Nyaguambo, 2010). In Nigeria, farmers are always faced with the problem of soil fertility decline which has been considered the most important biophysical constraints to crop yield and productivity (Odendo and Okwosa 2004). Developing soil fertility management options for increasing productivity of staple food crops is a challenge in most part of Nigeria, where soils are constrained by the major mineral element such as potassium, nitrogen and phosphorus deficiencies (Jemo *et al.*, 2010). Nitrogen, Phosphorus and potassium are among the limiting nutrients

for legumes production (Christianson & Vieck 1991). Adequate supply of nitrogen is beneficial for carbohydrates and protein metabolism, promoting cell division and cell enlargement (Shehu *et al.*, 2010). Poultry manure promotes transformation and mineralization of less labile inorganic and organic phosphorus into labile phosphorus in the rhizosphere, which results in higher root phosphorus concentration and higher total phosphorus uptake by plants (Waldrip *et al.*, 2011). Therefore, poultry manure could be a valuable fertilizer and could serve as a suitable alternative to chemical fertilizer in Nigeria (Eneje and Azu, 2009). The use of inorganic fertilizer has not been helpful under intensive agriculture because it is often associated with reduced crop yield, soil acidity and nutrients imbalance (Ojeniyi, 2000). The combined use of organic and inorganic fertilizers provides various benefits for enhancing the chemical and physical status of the soil as well as increasing yield in continuous cropping (Basso and Rictchie, 2005; Khaim *et al.* 2013). This study was designed to evaluate the effect of poultry manure and NPK on soil microorganisms, chemical properties, growth and yield of groundnut in Calabar, South Eastern Nigeria.

Materials and Method

Study location

The study was conducted at the University of Calabar Teaching and Research Farm which lies at latitude 4° 52' N and longitude 8° 34' E. The area is characterized by a tropical climate, with a mean annual rainfall of 2360 mm (range from 2290 to 2680 mm) and a bimodal distribution pattern with a distinct dry season of 3 - 4 months. The two

peaks period of rainfall in Calabar occurs between June to July and September to October. During the rainy season, there is a short spell called “August Break” which last for about two weeks in most part of Southern Nigeria. This connotes the ustic soil moisture regime. Ambient temperature and relative humidity are high throughout the year. The mean minimum temperature varies from 21°C to 24°C and the mean maximum temperature from 27°C to 30°C. The mean relative humidity varies between 82° to 87° with tropical maritime wind of 60 - 70 % due to tropical continental air masses, which cause dry atmosphere (Federal Airport Authority of Nigeria, 2015).

Treatment Description

The details of the treatments along with their representational symbols are as listed below;

- T₁ : Control
T₂ : Poultry manure (PM) = 5 t PM ha⁻¹
T₃ : NPK 15:15:15 (100 kg NPK ha⁻¹)
T₄ : 2.5 t PM + 50 kg NPK ha⁻¹

The four treatments were laid out in Randomized Complete Block Design (RCBD) with three replications of 2 m x 3 m plot size to give a total of twelve (12) plots. Pathways between blocks were 1.5 m while those between plots were 1 m.

The effects of the various treatments on plant growth characteristics of groundnut were periodical observed and measured at 30, 60 and 90 DAS (Table 3). Growth parameters such as plant height, number of branches and number of leaves per plant were measured at a regular interval of 30 days till 90 DAS. Four plants were selected randomly from each net plot by using

random numbers. All observations were recorded on these four plants.

Sowing

Groundnut variety SAMNUT 27 was sown three seeds per hole at a spacing of 50 cm x 20 cm as recommended by the International Institute of Tropical Agriculture (IITA). The groundnut seedlings were thinned to two seedlings per hole at the age of 10 DAS (days after sowing) giving at total of 222,223 plants/ha.

Manures and fertilizer application

The poultry manure was applied to the plots, spread evenly and incorporated to the soil using a hoe, at 5 t ha⁻¹ (in sole application) and 2.5 t ha⁻¹ (in combined application) at 2 weeks before sowing. NPK 15:15:15 was applied in ring form at 100 kg ha⁻¹ immediately after the first weeding, which occurred three weeks after sowing.

Weeding was performed as soon as weed emerged and continued until harvest.

Data collection

Plant height: Plant height was measured using a meter ruler from the base of the groundnut plant to the top of the terminal buds, and the average height per plot recorded at 30, 60, and 90 DAS.

Number of branches (NOB): The number of branches plant⁻¹ of groundnut was also determined at 30, 60, and 90 DAS.

Number of leaves per plant: The number of leaves per groundnut plant was determined at 30, 60, and 90 DAS by counting all the leaves on each of the tagged plants and the average recorded per plot.

Harvesting and threshing

Harvesting of experimental crops was done at physiological maturity corresponding to

three months after sowing. The remaining crops on the plot were harvested manually by uprooting. Harvested crop was dried in field for three to four days. Threshing of groundnut seeds was carried out and post harvest observations were recorded according to treatment.

Post-harvest data collection

Number of pods per plant (NOP): Total number of pods from tagged plants were collected, separated and counted individually to determine total number of pods per plant and per plot at the time of harvest.

Number of seed per pod: After shelling, the number of seeds from pods of tagged plants was counted and mean number of seeds pod⁻¹ was calculated and recorded.

Hundred seed weight (g): After harvest, the seed sample from each plot was taken randomly and 100 seeds were counted, weighed and recorded.

Seed yield (t ha⁻¹): The plant seeds from each plot were harvested and weighed separately and seed yield per plot was expressed in grams. Seed yield from various plots were extrapolated to seed yield in kilograms per hectare (kg ha⁻¹) for meaningful comparisons.

Soil sampling and analysis

Composite soil samples for laboratory analysis were taken from a depth of 0 - 20 cm from the experimental site prior to land preparation. The samples were taken randomly across the field using an auger. Samples were then air-dried under laboratory conditions, thoroughly mixed and passed through a 2 mm mesh sieve and stored for analyses. After groundnut was harvested, soil samples were collected from

each plot. The samples were analyzed to assess changes in soil fertility due to the effect of the application of organic and inorganic fertilizers.

Sampling of rhizosphere soils from groundnut stands were collected at a 30 days intervals (30, 60 and 90 days after planting) by uprooting two plants from each treated plot and keeping the soil around the root system intact for analysis. After removing the bits of plant roots and other debris from the intact root system (after uprooting), the soil particles that adhered strongly to the roots were immediately place in a plastic container and taken to the laboratory for microbial analysis without drying them, following the method as described by Basul *et al.* (2010).

Laboratory analysis

Soils samples collected were sieved with a 2mm mesh for laboratory analysis. The samples analyzed were soil pH, total nitrogen (Kjeldahl digestion method), and organic carbon (dichromate oxidation). Exchangeable base cations were determined in 1M NH₄OAC; pH 7.0, available phosphorus by Bray-1 method and particle size analysis was determined by the hydrometer method. The physical and chemical properties of the soils at the study areas are presented in Table 2.

Microbiological analysis

The media used in this study were Nutrient agar for Total Heterotrophic Bacteria Counts and Potato dextrose agar for Total Fungal Counts. All the media were prepared and sterilized according to manufacturer's specifications.

A measure of 1g of the soil samples collected from four treated plots was

serially diluted in tenfold up to 10^{-7} tubes. Then 1ml aliquots from the 10^{-4} tubes were aseptically inoculated onto already prepared plates of nutrient agar and potato dextrose agar using the pour plate method of inoculation. All plates were inverted and the nutrient agar (for bacteria) was incubated at 37°C for 24 hours while the potato dextrose agar plates (for fungi) were incubated at ambient laboratory temperature ($28 \pm 2^{\circ}\text{C}$) for 72 hours. After the incubation, the total bacterial and fungal colonies on plate that contain 30 – 300 colonies were counted using a colony counter. The number of colonies on a plate was multiplied by the dilution factor to give the plate count per ml of the soil sample and recorded as cfug^{-1} . E.g. if the counts for 2 plates of the 10^{-6} dilution were 55 and 65, the average is 60. Therefore, the original soil sample contains $60 \times 10 \times 10^6 = 6 \times 10^8 \text{ cfug}^{-1}$. The colonies were also repeatedly subcultured onto fresh nutrient and potato dextrose agar media to obtain pure isolates. The bacterial isolates were identified and characterized using cultural, morphological and standard biochemical tests. The fungal isolates were identified according to the methods described by Oladele *et al.* (2019) based on their colour of aerial hyphae and substrate mycelium, arrangement of hyphae, and conidial arrangement.

Statistical Analysis

The data obtained were assessed using analysis of variance (ANOVA). Duncan Multiple Range Test was used to separate

the significant means at 5% level of probability using SPSS software.

3.0 Results and discussion

3.1 Soil Physicochemical Properties of the Experimental Soil before Planting

Particle size distribution of the pre-cropped soil had a high content of sand (83.00 %) and low amount of silt (6.24 %) and clay (10.76 %). The textural class of the soil was sandy loam (Table 1). Such soils may lack absorptive capacity for basic plant nutrients and may be susceptible to erosion menace (Abua and Edet, 2007). The pH of the soil was 5.2 (distilled water) and was rated as strongly acid (Adaikwu & Ali 2013; Landon, 1991). The pH status is common for soils of the tropical region that are highly weathered and leached of basic cations from the soil *solum*. This may be due to high rainfall (exceeding 2000 mm per annum) associated with the tropical environment with the predominance of low activity clays and the porous nature of the soil (Obi, 1991). Soil organic carbon was 0.89 % and rated low (Adaikwu & Ali 2013; Landon, 1991). The soil was generally low in organic carbon (0.89 %), total nitrogen (0.10), ECEC (7.46 cmol/kg) and exchangeable bases but moderate in available phosphorus content (16.3 mg/kg) and high in base saturation (81.98 %) when compared to the critical minimum for Nigerian soils (Adaikwu & Ali, 2013; Landon, 1991). The low organic carbon and total nitrogen contents could be attributed to continuous cropping of the soil without adequate fallow period or additional nutrient supply.

Table 1: Physical and Chemical properties of the experimental field before planting

Soil properties	Values

Particle size distribution	
Sand	83.00
Silt	6.24
Clay	10.76
Textural classification (USDA)	Sandy loam
Chemical properties	
pH(H ₂ O)	5.2
Organic carbon (%)	0.89
Total nitrogen (%)	0.10
Available phosphorus (mg/kg)	16.3
Exch. Ca (cmol/kg)	5.0
Exch. Mg (cmol/kg)	0.8
Exch. K (cmol/kg)	0.09
Exch. Na (cmol/kg)	0.06
Al (cmol/kg)	0.12
H (cmol/kg)	1.20
ECEC (cmol/kg)	7.46
BS (%)	81.98

Av. P = Available phosphorus, E CEC = Effective cation exchange capacity, BS = Base saturation

Physical and chemical properties of the experimental soil at harvest

The soil physical and chemical properties after the application of different treatments are presented in Table 2.

3.2.1 Particle size distribution

The result obtained showed that there was no significant ($p > 0.05$) difference in sand, silt and clay contents between treated soils and the control soil.

3.2.2 Chemical properties

The result obtained showed that there was a significant ($p < 0.05$) difference in soil pH between the control plot and those treated with amendments. The soil pH planting was 5.20 and ranged from 4.86 - 6.80 at harvest. At the end of the cropping season, the highest pH value of 6.80 (almost neutral) was obtained from the plots that had 5 t ha⁻¹ poultry manure (T₂), while the lowest pH

value of 4.86 (very strongly acid) was obtained from that had 100 kg NPK ha⁻¹ (T₃). The application of chemical fertilizers raises the acidity level of the soil (El-sherbeny *et al.*, 2023; Ojeniyi, 2000). The application of poultry manure alone or in combination with inorganic fertilizers increased soil pH, a view which is also supported by Meelu *et al* (1994) who observed that organic materials have overall tendency to move the pH towards neutrality. Tisdale *et al.* (2003) also reported that the rise in soil pH can be due to

Table 2: Effect of amendments on physical and chemical properties of the experimental soil at harvest

Treatments	Particle size			pH (H ₂ O)	OC	TN	AV.P (mgkg ⁻¹)	Exch. Cations				Exch. Acidity		ECEC	BS (%)
								Ca	Mg	K	Na	Al ⁺³	H ⁺		
	sand	silt	clay												
	→ % ←														
T ₁	83.00a	6.34a	10.66a	5.73c	1.60d	0.11b	17.27d	1.24d	0.72c	0.08d	0.08a	0.09b	1.14d	8.34d	73.70c
T ₂	83.67a	7.35a	10.31a	6.80a	2.92b	0.19a	55.65b	1.55b	0.91a	0.13b	0.09a	0.12a	1.22c	13.19b	82.32a
T ₃	82.33a	6.35a	10.65a	4.86d	2.78c	0.18a	43.79c	1.38c	0.77b	0.11c	0.08a	0.12a	1.31b	11.58c	78.24b
T ₄	82.67a	7.12a	11.21a	6.54b	3.75a	0.19a	68.02a	1.57a	0.94a	0.15a	0.09a	0.08b	1.98a	14.02a	81.10ab

OC = Organic carbon, TN = Total nitrogen, AP = Available phosphorus, ECEC = Effective cation exchange capacity, BS = Base saturation,
T₁= Control, T₂= PM = 5 t Poultry manure ha⁻¹, T₃ = NPK 15:15:15 (100 kg NPK ha⁻¹), T₄= 2.5 t PM + 50 kg NPK ha⁻¹

Mean with the same letter(s) in the columns are not significantly different (Duncan's Multiple Range Test, (p ≤ 0.05))

the release of ammonia (NH_3) or addition of basic cations (during mineralization of manure) from decomposing organic materials.

The maximum organic carbon content, Av. P and ECEC were obtained from the application of $2.5 \text{ t PM ha}^{-1} + 50 \text{ kg NPK ha}^{-1}$ (T_4) followed by T_2 and T_3 , with the lowest values obtained from T_1 (Table 2). It was observed that the organic carbon contents of the treated soils were higher in plots amended with PM and its integration with inorganic fertilizer.

Positive influence of the integrated use of organic and inorganic fertilizers to increase soil organic carbon has also been reported by several researchers (Adeniyi and Ojeniyi, 2005, Iren *et al.*, 2012).

Highest available P (68.02 mg kg^{-1}) was obtained with T_4 and the lowest (17.27 mg kg^{-1}) obtained with T_1 . However, the values of available P obtained at the end of the cropping years were generally above the initial (pre-planting) P status of 16.3 mg kg^{-1} . This could be attributed to the enrichment of the soil P through the addition of the amendments and nutrient cycling enhanced by the root system of groundnut. There was also a significant difference ($p < 0.05$) in ECEC value amongst treatment plots. The application of T_4 resulted in the highest ECEC value of $14.02 \text{ cmol kg}^{-1}$, followed by the T_2 plot while the lowest ECEC value of $8.34 \text{ cmol kg}^{-1}$ was obtained in the T_1 plot. The increase ECEC content with T_4 could be attributed to high availability of OM which provide more nutrients (NPK) compared to the other single fertilizer treatments (T_2 and T_3). The ECEC values obtained at the end of the cropping year were generally moderate (Adaikwu & Ali, 2013) exceeding the initial pre-planting

concentration of $7.46 \text{ cmol kg}^{-1}$. These values are regarded as suitable for crop production if other factors are favourable (FAO, 2004).

The application of the amendments significantly ($p < 0.05$) increases the total nitrogen content when compared with the control plot. The highest value of 0.19 % was obtained with T_4 and T_2 , followed by T_3 while the lowest value of 0.11 % was obtained with T_1 . Therefore, it is ascertained that sole application of poultry manure and combined application of poultry manure and inorganic fertilizer released more nitrogen in soil. Generally, the total N content of the study area was low both before and after the experiments.

There were significant ($p < 0.05$) effects of the amendments in the retention of soil exchangeable Ca, Mg, Na and K nutrients after crop harvest. The highest exchangeable Ca value of $1.57 \text{ cmol kg}^{-1}$ was obtained in plots T_4 . The lowest calcium value ($1.24 \text{ cmol kg}^{-1}$) was obtained from the T_1 plot. The highest exchangeable Mg was obtained with T_4 while the lowest was found in the T_1 plot. The highest K concentration ($0.15 \text{ cmol kg}^{-1}$) was obtained with the T_4 . The highest sodium (Na) value was obtained with T_4 and T_2 while the lowest values were observed in T_3 and T_1 . The exchangeable bases were generally very low (Adaikwu & Ali, 2013) in all the treated plots. The low exchangeable bases can be attributed to the high sand content in the soil which predisposes the soil to excess leaching of the cations down the profile given the high rainfall in the study area (Igwe and Udegbuma, 2008).

Exchangeable acidity was mainly contributed by exchangeable Hydrogen ion (H^+). The result showed that there was a significant

($p < 0.05$) difference in exchangeable Al^{3+} and exchangeable H^+ between control soil and those treated with amendments. The highest exchangeable H^+ value ($1.98 \text{ cmol kg}^{-1}$) was obtained in plots T_4 while the lowest exchangeable H^+ value of $1.14 \text{ cmol kg}^{-1}$ was obtained in T_1 plot. The highest Exchangeable Al^{3+} values ($0.12 \text{ cmol kg}^{-1}$) were obtained in plots T_2 and T_3 . The lowest Exchangeable Al^{3+} value ($0.08 \text{ cmol kg}^{-1}$) was obtained from the T_4 plot.

The base saturation of the soil varied from 73.70 % to 82.32 %. Highest base saturation (82.32 %) was obtained with T_2 and the lowest (73.70 %) obtained with T_1 . According to Adaikwu & Ali (2013), the BS obtained with T_3 and T_1 plots were high (60-80 %) while that of T_2 and T_4 plots were rated very high (> 80 %).

Growth of plant

Effect of amendments on plant height

The effect of amendments on plant height of groundnut is shown in Figure 2. Results obtained indicated that the application of the treatments significantly ($p < 0.05$) enhanced the height of groundnut crop at 30, 60 and 90 days after sowing (DAS) relative to the control. At 30, 60 and 90 DAS, the

application of $50 \text{ kg NPK ha}^{-1} + 2.5 \text{ t PM ha}^{-1}$ (T_4) produced plant with the highest height (25.89 cm at 30 DAS, 32.65 cm at 60 and 41.56 cm at 90 DAS). It was followed by 5 t PM ha^{-1} (T_2) (24.67 cm at 30 DAS, 30.67 cm at 60 and 37.85 at 90 DAS). The lowest groundnut plant height at 30, 60 and 90 DAS (21.51cm, 24.86 and 31.43) was observed in the T_1 plot where no amendments were applied.

Effect of amendments on number of branches

The effect of amendments on the number of branches per groundnut plant is shown in Figures 3. The result obtained showed that the application of the amendments significantly ($p < 0.05$) enhanced the number of branches at 60 and 90 DAS. At 90 DAS the highest (12.54) number of branches were obtained with the application of the T_4 , followed by T_2 , and T_3 ($100 \text{ kg NPK ha}^{-1}$). Nevertheless, the T_1 (control) produced significantly lowest number of branches per plant (10.82). These results corroborate with the finding of Chaudhari *et al.*, (2015).

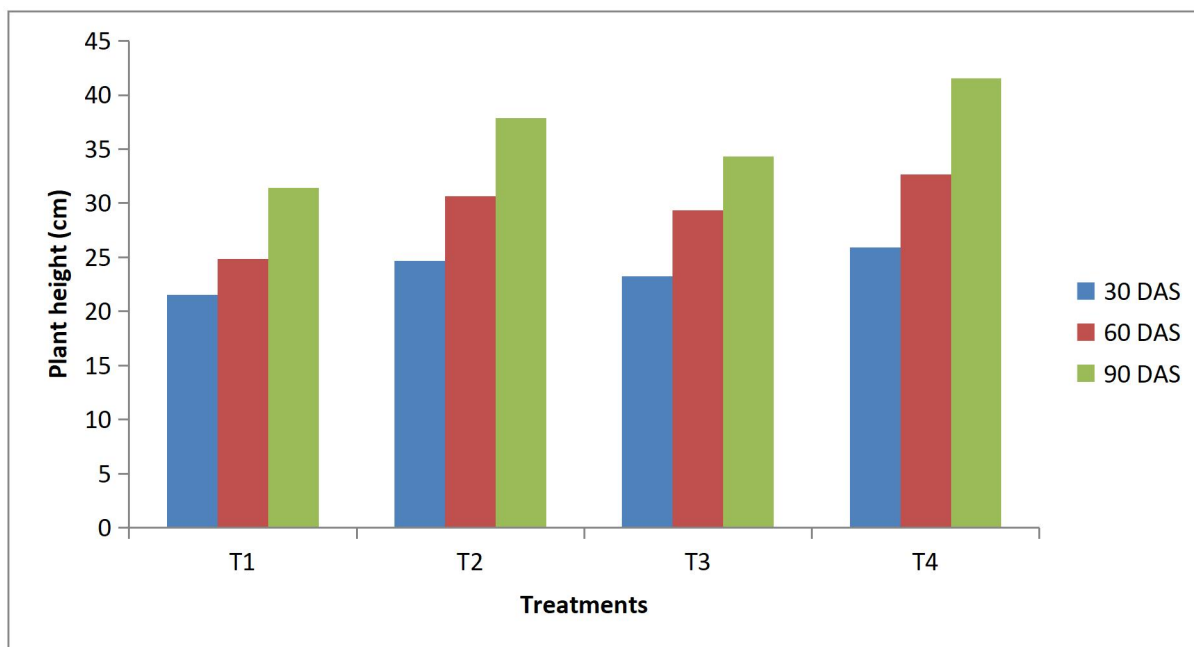


Figure 1: Plant height (cm) affected by the treatments at 30, 60 and 90 DAS

T₁ = Control

T₂ = Poultry manure (PM) = 5 t PM ha⁻¹

T₃ = NPK 15:15:15 (100 kg NPK ha⁻¹)

T₄ = 2.5 t PM + 50 kg NPK ha⁻¹

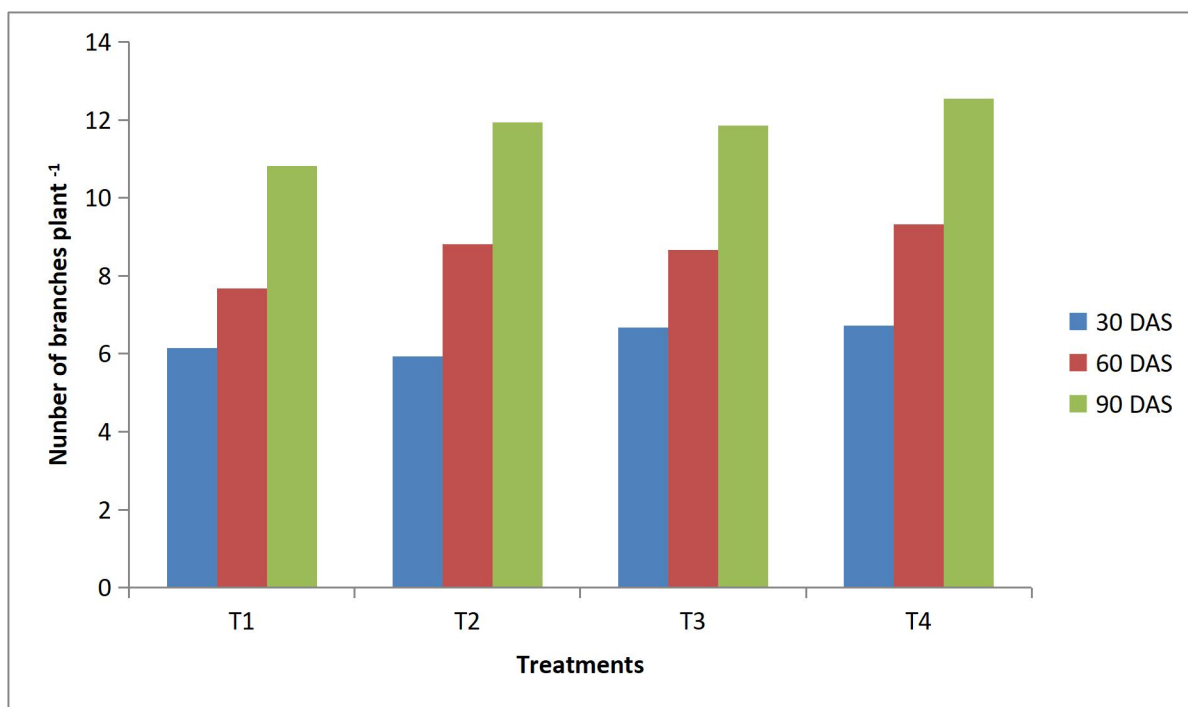


Figure 2: Number of branches affected by the treatments at 30, 60 and 90 DAS

T₁ = Control

T₂ = Poultry manure (PM) = 5 t PM ha⁻¹

T₃ = NPK 15:15:15 (100 kg NPK ha⁻¹)

T₄ = 2.5 t PM + 50 kg NPK ha⁻¹

Effect of amendments on number of leaves

The effect of amendments on number of leaves per groundnut plant is shown in Figure 4. The number of leaves plant⁻¹ was significantly ($p \leq 0.05$) increased at each

growth stage of observation. The highest number of leaves produced by the groundnut plant was obtained from plot amended with T₄ (50 kg NPK ha⁻¹ + 2.5 t PM ha⁻¹). Application of T₃ (100 kg NPK ha⁻¹) had the least number of leaves.

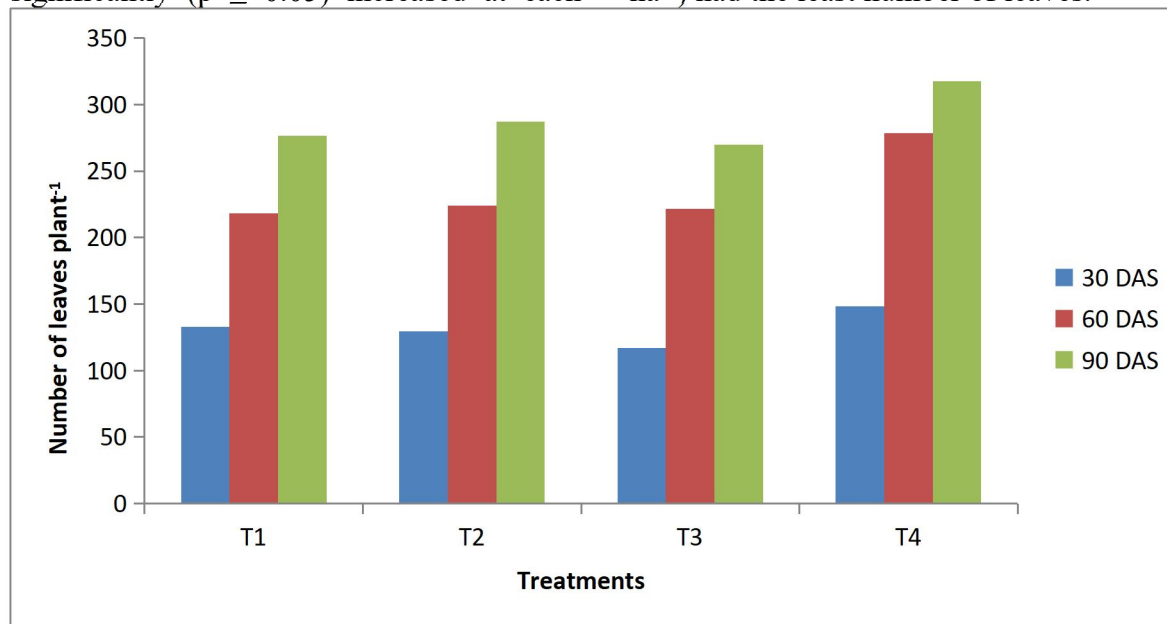


Figure 3: Number of leaves affected by the treatments at 30, 60 and 90 DAS

T₁ = Control

T₂ = Poultry manure (PM) = 5 t PM ha⁻¹

T₃ = NPK 15:15:15 (100 kg NPK ha⁻¹)

T₄ = 2.5 t PM + 50 kg NPK ha⁻¹

Post harvest observations

The effects of amendments on number of pods plant⁻¹, number of seeds pod⁻¹, 100 seed weight and seed yield of groundnut as influenced by different treatments at harvest are graphically depicted in Figure 4 to 7.

Number of pods plant⁻¹

The effect of different amendments on the number of pods per groundnut plant is graphically depicted in Figure 5. The result showed that the T₄ (50 kg NPK ha⁻¹ + 2.5 t PM ha⁻¹) produced significantly highest number of pods plant⁻¹ (24.45) at harvest, followed by T₂ (5 t PM ha⁻¹) and T₃ (100 kg

NPK ha⁻¹). However, the T₁ (16.75) produced significantly lower number of pods plant⁻¹ at harvest compared to the other treatments. The highest number of pods per plant with the combined application of organic and inorganic fertilizers may be attributed to the balanced supply of nutrients throughout the crop growth period as PM undergoes decomposition, during which a series of nutrient transformation phases take place that makes the nutrients available to the crops. This result is in accord with previous studies by Marimutha *et al.*, (2002), who

Table 3: Effect of amendments on yield attributes

NOP = Number of Pod plant⁻¹, NOS = Number of seed pod⁻¹, 100 SW =100 seed weight, SY = Seed yield

Treatment	Yield attributes			
	NOP	NOS	100 SW (g)	SY (kg ha ⁻¹)
T₁ Control	16.75d	2.03d	39.47d	1017d
T₂ PM (5 t ha⁻¹)	23.78b	2.86b	47.13b	2043b
T₃ NPK (100 kg ha⁻¹)	21.45c	2.56c	44.35c	1831c
T₄ PM (2.5 t ha⁻¹) + NPK (50 kg ha⁻¹)	24.45a	2.94a	53.85a	2234a

reported that, the integrated application of organic (PM) and inorganic fertilizers produced the highest seed yield per groundnut plant.

Number of seeds pod⁻¹

The effect of the different treatments on number of seeds per pod of groundnut is graphically depicted in Figure 6. Among the different treatment, the T₄ produced significantly higher number of seeds pod⁻¹ (2.94) than the rest of treatments, followed by the T₂ and T₃. However, the T₁ (2.03) produced significantly lowest number of seeds pod⁻¹ at harvest compared to the other treatments under study. Generally, the data shows that there was a slight difference or uniformity in the number of groundnut seeds per pod across the treatments. This uniformity could be attributed to consistent environmental condition and similar genetic characteristics of the crop.

100 seed weight (g)

The effect of the different treatments on 100 seed weight of groundnut is graphically depicted in Figure 7. Among the different treatments, the T₄ produced significantly higher 100 seed weight (265.3 g) over the

rest of treatments, followed by T₂ (235.67 g) then T₃ (221.75 g) but the T₁ (192.34 g) produced significantly lowest 100 seed weight.

Seed yield (kg ha⁻¹)

The effect of the different treatments on the seed yield of groundnut is graphically depicted in Figure 8. Application of T₄ produced significantly higher seed yield of groundnut (2734 kg ha⁻¹) over the rest of treatments, followed by the T₂ (2543 kg ha⁻¹) and T₃ (2331 kg ha⁻¹). The higher seed yield of groundnut obtained with T₄ could be ascribed to the synergistic effect of NPK fertilizer and poultry manure. Poultry manure provides essential nutrients such as N and P, which are vital for plant growth. NPK fertilizer supply N, P and K. P and K are crucial for root development flowering and fruiting. However, the T₁ (1467 ha⁻¹) produced significantly lowest seed yield of groundnut compared to the other treatments under study.

The increase in seed yield may be attributed to the increase in the number of branches and pods per plant. The combined application of PM and inorganic fertilizers (NPK) gave

Table 4: Correlation coefficient (r) between soil chemical properties and yield parameters

	pH	OC	TN	Av. P	Ca	Mg	K	Na	Al ³⁺	H ⁺	ECEC	BS	NOP	NOS	SW 100	SY
pH	1															
OC	.720**	1														
TN	.804**	.785**	1													
Av. P	.829**	.983**	.839**	1												
Ca	.932**	.914**	.866**	.972**	1											
Mg	.945**	.864**	.830**	.924**	.967**	1										
K	.799**	.929**	.750**	.938**	.913**	.900**	1									
Na	.474	.457	.458	.473	.505	.542	.609*	1								
Al ³⁺	-.031	-.071	.047	-.025	.026	-.140	-.224	-.216	1							
H ⁺	.437	.827**	.507	.752**	.629*	.665*	.829**	.480	-.557	1						
ECEC	.850**	.960**	.859**	.989**	.979**	.933**	.908**	.491	.073	.675*	1					
BS	.856**	.791**	.855**	.863**	.915**	.860**	.776**	.631*	.190	.436	.909**	1				
NOP	.850**	.940**	.847**	.974**	.971**	.918**	.873**	.497	.113	.625*	.993**	.935**	1			
NOS	.862**	.942**	.828**	.980**	.981**	.913**	.907**	.493	.116	.632*	.988**	.914**	.987**	1		
SW100	.768**	.970**	.772**	.963**	.911**	.908**	.966**	.534	-.278	.892**	.927**	.762**	.897**	.905**	1	
SY	.790**	.968**	.834**	.985**	.955**	.878**	.884**	.428	.138	.665*	.990**	.883**	.984**	.985**	.908**	1

** Correlation is significant at the 0.01 level (2-tailed).

* Correlation is significant at the 0.05 level (2-tailed).

SOM = soil organic matter, TN = total nitrogen, Av. P = available P, ECEC = Effective cation exchange capacity, NOP = Number of pods per plant, NOS = Number of seeds per pod, SW100 = 100 Seed Weight, SY = Seed Yield (t ha⁻¹)

higher yield than the other treatment. These results are in agreement with Kanwar *et al.* (1983) who reported higher yield due to sole application of PM or integrated application of organic (PM) and inorganic fertilizers.

Correlation coefficient (*r*) between soil chemical properties and yield parameters

A positive and significant correlation was observed between the soil pH and some soil chemical properties (OC, TN, Av.P, Ca²⁺, Mg²⁺, K⁺, ECEC and BS). Increase in soil pH has been shown to increase Av.P in soil (Eze and Loganathan, 1990; Sato and Comerford, 2005). This is because in highly weathered tropical soils, increase in soil pH reduces phosphorus fixation by iron and aluminium compounds. Organic Carbon had positive and significant relationship with other chemical properties and yield parameters except for sodium and aluminum. A decrease in sodium content will reduce the sodicity of the soil which positively impact crop productivity, while a decrease in OC indicates a decrease in nutrient availability. SOC act as a reservoir for N, P, S and micronutrients. As organic matter decomposes these nutrients are mineralized. All the chemical properties correlated positively and significantly with yield parameters with the exception of Na⁺ and Al³⁺. A strong relationship between the parameters and the seed yield per kg was observed, particularly between ECEC and SY ($r = 0.990^{**}$), which was the strongest relationship recorded between any two parameters in this study.

Conclusions

The study showed that the soils in Calabar were found to be low in nutrients; however

the combined use of organic and inorganic amendments (poultry manure and NPK) improved population of rhizosphere groundnut and improved groundnut growth and yield compared to sole application of either of them. The integrated application of PM and NPK fertilizer increased groundnut yield than the single application of NPK fertilizer. This experiment showed that the integrated application of PM and NPK fertilizer was more effective in increasing chemical properties of soil and groundnut performance.

The combined treatment was able to improve soil reaction, while assuring balanced plant nutrition and improved soil fertility. From the results obtained, it can be inferred that the soil amended with T₄ (2.5 t PM ha⁻¹+ 50 kg NPK ha⁻¹) increased the yield of groundnut in the study area. The yield of groundnut was in a decreasing order of T₄ (2.5 t PM ha⁻¹+ 50 kg NPK ha⁻¹) > T₂ (5 t PM ha⁻¹) > T₃ (100 kg NPK ha⁻¹) > T₁ (Control).

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235 - IMPACT OF ORGANIC FERTILIZERS ON SOIL FERTILITY AND CROP PRODUCTIVITY IN NORTHERN NIGERIA: A COMPREHENSIVE REVIEW AND META-ANALYSIS

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ABSTRACT

Soil fertility decline is a major challenge affecting agricultural productivity in Northern Nigeria, particularly among smallholder farmers who rely on low-input farming systems. The rising cost and environmental concerns associated with inorganic fertilizers have led to renewed interest in organic fertilizers as an alternative for improving soil health and crop yield. This study conducts a systematic literature review and meta-analysis to assess the impact of organic fertilizers on soil fertility and crop productivity in Northern Nigeria. Data were sourced from published research articles, technical reports, and student theses archived in libraries of agricultural research institutes and universities across Kano, Kaduna, and Jigawa states. A total of 23 different organic fertilizer sources were identified, including poultry manure, cow dung, farmyard manure, compost, green manure, municipal waste, biochar, and various crop residues. The meta-analysis revealed that organic fertilizers significantly improved soil organic carbon (SOC), nutrient availability, and crop yield. Organic fertilizer applications resulted in an average increase of 28-42% in grain yield, depending on the crop type and organic fertilizer source. Among the organic fertilizers analyzed, poultry manure, cow dung, and compost exhibited the highest nitrogen (N), phosphorus (P), and potassium (K) contents, leading to the most substantial yield improvements. On average, soils treated with organic fertilizers showed a 30-50% increase in SOC levels, enhancing soil structure, water retention, and microbial activity. Environmental benefits of organic fertilizer application were also observed. The use of composted organic waste and manure contributed to a 20-35% reduction in soil erosion and enhanced soil moisture retention by 15-25%. Additionally, organic fertilizer application resulted in a 10-20% decrease in greenhouse gas emissions compared to conventional synthetic fertilizers, which contribute significantly to agricultural carbon footprints. These findings underscore the potential of organic fertilizers as a sustainable alternative for enhancing soil fertility and agricultural productivity in Northern Nigeria.

Keywords: Organic fertilizers, soil fertility, crop productivity, meta-analysis, Northern Nigeria, sustainable agriculture

Introduction

Soil degradation represents one of the most pressing environmental challenges globally, affecting approximately 33% of the world's agricultural land and threatening food

security for millions of people, particularly in developing regions (FAO, 2015). In Sub-Saharan Africa, where agriculture remains the backbone of most economies, soil fertility decline has been identified as a primary biophysical cause of declining per

capita food production (Sanchez *et al.*, 1997). The situation is particularly acute in the Sahel region, where decades of intensive cultivation without adequate nutrient replenishment has resulted in severe soil nutrient depletion, with nitrogen and phosphorus deficiencies affecting over 80% of agricultural lands (Bationo *et al.*, 2006).

Agricultural soils in northern Nigeria play a pivotal role in producing diverse crops such as cereals (millet, sorghum, maize, rice, and wheat), legumes (cowpea, groundnut, and soybean), vegetables (tomato, onion), root and tubers (cassava, yam, and sweet potatoes), among others (Usman, 2007). Farmers in northern Nigeria have increasingly complained about poor soil quality, soil fertility, and low crop yields due to a lack of affordable and sustainable fertilizers in the region (Mortimore *et al.*, 1990). The spirit behind healthy and high economic crop yield in farm management systems lies within the heart of organic manures applied to soils for many years in the region (Hill, 1977). However, the intensification of inorganic fertilizers has diminished the values and economic benefits of organic materials over the past 35 years or more. This has resulted in increased soil acidity, decline in soil quality, and unsustainable soil fertility management in dryland and fadama areas of many states in the region (Bationo *et al.*, 2003). Revitalizing and renewing crop production under these circumstances must readapt the traditionally old system of using only organic manures and organic materials in Nigerian cropping systems. This could help transform our agricultural production systems into more sustainable ones, contributing to significant economic developments (Wickama and Mowo, 2001; Uzoma *et al.*, 2011; Usman, 2013).

Most soils of Kano State, Nigeria, are coarse-textured, fragile, highly weathered, and of poor fertility status (Abdulrahman *et al.*, 2019; Mustapha *et al.*, 2020). The coarse texture makes the soil more susceptible to leaching and surface runoff of nutrients, erosion, and desertification (Diacono and Montemurro, 2010; Epelde *et al.*, 2018). The increasing population places huge pressure and demand on agriculture, thereby increasing the rate of soil quality degradation. The global use of nitrogenous fertilizers (N) and phosphates (P) is expected to increase by 2050 due to the conversion of agricultural practices to intensive agricultural systems (Scotti *et al.*, 2015). In this scenario, the use of organic wastes on agricultural soils can be a suitable option to preserve soil quality (FAO, 2005).

Materials and Methods

Data Collection and Analysis

This systematic review and meta-analysis was conducted following the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines (Moher *et al.*, 2009). A comprehensive literature search was performed using multiple electronic databases including Google Scholar, Web of Science, Scopus, and African Journals Online (AJOL). The search strategy employed the following Boolean search strings: ("organic fertilizer" OR "organic manure" OR "compost" OR "poultry manure" OR "cow dung") AND ("soil fertility" OR "crop yield" OR "soil organic carbon") AND ("Northern Nigeria" OR "Kano" OR "Kaduna" OR "Jigawa" OR "Sokoto" OR "Zamfara").

Inclusion criteria for studies were: (1) field-based research conducted in Northern Nigeria; (2) studies comparing organic fertilizer treatments with control (no fertilizer) or inorganic fertilizer treatments;

(3) reporting of quantitative data on crop yield, soil organic carbon, or soil chemical properties; (4) studies published between 2000 and 2024; and (5) studies with clear methodology and replicable results. Exclusion criteria included: (1) laboratory or greenhouse studies without field validation; (2) review articles without original data; (3) studies with insufficient statistical information; and (4) conference abstracts without full-text availability.

To analyze the yield response of crops following manure application, a meta-analysis was conducted. Within this framework, we performed a systematic literature review using published articles, technical reports, and theses. Apart from online desktop literature searches, a physical literature search was conducted in libraries of Agricultural Research Institutes and Universities that have been doing research in the region for a long-term period (Lawan *et al.*, 2021). Studies were included if they were performed under field conditions and if a control was included. The analysis was done in two stages. Firstly, all treatments were used for the analysis irrespective of the number of years. All treatments with a duration of ≤ 1 year were removed in the second stage analysis to exclude short-term effects and the influence of cultivated crops (Han *et al.*, 2016).

Information on location coordinates, soil properties (initial SOC content, texture, bulk density, soil pH class), experiment characteristics (tillage intensity, duration, sampling depth), manure characteristics (type, chemical characteristics, added amount, additional mineral fertilizer use), and site characteristics (longitude, latitude, altitude, climate zone) were extracted when available. In order to analyze the total amount of manure added, annual amounts

were accumulated. If no information on SOC stocks was provided, we quantified them using the following equation (FAO, 2018):

$$SOC\ stock = SOC \times bulk\ density \times depth \times 0.1$$

where SOC stock is expressed as $Mg\ ha^{-1}$, bulk density as $g\ cm^{-3}$, depth as cm, and SOC as $g\ kg^{-1}$. In studies where no soil bulk density was given, different pedotransfer functions were used.

Response Ratio Calculation

To estimate the effects of manure applications on yield and SOC stock changes, we used two different indices. We calculated the response ratio (R), which is the mean of the manure treatment divided by the mean of the control group (all the same but without manure application), and we calculated the yield and SOC stock mean difference. To measure experimental effect sizes, R and ΔSOC are both very common and widespread in meta-analyses (Maillard and Angers, 2014). It is essential to calculate both indices as R only gives information on relative changes whereas ΔSOC considers the absolute impact. Considering the fact that only a few of the analyzed studies provide sufficient information on statistical measures and replicates, we used un-weighted meta-analysis, to include as many treatments as possible (Han *et al.*, 2016).

Results

Impact on Crop Yield

We consulted 410 publications but used data from 42 publications that met our criteria, giving a total of 358 treatments. Reasons for the rejection of studies included: no or unclear reporting of standard error or standard deviation for yields; no or unclear control in the treatment; lack of detail in description of

treatment types or levels. Also, laboratory experiments were not included in the analysis (Adunni and Doppler, 2007).

The results from the pairwise comparison of the yield response revealed significant responses to crop type, fertilizer type, and fertilizer category ($p < 0.05$). For crop type, we grouped the crops into their respective families (cereals, legumes, roots, trees, and vegetables). Different crops had different responses to organic fertilizer treatments. The yield of cereal crops increased by 126% (95% CI: 98-154%, $p < 0.001$) with the application of organic fertilizer. The response of legumes to organic fertilizer application was 60% (95% CI: 42-78%, $p < 0.001$). The low response observed may be because legumes have the ability to fix atmospheric nitrogen, thus, the differences between treatments and control may not be much. The root crops comprised of radish and sweet potato with a response of 129% (95% CI: 95-163%, $p < 0.001$). For vegetables, a response of 86% (95% CI: 68-104%, $p < 0.001$) was observed. Our analysis showed that responses are likely a function of the duration of the crop because of the slow release of minerals from organic fertilizer (Sekumade, 2017).

Note: Detailed yield response comparisons by crop type and organic fertilizer source are presented in Figure 9 (see supplementary materials). The figure illustrates the differential responses across cereal, legume, root, and vegetable crop categories.

Impact on Soil Organic Carbon (SOC)

The meta-analysis revealed significant responses in the change in SOC after the application of organic fertilizer in cereals and legumes ($p < 0.01$). The response observed in cereals and legumes was about 113% (95% CI: 87-139%, $p < 0.001$). No significant response was observed for tree

crops ($p = 0.18$), and this can be attributed to the fact that most of the studies were conducted annually and it becomes difficult to obtain a significant response after just a single year. The different organic sources used also revealed a significant response for the combination of different organic sources ($p < 0.05$), while no significant response was observed for Nomau organic fertilizer ($p = 0.42$).

Nomau organic fertilizer is a locally processed organic amendment derived from municipal waste compost in the Kano metropolitan area. It typically contains lower nutrient concentrations (N: 0.8-1.2%, P: 0.4-0.7%, K: 0.5-0.9%) compared to poultry manure and cow dung, and its variable quality due to inconsistent composting processes may explain the non-significant yield responses observed in our analysis (Dawaki *et al.*, 2017).

Note: SOC response patterns by crop type and organic fertilizer source are illustrated in Figure 14 (see supplementary materials), showing the differential carbon sequestration potential across various agricultural systems.

Discussion

Management Decisions and Site Properties

The impact of organic fertilizers on crop yield and SOC stocks is linked to several factors, including management decisions (tillage intensity, organic fertilizer amount, duration of application), site properties (climate, initial SOC content, soil texture), crop type (cereals, legumes, vegetables), organic fertilizer source (poultry manure, cow dung, compost, farmyard manure, crop residues), and organic fertilizer characteristics (manure origin and combined application with synthetic fertilizer) (McClean, 1982).

Our findings reveal critical insights into the complex interactions between organic fertilizer application and agricultural productivity in the Sudano-Sahelian region. The significantly higher response of cereals (126%) compared to legumes (60%) underscores the importance of crop-specific fertilization strategies. This differential response can be attributed to the symbiotic nitrogen fixation capacity of legumes, which reduces their dependency on external nitrogen sources. However, the substantial yield increase in cereals suggests that organic fertilizers can effectively address the nitrogen limitation that typically constrains cereal production in Northern Nigeria's degraded soils.

The 113% increase in SOC observed in our meta-analysis has profound implications for climate change mitigation and agricultural sustainability. Soil organic carbon serves as both a nutrient reservoir and a key indicator of soil health. The enhancement of SOC levels through organic fertilizer application not only improves soil structure and water retention but also contributes to carbon sequestration, potentially qualifying farmers for emerging carbon credit markets. This represents a significant opportunity for smallholder farmers to diversify their income streams while improving soil productivity.

Economic Viability

Economic analyses revealed that organic fertilizer usage is economically viable for maize and vegetable production in southern and northern Guinea savannas of Nigeria. In Oyo State, however, maize production using organic fertilizers was found to be less profitable, underscoring the necessity for region-specific strategies (Oyetunde-Usman *et al.*, 2021). Notably, vegetable production proved consistently profitable across both northern and southern states,

likely due to the lower nutrient uptake requirements of these crops (Adediran *et al.*, 2005).

The economic viability of organic fertilizer adoption extends beyond immediate yield benefits. Long-term cost-benefit analyses indicate that while initial investment in organic fertilizers may be higher due to transportation and application costs, the cumulative benefits of improved soil health, reduced input dependency, and enhanced resilience to climate variability result in positive net returns over a 5-7 year period. This finding challenges the conventional short-term economic evaluation framework and supports the integration of long-term sustainability metrics in agricultural policy decisions.

Chemical Characterization of Organic Materials

Nutrient Content

The chemical characterization of 19 organic materials commonly used as fertilizers in Nigeria revealed that animal-derived organic materials exhibit higher nitrogen, phosphorus, and calcium content, greater variability in potassium and magnesium, while those from plant sources have the highest carbon content (Abdulrahman and Aisha, 2021). Poultry manure contained 4.095% nitrogen and 17.36 g/kg phosphorus, making it a potent source of essential nutrients. Similarly, cow dung boasted a high phosphorus content of 21.86 g/kg (Irshad *et al.*, 2011).

Environmental Impact of Organic Fertilizers

Atmospheric Emissions

The main process of transforming organic fertilizers into high nutrient release fertilizers is through composting. Composting of organic materials involves the mineralization and partial humification of the organic matter, leading to a

stabilized final product, generally free of phytotoxic products and pathogens and with some good humic substances (Sharma *et al.*, 2001). Enclosure of compost pile halls, ventilation systems, and biofilters are often insufficient to minimize the burden of compost-derived compounds in the air. Gaseous emissions in composting facilities are typically constituted by volatile organic compounds (VOCs), nitrogen-based compounds, and sulfur-based compounds, as well as bioaerosols (Gaukar *et al.*, 2007). While organic fertilizers offer significant environmental advantages over synthetic alternatives, their production and application are not without environmental considerations. The 10-20% reduction in greenhouse gas emissions observed in our analysis must be balanced against potential methane and nitrous oxide emissions during the composting process. Future research should focus on optimizing composting techniques to minimize these emissions while maximizing nutrient retention. Additionally, the sourcing of organic materials must be managed sustainably to prevent depletion of livestock manure resources and ensure equitable access among smallholder farmers.

Adoption of Organic Fertilizers by Farmers

Socio-Economic Factors

Household size, land ownership, and access to extension services significantly influence the uptake of organic fertilizers. Larger households, secure land tenure, and better access to agricultural advice promote higher adoption rates (Kugbe *et al.*, 2019). Regional differences in organic fertilizer usage reflect the concentration of agricultural activities in the northern savanna regions where livestock rearing is

common, ensuring a steady supply of manure (Adeniyi, 2008).

The adoption barriers identified in our analysis highlight the need for integrated policy interventions. Government subsidies currently favoring synthetic fertilizers should be rebalanced to support organic fertilizer production and distribution networks. Extension services require strengthening to provide farmers with practical guidance on organic fertilizer application rates, timing, and integration with existing farming practices. Furthermore, public-private partnerships could facilitate the establishment of community-based composting facilities, reducing transportation costs and ensuring quality standardization.

Conclusion and Recommendations

Conclusion

Globally, organic fertilizer applications induce a rise in crop yield and SOC stocks. However, our results indicate that the increase effect is linked to many factors and can show large differences. These factors included management decisions, site properties, crop type, organic fertilizer source, and organic fertilizer characteristics. The analysis revealed that organic fertilizer sources like poultry manure, cow dung, and compost produced higher and stable responses of crop yield. These organic fertilizer sources should be promoted in achieving higher and sustainable crop yields. To better understand carbon dynamics, more long-term SOC field data are required, especially the factors influencing carbon saturation need to be further investigated (Mustapha *et al.*, 2020).

Recommendation

It is recommended that the use of organic fertilizer or combined application is more beneficial than artificial fertilizers to preserve soil properties and increase soil

productivity. Exposing farmers to local processes of composting organic materials will enhance their productivity. Encouraging small fertilizer companies to produce organic or organo-mineral fertilizers will assist small-scale farmers' production while ensuring environmental sustainability. Considering the crops investigated with different organic fertilizers in the region, we recommend an application rate of 5 tons/ha for organic fertilizers alone, as this will produce yields above average for most crops and can be easily sourced (Becker *et al.*, 2010).

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Acknowledgements

We would like to thank the Bayero University Kano, Kano State University of Science and Technology, International Institute for Tropical Agriculture, Federal University Dutse, Jigawa State Agricultural Research Institution, Institute of Agricultural Research, Division of Agricultural Colleges, University of Jos, Federal College of Forestry, Jos, and

Usman Danfodio University for their support and access to valuable resources. Special thanks to all the researchers whose work contributed to this comprehensive review.

Funding

This research was funded by LINKS Project, enabling us to conduct extensive field visits and gather crucial data.

COMPREHENSIVE ASSESSMENT OF SOIL ACIDITY AND RELATED SOIL PROPERTIES AT THE NOUN RESEARCH FARM, RIGACHIKUN, KADUNA, NIGERIA

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ABSTRACT

Soil acidity is a critical chemical constraint that affects nutrient availability, microbial activity, and overall soil fertility in tropical agricultural systems. In acidic soils, essential nutrients such as phosphorus, calcium, and magnesium may become less available, while potentially toxic elements, notably aluminum, can accumulate, limiting crop growth and productivity. This study assessed soil acidity and related soil properties at the National Open University of Nigeria (NOUN) Research Farm, Rigachikun, Kaduna State, Nigeria. Soil samples were collected from four experimental plots using a soil auger at a depth of 0–20 cm. A total of twenty composite samples were analyzed for soil pH (in water and 1N KCl), exchangeable acidity, total acidity, pH-dependent acidity, organic carbon content, and particle size distribution using standard laboratory procedures. The results showed that soils were slightly to moderately acidic, with pH-dependent acidity comprising the major portion of total soil acidity. Exchangeable acidity was generally low, indicating minimal risk of aluminum toxicity. Organic carbon levels were low, reflecting limited soil organic matter and potential constraints on nutrient cycling and soil structure. Soil textures ranged from sandy loam to sandy clay loam, suggesting moderate water retention and nutrient-holding capacity. These findings indicate that soil acidity and low organic matter may constrain crop productivity if unmanaged. Integrated soil fertility management, including lime application, organic amendments, and routine soil monitoring, is therefore recommended to enhance soil quality and support sustainable crop production at the research farm.

Keywords: Soil acidity, soil pH, soil fertility, organic carbon, Kaduna State, Nigeria.

Introduction

Soil is a fundamental natural resource for agricultural production, providing physical support, water, and essential nutrients required for plant growth. The productivity of any agricultural system depends on the interplay of soil chemical, physical, and biological properties, which collectively determine its fertility and capacity to sustain crops. Among these properties, soil acidity is a major factor influencing nutrient availability, microbial activity, and overall crop productivity. Soil acidity is defined by

the concentration of hydrogen ions in the soil solution and is commonly expressed as soil pH. Acidic soils are typically characterized by low pH values and elevated concentrations of hydrogen and aluminum ions, which can limit nutrient uptake and negatively affect plant growth (Brady & Weil, 2017; Havlin *et al.*, 2019). In tropical regions, soil acidity often develops as a result of both natural and anthropogenic factors. High rainfall contributes to the leaching of basic cations, including calcium, magnesium, potassium,

and sodium, from the soil profile, thereby promoting acidification (FAO, 2020). Continuous cropping without adequate nutrient replenishment, the repeated application of acid-forming fertilizers, and the weathering of acidic parent materials also exacerbate soil acidification over time (McLean, 2018). These processes alter soil chemical equilibrium, influencing nutrient dynamics critical for optimal plant growth. Soil acidity can have several adverse effects on soil fertility and crop production. Acidic soils reduce the availability of essential nutrients such as phosphorus, which can become fixed by aluminum and iron compounds, and decrease the accessibility of calcium and magnesium. Elevated aluminum and manganese concentrations in acidic soils can become toxic to plant roots, impairing nutrient uptake and reducing crop growth (Havlin *et al.*, 2019). Additionally, soil acidity affects microbial communities responsible for organic matter decomposition and nutrient cycling, further compromising soil fertility (Cao *et al.*, 2024). Consequently, crops grown on highly acidic soils may exhibit stunted growth and reduced yields. Tropical soils, including those in Nigeria, are often highly weathered, inherently low in organic matter, and characterized by low nutrient reserves and limited buffering capacity (Lal, 2020). Studies in Northern Nigeria have documented that continuous cultivation, poor soil management, and acidification have resulted in soils with reduced fertility and productivity, highlighting the importance of assessing soil chemical properties to guide sustainable management practices (Wells *et al.*, 2022).

The National Open University of Nigeria (NOUN) Research Farm at Rigachikun, Kaduna State, serves as a critical site for

agricultural research, training, and experimental crop production. However, detailed information on the soil acidity status and related soil properties of the farm remains limited. Understanding these characteristics is essential for developing site-specific soil fertility management strategies that enhance crop productivity and long-term soil sustainability.

The objective of this study was to comprehensively assess soil acidity and related chemical properties at the NOUN Research Farm, Rigachikun, Kaduna State, Nigeria. Specifically, the study aimed to evaluate soil pH, exchangeable acidity, total acidity, pH-dependent acidity, organic carbon content, and particle size distribution. The results are expected to provide a scientific basis for effective soil management practices that optimize nutrient availability and promote sustainable agricultural production at the research farm.

Materials and Methods

Study area

The study was conducted at the National Open University of Nigeria (NOUN) Research Farm located in Rigachikun, Kaduna State, Nigeria. Rigachikun lies within the Northern Guinea Savanna agro-ecological zone, approximately between Latitude 10°36'–10°40' N and Longitude 7°23'–7°27' E. The area experiences a tropical savanna climate characterized by distinct wet and dry seasons. Annual rainfall ranges from 900 to 1200 mm, with the rainy season occurring mainly between May and October, and the dry season extending from November to April. Mean annual temperatures range from 25°C to 35°C, with relatively high temperatures during the dry season. Relative humidity is generally higher during the rainy season and lower in the dry months.

The natural vegetation of the area is typical of the Northern Guinea Savanna, consisting predominantly of grasses with scattered shrubs and drought-tolerant trees. Common species include savanna grasses and woody plants adapted to seasonal rainfall patterns. The soils of the area are predominantly derived from Basement Complex rocks, and they range from sandy to loamy in texture. These soils are moderately weathered and may exhibit varying degrees of nutrient depletion due to historical agricultural use. The land within the NOUN Research Farm has been used for periodic crop production and agricultural research, which can influence soil fertility and acidity levels, highlighting the need for systematic soil assessment.

Soil Sample Procedure

Soil samples were collected from four experimental plots (Plot A, Plot B, Plot C, and Plot D) within the research farm. Sampling was carried out using a soil auger at a depth of 0–20 cm, representing the topsoil layer where most plant roots and biological activity occur. Within each plot, a systematic sampling approach was adopted, and multiple subsamples were collected from different points to ensure representative sampling. The subsamples from each plot were thoroughly mixed to form composite samples. In total, twenty (20) composite soil samples were collected, labeled according to their respective plots, and transported to the laboratory for further processing and analysis.

Sample Preparation

In the laboratory, soil samples were air-dried at room temperature to remove excess moisture. The dried samples were gently crushed using a mortar and pestle to break down soil aggregates without altering mineral composition. Crushed

samples were then passed through a 2 mm sieve to remove coarse debris, including stones, roots, and other plant residues. The sieved soil samples were stored in clean, labeled plastic bags prior to laboratory analysis.

Laboratory Analysis

Soil Acidity Indicators

Soil acidity was evaluated using multiple parameters. Soil pH was measured in both distilled water and 1 N potassium chloride (KCl) at a 1:2.5 soil-to-solution ratio using a calibrated digital pH meter. Exchangeable acidity, comprising hydrogen (H^+) and aluminum (Al^{3+}) ions, was determined by extracting soil samples with 1 N KCl and quantifying displaced ions via standard titration. Total acidity was also determined using titration procedures, and pH-dependent acidity was calculated as the difference between total acidity and exchangeable acidity:

$$\text{pH-dependent acidity} = \text{Total Acidity} - \text{Exchangeable acidity}$$

Related Soil Chemical Properties

Additional soil chemical properties relevant to fertility were analyzed. Organic carbon was determined using the Walkley–Black wet oxidation method. Total nitrogen was measured using the Kjeldahl digestion method. Available phosphorus was extracted using the Bray-1 method suitable for acidic soils and quantified colorimetrically. Exchangeable bases (Ca, Mg, K, and Na) were extracted with 1 N ammonium acetate (pH 7.0); calcium and magnesium were measured using atomic absorption spectrophotometry, while potassium and sodium were measured with a flame photometer. Cation exchange capacity (CEC) was calculated from the ammonium acetate method, and base

saturation was determined as the percentage of total exchangeable bases relative to CEC.

Particle Size Distribution

Soil texture was determined using the hydrometer method (Day, 1965), which measures the relative proportions of sand, silt, and clay, enabling classification of the soil texture for each plot.

Data Analysis

Laboratory data were analyzed using descriptive statistics, including means and ranges for all measured soil parameters. Results were compared with standard soil fertility rating scales to assess the soil acidity status, nutrient availability, and overall fertility potential of the study area. These analyses provided baseline information for developing effective soil management practices and improving sustainable crop production.

Results

The results of the soil analyses conducted on samples collected from the four experimental plots (Plot A, Plot B, Plot C, and Plot D) at the NOUN Research Farm, Rigachikun, Kaduna State, are summarized in Tables 1 and 2. The analyses focused on soil pH, acidity parameters, organic carbon content, and particle size distribution.

Soil pH values measured in both distilled water (H₂O) and 1 N potassium chloride (KCl) are presented in Table 1. The soil pH in water ranged from 5.6 to 6.1, while pH in KCl ranged from 5.0 to 5.5 across the four plots. The mean soil pH values were 5.85 in water and 5.25 in KCl. Based on standard soil pH classifications, the soils in the study area are moderately acidic. Plot B recorded the highest pH values (6.1 in water and 5.5 in KCl), while Plot C recorded the lowest values (5.6 in water and 5.0 in KCl).

The exchangeable acidity, total acidity, and pH-dependent acidity values for each plot are also shown in Table 1. Exchangeable acidity ranged from 0.25 to 0.35 cmol/kg, indicating that exchangeable aluminum and hydrogen ions are present at low levels. Total acidity ranged from 0.95 to 1.20 cmol/kg, while pH-dependent acidity contributed a major proportion of total acidity, ranging from 0.70 to 0.85 cmol/kg across the plots. These results suggest that most of the acidity in the soils is pH-dependent, reflecting the buffering effects of soil colloids and organic matter.

Organic carbon content of the soils (Table 1) ranged from 0.72% in Plot C to 0.85% in Plot B, with a mean value of 0.79%. These relatively low values indicate limited organic matter content, which can affect soil fertility, nutrient cycling, and water retention.

Soil texture analyses (Table 2) showed that the soils of the study plots were predominantly sandy loam, with Plot C classified as sandy clay loam due to higher clay content. Sand content ranged from 60% to 68%, silt from 18% to 20%, and clay from 14% to 22%. The predominance of sandy soils suggests moderate water retention and low nutrient-holding capacity, which may require proper soil fertility management to maintain productivity.

The summarized results indicate that soils at the NOUN Research Farm are moderately acidic, with low exchangeable acidity but substantial pH-dependent acidity, low organic carbon levels, and predominantly sandy textures. These characteristics provide a baseline understanding of soil chemical and physical conditions relevant to crop production and soil management strategies in the study area.

Table 1. Soil pH and Acidity Parameters of Study Plots

Plot	pH (H ₂ O)	pH (KCl)	Exchangeable Acidity (cmol/kg)	Total Acidity (cmol/kg)	pH-Dependent Acidity (cmol/kg)	Organic Carbon (%)
Plot A	5.8	5.2	0.30	1.10	0.80	0.78
Plot B	6.1	5.5	0.25	0.95	0.70	0.85
Plot C	5.6	5.0	0.35	1.20	0.85	0.72
Plot D	5.9	5.3	0.28	1.05	0.77	0.80

Table 2. Particle Size Distribution and Soil Texture

Plot	Sand (%)	Silt (%)	Clay (%)	Soil Texture
Plot A	68	18	14	Sandy Loam
Plot B	65	20	15	Sandy Loam
Plot C	60	18	22	Sandy Clay Loam
Plot D	63	19	18	Sandy Loam

Discussion

The results of this study indicate that soils at the NOUN Research Farm, Rigachikun, Kaduna State, are predominantly slightly to moderately acidic, with pH values ranging from 5.6 to 6.1 in water and 5.0 to 5.5 in KCl. These pH values suggest that while the soils are generally suitable for a wide range of tropical crops, nutrient availability may be constrained if appropriate management practices are not implemented. The observed acidity is consistent with findings from other tropical regions and Northern Nigerian soils, where high rainfall, leaching of basic cations, continuous cultivation, and the weathering of parent materials contribute to soil acidification (FAO, 2020; Brady & Weil, 2017).

Exchangeable acidity across the plots was relatively low, ranging from 0.25 to 0.35

cmol/kg, indicating that toxic levels of exchangeable aluminum and hydrogen ions

are currently not a major constraint to crop growth. However, the dominance of pH-dependent acidity (0.70–0.85 cmol/kg) suggests that soil colloids and organic matter strongly influence total soil acidity. Functional groups in clay minerals and soil organic matter release hydrogen ions as pH decreases, thereby contributing significantly to soil acidity (McLean, 2018). Over time, continuous cropping without adequate nutrient replenishment could increase soil acidity, affecting crop performance.

The study also revealed low organic carbon content across the plots (0.72–0.85%), reflecting the rapid decomposition of organic matter under tropical climatic conditions (Lal, 2020). Low organic matter negatively affects soil structure, water retention, and cation exchange capacity, and can reduce microbial activity, which is critical for nutrient cycling (Cao *et al.*, 2024; Wells *et al.*, 2022). This suggests that the current fertility status may limit

optimal crop growth unless soil organic matter is improved.

Soil texture varied from sandy loam to sandy clay loam, influencing water retention, nutrient holding capacity, and susceptibility to erosion (Day, 1965). Sandy loam soils in Plots A, B, and D generally have lower nutrient retention and are more prone to leaching, while the sandy clay loam in Plot C has higher clay content, offering improved cation exchange capacity but potentially retaining more acidity.

The combination of moderate acidity and low organic matter can reduce the availability of essential nutrients such as phosphorus, calcium, and magnesium. Phosphorus fixation under acidic conditions occurs due to complexation with aluminum and iron, reducing plant-available phosphorus (Havlin *et al.*, 2019). Similarly, calcium and magnesium deficiencies can occur in acidic soils, which may affect crop growth and productivity.

Agriculturally, these soils are suitable for staple crops such as maize, millet, and sorghum, but without intervention, crop yields may be limited by acidity and nutrient deficiencies. Recommended management strategies include lime application to neutralize soil acidity, incorporation of organic amendments (e.g., compost, manure, crop residues) to enhance organic carbon and microbial activity, and balanced fertilization to replenish essential nutrients (Zhang *et al.*, 2025; Ruiz *et al.*, 2024). Biochar amendments may also help improve soil pH, phosphorus availability, and soil carbon sequestration.

Overall, the findings underscore the importance of integrated soil fertility management, combining liming, organic

matter addition, and nutrient supplementation to sustain soil health and improve crop yields. Regular monitoring of soil pH, exchangeable acidity, and organic carbon content is recommended to guide long-term fertility management and ensure sustainable agricultural production at the NOUN Research Farm.

Conclusion

This study provided a comprehensive assessment of soil acidity and related soil properties at the NOUN Research Farm, Rigachikun, Kaduna State, Nigeria. The results revealed that the soils are generally slightly to moderately acidic, with pH values ranging from 5.6 to 6.1 in water and 5.0 to 5.5 in KCl. The observed difference between pH measured in water and in KCl indicates the presence of potential (pH-dependent) acidity, which is typical of tropical soils and can influence nutrient availability over time.

Exchangeable acidity levels were relatively low, suggesting that toxicity from aluminum and hydrogen ions is not currently a major constraint to crop growth. However, the dominance of pH-dependent acidity highlights the role of soil chemical reactions and the buffering effect of organic matter and clay minerals in regulating overall soil acidity.

The soils exhibited low organic carbon content (0.72–0.85%), reflecting limited organic matter input and rapid decomposition under tropical climatic conditions. Low organic carbon reduces nutrient retention, microbial activity, and soil structural stability, which could limit long-term soil fertility and productivity. Soil texture ranged from sandy loam to sandy clay loam, influencing water retention, nutrient holding capacity, and susceptibility to leaching. Sandy loam soils, which are predominant in the study area,

provide good drainage and aeration but require careful fertility management to sustain productivity.

Overall, the fertility status of the soils at the NOUN Research Farm is constrained by a combination of slight to moderate acidity, low organic matter, and texture-dependent nutrient retention. Essential nutrients such as phosphorus, calcium, and magnesium may be deficient under these conditions.

To enhance soil fertility and support sustainable crop production, it is recommended to adopt integrated soil fertility management practices, including:

- **Liming** to neutralize acidity and improve nutrient availability.
- **Incorporation of organic amendments** such as compost, manure, or crop residues to increase organic carbon content and enhance microbial activity.
- **Balanced fertilizer application** to replenish essential nutrients and sustain crop growth.

Implementation of these measures will improve soil chemical and physical properties, enhance nutrient availability, and promote long-term sustainable agricultural productivity at the NOUN Research Farm.

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UTILIZING GEOSPATIAL TECHNIQUE FOR IMPROVED SOIL CHARACTERIZATION IN MOUNTAINOUS TERRAIN OBANLIKU, CROSS RIVER STATE

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ABSTRACT

This study assessed and predicted soil total nitrogen, available phosphorus, and exchangeable calcium in mountainous area in Obanliku using geostatistical models. A total of 60 composite soil samples were collected randomly at an interval of 200 to 500 meters from a depth of 0-30 cm and analyzed for these properties. Ordinary kriging (OK), simple kriging (SK), inverse distance weighting (IDW) and universal kriging (UK) were used for prediction and were evaluated using coefficient of determination (R^2), correlation concordance coefficient (CCC), means square error (MSE) and root mean square error (RMSE). Our results revealed that available P, total nitrogen and exchangeable cations were low in the area. The maximum predicted TN and available P values in the study area were dominant in the southwestern part of the study area especially for IDW and UK models, while the minimum predicted value for TN was dominant in the northeastern part of the study area across all the model investigated. Maximum predicted values of Ca were dominant in the Southwestern part of the study area while minimum predicted values were dominated northeastern part of the study area for all models. IDW model demonstrated robust predictive capability for TN better than other models having $R^2=0.168$, $CCC=0.261$, $MSE=0.541$). Available phosphorus was better predicted by UK model ($R^2=0.11$, $CCC=0.261$) than other models while IDW predicted exchangeable calcium better than other models. Understanding the spatial distribution and accurate mapping of soil properties at large scale are essential for precision farming, environmental monitoring and modeling.

Keywords: Spatial distribution, prediction, geostatistical models, soil properties

INTRODUCTION

Soil is a dynamic entity with distinct chemical, physical, biological and mineralogical attributes that ceaselessly differ over time and space (Rogerio *et al.* 2006). Variations in these properties are influenced by several factors including parent materials, vegetation, climate, relief and time (Brady and Weil, 2014). Understanding soil variation can be achieved through soil characterization which is very important for sustainable land use and management, and soil productivity.

Essentially, soil characterization ensures that soil is put to the most appropriate and sustainable use (Onyekanne *et al.*, 2012). It provides a powerful resource for the benefit of mankind especially in the area of environmental sustainability and food security (Esu, 2004).

Evaluation and analysis of soil characterization is the main application of geospatial technology in agriculture. Efficient monitoring of soil nutrient contents from geospatial technology is very crucial for farmland soil productivity, sustainable agricultural development and

food security (Peng *et al.*, 2019). Characterization of soil is fundamental to all soil studies, as it is an important tool for soil classification. Soil characterization also helps to document soil properties at research sites, which is essential for the successful transfer of research results to other locations (Boul *et al.*, 2003).

Geospatial technology provides better alternatives to conventional traditional methods, as they can cover large regions with information on spatio-temporal variations in soil characterizations (Mohamed *et al.*, 2019). Such spatio-temporal variations accounts for the soil heterogeneity which tends to occur both at small and large scale within the soil of mountainous terrain (Feng *et al.*, 2008). Concise and correct mapping of soil properties in mountainous soils provides information about the relationship between biogeochemistry cycle and global climatic condition (Bangroo *et al.*, 2017). Soil heterogeneity may be either due to intrinsic soil forming factors influencing differentially during the pedogenic processes or extrinsic factors such as tillage, irrigation, crop rotation and land degradation etc.

Mountains are the inclination of land, causing gravity in interaction with geology to structure the landscape with the resulting topography in turn interacting with climate (solar radiation, wind, snow distribution and allocation of water and substrate) to create a rich habitat diversity (Korner, 2004). Nigeria has over 2000 mountains and hills, prominent among which is the Obudu mountain resort or

cattle ranch. The Obudu cattle ranch occupies an area 24 km² in a mountainous area of Obanliku in northern Cross River State (Al-Amin, 2007). The area is a tourist site that is well known due to its peculiar land form which is characterized by high mountains, abyss, canyons, cold weather condition and has an elevation of over 1650 m above sea level (asl). The inhabitants of the Obudu cattle ranch are peasant farmers who depend solely on agriculture as their source of livelihood, yet little or none is known about the soil soils of the area. This study was designed to (1) predict the distribution of total nitrogen, available phosphorus and calcium, (2) compare the accuracy of OK, UK, IDW and SK in predicting total nitrogen, available phosphorus and calcium in the Obudu cattle ranch.

MATERIALS AND METHODS

Location of the study area

This study was carried out in Obudu cattle ranch, Obanliku Local Government Area of Cross River State. Obudu Cattle Ranch lies between latitude 6° 21' N to 6° 24' N and longitude 9° 22' E to 9° 25' E (Fig. 1). The area has diverse topographic conditions with moist tropical humid climate and elevation up to 1654 meters above sea level. The main parent materials underlying soils of the area is basement complex. The vegetation is that of a tropical rainforest. Annual rainfall in the area is well above 2000 mm. Temperature varies from 15 to 31.80 °C with a mean of 23 °C. Major crops cultivated are vegetables, maize, yam, rice, okra, groundnut and cocoyam.

Fig. 1: Map of Cross River State showing location of the study area

Soil sampling

Sixty (60) composite soil samples were collected after an interval between 200 to 500 meters. The exact locations of the sampling points were determined using Global Positioning System (GPS Model eTrex Legend H) receiver. Soil samples were transported to the soil science plastic bags. Next soil sample was

laboratory of the University of Calabar for physicochemical and analysis.

Laboratory analysis

In the laboratory, soil samples were airdried, gently crushed with pestle, sieved with 2 mm sieve properly stored after which it was analyzed for total nitrogen (TN), available phosphorus (avail P) and exchangeable ca. Total nitrogen was analyzed with modified micro-kjeldhal method (Udo *et al.*, 2009) while available phosphorus was obtained using Bray P-1 method according to the procedures of Kuo (1996). Exchangeable calcium was determined using the extract obtained after leaching samples with one normal neutral ammonium acetate (1 N, NH₄OAC, pH 7.0) solution. Calcium was analyzed using the EDTA titration method as outlined by Udo *et al.* (2009).

Statistical Analysis

The data collected was subjected to descriptive statistical analysis such as mean, minimum, maximum, standard deviation, coefficient of Variation skewness and kurtosis using SPSS software (version 25) and Microsoft Excel 2013. Interpolation and predictions were done using ArcGIS 9.8 and R package.

Geostatistical interpolation methods

The geostatistical techniques used in this study were ordinary kriging (OK), simple kriging (SK), universal kriging (UK) and Inverse Distance Weighting (IDW). OK is broadly used geostatistical method that creates an optimal estimated surface using semi variogram based on regionalized variables. The OK makes use of an assessed average of a given soil characteristics in a location known to forecast the value of location not sampled (Grunwald *et al.*, 2008) (Eqn. 1). SK and UK are aspect or continuation of the kriging procedure which combines the

information determined by a secondary index in relation to the primary quantity that is being forecasted.

$$Z'(x_0) = \sum_{i=1}^n \lambda_i \cdot Z(x_i) \quad (1)$$

where: $Z'(x_0)$ is the estimated/forecasted value for point x_0 , $Z(x_i)$ is the value known, and λ_i stands for kriging weight for the $Z(x_i)$ values. It obtained using a semi-variance function of the variables with criterion that the predicted value is not biased and optimal (Eqn. 2).

$$\gamma(h) = \frac{1}{2N(h)} \sum_{i=1}^n [Z(X_i) - Z(X_i + h)]^2 \quad (2)$$

Where;

$\gamma(h)$ is the semivariance, h the lag distance, Z stands for soil property, $N(h)$ the number of pairs of areas disconnected by a lag distance h , $Z(x_i)$, and $Z(X_i + h)$ are values of Z at positions x_i and $x_i + h$ according to Wang *et al.* (2013).

Four variogram models (spherical, exponential, linear and Gaussian) were used to describe the semivariograms and the best-fitted models were selected with the lowest RMSE, MSE and ME between model predicted variances and the measured values of soil property.

The nugget/sill ratio would be used as a criterion to classify the spatial dependence of soil properties. If the ratio is less than 25%, the variable has strong spatial dependence; between 25 and 75%, the variable has moderate spatial dependence; and greater than 75%, the variable shows only weak spatial dependence (Cambardella *et al.* 1994).

According to Burrough & McDonnell (1998), "IDW is based on the assumption that the value of an attribute in an unsampled area is that of the weighted average of the known data points within a

local neighborhood surrounding the unsampled location”. Estimated values will be interpolated based on the data from surrounding locations using the formula:

$$Z(x_0) = \sum_{i=1}^n w_i Z(x_i) \quad (3)$$

Where,

$Z(x_0)$ is the estimated value, w_i is the weight assigned to the value at each location $Z(x_i)$, n is the number of close neighbouring sampled data points used for estimation.

The weights were estimated using:

$$w_i = \frac{1/d_i^p}{\sum_{i=1}^n 1/d_i^p} \quad (4)$$

Where,

d_i is the distance between the estimated point and the sample point, p is an exponent parameter.

Evaluation of models

The dataset was randomly calibrated into two with a ratio of 70 % and 30%, respectively. The 70 % of the dataset was used for training the model, while 30 % used for validation. Coefficient of determination (R^2), root mean square error (RMSE), and Lin’s concordance correlation coefficient (CCC) were used to compare and select the best model. The formulas are given as:

$$R^2 = 1 - \frac{\sum_{i=1}^n (Z_{oi} - Z_{pi})^2}{\sum_{i=1}^n (Z_{oi} - \bar{Z}_{pi})^2} \quad (5)$$

$$RMSE = \sqrt{\frac{1}{n} \sum_{i=1}^n (Z_{pi} - Z_{oi})^2} \quad (6)$$

$$CCC = \frac{2r\sigma_o\sigma_p}{\sigma_o^2 + \sigma_p^2 + (\bar{Z}_p - \bar{Z}_o)^2} \quad (7)$$

where, Z_{pi} = predicted values, Z_{oi} = observed values, n = the size of the observations, for the i -th term observation, $\bar{Z}_p$ = average of the predicted values, $\bar{Z}_o$ = average of the predicted values, CCC = Lin’s concordance correlation coefficient, σ_o^2 and σ_p^2 are the variances of the predicted and observed values; and r is the Pearson correlation coefficient between the predicted and observed values.

RESULTS AND DISCUSSION

Properties of the studied soil

Total nitrogen (TN) and available phosphorus ranged from 0.1 to 3.8 mg/kg and 2 to 9.25 mg/kg with means of 2.167 mg/kg and 3.89 mg/kg while Ca varied 0.8 to 7.6 cmol/kg with mean of 1.98 cmol/kg. Both TN, available P and Ca were low (Landon, 1991). TN values obtained in this study are in agreement with the results of Akinbola *et al.*, (2001) who stated that most soils of southern Nigeria are low in TN and reported range of 2.4 g/kg and 0.3 g/kg surface and sub-surface soils. Nitrogen is an integral part of many essential plant components such as amino acids, nucleic acids, chlorophyll etc. (Brady and Weil, 2014). Low TN obtained in these soils therefore has serious negative implication for crop photosynthesis and overall performance of crops in the area. Low available P in the studied soils may be due to deficiency of apatite mineral in basement complex parent materials. The deficiency of phosphorus in soil impairs fruit production and quality traits during the plant vegetative growth cycle (Li *et al.*, 2021). In response to limited phosphorus availability, plants undergo adaptive changes to enhance photosynthetic efficiency (Khan *et al.*, 2023). Furthermore, low Ca content of these

studied soils may have resulted from counter-cation for inorganic and organic leaching due to high rainfall that anions in the vacuole, and as an characterizes the Obudu cattle ranch. intracellular messenger in the cytosol Calcium plays structural roles in plant cell (White and Broadley, 2003). wall and membranes and serves as a

Table 1: Summary statistics for studied soil properties

Soil property	Min.	Max.	Mean	Standard Dev.	CV	Skewness	Kurtosis
TN (mg/kg)	0.1	3.8	2.167	0.826	0.381	-0.252	-0.261
Avail. P (mg/kg)	2.0	9.25	3.89	3.309	0.77	5.725	38.586
Ca (cmol/kg)	0.8	7.6	1.989	1.302	0.655	2.812	8.157

CV = Coefficient of Variation

Spatial dependency of measured soil properties

The results in Tables 2, 3 and 4 show the parameters of measured total nitrogen, available phosphorus and exchangeable calcium model through semivariograms (Figures 2, 3 and 4). Exponential, Gaussian, and spherical models had different capacities in modelling TN, available P and calcium with OK, SK and UK interpolation techniques. The TN had a nugget/sill ratio of 9.7 %, 29.41 % and 39.81 % with OK, SK and UK models while available phosphorus had a nugget/sill ratio of 46.39 %, 15 % and 22.14 % with OK, SK and UK models respectively. Similarly, calcium had a Nugget/Sill ratio of 7.72 %, 0.083 % and 0.053 % with OK, SK and UK models accordingly. The TN model estimated through OK had strong degree of spatial dependence (nugget/sill ratio < 25 %) while TN estimated with SK and UK models had moderate degree of spatial dependence (nugget/sill ratio = 25-75%) (Table 2). The available P model estimated through OK and UK had moderate degree of spatial dependence (nugget/sill ratio =

25-70 %) while available P estimated with SK model had strong degree of spatial dependence (nugget/sill ratio < 25 %). Furthermore, calcium model estimated through OK and UK all had strong degree of spatial dependence (nugget/sill ratio <25 %) (Table 4). A lower nugget/sill ratio for these investigated soil properties suggests that factors such as climate, parent material, topography, soil properties and other natural factors, play a significant role in their spatial variability in the study area. The range values were higher for calcium than other properties and were of 165.05 m (OK), 150.32 m (SK) and 795.26 m (UK) for TN, 1,103 m (OK), 70 m (SK) and 95.89 m (UK) for available P and 389.36 m (OK), 987.33 m (SK) and 1027 m (UK) for calcium meaning distance larger than the range of values obtained in this study, spatial dependence does not exist for these soil properties. In a similar study, Pham *et al.* (2019) obtained lower nugget/sill value of 0.13 for TN and opined that since the nugget/sill is greater than zero, the separated observation by smallest distances is dissimilar.

Table 2: Semivariogram parameters of measure total nitrogen (mg/kg)

Interpolation technique	Model	Nugget (C ₀)	Partial Sill (C ₁)	Sill (C ₀ +C ₁)	Range (m)	Nugget /Sill	Spatial Class
OK	Exponential	0.0563	0.524	0.5803	165.05	9.70	Strong
SK	Gaussian	0.155	0.372	0.527	150.32	29.41	Moderate
UK	Spherical	0.248	0.375	0.623	795.26	39.81	Moderate

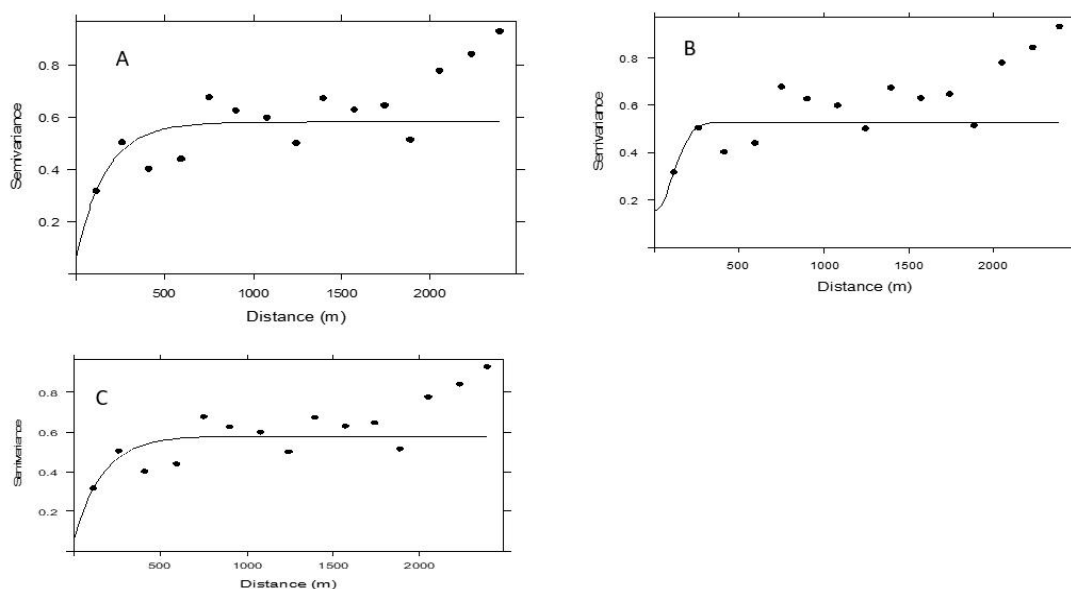


Fig. 2: Simivariogram model for measured soil total nitrogen

Table 3: Semivariogram parameters of measure available phosphorus (mg/kg)

Interpolation technique	Model	Nugget (C ₀)	Partial Sill (C ₁)	Sill (C ₀ +C ₁)	Range (m)	Nugget/ Sill	Spatial Class
OK	Gaussian	1.488	1.719	3.207	1103.30	46.39	Moderate
SK	Gaussian	0.501	2.661	3.162	70.01	15.8	Strong
UK	Gaussian	0.700	2.461	3.161	95.89	22.14	Moderate

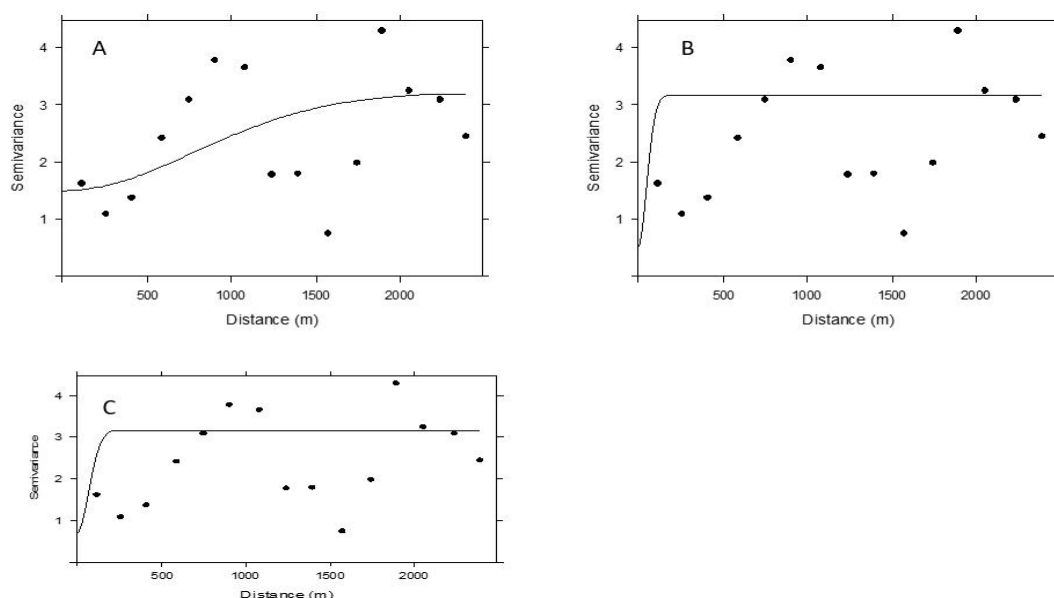


Fig. 3: Simivariogram model for measured soil available phosphorus

Table 4: Semivariogram parameters of measure exchangeable calcium (cmol/kg)

Interpolation technique	Model	Nugget (C_0)	Partial Sill (C_1)	Sill (C_0+C_1)	Range (m)	Nugget/Sill	Spatial Class
OK	Gaussian	0.099	1.184	1.283	389.36	7.72	Strong
SK	Spherical	0.001	1.202	1.203	987.33	0.083	Strong
UK	Exponential	0.001	1.889	1.89	1027.75	0.053	Strong

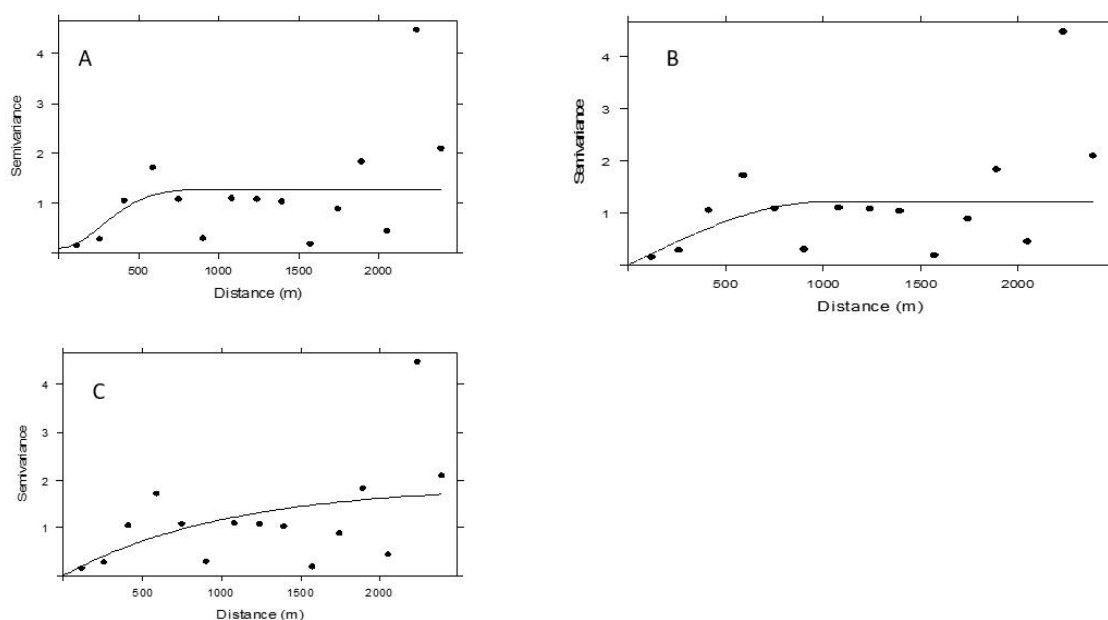


Fig. 4: Semivariogram model for measured soil exchangeable calcium

Spatial prediction and mapping of soil properties

The spatial distribution maps of soil TN, available P and calcium predicted by IDW, OK, SK and UK are given in figures 5, 6 and 7 while their summary statistic are presented Table 5. The mean values of TN predicted were 2.23 mg/kg (OK), 2.21 mg/kg (SK), 2.25 mg/kg (IDW) and 2.31 mg/kg while the mean predicted values of available P were 4.08 mg/kg (OK), 4.05 mg/kg (SK), 4.19 mg/kg (IDW) and 4.35 mg/kg (UK). Similarly, the predicted mean values of calcium were 2.32 cmol/kg (OK), 2.14 cmol/kg (SK), 2.39 cmol/kg (IDW) and 2.44 cmol/kg (UK). These values are within the range of measured mean values of 1.98 cmol/kg, 3.89 mg/kg and 2.167 mg/kg obtained for calcium, available P and TN in the study area. The results also showed that both minimum and maximum predicted values of the studied soil properties are within the range of measured values obtained from the study area (Tables 5). The maximum measured TN in the study

area was 3.80 and the maximum predicted values by OK, SK, IDW and UK were 3.25 mg/kg, 3.25 mg/kg, 3.71 mg/kg and 3.43mg/kg respectively (Fig. 5) which was dominant in the southwestern part of the study area in especially for IDW and UK models while the minimum predicted values dominated northeastern part of the study area across all the model investigated. Similarly, the maximum predicted available phosphorus dominated southwestern part of the study area in especially for IDW and UK models while the minimum predicted values spread across the entire area (figure 6). The spatial distribution map of exchangeable Ca (Fig. 7) shows that maximum predicted values of Ca were dominant in the Southwestern part of the study area while minimum predicted values were dominated northeastern part of the study area for all models. The findings of this study are in line the studies of John *et al.* (2020) and Mosleh *et al.* (2016) on spatial mapping of soil properties.

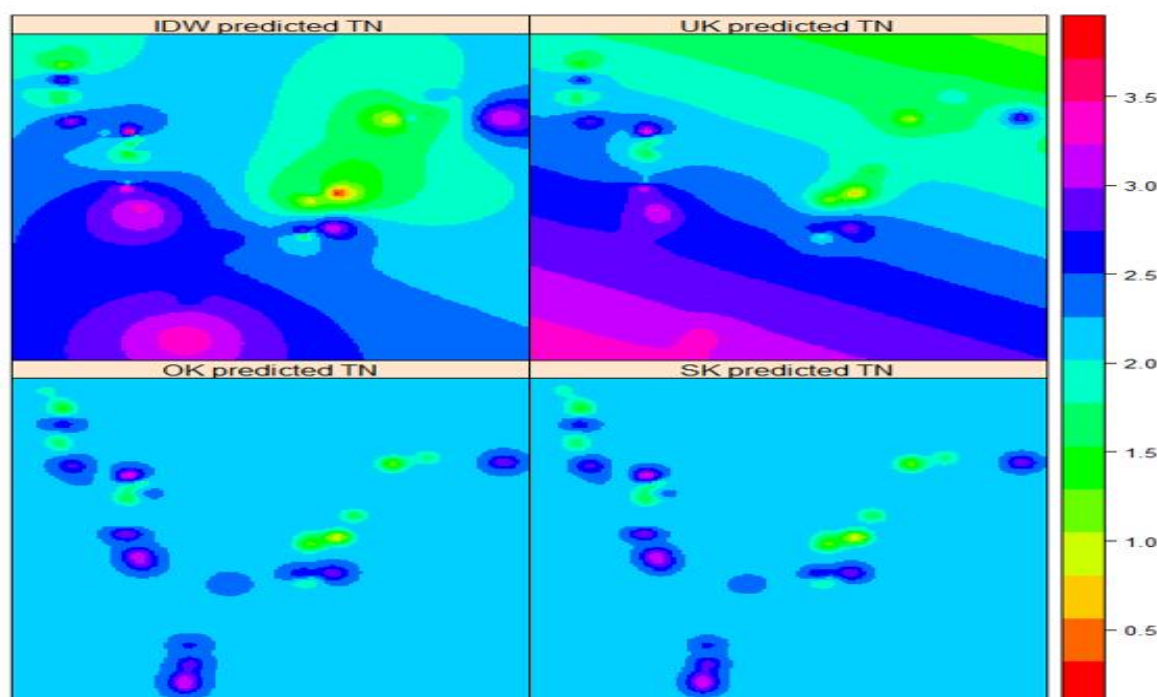


Figure 5: Spatial distribution of total nitrogen by IDW, OK, SK and UK

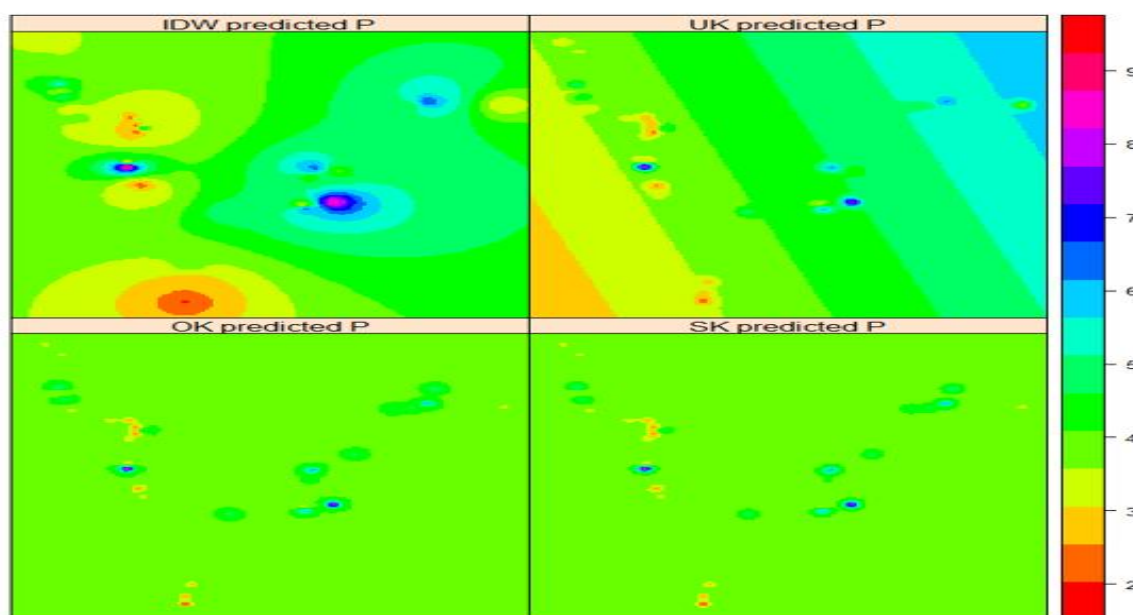


Figure 6: Spatial distribution of available P by IDW, OK, SK and UK

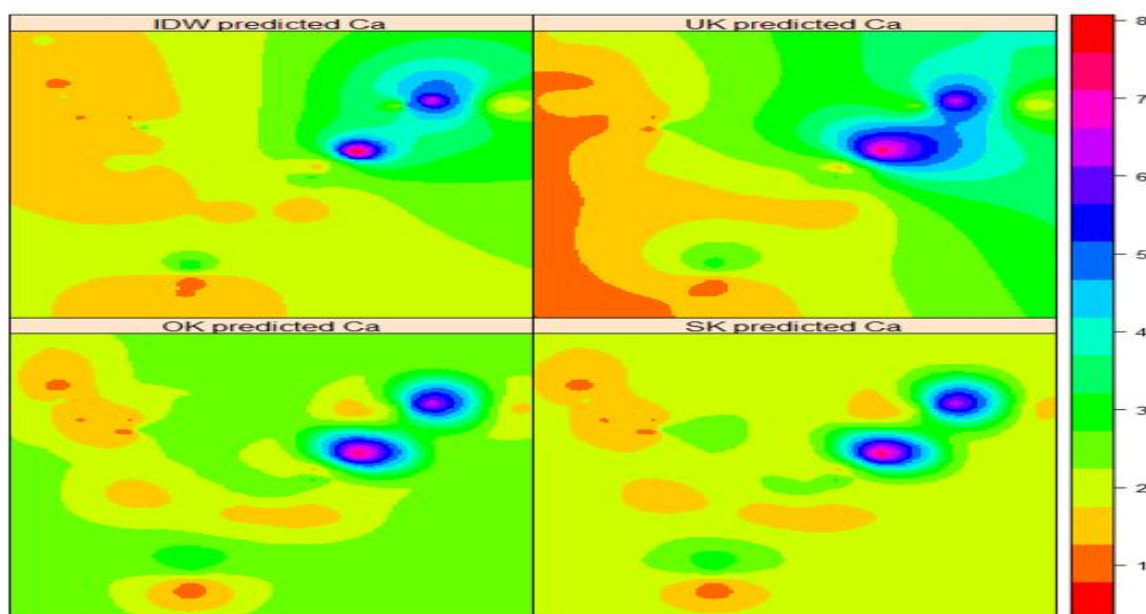


Figure 7: Spatial distribution of exchangeable calcium by IDW, OK, SK and UK

Evaluation of model performance

The average MSE, RMSE, R^2 , and CCC for TN, available P and Ca prediction by cross-validation are shown in Table 6. The results showed that the models have different abilities to predict TN, available P and Ca. IDW better predicted TN ($R^2 = 0.16$) and Ca ($R^2 = 0.662$) with high

precision while OK indicated least capability or poor prediction

for TN as shown by its least R^2 values for TN and Ca. Contrarily, UK best predicted available P ($R^2 = 0.11$) compared to other models. Contrary to the results of this study where IDW best predicted TN, Pham *et al.* (2019) reported that OK was more

accurate in prediction of TN than other models in their study. Furthermore, the Yao *et al.*

Table 5: Descriptive statistics of predicted TN, Avail. P and Exch. Ca

	TN (mg/kg)			Avail. P (mg/kg)			Exch. Ca (cmol/kg)		Mean
	Min	Max	Mean	Min	Max	Mean	Min	Max	
Lab. Det. value	0.10	3.80	2.167	2.0	9.25	3.89	0.80	7.60	1.98
OK predicted	0.874	3.258	2.237	2.40	8.38	4.08	1.02	7.53	2.32
SK predicted	0.866	3.252	2.211	2.4	8.37	4.05	1.02	7.52	2.14
IDW predicted	0.314	3.716	2.252	2.01	9.25	4.19	1.00	7.58	2.39
UK predicted	0.597	3.435	2.307	2.35	7.85	4.35	0.76	7.54	2.44

(2020) in their study stated that indices of cross-validation of machine learning models such as mean error, mean standardization error obtained were close to zero for OK indicating it reliable method to predict spatial distribution of TN. Nevertheless, different indices have been used in different studies to cross-validate or evaluate machine learning models with such studies showing that capability of prediction of soil properties varies with machine learning models. For instance, Zhang *et al.* (2010) in their study found that kriging with land use-soil type information (KLUST) ($r=0.854$, $RMSE=3.47$ g/kg) better predicted soil properties than OK ($r=0.383$, $RMSE=6.49$ g/kg) while Lu *et al.* (2024) found that geographically weighed regression kriging (GWRK) demonstrated better predictive capability for total phosphorus ($R^2=0.67$) than OK ($R^2=0.62$) and regression kriging ($R^2=0.63$).

Conclusion

Soil total nitrogen, available phosphorus, and exchangeable calcium are essential indicators of soil fertility. Understanding the spatial distribution and accurate mapping of soil properties at large scale are essential for precision farming, environmental monitoring, and modeling. Measured TN, available P and Ca were rated low in the soil. Soil available phosphorus and exchangeable calcium were best modelled by gaussian model while TN was best modelled by exponential model with OK, SK and UK interpolation techniques. The IDW had robust capability for prediction of TN and exchangeable calcium than other models whereas UK model predicted available phosphorus better than other models. The maximum predicted TN in the study area was dominant in the Southwestern part of

the study area in especially for IDW and UK models, while the minimum predicted TN was dominant in the northeastern part of the study area across all the model investigated. The maximum predicted available phosphorus in the study area was dominant in the southwestern part of the study area in especially for IDW and UK models, while minimum value for available phosphorus was dominant across the entire study areas for all models under investigated. The maximum predicted exchangeable calcium in the study area was dominant in the southwestern part of the study area in for all models, while the minimum predicted value for exchangeable calcium dominated nearly the northeast directions.

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Table 6: Performance of machine learning model in predicting TN, Avail. P and Ca

Model	TN					Avail. P					Exch. Ca				
	R2	CCC	MSE	RMSE	Bias	R2	CCC	MSE	RMSE	Bias	R2	CCC	MSE	RMSE	Bias
OK	0.018	0.054	0.657	0.811	0.134	0.008	0.024	0.827	0.909	0.485	0.598	0.686	0.584	0.764	0.367
SK	0.021	0.058	0.650	0.806	0.117	0.009	0.025	0.806	0.897	0.464	0.612	0.703	0.534	0.732	0.326
IDW	0.168	0.261	0.541	0.735	0.061	0.075	0.217	0.965	0.982	0.448	0.662	0.729	0.501	0.708	0.339
UK	0.109	0.219	0.589	0.767	0.098	0.11	0.261	0.881	0.938	0.444	0.653	0.714	0.565	0.752	0.385

EVALUATION OF COASTAL PLAIN SANDS UNDER COMBINED USE OF CaCO_3 AND NPK FERTILIZER FOR GROUNDNUT (*ARACHIS HYPOGAEA*) PRODUCTION

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ABSTRACT

The inherently low fertility status of tropical soils, especially coastal plain sands, has necessitated the need for sound soil fertility improvement practices which in recent time have included adoption of appropriate and adequate fertilizer packages. This study evaluated the effects of inorganic fertilizer (NPK) and lime on soil physicochemical properties under groundnut cultivation. Fertilizer (NPK) rates of 0, 100, 150 and 200 kg/ha in factorial combination with two levels of lime in the form of calcium carbonate [without (0 kg/ha) and with (500 kg/ha)] were laid out in a completely randomized design. The study results showed that application of lime significantly ($p \leq 0.05$) influenced the soil chemical composition as did the NPK. The soil organic matter, total nitrogen, available phosphorus, exchangeable calcium, magnesium, potassium and sodium were significantly ($p \leq 0.05$) higher across the treated plots than in the control plots. These nutrients were similarly influenced ($p \leq 0.05$) by liming and were highest in the 200 kg/ha plus lime plots. The activities of H^+ were significantly reduced mainly due to the liming materials applied which enhanced the availability of exchangeable bases for uptake. Therefore, for acidic soils, lime-combined fertilization schemes can increase fertilizer use efficiency for crop productivity. Thus, to achieve optimum production of groundnut, in acidic soils of South-Eastern Nigeria, application of 200 kg/ha NPK and CaCO_3 (500 kg/ha) could be recommended, though subject to field validation in future trials.

Keywords: Soil acidity; coastal plain sands; lime; inorganic fertilizer; *Arachis hypogaea*

Introduction

Coastal plain sands refer to the type of soil found in coastal areas that are primarily composed of sand particles. These soils do have good drainage due to large particles, but they often lack essential nutrients and organic matter (Alfred *et al.*, 2003). Coastal plain sands are commonly used for agriculture but may require nutrient management to support plant growth and development. They exhibit several distinct

characteristics such as high aluminum saturation, which is the most widespread problem with acid soils that could lead to P adsorption, reduction in P mobility and its availability for plant uptake (Kopittke *et al.*, 2016). Coastal plain sands are low in basic nutrients (TN, OC, Ca, Mg, P and K) and high in soluble and exchangeable Al and Mn (Hanson, 2011). They also exhibit low fertility status due to their low nutrient-holding capacity, poor water retention,

rapid decline in productivity and high rates of soil and environmental degradation (Obi and Udoh, 2012). Lime application (CaCO_3) is very effective as an acid ameliorant and calcium source for groundnut yield on acidic soils. Liming is the most common management practice used to neutralize the acid produced in soil, and to also overcome the problems associated with soil acidification (Fageria and Baligar, 2003). Most plants grow well at a pH range of 5.5–6.5 (Perry, 2012), and liming is aimed to maintain the pH at this range. Surface liming ameliorates topsoil acidity. However, there is need to take into consideration lime placement on both top and sub-soil surfaces to ensure optimum release of nutrients and maximum yields. It enhances soil properties and supports the mobilization of plant nutrients, immobilization of toxic heavy metals, and improvements in soil structure and hydraulic conductivity (Adriano, 2001). Groundnut (*Arachis hypogaea* L.), also known as *Peanut*, *Goober*, *Pindar* or *Monkey nut* is a member of *Fabaceae* (or *Leguminosae*) commonly known as the legume, bean or pea family. Groundnut is a popular oil seed crop grown in many countries across the globe. It is economically very important and has several uses (Mbonwa, 2013). Groundnut is a self-pollinating annual, herbaceous legume crop grown mainly for its edible seeds (Sun, 2005). Growing ground nuts without replenishing calcium in soil has a direct impact on its production, particularly in yield and quality (Sorenson and Butt, 2008). World annual production of shelled groundnuts was 44 million tons/ha in 2016, led by China with 38 % of the world total production rate (Pathak, 2010). In West Africa, Nigeria is the largest groundnut producing country accounting for 51 % of

groundnut production in the region, 39 % in Africa and 10 % in global groundnut production (Ajeigbe *et al.*, 2014). Groundnut is valued for its high oil quality content which ranges from 44 % to 56 % with an average of 50 % (Cobb and Johnson, 2010).

Although inorganic NPK fertilizers increase soil fertility and crop yield, they are very expensive and therefore increase cost of production. The improvements of environmental conditions as well as the need to reduce cost of fertilizing crops are reasons for advocating for the use of agricultural limes for better nutrient cycling. Continuous application of mineral fertilizers in tropical soils is associated with reduced crop yield, increased soil acidity and nutrient imbalance. Therefore, a combination of organic materials, including lime and mineral fertilizers is important for management of these soils for high yield and quality harvest (Hassan *et al.* 2007; Otie *et al.*, 2018). The production of groundnut on acid soils of South-Eastern Nigeria has been hindered by soil acidity (Nte *et al.*, 2022). In this study, we tested the effectiveness of NPK (15:15:15) with or without lime application in supporting the growth and yield of groundnut on an acid soil.

Materials and methods

Study area

The study was conducted in the screen house of the University of Calabar, Calabar. The University of Calabar lies between the coordinates 4.9738° N and 8.3410° E. The area has an average annual rainfall of 2750 mm and an annual average temperature of 26.1°C.

Soil sample collection and preparation

Soil samples were collected randomly from 24 points in the experimental area designated for use in groundnut cultivation,

using a soil auger to the plough layer of 0-15 and 15-30 cm. The composite samples were weighed (2.0 kg) into a polythene bag for initial soil physicochemical analysis. Subsequently, samples were collected from each experimental unit after harvest and composited according to the treatment combinations and sent for post-cropping soil analysis in the Soil Science Research Laboratory of the University of Calabar, Calabar.

Experimental design

The study was a factorial experiment with four levels of NPK fertilizer (0 kg/ha NPK-control, 100 kg/ha NPK, 150 kg/ha NPK and 200 kg/ha NPK) and two levels of agricultural lime (CaCO_3) (without-0 kg/ha and with-500 kg/ha) arranged in a completely randomized design (CRD). The total number of treatment combinations were $4 \times 2 = 8$ and replicated four (4) times to give a total of thirty-two (32) experimental plots.

Laboratory Analysis

Particle size distribution was determined by Bouyocous Hydrometer method (Udo *et al.*, 2009) using sodium hexametaphosphate as dispersant. The chemical analysis was done using the standard procedures of Udo *et al.* (2009). The soil pH was determined with a pH meter in a 1:2.5 soil: water suspension using a glass-electrode. Total N was determined by micro-Kjeldahl method (Black, 1965) as modified by Jackson (1989). Available phosphorus was extracted with acidic fluoride using the Bray P1 method (Bray and Kurtz, 1945); phosphorus in the extract was determined calorimetrically by the molybdenum blue method of Murphy and Riley (1962). Exchangeable bases (K, Ca, Mg and Na) were extracted with IN NH_4OAc using 1:10 soil solution ratio. Potassium and sodium in the filtrate were

determined with a flame photometer, while calcium and magnesium were determined with an atomic absorption spectrophotometer (Model 6405 UV/visible spectrophotometer, Jenway, U K). Exchangeable acidity was determined by successive leaching of the soil with neutral un-buffered IN KCl using a 1:10 soil liquid ratio. The amount of acidity (H and Al) in the leachate was estimated by titration with 0.05 NaOH to a permanent pink end point using phenolphthalein indicator (Maclean, 1982). The effective cation exchange capacity (ECEC) was determined by summing the exchangeable bases and exchangeable acidity (Juo, 1981). Organic carbon was determined by the dichromate wet oxidation method of Walkley and Black (1934). The result was multiplied by vanBemmelen factor of 1.724 (Page *et al.*, 1982) to estimate the soil organic matter content.

Statistics

The experimental soil data were subjected to analysis of variance using GenStat software 16.1 (GenStat Sixteenth Edition, Rothamsted Experimental Station, Harpenden, UK) to partition the effects of the 2-factor experiment and their interactions. Means were compared using Duncan's new multiple-range test at a 5 % level of probability.

Results and Discussion

Physicochemical properties of experimental soil

The physicochemical properties of the soil before planting are presented in Table 1. The particle size distribution of the pre-cropped soil was dominated by sand with 663.0 gkg^{-1} , followed by clay (177.0 gkg^{-1}) and silt (160.0 gkg^{-1}). The soil was

classified as sandy loam and characterized by weak surface aggregation. Such soil drains excess water quickly and cannot hold significant amounts of water or nutrients for plant use. The soil reaction (5.2) was strongly acid. The acidity levels in the soil could be partly attributed to moderate rainfall and removal of bases during eluviation process (Faji and Mohammed, 2000). The organic matter content of the plough layer (0-30 cm) was 12.80 g kg^{-1} . This low value may be due to high mineralization resulting to increased microbial activities, and low natural organic matter returns (Ovie *et al.*, 2013). Similarly, the total nitrogen content was low (1.10 g kg^{-1}), which confirmed the general observation that Calabar soils are deficient in total nitrogen. Available phosphorus (Av. P) was high (18.25 mg kg^{-1}) suggesting high rate of P mineralization together with high inorganic available P within the experimental soil (Ubi *et al.*, 2013). The exchangeable base values (cmol kg^{-1}) were 6.80 for Ca, 1.20 for Mg, 0.09 for Na and 0.11 for K. The low exchangeable bases, especially Na and K, may be due to effect of annual water table fluctuations that leach nutrients down the soil profile, a peculiar characteristic of coastal sands. Among the exchangeable cations, higher Mg and Ca contents were observed to be the most predominant cation in tropical soils due to their strong absorption and rapid release into the soil through mineral weathering (Onwudike *et al.*, 2017; Ekpenkhio, 2018). The low exchangeable acidity values for Al^{3+} and H^{+} (0.52 and $0.80 \text{ cmol kg}^{-1}$) indicate that Al toxicity was not likely to occur (Raji and Mohammed, 2000). The soil was also characterized by moderate effective cation exchange capacity (ECEC) of $9.52 \text{ cmol kg}^{-1}$ as against its standard range of <10

cmol kg^{-1} , showcasing the poor fertility status of the soil. Soils of coastal plain sands are generally low in soil fertility (Obi and Udoh, 2012), which affects crop production negatively. The soil base saturation (860.0 g kg^{-1}) was high, but could support crop production, despite the 600 g kg^{-1} recommended for agricultural soils (Labaz *et al.*, 2016).

Physicochemical properties of the experimental soil after sowing

There was no significant effect of the treatments, whether singly or in combination on the soil particle size distribution in the study (Table 2). This may be due to the parent material of the coastal plain sands that originates from cretaceous sandstones and pleistocene unconsolidated coastal sediments (Ogunleye *et al.*, 2024). The same trend occurred in plots that were amended with CaCO_3 . Lime materials are known to have neutralizing effects on acid soils (Nweke and Nsoanya, 2013). The highest pH value of 7.54 was obtained where 500 kg ha^{-1} CaCO_3 was applied. This result may probably be related to the high concentration of basic cations in lime materials (Erniani *et al.*, 2004). The treatment combination also boosted the soil OM contents. The highest OM was obtained in the highest NPK plots plus lime treatment ($F_1Lm_1 = 50.36 \text{ g kg}^{-1}$), relative to the control ($F_0Lm_0 = 6.10 \text{ g kg}^{-1}$). The increase in OM content of the soil across the treatments might be due to a progressive increase on the activities of beneficial microbes in the rhizosphere where root growth is improved by fixation of atmospheric nitrogen (Olalekan *et al.*, 2017). Nitrogen content (TN) of the soil was increased ($p \leq 0.05$) remarkably as a result of the treatments effect. However, the NPK application revealed a lower TN

content, which decreased with decreasing plant's active uptake of $\text{NO}_3^- \text{N}$ (Nacry *et al.*, 2013). NPK rates applied. This observation could

be attributed to a direct consequence of the

Table 1. Soil physicochemical properties before sowing

Soil property	Value	Sufficiency limit
Particle size:		
Clay (g kg^{-1})	177.0	NL
Silt (g kg^{-1})	160.0	NL
Sand (g kg^{-1})	663.0	NL
Soil texture	Sandy Loam	-
pH (H_2O)	5.2	5.5 - 6.5
Organic matter (g kg^{-1})	12.80	20 ++
Total Nitrogen (g kg^{-1})	1.10	2.0 ++
Available P (mg kg^{-1})	18.25	2.0 +++
Exchangeable Bases (cmol kg^{-1}):		
Calcium (Ca)	6.80	10.20 +++
Magnesium (Mg)	1.20	3 - 8 +++
Sodium (Na)	0.09	0.7 – 1.2 +++
Potassium (K)	0.11	0.6-1.2 +++
ECEC (cmol/kg)	9.52	10.0 +++
Base saturation (g kg^{-1})	860.0	600 - 800 +
Exchangeable acidity (cmol kg^{-1}):		
Aluminum (Al^{3+})	0.52	4.1 +++
Hydrogen (H^+)	0.80	2.1-4 +++

NL = No Limit; + = Landon (1991); ++ = FPDD (1990); +++ = Holand *et al.* (1989)

The significant impact of plant uptake on N highlights the dynamic nature of nutrient exchange between the soil and the plant. Significant differences ($p \leq 0.05$) in available P occurred because of combined NPK application and CaCO_3 . The reduction in soil acidity due to liming must have encouraged the solubility of adsorbed P (Osodeke and Ubah, 2005).

Liming can contribute to lowering Al toxicity and increase available P (Mbah *et al.*, 2010). Exchangeable bases (Ca and Mg) were significantly higher in plots treated with sole CaCO_3 than those of NPK (Table 4). Highly weathered tropical soils are low in exchangeable bases and crops grown on such soils exhibit deficiency, especially when exchangeable Ca is $< 1 \text{ cmol kg}^{-1}$ (Achal *et al.*, 2012).

Sources of variance	Sand (g kg^{-1})	Silt (g kg^{-1})	Clay (g kg^{-1})
NPK levels (F)	NS	NS	NS
CaCO_3 (Lm)	NS	NS	NS

F x Lm

NS

NS

NS

Table 2.
Summary

of analysis of variance for soil particle size distribution after sowing

NS= not significant at $p \leq 0.05$

Table 3. Summary of analysis of variance for soil reaction, organic matter, total nitrogen, available phosphorus, calcium and magnesium

Sources of variance	pH (H ₂ O)	OM (g kg ⁻¹)	TN (g kg ⁻¹)	Av. P (cmol kg ⁻¹)	Ca (cmol kg ⁻¹)	Mg (cmol kg ⁻¹)
NPK levels (F)	<.001**	<.001**	<.001**	<.001**	<.001**	<.001**
CaCO ₃ (Lm)	<.001**	<.001**	<.001**	<.001**	<.001**	<.001**
F x Lm	<.001**	<.001**	<.001**	<.001**	<.001**	<.001**

** highly significant at $p \leq 0.05$

Table 4. The interaction effect of NPK rates and lime on soil reaction, organic matter, total nitrogen, available phosphorus, calcium and magnesium sown to

Treatment	pH (H ₂ O)	OM (g kg ⁻¹)	TN (g kg ⁻¹)	Av. P (cmol kg ⁻¹)	Ca (cmol kg ⁻¹)	Mg (cmol kg ⁻¹)
Pre-cropping	5.2	12.80	1.10	18.25	6.80	1.20
F x Lm						
F ₀ Lm ₀	4.52 e	6.10 h	0.27 g	27.65 f	2.60 f	0.30 e
F ₀ Lm ₁	5.87 c	18.32 d	0.76 cd	35.59 c	4.45 cd	0.93 d
F ₁ Lm ₀	5.33 d	15.32 e	0.63 de	33.56 d	3.89 de	0.53 e
F ₁ Lm ₁	7.54 a	50.36 a	1.90 a	49.93 a	7.30 a	2.21 a
F ₂ Lm ₀	5.14 d	14.20 f	0.55 ef	32.83 d	3.89 de	0.48 e
F ₂ Lm ₁	6.52 b	20.93 b	1.07 b	38.83 b	5.89 b	1.72 b
F ₃ Lm ₀	5.20 d	11.38 g	0.41 fg	29.63 e	3.47 e	0.41 e
F ₃ Lm ₁	6.01 c	19.66 c	0.85 c	35.95 c	4.77 c	1.32 c

groundnut

The effect of NPK and lime on the soil properties (K, Na, H⁺, ECEC, and BS) is shown in Table 5. The increasing NPK rate significantly increased K and Na, except at

the 100 kg/ha rate. In Nigeria, soil acidity is a major limitation to economical yield of legumes due to poor root proliferation, which affects nutrition. Amendment of lime on acidic soils has been noted to improve soil properties by stabilizing organic matter content through enhanced nutrients mineralization. Among the nutrients stimulated and made available in the soil include: N, P, K, Na, Ca and Mg (Adeli et al., 2017). Calcium carbonate at the 500 kg/ha level supplied more bases (K and Na)

relative to the control. Lime applied at 500 kg/ha plus 200 kg/ha NPK recorded the highest ($p \leq 0.05$) K and Na ($F_1Lm_1 = 0.99$ and 0.21 cmol/kg, respectively), relative to the control ($F_0Lm_0 = 0.07$ and 0.05 cmol/kg, respectively). Soil acidity is inhibitive to nutrients precipitation and suppressive to crop growth and yield. In support of this, Mulungu *et al.* (2013) noted that in acidic soil, K, Ca or Mg availability is hindered in addition to beneficial nutrients such as N, P and S, which are important to groundnut production. The exchangeable acidity (H^+)

Table 5. The effect of NPK rates and lime on soil potassium, sodium, exchangeable acidity, effective cation exchange capacity and base saturation of soil sown to groundnut

Treatment	K (cmol kg ⁻¹)	Na (cmol kg ⁻¹)	H ⁺ (cmol kg ⁻¹)	ECEC (cmol kg ⁻¹)	BS (g kg ⁻¹)	Mean pairs with in a column with different letters are significantly different at the 5% prob
Pre-cropping	0.11	0.09	0.80	9.52	860.0	
F x Lm						
F ₀ Lm ₀	0.07 f	0.05 e	0.95 a	4.81 f	727.94 c	
F ₀ Lm ₁	0.32 d	0.10 cd	0.66 cd	6.68 c	851.76 b	
F ₁ Lm ₀	0.21 e	0.09 d	0.71 c	5.88 de	874.02 ab	
F ₁ Lm ₁	0.99 a	0.21 a	0.35 f	9.91 a	938.38 a	
F ₂ Lm ₀	0.11 f	0.08 de	0.81 b	5.32 ef	870.68 ab	
F ₂ Lm ₁	0.72 b	0.17 b	0.48 e	7.38 b	894.03 ab	
F ₃ Lm ₀	0.12 f	0.08 de	0.92 a	5.26 ef	853.88 b	
F ₃ Lm ₁	0.53 c	0.13 c	0.57 de	6.29 cd	870.00 ab	

ability level according to Duncan's new multiple-range test; NPK level (F); F₀= 0 kg/ha NPK; F₁= 200 kg/ha NPK; F₂= 150 kg/ha NPK; F₃= 100 kg/ha NPK; CaCO₃= Lm; Lm₀= without CaCO₃ application; Lm₁= with CaCO₃ application.

was generally low following the treatment effects, especially at the 200 kg/ha rate, with or without liming. These low levels of exchangeable acidity could have boosted the CEC activity (Adeli *et al.*, 2017). The ECEC was similarly improved ($p \leq 0.05$) following the NPK and lime effects. Liming acidic soils indirectly increases the effective cation exchange capacity (ECEC) of the soils. The highest (9.91 cmol/kg) value of ECEC were observed under the highest treatment application, indicative that liming agricultural soil is profitable and could hydrolyze Al and Fe ions for the release of bases (Kisinyo, 2016), through a remarkable change in soil pH (Buri *et al.*, 2014) for a better improvement in soil fertility.

Conclusion

NPK fertilizer applied at the 200 kg/ha rate and lime at 500 kg/ha improved soil chemical properties sown to groundnut, especially the levels of organic matter, total N, available P, exchangeable bases, ECEC and BS, and their availability. The lime effects reduced the hydrogen ion concentration in the exchangeable site and raised the pH for the release of nutrients from fixation. For sustainable agricultural systems within small-scale farming, liming and chemical fertilizer applications could be a good option for effective soil-plant nutrient management strategies for groundnut production in acid soils.

Recommendations

- From the results of this study, the following recommendations are proposed: For optimum production of groundnut in acidic soils of South-Eastern Nigeria, application of 200 kg/ha NPK and CaCO_3 (500 kg/ha) is ideal for sustained soil fertility.

- Split applications of fertilizer (NPK) should be practiced avoiding soil nutrient loss for maximized uptake.

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Groundnut (*Arachis hypogaea* L.)
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**EFFECT OF COW DUNG AND NITROGEN RATES ON SOIL CHEMICAL
PROPERTIES, PENETRATION RESISTANCE AND MAIZE YIELD
PARAMETERS IN NORTHERN GUINEA SAVANNA, NIGERIA**

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ABSTRACT

The rising cost of inorganic fertilizers, coupled with their adverse effects on soil conditions, has resulted in increased interest in application of inorganic fertilizer alongside organic amendments. This research was aimed at investigating the effect of cow dung and nitrogen fertilizer on soil penetration resistance, soil chemical properties and yield of maize. To achieve the proposed objective, field experiment was designed by Randomized Completely Block Designed (RCBD) with 3 level of cow dung (0, 3 and 6 tonnes/ha) and 4 Nitrogen rates (0, 50, 100 and 150 kg N/ha) as treatment and were replicated 3 times. The maize was sowed and data on chemical soil properties (soil pH, organic carbon and total nitrogen), penetration resistance (at 0, 10, 20 and 30 cm) and yield parameters (grain yield, stover yield, number of cobs and 1000 grain weight) were collected from vegetative to maturity and harvest. The result obtained showed that, application of cow dung reduces penetration resistance while application of nitrogen showed no effect on penetration. Soil properties and yield parameters found to be optimum at 3 tonnes of cow dung and 100 kgN/ha. From the result, it can be concluded that application of 3 tonnes/ha in combination with 100 kgN/ha gave a better soil condition and maize yield in the study area. It is also recommended that the application of nitrogen fertilizer can be reduce to 100 kgN/ha /ha of when up to 3 tonnes/ha of cow dung is incorporated in the soil.

Keyword: cow dung, fertilizer, maize, nitrogen, penetration resistance, soil chemical properties,

Introduction

Maize (*Zea mays* L.) is one of the most important cereal crops cultivated worldwide and serves as a major source of food, feed, and industrial raw materials. It plays a significant role in food security and economic development in many developing countries. However, maize productivity is often limited by poor soil fertility and unfavorable soil physical conditions, which restrict plant growth and reduce yield potential (Lal, 2022).

Among the soil physical constraints affecting crop production, soil compaction

is a major problem in intensively cultivated agricultural soils. Soil compaction reduces pore space, limits water infiltration, and restricts root

development. These conditions reduce the ability of plant roots to explore soil for water and nutrients, thereby negatively affecting crop performance (Hamza and Anderson, 2021). Consequently, evaluating soil compaction is important for understanding soil conditions that influence crop growth. Soil penetration resistance is commonly used as an indicator of soil compaction and soil strength. High soil penetration resistance can restrict root elongation and reduce root penetration into deeper soil layers. This condition limits water and nutrient uptake by crops and can ultimately reduce crop productivity (Bengough *et al.*, 2022). Therefore, improving soil physical conditions that reduce penetration resistance is essential for sustainable crop

production. Organic amendments such as cow dung have been widely recognized for their ability to improve soil physical and chemical properties. The addition of cow dung increases soil organic matter content, improves soil aggregation, enhances soil porosity, and reduces soil bulk density. These improvements help to reduce soil penetration resistance and create a favorable environment for root growth and nutrient absorption (Blanco-Canqui and Lal, 2021).

In addition to improving soil structure, crops require adequate nutrient supply for optimal growth and development. Nitrogen is one of the most essential nutrients required for plant growth because it is a major component of chlorophyll, proteins, and enzymes involved in plant metabolic processes. Adequate nitrogen availability enhances vegetative growth, photosynthesis, and ultimately crop yield (Marschner, *et al.*, 2021). However, continuous reliance on inorganic nitrogen fertilizers alone may not sufficiently improve soil physical properties or maintain long-term soil productivity.

Integrated nutrient management, which involves the combined use of organic and inorganic nutrient sources, has been recommended as a sustainable strategy for improving soil fertility and maintaining soil quality. Organic materials such as cow dung contribute organic matter that improves soil structure, while inorganic fertilizers provide readily available nutrients required for crop growth (Vanlauwe *et al.*, 2022). The integration of these nutrient sources can also enhance nutrient uptake by crops by improving root growth and soil nutrient availability. Despite the recognized benefits of organic and inorganic fertilizers, limited information is available on how their

combined application influences soil penetration resistance and nitrogen uptake under maize production. Understanding these interactions is important for developing sustainable soil management practices that improve soil physical conditions and nutrient utilization efficiency. Therefore, this study was conducted to evaluate the effects of cow dung and nitrogen fertilizer on soil penetration resistance and nitrogen uptake under maize production.

Materials and Methods

The study was conducted at the Experimental farm of the Institute for Agricultural Research (IAR), Samaru. Samaru is located at the geographic coordinates of latitude 11° 11'N and longitude 07° 38'E, with an altitude of 686 m above sea level in the Northern Guinea Savanna Ecological zone of Nigeria.

The treatments for this study include 3 organic manure levels and 4 rates of nitrogen. Phosphorus and potassium was blanket applied at 60 P₂O₅kg/ha and K₂Okg/ha. The Organic manure levels were 0, 3, 6 tonnes/ha, while the nitrogen levels were 0, 50, 100 and 150 kgN/ha. The experimental design was Randomize Complete Block Design (RCBD) replicated 3 times.

The test crop used for the study was Hybrid maize variety Oba-super 2 planted at spacing of 75 cm between and 25 cm within row. Cow dung was applied 2 weeks before planting at the rate of 0, 3 and 6 tons /ha while Urea was split applied at 2 and 6 weeks after planting (WAS). The muriate of potash and single super phosphate were applied with first split dose of N at 2 WAS. Thinning was done at two weeks after sowing (2 WAS). Weeding was done at 4 and 8 weeks after

sowing (WAS). The harvesting was done at maturity at about 112 days after sowing.

Data collection

At harvest, data on number of cobs, stover yield, Grain yield (tha^{-1}) and 1000-grain weight (g) were taken.

Penetration resistance was measured during the growing period of the plant. The measurement was done when the soil was at field capacity by using soil penetrometer at the depth of 0-30 cm. The penetrometer was pushed into the soil and the reading of the penetrometer was recorded at each 10 cm depth of the soil. The measurement was repeated at 0, 10, 20, and 30 cm soil depth from each plot and the values was recorded.

The soil samples were collected at harvest from 0-15cm using auger, labeled, air dried in the laboratory, crushed and sieved through 2mm. The soils were then analyzed for the following parameters: soil pH, organic carbon and total nitrogen. pH was determined electrometrically in a soil solution ratio of 1:2.5, using the glass electrode pH meter. The organic carbon was analysed by wet oxidation method of Walkley and Black as modified by (Nelson and Sommers, 1982). Total nitrogen by the micro- Kjeldahl distillation procedure according to (Bremner, 1996).

Statistical analyses of all parameters collected from the field on soil, plant, and from laboratory analysis were subjected to Analysis of Variance (ANOVA) using SAS package (SAS, 1999). The means were separated using the Duncan Multiple Range (DMRT) at 5% level of probability

Result and Discussion

Characterization of soil used for the study

The field soil characterization is presented in Table 1. The pH (H_2O) and pH (CaCl_2) ranged from 4.25 to 5.41 and were slightly

acidic. The pH (CaCl_2) value was consistently lower implying net negative charge on the colloidal surface and a fertile soil. The organic carbon content for the control (9.4 g/kg) was low while the total N contents (3.9 g/kg) was moderate. Available phosphorus contents were (13.72 mg/kg). With respect to the effective cation exchange capacity (4.84 C mol/kg), the value was considered low with Ca dominating the exchange complex. The electrical conductivity (0.06 dms^{-1}), was low which indicates low salinity condition of all the soils. The micronutrient content for all the treatments and control were moderate.

The pH of the soils measured in 0.01M CaCl_2 and water (H_2O) indicate moderate to mild acidity for both the screen house and field soils. The soils can be said to have seemingly established savanna characteristics with average pH (H_2O) range of 4-6.5 (FAO, 2022). Organic carbon of the soils was low (0.42-0.97%), a typical characteristic of savanna soils due to low density of vegetation and rapid decomposition of organic matter. Electrical conductivity ($0.04 - 1.35 \text{ dms}^{-1}$) and effective cation exchange capacity (4.84 – 5.97 cmol/kg) were low (Table 4.1). The low electrical conductivity (EC) indicated low salt content, while the low CEC could be due to domination of low activity clay and low organic matter content.

Characterization of cow dung used for the study

The characterization of the cow dung manure used for the study is presented in Table 2. The analysis of the cow dung would provide information on the fertilizer value of the material before use as a soil amendment. The results obtained were: total N (14.5 g/kg), P (13 mg/kg) and K (0.68 cmol/kg). These results are similar to

the works of some scientists on cow dung. ecological zone. The results revealed that Lawal *et al.*, (2021) who reported values of the N, P and K content of the cow dung 1.55% N, 0.37% P, and 0.65 % K, for cow was moderate and good (FAO, 2022) dung for the savanna in this same

Table 1. Characterization of soil prior to treatment application as inserted

Parameter	Control
Sand (g/kg)	400
Silts (g/kg)	460
Clay (g/kg)	140
Texture	loam
pH (H ₂ O)	5.54
pH (CaCl ₂)	4.97
Org. Carbon (g/kg)	9.4
Total N (g/kg)	3.9
Av. P (mg/kg)	13.72
EC (dms ⁻¹)	0.06
K (C mol/kg)	0.17
Mg (C mol/kg)	0.97
Ca (C mol/kg)	2.80
Na (C mol/kg)	0.10
E.CEC(C mol/kg)	4.84
Zn (mg/kg)	3.60
Cu (mg/kg)	2.23
Mo (mg/kg)	13.72
Fe (mg/kg)	44.1
Exchg. Acidity	0.8

Table 2. Characterization of cow dung used for the screen house and field study

Nitrogen (g/kg)	Phosphorus (mg/kg)	potassium (Cmol/kg)
14.5	13.00	0.68

Effects of Treatments Factors on Selected Soil Chemical Properties

Soil pH

The effects of cow dung (CD) on pH (Table 3) were significant. Mean values ranged from 6.31 to 6.03 for 6 t/ha CD and 0 t/ha CD respectively. The soil pH in (H₂O) increased with increase in rates of CD, signifying profound influence of the processes of decomposition on soil pH values. Similar result by Adekiya *et al.* (2021), reported an increase in soil pH after the incorporation of organic amendments by the release of NH₃ which

accompany the process of organic N mineralization. The effects of the nitrogen rates on soil pH was erratic for pH in (H₂O) but followed a general trend of consistent decrease with increase in N rates. This is reflected in the more buffered CaCl₂ solution though with marginal differences in mean pH CaCl₃ values. Mean effects were significant for pH in (H₂O) but not for pH in CaCl₂. The result agrees with the finding of Usman *et al.* (2022) where pH in CaCl₂ was low in N application plots over that of high application plots.

Table 3: Effect of tillage practices, cow dung and nitrogen rates on selected soil chemical properties

Treatments	pH (H ₂ O)	pH (CaCl ₂)	Organic Carbon (g/kg)	Total Nitrogen (g/kg)
Cow dung (t/ha)				
0	6.03 ^b	5.44 ^{ab}	6.4 ^b	1.9 ^{ab}
3	6.06 ^b	5.43 ^b	7.2 ^a	0.8 ^b
6	6.31 ^a	5.57 ^a	6.7 ^b	2.5 ^a
Mean	6.13	5.48	0.68	0.18
S.E±	0.02**	0.05	0.02**	0.05*
N rate (kg/ha)				
0	6.13 ^a	5.55	6.9 ^{ab}	1.5
50	6.18 ^a	5.46	6.5 ^b	2.1
100	6.06 ^b	5.48	6.5 ^b	1.3
150	6.15 ^a	5.44	7.1 ^a	2.3
Mean	6.13	5.48	0.68	0.18
S.E±	0.02**	0.05	0.02	0.05

Means follow by the same letter(s) in the same column are not significantly different at 5% level of probability, NS= not significance, *=significance, **=highly significant

Organic Carbon

The effects of cow dung application rates on organic carbon was highly significant and values were higher at 3 tonnes/ha CD indicating the possible acceptable load of manure application for the soils (Table 3). Value were moderate at the higher rate (6 tonnes/ha) of CD applied. This result

corroborates the findings of Adekiya *et al.* (2021). The effects of N rates on organic carbon content of the cropped soils showed that the effects were significant and values ranged from 6.5 to 7.1g/kg, and seemed to increase with increasing N rates. The high values observed for 0 kg N/ha (6.9 g/kg) may have resulted from these low yield

plots with much less activity and high accumulation of soil carbon. Similar result was also found by Zhang *et al.* (2022).

Total Nitrogen

The effects of cow dung rates on N content were significant and the variation with CD rates was definitely influenced by a combination of factors such as N mineralization of CD applied and infiltration capacity of the soil. However, N content increase with increasing levels of CD applied. The very low amount with 3t/ha may be due to higher plant vigor and greater uptake (Table 3) of N from the soil therefore depleting the soil much more. The result agrees with finding of Adekiya *et al.* (2021) that reported the high total nitrogen content with high application of the cow dung. The effect of N rates on soil N content increased up to the highest level of N tested, as expected, though the increased was not consistent. The greater effect of treatments on N content was interaction of CD and tillage. The reasons have been explained in content above. This result is in accord with finding of Usman *et al.* (2022).

Effect of Tillage Practices, Cow Dung and Nitrogen Rates on Soil Penetration Resistance

The effects of cow dung application and rates were consistent (Table 4). Though mean differences were not significant at 20

cm depths, values were 1.48 Kgf/cm², 1.36 Kgf/cm² and 1.19 Kgf/cm² for 0, 3 and 6 t/ha CD rates. The results show that the key factor in providing a good and sustainable rooting medium is the organic matter content. Penetration resistance reduced with increase in CD application rates over the depths determined. With increase in CD application, the soil would be less compacted more aerated and of higher with microbial activity to the extent of the soil capacity as influenced by treatments. This is in accord with the finding of Adekiya *et al.* (2021), who recorded a decrease in penetration resistance due to application of cow dung by reducing compaction through improvement in soil properties such as encrustation, water infiltration, moisture content, drainage, tilt, aeration and root penetration. Similarly, Blanco-Canqui *et al.* (2022) found a reduction in soil penetration resistance with addition of cow dung.

The influence of N application and rates on penetration resistance (Table 4) was less dramatic and effects were erratic. Nitrogen rates may therefore contribute less influence on the factor of soil compaction in soils. Similar finding was obtained by Taiwo *et al.* (2021) who observed no significant difference in PR between the control and nitrogen applied plots.

Table 4: Effect of tillage practices, cow dung and nitrogen rates on soil penetration resistance

Treatments	Penetration Resistance (Kgf/cm ²)			
	0cm	10cm	20cm	30cm
<u>Cow dung (t/ha)</u>				
0	0.79 ^a	1.21	1.48 ^a	1.56 ^a
3	0.69 ^{ab}	1.07	1.36 ^{ab}	1.41 ^{ab}
6	0.62 ^b	1.05	1.19 ^b	1.37 ^b
Mean	0.69	1.11	1.34	1.43

S.E±	0.07*	0.07	0.07*	0.06*
<u>N rate (kg/ha)</u>				
0	0.64	1.10	1.41	1.51
50	0.75	1.21	1.37	1.35
100	0.74	1.11	1.28	1.34
150	0.67	1.03	1.31	1.53
Mean	0.69	1.11	1.34	1.43
S.E±	0.08	0.08	0.08	0.07

Means follow by the same letter(s) in the same column are not significantly different at 5% level of probability, NS= not significance, *=significance, **=highly significance

Effect of Tillage Practices, Cow Dung and Nitrogen Rates on Maize Yield Parameters

Number of cobs

The effect of cow dung application and rates on number of cobs per plot presented on Table 5 was also highly significant with mean values of 59.5 for 3 t/ha CD, the best performing CD rate. The 0 t/ha CD was least with 51 cobs/plot. It was apparent that the competing demand of microbes for nutrients, such as nitrogen above the threshold or carrying capacity of the soil, as seen with the 6 t/ha treatment, would result in nutrient immobilization by the microbes. The CD application threshold rates was 3 t/ha. This is in agreement with the finding of Adekiya *et al.* (2021) who found an increased grain yield and yield related components of maize with cow dung application compared with control plots.

The effect of nitrogen application and rates on number of cobs were also highly significant ($p>0.01$) and increased to the highest rates of 150 kg N/ha applied. However, the practices of N fertilization alone stimulated similar response, as mean values for the N rates were not significant different, but were all superior to the N control (0 kg N/ha) plot by an average of

21%. Though this parameter can be said to be strongly controlled by the genetic factor, it can also be strongly enhanced by high level of fertilization and faster growth response. This result agrees with that of Usman *et al.* (2022) and Zhang *et al.* (2023).

1000 grain weight

The effect of cow dung application and rates on 1000 grain weight were highly significant and 3 t/ha maintained the CD application for the soil with a superior performance of 292 gms 1000 grain weight, which was 19% over the CD control (0 t/ha CD), but was similar to 6 t/ha CD treatment. This would further buttress the finding in this study, of the optimum carrying of 3 t/ha CD for the soil as stated for number of cobs. Similar observation was also obtained by Adekiya *et al.* (2021) in their study.

Response of 1000 gms grain weight to N application (Table 5) increased with increase in N rates to the highest level tested (150 kg/ha). All N treatment plots were significantly different from the N control plots, but differences were not statistically significant across N rates. The

high grain weight found in 150 (kg/ha) is in line with the finding of Abate *et al.* (2022).

Stover yield

The response of stover yield to the CD application and rates (Table 5) was highly significant. The 3 t/ha treatment gave the highest stover yield, and the mean values (5794 kg/ha) was statistically significant and superior to the CD control mean by 34% and to 6 t/ha CD by 11%. The need to apply manure to the soil to improve the SOM content was demonstrated and 3 t/ha CD still maintained the strong suggestion as the threshold application rate of CD for the soils. This is in agreement with finding of (Adekiya *et al.*, 2021).

The effects of N rates on stover yield were highly significant, and response to applied N was significant up to the highest rate of N applied (150 kg/ha N/ha), and mean values at 100 kg/ha and 150 kg N/ha were significantly different. Stover yield increased consistently with increase in N rates. The result agrees with finding of Abate *et al.* (2022).

The influence of CD application on grain yield was presented on Table 5. The mean differences were highly significant ($p \geq 0.05$). The 3 t/ha treatment produced the highest yield (3249 kg/ha) and was

significantly different from the 0 t/ha CD (CD control) by 31%, but was not statistically different from the 6 t/ha CD, which was by only 3%. The 3 t/ha CD rate represents the carrying capacity for the soil as response was only up to this level of application. Grain yield declined at 6 t/ha (3235.8 kg/ha). The processes of microbial decomposition of organic matter and net immobilization of nutrients at higher rates, may explain the observed grain yield results obtained. This observation was also obtained by Adekiya *et al.* (2021) in their study.

The effects of N application and rates on grain yield (Table 5) were highly significant, and yield values increased to the highest rate of N applied (3580 kg/ha at 150 kg/ha). Significant response was only up to 100 kg N/ha as this rate was not significantly different from 150 kg N/ha. Yield values were low at 0 kg N/ha treatment (2273 kg/ha) grain yield. The result agrees with finding of Abate *et al.* (2022).

In summary, the treatment combination that would produce high and optimum grain yield in these soils, from all presented yield component results, would be CD at 3 t/ha and 100 kg N/ha as obtained in this study.

Table 5: Effect of tillage practices, cow dung and nitrogen rates on maize yield parameters

Treatments	Number of cobs	1000 Grain Weight (g)	Stover Yield (kg)	Grain Yield (kg)
Cow dung (t/ha)				
0	50.94 ^b	245 ^b	4335.6 ^b	2557.8 ^b
3	59.50 ^a	292 ^a	5794.4 ^a	3349.2 ^a
6	54.36 ^b	288 ^a	5229.0 ^{ab}	3235.8 ^a
Mean	54.96	275	5119	3047.6
S.E±	5.69**	276**	359**	1.03**

<u>N rate (kg/ha)</u>				
0	46.89 ^b	234 ^b	4003.2 ^b	2273.1 ^c
50	56.41 ^a	277 ^a	5184.0 ^a	3027.2 ^b
100	57.33 ^a	291 ^a	5228.1 ^a	3309.9 ^{ab}
150	59.11 ^a	298 ^a	6063.5 ^a	3580.1 ^a
Mean	54.96	275	5119	3047.6
S.E±	4.93**	239**	409	161**

Means follow by the same letter(s) in the same column are not significantly different at 5% level of probability, NS= not significance, *=significance, **=highly significance

Conclusion and Recommendation

From the finding, it can be concluded that yield component of maize determined in this study, which included number of cobs, 1000 grain weight and stover yield were duly influenced maximally by the treatment combination of 3t CD/ha and 100 kg N/ha. With these yield components, 3 t CD/ha outperformed 6 tonnes/ha and control plot (0 tonnes/ha), and mean N response was only upto 100 kg N/ha for all parameters. Generally, Response of grain yield to CD application was significant up to 3 t/ha as it was with other agronomic parameters presented. Manure level of 3 t CD/ha was superior to 0 t/ha CD by 31% and to 6 t CD/ha level by 3%. Application of treatment factors on the soil properties (CD and nitrogen) increased the soil pH, SOM and N content of the soils with increased in levels of application suggesting the need for these management practices for the soils. The field study clearly revealed that application of cow dung reduces compaction on the soil. A penetration resistance value of below 1.25 kgf/cm² is considered suitable for root penetration and nutrients cycling.

It can be recommended that, Practices that would enhance surface run-off and low infiltration rate such as excessive soil disturbance, over fertilization and odd timing application should be discouraged

to ensure improvement of yield and good soil conditions.

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EVALUATION OF MACHINE LEARNING MODEL TO ESTIMATE NUTRIENT LIMITATIONS OF MAIZE GROWING ENVIRONMENTS IN NORTHERN NIGERIA

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ABSTRACT

Soil nutrient limitations significantly impact maize productivity, necessitating precise nutrient management strategies. This study integrates machine learning models, hotspot analysis, and spatial interpolation techniques to identify nitrogen (N), phosphorus (P) and potassium (K) deficiencies across maize-growing areas in Kaduna (with experimental fields in Soba, Ikara and Makarfi, local government areas), Katsina (with experimental fields in Funtua, Faskari and Bakori local government areas) and Kano (with experimental fields in Tofa, Bunkure and Kura local government areas) respectively in northern Nigeria. Using jupyter notebook, a multioutput random forest classification model was used to identify and classify limiting nutrients. The model was

developed to predict site-specific nutrient limitations and evaluated based on accuracy. Spatial autocorrelation techniques, including Moran's I, were employed to assess the clustering patterns of nutrient limitations in the study locations. The output from the multioutput random forest classifier model was selected based on key metrics precision, recall and F1 score. Results revealed Nitrogen limitations across all the study locations, distinct hotspots of P limitation were observed in Dandume, Funtua, Faskari, and Bakori LGAs in Katsina State, while K limitations exhibited a random spatial distribution, suggesting localized variability. The findings emphasize the need for precision fertilizer recommendations, moving away from blanket applications to targeted nutrient management zones (NMZs). By integrating machine learning predictions with spatial analysis techniques, this study provides a data-driven framework for optimizing nutrient management improving fertilizer use efficiency (FUE), and enhancing maize yield in the region.

Keywords: machine learning algorithm, nitrogen, limitations, maize crops.

INTRODUCTION

Soil fertility is a critical determinant of crop productivity in the Savanna agroecological zone of northern Nigeria, where maize production plays a significant role in food security and economic development. However, nutrient limitations, particularly in nitrogen (N), phosphorus (P), and potassium (K), pose significant challenges to sustainable agricultural productivity

(Sanchez *et al.*, 2009). Traditionally, soil fertility recommendations have been derived from conventional agronomic trials and expert-based systems, which are often time-consuming, resource-intensive, and less responsive to spatial variability in soil properties (Vanlauwe *et al.*, 2014). In contrast, machine learning (ML) models offer a data-driven approach to estimate limiting nutrients and optimize fertilizer recommendations by leveraging historical soil and yield data, climatic factors, and site-specific nutrient requirements (Shahhosseini *et al.*, 2019). The Sudan Savanna zone is characterized by sandy soils with low organic matter content and inherent fertility constraints (Bationo &

Mokwunye, 1991). Due to continuous cropping and minimal nutrient replenishment, nutrient mining has led to declining soil fertility and suboptimal maize yields. To address this challenge, precision nutrient management approaches are essential. Conventional soil testing methods, while effective, are not widely accessible to smallholder farmers due to cost and logistical constraints (Schut *et al.*, 2018). Machine learning-based nutrient estimation models provide an alternative by predicting soil fertility status using readily available environmental and yield data, enabling tailored fertilizer recommendations. ML models have shown promise in agricultural applications, including soil fertility assessment, crop yield prediction, and nutrient management (Hengl *et al.*, 2017). These models utilize supervised learning techniques such as Random Forest (RF), Gradient Boosting Machines (GBM), and Artificial Neural Networks (ANNs) to identify key factors influencing soil fertility and predict limiting nutrients based on historical data (Moges *et al.*, 2020). By incorporating spatial and temporal variability, ML models enhance the accuracy of nutrient

recommendations, ensuring optimal input use efficiency.

In this study, a Machine learning model was developed to estimate nutrient limitations of nitrogen, phosphorus and potassium (N, P, K) based on a historical dataset encompassing soil nutrient properties, climatic and topographic variables. The model aim is to identify and map out the areas with N, P and K limitations in some of the maize growing environments in the Savanna region of northern Nigeria.

METHODOLOGY

Study site

The study was conducted in the maize belt region of Nigeria; Kano, Kaduna and Katsina. Dominant soils in the area are Entisols/Inceptisols, Alfisols, Ultisols, and Vertisols (Federal fertilizer department - FFD, 2012). The agroecological zone of the northern Guinea and Sudan savanna is a subhumid to semiarid zone with an annual rainfall of 900– 1,400 mm (Ayanlade, 2009). The predominant soil types in the region are Acrisols and Lixisols with variable proportions of Plinthosols and Cambisols (Dewitte *et al.*, 2013). Average cumulative precipitation and average monthly minimum and maximum temperatures in the 12 focal LGAs are shown in Figure 2. Crop production in the region is significantly at subsistence level and is dominated by smallholders (75%) with an average land holding between 0.8

and 1.5 ha (Abdoulaye, Wossen, and Awotide, 2018). Major crops grown in the area are cereals, which include maize, sorghum, millet, and rice cultivated as sole, intercropped, or in rotation mostly with legumes such as cowpea, soybean, and groundnuts (Ado and Yusuf 2008; Adewopo, 2019). The study sites were chosen because they are known to cover a broad range of maize growing conditions across the high production potential areas in the Northern Nigerian Savanna and to involve areas where research for development can support extension support programs engaged in maize value chain initiatives.

The history of secondary data was obtained from published (95 data points described by Shehu *et al.*, 2018) and unpublished data sets (292 points) collected between 2015 and 2017 by the project “Taking Maize Agronomy to Scale in Africa” (TAMASA) in Nigeria. Predictions based on AfSIS Bruker-Alpha KBr Mid InfraRed (MIR) spectral models will be used for individual Mehlich-3 extractable nutrient contents as well as pH, effective cation exchange capacity (ECEC), SOC, and total N (N_{tot}) for the 3000 soil samples. The procedure for soil sampling and laboratory analyses of both the published and unpublished datasets obtained from the TAMASA project remains the same as described by Shehu *et al.*, (2018).

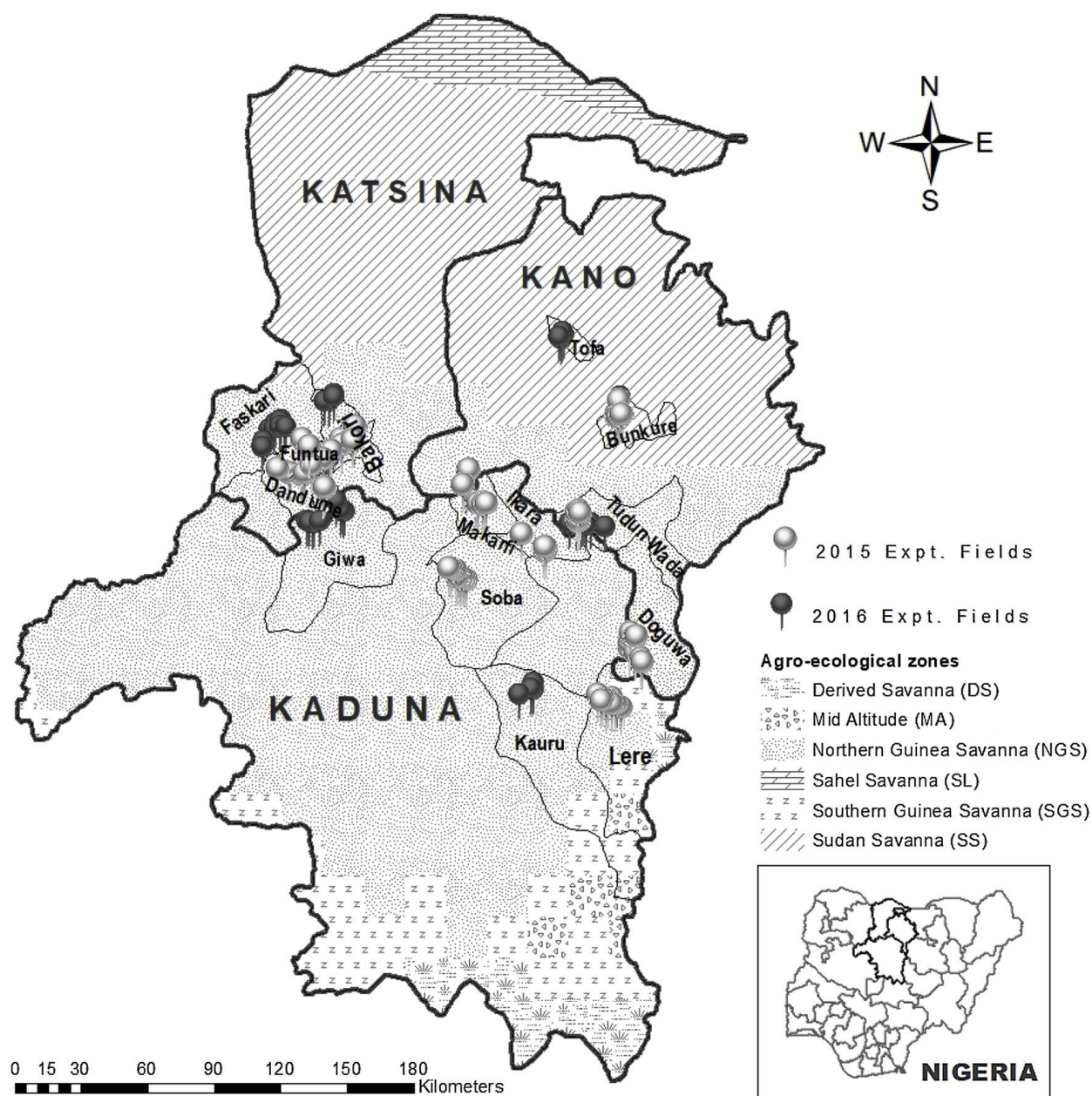


Figure 1: Map of the various agroecological zones in Nigeria (Shehu *et al.*, 2020).

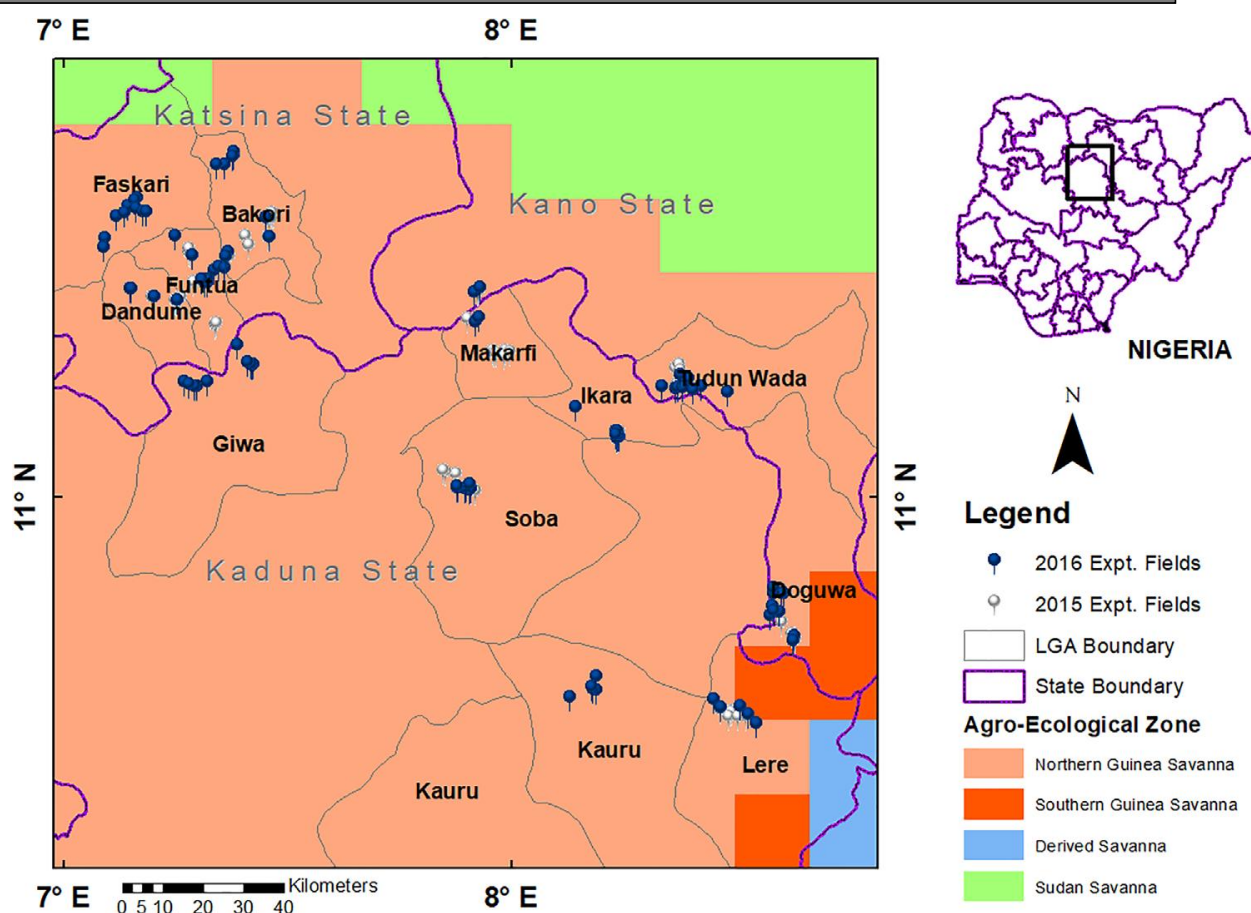


Figure 2: Map of Nigeria showing the study local government areas (LGA) and experimental fields where diagnostic nutrient omission trials were conducted during the 2015 and 2016 rainfed seasons (Kamaludin *et al.*,2020)

Soil sampling and processing

A stratified multistage sampling procedure on a 1 km² resolution Discrete Global Grid (DGG) of the study area were used for soil sampling site selection. 10 soil samples will be collected from each LGAs; Kaduna (with experimental fields in Soba, Ikara and Makarfi, local government areas), Katsina (with experimental fields in Funtua, Faskari and Bakori local government areas) and Kano (with experimental fields in Garun malam, Bunkure and Tudun Wada local government areas). All the 9 LGAs were selected based on the criterion that they contain more than 3 unique cropland sentinels. In each of the 9 selected LGAs, a

10 × 10 km sentinel will be further selected at random. Experimental fields were selected by generating one or two 10 km×10 km grid(s) in each study site (depending on the size of the study site) using ArcGIS software (Environmental System Research Institute, Redlands, CA, USA). Within each of these 10 km×10 km grid (s), five 1 km×1 km sub-grids were delineated evenly. In each of the 1 km×1 km sub-grids, a field for experimentation was randomly selected, considering the willingness of a farmer and availability of land for the trial setup. Soil samples to be used were collected by sampling from 4 points at each identified site at a depth of 0–20 cm using a soil auger. Over all, the

study sites fell within two agro-ecological zones; the Northern Guinea Savanna (NGS) and Sudan Savanna (SS) (Fig. 1).

2.3 Soil analysis

Soil samples were collected by TAMASA (taking maize agronomy to a scale in Africa) from the various locations at 0 to 20 cm depths. The collected samples were subjected to laboratory analysis which include total soil organic carbon (OC_{tot}) which were assessed using a modified Walkley & Black chromic acid wet chemical oxidation and spectrophotometric method (Heanes, 1984). Total nitrogen (N_{tot}), will be determined using a micro-Kjeldahl digestion method (Bremner, 1996). Soil pH in water (soil/water ratio of 1:1) were measured using a glass electrode pH meter and the particle size distribution with the hydrometer method (Gee and Or, 2002). Available phosphorus (P_{av}), available sulphur (S_{av}), exchangeable cations (K, Ca, Mg and Na) and micronutrients (Zn, Fe, Cu, Mn and B) were analysed based on the Mehlich-3 extraction procedure (Mehlich, 1984) preceding inductively coupled plasma optical emission spectroscopy (ICP-OES, Optima 800, Winlab 5.5, PerkinElmer Inc., Waltham, MA, USA). Exchangeable acidity (H⁺Al) was determined by extracting soil with 1 N KCl and titration of the supernatant with 0.5M NaOH (Anderson and Ingram, 1993). Effective cation exchange capacity (ECEC) was calculated as the sum of exchangeable cations (K, Ca, Mg and Na) and exchangeable acidity (H⁺Al).

Model building

Secondary datasets were used to build the models. A historical dataset was collected (between 2015-2017) by TAMASA consisting of maize crops and their corresponding fertilizer datasets. The

datasets were pre-processed to remove any missing or replicated values, and normalized to a specific range to facilitate efficient training. The most important step in the routine is the pre-processing of the data so that the machine could understand it. This will involve combining multiple data files from different sources into one, integrating all the data into a single unit system, formatting entries, addressing and identifying missing or wrong entries, and cleaning the data.

The next step was to divide the dataset into training and validation sets, with the validation set consisting of 20% of the entire dataset, selected randomly to ensure that it is a representative of the overall dataset. The model was trained using only Multioutput ensemble Random Forest classifier because it was the only model that could predict the three targets nutrients simultaneously since soil nutrients often interact. The aim was to determine limiting nutrients (N, P, K) across the study areas. Throughout the training process, the hyperparameters were carefully adjusted for each algorithm to achieve the best possible performance. For model evaluation, a range of metrics were utilized including accuracy, precision, recall, and F1-score, to assess their effectiveness.

By leveraging this information, our overall approach resulted in identification of N, P and K limited sites which can further be put into use for N, P and K fertilizer recommendation to enhance crop yield with minimal environmental impacts.

Data Processing & Feature Engineering

Data were collected and preprocessed using relevant soil properties (N, P, K, pH, OC e.t.c), environmental and climatic variables (temperature, rainfall), and topographic variables (longitude, latitude and altitude). Data Cleaning which include

handling missing values, outlier detection, and data transformation. Feature Engineering include Calculating nutrient ratios (N:P, N:K, P:K).

2.6 Machine Learning for Predicting Limiting Nutrients

To predict limiting nutrients (N, P, K), different ML models were evaluated.

1. Model Selection:

- Multioutput Random Forest (RF): Handles non-linearity and feature importance.

2. Model Training & Hyperparameter Tuning:

- Models were trained using cross-validation (k-fold = 5 or 10).
- Grid search was used to optimize hyperparameters.
- Performance metrics: Accuracy, Precision, Recall, and F1-score.

3. Model Selection Criteria:

- The multioutput random forest classifier model was selected based and the output was iterated.

Spatial Analysis and Hotspot Identification

Once the best ML model was selected, it was applied to predict limiting nutrients across the study area. For Hotspot Analysis, Spatial clustering techniques Moran's I was used to identify nutrient-deficient areas.

Data analysis

The analysis was conducted in Jupyter Notebook using IPython (8.20.0), an interactive computing environment that integrates Python-based computations, data analysis, and visualization.

RESULTS AND DISCUSSION

Classification Model for Nutrient Limitation (2015-2017) and Mapping Model Development

A Multi-Output Classification (Random Forest + Multi Output Classifier) framework was the only model used in this analysis to handle multiple target variables simultaneously. This is to leverage the relationships between each of the target variables which is likely since soil nutrients often interact. Which is unlikely for Independent Classification models such as SVM (support vector machine) and other classification models like gradient boosting, stacking e.t.c they do not support multi output learning and each target are trained independently.

Model Selection & Training:

N, P and K columns were selected from the original df and categorized as limiting, sufficient and excessive using the critical values ratio method. N limiting, P limiting and K limiting were encoded as binary (0-non limiting,1-limiting) and set as target variables to be used to run the models.

In this study, the multioutput random forest (rf) model was trained using 100 estimators with a fixed random state for reproducibility. Learns dependencies between the targets—if N_Limiting is 1, it might affect predictions for P_Limiting and K_Limiting. Uses a single fit) call and trains all outputs together. Handles missing values and interdependencies in one go. Captures interactions between N_Limiting, P_Limiting, and K_Limiting. More efficient (faster training) since a single model learns all labels. Works well if the outputs are correlated (which is likely, since soil nutrients often interact). Often used If you want to leverage relationships between the limiting nutrients. If efficiency matters (one model instead of three).

Table 1. Summary statistics of feature variables

Metrics	Year	Longitude	Latitude	Altitude	pH water (1:1)	OC (%)	%SAND
Count	2101.0000	2101.0000	2101.0000	2101.0000	2101.0000	2101.0000	2101.0000
Mean	2015.0000	11.2511	7.9219	666.2424	5.8777	0.6854	48.5020
Std	0.1534	0.1170	0.1617	23.4893	0.1487	0.0811	3.5228
Min	2015.0000	10.4875	7.0887	468.0000	4.8000	0.2042	23.2000
25%	2015.5202	11.2511	7.9219	666.2424	5.8777	0.6855	48.5050
50%	2015.5202	11.2511	7.9219	666.2424	5.8777	0.6855	48.5020
75%	2015.5202	11.2511	7.9219	666.2424	5.8777	0.6855	48.5020
Max	2016.0000	12.0171	8.6363	798.0000	7.2000	1.5500	77.2000

Table 2 Summary statistics of feature variables

%SILT	%CLAY	Ca(cmol/ kg)	N_P_Ratio	N_K_Ratio	P_K_Ratio	N(%)	P(ppm)	K(cmol/kg)
2101.000	2101.000	2101.00	2101.00	2101.0	2101.0	2101.00	2101.00	2101.000
29.6060	21.7813	2.3517	0.0053	0.2129	46.1076	0.04520	9.7883	0.2186
2.5437	1.7855	0.3033	0.0046	0.0580	19.8605	0.004375	2.7692	0.0485
9.2000	11.6000	0.2785	0.0007	0.0320	0.8314	0.0170	0.6427	0.0600
29.6060	21.7813	2.3517	0.0046	0.2059	44.7760	0.04502	9.7883	0.2186
29.6060	21.7813	2.3517	0.0046	0.2059	44.7760	0.04502	9.7883	0.2186
29.6060	21.7813	2.3517	0.0046	0.2059	44.7760	0.04502	9.7883	0.2186
59.0000	42.0000	9.7800	0.0944	1.1343	299.1832	0.0981	49.9947	1.3500

3.1.3 Categorizing the targets variables using the critical value ratio

Define the thresholds

n_thresholds = [0, 0.1, 0.3, float('inf')]

p_thresholds = [0, 5, 15, float('inf')]

k_thresholds = [0, 0.2, 0.5, float('inf')]

Define the labels

labels = ['Limiting', 'Sufficient', 'Excessive']

Categorize the variables

numerical_df['N_Category'] = pd.cut(numerical_df['N (%)'], bins=n_thresholds, labels=labels, include_lowest=True)

numerical_df['P_Category'] = pd.cut(numerical_df['P(ppm)'], bins=p_thresholds, labels=labels, include_lowest=True)

numerical_df['K_Category'] = pd.cut(numerical_df['K(cmol/kg)'], bins=k_thresholds, labels=labels, include_lowest=True)

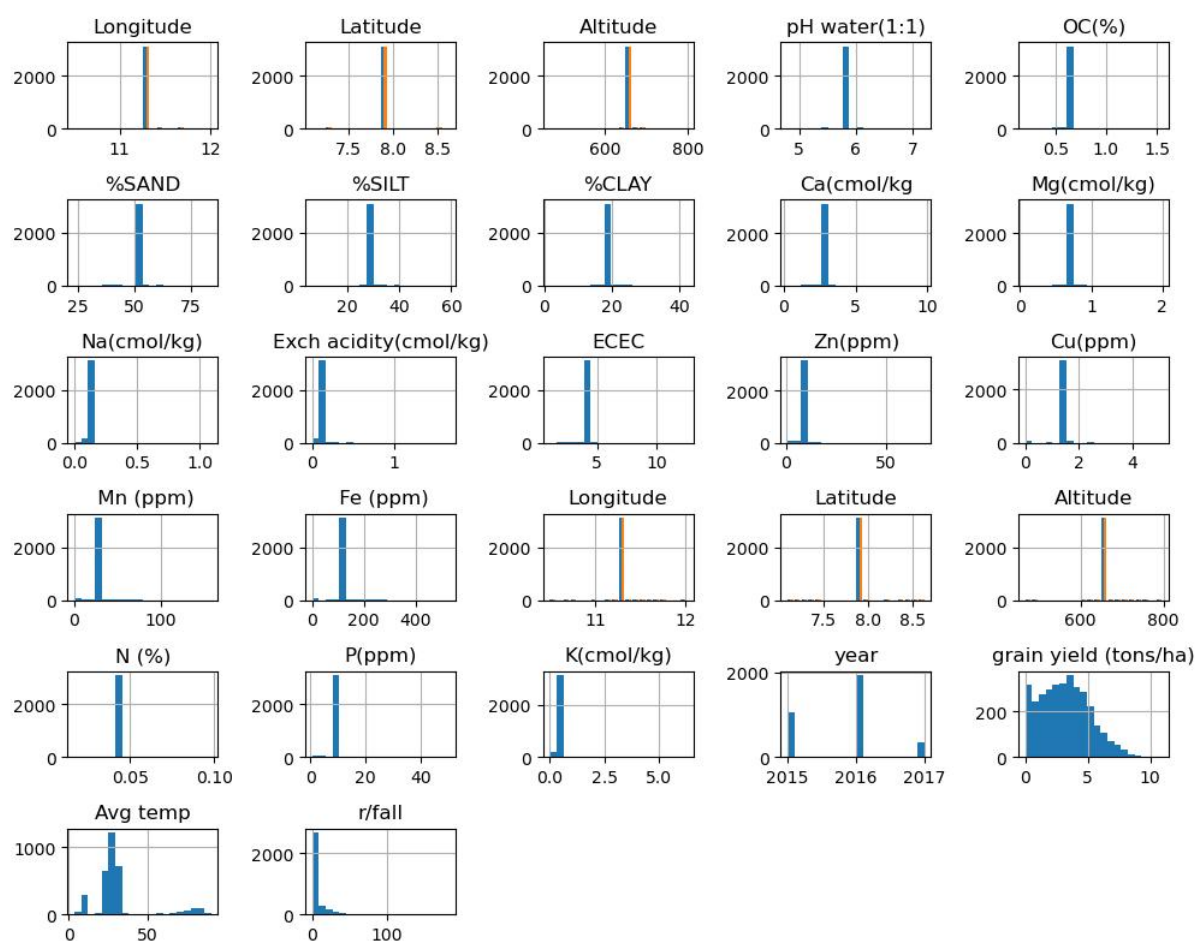


Figure 3: Data distribution of variables using histogram

Table 2 Classification report for limiting nutrients (npk)

Metrics	Precision	Recall	F1-score	support
N Limiting				
1(limiting)	1.00	1.00	1.00	670
Accuracy			1.00	670
Macro avg	1.00	1.00	1.00	670
Weighted avg	1.00	1.00	1.00	670
P Limiting				
0 (non-limiting)	1.00	1.00	1.00	644
1 (limiting)	0.96	1.00	0.98	26
Accuracy			1.00	670
Macro avg	0.98	1.00	0.99	670
Weighted avg	1.00	1.00	1.00	670
K Limiting				
0 (non-limiting)	1.00	1.00	1.00	635
1 (limiting)	0.96	1.00	0.98	35
Accuracy			1.00	670
Macro avg	1.00	1.00	1.00	670

Weighted avg	1.00	1.00	1.00	670

Summary of Classification Results (multioutput Random Forest model)

The model achieved perfect or near-perfect classification for predicting limiting nutrients (N, P, K). Extremely high accuracy was observed for the three nutrients (100% for N and K, almost 100% for P). No errors or misclassifications for N and K, and only a minor drop in precision for P-Limiting. Well-balanced performance across all classes was observed (even minority classes are classified well).

Here’s a breakdown:

N_Limiting Classification:

- Perfect performance: Precision, recall, and F1-score are all 1.00. All 670 samples were classified correctly (suggesting no misclassification).

P_Limiting Classification:

- Nearly perfect classification: Class 0 (Not P-Limiting): Precision, recall, and F1-score are 1.00 (644 samples). Class 1 (P-Limiting): Precision 0.96, recall 1.00, F1-score 0.98 (26 samples). Few misclassifications for the minority class (P-Limiting), but overall, performance remains very strong.

K_Limiting Classification:

- Perfect classification again: Precision, recall, and F1-score are all 1.00. Both majority (not limiting) and minority (K-limiting) classes were classified with 100% accuracy.

Cross validation score for the classification model

Accuracy Scores: [0.99850746 1.1.1. 1.]

Mean Accuracy: 0.9997 ± 0.0006

Precision Scores: [1. 1. 1. 1. 1.]

Mean Precision: 1.0000 ± 0.0000

Recall Scores: [0.98717949 1. 1. 1. 1.]

Mean Recall: 0.9974 ± 0.0051

F1 Scores: [0.99346405 1. 1. 1. 1.]

Mean F1: 0.9987 ± 0.0026

1. Accuracy (0.9997 ± 0.0006)

- Accuracy is nearly 100%, meaning that almost all predictions match the actual values.
- The small standard deviation (± 0.0006) suggests that performance is consistent across different cross-validation folds.

2. Precision (1.0000 ± 0.0000)

- Precision is 1.0000 (100%) across all folds, meaning zero false positives.
- Every instance predicted as a certain class was actually correct.

3. Recall (0.9974 ± 0.0051)

- Recall is also extremely high (~99.74%), meaning very few false negatives.
- One-fold had a slightly lower recall (0.9871), but the overall variation is minimal (± 0.0051).

4. F1 Score (0.9987 ± 0.0026)

- The F1 score combines precision and recall, confirming a nearly perfect balance between the two.
- A mean F1 of 99.87% with minimal variation means the model is highly effective and consistent.

Table 4. Table showing the Feature importance for each Target Variables

Features	N limiting	Features	P limiting	Features	K limiting
Longitude	0.0	N_P_ratio	0.2764	K(cmol/kg)	0.3315
Cu(ppm)	0.0	P(ppm)	0.2670	N_K_ratio	0.1987
N_K_ratio	0.0	P_K_ratio	0.1420	Na(cmol/kg)	0.0544
N_P_ratio	0.0	Na(cmol/kg)	0.0611	P_K_ratio	0.0493
r/fall	0.0	%clay	0.0387	Exch acidity	0.0421
Avg temp	0.0	Cu(ppm)	0.0186	Avg temp	0.0364
Grain yield	0.0	Latitude	0.0175	N_P_ratio	0.0350
Year	0.0	Altitude	0.0164	Altitude	0.0350
K(cmol/kg)	0.0	%Sand	0.0158	ECEC	0.0256

Feature importance for Target Variables; Limiting Nutrients – N_Limiting, P_Limiting, K_Limiting

Feature Importance for N_Limiting
All features have 0 importance, meaning the model is not using any input features to classify whether nitrogen is limiting. This suggests that nitrogen limitation is constant across all the study areas (i.e., every sample is either always N-limiting or not). Studies in West Africa's savanna zones has highlighted the deficiency of N as a major constraint due to Low soil organic matter (SOM) (Bationo *et al.*, 2012), high leaching potential in sandy soils (Fageria & Baligar, 2005) and Limited biological N-fixation in continuous maize-based systems (Vanlauwe *et al.*, 2015).

Feature Importance for P_Limiting

The model identifies N_P_Ratio (0.28) the ratio between nitrogen and phosphorus as shown in Figure 5. Higher values suggest P deficiency if N is abundant but P is low. P(ppm) 0.27 as shown in table 4 which directly indicates phosphorus levels in the soil. Lower values likely correlate with P limitation. P_K_Ratio (0.14) the balance between phosphorus and potassium. If the ratio is skewed, it could indicate that P is limiting. Na(cmol/kg) 0.06 () high sodium levels can reduce phosphorus availability in soil. %CLAY (0.04) Soils with table 4

more clay often bind phosphorus, making it less available. Cu(ppm) 0.036 (table 4) Copper can influence phosphorus uptake in plants.

From the result, Phosphorus limitation is strongly influenced by P availability, nutrient ratios (N_P_ratio, P_K_ratio), and soil composition (clay, sodium levels, copper interactions). This suggests the model is making reasonable decisions based on soil chemistry. Sanchez *et al.*, (1997) reported that P fixation in acidic and highly weathered soils can reduce plant-available P. High clay content (kaolinitic soils) binds P, making it less available to plants (Bekunda *et al.*, 2010). Additionally, Imbalanced nutrient ratios (high N_P_ratio or P_K_ratio) could impact P uptake efficiency (Tittonell *et al.*, 2008).

Feature Importance for K_Limiting

As shown in Figure 6, the model considers that K(cmol/kg) 0.33 (table 4) directly represents soil potassium levels. Low values may likely lead to K limitation. An N_K_ratio of 0.20 Shows the balance between nitrogen and potassium. If N is high but K is low, potassium becomes limiting. Na(cmol/kg) 0.05, high sodium can interfere with potassium uptake. P_K_ratio 0.05 (table 4) shows phosphorus-to-potassium balance. If this ratio is too high, it might mean potassium

is deficient. This is in line with the study of Schroeder (1985) who reported that high N_K and P_K_ratio can reduce K uptake efficiency which can affect maize productivity. Exch acidity (0.04) high acidity can reduce K availability. Marschner (2012) also reported that K deficiency is more common in areas with high Na levels due to ion competition. Avg temp (0.036) temperature affects nutrient uptake and leaching. As indicated in table 4, Altitude (0.035) affects soil composition and nutrient retention. ECEC (0.034) high ECEC values indicate greater nutrient-holding capacity. Cu(ppm) (0.026) copper interactions might affect K availability.

The interaction between K and exchangeable ions could results from the nature of the soil of these areas as most soils are developed from basement complex rocks which contains large content of these cations. Møberg and Esu (1991) also reported an appreciable presence of K-bearing feldspar minerals in sand and silt particles of Savanna soils of Nigeria. Therefore, Potassium limitation is largely determined by K levels, nutrient ratios (N: K, P: K), sodium interference, soil acidity, and environmental factors (Figure 6). The model correctly identifies these as key soil properties that affect K uptake in plants.

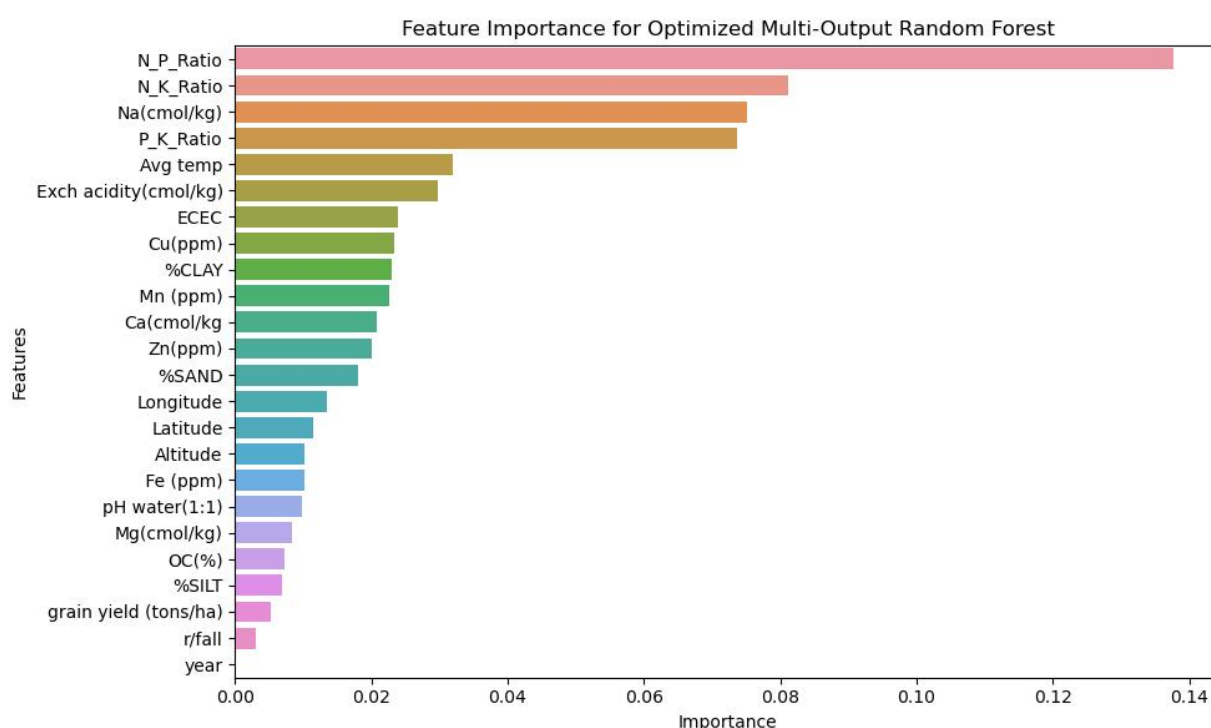


Figure 4: Feature importance plot for the multioutput random forest model

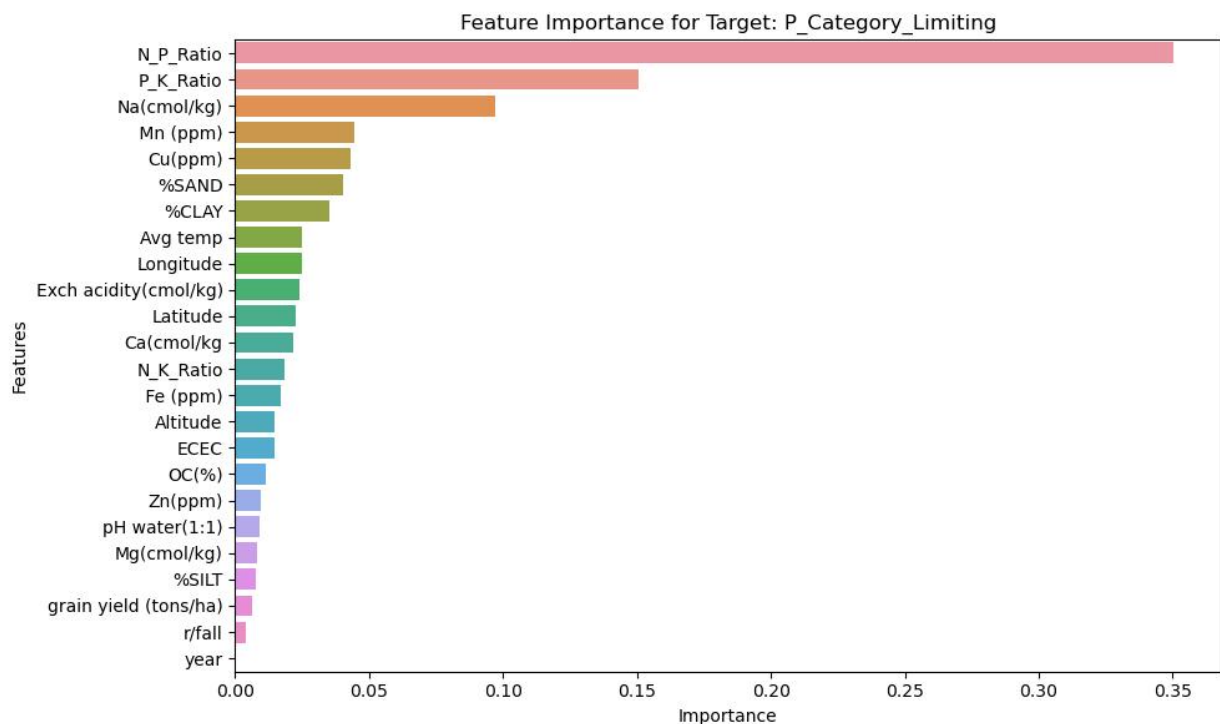


Figure 5: Feature importance plot for target P limiting category

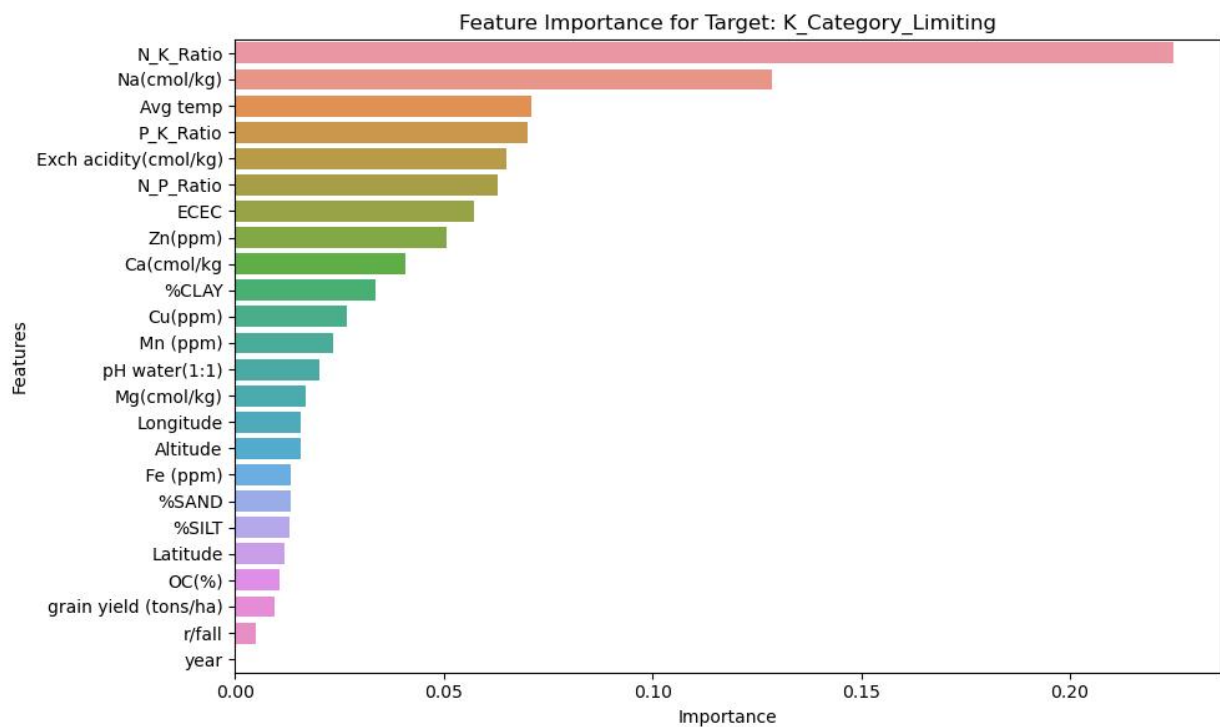


Figure 6: Feature importance plot for target K limiting category

Spatial Analysis – Mapping Limiting Nutrients

Spatial distribution of limiting nutrient

It was observed that nitrogen is limiting (Figure 7) across all the study locations.

Studies by Jibrin *et al.*, 2012, Shehu *et al.*, 2018 confirm that N is the most limiting nutrient in maize belt region in Nigerian savannas, especially under low-input conditions. This is in line with earlier

studies that highlighted the deficiency of N as a major constraint due to Low soil organic matter (SOM) (Bationo *et al.*, 2012), high leaching potential in sandy soils (Fageria & Baligar, 2005) and Limited biological N-fixation in continuous maize-based systems (Vanlauwe *et al.*, 2015). From Figure 8, Dandume, Faskari, Bakori and Funtua showed the highest P limitation areas suggesting that soils in these areas are more deficient in P relative to the crop needs while other LGAs are much less P-limited. In other words, Phosphorus limitation is more location-specific and strongly influenced by P availability in soil, nutrient ratios (N_P_ratio, P_K_ratio), soil texture (clay levels), sodium interactions, and copper presence as shown in Figure 8. Additionally, the importance of N_P_ratio, micronutrients (Mn, Cu), and soil texture aligns with literature emphasizing the role of balanced nutrient ratios and microelements in phosphorus availability. The impact of Na and exchangeable acidity reflects possible P fixation challenges in P limitation areas. Although, past studies have reported the limitation of P such as Kamara *et al.*, and Shehu *et al.*, (2015) in some parts of the study areas in the savanna region while the available P could be explained by the residual effects of the previous P applications. Figure 9 showed areas with yellow patches showed areas with limiting K implying that Lere, Doguwa, Tundun wada, Soba, Tofa and Doguwa exhibited high K limitation. The

prominence of NK and NP ratios, Na, and exch acidity in the model is supported by agronomic findings: potassium availability is sensitive to nutrient balance and soil physicochemical properties. While clay shows positive correlation, its lower feature importance suggests its role is mediated by other soil properties like ECEC and Na levels. However, these yellow patches are randomly scattered across LGAs suggesting no obvious spatial patterns. Similar patterns of nutrient limitation have been reported in SSA (sub Saharan Africa), where sandy soils are linked to N/K leaching, and acidic/sodic soils reduce P/K uptake (e.g., Vanlauwe *et al.*, 2010; Sanchez, 2002).

In a comprehensive study across the maize belt region Aliyu *et al.*, (2020) observed that available P were generally low with a mean of 4.29mg/kg and exhibited a high spatial variability. Contrary to exchangeable K which was classified as high 0.65cmol/kg but also with a significant spatial variability. Similarly, a study conducted by Lawal *et al.*, (2021) on a 1.3ha maize farm in Minna reported high spatial variability for K. Additionally, Shehu *et al.*, (2018) conducted nutrient omission trials across farmers' fields in the northern Nigeria and observed moderate to large variability in soil characteristics including P and K. These findings emphasized the spatial variability in P and K and the need for site specific fertilizer recommendation to enhance soil fertility and improve maize yield.

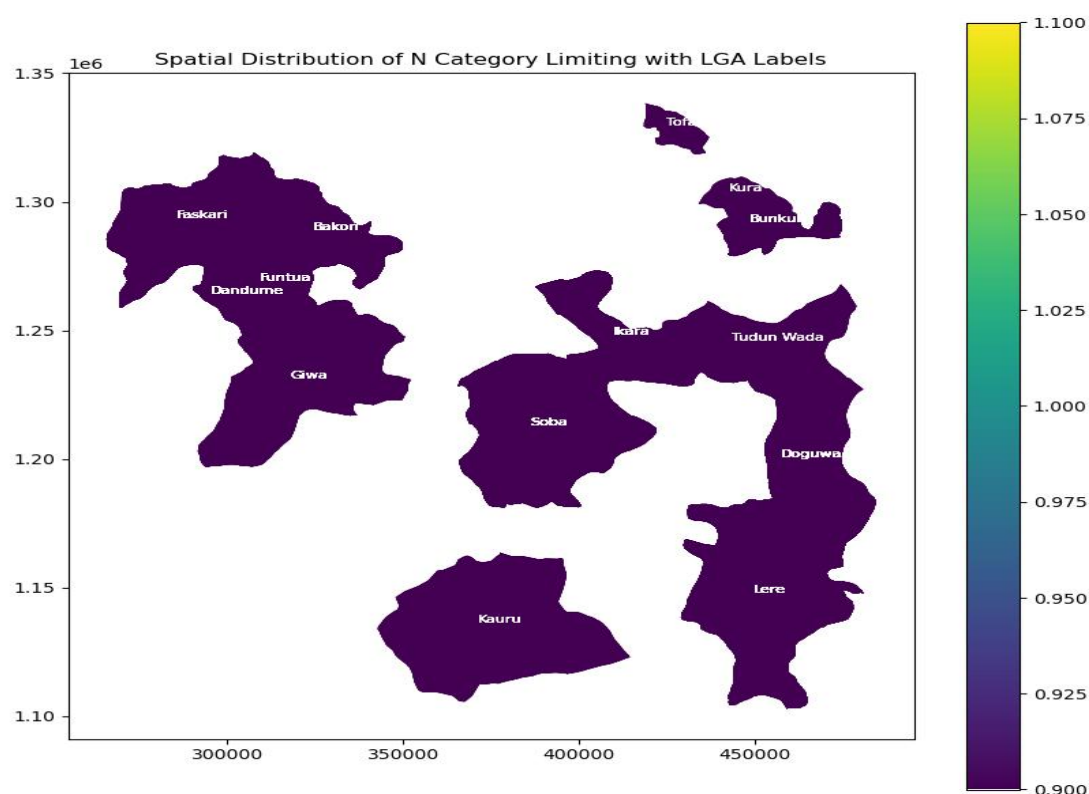


Figure 7: Map showing the distribution of predicted limiting nitrogen across the study areas

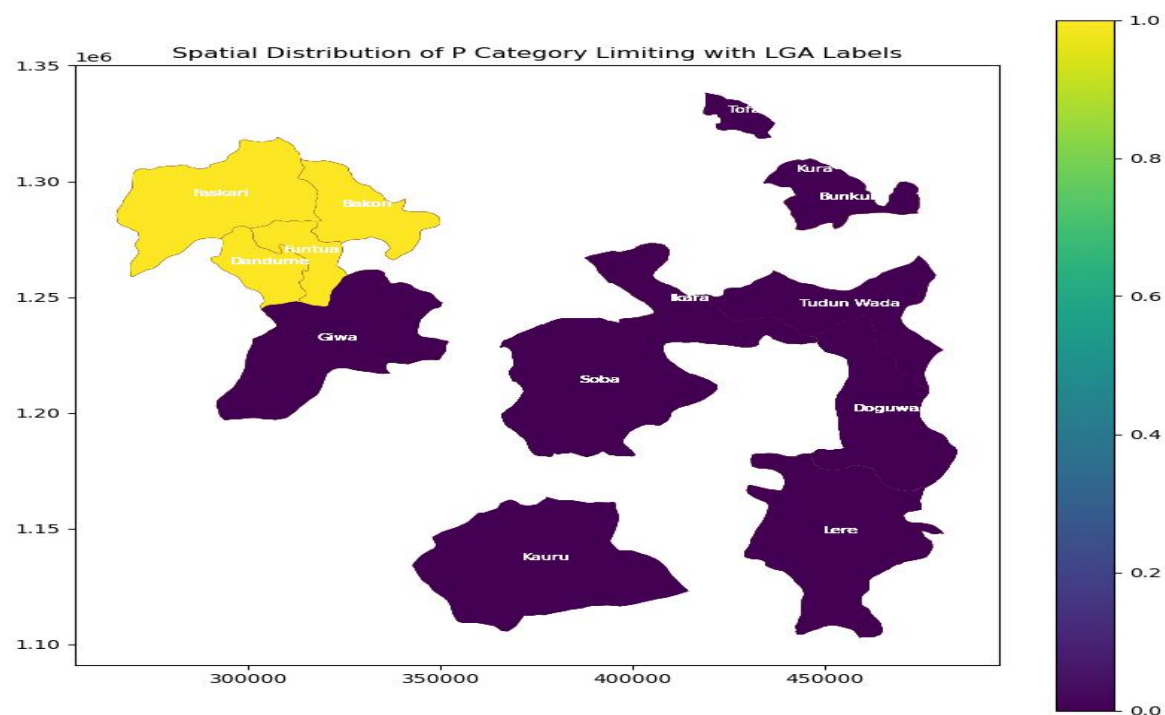


Figure 8: Map showing the distribution of predicted limiting phosphorus across the study areas

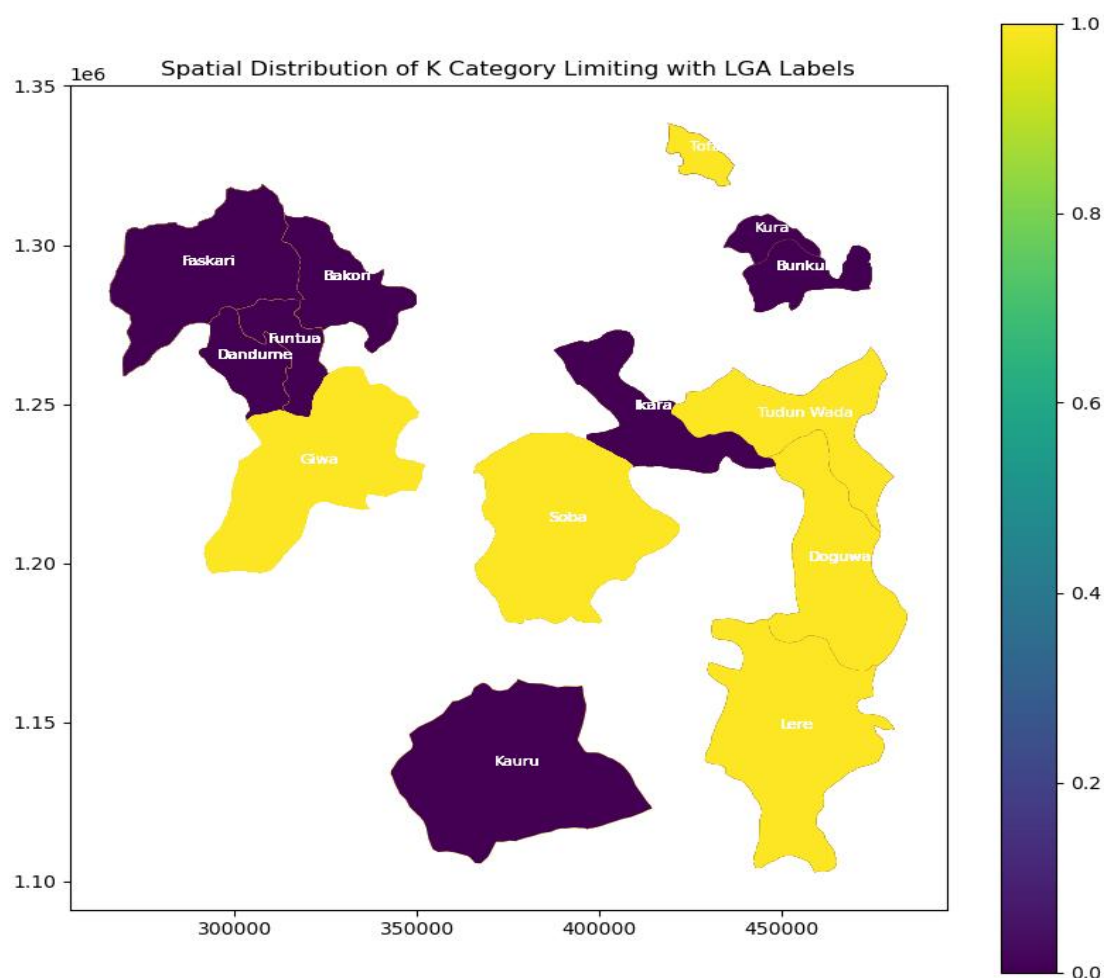


Figure 9: Map showing the distribution of predicted limiting potassium across the study areas

Map showing the spatial analysis techniques using moran's I to identify hotspots for limiting nutrients

Table 5: Local moran's I value for limiting nutrients

Nutrients	Moran's I	P-value
N limiting	Nan	0.001
P limiting	0.158	0.001
K limiting	-0.0001	0.337

N_Limiting (Moran's I = NaN, p = 0.001):

The NaN value suggests no variability (e.g., all values are the same). P_Limiting (Moran's I = 0.158, p = 0.001): Slight clustering of P_Limiting values, meaning high-P-limiting areas are somewhat grouped together, and low-P-limiting areas

are also somewhat grouped. Since p-value = 0.001 (< 0.05), the clustering is statistically significant. However, the correlation is weak (0.158 is close to 0), so spatial clustering is not very strong. K_Limiting (Moran's I = -0.0001, p = 0.337): No significant spatial

autocorrelation (values appear randomly distributed). The very small negative value suggests slight dispersion, but it is not statistically significant ($p = 0.333$). This means K_Limiting is randomly distributed across the study area, without any meaningful clustering or dispersion pattern.

Conclusion

The analysis revealed distinct spatial and predictive patterns among the three macronutrients (N, P, and K) that limit maize productivity across the study area. Moran's I statistics showed a significant spatial dependence for phosphorus (P) limitation (Moran's I = 0.158, $p = 0.001$), indicating moderate positive spatial autocorrelation and suggesting that areas with similar P limitation tend to cluster spatially. Nitrogen (N) limitation, though returning a non-numeric Moran's I value (NaN), exhibited a highly significant p -value (0.001), implying a spatial pattern likely influenced by uniform N deficiency across the region. Conversely, potassium (K) limitation showed no significant spatial autocorrelation (Moran's I = -0.0001, $p = 0.337$), reflecting random distribution of K limitation across locations.

Feature importance analysis identified distinct drivers for each nutrient limitation. Nitrogen limitation was primarily influenced by nutrient ratios (N_P and N_K) and soil micronutrients such as Cu (ppm), suggesting that nutrient interactions and soil fertility status jointly control N availability. Phosphorus limitation was most strongly associated with P concentration (ppm), N_P ratio, Na (cmol/kg), and % clay, indicating that both soil chemical composition and textural properties significantly influence P bioavailability. Potassium limitation was mainly controlled by exchangeable K

(cmol/kg), N_K ratio, Na (cmol/kg), and exchange acidity, reflecting the interplay between cation balance and soil acidity in determining K supply.

Machine learning classification performance showed outstanding accuracy across all nutrients, with precision, recall, and F1-scores reaching 1.00 for nitrogen and near-perfect values for phosphorus and potassium (macro average F1-score = 0.99–1.00). These results demonstrate the robustness and predictive reliability of the model in identifying limiting nutrients from soil and environmental variables.

Overall, the findings suggest that nitrogen remains the most spatially pervasive limiting nutrient across the study area, while phosphorus limitation exhibits clustered patterns likely influenced by soil chemistry and texture. Potassium limitation appears localized and less spatially structured. The high model accuracy underscores the potential of machine learning and spatial analysis in developing site-specific nutrient management strategies that can enhance fertilizer efficiency and optimize maize yield across varying agroecological zones

Limitations

Potential biases observed was inadequate soil data (NPT missing soil variables), possible overfitting due to 100% classification accuracy.

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EFFECTS OF POULTRY AND SHEEP MANURE ON DRY MATTER YIELD AND FRESH FRUIT YIELD OF *CUCUMIS SATIVUS* L. IN IMO STATE, NIGERIA

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ABSTRACT

*The realization of the importance of fruits in our diets and over whelming importance of cucumber (*Cucumis sativus* L.) and its health benefits resulted in an increase in demand for the product in Nigeria. This probed the research on the effects of poultry and sheep manure on dry matter yield and fresh fruit yield of *Cucumis sativus* L. in Imo State, Nigeria. The levels of poultry and sheep manure applied were equivalent to 0, 30 and 60 % N in a 3 × 2 factorial experiments arranged in randomized complete block setup with three replications. Cucumber dry matter and fresh fruit yields were determined at flowering and growth termination stages in wet and dry seasons of the years 2019 and 2020. The dry matter and fresh fruit yields increased with both single applications relative to control. Averaged over seasons and yields, optimum rate for dry matter and fresh fruit yields were with $P_{60}S_{60}$. Consequently, combination of poultry and sheep manures at 60 % N each will be useful for efficiency of nutrient utilization and sustained *Cucumis sativus* L. yields. Further study is recommended to illuminate this fact in different environment.*

Keywords: Poultry manure, sheep manure, *Cucumis sativus* L., dry matter yield, fresh fruit yield.

INTRODUCTION

As decrease global population and food demand increases, there was pressure on soil nutrients leading to a decrease in soil fertility. Meanwhile, decline in soil organic matter under intensive farming systems is a major cause of soil fertility loss (Scotti, Bonanomi, Scelza, Zonia & Rao, 2015^b). Such fertility can be restored through

application of good soil management as increased demographic pressure on land demands an efficient nutrient management to ensure increased agricultural productivity. This requires understanding of nutrient dynamics such that applications could be planned to synchronize peak periods of nutrient release with crop uptake.

Organic amendments increase soil organic matter (Thangarajan, Bolan, Tian & Naidu 2013; Khaliq & Abbasi, 2015), promote soil aggregate stability, water holding capacity and soil porosity (Leroy, Robinson & Goldsmith 2008; Li, Feng, Tewolde, Zhang, Yan & Yang, 2021), thus improving soil quality (Scotti *et al.*, 2015^a). Soil organic matter content affects crop yield through its role in enhancing and sustaining soil quality (Reeves, 1997) and soil health (Lal, 2016).

Cucumber is one of the monoecious annual crops of the cool climates (Thoa, 1998; Best, 2000; Nwofia, Amajuoyi & Mbah, 2015); though some may produce bisexual flowers (Perl-Trevers, 1999). Cucumber is a member of the Cucurbitaceae family (Valenzuela *et al.*, 2017) and comprises of 118 general and 825 species (Adinde *et al.*, 2016). The fruit is soft and succulent (Arunkumar, Patil, Hanchinamani, Goud & Hiremath, 2011; Nwofia *et al.*, 2015; Khadija, Fatima & Usman, 2022). According to Ikeh *et al.* (2012), the soils where cucumber is cultivated require moderate to high nutrients levels so as to achieve high yields. High light intensity is needed for optimum yields (Agriculture Nigeria, 2017).

In Nigeria, cucumbers are grown majorly in the North particularly Jos; due to the climatic requirements. If the rain is moderate, the cucumber will yield very well in Southeastern Nigeria (Agriculture

Nigeria, 2017). Cucumber requires a constant water supply to reach high quality and yields. There was a general belief that cucumber can only be grown in the Northern part of Nigeria (Adinde *et al.*, 2016). However, cucumber cultivation in the Southeastern Nigeria has been found to be achievable under moderate rainfall (Enujeke, 2013: 2014).

The study was justified by the affordability and availability of experimental materials such as manures and planting materials and also the tendency to promote crop production at low cost. The aim of this experiment was to determine the biomass yields of cucumber at flowering and fruiting stages during first and second planting.

MATERIALS AND METHODS

Location of the experimental site

The study location was the Teaching and Research farm of Federal University of Technology, Owerri, Imo State. Owerri lies between Latitudes 5° 05' and 5° 23' N and Longitudes 7° 02' and 7° 21' E on an elevation of 124 metres above sea level in the humid rain forest agro-ecological zone of Nigeria. Its mean annual rainfall, daily temperature and monthly relative humidity varied as 2,500 mm, 32 °C and 85 % respectively (IPEDC, 2006). Also, weather measurements of the experimental locations in FUTO were made during the 2019 and 2020 cropping periods (Table 1).

Table 1: Weather data of FUTO in 2019 and 2020 cropping seasons.

Climatic properties

Period	Rainfall/ Month (mm)	Relative Humidity/ day (%)	Temperature/ day (°C) (Atmosphere/ Soil)
Year 2019			
June	53.7	93	31.1 29.6
July	202.6	95	28.3 26.12
August	35.2	83	29.22 27.3
September	136	76.9	32.3 25.17
October	94.4	76..10	29.97 27.3
November	15.6	70.4	34 29.24
Total	537.5	494.4	184.89 164.73
Mean	89.58	82.4	30.82 27.46
Year 2020			
June	45.8	94	27.2 26.7
July	189.4	100	27.3 23.23
August	40.1	97.01	32.5 25.22
September	82.1	77.5	29.8 26.2
October	75	81.6	32.5 27.1
November	20.8	74.4	30.5 29
Total	453.2	524.51	179.8 157.45
Mean	75.53	87.42	29.97 26.24

Soil temperature at the depth of 20 cm

Source: Using the instrument.

Field Study

Field study was conducted for four cropping cycles in two years (2019 and 2020), with each year consisting of two cycles; the early or rainy and late or dry season in each year. The early and late planting seasons were between the months of June – August and September – November, respectively in the two years, and fell within the recommended planting

periods between April to October for cucumber production (Valenzuela *et al.*, 2017).

Plot layout and experimental design

Total land area measuring 0.192 ha and consisting of 0.048 ha per cropping cycle was used for the study. The area of 0.048 ha equivalent of $37 \times 13 \text{ m}^2$ (481 m^2) for each cropping cycle was partitioned into plots measuring $3 \times 3 \text{ m}$ and total area per rep was $12 \times 12 \text{ m}^2$. In each cropping cycle, the land was manually cleared using machete, partitioned into plots each

measuring $3 \times 3 \text{ m}^2$ and beds constructed with 3 m high using hoes and spade. Treatments consisting of poultry and sheep manures were applied on the beds. Prior to application, the poultry and sheep manures were air dried and ground using a wiley mill. The treatment consisted of three rates of 0, 30 and 60 % N equivalent to 0, 1.08 and 2.16 and 0, 0.62 and 1.24 t ha⁻¹ of poultry and sheep manures respectively were applied and thoroughly incorporated into the soil using spades. The experimental design was a 3² factorial replicated three times in randomized complete block set-up and giving a total of 27 treatments (3 × 3 × 3 for poultry × sheep × replicates).

The cucumber crops were then grown to maturity and agronomic measurements were obtained and then, harvesting of healthy matured fruits commenced by hand picking at 42 till 60 days after planting. This was in line with the recommendations of 40 – 60 days after planting (TNAU, 2013; Laifa, 2017; Valenzuela *et al.*, 2017).

Agronomic calculations

Fresh fruit yield (t ha⁻¹)

The total fruit weight from net plots (4 m²) was measured in kilograms (FFW kg⁻¹) using loaded scale and these were converted to kilogram per hectare using the formula as follows

$$FFW (kgha^1) = \frac{FFW (kg \text{ net plot}^{-1}) \times 10,000 \text{ m}^2}{\text{Area per net plot (4 m}^2\text{)}}$$

Eqn

1

Where FFW = fresh fruit weight

$$FFY (kgha^1) = \frac{FFW (kg \text{ net plot}^{-1})}{1,000 \text{ kg}}$$

Eqn 2

Where; FFY = fresh fruit yield (t ha⁻¹)

FFW = fresh fruit weight (kg ha⁻¹)

Conversion factor = 1000

Dry matter yield (t ha⁻¹)

The plant samples collected were oven dried at 72 °C for 48 hours and weighed until constant weight was attained after which it was milled using a Wiley mill. The dry matter yield/ plant (g) determined thereafter. The dry matter yield (t ha⁻¹) was calculated with conversion formula (Victoria, 2023) as shown below;

$$\text{Dry matter yield (tha}^1\text{)} = \frac{\text{Dry matter yield (g)} \times \text{Dplantpopulation (tha}^1\text{)}}{1,000,000}$$

Eqn

3

Statistical Analysis

All data generated were subjected to Analysis of Variance (ANOVA) and means separated using Fisher's Protected Least Significant Difference Test at 5 % probability level. All analyses were computed using Genstat Statistical package (discovery edition 12 software) (Genstat, 2012).

RESULTS AND DISCUSSION

Characterization of the manures used for the study.

Chemical properties of the poultry and sheep manures used for this study were presented in Table 2. The pH values of the organic manures are within the mean of 7.8; characterized as alkaline (Pam & Brian, 2007), a suggestion that it can promote soil pH on application. It has been noted that application of organic manure can improve the soil pH (Hargreaves, Adi & Warman, 2008; Saka *et al.*, 2023). Several researchers have reported an increase in soil pH with poultry and livestock manures (Iren, John & Imuk 2014; Li, Zhong, Wang & Zhao, 2018). Electrical conductivity was higher in poultry (14.23) than sheep (9.45 dS m⁻¹)

indicating the tendency of high salt concentration in the former than later.

The EC values of both manures were above 3.2 dS m⁻¹ which is classified as very strongly saline by LAS (2014). Its higher value in poultry manure (value) than sheep manure (value) could be due to the high soluble salt contents and as such might increase salt contents to applied soils. Other researchers have also noted high EC values of poultry manure than cattle and goat manures (Azeez & Van Averbek, 2010^a; 2010^b; Usman, 2015; Saka *et al.*, 2025). The high sodium content of poultry manure than sheep manure could be responsible for its high EC value.

Nutrient concentrations especially total N, P and K were better in poultry than sheep manure with the values equivalent to 89.66, 4.68 and 9.13 g kg⁻¹ in poultry manure and 83.36, 4.22 and 8.93 g kg⁻¹ for sheep manure. This corroborated the work of Usman (2015), who stated that

the fertility status of the soil proved to be beneficial, with poultry manure than any other organic manure in his research. Conversely, sheep manure was higher in calcium, magnesium and organic carbon with values equivalent to 6.92, 5.69 and 515.44 g kg⁻¹ in sheep and 6.89, 5.64 and 298.98 g kg⁻¹ in poultry manure. Sheep manure increased soil organic carbon. Hence, manure also contains large amounts of organic P such as phospholipids and nucleic acids, which could be released to increase soil inorganic P concentrations by mineralization (Shen *et al.*, 2011). Mixing manure with sandy soils help to retain moisture levels. Manure produces increased soil carbon, which is an important source of energy that makes nutrients available to plants. It reduces runoff and leaching of nitrates in the soil (Osama *et al.*, 2016). Manure is quickly decomposed under warm, moist soil conditions (Christensen, 2017).

Table 2: Properties of poultry and sheep manures used for the study.

Chemical Properties	Manures	
	Poultry	Sheep
pH	7.8	7.8
EC (dS m ⁻¹)	14.23	9.45
Total nitrogen (g kg ⁻¹)	89.66	83.36
Organic carbon (g kg ⁻¹)	298.98	515.44
Carbon: Nitrogen	3.34	6.18
Total phosphorus (g kg ⁻¹)	4.68	4.22
Total potassium (g kg ⁻¹)	9.13	8.93
Total sodium (g kg ⁻¹)	0.89	0.79
Total calcium (g kg ⁻¹)	6.89	6.92
Total magnesium (g kg ⁻¹)	5.64	5.69
Exchangeable acidity (cmol ⁺ kg ⁻¹)	0.6	0.6

Characterization of Pre-treatment Soils used for the Study.

The physico- chemical properties of the studied soils in wet (early) and dry (late) seasons in 2019 and 2020 are presented in

Tables 3 and 4, respectively. In Table 3, sand, silt and clay contents ranged from 682.00 – 701.00, 41.00 – 48.00 and 25.70 – 28.80, and 726.00 – 741.00, 18.00 – 26.00 and 23.80 – 25.30 g kg⁻¹ in wet and dry seasons of 2019, respectively. In both seasons, distribution of the various soil particles was irregular with soil depths and with mean concentrations being an increasing order of sand > clay > silt. The textures of the soils are between sandy loam and loam sandy in wet and dry seasons (first and second locations), respectively. This would support the growth of cucumber as it thrives in a sandy loam soil (Agricultural Nigeria, 2017).

In 2019 crop year, the result showed that soil pH, EC, TN, NH₄⁺-N, NO₃⁻-N ranged respectively from 4.10 – 4.80, 0.10 - 0.20 dS m⁻¹, 1.99 – 2.07 g kg⁻¹, 118.50 – 126.50 mg kg⁻¹ and 11.21 – 11.73 mg kg⁻¹ (wet season) and 4.4 – 4.6, 0.20 - 0.20 dS m⁻¹, 1.70 – 1.79 g kg⁻¹, 118.80 – 120.00 mg kg⁻¹ and 10.56 – 10.89 mg kg⁻¹ (dry season) (Table 3). The ranges in 2020 (Table 4) were 4.45 – 4.87, 0.20 - 0.40 dS m⁻¹, 0.60 – 0.80 g kg⁻¹, 52.70 – 92.63 mg kg⁻¹ and 27.22 – 50.39 mg kg⁻¹ in the wet season and 4.03 – 4.33, 0.20 - 0.30 dS m⁻¹, 0.80 – 1.10 g kg⁻¹, 71.08 – 83.44 mg kg⁻¹ and 53.11 – 66.43 mg kg⁻¹ in the dry season (Table 3).

The values for soil pH were indicated as slightly - moderately acidic (Adaikwu &

Ali, 2013; Ukaegbu, 2020) with the degree greater down soil depth, probably due to its poor organic matter content. Distribution of total N down soil depth was irregular in the wet and dry seasons of 2019 but decreased with depth in both seasons in 2020. Mean values were 1.74 – 2.03 and 0.70 – 0.93 g kg⁻¹ in wet and dry seasons of 2019 and 2020 respectively, with those of 2019 greater than 2020. Mean concentrations of both seasons and years, 0.70 (wet) and 0.93 (dry) were low compared to the critical value of 12.50 g kg⁻¹ for Southeastern Nigerian soils (Enwezor, Ochiri, Opuwaribo & Udoh, 1990^a), indicating N deficiency in the soils which could retard the performance of the *Cucumis sativus* L. Mean NH₄⁺-N in wet and dry seasons were 123.35 and 118.50 for wet season (Table 3) and 75.11 and 78.57 mg kg⁻¹ for dry season. In 2020 crop year, the values of NO₃⁻-N were 11.51 and 10.72 and 38.61 and 58.02 mg kg⁻¹ for wet and dry cycle, respectively. Values of NH₄⁺-N were greater than NO₃⁻-N in both seasons and years; this might be due to poor nitrification process. Also, mean total P were 1.46 and 1.27 and 0.39 and 0.30 g kg⁻¹ in wet and dry seasons with concentrations higher in wet than dry seasons and in 2019 than 2020. These values were within the ranges reported by ENDMEMO (2015; Saka *et al.*, 2023^{a,b}).

Table 3: Selected physico-chemical properties of the soils studied in early and late seasons of 2019.

Physico chemical properties	Wet Season 2019					Dry Season 2019				
	Soil Depths (cm)					Soil Depths (cm)				
	0 - 5	0 - 10	10 - 20	20 - 40	Mean	0 - 5	0 - 10	10 - 20	20 - 40	Mean
Sand (g kg ⁻¹)	682.00	680.00	701.00	684.00	686.75	726.00	741.00	738.00	728.00	733.30

Cucumber (*Cucumis sativus* L.) dry matter yield (t ha⁻¹) at flowering and growth termination stages in wet and dry seasons of 2019 and 2020.

Effects of manures on dry matter yield of cucumber at flowering and growth termination stages in wet and dry seasons in 2019 and 2020 were presented in Table 5. Dry matter yield at flowering stage was significantly ($p \leq 0.05$) higher at P₆₀ (0.118 and 0.265 t ha⁻¹) in wet and P₃₀ (0.405 and 0.235 t ha⁻¹) in dry seasons of 2019 and 2020 using only poultry manure. In both seasons and years, wet season dry matter yield at flowering was better in 2020 while that dry season was in 2019. Also, yield at growth termination stages was better at P₆₀ (0.760 and 0.391 t ha⁻¹) in wet seasons of 2019 and 2020 and dry season of 2019 (0.493 t ha⁻¹) but P₃₀ (0.272 t ha⁻¹) in dry season of 2020 with addition of only poultry manure. In both years and seasons, the highest yield (0.588) was in dry season of 2019.

Similarly, addition of only sheep manure gave the best yields at flowering stage at S₃₀ (0.106 and 0.343 t ha⁻¹) in wet and dry seasons of 2019 and S₆₀ (0.249 t ha⁻¹) in wet season of 2020 but S₀ (0.210 t ha⁻¹) in dry season of 2020. Also, best yield at growth termination stages were at S₆₀ in wet and dry seasons of 2019 (0.680 and 0.588) and 2020 (0.440 and 0.337 t ha⁻¹ respectively).

Amongst seasons and yields, best yield at flowering was with S₃₀ in wet season of 2019. This suggests the attainment of optimum nutrient conditions for cucumber at different sheep manure rates in wet season of 2019.

Cucumber yields at flowering and growth termination stages differed with

integrations of poultry and sheep manures. At flowering stage, it was significantly ($p \leq 0.05$) higher with P₆₀S₃₀ (0.149 t ha⁻¹) in wet and P₃₀S₆₀ (0.436 t ha⁻¹) in dry season of 2019 and P₃₀S₀ (0.337 t ha⁻¹) and 0.348 t ha⁻¹) in both wet and dry seasons of 2020. Also at growth termination stage, yields were significantly ($p \leq 0.05$) better with P₆₀S₆₀ (0.911) and P₀S₆₀ (0.588 t ha⁻¹) in wet and dry seasons of 2019 respectively and P₆₀S₆₀ (0.553) and P₀S₆₀ (0.337 t ha⁻¹) in wet and dry seasons of 2020 respectively. This shows that best yields at flowering and growth termination was obtained with P₃₀S₆₀ and P₀S₆₀ in dry season of 2019, respectively suggesting the existence of favorable conditions for the crop during that season of the year. Equally, amount of integration of poultry and sheep manures gave significant higher values in both seasons and years at both flowering and growth termination stages than the control. This has been attributed to increased nutrient supply from the integration.

Fresh Fruit Yield (FFY) of Cucumber (*Cucumis sativus* L.).

Impact of manures on cucumber fresh fruit yield in wet and dry seasons of 2019 and 2020 is shown in Table 6. Yields were significantly ($p \leq 0.05$) better with P₆₀ in wet (11.30 t ha⁻¹) and dry (5.82 t ha⁻¹) seasons of 2019, and wet season (7.96 t ha⁻¹) and dry season (11.60 t ha⁻¹) of 2020. Thus, amongst seasons and years, yields were better in dry season of 2020 at P₆₀ rates of only poultry manure. It was distinctly better using S₆₀ in wet (6.44) and dry (8.44 t ha⁻¹) seasons of 2019 and S₃₀ and S₆₀ (8.44) in wet season of 2020 and S₆₀ (13.09 t ha⁻¹) in dry season of 2020.

Table 5: Dry matter yield (t ha⁻¹) of *Cucumis sativus* L. at flowering and termination stages during first and second planting in 2019 and 2020.

Years and Plantings	2019 a		2019 b		2020 a		2020 b	
Manure Rates	1	2	1	2	1	2	1	2
P ₀ S ₀	0.064	0.431	0.190	0.073	0.076	0.100	0.035	0.069
P ₀ S ₃₀	0.096	0.539	0.360	0.470	0.245	0.283	0.184	0.330
P ₀ S ₆₀	0.087	0.613	0.290	0.588	0.231	0.447	0.107	0.337
Mean	0.082	0.528	0.280	0.377	0.184	0.277	0.109	0.245
P ₃₀ S ₀	0.057	0.681	0.392	0.487	0.337	0.330	0.348	0.260
P ₃₀ S ₃₀	0.073	0.471	0.387	0.524	0.212	0.267	0.179	0.287
P ₃₀ S ₆₀	0.076	0.515	0.436	0.469	0.212	0.320	0.179	0.270
Mean	0.069	0.556	0.405	0.493	0.254	0.306	0.235	0.272
P ₆₀ S ₀	0.065	0.639	0.277	0.487	0.207	0.287	0.248	0.237
P ₆₀ S ₃₀	0.149	0.731	0.281	0.410	0.283	0.333	0.153	0.254
P ₆₀ S ₆₀	0.141	0.911	0.279	0.576	0.304	0.553	0.120	0.283
Mean	0.118	0.760	0.279	0.491	0.265	0.391	0.174	0.258
S ₀	0.062	0.584	0.286	0.349	0.207	0.239	0.210	0.189
S ₃₀	0.106	0.580	0.343	0.468	0.247	0.294	0.172	0.290
S ₆₀	0.101	0.680	0.335	0.544	0.249	0.440	0.135	0.297
LSDs (0.05)								
P	0.04	0.19	0.07	0.04	0.16	0.15	0.13	0.09
"								
S	0.04	0.19	0.07	0.04	0.16	0.15	0.13	0.09
'								
P x S								
S	0.06	0.33	0.12	0.07	0.28	0.26	0.23	0.14

a = wet season, b = dry season, 1 = flowering stage, 2 = termination stage, p = poultry, s = sheep and p × s = poultry and sheep manures interaction

Yields were better in wet season of 2019 than dry seasons in both years using only sheep manure.

Equally, best yields using integrations of manures (poultry and sheep) were at P₆₀S₆₀ (12.22) in wet and P₀S₃₀ (8.07 t ha⁻¹) in dry seasons of 2019 and P₆₀S₆₀ (11.38 and 18.53 t ha⁻¹) in wet and dry seasons of 2020, respectively, indicating the superiority of P₆₀S₆₀ over other rates and wet season of 2019 over dry periods. Amongst single and manure integrations,

yields were better with the later than the former.

Conclusion

The levels of N, P and K forms were considered as the major limiting factors in crop growth, development and economic yield. More so, the poultry and sheep amendment treated soils had increased influence on *Cucumis sativus* L. dry matter yield and fresh fruit yield. The manure application rates of P₆₀S₆₀ gave the best DMY and FFY. Further research

elsewhere is needed on the field to substantiate the findings.

Table 6: Fresh fruit yield (t ha⁻¹) of *Cucumis sativus* L.at harvesting during first and second planting in 2019 and 2020.

Years and Plantings	2019 a	2019 b	2020 a	2020 b
Manure Rates				
P ₀ S ₀	4.83	1.51	2.27	2.31
P ₀ S ₃₀	8.63	8.07	6.33	9.45
P ₀ S ₆₀	12.00	3.86	3.86	9.64
Mean	8.49	4.48	4.15	7.13
P ₃₀ S ₀	8.29	4.75	7.29	6.79
P ₃₀ S ₃₀	6.69	4.67	6.41	6.49
P ₃₀ S ₆₀	11.32	8.05	10.08	11.09
Mean	8.77	5.82	7.93	8.13
P ₆₀ S ₀	10.10	2.77	5.79	7.88
P ₆₀ S ₃₀	11.58	6.57	6.71	8.38
P ₆₀ S ₆₀	12.22	7.36	11.38	18.53
Mean	11.30	5.57	7.96	11.60
S ₀	7.74	3.01	5.12	5.66
S ₃₀	8.97	6.44	6.48	8.11
S ₆₀	11.85	6.42	8.44	13.09
LSDs (0.05) P	3.53	1.27	0.16	0.13
" S	3.53	1.27	0.16	0.13
' P x S	6.12	2.20	0.28	0.23

a = wet season, b = dry season, p = poultry, s = sheep and p × s = poultry and sheep manures interaction

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EFFECTS OF INCORPORATION OF PLANT MATERIALS ON PARTICULATE ORGANIC MATTER FRACTIONS AND MAIZE [*Zea mays* L.] PERFORMANCE IN OGUN STATE, NIGERIA

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ABSTRACT

Particulate fraction of soil organic matter is a major reservoir of plant nutrients. In order to determine the effects of the residue quality of plant materials on the particulate organic matter (POM) fraction, a field experiment was conducted at the Organic Research Farm, Federal University of Agriculture, Abeokuta, in the wet season of 2014 with Maize (TZEE-I-Y) as a test crop. The experimental design was Randomized Complete Block Design with three replications. The treatments constituting of plant residues include: *Chromolaena odorata* (CD), *Leucaena leucocephala* (LL), Maize stover (MS), Neem clippings (NC), *Panicum maximum* (PM) and Banana leaves (BL), each at 2 levels (10 and 20 t ha⁻¹) and the control. Three fractions (0.05-0.25 mm, 0.25-0.5 mm and 0.5-2.0mm) of POM were quantified at 1, 3 and 6 months after incorporation (MAI) of plant materials. Data were subjected to analysis of variance and the means were separated using Duncan Multiple Range Test (DMRT) at $p \leq 0.05$. Incorporation of LL and NC increased 0.5-2.0 mm (coarse fraction) compared to control and other treatments at 1MAI. There were significant ($p \leq 0.05$) differences in 0.25-0.5 mm fraction (medium fraction) between BL and MS at 1 MAI, and LL and PM at 3 MAI. However, changes in POM fraction of size range 0.05-0.25 mm (fine fraction) were only statistically significant at 1 MAI. Incorporation of plant materials increased plant height, stem girth, and number of leaves of maize compared to control. Only *Leucaena leucocephala* increased cob yield of maize above control. It was concluded that *Leucaena leucocephala* incorporation would increase soil particulate organic matter under maize cropping for improved yield.

Keywords: Incorporation, particulate organic matter, plant materials, residue.

INTRODUCTION

Soil organic matter (SOM) consists of plant and animal residues at various stages of decomposition. Organic matter is periodically returned to the soil either as litter, crop residue, or as animal waste products, but which differs in amount and quantities (Karanja *et al.*, 2006; Chivenge *et al.*, 2009). Such practices can enhance soil fertility and promote soil rehabilitation. The beneficial effect of soil organic matter on soil productivity is by enhancing cation exchange capacity, supplying plant nutrients, improving soil and water

retention and soil aggregation (Six *et al.*, 2000; Mikha and Rice, 2004).

Particulate organic matter (POM) fraction referred to all soil organic matter (SOM) particles less than 2 mm and greater than 0.053 mm in size (Cambardella *et al.*, 1992). The POM in soil is biologically and chemically active and is part of the labile (easily decomposable) pool of SOM. The POM is especially important to N retention and availability in sandy soils, because the proportion of total N in POM is higher than in fine-textured soils (Hook and Burke, 2000).

Incorporation of plant materials (crop residues) is a traditional practice in cultivation with the aim at controlling soil temperature and heat scorching. It also helps in the maintenance of a good soil physical condition by conserving soil moisture and enhancing water infiltration and stabilizing soil structure. Crop residue incorporation improves biotic activity and adds nutrients to soil thereby improving soil fertility (Awodun and Ojeniyi, 1999; Ojeniyi and Adetoro, 1993). Crop residue incorporation was found to increase the yield of crops like yam, cocoyam, maize and tomato. The type of crop residue incorporation has impact on soil physical and chemical properties and crop yield due to difference in biochemical quality of plant material added (Awodun and Ojeniyi, 1999). Crop residues have the potential to positively alter soil organic matter content by increasing the total biomass produced by a cropping system. *Chromolaena odorata* grows on most soil types but prefers well drained soils in full sun. It has ability to survive fires and propagates back briskly following rain. It is an invasive plant with potentially organic manure. Banana leaves are versatile and effective organic fertilizer that can help plants grow

healthy and strong. Incorporating banana leaves into the soil helps retain moisture, suppress weeds, and keep the soil temperature consistent. *Panicum maximum* have the adaptation to different soil and climate conditions (Braz *et al.*, 2017). Furthermore, Neem products (*Azadirachta indica*) have been known to contain more N, P, K, Ca, and Mg (BOSTID 1992). Researchers have shown the ability of neem products (seeds and leaves) to provide soil nutrients for crop development (Reddy *et al.*, 1993). Maize stover has been known with large volume of biomass production and wide availability around the world. Incorporation of stover into agricultural soil can improve soil quality by prevention of soil erosion, maintenance of SOC, nutrient recycling and so on. *Leuceana leucocephala* on the other hand have been widely used for green manure in cropping systems. The leaves are fragile and decompose quickly thereby providing a very rapid, short-term influx of nutrients related to a low C:N ratio (Hocking, 1993). The entire crop residue used were generally the most common organic residues in most cropping systems in Nigeria and much available for farmers to use. Sustainable maize production could be achieved through proper nutrient recycling to meet crop for the needs for these nutrients.

The main objective of this study was to evaluate the effect of plant materials on the:

- i. particulate organic matter fractions of soil as affected by incorporation of different plant materials
- ii. performance of maize in relation to the levels of particulate organic matter in soil during the growing season.

MATERIALS AND METHODS

Site description

The study was carried out at Federal University of Agriculture Abeokuta (FUNAAB), Ogun state, Nigeria, (Latitude 7°13'N and 7°20'N and Longitude 3°20'E and 3°28'E). The university is located in the transition zone between tropical humid and savannah climate, characterized by distinct wet and dry seasons. The mean annual rainfall is 1200 mm with bimodal distribution. Mean annual temperature of about 22.2 °C and mean annual maximum temperature of about 33.3 °C

Experimental Design

Experiment was designed as a factorial experiment in Randomized Complete Block Design (RCBD). The treatments were six plant materials (*Chromolaena odorata*, Maize stover, *Leucaena leucocephala* clippings, Neem clipping, *Panicum maximum* and banana leaves) each at 2 levels (10 and 20 t ha⁻¹), and the control. All treatments were replicated three times.

Land preparation, treatment application and planting

The field used for the experiment was cleared manually using hoe and cutlass after which pegging was carried out. Experimental land size was 1276 m². Plots measuring 4 m x 4 m (16 m²) were demarcated with 1 m intra- and inter-row spacing. Plant materials were uniformly spread manually and incorporated into the soil at the rate of 0, 10 and 20 t ha⁻¹. The crop used for this study is TZEE 1-Y variety of maize which was sourced from International Institute of Tropical Agriculture (IITA). The variety is nutrient-rich and matures early. Seeds were planted manually two weeks after incorporation of plants materials into the soil. Planting was done at a spacing of 75 cm x 25 cm and 3

seeds per hole. Thinning was done to two plants per stand after one week of planting.

Soil sampling

Prior to the incorporation of plant residues, a composite soil sample was obtained by collecting samples (0-20 cm depth) randomly at 8 different points with the aid of soil auger on the experimental site for determination of initial soil properties. Soil samples were air-dried, grounded, passed through 2.0 mm sieve for general analysis while a sub sample was ground to pass through 0.5 mm sieve for total N and soil organic matter determination.

Determination of soil physical and chemical properties

Particle size analysis was determined by the hydrometer method of Bouyoucos (Okalebo *et al.*, 2002) using sodium hexametaphosphate as dispersing agent. The proportion of sand, clay and silt was used to determine the textural class of the soil using USDA textural triangle. Soil pH was obtained (1:1 Soil: Water ratio) using pH glass electrode meter (Thomas, 1996). Soil organic carbon was determined using the dichromate wet oxidation methods (Nelson and Sommers, 1996). Total nitrogen was determined by Khedhal method of Bremner (1996). Available phosphorous was extracted with Bray1 solution and colorimetrically determined using the vanado-molybdate method (Okalebo *et al.*, 2002). Exchangeable bases were extracted with ammonium Acetate (1N NH₄OAc) buffered at pH 7. Sodium and potassium in the extract was determined by flame photometer while Ca and Mg was determined using AAS.

Physical fractionation of soil organic matter

Soil samples were collected at 1, 3, and 6 months after incorporation (MAI) of plant

materials for physical fractionation of soil organic matter and by wet sieving method (Retsch, 2005). The wet sieving was carried out using four sieve sizes (2.0 mm, 0.5 mm, 0.25 mm, and 0.05 mm). The sieves were assembled in descending order of wire mesh size. Fifty gram (50 g) of fresh soil sample was dispersed adding 20 ml of Sodium hexametaphosphate (Calgon) and 100 ml of distilled water was also added until it becomes a suspension, the solution was shaken and left for 24 hours. The sieves were stacked according to their sizes on top of collector outlet. The complete stack was placed on the Endecotts EFL 1 Mk3 sieve shaker, the dispersed soil sample was placed on the uppermost sieve, and the clamping device was fixed into a place. The shaker and water supply were turned on. Each sieving process was completed when the water leaving the outlet became clear. Fractions from each sieve were placed into a paper filter inside a moisture can and oven-dried at 105°C to constant weight. The fractions were weighed and analysed for soil organic matter following the procedure of Walkley and Black dichromate wet oxidation method (Nelson and Sommers, 1996). The POM was calculated using the formula below:

$$POM (\%) = \frac{\text{Organic matter fraction}}{100} \times 100$$

Agronomic data Collection

Five (5) plants were randomly selected on each plot and the agronomic parameters were measured at 2 weeks interval. Plant height was obtained with the aid of a graduated meter rule, by measuring from soil level to the tip of the last apical leaf, stem girth with the aid of vernier caliper,

number of leaves by physical counting, and cob yield using weighing balance.

Statistical analysis

Data obtained was subjected to analysis of variance using Statistical Analysis System (SAS, 2003). Means were separated using Duncan Multiple Range Test (DMRT) at 5 % level of probability.

RESULTS

Physical and chemical properties of the experimental Soil

The physical and chemical properties of the soil used for this study are presented in Table 1. The soil used was sandy loam in texture with 862 g sand kg⁻¹ soil, 120 g clay kg⁻¹ soil and 18 g silt kg⁻¹ soil particles. The soil was slightly acidic with pH of 6.2. The levels of organic carbon (1.12 g kg⁻¹) and total nitrogen (0.18 g kg⁻¹) in the soil were very low. While exchangeable potassium (0.08 cmol kg⁻¹) was also below critical level, Available phosphorus (Bray 1 P) of the soil was high (22.4 g kg⁻¹) and adequate for maize production. Exchangeable magnesium was high (2.5 cmol kg⁻¹) whereas exchangeable calcium (1.25 cmol kg⁻¹) and exchangeable sodium (0.22 cmol kg⁻¹) were low.

Properties of the plant materials incorporated

Properties of the plant materials incorporated were shown in Table 2. Organic carbon in the plant material ranged from 77.6-97.3 g kg⁻¹ in which Neem clipping had the highest organic carbon among other plant residues.

Leucaena leucocephala was the highest in total nitrogen of 19.9 g kg⁻¹ and the lowest carbon to nitrogen (C/N) of 4.84 while Neem clipping was highest in C/N (9.44). Meanwhile, the highest levels of phosphorus and potassium were observed in *Panicum maximum* (41.8 mg kg⁻¹) and banana leaves (3.6 g kg⁻¹) respectively.

Sodium in the plant materials ranged from 5.7- 9.5 g kg⁻¹, neem clipping had the

Table1: Properties of soil used for the experiment before treatment application

Soil Properties	Units	Values
Soil pH		6.2
Organic Carbon	(g kg ⁻¹)	1.12
Total Nitrogen	(g kg ⁻¹)	0.18
Available Phosphorus	(mg kg ⁻¹)	22.4
Exchangeable Cations		
Calcium	(cmol kg ⁻¹)	1.25
Magnesium	(cmol kg ⁻¹)	2.5
Potassium	(cmol kg ⁻¹)	0.08
Sodium	(cmol kg ⁻¹)	0.22
Particle size		
Sand	(g kg ⁻¹)	862
Clay	(g kg ⁻¹)	120
Silt	(g kg ⁻¹)	18
Textural class	Sandy loam	

Table 2: Chemical composition of the plant materials before incorporated into soil

Properties	Units	CD	MS	NC	LL	PM	BL
Organic Carbon	g kg ⁻¹	87.2	77.6	97.3	96.5	96.0	90.2
Total Nitrogen	g kg ⁻¹	11.3	10.5	10.3	19.9	12.8	11.1
Carbon:Nitrogen	(C/N)	7.73	7.39	9.44	4.84	7.50	8.13
Phosphorus	mg kg ⁻¹	32.4	29.3	34.5	37.4	41.8	39.1
Potassium	g kg ⁻¹	3.3	2.7	2.7	2.6	2.7	3.6
Sodium	g kg ⁻¹	6.3	5.7	9.5	8.6	8.6	8.0
Calcium	g kg ⁻¹	4.2	3.6	4.0	5.2	4.2	4.2
Magnesium	g kg ⁻¹	6.3	4.6	7.4	7.5	6.9	6.3

CD-*Chromoleana odorata*, MS-Maize Stover, NC-Neem Clipping, LL-*Leucaena leucocephala*, PM-*Panicum maximum*, BL-Banana Leaves

highest sodium of 9.5 g kg⁻¹ among other plant materials while the least was observed with Maize Stover.

Among the plant materials, *Leucaena leucocephala* had the highest calcium and magnesium content of 5.2 g kg⁻¹ and 7.5 g kg⁻¹ respectively.

Particulate organic matter fraction

There was significant ($p \leq 0.05$) difference in particulate organic matter (POM) in

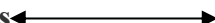
response to plant material incorporated at 1 month after incorporation (MAI). The fine fraction (0.05-0.25 mm) of POM ranged from 5.1-8.9 g kg⁻¹ at 1 MAI (Table 3). *Chromoleana odorata* (CD) significantly increased POM of fine fraction above control. Soil amended with Banana leaves (BL) (6.5 g kg⁻¹), *Leucaena leucocephala* (LL) (7.7 g kg⁻¹), maize stover (MS) (5.6 g kg⁻¹), neem clipping NC (5.8 g kg⁻¹) and

Panicum maximum (PM) (8.3 g kg⁻¹) were not statistically different from one another in POM at 1 MAI. There were no significant differences in POM between the plant materials at 3 and 6 MAI, although, *Leucaena leucocephala* produced the highest POM at 3 MAI (10.6 g kg⁻¹) and neem clipping at 6 MAI (10.3 g kg⁻¹).

Table 4 shows the effect of residue types on medium fraction (0.25-0.5 mm) of particulate organic matter (POM) in soil.

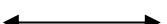
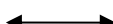
Plant materials had significant effects on POM at 1 MAI. The POM in soil ranged from 1.8-5.2 g kg⁻¹. Banana leaves stimulated higher POM at 1 MAI than control plot, whereas *Chromolaena odorata* (2.8 g kg⁻¹), *Leucaena leucocephala* (3.2 g kg⁻¹), Maize stover (2.5 g kg⁻¹), Neem Clipping 3.3 g kg⁻¹) and *Panicum maximum* (2.1 g kg⁻¹) were not significantly different from one another in POM.

Table 3: Effect of residue type on POM of fine fraction (0.05-0.25 mm) in g kg⁻¹ in soil over time

Residues	Months  After		
	Incorporation		
	1	3	6
Banana leaves	6.5ab	8.2	6.7
<i>Chromolaena odorata</i>	8.9a	7.7	9.2
<i>Leucaena leucocephala</i>	7.7ab	10.6	7.9
Maize Stover	5.6ab	6.9	7.5
Neem Clipping	5.8ab	10.0	10.3
<i>Panicum maximum</i>	8.3ab	8.3	10.1
Control	5.1b	7.4	6.2
DMRT(p<0.05)	**	NS	NS

Note-** Highly Significant, NS-Not Significant, DMRT-Duncan Multiple Range Test (p<0.05)

Table 4: Effect of residue type on POM of medium fraction size (0.25-0.5 mm) in g kg⁻¹ in soil over time

Residues	Months  After  Incorporation		
	1	3	6
Banana leaves	5.2a	3.0ab	4.6

<i>Chromoleana odorata</i>	2.8ab	3.6ab	4.8
<i>Leucaena leucocephala</i> ,	3.2ab	5.0a	5.0
Maize Stover	2.5ab	3.1ab	3.2
Neem Clipping	3.3ab	4.2ab	6.8
<i>Panicum maximum</i>	2.1ab	3.0ab	5.1
Control	1.8b	2.7b	3.2
DMRT(p<0.05)	**	**	NS

Note-** Highly Significant, NS-Not Significant, DMRT–Duncan Multiple Range Test (p<0.05)

At 3 MAI, POM value ranged from 2.7-5.0 g kg⁻¹. Plot treated with *Leucaena leucocephala* (LL) resulted in higher POM of medium fraction than control plot. However, POM due to incorporation of banana leaves, *Chromoleana odorata*, maize stover, neem clipping and *Panicum maximum* were not significantly different in POM at 3 MAI. Treatment effects were not significant at 6 MAI. Although, neem clipping resulted in highest POM among other treatments applied.

The effect of residue types on coarse fraction (0.5-2.0 mm) of particulate organic matter (POM) in soil was shown in Table 5. Coarse particulate organic matter at 1 MAI of plant material ranged from 3.6-13.2 g kg⁻¹. There was a significant effect of plant materials on POM. Plot amended with *Leucaena leucocephala* (13.2 g kg⁻¹) stimulated significant highest POM compared to control and other plant materials incorporated. *Chromoleana odorata* (8.0 g kg⁻¹) and Neem Clipping (11.8 g kg⁻¹) had similar effect, while the

effect of Banana leave (5.5 g kg⁻¹), Maize stover (3.6 g kg⁻¹) and *Panicum maximum* (6.6 g kg⁻¹) were not different from the control plot (6.2 g kg⁻¹). Coarse POM at 3 MAI of plant material ranged from 4.0-8.0 g kg⁻¹. There were no significant differences in POM of plant material incorporated at 3 MAI, Neem clipping increased POM compared to control while banana leaves, *Chromoleana odorata*, maize stover and *Panicum maximum* decreased POM. Similarly, no significant effect was observed in POM of plant materials incorporated at 6 MAI, although, all the plant material increased POM above the control while *Leucaena leucocephala* increased POM.

Effect of plant residues on plant height (cm) of Maize

At 2, 6, 8 and 10 WAP, incorporation of plant materials resulted in significant higher plant than the control except banana leaves and maize stover at 2 WAP which were not statistically different from control (Table 6).

Table 5: Effect of residue type on POM of 0.5-2.0 mm fraction (g kg⁻¹) in soil over time

Residues	Months	After	Incorporation
	1	3	6
Banana leaves	5.5c	4.5	7.7
<i>Chromoleana odorata</i>	8.0bc	4.0	6.5

<i>Leucaena leucocephala</i>	13.2a	6.9	11.6
Maize Stover	3.6c	4.6	5.8
Neem Clipping	11.8b	8.0	10.1
<i>Panicum maximum</i>	6.6c	4.8	8.3
Control	6.2c	5.2	5.6
DMRT(p<0.05)	**	NS	NS

Note-** Highly Significant, NS-Not Significant, DMRT-Duncan Multiple Range Test (p<0.05).

Table 6: Effect of plant residues on plant height (cm) of Maize

Residues	2 WAP	6 WAP	8 WAP	10 WAP
<i>Leucaena leucocephala</i>	61.23a	167.06a	224.89a	233.65a
<i>Chromolaena odorata</i>	58.55ab	166.82a	206.72ab	215.10ab
<i>Panicum maximum</i> ,	57.07ab	161.28a	208.28ab	217.38ab
Neem Clipping	56.00ab	171.67a	207.56ab	216.25ab
Banana leaves	51.20abc	157.06a	195.94bc	204.90bc
Maize Stover	49.50c	147.17a	177.78c	187.73c
Control	44.61c	115.99b	150.87d	160.56d
Rates				
0	44.61b	115.99c	150.87c	160.56c
10	54.28ab	153.33b	196.87b	205.85b
20	56.90a	170.35a	210.19a	219.16a
DMRT(p<0.05)	**	**	**	**

Note-** Highly Significant, DMRT-Duncan Multiple Range Test (p<0.05), WAP-Weeks After Planting

Leucaena leucocephala stimulated tallest plant at 2 WAP (61.23 cm), 8 WAP (224.89 cm) and 10 WAP (233.65 cm) whereas; all the amendments increased height of maize than control plot at 6 WAP. *Chromolaena odorata* (58.55 cm), *Panicum maximum* (57.07 cm) and neem clipping (56.00 cm) were not statistically different from one another at 2 WAP while similar effect was observed at 8 and 10 WAP. Residues applied at 20 t ha⁻¹ enhanced plant height compared to 10 t ha⁻¹ and control at all weeks of sampling.

Effect of plant residues on number of leaves of Maize

Number of leaves was significantly affected by plant residues (Table 7). At 2 WAP, all the treatments applied significantly increased number of leaves above the control while *Chromolaena odorata* among other treatments resulted in the largest number of leaves (6.66). There was no significant effect of amendments and rate of incorporation on the number of leaves at 8 WAP. Meanwhile, *Leucaena leucocephala* significantly enhanced number of leaves of maize more than other

amendments at 8 WAP (12.5) and 10 WAP (13.1). There was no significant difference between *Chromoleana odorata* (11.8), *Panicum maximum* (11.6) and Banana leaves (11.9) as well as Neem Clipping (10.5) and Maize Stover (10.9) at 8 WAP. Similar trend was also observed at 10 WAP. However, residues applied at 10 and 20 t ha⁻¹ enhanced the number of leaves than control plot at all weeks of sampling.

Effect of plant residues on stem girth of Maize

Table (8) shows the effect of plant residues incorporation on stem girth of maize. At 2 WAP, all treatments applied resulted in significantly wider stem than the control. There were significant different between residue applied at 6 WAT with *Leucaena leucocephala* having produced wider stem (7.99 cm) than control plot (6.64 cm) while *Chromolaena odorata*, *Panicum maximum*, Neem clipping, Banana leaves and maize stover were not statistically different from

Table 7: Effect of plant residues on number of leaves of Maize

Residues	2 WAP	6 WAP	8 WAP	10 WAP
<i>Leucaena leucocephala</i>	6.3a	9.3	12.5a	13.1a
<i>Chromoleana odorata</i>	6.6a	9.5	11.8ab	12.3ab
<i>Panicum maximum</i>	6.3a	9.0	11.6ab	12.1ab
Neem Clipping	6.5a	8.6	10.5b	10.9b
Banana leaves	6.0a	9.5	11.9ab	12.4ab
Maize Stover	6.5a	9.0	10.9b	11.5b
Control	5.4b	8.0	10.4c	11.1b
Rates				
0	5.4b	8.0	10.4b	11.1b
10	6.3a	9.2	11.5a	13.4a
20	6.5a	9.2	11.8a	12.9a
DMRT(p<0.05)	**	NS	**	**

Note-** Highly Significant, Duncan Multiple Range Test (p<0.05), WAP- Weeks After Planting

Table 8: Effect of plant residues on stem girth (cm) of Maize

Residues	2 WAP	6 WAP	8 WAP	10 WAP
<i>Leucaena leucocephala</i>	2.44a	7.99a	10.75a	11.17a
<i>Chromoleana odorata</i>	2.17a	7.48ab	9.26ab	9.74b
<i>Panicum maximum</i>	2.10a	7.21ab	9.31ab	9.67b
Neem Clipping	2.05a	7.60ab	9.18ab	9.52b
Banana leaves	1.97a	7.12ab	8.88b	9.29b
Maize Stover	2.12a	7.11ab	8.58b	9.06b
Control	1.28b	6.64b	8.63c	9.18b

Rates				
0	1.32b	5.81c	6.94b	7.94b
10	2.10a	7.19b	8.31a	8.59a
20	2.19a	7.65a	8.59a	9.00a
DMRT(p<0.05)	**	**	**	**

Note-** Highly Significant, Duncan Multiple Range Test (p<0.05), WAP- Weeks After Planting

one another. At 8 WAP, all treatments applied increased stem girth above control. Plot treated with *Leucaena leucocephala* stimulated wider stem (10.75 cm) better than all other treatments while control plot had the least. Incorporation of *Chromolaena odorata*, *Panicum maximum* and neem clipping as well as banana leaves and maize stover were not statistically different from one another. At 10 WAP, *Leucaena leucocephala* was significantly enhanced the girth of maize compared to control and all other plant materials. *Chromolaena odorata*, *Panicum maximum*, neem clipping, banana leaves and maize stover were not statistically different from control. However, residues applied at 10 and 20 t ha⁻¹ increased stem girth of maize than control plot at 2, 8 and 10 WAP whereas, only 20 t ha⁻¹ enhanced the stem

girth of maize at 6 WAP followed by 10 t ha⁻¹ and the least in control plot.

Effect of residue types on maize performance.

Table 9 shows that all the plant growth parameters measured (plant height, stem girth and number of leaves at 4 weeks after planting and weight of cob at harvest) were significantly affected by residue application. Incorporation of residues resulted in significantly higher growth than in control plot. Plant height responded better to incorporation of *Leucaena leucocephala* better than Maize Stover while Banana leaves, Neem Clipping, *Panicum maximum* and *Chromolaena odorata* were not statistically different from one another. However, the rate of application was also significant with 20 t ha⁻¹ having produced taller plants (112.81cm) than 10 t ha⁻¹ (100.70 cm) while control plot had the least (77.83 cm).

Table 9: Effect of residue type application on mean growth parameters of maize at 4 WAT and cob yield of maize at harvest

Residue	Plant height (cm)	Number of leaves	Stem girth (cm)	Cob yield (g) at harvest
Banana leaves	101.80ab	7.83a	4.96ab	5.04b
<i>Leucaena leucocephala</i>	116.47a	8.67a	5.62a	7.63a
Maize Stover	94.10c	7.67a	4.77ab	5.43b
Neem Clipping	112.37ab	8.00a	5.39ab	5.64ab
<i>Panicum maximum</i>	108.17ab	8.00a	5.59a	5.60ab
<i>Chromolaena odorata</i>	107.63ab	8.33a	5.32ab	5.89ab
Control	77.83d	6.41b	3.42c	3.66b
Rates (t ha ⁻¹)				

0	77.83c	6.50c	3.48c	3.66c
10	100.70b	7.83b	5.06b	5.09b
20	112.81a	8.33a	5.49a	6.65a
DMRT(p<0.05)	**	**	**	**

Note- ** Highly Significant, DMRT-Duncan Multiple Range Test (p<0.05).

Residues applied increased the number of leaves above the control plot. The largest number of leaves value was observed with *Leucaena leucocephala* (8.67) while residues applied at 20 t ha⁻¹ showed larger number of leaves than 10 t ha⁻¹ and the least was observed in control plot. Stem girth of maize was significantly enhanced by *Leucaena leucocephala* better than *Panicum maximum* while Banana leaves, Maize Stover, Neem Clipping and *Chromolaena odorata* were not statistically different from one another.

Also, residues applied at 20 t ha⁻¹ enhanced stem girth compared to 10 t ha⁻¹ while the least was observed in control plot. *Leucaena leucocephala* incorporated enhanced the Cob of maize at harvest compared to other treatments. Neem Clipping, *Panicum maximum* and *Chromolaena odorata* were not statistically different from one another while the effect of Banana leaves and Maize Stover were not different from control. Residues incorporated at 20 t ha⁻¹ resulted in highest Cob than 20 t ha⁻¹ and control plot.

DISCUSSION

The benefit of incorporating plant materials for crop production, particularly maize has been demonstrated by this study which showed that incorporation of plant materials or residues into the soil enhances particulate organic matter. Experimental soil was slightly acid in reaction but low in nutrient status probably due to continuous cropping which had been the practice on

the land. However, the effects of type of plant material incorporated into the soil on POM fractions were only significant at the early stage, and especially of the coarse (0.5-2.0) fraction. Materials with high C:N ratio decompose slowly, temporarily accumulating as coarse POM. The general increase in the POM of 0.05-0.25 mm over time is an indicator of addition to soil through decomposing plant materials, while the higher levels of POM of 0.5-2.0 at 1 MAI and 6 MAI is a reflection of the heterogenous nature of the plant materials. Leaf litter decompose faster than twigs and quickly increase the particulate organic matter stock in soil while the twigs take months to decompose and to the soil organic matter stock. *Leucaena leucocephala* and Neem had similar effect on 0.05-0.25 mm and 0.25-0.5 mm of particulate organic matter at 3 and 6 MAI respectively. Whereas, *Chromolaena odorata*, maize stover, Neem and *Panicum maximum* produced particulate organic matter at 6 MAI for all level of fractions (sieve sizes). *Leucaena leucocephala* at 20 t ha⁻¹ performed better than all other residues application in terms of maize growth and cob yield. This could be due to its decomposition rate; *Leucaena leucocephala* leaves decompose quickly thereby provides green manure in alley cropping systems (Shelton *et al.*, 1998). It also has the ability to fix large amount of nitrogen of about 150 to 300 kg ha⁻¹ thus promoting maize growth and development (Leucaena.net, 2009). This result

corroborates with findings of Mafongoya and Dzowela (1999); Mugendi, *et al.*, (1999) who reported increased in maize yield after incorporating *Leucaena leucocephala* biomass. This was due to the fact that *Leucaena leucocephala* biomass increased soil organic carbon, water retention as well as nutrient availability which increased plant growth and development. Higher values of growth parameters of maize in plant residues applied than control plot could be as a result of availability of essential nutrients required for plant growth in the six plant residues than control. The reduction in cob yield of maize at 4 weeks after planting in the maize stover and banana leaves treatments could be attributed to N immobilization by maize stover and banana leaves hence, reduction in N availability. Only *Leucaena leucocephala* increased cob yield of maize more than control plot at harvest and this could be attributed to the improvement of plant height, stem girth and number of leaves due to the beneficial effect of *Leucaena leucocephala* incorporation as also reported by Latt *et al.*, (2009).

CONCLUSION

RECOMMENDATIONS

This study was carried out to examine the effect of incorporation of plant materials on particulate organic matter fractions in soil in order to achieve optimum use of plant residue as it acts as organic fertilizer for crop production. *Leucaena leucocephala* and Neem had similar effect on 0.05-0.25 mm and 0.25-0.5 mm of particulate organic matter at 3 and 6 MAI respectively. Whereas, *Chromolaena odorata*, maize stover, Neem and *Panicum maximum* produced particulate organic matter at 6 MAI for all level of fractions (sieve sizes). Among the plant residues

incorporated, *Leucaena leucocephala* resulted in significant highest number of particulate organic matter 0.5-2.0 mm size range at 1 MAI than other levels of fractions and also performed better than all other residues application in terms of maize growth and yield. Also, residues applied at 20 t ha⁻¹ enhanced plant growth than 10 t ha⁻¹. *Leucaena leucocephala* can be used to improve soil structure, water retention, pH regulation as well as fertility booster. *Leucaena leucocephala* is a good source of organic matter needed for absorption by crops for their good performance. However, in order to optimize the benefit of plant residues on soil quality improvement, it is important to synchronize the release of nutrients from residue decomposition with patterns of plant nutrient uptake, which may minimize the loss of available nutrients via leaching, runoff and erosion (Sylvia *et al.*, 2005). Based on the findings of the experiment, *Leucaena leucocephala* is therefore recommended for higher particulate organic matter in soil and optimum growth performance of Maize production.

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ISOLATION AND SCREENING OF NITROGEN-FIXING CYANOBACTERIA FROM IRRIGATED VEGETABLE FARMS IN MAIDUGURI

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ABSTRACT

Cyanobacteria are among the oldest living organisms on earth and are capable of surviving in diverse environments such as water bodies, soils, rock surfaces, and extreme temperature conditions. They are recognized as important soil microorganisms because of their significant roles in biotechnology and agriculture, particularly in maintaining soil fertility and enhancing crop growth and yield as natural biofertilizers. This study investigated the occurrence of nitrogen-fixing cyanobacteria in four major irrigated vegetable farms in Maiduguri and evaluated their nitrogen fixation potential for possible use as biofertilizers. A total of 20 soil samples were collected and analyzed for physicochemical properties, while cyanobacteria were isolated using soil culture inoculum in BG11 nutrient medium. In total, 38 cyanobacterial species belonging to five genera were identified, including four heterocystous genera (Nostoc, Calothrix, Tolypothrix, and Anabaena) and one non-heterocystous genus (Oscillatoria). The heterocystous genera were commonly found across all sites, whereas Oscillatoria occurred less frequently. Anabaena had the highest frequency of occurrence (39.5%), followed by Nostoc (28.9%), while Calothrix and Tolypothrix accounted for 13.2% each and Oscillatoria 5.2%. The highest nitrogen fixation capacity was recorded in Anabaena (73.49 mg/L), whereas Oscillatoria showed the lowest value (50.78 mg/L). Significant positive correlations were observed between cyanobacterial population and soil pH ($r = 0.713$), organic carbon ($r = 0.9503$), and nitrogen ($r = 0.705$; $p < 0.05$), indicating that soils rich in nutrients and organic matter favor cyanobacterial abundance and activity. The results suggest that the isolated nitrogen-fixing cyanobacteria have promising potential for application as biofertilizers.

Keywords: Nitrogen-fixation, biofertilizer, heterocystous cyanobacteria, non-heterocystous cyanobacteria, vegetable farms.

Introduction

Cyanobacteria are ubiquitous, prokaryotic and photoautotrophic microorganisms, some are facultative heterotrophs capable of using various sources of carbon and organic nitrogen, they are found in all types of habitats, even if they are of extreme nature (Pham *et al.*, 2017). They can exhibit

a wide range of morphologies, from unicellular to filamentous thalli (Kumar *et al.*, 2013), and some common genera include *Anabaena*, *Noctoc*, *Oscillatoria*, and *Chroococcus* (Zaki *et al.*, 2021). Although they were first assumed to be algae due to their ability to photosynthesize, they are now classified as

Gram-negative prokaryotes (Cohen, 2002). Their importance is summarized by their diverse characteristics, including being autotrophic or heterotrophic, free-living or symbiotic, psychrophilic or thermophilic, acidophilic or alkylotrophic, and planktonic or epiphytic (Alam *et al.*, 1989). Cyanobacteria have been shown to enhance nitrogen and soil organic carbon and have been used as inoculants to improve soil structure and fertility (Afify *et al.*, 2023). Their ability to fix inorganic atmospheric nitrogen (N_2) into organic nitrogen to be used by plants makes them ideal for their use as biofertilizers. There are other advantages of using cyanobacteria as biofertilizers, such as production of plant growth promoting hormone, nutrient solubilization and as well as indirectly providing antagonism effect to pathogenic fungi through siderophore production (Swarnalakshmi *et al.*, 2013). Moreover, they contain a wide variety of vitamins and produce a diversity of secondary metabolites that are a source of bioactive molecules, which also have herbicidal, insecticidal, and immune suppressive activities (Chittora *et al.*, 2020).

Several researchers have analyzed the use of cyanobacteria as bio fertilizers in countries such as India, Japan, the Philippines and Iran for cultivating rice. In addition, the potential of cyanobacteria to increase nutrient bioavailability in other crops such as wheat, corn, beans, and cassava has been studied (Wang *et al.*, 2015). Studies focusing on the inoculation of soils with these microorganism have been documented in recent years (Kholssi *et al.*, 2022). Cyanobacteria can improve soil structure, promote water retention, and stimulate plant growth by increasing the availability of nutrients or releasing

biologically active compounds such as; osmolytes, phenolics, proteins, vitamins, carbohydrates, amino acids, polysaccharides, and phytohormones) that can act as natural bio stimulants and/or mitigate biotic and abiotic stresses in plants as well as improve soil health (Alvarez *et al.*, 2021).

Inoculation of Cyanobacteria can restore degraded soil environment, increase soil fertility by fixing atmospheric nitrogen and boost crop yield. Despite the importance of Cyanobacteria in agriculture and environmental applications, no work regarding their occurrence in soil and potentials for use as biofertilizer has been conducted in the study area. In this regard it is important to isolate Cyanobacteria strains that are already adapted to local conditions with nitrogen-fixing ability for possible production of biofertilizer and to correlate the effect of soil properties on the population of cyanobacteria.

Materials and Methods

Study Area

The study was carried out in University of Maiduguri, Borno state. Maiduguri lies within latitude 11° 50' North and longitude 13° 09'. The area is characterized by dry and hot seasons, minimum temperature of 15°C – 20°C and maximum temperature 37°C – 45°C with an annual rainfall of 500mm to 700 mm per annum [Nigerian Metrological Association (NMA, 2008)]. The rainy season usually starts around May to October with low relative humidity and short wet season.

Collection of Soil Samples

The soil samples were collected in March 2025 from some selected farms in Maiduguri Metropolis, these include; Sheraton-Farms (SF), UniMaid-Farm (UF), Maiduguri-Faria (MF) and Farm-Centre

(FC) respectively. Soil samples from 0–10-centimeter depth were randomly collected from all the sites. The collected samples were composited and labeled accordingly in resealable polythene pouches measuring 5 x 6 inches. The samples were transported to the laboratory and spread to dry. The air-dried samples were sieved and divided into two; one portion for soil physico-chemical analysis and the other for isolation of cyanobacteria.

Soil Physico-chemical Analysis

Soil pH and electrical conductivity (EC) were determined by potentiometric methods using 1:2.5 soil:water ratio. Organic carbon (OC) was determined by the Walkley and Black wet oxidation method as described by Black (1965), Nitrogen was determined using Kjeldahl digestion and distillation procedure, particle size distribution was determined using hydrometer method (Bouyoucos, 1962), K was determined through the use of flame photometer and available phosphorous (AP) was determined using Bray and Kurtz (1945) method.

Microbiological Analysis

Media preparation

The necessary stock solutions of the BG11 medium's nutrient composition include; NaNO₃ 15g, K₂HPO₄ 0.04g, MgSO₄.7H₂O 0.075g, CaCl₂.2H₂O 0.036g, citric acid 0.006g, Ammonium ferric citrate green 0.006g, Na₂EDTA 0.10 g, Na₂CO₃ 0.02g, Agar 15g litre, H₃BO₃ 2.86 g, MnCl₂.4H₂O 1.81 g, ZnSO₄.7H₂O 0.222 g, Na₂MoO₄.2H₂O 0.39 g, CuSO₄.5H₂O 0.08 g, Co(NO₃)₂.6H₂O 0.0494 g, were added. The pH level was adjusted to 7.5 and autoclaved for 30 minutes.

Isolation and Purification of Cyanobacteria from Soil Samples

Serial dilution technique was adopted for isolation of Cyanobacteria from Soil

Samples. This technique is founded on the idea that the sample mixture becomes dispersed and subsequent dilutions result in the isolation of single species. This procedure was done until the material was diluted 1/10 (10-fold) (Castenholz, 2015). Following that, 1 ml of the diluent was used as an aliquot of soil suspension to initiate cyanobacterial cultures on solidified growth media containing BG 11 using spread plate method

Enumeration, Morphological Identification and Isolation of Culturable Cyanobacteria

After one week of culturing, number of colony forming units (CFU) in each replicate plate were counted using a colony counter. Purification and isolation of cyanobacterial colonies were done by transferring to new plates by streaking. Liquid cultures were prepared using isolated colonies and were kept on a shaker at 60 rpm. Observations on morphological characteristics such as presence or absence of sheath, shape and size of vegetative cells, heterocysts, akinetes and branching pattern were made using a light microscope and culturable cyanobacteria were identified as described by Komarek and Komarkova, (2002).

Nitrogen fixation

The Cyanobacteria isolates were screened for their nitrogen fixation ability on the basis of per mg of sucrose consumed and the amount of nitrogen fixed was estimated by Micro-Kjeldhal's method (Jackson, 1973).

Statistical analysis

Collected data were analyzed using descriptive statistics (frequency count, percentage, mean and standard deviation) and the relationships between cyanobacteria population and soil chemical properties was determined using Pearson

correlation coefficient. Differences between treatments were separated using Fisher's least significant difference (LSD) at 5%.

Results

Physicochemical Properties of Soil Samples

The table below summarizes the physical and chemical characteristics of soil from experimental sites. The pH level of experimental sites for all the samples ranges from 5.7-6.50 which indicates that

the soil is slightly acidic to neutral. The level of EC recorded for Farm-Centre, Maiduguri-Faria, UniMaid-Farm and Sheraton-Farm are: 0.114, 0.128, 0.144 and 0.102 respectively. The highest %O.C, N-NO₃, available P and K were recorded in Farm-Centre (3.55%, 44.3 mg/kg, 39.0 mg/kg and 30.8 mg/kg) respectively and the lowest was recorded in UniMaid-Farm. The pH values ranged from 6.32 – 6.50 while Sheraton-Farm has a pH value of 5.7.

Table 1: Physicochemical characteristics of soil from experimental sites at 0–10 cm depth

Location	Parameters						
	pH	EC (dS/cm)	OC (%)	N-NO ₃ (mg/kg)	P (mg/kg)	K (Cmol/kg)	Soil texture
Farm-Centre	6.50	0.114	3.55	44.3	39.0	30.8	Sandy loam
Maiduguri-Faria	6.50	0.128	3.29	37.0	29.8	31.7	Clay loam
UniMaid-Farm	6.32	0.144	2.19	34.3	23.5	15.4	Sandy loam
Sheraton-Farm	5.70	0.102	3.20	42.0	19.3	20.0	Sandy loam

Abundance and Diversity of Cyanobacteria from Different Study Location

Result from the present study revealed the occurrence and diversity of Cyanobacteria from the four experimental locations as depicted in Figures 1, 2 and Table 2. A total of 38 Cyanobacterial species were isolated from all the sites belonging to 5 genera which included 4 heterocystous (*Nostoc*,

Calothrix, *Tolypothrix* and *Anabaena*) and one non- heterocystous (*Oscillatoria*) as shown in Table 2. Farm-Center recorded

the highest cyanobacteria population count while UniMaid-Farm recorded the lowest (Figure 1). Relative abundance and diversity revealed *Nostoc*, *Calothrix*, *Tolypothrix* and *Anabaena* were common in all the sites while *Oscillatoria* are rare and missing in UniMaid-Farm (Fig. 2). *Anabaena* recorded the highest frequency of occurrence (39.5 %) followed by *Nostoc* (28.9 %) while *Oscillatoria* was 5.2% (Table 2). The distribution and abundance of cyanobacterial genera isolated from the study sites are presented in Table 2. A total of 38 cyanobacterial species belonging to five genera were identified, namely *Anabaena*, *Nostoc*, *Calothrix*, *Tolypothrix*, and *Oscillatoria*. Among these, *Anabaena* recorded the highest abundance (39.5%), followed by *Nostoc* (28.9%), while

Calothrix and Tolypothrix each accounted for 13.2% of the isolates with *Oscillatoria* showing the lowest abundance (5.2%).

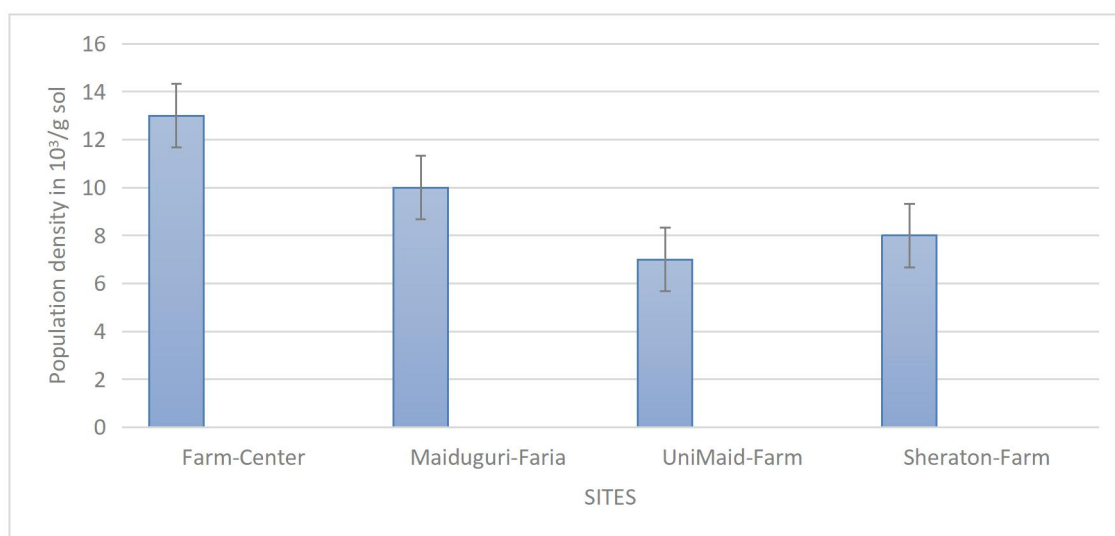


Figure 1: Cyanobacterial population density isolated from different study location

Table 2: Total percent abundance of isolated Cyanobacteria genera (summed up over all locations)

Genus	Total No. of species	Percent abundance
<i>Anabaena</i>	15	39.5
<i>Nostoc</i>	11	28.9
<i>Calothrix</i>	5	13.2
<i>Tolypothrix</i>	5	13.2
<i>Oscillatoria</i>	2	5.2
Total	38	100

Table 3 showed that all the species of cyanobacterial isolates had the ability of fixing N but *Anabaena* and *Nostoc* significantly differed with other isolates in these traits. *Anabaena* and *Nostoc* fixed more nitrogen (73.49 mg/l and 70.56 mg/l, respectively) than other species. The lowest nitrogen fixation was observed in *Oscillatoria* (50.78 mg/l).

Correlation between Population of Cyanobacteria and Selected Soil Chemical Properties

Relationship between population of Cyanobacteria and some important soil

chemical parameters is presented in Table 4. The correlation coefficient (r) between population of cyanobacteria and some selected soil chemical properties indicated a positive correlations with most of the parameters determined. There was a strong correlation between population of Cyanobacteria and soil pH ($r = 0.713$) and soil organic carbon was also observed ($r = 0.9503$). On the other hand, the Table shows a significant correlation between population of cyanobacteria and N, P and K content of soils of the study area ($p < 0.05$).

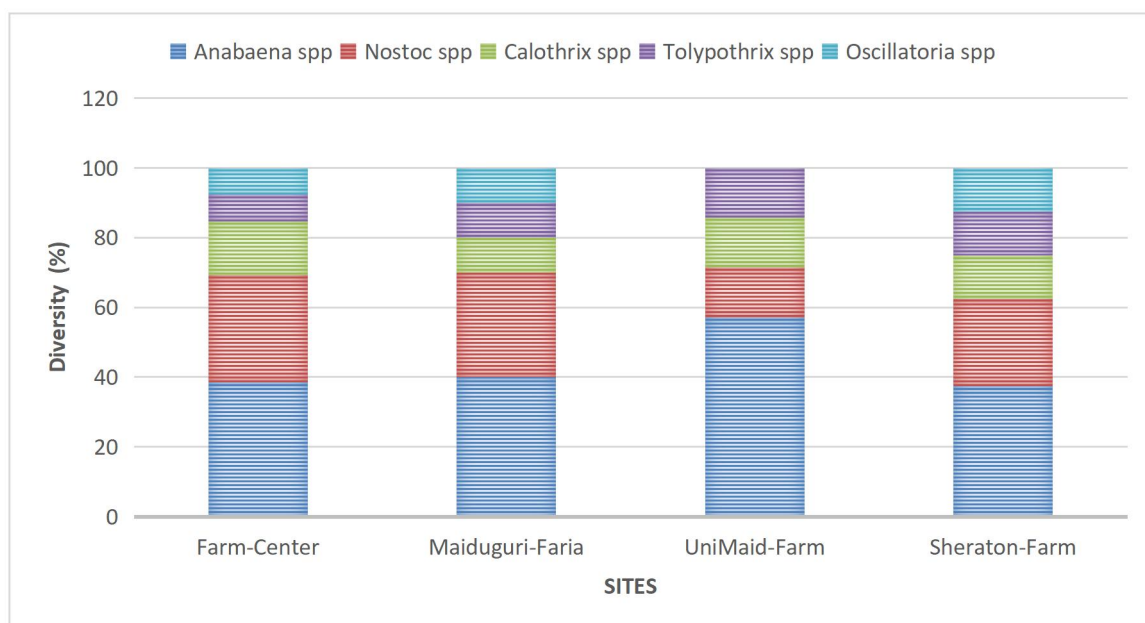


Figure 2: Cyanobacterial genus diversity from different study sites
Nitrogen Fixation by Cyanobacteria

Table 3: Nitrogen Fixation from isolated cyanobacterial species

Cyanobacteria	Estimated Nitrogen (mg/l)
<i>Anabaena</i>	73.493 ^a
<i>Calothrix</i>	61.683 ^b
<i>Nostoc</i>	70.563 ^a
<i>Oscillatoria</i>	50.777 ^c
<i>Tolypothrix</i>	59.053 ^b
SE±	1.7802

Means followed by same letter within a column are not significantly different according to LSD test at 5% level of probability

Table 4: Correlation matrices between population of cyanobacteria and some selected soil chemical properties

	Population of cyanobacteria	pH	OC	EC	N	P	K
Population of cyanobacteria	-						
pH	0.713**	-					
OC	0.950***	0.651*	-				
EC	-0.340 ^{ns}	0.336 ^{ns}	-0.402	-			
N	0.705*	0.198 ^{ns}	0.765**	0.758**	-		

P	0.783**	0.880***	0.778**	0.189 ^{ns}	0.399 ^{ns}	-
K	0.881***	0.760**	0.849***	-0.291 ^{ns}	0.638*	0.715**

Number of pairs of observation used in computation of r value, i.e, N = 12. * = significant at 5% level. ** = significant at 1% level. *** = significant 0.1% level. ns = not significant. Levels of significance for r values were determined using the P-values for each of the correlation coefficient.

Discussion

The occurrence of nitrogen fixing Cyanobacteria was confirmed in the study area. The results obtained from this study showed that soil chemical characteristics played a crucial role in determining the distribution, abundance, and functional activity of soil cyanobacteria (Granhall 1975; Metting, 1981). The Pearson correlation coefficients showing the relationships between the population of cyanobacteria and selected soil chemical properties, namely soil pH, organic carbon (OC), electrical conductivity (EC), nitrogen (N), phosphorus (P), and potassium (K) suggested that increased cyanobacterial abundance was associated with higher soil pH values. This finding indicates that cyanobacteria may prefer neutral to slightly alkaline soil conditions, which are generally favorable for microbial metabolic activity and nutrient availability. Soil pH is known to influence microbial growth by affecting enzyme activity, nutrient solubility, and microbial community structure. Previous

studies have reported that soil pH is one of the most important environmental factors controlling microbial diversity and activity in soils, including Cyanobacterial communities (Rousk *et al.*, 2010; Singh *et al.*, 2016). Most cyanobacteria thrive under neutral to slightly alkaline conditions where metabolic processes and nutrient availability are optimal (Singh *et al.*, 2021).

However, the pH range observed in this study have provided favorable conditions for the growth and proliferation of cyanobacteria across the study sites. Zhang *et al.*, (2017) reported abundance of cyanobacteria in acidic soils indicating the cyanobacterial preference on neutral to alkaline pH may not be universal in soil ecosystem. Electrical conductivity values recorded in the soils ranged from 0.102 to 0.144 dS cm⁻¹, indicating non-saline soil conditions. Low salinity levels are generally favorable for microbial activity because high salt concentrations can inhibit microbial metabolism and reduce photosynthetic efficiency in Cyanobacteria (Kumar *et al.*, 2022). For cyanobacterial species, photosynthesis is more efficient under low salinity conditions (Wada and Mizusawa, 2009). The low EC values observed in this study suggest that salinity did not pose any limitation to microbial growth, thereby supporting the establishment of diverse Cyanobacterial communities. The strong positive correlations observed between cyanobacteria population and organic carbon, nitrogen, phosphorus, and potassium indicate that nutrient-rich soils support greater cyanobacterial abundance and activity. These findings are consistent with previous studies conducted in various agricultural and natural ecosystems, which have reported that soil nutrient availability, organic matter content, and pH are key environmental drivers shaping

cyanobacterial community structure (Singh *et al.*, 2021; Kumar *et al.*, 2022; Priya *et al.*, 2023). Furthermore, cyanobacteria themselves contribute to soil organic carbon through photosynthetic biomass production and the release of extracellular polymeric substances that stabilize soil aggregates (Singh *et al.*, 2016; Abed *et al.*, 2019). The strong association between organic carbon ($r = 0.950$, $P < 0.001$), and cyanobacterial population therefore highlights the importance of soil organic matter in maintaining microbial productivity. The results also revealed a significant positive correlation between cyanobacterial population and soil nitrogen ($r = 0.705$, $P < 0.05$). This relationship is expected because many cyanobacteria possess the ability to fix atmospheric nitrogen through the nitrogenase enzyme system, particularly heterocystous genera such as *Anabaena*, *Nostoc*, and *Calothrix*. Through biological nitrogen fixation, cyanobacteria convert atmospheric nitrogen into forms available for plant uptake, thereby enriching soil nitrogen content. Consequently, soils with higher cyanobacterial populations tend to exhibit increased nitrogen levels (Singh *et al.*, 2016; Kuypers *et al.*, 2018). This observation highlights the ecological importance of cyanobacteria in improving soil fertility and supporting sustainable agricultural systems.

The dominance and nitrogen fixing potential of Heterocystous cyanobacteria (*Anabaena*, *Nostoc*, *Calothrix* and *Tolypothrix*) over non-heterocystous (*Oscillatoria*) in the study sites can be attributed to their ability to perform biological nitrogen fixation through specialized heterocyst cells (Hutchins and Capone, 2022, Sánchez-Baracaldo *et al.*, 2022). *Anabaena* and *Nostoc* are widely

recognized as efficient nitrogen-fixing cyanobacteria capable of enriching soil nitrogen content and improving soil fertility (Vijayan and Ray 2015). Heterocystous cyanobacteria possess specialized cells that create an oxygen-free environment necessary for the functioning of the nitrogenase enzyme responsible for nitrogen fixation (Rai *et al.*, 2022). The relatively lower abundance of *Oscillatoria* observed in this study may be attributed to its non-heterocystous nature, which limits its nitrogen fixation ability under aerobic conditions. Consequently, heterocystous cyanobacteria such as *Anabaena* and *Nostoc* may outcompete non-heterocystous genera in soil environments where nitrogen fixation provides a competitive advantage.

Cyanobacteria contributes about 20 – 30 kg N/ha as well as organic matter to the soil, several cyanobacterial species such as *Anabaena variabilis*, *Nostoc muscorum*, *Aulosira fertissima*, and *Tolypothrix tenuis* were found to be effective biofertilizers. Many Asian countries like China, Vietnam, India, etc., have been utilizing cyanobacteria in paddy cultivation as the alternative to nitrogen fertilizers (Lumpkin and Plucknett, 1982). According to Singh and Singh, (2008) who reported that the availability of N to plants increases due to application of cyanobacteria in agriculture ecosystems, particularly rice fields. Several researchers have investigated that inoculation of cyanobacteria (in vitro) in wheat crops, could enhance the plant shoot/root length, dry weight, and yield (Karthikeyan *et al.*, 2007).

Conclusion

In conclusion, the study has provided valuable insights on the occurrence of Cyanobacterias and demonstrate that their abundance is closely associated with key soil fertility parameters, particularly

organic carbon, nitrogen, and soil pH. The strong correlations observed suggest that favorable soil chemical conditions promote Cyanobacterial growth and activity, while Cyanobacteria themselves contribute to improved soil nutrient status through processes such as biological nitrogen fixation and organic matter accumulation. The presence of abundant cyanobacterial populations in the study sites therefore suggests that these microorganisms may play an important role in maintaining soil productivity and their potential contribution to sustainable agricultural practices. Overall, the findings of this study demonstrate that the population dynamics of cyanobacteria are strongly influenced by soil chemical properties, particularly organic carbon, nitrogen, phosphorus, potassium, and pH. These factors collectively create favorable environmental conditions that support cyanobacterial growth and activity. The significant relationships observed between cyanobacteria population and soil nutrients further highlight the important role of these microorganisms in soil fertility enhancement and nutrient cycling within the studied ecosystems.

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EFFECT OF FERTILIZER MANAGEMENT ON SOIL PROPERTIES AND RICE YIELD UNDER INTENSIVE CULTIVATION AT THE KANO RIVER IRRIGATION SCHEME

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ABSTRACT

Intensive rice cultivation in irrigation schemes, such as the Kano River Irrigation Scheme (KRIS) in Nigeria, necessitates meticulous fertilizer management to optimize crop yields while preserving soil health after a long period. A comprehensive study conducted at KRIS between 2020 and 2021 aimed to assess the impact of varying fertilizer management practices (sources and rates) on soil properties and rice productivity. The research involved 34 farmers across three local government areas in Kano State and employed a Randomized Complete Block Design using farmers' fields as pseudo-replicates. Four fertilizer treatments were evaluated including Farmers Practice (Average 175 kg N ha⁻¹, 52.5 kg P₂O₅ha⁻¹ and 52.5 kg K₂O5ha⁻¹), Recommended Fertilizer Application (76 kg N ha⁻¹, 30 kg P₂O₅ ha⁻¹, and 30 kg K₂O ha⁻¹), Poultry Manure (6 tons ha⁻¹), and Cow Manure (6 tons ha⁻¹), respectively. The results showed that all treatments affected soil conditions, with poultry manure significantly improving most of the chemical soil properties. Notably, poultry manure application led to superior rice growth, with a plant height of 96.7 cm and a grain yield of 6.56 t/ha, surpassing other treatments. Although poultry manure incurred higher costs due to increased labor and material expenses, it offered improved rice yield and enhanced soil nutrient levels. This study demonstrated the potential of organic fertilizers, particularly poultry manure, in boosting soil fertility and rice productivity in similar agroecological zones. While synthetic fertilizers may provide short-term benefits, the long-term advantages of organic amendments to soil health and crop performance are substantial. These findings can inform sustainable fertilizer management strategies for rice cultivation in irrigation schemes, emphasizing the importance of balancing short-term productivity gains with long-term environmental sustainability.

Keywords: KRIS, Fertilizer Application, Poultry Manure, Rice.

INTRODUCTION

Soil fertility encompasses both the chemical and physical aspects of soil. Fertile soil contains adequate amounts of nutrients necessary for plant growth, is neither excessively acidic nor alkaline, and is free from toxic substances. However, the overall suitability of soil for plant growth depends not only on the presence and

quantity of chemical nutrients and the absence of toxicity but also on the state and mobility of water and air, mechanical attributes, and thermal regime (Mueller *et al.*, 2010). With over 50% of global soils degraded some regions approaching 70% anthropogenic land degradation, nutrient mining, excessive inorganic fertilizer use, continuous cultivation, and erosion threaten our ability to meet food and fiber demands in the 21st century. Therefore, managing soil will significantly influence plant growth and ecosystems due to its effects on water resources, human settlements, atmospheric quality, and land pollution, as well as vegetation type and distribution (Agbede, 2003; Joseph *et al.*, 2014).

In sub-Saharan Africa (SSA), yields of major cereal crops have stagnated at less than 25% of their potential, while per capita food production has decreased over the past five decades. In many SSA regions, cereal crop yields are below 1.5 tons per hectare, despite potential yields exceeding 5 tons per hectare. Low yields are largely due to inadequate use of organic and mineral nutrients, resulting in negative nutrient balances (Smaling *et al.*, 1993). In Nigeria, recent declines in crop yields have drawn attention to issues such as soil fertility deterioration, increased production costs, and low diversity in production systems (Arifalo and Mafimisebi, 2011). Rain-fed and irrigated systems suffer from insufficient nutrient replenishment through fertilizers and manures, leading to the depletion of native reserves over time. The intensification of agricultural land use, particularly around irrigated and Fadama areas, has resulted in a mismatch between land quality and use, leading to fertility decline and general land degradation (Batjes, 2001; UNEP, 2003).

These intensification and poor land management often cause significant damage, including waterlogging, salinity and sodicity buildup, groundwater depletion and pollution, and increased pest and disease prevalence (Bationo *et al.*, 2004). Evidence from the Kano River Irrigation Scheme (KRIS) area in Nigeria's Sudan savanna region shows soil fertility decline due to land use intensification and mismatches between land quality and use (HJRBDA, 1999; Abubakar *et al.*, 2004).

There is a dearth of information on evaluation different fertilizer management approaches and their impact on soil dynamics and rice yield in KRIS amidst of farmers' reported salinity/sodicity occurrences in the scheme.

MATERIALS AND METHODS

Study Area

The study was conducted at the Kano River Irrigation Scheme (KRIS). Kano River Irrigation Scheme (KRIS) lies between latitudes 11° 35'00" and 12° 50'06" North of the equator and longitudes 08 ° 20'45" and 09 ° 40'05" East of the Greenwich meridian. It is located in a vast area over 25km south of Kano city and it is essentially the most irrigable land on both sides of the Kano-Zaria highway and both sides of the Karfi – Rano highway. It is a project designed to provide irrigation facilities for about 22,000 hectares of land utilizing water released from the Tiga dam (via the Ruwan Kanya reservoir) (HJRBDA, 1999).

Experimental Design and Treatment

The experiments were conducted on-farm using a Randomized Complete Block Design (RCBD) involving four treatments in a total of 34 farmers' fields in 2021 and 2022 (9 farmers' fields in 2021 and 25 farmers' fields in 2022) (Table 1). Each farmer's field served as pseudo or false

replicates. The treatments consisted of T1-Control, which followed the farmers' practice using NPK 20-10-10 and Urea 46; T2, which involved the recommended fertilizer application of NPK 15-15-15 and Urea 46; T3, which used Poultry Manure (PM); and T4, which used Cow dung manure (CM). Each experimental plot for the treatments was 10m x 10m in size, covering an area of 100m². The application of the recommended fertilizer involved 2kg of NPK 15:15:15 applied two weeks after transplanting, followed by 1kg of urea at four weeks, corresponding to 76 kg N ha⁻¹, 30 kg P₂O₅ ha⁻¹, and 30 kg K₂O

ha⁻¹. Poultry Manure and Cow Manure were each applied at a rate of 6 tons/ha during basin leveling and preparation. In contrast, the farmers' practice treatment allowed farmers to apply fertilizers according to their local methods without adhering to recommended rates. Notably, none of the farmers used organic fertilizers in their practices, and the amount of inorganic fertilizer used by farmers in each local government area was recorded, with the average usage presented in Table 2. The rice variety used for the experiment was FARO 44.

Table 1: Description of number of farmers' fields by LGA where the on-farm field experiments were conducted in the two years of study (i.e., 2021 and 2022).

LGA	2020		2021	
	No. of Farmers	No. of fields	No. of Farmers	No. of fields
Kura	4	4	9	9
Garun Malam	5	5	8	8
Bunkure	0	0	8	8
Total	9	9	25	25

Table 2: Summary of Fertilizer treatments and the Quantity Used by the Farmers across demonstration fields

LGA	Type of Fertilizer	N/Kg/ha	P ₂ O ₅ kg/ha	K ₂ O kg/ha
2020				
Kura	NPK (20-10-10)/Urea (46%)	263.3	25	25
Garun Malam	NPK (20-10-10)/Urea (46%)	163.3	15.5	15.5
Across LG	NPK (20-10-10)/Urea (46%)	213.3	20.25	20.25
2021				
Kura	NPK (20-10-10)/Urea (46%)	155.5	26.10	26.10
Garun Malam	NPK (20-10-10)/Urea (46%)	167	37.5	37.5
Bunkure	NPK (20-10-10)/Urea (46%)	202.8	93.75	93.75
Across LG	NPK (20-10-10)/Urea (46%)	175.1	52.45	52.45

Soil sampling

Composite soil samples were collected from each of the experimental fields at the

initial stage of the experiments using an auger before applying the treatments (Baseline), each composite sample

represents a field of its own for analysis. To assess the impact of the treatments, composite soil samples were equally collected using an auger from each experimental plot at harvest (Endline).

Relative Change percentage (RC) of soil parameter or indicator from each treatment plot was calculated using the following equation:

$$RC = \left(\frac{\text{Endline Soil Content} - \text{Baseline Soil Content}}{\text{Baseline Soil Content}} \right) \times 100\% \quad \dots \text{Eqn 1}$$

Preparation of soil sample and analytical methods:

The collected soil samples were air-dried and passed through a 2mm mesh for laboratory analysis. Particle size distribution of the soil less than 2 mm fine earth fraction was analyzed using the hydrometer method as described by Gee and Bauder (1986). Soil organic carbon was determined by the Walkley-Black wet oxidation method (Nelson and Sommers, 1982). Total nitrogen was analyzed by the micro Kjeldahl digestion method (Bremner and Mulvaney, 1982). Determination of P was by colorimetry using spectrophotometer using a blank and standards prepared in the Bray P-1 extracting solution. Exchangeable bases (Ca, Mg, K, and Na) were analyzed by flame spectrophotometry and atomic absorption spectrophotometer. Available sulphur was determined by Flame Atomic Absorption Spectrophotometer (FAAS), and the concentrations of Fe, Cu, Mn, and Zn in the soil samples were determined by Atomic Absorption Spectrophotometer (AAS) by using hollow cathode lamps with air acetylene flame. Exchangeable Sodium Percentage was determined as computed by equation 2:

$$ESP = \frac{\text{Exchangeable Na}^+ (\text{Meq}/100\text{g soil})}{\text{Cation exchange capacity} (\text{Meq}/100\text{g soil})} \times 100 \quad \dots \text{Eqn 2}$$

Field data collection:

Crop height was measured using meter rule at maturity stage of four (4) random selections for each treatment plot, Leaf area index (LAI) at 6 and 9 weeks after transplanting were measured using Ceptometer. Panicle length was measured from random selection of plot yield collected from each experimental plot of 2 by 2m² quadrat. Productive tillers were counted from the quadrat field of each experimental plot collected, four (4) at random. Grain and stalk yield at maturity were measured using a measuring scale.

Results

Soil condition of the on-farm experimental fields

The topsoil (0-10 cm) properties in the Kano River Irrigation Scheme (KRIS) were analyzed over two years, 2020 and 2021. The results, presented in Table 3, show that the soil texture was predominantly sandy loam, with a composition of 62.3% Sand, 23.9% silt, and 13.8% clay in 2020, and 66.0% sand, 22.5% silt, and 11.5% clay in 2021. The pH levels indicated a slightly acidic condition, ranging from 6.01 to 6.96 in 2020 and from 5.55 to 6.66 in 2021. The electrical conductivity (EC) values were very low, suggesting that the soils were not saline. Organic carbon content was also low, ranging from 0.3 to 0.7% with an average of 0.48% across both years. Nitrogen levels were similarly low, averaging 0.07% in both years. Phosphorus content averaged 6.1 mg/kg in 2020 slightly higher than 5.0 mg/kg in

2021. Calcium levels ranged from 1.5 to 4.1 cmol(+)/kg, with mean values of 2.8 cmol(+)/kg in 2020 and 2.4 cmol(+)/kg in 2021. Magnesium levels were between 0.5 and 0.9 cmol(+)/kg, averaging 0.7 cmol(+)/kg across both years. Exchangeable sodium was low, leading to low Exchangeable

Sodium Percentage (ESP) values, which ranged from 1.9% to 3.4% in 2020 and slightly increased in 2021. Potassium content was consistent at 0.2 cmol/kg in both years.

Table 3: Soil properties under continuous rice production in KRIS

Parameter	2020				2021				Both seasons			
	Min	Max	Mean	Std Dev	Min	Max	Mean	Std Dev	Min	Max	Mean	Std Dev
Sand%	47.3	77.4	62.3	11.2	45.7	76.9	66.0	8.6	45.74	77.36	64.77	9.62
Silt%	8.5	46.4	23.9	12.5	6.4	36.9	22.5	8.2	6.44	46.39	23.00	9.83
Clay%	4.6	23.6	13.8	4.8	6.5	18.0	11.5	3.4	4.55	23.59	12.23	4.06
pH	6.01	6.96	6.33	0.29	5.55	6.66	5.96	0.26	5.55	6.96	6.09	0.32
EC (dS/m)	0.20	0.20	0.20	0.00	0.10	0.10	0.10	0.00	0.06	0.22	0.12	0.04
OC (%)	0.30	0.70	0.40	0.10	0.30	0.70	0.50	0.10	0.25	0.73	0.48	0.13
N (%)	0.04	0.10	0.07	0.01	0.04	0.10	0.07	0.01	0.01	0.10	0.06	0.01
P (mg/kg)	3.00	8.80	6.10	1.80	1.10	9.40	5.00	2.60	1.11	9.42	5.35	2.42
Ca (cmol(+)/kg)	1.50	3.70	2.80	0.45	3.70	4.10	2.40	0.65	1.50	4.10	2.50	0.24
Mg (cmol(+)/kg)	0.50	0.80	0.70	0.11	0.60	0.90	0.70	0.11	0.50	0.90	0.70	0.16
K (cmol(+)/kg)	0.10	0.30	0.20	0.00	0.10	0.30	0.20	0.00	0.10	0.28	0.18	0.05
Na (cmol(+)/kg)	0.10	0.20	0.10	0.00	0.10	0.10	0.10	0.00	0.06	0.15	0.09	0.02
ESP (%)	1.90	3.40	2.50	0.60	1.80	3.40	2.70	0.50	1.79	3.43	2.68	0.51

Effect of fertilizer management approaches on growth and phenology of rice

The effects of different fertilizer application rates on the growth parameters of rice under continuous cultivation in KRIS are presented in Table 4. The application of Poultry Manure (PM) resulted in a significantly higher Leaf Area Index (LAI) of 2.38 at 6 weeks after transplanting (6WAT), surpassing all other treatments. It was followed by Farmer Practice (FP) with an LAI of 2.05 and NPK/Urea with 1.98.

Cow Manure (CM) recorded the lowest LAI at 1.92, which was statistically similar to FP and NPK/Urea. At 9WAT, PM again yielded the highest LAI at 3.055, while CM recorded the lowest at 2.774. In terms of panicle length, CM produced the longest panicles at 24.83 cm, whereas FP resulted in the shortest at 23.66 cm. Plant height varied from 93.4 cm for CM to 96.7 cm for PM, with FP and NPK/Urea measuring 94.1 cm and 93.8 cm, respectively. Poultry manure also led to the highest number of productive tillers at 17.3, followed by CM at 16.8 and NPK/Urea at 16.1, while FP had the lowest at 15.9.

Effect of Different Fertilizer Application Rates on Rice Yield

Table 5 reveals no significant differences among the treatments for grain and stalk yields in the 2020 season. However, the application of poultry manure (PM) resulted in the highest grain yield at 6.56 t/ha, followed by NPK/Urea at 6.02 t/ha, farmyard manure (FP) at 5.8 t/ha, and the lowest yield was recorded with compost manure (CM) at 5.79 t/ha. For stalk yield in the same year, the range was from 4.94 t/ha with CM to 6.59 t/ha with NPK/Urea.

Table 4: Effect of different fertilizer application rates on rice growth in both seasons under continuous cropping in KRIS

Treatment	LAI at 6WAT	LAI at 9WAT	Panicle length at harvest (cm)	Plant height at harvest (cm)	Maximum No. of productive tiller
Farmer Practice	2.05 ^b	2.821	23.66	94.1	15.9
NPK/Urea	1.98 ^b	2.837	24.75	93.8	16.1
Poultry Manure	2.38 ^a	3.055	24.67	96.7	17.3
Cow Manure	1.92 ^b	2.774	24.83	93.4	16.8
P-Value	0.05	0.249	0.462	0.16	0.337
SE ±	0.173	0.1491	0.832	1.6	0.81

Means in the same column with different superscripts are significantly different at (P<0.05) LAI = Leaf Area Index, WAT = Weeks After Transplanting

Table 5: Effect of different fertilizer application rates on rice yield parameters in both seasons under continuous cropping in KRIS

Treatment	2020		2021	
	Grain yield (ton/ha)	Stalk yield (ton/ha)	Grain yield (ton/ha)	Stalk yield (ton/ha)
Farmer Practice (FP)	5.80	6.45	6.87 ^{ab}	8.01 ^b
NPK/Urea	6.02	6.59	6.88 ^{ab}	8.04 ^b
Poultry Manure (PM)	6.56	6.09	7.31 ^a	9.20 ^a
Cow Manure (CM)	5.79	4.94	6.39 ^b	7.35 ^c
P-Value	0.4	0.306	0.0465	0.021
SE±	0.5	0.931	0.509	0.582

Means in the same column with different superscripts are significantly different at (P<0.05). ha = hectares

In contrast, 2021 showed significant differences among the treatments for both grain and stalk yields. Poultry manure again led with the highest yields, achieving 7.31 t/ha for grain and 9.20 t/ha for stalk. NPK/Urea and FP followed closely, with grain yields of 6.88 and 6.87 t/ha, respectively, and stalk yields of 8.04 and 8.01 t/ha, respectively. The lowest yields were recorded with compost manure, at 6.39 t/ha for grain and 7.35 t/ha for stalk.

6.39 tons per hectare for grain and 7.35 t/ha for stalk. These findings highlight the effectiveness of different fertilizer types in enhancing rice yields under continuous cropping conditions.

Impact of Different Fertilizer Applications on Endline Changes of Soil Macronutrients, pH, and Salinity Indicators

The 2020 results from Table 6 revealed no significant differences among all the treatments regarding the end-line changes in soil macronutrients, pH, and salinity indicators. However, certain trends were observed: increases in organic carbon (OC), nitrogen (N), calcium (Ca), and exchangeable sodium percentage (ESP) were noted, while decreases occurred in phosphorus (P), magnesium (Mg), pH, and electrical conductivity (EC). Potassium (K) and sodium (Na) showed varied responses across different treatments. The application of poultry manure (PM) led to the highest increase in OC, with a 54.12% rise, followed by NPK/Urea at 50.82%, cow manure (CM) at 49.15%, and farmer practice (FP) at 48.1%. Similarly, PM and NPK/Urea significantly increased nitrogen levels by 18.6% and 16.9%, respectively, compared to a much lower increase of 0.3% with FP.

Phosphorus content decreased across all nutrient management practices. PM and NPK/Urea increased potassium content by 5.13% and 3.18%, respectively, while CM and FP decreased by 8.06% and 5.4%, respectively. CM increased magnesium by 23.42%, and PM by 17.79%. The highest reduction in calcium content was observed with FP at 10.1%, followed by CM, NPK/Urea, and PM reductions of 8.3%, 7.8%, and 3.9%, respectively. PM increased sodium content by 7.3%, while CM and FP reduced it by 0.7% and 2.7%,

respectively, compared to a 5.19% increase with NPK/Urea. All treatments decreased soil pH, ranging from a 2.05% decrease with NPK/Urea to a 3.78% decrease with FP. Similarly, all treatments reduced soil EC, with NPK/Urea decreasing it by 41.97%, CM by 40.84%, PM by 38.21%, and FP by 36.83%. The highest increase in ESP was recorded with CM at 12.7%, followed by PM at 10.73%, and the least with NPK/Urea at 6.1%.

Additionally, Table 7 revealed no significant differences among all the treatments regarding the end-line changes of the soil micronutrients in 2020. All treatments increased Fe, Mn, and Zn while generally causing a decrease in Cu, except for poultry manure (PM). Poultry manure increased the Cu content of the soil by 18.6%, whereas FP, CM, and NPK/Urea reduced it by 33.42%, 26.93%, and 24.73%, respectively. The application of PM resulted in the highest increase in Fe content, at 33.01%, followed by FP at 31.02%, and the least increase was observed with NPK/Urea at 15.01%. Poultry manure application led to the highest increases in Mn and Zn contents, with 16.34% and 97.25%, respectively. In contrast, FP recorded the least increase for Mn and Zn, with values of 0.31% and 41.48%, respectively. NPK/Urea increased the Mn content by 7.46% and Zn by 79.09%, while CM increased by 5.17% for Mn and 94.96% for Zn.

In 2021, as shown in Table 8, most soil parameters did not exhibit significant differences among the treatments, except for calcium (Ca).

All fertilizer management practices resulted in increased levels of organic carbon (OC), phosphorus (P), and magnesium (Mg), while sodium (Na) content decreased. The most substantial

increase in OC was observed with the application of FP, which rose by 26.8%, followed by CM (21.13%), NPK/Urea (17.09%), and PM (16.48%). Across all treatments, nitrogen levels also increased, with CM showing the highest increase at 9.63%, followed by FP at 6.48%, and PM at 2.40%.

The phosphorus content in the soil was significantly increased by NPK/Urea (27.01%) and PM (14.68%), compared to FP (4.45%) and CM (1.27%). Potassium (K) levels were boosted by PM (20.25%), CM (16.81%), FP (14.94%), and NPK/Urea (9.72%). The application of PM increased soil Ca by 9%, whereas FP, NPK/Urea and CM reduced Ca content by 12.22%, 9.05%, and 8.46%, respectively. Magnesium levels rose with PM (3.81%), FP (2.95%), NPK/Urea (1.63%), and CM (1.49%). Sodium content decreased most

with CM (14.63%), followed by NPK/Urea (8.04%), FP (6.46%), and PM (3.84%). The pH of the soil increased by about 1% with all treatments except PM, which caused a slight decrease of 0.48%. Electrical conductivity (EC) increased with most treatments, except FP, which reduced EC by 4.65%, and NPK/Urea, CM, and PM, which decreased it by 6.92%, 5.63%, and 2.89%, respectively. The exchangeable sodium percentage (ESP) in the soil was significantly increased by FP (615%) and NPK/Urea (3.52%), while CM and PM reduced ESP by 5.64% and 3.42%, respectively.

Table 6: Effect of different fertilizer application rates on end-line changes of soil macronutrient, pH, and salinity indicators in 2020.

Treatment	OC (%)	N (%)	P (%)	K (%)	Ca (%)	Mg (%)	Na (%)	pH (%)	EC (%)	ESP (%)
FP	48.1	0.25	-25.68	-5.4	18.63	-10.1	-2.675	-3.78	-36.83	7.72
NPK/ Urea	50.82	16.87	-34.16	3.18	18.56	-7.8	-5.193	-2.05	-41.97	6.1
PM	54.12	18.6	-22.67	5.13	17.79	-3.9	7.258	-2.85	-38.21	10.73
CM	49.15	4.44	-20.76	-8.06	23.42	-8.3	-0.661	-3.01	-40.84	12.7
P-Value	0.986	0.591	0.956	0.711	0.944	0.962	0.606	0.792	0.712	0.963
SE±	12.21	11.24	18.37	9.44	7.16	8.42	6.79	1.2	3.47	9.8

FP = Farmer practice, PM = Poultry manure, CM = Cow manure, SE = standard error of means

Table 7: The effect of different fertilizer application rates on the end-line of soil micronutrients in 2020

Treatment	Cu (%)	Fe (%)	Mn (%)	Zn (%)
FP	-33.42	31.02	0.31	41.48
NPK/Urea	-24.73	15.01	7.46	79.09
PM	18.60	33.01	16.34	97.25
CM	-26.93	19.98	5.17	94.96
P-Value	0.7908	0.4214	0.8969	0.6416
SE±	7.47	8.75	15.12	34.14

FP = Farmer practice, PM = Poultry manure, CM = Cow manure, SE = standard error of mean

In 2021 the impact of different fertilizer management treatments on changes in soil micronutrients, as detailed in Table 9 showed a significant effect of these application rates on copper (Cu) levels, but no significant impact on iron (Fe), manganese (Mn), or zinc (Zn) levels. Different fertilizers had distinct effects on micronutrient content. Poultry manure (PM) increased Cu content by 25.53%, followed by cow manure (CM) with a 14.69% increase, and farmer practice (FP) with a 7.71% increase. In contrast,

NPK/Urea applications resulted in a 1.09% decrease in Cu content. For iron, FP and CM led to increases of 6.27% and 3.46%, respectively, while PM and NPK/Urea caused reductions of 2.24% and 1.58%, respectively. The fertilizer treatment generally increased Mn content, except for PM, which caused a 1.87% decrease. NPK/Urea, FP, and CM increased Mn content by 9.47%, 2.53%, and 2.48%, respectively. All treatments enhanced Zn content, with increases ranging from 0.79% for PM to 20.34% for CM.

Table 8: Effect of different fertilizer rates on end-line of soil macronutrients, pH, and salinity indicators in 2021

Treatment	OC	N (%)	P (%)	K (%)	Ca (%)	Mg	Na	pH	EC	ESP
FP	26.8	6.48	4.45	14.94	-12.22 ^b	2.95	-6.46	1.04	-4.65	6.15
NPK/Urea	17.09	0.71	27.01	9.72	-9.05 ^b	1.63	-8.04	1.29	6.92	3.52
PM	16.48	2.40	14.68	20.25	9.00 ^a	3.81	-3.84	-0.48	2.89	-3.42
CM	21.13	9.63	1.27	16.81	-8.46 ^b	1.49		1.29	5.63	-5.64
P-Value	0.712	0.345	0.579	0.563	0.005	0.96	0.123	0.313	0.213	0.076
SE±	7.04	4.96	14.33	5.31	4.45	3.56	3.25	0.77	4.18	3.61

Means in the same column with different superscripts are significantly different at ($P < 0.05$) FP = Farmer practice, PM = Poultry manure, CM = Cow manure, SE = standard error of means

Table 9: Effect of different fertilizer application rates on end-line changes of soil micronutrients in 2021.

Treatment	Cu (%)	Fe (%)	Mn (%)	Zn (%)
FP	7.71 ^{ab}	6.27	2.53	10.07
NPK/Urea	-1.09 ^b	-1.58	9.47	10.78
PM	25.53 ^a	-2.24	-1.87	0.79
CM	14.69 ^{ab}	3.46	2.48	20.34
P-Value	0.0257	0.2434	0.4457	0.8325
SE±	6.19	3.43	4.96	14.88

Means in the same column with different superscripts are significantly different at ($P < 0.05$) FP = Farmer practice, PM = Poultry manure, CM = Cow manure, SE = standard error of means

Combined analysis of different fertilizer application rates on end-line changes in soil macronutrients in both years

The results show that there were no significant differences among the fertilizer management treatments regarding the end-line changes in soil macronutrients, pH, and salinity indicators (Table 10). However, despite these non-significant differences, all treatments resulted in a notable increase in organic carbon content, ranging from 33% to 35%. Additionally, nitrogen levels in the soil increased by 7 to

8% across all treatments (PM, NPK/Urea, CM), which was higher than the 3.4% increase observed in farmers' practice (FP) over the two-year study period. The changes in other soil nutrients varied across treatments. For instance, the reduction in soil phosphorus (P) content ranged from 2.3% in NPK to 9.34% in FP. Poultry manure (PM) led to a significant increase in soil potassium (K) content, with a rise of about 12% over two years, which was double the increase observed in the other treatments. Calcium (Ca) levels

decreased by 6.13% with cow manure (CM), followed by a 5.1% decrease with NPK/Urea and a 3.04% decrease with FP, while PM resulted in a 3.22% increase. Poultry manure also caused a substantial decrease in magnesium (Mg) content, reducing it by 10.05%, which was about three times more than the reductions observed in other treatments.

The increase in soil sodium (Na) content varied among treatments, with NPK/Urea causing a 10.11% increase and CM leading to a 12.47% increase. The pH of the soil

decreased by about 2.29% with PM, while the least decrease was observed with NPK/Urea, at about 1%. Soil electrical conductivity (EC) decreased by 22.04% in FP, compared to an 18% reduction in the other treatments. Finally, the application of organic materials like PM and CM reduced the exchangeable sodium percentage (ESP) by 0.5%, whereas FP and NPK/Urea resulted in increases of 2.85% and 0.72%, respectively.

Table 10: Combined analysis of 2020 and 2021 seasons on different fertilizer application treatments for end-line soil nutrients, pH, and salinity indicators.

Treatment	OC (%)	N (%)	P (%)	K (%)	Ca (%)	Mg (%)	Na (%)	pH (%)	EC (%)	ESP (%)
FP	35.66	3.41	-9.34	4.64	-3.04	-3.62	10.81	-1.99	-22.04	2.85
NPK/ Urea	32.17	8.83	-2.3	6.33	-5.1	-0.94	10.11	-1.01	-18.83	0.72
PM	33.51	8.42	-2.72	12.57	3.22	-	10.91	-2.29	-18.96	-0.44
CM	33.35	7.08	-8.48	4.25	-6.13	-0.85	12.47	-1.49	-18.9	-0.56
P-Value	0.994	0.887	0.978	0.814	0.293	0.160	0.979	0.704	0.915	0.952
SE±	9.68	5.65	15.35	7.25	3.95	4.83	4.22	0.87	4.02	4.98

FP = Farmer practice, PM = Poultry manure, CM = Cow manure, SE = standard error of means

The combined analysis of the effects of different fertilizer management approaches on the end-line changes of soil micronutrients is presented in Table 11. This analysis reveals that there was no significant difference among the treatments regarding the end-line changes of soil micronutrients. However, copper (Cu) showed a varied response to the treatments, while iron (Fe), manganese (Mn), and zinc (Zn) all increased over the two years across different practices. Poultry manure was found to increase the soil Cu content, whereas other treatments resulted in a reduction of Cu content by

approximately 5.78 to 9.43%. The increase in Fe content was most pronounced with farmyard poultry (FP), which increased it by 22.57%, followed by poultry manure (PM), cow manure (CM), and NPK/Urea, which increased it by 19.3%, 15.63%, and 10.63%, respectively. In terms of Mn content, NPK/Urea and PM showed increases of 7.6% and 6.37%, respectively, compared to a much smaller increase of 0.55% with FP. The increase in Zn content varied significantly across treatments, ranging from a 36.81% increase with FP to a substantial 68.68% increase with CM.

Table 11: Combined analysis of 2020 and 2021 years on different fertilizer application treatments for end-line soil available micronutrients

Treatment	Cu (%)	Fe (%)	Mn (%)	Zn (%)
FP	-9.35	22.57	0.55	36.81
NPK/Urea	-9.43	10.63	7.6	54.46
PM	2.8	19.3	6.37	60.05
CM	-5.78	15.63	2.95	68.68
P-Value	0.559	0.359	0.883	0.595
SE±	7.31	5.19	7.28	17.89

FP = Farmer practice, PM = Poultry manure, CM = Cow manure, SE = standard error of means

Discussion

Soil Condition of Continuous Rice Production Fields in Kano River Irrigation Scheme (KRIS).

The soil in the Kano River Irrigation Scheme (KRIS) predominantly exhibits a sand-dominated texture, typical of arid and semi-arid regions due to aeolian deposits. These deposits often overlay soils developed from different parent materials, such as alluvial deposits found in Fadama regions like KRIS (Abdul-Rahman,2019). The soil pH in the irrigated plots ranges from 5.55 to 6.96, with a mean of 6.96 over two years, indicating weakly alkaline soils. This pH range is comparable to values reported in Jigawa and Niger states but slightly higher than those found by Jibrin *et al.* (2008). The mild acidity in some areas may result from frequent ponding and leaching of exchangeable bases during irrigation and flooding. Both high and low pH values can lead to nutrient deficiencies and reduced soil health.

The electrical conductivity (EC) of the soil is low, ranging from 0.06 to 0.22 dS/m, which classifies them as non-saline according to USDA standards (Garba *et al.* 2022; Adamu *et al.* 2013). This makes the soil suitable for irrigation activities, consistent with findings by Jibrin *et al.*

(2008). The mild acidity of the soils may contribute to the low EC values. The organic carbon content is low, ranging from 0.25 to 0.73% with a mean of 0.48%, indicating low levels of organic matter. This is likely due to practices such as overgrazing, bush burning, and the use of crop residues for animal feed (Abdul-Rahman,2019). The nitrogen content is also low, ranging from 0.01 to 0.1%, like other irrigation projects in the region. Phosphorus levels are moderate, with an average of 8.8 mg/kg, while potassium content is very low. Calcium is the major cation, with levels within permissible ranges, though lower than previously reported. Magnesium, potassium, and sodium have low concentrations but are within acceptable limits, indicating a non-sodic status suitable for irrigation (Jibrin *et al.*, 2008). However, extensive cropping without nutrient replacement may lead to chemical deterioration of the soil.

The availability of nutrients in organic sources is enhanced by microbial activity and improved soil physical conditions, making them more readily accessible for plant uptake (Sarker *et al.*, 2004). Nutrient absorption is influenced by factors such as soil type, environmental conditions, fertilizer application techniques, and rice cultivar (Huang *et al.*, 2008). Organic

waste products and composts can be as effective as chemical fertilizers if properly managed (Naing *et al.*, 2010; Bajgai *et al.*, 2014).

Effect of fertilizer management approaches on growth, phenology and yield of rice

In our study, the application of poultry manure (PM) resulted in the highest leaf area index (LAI) at both 6 and 9 weeks after transplanting (WAT), while the application of chemical manure (CM) produced the lowest LAI. This outcome is likely due to an increase in leaf number and size resulting from adequate nutrition provided by PM. Consequently, PM also yielded the highest plant height, maximum number of tillers, grain yield, and straw yield. This could be attributed to enhanced root growth and increased carbohydrate translocation from sources to growing points, thereby improving nutrient absorption (Singh and Agarwal, 2001).

The results align with previous studies indicating that organic manure can positively affect rice plant height. For instance, Abdul-Rahman (2019) reported that applying organic manure alone or in combination with chemical fertilizers had a positive effect on plant height. Similarly, Amanullah (2016) and Mahmud *et al.* (2016) observed increases in plant height from the application of organic manure and compost. Tillering is crucial for grain production and is enhanced by improved soil conditions resulting from organic manure addition (Usman *et al.*, 2003). In this study, the highest productive tillers were observed in plots treated with PM, consistent with findings by Rakshit *et al.* (2008) and Mahmud *et al.* (2016).

The use of soil management techniques, particularly organic fertilizers like PM, has been shown to significantly increase rice

growth and yield. This is attributed to improved nutrient and water availability, which enhances nitrogen and other essential element absorption, leading to increased grain yield (Ebaid *et al.*, 2007). Many crops respond well to organic fertilizers in terms of growth and yield (Hammed *et al.*, 2019; Purbajanti *et al.*, 2019). The available nutrients from organic sources can stimulate leaf growth, enhance photo assimilation, and increase dry matter accumulation. Studies have documented substantial increases in rice yields using soil management techniques, with reported increases of over 200% (Efe and Ugboma, 2011). Similar findings have been reported by Swarup and Yaduvanshi (2000), Yadana *et al.* (2009), Sarwar *et al.* (2008), El-Refaei *et al.* (2006), and Awad (2001).

Impact of Different Fertilizer Application Treatments on Soil Changes

The application of various fertilizer treatments in 2020 resulted in several notable changes in soil properties. The electrical conductivity (EC) of the soil decreased across all treatments, potentially due to the soil's ability to reduce leaching or loss of exchangeable bases. This finding aligns with previous studies by Bharadwaj *et al.* (2011) and Mahmoud and Ibrahim (2012), who observed similar decreases in soil EC following the addition of different soil amendments. The treatments also led to a modest reduction in soil pH, which could be attributed to the buildup of acidic organic components or the pH of the amendments themselves. The pH decrease was most pronounced with the application of FP, CM, and PM, with reductions of 3.78%, 3.01%, and 2.85%, respectively. Similar pH reductions have been reported by Smiciklas *et al.* (2002), Pattanayak *et al.* (2001), and Yaduvanshi (2001) following

the use of organic materials. Additionally, the nitrification of applied fertilizer nitrogen and subsequent nitrate leaching may have contributed to soil acidity.

Despite no significant differences in the increase of organic carbon (OC) among treatments, OC levels improved overall. The highest increase in OC was observed with PM application (54.12%), while the least was under FP (48.1%). Regular manure application enhances soil organic matter and carbon storage, supporting microbial activity and biomass. Inorganic fertilizers also improved OC content, consistent with findings by Manjaiah and Singh (2000). The treatments affected the availability of key plant nutrients, including nitrogen, phosphorus, and potassium. PM application increased nitrogen content by 18.60%, while NPK/Urea application raised it by 16.87%. These results align with research by Rajkhowa *et al.* (2003) and Gaikwad *et al.* (2011). However, NPK/Urea application led to a significant decrease in phosphorus concentration, possibly due to previous over-fertilization or crop removal. Potassium content increased with PM and NPK/Urea applications but decreased with FP and CM, likely due to nutrient mining by crops. Sodium content in the soil decreased with most practices, except for PM, which increased by 7.25%. The least reduction in sodium was observed with CM application (0.66%). The exchangeable sodium percentage (ESP) increased, particularly with PM and CM applications. The use of amendments also raised levels of magnesium, iron, copper, manganese, and zinc, while calcium content decreased. These findings are supported by studies demonstrating the positive effects of organic manures on micronutrient availability. The study in

2021 showed that all treatments, except for the FP treatment, which resulted in a decrease, enhanced soil electrical conductivity (EC). The NPK/Urea treatment had the most significant increase in EC at 6.92%, followed by CM at 5.63%. This increase can be attributed to soil practices and cation adsorption in the cation exchange capacity (CEC), which is similar to findings by Badawi (2003), who noted that composted plant wastes release soluble salts during decomposition, increasing EC. In contrast to the 2020 results, all treatments except PM led to an increase in soil pH in 2021. NPK/Urea, CM, and FP each increased soil pH by 1.29%, 1.04%, and 1.04%, respectively. The initial pH of the amendment materials likely influenced the direction of pH change. The application of CM resulted in the greatest increase in organic carbon (OC) at 21.13%, while PM recorded the least increase. This outcome aligns with findings from the Northwestern Himalayas, where integrated plant nutrition systems similarly enhanced OC levels Badawi (2003).

The implementation of these practices in 2021 also enhanced soil nitrogen (N) content, with CM showing the largest increase at 9.63%, followed by FP and PM. This is consistent with research indicating that organic manures increase available nitrogen more than inorganic fertilizers due to the slow release of nutrients. The data also showed an increasing trend in phosphorus (P) content, with NPK/Urea having the largest increase at 27.01%, followed by PM. The interactions between anionic exchange and organic compounds produced during PM mineralization may have contributed to this increase (Lakhdar *et al.* 2008). Potassium (K) content increased across all treatments, with PM

causing the highest increase at 20.25%, followed by CM. This supports previous findings that compost, and organic amendments can increase accessible K in soil by raising the cation exchange capacity (CEC) (Lakhdar *et al.* (2008). All practices resulted in a decrease in sodium (Na) content, with the highest decrease observed in the application of cow dung manure. This reduction in sodicity aligns with previous studies showing that organic amendments can substitute exchangeable Na⁺ with other cations, improving soil structure. Finally, the study noted an increase in iron (Fe), copper (Cu), manganese (Mn), and zinc (Zn) levels due to the use of FP and CM, while NPK/Urea and PM applications resulted in decreases for some of these micronutrients. These findings are consistent with research indicating that organic manures can enhance the availability of these micronutrients in soil Haq *et al.* (2007). Over two years (2020 and 2021), the application of fertilizers resulted in significant changes to soil properties. One notable effect was the reduction in electrical conductivity (EC), with the largest decrease observed in FP (22.04%), followed by PM (18.96%), CM (18.90%), and NPK/Urea (18.90%) applications. This reduction could be attributed to the constant application of fertilizers, which may fix soluble sodium ions in the soil, similar to findings by Bharadwaj *et al.* (2011) and Haq *et al.* (2007). In addition to changes in EC, the application of fertilizers also led to a decrease in soil pH over the two years. The most significant reduction was seen with PM (2.29%), while the least was observed with NPK/Urea (1.01%). These results are consistent with previous studies by Haq *et al.* (2007) and Joachim *et al.* (2007), which

found that adding organic matter to salinity-rich environments can decrease pH values. Despite these changes, all fertilizer applications increased organic carbon (OC) content over the two years. Notably, FP showed a greater increase in OC (35.66%) compared to organic and inorganic manure. This increase can be attributed to the accumulation of organic residues in the soil, which enhance root development and contribute to higher OC levels after decomposition, as supported by Ashraf *et al.* (2023) and earlier studies by Kumpawat and Jat (2005) and Balyan *et al.* (2006).

The use of PM and CM led to a reduction in exchangeable sodium percentage (ESP), whereas NPK/Urea and FP increased it. This reduction in ESP with organic manures aligns with findings by Benazzouk *et al.* (2019), who noted that vermicompost can reduce salt buildup by enhancing leaching and cation exchange, thereby improving soil characteristics. Lastly, the application of fertilizers influenced nutrient content in the soil. Nitrogen (N) and potassium (K) levels increased over the two years, with NPK/Urea adding the most N and PM recording the highest K increment. However, phosphorus (P) content decreased because of the treatments. The increase in K content with organic materials is consistent with Lakhdar *et al.* (2008) and Hanay *et al.* (2004), who found that adding diverse organic materials helps maintain potassium levels in the soil.

Conclusion

The study demonstrated the potential of organic fertilizers, specifically poultry manure, in improving soil fertility and enhancing rice productivity in the KRIS area. Although synthetic fertilizers may provide superior short-term results, the

long-term advantages of organic amendments on soil health and crop performance are significant. These findings can guide the development of sustainable fertilizer management strategies for rice cultivation in similar agroecological zones. The soil in the KRIS area is characterized by low levels of nitrogen, phosphorus, potassium, and organic carbon, indicating that continuous cultivation has depleted the fertility reserves of the fields. To address this, the adoption of Integrated Soil Fertility Management Practices (ISFM) is recommended, as it would significantly help restore fertility reserves and enhance soil responsiveness to fertilizers. Notably, poultry manure applications at a rate of 6 tons per hectare outperformed other amendments in terms of soil improvement and rice yield, making it a recommended practice for the study area.

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ASSESSMENT OF RELATIONSHIPS BETWEEN PHOSPHORUS AND SOME SOIL PROPERTIES IN MODIBBO ADAMA UNIVERSITY, TEACHING AND RESEARCH FARM, YOLA, ADAMAWA STATE, NIGERIA

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ABSTRACT

*This study was carried out to assess the relationships between phosphorus and some soil properties in Modibbo Adama University, Teaching and Research Farm, Yola. was conducted in Modibbo Adama University (MAU) Yola (Soil Science department). Two hectares were chosen for the purpose of this research work, fifteen surface (0-20cm) and fifteen sub-surface (20-50cm) soil sample were collected at random location, making a total of 30 soil samples. The collected soil samples were prepared and for routine analysis in the Laboratory. The soil samples were analyzed using standard laboratory procedures. The investigation showed that; the soil is predominantly sandy and low in nutrients. But Available phosphorus (AVP) was high for both surface and sub-surface (22.89-24.29) and was statistically correlated with sand content in surface soils, (0.565 *) and not significantly correlated with other soil properties. The pH was moderately acidic (5.86-5.99), in both surface and sub-surface, The E.C is non saline (0.09-0.12), O.M (2.08-0.88) and O.C (1.21-0.51) were very low to low, Total N was low (0.12-0.09). The study recommends the incorporation of organic matter (OM) through of plant residue, organic amendments or composed materials and intercropping cereals with legumes could be recommended. For the enhancement and sustainable crop productivity, application of recommended quantity and quality fertilizers to improve soil fertility is recommended.*

KEYWORDS: Phosphorus availability, Soil fertility, Soil properties, Organic matter, Sustainable Agriculture

INTRODUCTION

Phosphorus (P) is one of the most important plant nutrients (Mengel 2001, Gollet *et al.* 2012). The total P content of soil usually ranges from 0.02% to 0.15%. The major part of soil P is not available to plants and is therefore often a limiting nutrient in crop production (Fuhrman *et al.* 2005, Jakab 2020). Nowadays, increased environmental concerns and continuously decreasing P resources drive the study of P cycling processes in the soil-plant system (Helfenstein *et al.* 2018).

Phosphorus is an important element affecting the growth of plants right from the cellular to whole plant level. These growth parameters include plant height, leaf area, leaf number and shoot dry biomass. It plays an important role in cell division and cell enlargement (Assuero *et al.* 2004). Next to nitrogen, phosphorus (P) is the second most important macronutrient as an essential plant nutrient (Srinivasan *et al.* 2012). It is a key nutrient for higher and sustained agricultural productivity and which limits plant growth

in many soils. Phosphorus (P) is a naturally occurring, essential macronutrient required by plants for photosynthesis, respiration, seed production, root growth and other critical plant functions (Gichangiet *al.*, 2008). Adequate P results in improved crop quality, greater stalk strength, increased root growth, and earlier crop maturity (Brady and Weil, 2008). Thus, P deficiency can impede numerous developmental processes, resulting in reduced plant growth, delayed maturity and a reduction in the quality and quantity of crop yield (Gichangi *et al.*, 2008).

Phosphorus is an element essential to sustaining life largely through phosphates, compounds containing the phosphate ion, PO_4^{3-} . Phosphates are a component of DNA, (Deoxyribonucleic acid) RNA, (Ribonucleic acid) ATP, (Adenosine triphosphate) and phospholipids, complex compounds fundamental to cells. The vast majority of phosphorus compounds mined are used as fertilizers. Phosphate is needed to replace the phosphorus that plants remove from the soil, and its annual demand is rising nearly twice as fast as the growth of the human population. (Wikipedia, 2021).

The key importance of phosphorus to plants include: Phosphorus enables photosynthetic energy transformations in plants, Phosphorus enables the buildup of nucleic acids, proteins and enzymes, Phosphorus also facilitates roots growth in plants, It strengthens stems and stalks of plants, Improves the formation of flowers and seeds, It promotes crop uniformity, Contributes to the early maturity of plants, It also increases the ability of plants to resist diseases, Improves plants overall quality, Increased nitrogen N-fixing capacity of legumes, Supports

development throughout entire life cycle (Mengel 2001, Goll *et al.* 2012). Soils in their undisturbed state are severely deficient in phosphorus and most cropping systems require supplemental phosphorus to maximize their yield potential, The major part of soil P is not available to plants and is therefore often a limiting nutrient in crop production (Fuhrman *et al.* 2005).

Phosphorus availability in any type of soil is very essential for optimal crop production due to its critical role in plant growth and development. However, both deficiency and excess of phosphorus can negatively affect crop performance and may pose environmental risks. Despite its importance, there is limited information on the relationship between available phosphorus and key soil properties in the study area. This lack of localized data makes it difficult to develop appropriate nutrient management strategies for sustainable crop production. Therefore this study was conducted to assess the level of available phosphorus and its relationship with selected soil properties in order to provide a scientific basis for effective soil fertility management in the study area

This study brings to the knowledge of the content of phosphorus in the study area. This will guide the farmers, extension agent as well as other Soil Science researchers for proper application of P in the soil of the study area.

Aim and Objectives

The aim of this study is to determine the availability of phosphorus in the study area with the specific objectives as follows to:

- i. To assess the physical and chemical properties of the soil
- ii. To assess the available phosphorus in the soil of the study area

- iii. To assess the correlation between available p and some soil properties

Factors Affecting P Availability in Soils

Phosphorus availability in soil is mainly controlled by factors such as soil pH, organic matter, clay mineralogy, and the presence of iron and aluminum oxides, which influence its adsorption, precipitation, and overall mobility (Shinjiro 2003; Reddy and DeLaune.2008; Hadgu *et al.*, 2014). In acidic soils, phosphorus tends to bind with iron and aluminum, while in alkaline conditions it reacts with calcium and magnesium; meanwhile, organic matter can increase phosphorus availability by reducing fixation through complexation and competition for adsorption sites (Fageria 2008; Haynes and Mokolobate 2001; Borggaard *et al.*, 2005; Brady and Weil 2008).

Additionally, higher clay content, abundant Fe and Al oxides, and temperature changes can enhance phosphorus retention or release, thereby affecting its accessibility by plants (Barrow 2006; Niang *et al.*, 2002; Mnthambala *et al.*, 2015).

MATERIALS AND METHODS

The Teaching and Research Farm is located between latitudes 9° 18' 00" N and 9° 21' 40" N and longitudes 12° 28' 30" E and 12° 30' 30" E. It lies at an elevation of 150 m above sea level situated within the University (Modibbo Adama University, Yola). The relief which is the physiographical pattern of the area is characterized by the slope which rises gradually undulating to fairly flat. Soil samples were collected randomly at a depth of 0-20 cm for surface and 20–50cm for the sub-surface soils, using an auger. The soil samples were air dried at room temperature, crushed in a wooden mortar and sieved through a 2mm mesh

sieve prior to laboratory analysis. Subsamples were taken, put in polyethylene bags and kept for routine analysis.

Laboratory Analysis

Physical properties

Determination of Particle size distribution

Particle size distribution test was carried out using hydrometer method of Brown (2003).

Determination of Bulk and particle densities

Bulk density of the soils was determined by drying the undisturbed core samples to constant weight at 105°C and dividing the oven dried weight of the samples by its volume. Particle density was also determined in the laboratory.

Determination of Porosity

Total porosity was calculated using the formula:

$$f = \left(1 - \frac{\rho_b}{\rho_p} \right) \times 100$$

Where;

F = total porosity

Db=Bulk density

Dp=particle density

Determination of Water holding capacity

Water holding capacity was determined using the formula percentage water holding capacity;

$$\%WHC = \left(\frac{W3 - W2}{W4 - W1} \right) \times 100$$

Where,

W1 = the weight of the container that will be used

W2 = the weight of the container plus dry soil

W3 = the weight of sample at saturation

W4 = the weight of sample after oven dry.

Chemical properties

Determination of Soil reaction (pH) and electrical conductivity (EC)

The pH of the soil was measured in a 1:2.5 soil-water suspensions. The electrical conductivity of the soil samples was measured alongside pH with an EC meter using the same soil-water suspension used for measuring the soil pH in water (Black, 1965, Jaiswal, 2003).

Determination of Organic carbon / Organic matter

Two grams of soil samples were weighed into 250ml conical flask, 10ml of 1N Potassium dichromate ($1N K_2 Cr_2O_8$) and 20ml of concentrated sulphuric acid using a measuring cylinder were added and mixed thoroughly. The samples were allowed to cool for 30mins.

Then 100ml of distilled water, 3-5 drops of diphenylamine indicator were added and finally the content of the flask were titrated with 0.5N ferrous sulfate until color changes from black-bluish to deep green end point. Blank sample were run using all the reagents except the soil sample. The constant value 1.724 was used to calculate soil organic matter content.

Determination of Exchangeable Bases

The exchangeable bases were extracted using 1M ammonium acetate solution, Ca, Mg, K and Na were analyzed from the extract by EDTA titration method while K and Na was done by flame photometer (AAS, MEDTECH) atomic absorption spectrophotometer (AAS).

Determination of Total exchangeable acidity (TEA)

Exchangeable acidity of the soil samples was analyzed using 1N KCl extraction and titration as described by (Jaiswal 2003).

Determination of Effective cation exchange capacity (ECEC)

The effective cation exchange capacity was determined by summing up the total exchangeable bases and the total exchangeable acidity (Black, 1965).

Determination of Total Nitrogen

Total N was determined with Kjeldahl method (Jackson, 1958).

Determination of Available phosphorus

Bray-1P method was used for the determination of available phosphorus. Two grams of air dried soil samples passed through 2mm sieve was weighed and transferred into a conical flask and 14ml of P extraction solution (Bray-1Preagent) was added, 2ml of the filtrate was pipetted into a 20ml test tube and 5ml of the distilled water was added, 2ml ammonium molybdenum and 1ml dilute stannous chloride was added. About 5-20 minutes was allowed for color development, percentage transmittance was measured using a spectrophotometer at wavelength of 660nm. Standard curve was plotted with percentage transmittance against standard P concentration in ppm, (ASNSS 2005). The result obtained was subjected to calculations, interpretation and compared with established standard.

Determination of Percentage base saturation (PBS)

The calculation of base saturation was determined by dividing the sum total of exchangeable bases by ECEC and multiplying the answers by 100 (Jaiswal 2003).

Statistical analysis

Soil physical and chemical properties were analyzed using Simple descriptive statistic using Microsoft excel office (2013) Pearson Correlation Analysis was used to assess the correlation between phosphorus and some soil properties.

RESULTS AND DISCUSSION

Soil Physical and Chemical Properties

The physical and chemical properties of the soils in the study area are presented in Tables (1–4). The particle size distribution revealed that the soils are predominantly sandy in both surface and sub-surface horizons. Sand fraction constituted the largest proportion of the soil separates, while silt and clay fractions were comparatively low across all sampling

points. This indicates a coarse-textured soil system.

Bulk density values were generally moderate to high in both depths, with slightly lower values observed in the sub-surface soils. Porosity values were moderate to high across the study area, while particle density remained relatively constant and within the normal range for mineral soils.

Water holding capacity was generally low in both surface and sub-surface soils, although slightly higher values were observed in the sub-surface layer.

In terms of chemical properties, soil pH ranged from moderately acidic to near neutral across the study area. Electrical conductivity values were low in both depths, indicating low soluble salt content. Organic carbon and organic matter contents were low to moderate, with higher values recorded in the surface soils compared to the sub-surface soils. Total nitrogen content was generally low across both depths.

Available phosphorus levels were relatively high in both surface and sub-surface soils. Exchangeable bases varied across the study area, with calcium and magnesium present in low to moderate quantities, potassium in moderate amounts, and sodium generally low.

Total exchangeable bases and effective cation exchange capacity were low to moderate, while total exchangeable acidity values were low. Percentage base saturation was high across both soil depths. Sodium adsorption ratio and exchangeable sodium percentage were generally low.

The predominance of sand in the soil indicates that the soils are coarse-textured, which has important implications for soil productivity and management. Sandy soils are typically characterized by high

infiltration rates and rapid drainage, which can result in significant nutrient losses through leaching. This agrees with the findings of Brady and Weil (2016), who reported that coarse-textured soils have limited capacity to retain nutrients due to low surface area and weak adsorption properties.

The moderate to high bulk density observed in the study area suggests some degree of soil compaction, particularly in the surface layers. High bulk density can restrict root growth, reduce soil aeration, and limit water movement within the soil profile. Despite the moderate to high porosity values, the effectiveness of these pores in water retention is limited because sandy soils are dominated by macro-pores, which facilitate rapid drainage rather than water storage.

The low water holding capacity recorded in this study further confirms the influence of soil texture on moisture retention. This condition can expose crops to moisture stress, especially under rain-fed agricultural systems commonly practiced in Nigeria.

The soil pH values observed, which range from moderately acidic to near neutral, are generally favorable for crop production. This pH range enhances the availability of most essential nutrients and supports microbial activity. This finding is consistent with the report of Usman (2005), who observed similar soil reaction in soils of Adamawa State.

The low electrical conductivity values indicate that the soils are non-saline and suitable for crop production. This suggests that salinity is not a limiting factor in the study area, which aligns with the findings of Usman (2005).

The low to moderate organic carbon and organic matter contents reflect limited

organic matter accumulation and rapid decomposition under tropical climatic conditions. The decrease in organic matter with depth is expected due to reduced biological activity and organic inputs in sub-surface layers. This observation agrees with Usman (2005).

The low total nitrogen content indicates that nitrogen is a limiting nutrient in the study area. This is a common characteristic of tropical soils, where nitrogen is easily lost through leaching and volatilization. Therefore, nitrogen supplementation through fertilizers or organic amendments is essential for sustainable crop production. In contrast, the relatively high available phosphorus levels suggest that phosphorus may not be a limiting nutrient in the study area. According to Aduayi *et al.* (2002), such levels are considered adequate to high for most crops.

The exchangeable bases indicate moderate fertility status, with calcium and magnesium present in sufficient amounts to support plant growth. The low sodium levels further indicate that the soils are not affected by sodicity, which is beneficial for maintaining soil structure. Potassium levels were moderate, suggesting adequate supply for crop uptake. These findings are consistent with the report of Kparmwang *et al.* (2000).

The low to moderate effective cation exchange capacity observed in the study area reflects the sandy nature and low organic matter content of the soils. This limits the soil's ability to retain nutrients and maintain long-term fertility.

The low total exchangeable acidity indicates that soil acidity is not a major constraint in the study area. However, the high percentage base saturation suggests that most exchange sites are occupied by basic cations, which is generally favorable

for plant growth. This observation, however, differs from the findings of Kparmwang *et al.* (2000), possibly due to variations in soil management practices or parent material.

The low sodium adsorption ratio and exchangeable sodium percentage confirm that the soils are non-sodic and structurally stable. This indicates that the soils are suitable for sustained agricultural use without the risk of sodicity-related degradation, which agrees with Usman (2005).

Correlation Studies

Available Phosphorus and Physical Properties

The correlation analysis between available phosphorus and the physical properties of the soil (Table 5) showed that available phosphorus was positively correlated with sand ($r = 0.565^*$). This positive relationship may be attributed to the low adsorption capacity of sandy soils due to their low clay content and reduced presence of iron and aluminum oxides, which are responsible for phosphorus fixation. As a result, phosphorus remains more available in sandy soils (Brady and Weil, 2008; Havlin *et al.*, 2014).

Conversely, sand showed a negative correlation with silt ($r = -0.783^{***}$), which is expected due to the inverse relationship

Table 3: Chemical Properties of surface soil samples of the study area (0- 20cm)

S/N	SAMPLE	DEPTH (cm)	PH	EC (dS/m)	OC (g/kg)	OM (g/kg)	%TN	AVP (mg/kg)	Ca	Mg	K	Na (cmol/kg)	TEB	TEA	ECEC	PBS	SAR	ESP
1	p1	0-20	6.00	0.08	0.74	1.28	0.12	9.10	2.60	2.00	0.06	0.03	4.69	0.25	4.94	94.94	0.01	0.53
2	p2	0-20	6.28	0.07	2.43	4.18	0.53	28	3.00	0.60	0.18	0.04	3.82	0.35	4.17	91.60	0.02	0.86
3	p3	0-20	5.99	0.09	0.48	0.83	0.10	29.75	3.80	0.20	0.23	0.04	4.27	0.15	4.42	96.60	0.02	0.82
4	p4	0-20	5.60	0.10	0.75	1.29	0.07	21.35	2.60	2.60	0.13	0.04	5.37	0.45	5.82	92.27	0.02	0.74
5	p5	0-20	5.43	0.09	2.74	4.72	0.05	16.10	3.40	1.80	0.27	0.04	5.51	0.30	5.81	94.84	0.02	0.74
6	p6	0-20	5.45	0.12	0.43	0.74	0.06	23.45	2.40	3.80	0.14	0.04	6.38	0.25	6.63	96.23	0.02	0.65
7	p7	0-20	5.80	0.11	0.66	1.15	0.10	23.80	3.40	0.40	0.12	0.05	3.96	0.55	4.51	87.81	0.02	1.04
8	p8	0-20	5.66	0.09	2.73	4.71	0.11	28	3.60	1.00	0.13	0.03	4.75	0.60	5.35	88.80	0.01	0.52
9	p9	0-20	6.06	0.08	0.29	0.52	0.09	22.75	3.60	0.40	0.17	0.04	4.21	0.25	4.46	94.39	0.02	0.96
10	p10	0-20	5.82	0.09	0.48	0.83	0.11	23.80	3.00	0.80	0.13	0.12	4.05	0.75	4.80	84.38	0.07	2.58
11	p11	0-20	5.97	0.08	2.36	4.07	0.09	23.45	4.12	0.28	0.12	0.03	4.54	0.95	5.49	82.71	0.01	0.51
12	P12	0-20	5.88	0.09	0.78	1.35	0.11	23.45	3.28	0.52	0.15	0.01	3.97	0.15	4.12	96.35	0.01	0.29
13	p13	0-20	5.94	0.08	0.59	1.02	0.05	22.75	2.80	1.80	0.15	0.01	4.76	0.55	5.31	89.64	0.00	0.11
14	p14	0-20	5.97	0.09	2.28	3.94	0.09	23.80	3.20	1.00	0.04	0.00	4.24	0.50	4.74	89.46	0.00	0.08
15	P15	0-20	6.09	0.08	0.37	0.65	0.10	23.80	2.00	2.80	0.27	0.05	5.12	0.60	5.72	89.50	0.03	0.82
	Minimum		5.43	0.07	0.29	0.52	0.05	9.10	2.00	0.20	0.04	0.00	3.82	0.15	4.12	82.71	0.00	0.08
	Maximum		6.28	0.12	2.74	4.72	0.53	29.75	4.12	3.80	0.27	0.12	6.38	0.95	6.63	96.60	0.07	2.58
	Average		5.86	0.09	1.21	2.08	0.12	22.89	3.12	1.33	0.15	0.04	4.64	0.44	5.09	91.30	0.02	0.75

KEYS: EC- Electrical conductivity, O.C-Organic Carbon, O.M-Organic Matter, TN-Total Nitrogen, AVP-Available phosphorus, TEB- Total Exchangeable Bases, TEA, Total exchangeable Acidity, ECEC-Effective Cation Exchange Capacity, PBS-Percentage Base Saturation.

Table 4: Chemical properties of Sub-surface soil samples the study area (20-50)

S/N	SAMPLE	DEPTH (cm)	PH	EC (dS/m)	OC (g/kg)	OM (g/kg)	%TN	AVP (mg/kg)	Ca	Mg	K	Na (cmol/kg)	TEB	TEA	ECEC	PBS	SAR	ESP
1	p1	20-50	5.90	0.07	0.45	0.77	0.09	16.80	3.20	1.60	0.05	0.01	4.86	0.45	5.31	91.52	0.00	0.15
2	p2	20-50	5.74	0.08	0.40	0.69	0.11	23.45	2.60	1.80	0.14	0.04	4.58	0.45	5.03	91.05	0.02	0.72
3	p3	20-50	6.08	0.22	0.44	0.76	0.09	23.10	3.40	0.80	0.15	0.04	4.39	0.30	4.69	93.60	0.02	0.77
4	p4	20-50	6.00	0.09	0.50	0.86	0.08	30.80	2.80	2.00	0.05	0.01	4.86	0.50	5.36	90.67	0.00	0.15
5	p5	20-50	6.17	0.06	0.35	0.61	0.09	28.00	3.20	2.60	0.33	0.03	6.16	0.45	6.61	93.19	0.01	0.39
6	p6	20-50	7.21	0.09	0.49	0.85	0.09	23.45	3.40	0.00	0.17	0.04	3.60	0.80	4.40	81.83	0.02	0.82
7	p7	20-50	5.34	0.08	0.76	1.32	0.05	23.45	2.60	0.80	0.40	0.04	3.84	0.30	4.14	92.75	0.02	1.04
8	p8	20-50	5.30	0.08	0.50	0.86	0.11	23.80	3.20	0.40	0.31	0.08	3.98	0.40	4.38	90.88	0.04	1.78
9	p9	20-50	5.38	0.08	0.45	0.78	0.10	23.10	3.00	2.00	0.18	0.04	5.22	0.30	5.52	94.56	0.02	0.65
10	p10	20-50	6.03	0.18	0.72	1.24	0.09	23.45	3.00	3.80	0.09	0.01	6.90	0.70	7.60	90.79	0.00	0.14
11	p11	20-50	6.12	0.09	0.48	0.84	0.08	28.35	6.80	0.20	0.27	0.04	7.30	0.60	7.90	92.41	0.01	0.46
12	p12	20-50	6.30	0.08	0.49	0.85	0.05	23.45	2.80	2.40	0.08	0.01	5.28	0.95	6.23	84.76	0.00	0.13
13	p13	20-50	5.77	0.07	0.44	0.77	0.10	28.00	3.00	3.40	0.13	0.03	6.56	0.45	7.01	93.58	0.01	0.40
14	p14	20-50	6.79	0.24	0.40	0.69	0.11	22.75	2.80	0.60	0.32	0.03	3.75	0.45	4.20	89.27	0.01	0.62
15	p15	20-50	5.69	0.23	0.75	1.30	0.05	22.40	2.60	1.60	0.18	0.05	4.43	0.40	4.83	91.72	0.03	1.12
Minimum			5.30	0.06	0.35	0.61	0.05	16.80	2.60	0.00	0.05	0.01	3.60	0.30	4.14	81.83	0.00	0.13
Maximum			7.21	0.24	0.76	1.32	0.11	30.80	6.80	3.80	0.40	0.08	7.30	0.95	7.90	94.56	0.04	1.78
Average			5.99	0.12	0.51	0.88	0.09	24.29	3.23	1.60	0.19	0.03	5.05	0.50	5.55	90.84	0.02	0.62

KEYS: EC- Electrical conductivity, O.C-Organic Carbon, O.M-Organic Matter, TN-Total Nitrogen, AVP-Available phosphorus, TEB- Total Exchangeable Bases, TEA, Total exchangeable Acidity, ECEC-Effective Cation Exchange Capacity, PBS-Percentage Base

Table 5: Correlation Analysis of AVP and some Soil Physical Properties of Surface Soils.

	AVP	SAND	SILT	CLAY	WHC	BD	PD	Porosity
AVP	1							
SAND	0.565 *	1						
SILT	NS	-0.783 **	1					
CLAY	NS	-0.751 **	NS	1				
WHC	NS	NS	0.626 *	NS	1			
BD	NS	0.553 *	-0.612 *	NS	-0.589 *	1		
PD	NS	NS	NS	NS	NS	NS	1	
Porosity	NS	NS	NS	NS	NS	-0.792 **	0.767 **	1

* =Significant at ($r>0.05$) % level of significance

* * = Significant at ($r>0.01$) % level of significance

NS = Not Significant

N = 13

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Table 6: Correlation Analysis for AVP and some Soil Physical Properties in Subsurface soils.

	AVP	SAND	SILT	CLAY	WHC	BD	PD	Porosity
AVP	1							
SAND	NS	1						
SILT	NS	-0.876 **	1					
CLAY	NS	-0.746 **	NS	1				
WHC	NS	-0.645 **	NS	0.810 **	1			
BD	NS	0.578 *	NS	-0.632 *	NS	1		
PD	NS	NS	NS	NS	NS	NS	1	
Porosity	NS	-0.606 *	NS	0.609 *	NS	-0.852 **	0.691 **	1

* = Significant at ($r>0.05$) % level of significance

* * = Significant at ($r>0.01$) % level of significance

NS= Not Significant

N = 13

between soil particle size fractions. The negative relationship between available phosphorus and finer soil fractions such as silt and clay may be due to increased phosphorus adsorption and fixation in these fractions. Clay particles have larger surface areas and more active sites that enhance phosphorus sorption, thereby reducing its availability in the soil (Sparks, 2003; Fageria, 2008).

Available Phosphorus and Chemical properties

The relationship between available phosphorus and soil chemical properties indicated weak or non-significant correlations with parameters such as soil pH, organic matter, and exchangeable bases. The weak correlation between available phosphorus and soil pH may be attributed to the relatively narrow pH range within the study area, as phosphorus availability is strongly influenced only under extreme acidic or alkaline conditions (Lindsay, 1979; Fageria, 2008). Similarly,

Table 8: Correlation Analysis of some Chemical Properties in Surface Soils of the Study Area (0-20cm)

	PH	EC	OC	OM	%TN	AVP	Ca	Mg	K	Na	TEB	TEA	ECEC	PBS	SAR	ESP
PH	1															
	-0.748*															
EC	*	1														
OC	0.571*	NS	1													
OM	0.571*	NS	1	1												
%TN	0.571*	NS	1	1	1											
AVP	NS	NS	NS	NS	NS	1										
Ca	NS	NS	NS	NS	NS	NS	1									
							-0.822*									
Mg	NS	NS	NS	NS	NS	NS	*	1								
K	NS	NS	NS	NS	NS	NS	NS	NS	1							
Na	NS	NS	NS	NS	NS	NS	NS	NS	NS	1						
	-							0.885*								
TEB	0.700* *	NS	NS	NS	NS	NS	NS	*	NS	NS	1					
TEA	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	1				
	-0.666*										0.949*					
ECEC	*	NS	NS	NS	NS	NS	NS	NS	NS	NS	*	NS	1			
												-0.975*				
PBS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	*	NS	1		
SAR	NS	NS	NS	NS	NS	NS	NS	NS	NS	0.998* *	NS	NS	NS	NS	1	
															0.989*	
ESP	NS	NS	NS	NS	NS	NS	NS	NS	NS	0.984* *	NS	NS	NS	NS	*	1

* = Significant at (r>0.05) % level of significance

* * = Significant at (r>0.01) % level of significance

NS= Not Significant

N = 13

Table 8: Correlation Analysis of some Chemical Properties in sub-surface Soil of the Study Area (20-50cm)

	PH	EC	OC	OM	%TN	AVP	Ca	Mg	K	Na	TEB	TEA	ECEC	PBS	SAR	ESP
PH	1															
EC	NS	1														
OC	NS	NS	1													
OM	NS	NS	1	1												
%TN	NS	NS	1	1	1											
AVP	NS	NS	NS	NS	NS	1										
Ca	NS	NS	NS	NS	NS	NS	1									
Mg	NS	NS	NS	NS	NS	NS	NS	1								
K	NS	NS	NS	NS	NS	NS	NS	NS	1							
								-0.523	0.593							
Na	NS	NS	NS	NS	NS	NS	NS	*	*	1						
							0.523	0.592								
TEB	NS	NS	NS	NS	NS	NS	*	*	NS	NS	1					
TEA	0.614*	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	1				
							0.523	0.586			0.989					
ECEC	NS	NS	NS	NS	NS	NS	*	*	NS	NS	*	*	NS	1		
	-0.719*											-0.812				
PBS	*	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	*	*	NS	1	
								-0.522	0.585	0.987				-0.536		
SAR	NS	NS	NS	NS	NS	NS	NS	*	*	*	NS	NS	*	NS	1	
								-0.572	0.579	0.969	-0.565		-0.604		0.993*	
ESP	NS	NS	NS	NS	NS	NS	NS	*	*	*	*	NS	*	NS	*	1

* = Significant at ($\alpha > 0.05$) % level of significance

* * = Significant at ($\alpha > 0.01$) % level of significance

NS= Not Significant

N = 13

the weak relationship between available phosphorus and organic matter could be due to the dual role of organic matter in soil. Organic matter can enhance phosphorus availability by forming complexes with iron and aluminum, thereby reducing phosphorus fixation, but it can also immobilize phosphorus depending on microbial activity and decomposition processes (Brady and Weil, 2008; Stevenson, 1994).

Furthermore, the non-significant correlation between available phosphorus and exchangeable bases or effective cation exchange capacity (ECEC) suggests that phosphorus availability is more strongly controlled by sorption and fixation processes rather than cation exchange reactions (Havlin *et al.*, 2014).

CONCLUSION

The study revealed that the soils of the study area are predominantly sandy, with coarse texture influencing most of their physical and chemical characteristics. The soils exhibited moderate to high bulk density, moderate porosity, and low water holding capacity, which may limit moisture availability to crops.

Chemically, the soils were moderately acidic to neutral, with low electrical conductivity, indicating non-saline conditions suitable for crop production. However, the soils were generally low in organic carbon and total nitrogen, suggesting poor nutrient reserves. In contrast, available phosphorus was relatively high, while exchangeable bases were present in low to moderate amounts. The effective cation exchange capacity was low, indicating limited ability of the soils to retain nutrients, although percentage base saturation was high.

Overall, the soils possess moderate fertility status but are constrained by low nutrient

retention and moisture holding capacity, which may affect sustainable crop production.

Based on the findings of this study, the following recommendations are proposed:

Incorporation of organic matter (such as compost, farmyard manure, and crop residues) should be encouraged to improve soil structure, increase water holding capacity, and enhance nutrient retention. Application of nitrogen fertilizers is necessary to address nitrogen deficiency and improve crop yield. Mulching practices should be adopted to reduce moisture loss, regulate soil temperature, and improve soil organic matter content.

Integrated soil fertility management (ISFM) practices should be implemented to ensure balanced nutrient supply and sustainable soil productivity.

Efficient irrigation practices should be considered, especially during dry periods, to compensate for the low water holding capacity of the soils.

Regular soil testing should be carried out to monitor soil fertility status and guide appropriate management decisions.

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EFFECT OF CROP ROTATION, NITROGEN FERTILIZER AND TILLAGE ON MAIZE GRAIN AND STOVER YIELD

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ABSTRACT

A long-term field experiment was established in 2003 at the Institute for Agricultural Research Samaru, northern Guinea savanna of Nigeria to evaluate the effect of N fertilizer, tillage and crop rotation. In 2022, crop data were collected to determine the influence of N fertilizer, tillage and crop rotation on maize grain and stover yield. To achieve these objectives, maize was sown on all the plots, data were taken from the maize phase of the rotation where maize was grown in rotation with maize, maize in rotation with soybean and maize in rotation with cowpea, under conventional and reduced tillage, with N fertilization of 0 kg N ha⁻¹, 30 kg N ha⁻¹, 60 kg N ha⁻¹ and 90 kg N ha⁻¹. The experiment was arranged in a split plot design, replicated three times. Analysis of variance was performed on the data using the General Linear Model Proc. of SAS. The result on maize stover yield was significant with maize in rotation with cowpea and maize in rotation with soybean (73.91g) under conventional tillage (87.80g) and the application of N fertilizer at 90 kg N ha⁻¹ (100.94g) gave higher stover yield of maize. The result on maize grain yield also shows the significance of crop rotation where maize in rotation with cowpea (2,791 kg ha⁻¹) and maize in rotation with soybean (3,262kg ha⁻¹) under conventional tillage (3,401 kg ha⁻¹) and the application of N fertilizer at 60 kg N ha⁻¹ (3,564 kg ha⁻¹) gave higher maize grain yield in the experiment.

Keywords: Crop rotation, Nitrogen fertilization, Tillage, Maize.

Introduction

Maize (*Zea mays* L.) is an annual plant of the grass Gramineae family. It is an open-pollinated plant which matures usually within 100 - 120 days (Bruce *et al.*, 2020). Maize yield in Nigeria stands at less than two tonnes per hectare (t/ha) relative to 4.9 t/ha and 4.2 t/ha in South Africa and Ethiopia respectively. This is due to continued usage of open pollinated variety (OPV) rather than improved

hybrid seeds by the country's maize farmers (PWC, 2021). Good land management such as tillage, crop rotation, residue management etc are soil related action necessary for increasing yield in crop production (Dugan *et al.*, 2021).

Crop rotation is the growing of a series of dissimilar or different types of crops in the same area in a sequential seasons, it has been shown to provide various nutrients to the soil.

A traditional element of crop rotation is the replenishment of nitrogen through the use of green manure in sequence with cereals and other crops. A crop that depletes the soil of one kind of nutrient is followed during the next growing season by a dissimilar crop that returns that nutrient to the soil or draws a different ratio of nutrients: for example, rice followed by cotton (Appropedia, 2024). Studies have shown that legume-cereal rotation produce relatively higher grain yields than either crop grown alone. Rotating maize with grain legumes is often targeted towards utilizing biologically fixed-nitrogen by legumes for the benefit of the maize (Lengwati *et al.*, 2020).

Nitrogen fertilizers are most effectively used as part of a balanced fertilization plan that aims to maximize economic return of a cereal-legume rotation system. Long-term field experiments with N fertilization can give valuable information about how those changes occur and indicate the trends of the changes (Dragan *et al.*, 2010). Therefore, proper management of soil in terms of method of tillage practice and cropping system is very important in determining the amount of N in the soil.

Tillage practice is very important in relation to cereal – legume rotation; it could be divided into conventional, reduced and zero tillage. Conventional tillage refers to tillage operations considered standard for a specific location and crop (Usman, 2017). Reduced tillage involves no ridging and less weeding, it also refers to any method of soil cultivation that leaves the previous year's crop residue on fields before and after planting the next crop to reduce soil erosion and runoff (MDA, 2014). Conservation (reduced or zero) tillage

increases soil organic carbon in the surface layer (Lo'pez-Bellido *et al.*, 2010), improves soil aggregation and preserves soil resources better than conventional tillage practices.

The major problem facing maize production in the region are weed infestation, erratic rainfall, and poor soil fertility. Unstable rainfall early in the growing season has been reported to cause drought for crops. This resulted to large number of plants being barren cobs, which is a common feature of severely stressed maize. It is however a known phenomenon that savanna soils in Nigeria have low inherent fertility status, low organic matter, low total nitrogen and phosphorus, low water infiltration capacity, poor internal drainage due to poor structure. As a result of the low fertility level in the soil, farmers apply fertilizer to make up for the deficient nutrient, also they practice crop rotation, rotating cereals with legumes in order to utilize N fixation by the legumes and also perform conventional tillage activities to improve yield. However, these fertilizers are not applied at recommended rates, crops are also not rotated properly and conservation tillage practices are not practiced by most farmers, hence crop productivity declines gradually thereby causing low maize yield (Usman, 2017). Maize, though the second most essential cereal crop after sorghum has now become more important and is grown much more intensively than estimated since 1985 (FAO, 2020). Maize is produced by both small- and large-scale farmers in the Northern Guinea savanna of Nigeria, where it is widely consumed as a staple food by poor rural and urban households. Maize is now a very essential food stable for both the rich and the poor. Maize is also processed

industrially for flour, animal feeds, biscuits, beverages and beer and in these forms is consumed widely across Nigeria. The ban on importation of cereals by the Federal Government of Nigeria since 1986 has greatly expanded these latter uses and thus overall demand for maize. As a result, all these importance of maize, various studies carried out have shown the effects of different tillage management systems, N fertilization and crop rotation on maize grain yield (Melero *et al.*, 2011). However, information on changes produced by the interaction of tillage system, crop rotation, rate of N fertilization on maize grain yield over a long time is very scarce (Melero *et al.*, 2011). Therefore, in an effort to reduce soil nutrient depletion problems, the rising expense of all food items due to poor management practices and excessive dependence on fertilizer in Nigeria, especially in the northern Guinea savanna of Nigeria, the contributions of crop rotation under conventional and reduced tillage practices in improving the grain and stover yield of maize using different N fertilizer rates were investigated.

The main objective of this research was to determine the effect of long-term rotation, nitrogen fertilizer and tillage on maize yield in the northern Guinea savanna of Nigeria.

MATERIALS AND METHODS

Experimental Site

The study was carried out at the Institute for Agricultural Research (IAR) farm in Samaru, with coordinates 11° 09, 943N', 007° 37. 956E' and 686 m above the sea level in the northern Guinea savanna (NGS) of Nigeria. The soil type is an Alfisol derived from Pre-Cambrian Crystalline basement complex rocks with some quaternary Aeolian deposits.

The experimental field was relatively flat with a mono modal rainfall pattern and a mean annual rainfall of 1011 ± 161 mm concentrated almost entirely from May to October. Samaru has minimum and maximum temperatures of 21°C and 33.5 °C, with a mean daily temperature of 24 °C and relative humidity of 55.23 % (IAR, 2015 and Usman, 2017). This study was carried out in the wet season of 2022. A long-term field experiment begun in 2002 at the Institute for Agricultural Research, (I.A.R) farm in Samaru, to evaluate the effect of long term N fertilization on crop rotation, the site was later modified to accommodate tillage as an additional experimental factor in 2009. Now the experimental field has N fertilization, crop rotation and tillage practices.

Treatment Structure and Experimental Design

The treatments were factorial combination of three crop rotations (Maize - Maize, Maize – Cowpea and Maize – Soybean), two tillage practices (Reduced and Conventional) and four N levels (0 kg N ha⁻¹, 30 kg N ha⁻¹, 60 kg N ha⁻¹ and 90 kg N ha⁻¹), arranged in split plot design replicated three times. The main plot consisted of combinations of crop rotation and tillage, while the sub-plot consisted of N rate. Maize was sown on all the plots during this experiment.

Agronomic Practices

The conventional tilled plots were manually ridged and remoulded at 0.75 m inter-row spacing, the reduced tillage plots were not ridged and remoulded, but seeds were sown at 0.75 m inter-row spacing using a rope to mark the planting points. The main plot and sub plot both measured 4.5 m x 6 m giving an area of 27 m², with a total of 6 ridges per plot, separated 1 m between block and 0.5 m

between plots. Within the plots, four (4) ridges were the net plot while the outer rows were regarded as the border rows which destruction samples were taken. All plots were sprayed with glyphosate at 2 litres per hectare at approximately 2 weeks before sowing. SAMMAZ 14 seeds were sown in 2013 manually at the rate of two seeds per hole. This was later thinned to one plant per stand at an intra-row spacing of 25 cm and inter-row spacing of 75 cm. This brought the plant population to 24 plants per ridge and 144 plants per plot. Phosphorus and potassium fertilizers were applied by drill method once at planting based on the recommended rate of fertilizer application for maize at 60 kg P₂O₅ ha⁻¹ and 60 kg K₂O ha⁻¹. Nitrogen was applied in two split dose (also using drill method) at 3 WAS and 6 WAS at 0 kg N ha⁻¹, 30 kg N ha⁻¹, 60 kg N ha⁻¹ and 90 kg N ha⁻¹ levels in the various experimental plots corresponding to the N level. Weeding was done twice at both the conventional tillage plots and reduced tillage plots at three weeks after sowing and at six weeks after sowing. The conventional tillage plots were earthened up using hoe at 8WAS only, while the reduced tillage plots were not earthen up.

Data Collection

Four plants were randomly tagged in each plot on the ridges adjacent to the border rows. Data on growth parameters were recorded on the tagged plants at two weeks intervals, beginning from 4 WAS and continued until 12 WAS. The parameters observed were: Plant height (cm), Number of leaves per plant, Leaf width, Leaf length, Leaf area (LA) cm² plant⁻¹

This was determined by the equation below as:

$$\text{Leaf area (Y)} = 0.5L\frac{n}{w} + 1.05n + 53.61 \dots\dots\dots \text{eqn. 1}$$

Where;

L = Leaf length.

w = Leaf width

n = Number of leaves (Usman, 2017).

Dry matter yield of maize

Dry matter yield per plant was determined at five different stages of plant growth (4 WAS, 6 WAS, 8 WAS, 10 WAS and 12 WAS) during the experiment. Five plants were uprooted from the border rows in the gross plot. They were inserted into a labeled envelope and oven dried for 3 to 4 days, at a temperature of 70 °C. This was weighed and the average was calculated to obtain the weight per plant. Harvesting of the maize cob was done when the plant reached its harvest maturity. Harvesting was done by hand and 15 maize plants were selected and uprooted to determine both growth and yield parameters. 100 grain weight (g): One hundred grains were randomly selected and weighed to determine 100 seed weight from the 15 maize plants harvested. Grain Yield (kg/ha): Fifteen maize plants were uprooted, 15 cobs were threshed, weighed and extrapolated as shown below: a. Grain yield per plot = Grain weight per cob x Total number of cobs

b. Grain yield per hectare = (grain yield per plot x 10,000 m²) / plot area

Statistical Analyses

The data obtained was analyzed using the standard ANOVA procedures for a Split plot design. Analysis of variance was performed using the General Linear Model Proc. of SAS (SAS, 2013); treatment means were compared using Duncan's Multiple Range

Test (Duncan, 1955) at 5% level of significance ($p < 0.05$).

RESULTS AND DISCUSSION

Plant height

The effects of crop rotation, tillage and nitrogen rates on maize plant height are shown in Table 3.1. The result shows that crop rotation was not significant ($P > 0.05$) throughout the period of the experiment. However, tillage significantly affected plant height throughout the period of the experiment with conventional tillage giving the highest plant height from 4 weeks after sowing (WAS) to 12 WAS and the reduced tillage giving the lowest height from 4 WAS to 12 WAS. Nitrogen rate did not have a significant ($P > 0.05$) effect on plant height at 4 WAS and 6 WAS, but was significant ($P < 0.05$) on plant height from 8 WAS to 12 WAS with 90 kg N ha⁻¹ having the highest height at 8 WAS, 10 WAS and 12 WAS, while 0 kg N ha⁻¹ had the lowest height at 8 WAS, 10 WAS and 12 WAS. There was also no significant ($P > 0.05$) difference between the nitrogen rate of 0 kg N ha⁻¹ and 30 kg N ha⁻¹ at 8 WAS and 10 WAS. The interaction of the treatments on plant height was not significant throughout the period of the experiment.

The plant height was taller in the conventional tillage plots than in the reduced tillage plots because it helps in loosening and aerating the top layer of the soil, it helps

destroy weed mechanically, it helps to mix crop residue, organic matter (humus), and nutrients evenly into the soil (Ray, 2013). This result collaborates with the work of Lawal (2015) who reported maize plant height in the conventional tillage to be significantly higher than in reduced or no

tillage at 6 WAS in 2013 cropping season. Conventional tillage increased plant height. Nitrogen fertilizer was applied at 2 WAS and 6 WAS for the first and second dose respectively, so the effect of the fertilizer was seen from 8 WAS. The result showed plant height of maize increasing as the nitrogen fertilizer rate was increasing from 30 kg N ha⁻¹ to 90 kg N ha⁻¹. This shows that nitrogen contributes to forage biomass production. A steady supply is needed during the early growth stage and this steady supply can be provided by the action of soil microorganisms on the soil organic matter (SOM) or by application of inorganic fertilizers (Eche, 2011).

Total dry matter yield per plant (g) (Stover yield)

The effects of crop rotation, tillage and nitrogen rates on maize dry matter yield (DMY) are shown in Table 3.3. From the table, crop rotation had no effect ($P > 0.05$) on DMY at 4WAS but a significant ($P < 0.05$) effect was observed from 6 WAS to 12 WAS. During these periods, maize in rotation with cowpea had the highest DMY, followed by maize in rotation with soybean, Continuous maize had the lowest DMY from 6 WAS to 12 WAS. The result also shows that there was no significant difference ($P > 0.05$) between maize following cowpea and maize following soybean at 10 WAS and 12 WAS, with both being superior to continuous maize. Tillage effect was not significant ($P > 0.05$) at 4 WAS but was significant from 6 WAS to 12 WAS, with conventional tillage giving the highest weight from 6 WAS to 12 WAS while the reduced tillage had the lowest DMY during this period. Nitrogen rates

were significant ($P<0.05$) throughout the period of the experiment with 90 kg N ha⁻¹ constantly

Table 3.1: Effect of crop rotation, tillage and nitrogen rates on maize plant height (cm).

Treatment	Weeks after sowing				
	4	6	8	10	12
Rotation					
Maize	40.27	79.88	149.67	186.81	198.19
Cowpea	39.60	92.19	155.07	195.56	206.53
Soybean	44.30	90.28	157.57	194.48	205.04
SE±	4.18	5.00	9.70	7.49	6.62
Tillage					
Reduced	36.22 ^b	75.64 ^b	142.08 ^b	181.74 ^b	194.23 ^b
Conventional	46.57 ^a	99.26 ^a	166.13 ^a	202.68 ^a	212.28 ^a
SE±	6.28	7.51	14.55	11.23	9.93
Nitrogen rate (kg N ha⁻¹)					
0	44.34	82.15	141.56 ^b	178.51 ^b	181.38 ^c
30	42.64	83.81	145.35 ^b	189.31 ^b	197.96 ^b
60	40.06	86.45	154.19 ^b	193.84 ^{ab}	206.58 ^b
90	38.52	87.39	175.32 ^a	207.62 ^a	227.10 ^a
SE±	4.14	3.75	7.27	5.62	4.97
Interaction					
Tillage*Rotation	NS	NS	NS	NS	NS
Tillage*N rate	NS	NS	NS	NS	NS
Rotation*N rate	NS	NS	NS	NS	NS
Tillage*Rotation*N rate	NS	NS	NS	NS	NS

Means in the same column and under the same factor, followed by different letters are significantly different at $P<0.05$ level of probability. NS = Not Significant.

giving higher DMY during sampling periods, 60 kg N ha⁻¹ and 30 kg N ha⁻¹ had no significant difference ($P>0.05$) at 8 WAS, 10 WAS and 12 WAS. Similarly, 30 kg N ha⁻¹ and 0 kg N ha⁻¹ were not different statistically at 8 WAS, 10 WAS and 12 WAS. The Interaction between crop rotation, tillage and Nitrogen rate was not significant ($P>0.05$) throughout the period of the experiment.

Cowpea and soybean are both legumes as compared to maize which is a cereal and they both produced higher DMY than the cereals. Studies have shown that legume - cereal rotation produce relatively higher grain yields and dry matter yield than either crop grown alone (Mpairwe *et al.*, 2002 and Dapaah *et al.*, 2003). Nutrients cycling needs time to take full effect on the maize, Hence there was no significant effect on crop rotation at the first week of the

experiment, however, the effect was seen from 6 WAS to the end of the experiment, hence tillage affected DMY by reducing competition for nutrient and improving aeration to the maize plant.

Table 3.2: Effect of crop rotation, tillage and nitrogen rate on maize leaf area (cm²).

Treatment	Weeks after sowing				
	4	6	8	10	12
Rotation					
Maize	87.65	108.75	118.67	105.88	101.73
Cowpea	88.98	107.57	117.95	105.35	101.34
Soybean	89.73	107.66	117.40	106.43	103.29
SE±	3.10	3.70	4.96	5.01	2.55
Tillage					
Reduced	85.30 ^b	102.44 ^b	115.00 ^b	103.29 ^b	101.18 ^b
Conventional	92.27 ^a	113.55 ^a	121.01 ^a	108.49 ^a	103.05 ^a
SE±	4.65	5.55	7.44	3.34	3.82
Nitrogen rate (kg N ha⁻¹)					
0	90.01	109.84	118.38	106.83	101.46
30	88.77	108.02	113.60	103.89	100.01
60	87.46	109.92	123.10	106.67	105.07
90	88.90	104.20	116.95	106.17	101.93
SE±	2.32	2.77	3.72	2.51	1.91
Interaction					
Tillage*Rotation	NS	NS	NS	NS	NS
Tillage*N rate	NS	NS	NS	NS	NS
Rotation*N rate	NS	NS	NS	NS	NS
Tillage*Rotation*N rate	NS	NS	NS	NS	NS

Means in the same column and under the same factor, followed by different letters are significantly different at $P < 0.05$ level of probability. NS = Not Significant.

The current N fertilizer recommendation for the northern Guinea savanna is 120 kg N ha⁻¹ for open pollinated and 150 kg N ha⁻¹ for hybrid (Chude, 1996); the DMY was highest for 90 kg N ha⁻¹ as compared to 0 kg N ha⁻¹, 30 kg N ha⁻¹ and 60 kg N ha⁻¹ because the latter did not meet the fertilizer N requirement for maize production in the northern Guinea savanna, therefore potential

DMY is an important factor in determining the nitrogen need of a given crop.

100 Grain weight (g)

The result shows that crop rotation was not significant ($P > 0.05$) on 100 grain weight but the effects of tillage and nitrogen rates were significant (Table 3.4). Conventional tillage gave higher 100 grain weight than reduced tillage. Nitrogen rate was significant ($P < 0.05$) with 90 kg N ha⁻¹ producing

higher 100 grain weight than 60 kg N ha⁻¹, 100 grain weight between 90 kg N ha⁻¹, 60 kg N ha⁻¹ and 0 kg N ha⁻¹. However, there was no significant difference ($P>0.05$) in

Table 3.3: Effect of crop rotation, tillage and nitrogen rate on maize total dry matter yield (g) (stover yield).

Treatment	Weeks after sowing				
	4	6	8	10	12
Rotation					
Maize	3.87	13.17 ^b	38.68 ^c	52.55 ^b	54.54 ^b
Cowpea	4.02	15.30 ^a	66.89 ^a	80.76 ^a	82.75 ^a
Soybean	4.10	14.94 ^{ab}	58.05 ^b	71.92 ^a	73.91 ^a
SE±	0.14	1.10	8.24	8.24	8.24
Tillage					
Reduced	3.93	13.41 ^b	37.15 ^b	51.01 ^b	53.01 ^b
Conventional	4.06	15.53 ^a	71.94 ^a	85.80 ^a	87.80 ^a
SE±	0.22	1.65	12.36	12.36	12.36
Nitrogen rate (kg N ha⁻¹)					
0	1.88 ^d	7.99 ^d	29.80 ^c	43.67 ^c	45.66 ^c
30	4.09 ^c	12.38 ^c	46.41 ^{bc}	60.27 ^{bc}	62.27 ^{bc}
60	4.78 ^b	15.30 ^b	56.88 ^b	70.75 ^b	72.74 ^b
90	5.24 ^a	22.21 ^a	85.08 ^a	98.94 ^a	100.94 ^a
SE±	0.11	0.83	6.18	6.18	6.18
Interaction					
Tillage*Rotation	NS	NS	NS	NS	NS
Tillage*N rate	NS	NS	NS	NS	NS
Rotation*N rate	NS	NS	NS	NS	NS
Tillage*Rotation*N rate	NS	NS	NS	NS	NS

Means in the same column and under the same factor, followed by different letters are significantly different at $P<0.05$ level of probability. NS = Not Significant.

and 30 kg N ha⁻¹. The Interaction level was not significant ($P>0.05$) to 100 grain weight throughout the period of the experiment. Conventional tillage helps to optimize conditions for germination, seedling establishment and crop growth and development (Majiyabo 2014), hence conventional tillage had higher 100 grain weight than the reduced tillage.

Nitrogen fertilization at 90 kg N ha⁻¹ is closer to the fertilizer recommended rate of maize at 120 kg N ha⁻¹ than 60 kg N ha⁻¹, 30 kg N ha⁻¹ or 0 kg N ha⁻¹, hence the 90 kg N ha⁻¹ rate had higher 100 grain weight than the other rates in the experiment. From the results, it is clear that N fertilization was necessary because there was a clear difference between application of fertilizer

and not applying fertilizer. This collaborates with the findings of Erisman *et al.* (2005) and Freney (2005) which states that fertilizer application has by far the most important effects in terms of increasing crop production such as in maize.

Table 3.4: Long term effect of crop rotation, tillage and nitrogen rate on 100 grain weight and grain yield of maize.

Treatment	100 grain weight (g)	grain yield (kg/ha)
Rotation		
Maize	20.62	2327 ^b
Cowpea	21.16	2791 ^{ab}
Soybean	21.73	3263 ^a
SE±	0.80	931
Tillage		
Reduced	20.58 ^b	2186 ^b
Conventional	21.76 ^a	3401 ^a
SE±	1.20	1396
Nitrogen rate (kg N ha⁻¹)		
0	19.60 ^b	1610 ^b
30	21.48 ^a	2134 ^b
60	21.53 ^a	3564 ^a
90	22.07 ^a	3866 ^a
SE±	0.60	698
Interaction		
Tillage*Rotation	NS	*
Tillage*N rate	NS	NS
Rotation*N rate	NS	NS
Tillage*Rotation*N rate	NS	NS

Means in the same column and under the same factor, followed by different letters are significantly different at $P < 0.05$ level of probability. NS = Not Significant. * = Significant.

Grain yield (kg/ha)

The effects of crop rotation, tillage and nitrogen rates on maize grain yield per hectare are shown in Table 3.4. The effects were significant ($P < 0.05$) for crop rotation, tillage practices and nitrogen rate. Maize in rotation with soybean had the highest grain

yield, followed by maize in rotation with cowpea, while continuous maize gave the lowest grain yield. Maize in rotation with soybean and maize in rotation with cowpea had statistically similar effect on maize grain yield, while conventional tillage had higher grain yield per hectare than reduced tillage. Nitrogen rate also had a significant ($P < 0.05$) effect on maize yield with 90 kg N ha⁻¹ and 60 kg N ha⁻¹ resulting in higher grain yield than 30 kg N ha⁻¹ and 0 kg N ha⁻¹. The

effects of 90 kg N ha⁻¹ and 60 kg N ha⁻¹ on grain yield were not significantly different from each other, while 30 kg N ha⁻¹ and 0 kg N ha⁻¹ were also significantly at par in grain yield ($P>0.05$). The interaction was significant ($P<0.05$) only between crop rotation and tillage practices.

The result of crop rotation with legumes – cereals produced higher grain yield than cereal – cereal rotation, this is because studies have shown that legume-cereal rotation produce relatively higher grain yields than either crop grown alone (Dapaah *et al.*, 2003 and Eche, 2011), hence soybean and cowpea giving the highest grain yield.

The conventional tillage produced higher grain yield than the reduced, this is because

tillage interacts with nitrogen and phosphorus rates positively to influence higher grain yield than the average of 2.0 t/ha normally obtained by farmers field in the Guinea savanna area of Nigeria (Chude, 1996 ; Ebirere, 2013).

The result of the interaction between crop rotation and tillage on maize grain weight

per hectare shows that the interaction was significant (Figure 1), with maize in rotation with soybean under conventional tillage having the highest grain yield, followed by continuous maize under conventional tillage which was equal to maize in rotation with cowpea under conventional tillage. Maize in rotation with cowpea under reduced tillage was equal to maize in rotation with soybean under reduced tillage, while continuous maize under reduced tillage had the lowest grain yield.

Crop rotation with legumes and cereals under conventional tillage produced higher grain yield because studies have shown that cultivation practices such as tillage and crop rotation can modify soil organic matter content, thereby influencing the nutrient content of the soil (Melero *et al.*, 2009), and influencing grain yield, hence the difference in crop rotation and tillage practices.

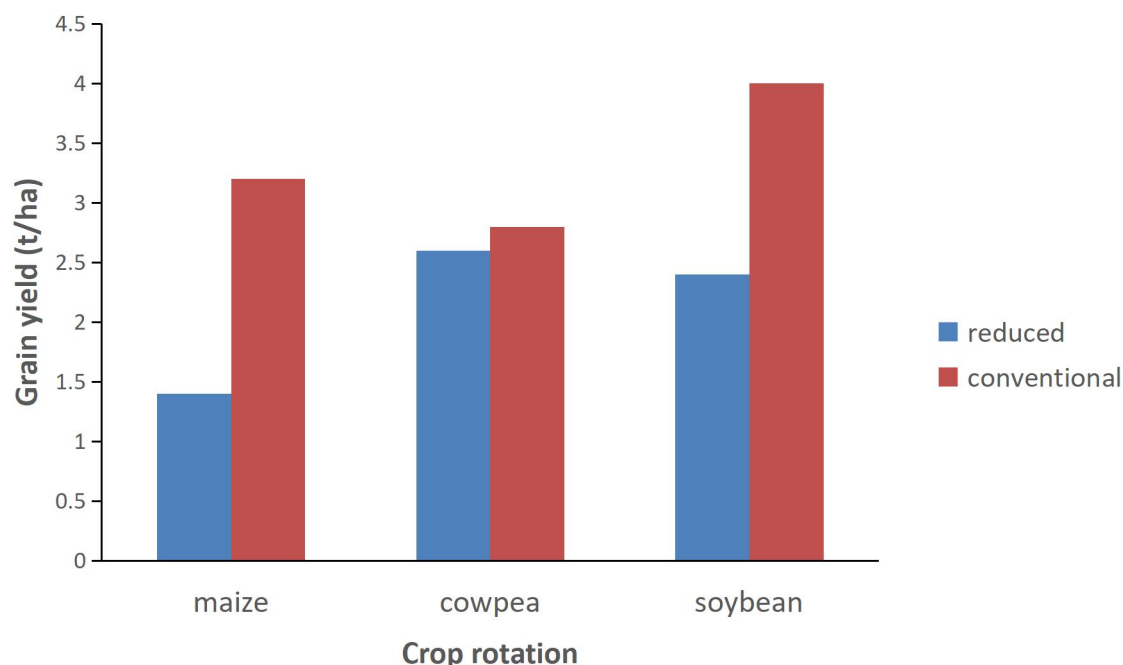


Figure 1: Interaction of tillage and crop rotation on maize grain yield

SUMMARY AND CONCLUSION

Summary

The result shows that crop rotation and tillage had no effect ($P>0.05$) on DMY at 4WAS but a significant ($P<0.05$) effect was observed from 6 WAS to 12 WAS, the result was significant across all the period for N rates. The result of grain yield per hectare was significantly affected by crop rotation, tillage practices and N rates, maize in rotation with soybean had the highest grain yield under conventional tillage at 90 kg N ha⁻¹.

Conclusion

Crop rotation practices with legumes and cereals under conventional tillage practices at 60 kgN/ha over a long period of time (e.g 12 years) improved maize grain and stover yield respectively.

Recommendation

Due to the low fertility status of the soils in the Northern Guinea savanna of Nigeria that leads to farmer's not applying fertilizers at the recommended rates, also the continuous increase in cost of all food items in the country necessitates this research. This research therefore recommends the use of legumes - cereal rotation such as maize in rotation with cowpea and maize in rotation with soybean, under conventional tillage and the application of N fertilizer at 90 kgNha⁻¹ by farmers will improve Stover yield over a long period of time. Also, from the study, legumes - cereal rotation such as maize in rotation with soybean under conventional tillage and the application of N fertilizer at 60 kg N ha⁻¹ is recommended to farmers for higher grain yield of maize in the northern Guinea savanna (Alfisol) of Nigeria.

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ENHANCING SUGARCANE PRODUCTIVITY THROUGH INTERCROPPING IN THE NIGERIAN SAVANNA: AGRONOMIC, SOIL, AND ECONOMIC PERSPECTIVES

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ABSTRACT

Optimizing sugarcane (*Saccharum officinarum* L.) productivity through sustainable soil and weed management remains a major challenge in the Nigerian Sudan Savanna. This study evaluated the effects of intercropping on soil physicochemical properties, weed dynamics, and industrial sugarcane productivity at Badeggi, Nigeria, during the 2018 and 2019 seasons. The experiment was arranged in a randomized complete block design with three replications, comparing sole sugarcane with sugarcane intercropped with dwarf sorghum, sesame, soybean, and groundnut. Results showed that sugarcane + groundnut and sugarcane + soybean significantly ($p < 0.05$) increased soil organic carbon and total nitrogen relative to sole cropping. These systems also reduced weed biomass through improved canopy cover. The sugarcane + groundnut intercrop performed best, achieving 83.3% germination, higher tillering, and a stalk girth of 3.5 cm. It also recorded superior industrial quality and yield, with 21.0% brix and 87.6 t ha⁻¹ cane yield. Economic analysis indicated that sugarcane + groundnut was most profitable, with a benefit–cost ratio of 2.14 compared to 1.15 for sole sugarcane. Intercropping sugarcane with groundnut is therefore an effective agroecological strategy for improving soil fertility, suppressing weeds, and increasing productivity and profitability in the Nigerian Savanna.

Keywords: *Saccharum officinarum*, Intercropping, Soil Fertility, Sugar quality, Weed Suppression, Benefit-Cost Ratio.

Introduction

Sugarcane (*Saccharum officinarum* L.), a high-value C₄ perennial grass of the Poaceae family, remains a cornerstone of the global agricultural economy, accounting for approximately 75% of the world's sucrose production. In Nigeria, the crop serves as a vital industrial feedstock, providing direct and indirect employment to over a million people while contributing significantly to the national exchequer through both raw sugar

production and its emerging role in renewable bioethanol energy systems (Bassey *et al.*, 2024a; Okoro *et al.*, 2024). Despite a vast estimated cultivation potential of over 500,000 hectares and a theoretical yield capacity exceeding three million metric tons, a persistent gap remains between domestic production and national demand (Bassey *et al.*, 2021; 2024b). This shortfall is driven by a rapidly increasing population, food scarcity, and a heavy reliance on sugar importations, which

underscores the urgent need for a transition toward more self-sufficient and intensive production models.

The current stagnation in Nigerian sugarcane output is largely attributed to the limitations of conventional monocropping systems, which are increasingly viewed as ecologically and economically exhaustive. These systems lead to significant soil nutrient depletion and are struggling to keep pace with the demands of modern farmers due to low yield potentials and the shrinking availability of cultivable land caused by urbanization and industrialization (Pang *et al.*, 2021a; 2021b). A critical but often overlooked inefficiency in sugarcane agronomy is the crop's long juvenile period of 100-120 days and its wide row spacing (1.0-1.5 m). This creates a substantial temporal and spatial "vacuum" during the early growth stages, where inter-row spaces remain fallow, leading to wasted solar radiation, moisture loss, and increased weed infestation (Raza *et al.*, 2024).

Intercropping presents a strategically viable solution to these challenges by utilizing these vacant inter-spaces to grow short-duration companion crops. Because sugarcane possesses an innate ability to compensate for early tiller loss and has a slow initial growth rate, it offers an ideal niche for the integration of cereals, legumes, vegetables, or spices without compromising the primary crop's development (Kumar *et al.*, 2025). Evidence from major sugar-producing nations like Egypt and India suggests that intercropping sugarcane with crops such as soybean or potato significantly enhances total land equivalent ratios, soil properties, and final sugar quality (Singh *et*

al., 2021; Zhang *et al.*, 2024). These systems ensure the judicious use of resources, provide an additional income stream for smallholder farmers, and act as a natural mechanism for weed suppression.

Despite extensive global evidence supporting sugarcane intercropping, most existing studies have focused on smallholder or chewing cane systems in Asia and Latin America, with limited emphasis on industrial sugarcane under sub-Saharan African conditions. In Nigeria, available recommendations are largely generalized and lack empirical validation for savanna agro-ecologies, where soil degradation, weed pressure, and resource constraints differ markedly from other regions. Moreover, previous studies have often examined intercropping effects in isolation, with little integration of soil physicochemical properties, weed dynamics, sugar quality indices (e.g., brix and purity), and economic performance within a single experimental framework. This creates a critical knowledge gap in identifying holistic, productivity-driven intercropping systems suitable for industrial sugarcane production in the Nigerian savanna.

Accordingly, this study aims to: (i) evaluate the effects of selected intercropping systems on soil physicochemical properties and nutrient status; (ii) assess their influence on weed dynamics and suppression efficiency; (iii) determine their impact on sugarcane growth, yield, and industrial quality parameters; and (iv) analyze the economic viability of these systems under Nigerian savanna conditions. It is hypothesized that legume-based intercropping systems will improve soil fertility, reduce weed pressure,

and enhance both yield and profitability compared to sole sugarcane.

Materials and Methods

Experimental Site and Environmental Conditions

Field trials were conducted during the 2018 and 2019 wet and dry seasons at the upland sugarcane experimental field of the National Cereals Research Institute (NCRI), Badeggi, Nigeria (Lat. 9° 45' N, Long. 6° 07' E and 89 m above sea level). The site is located within the Southern Guinea Savanna agro-ecological zone. Environmental conditions during the study periods were characterized by a total rainfall of 1504.1 mm in 2018 and 1045.4 mm in 2019. The mean air temperature ranged from 35 to 38°C in 2018 and 34 to 36°C in 2019. To ensure optimal crop establishment in May, natural rainfall was supplemented with irrigation.

Soil Sampling and Laboratory Analysis

Baseline composite soil samples were taken from ten spots along a diagonal and at harvest from each treatment plot from 0 to 15 cm depth, and subjected to routine analyses. Particle size distribution was determined using the Bouyoucos hydrometer method as described by Gee and Or (2002). Soil pH was measured in a 1:2 soil–water ratio using a digital electronic pH meter. The soil organic carbon was determined via the Walkley-Black dichromate wet oxidation method (Nelson & Sommers, 1996). Total nitrogen was assessed using the micro-Kjeldahl digestion method (Bremner & Mulvaney, 1982). The available phosphorus was extracted using the Olsen method while exchangeable potassium was determined through flame photometry (Okalebo *et al.*, 2002).

Treatments and Experimental Design

The experiment was laid out in a Randomized Complete Block Design (RCBD) with three replications. The treatments consisted of sugarcane intercropped with four companion crops: Dwarf Sorghum, Sesame, Soybean, and Groundnut alongside a Sole Sugarcane as control. The gross plot size was 6 x 5 m (30 m²) consisting of 5 sugarcane rows, and four rows of component crops, while net plot size was 3 x 5 m (15 m²). Sugarcane was planted at 1.5 m inter – row spacing a month before the component species were planted in between at 0.75 m inter – row spacing.

Cultural Practices

Before cultivation, the vegetative cover of the experimental site was manually cleared, ploughed and harrowed with a tractor. Thereafter, the land was marked out into plots with bunds at the edges for water retention. Six-month-old healthy sugarcane stalks were used as planting material, cut into three-bud setts and planted continuously end-to-end in shallow sunken beds at an inter-row spacing of 1.5 m. Component species were inter-sown one month later at an inter-row spacing of 0.75 m.

NPK fertilizer was applied at a rate of 150 kg N, 60 kg P₂O₅ and 90 kg K₂O in two equal splits: at planting and at 10 weeks after planting (WAP). Rainfall was supplemented with irrigation in May which was the establishment of the rainy season.

Data collection and Measurements

Weed Dynamics

Weed samples were collected using a 1×1 m² quadrat at 3, 6, and 9 months after planting (MAP). Seedlings were clipped at soil level, identified according to Akobundu *et al.* (2016), and oven-dried at 80°C to a constant weight to determine weed dry biomass

Growth Parameters

Sugarcane germination (%) was taken by counting the number of sprouted buds per plot at three weeks after planting and expressed as follows:

$$\text{Germination percentage} = \frac{\text{Number of sprouted buds per net plot}}{\text{Total number of buds on the setts planted per plot}} \times 100$$

Number of tillers per plot was taken by counting the number of axillary tillers per plot at two months after planting. Plant height was measured using meter rule from the base of the plant to the top of the uppermost leaf at 3 and 6 MAP and expressed in centimeters.

Stalk height was measured using meter rule from the base of the plant to the uppermost node at 6, 9 and 12 MAP and expressed in centimeters.

Stalk girth was measured using digital vernier caliper from the middle of the plant at 8, 10 and 12 MAP and expressed in centimeters.

Yield and Quality Parameters

At 12 MAP, the number of sugarcane stools and millable stalks per stool were recorded. Stalk (cane) yield was determined from the net plot, tied into bundles, and weighed (tons ha⁻¹). Sugar quality was assessed via Percent Brix, measured using a hand refractometer at the base of the plant at 9 and 12 MAP.

Economic return

BCR values were derived from the original Net Farm Income data to reflect investment efficiency. Note: Figures for Costs and Returns are based on prevailing market prices during the 2018 and 2019 seasons at Badeggi, Nigeria.

$$\text{BCR} = \frac{\text{Total Gross Returns}}{\text{Total Variable Costs}}$$

In this analysis, a BCR > 1.0 indicates that the system is profitable

Statistical Analysis

All data generated were subjected to analysis of variance (ANOVA) using SAS version 9.0 statistical package. Treatment means were compared using Duncan Multiple Range Test at 5% level of probability.

Results

Soil physical and chemical characterization

The soil at the experimental site was classified as sandy loam in both years (Table 1). Sand content increased from 722 g kg⁻¹ in 2018 to 765 g kg⁻¹ in 2019, while silt increased from 135 to 156 g kg⁻¹. Clay content decreased from 143 to 72 g kg⁻¹ over the same period.

Soil pH increased from 5.80 in 2018 to 6.40 in 2019. Organic carbon rose from 2.37 to 3.45 g kg⁻¹, while total nitrogen increased from 0.06 to 0.33 g kg⁻¹. Available phosphorus increased slightly from 20.29 to 23.15 mg kg⁻¹.

Exchangeable cations also increased between years: Ca (2.48–4.18 cmol kg⁻¹), Mg (1.38–3.68 cmol kg⁻¹), K (0.16–0.30 cmol kg⁻¹), and Na (0.09–0.22 cmol kg⁻¹). Exchangeable acidity remained relatively stable (1.03–1.07

Table 1: Baseline soil physical and chemical properties of the Experimental fields

Soil properties	2018	2019
Physical		
Sand (g kg ⁻¹)	722	765
Silt (g kg ⁻¹)	135	156
Clay (g kg ⁻¹)	143	72
Textural class	Sandy loam	Sandy loam
Chemical		
pH (H ₂ O)	5.80	6.40
Organic Carbon (g kg ⁻¹)	2.37	3.45
Total Nitrogen (g kg ⁻¹)	0.06	0.33
Available Phosphorus (mg kg ⁻¹)	20.29	23.15
Exchangeable bases (cmol kg⁻¹)		
Ca ⁺⁺	2.48	4.18
Mg ⁺⁺	1.38	3.68
K ⁺	0.16	0.30
Na ⁺	0.09	0.22
Exchangeable acidity	1.03	1.07
ECEC	5.14	9.45

Analyzed at National Cereals Research Institute Laboratory

LSD – Least significant difference

cmol kg⁻¹), while effective cation exchange capacity (ECEC) increased from 5.14 to 9.45 cmol kg⁻¹.

Weed biomass (g m⁻²)

Intercropping significantly ($p < 0.05$) affected weed dry biomass across sampling periods (Table 2). In 2018 and 2019, sugarcane intercropped with groundnut and soybean recorded lower weed biomass at 3 and 6 months after planting (MAP) compared to sole sugarcane.

At 9 MAP, the lowest weed biomass was observed in the sugarcane + soybean treatment (0.20 g m⁻²), followed by sugarcane + groundnut. In contrast, sugarcane + sesame and sole sugarcane consistently recorded higher weed biomass across both years.

Growth parameters

Germination count (%) was significantly ($p < 0.05$) different between the sugarcane intercrops in both year of study (Table 3). Sugarcane intercropped with groundnut significantly ($p < 0.05$) resulted in higher germination percentage compared to other intercrops in seasons (Table 3). Furthermore, the Sugarcane intercropped with groundnut consistently produced more tillers than the other intercrops in each year of study (Table 3). Taller sugarcane were produced under sugarcane intercropped with groundnut than the rest intercrops combination in both seasons (Table 3). Stalk height and internode length were significantly ($p < 0.05$) different between the sugarcane intercrops in both year

Table 2: Sugarcane intercropping effects on Weed biomass (g m⁻²)

Treatments	Weed biomass (g m ⁻²)					
	Months after planting (MAP)					
	3		6		9	
	2018	2019	2018	2019	2018	2019
Sugarcane Sole	0.68	0.60	0.58	0.50	0.47	0.41
Sugarcane + Dwarf sorghum	0.64	0.63	0.52	0.51	0.33	0.38
Sugarcane + Sesame	0.71	0.63	0.62	0.54	0.39	0.42
Sugarcane + Soybean	0.62	0.60	0.51	0.51	0.20	0.20
Sugarcane + Groundnut	0.61	0.63	0.53	0.48	0.33	0.33
LSD (0.05)	0.1	0.1	0.2	0.1	0.2	0.1

LSD – Least significant difference

of study (Table 3). Sugarcane + Groundnut (21.0%) across both years. This treatment

Table 3: Intercropping effects on some sugarcane parameters and Soil C/ N content

Treatments	Germination count (%)		Tiller count plot ⁻¹		Plant height (cm)	Stalk height (cm)		Soil C (g kg ⁻¹)		Soil N (g kg ⁻¹)		
	2018	2019	2018	2019		2018	2019	2018	2019	2018	2019	
Sugarcane Sole	53.8	66.7	36.5	49.3	150.4	176.4	119.9	150.2	2.41	3.23	0.12	0.17
Sugarcane + Dwarf sorghum	50.5	67.0	35.8	47.7	144.8	184.5	118.6	155.3	2.44	3.36	0.15	0.19
Sugarcane + Sesame	50.9	70.3	36.3	58.7	141.7	176.1	119.5	160.2	2.45	3.37	0.15	0.18
Sugarcane + Soybean	54.0	72.0	39.3	64.7	154.2	190.6	127.4	166.9	2.47	3.39	0.16	0.19
Sugarcane + Groundnut	59.0	83.3	43.2	67.0	164.8	198.3	136.3	175.5	2.51	3.45	0.19	0.24
LSD (0.05)	5.8	5.2	6.5	3.9	15.0	4.4	14.8	3.4	0.02	0.01	0.01	0.02

intercropping had consistently higher soil C and N than other intercrops in both years of study (Table 3).

Yield Components, Sugar Quality, and Economic Profitability

Intercropping significantly ($p < 0.05$) influenced yield components and sugar quality (Table 4). The sugarcane + groundnut system recorded the highest stalk girth (3.5 cm) and brix content (up to

also produced the highest number of millable canes and stools per plot, resulting in the highest cane yields (87.6 and 85.8 t ha⁻¹ in 2018 and 2019, respectively).

Economic analysis showed that intercropping systems had higher benefit–cost ratios (BCR) than sole sugarcane. The sugarcane + groundnut system recorded the highest BCR (2.14), compared to 1.15 for sole sugarcane.

Table 4: Sugarcane intercropping effects on some yield parameters and profitability of sugarcane

LSD – Least significant difference

Treatments	Stalk girth (cm)		Brix (%)		Millable cane Plot ⁻¹		Stools/Plot		Cane yield (t ha ⁻¹)		Net farm income (Naira ha ⁻¹)	
	2018	2019	2018	2019	2018	2019	2018	2019	2018	2019	2018	2019
Sugarcane Sole	3.1	2.7	14.9	18.1	73.9	94.7	15.9	14.3	66.1	59.9	2577	3204.7
Sugarcane + Dwarf sorghum	2.9	2.7	14.5	18.2	71.5	94.9	17.6	15.3	71.7	66.4	5493	5750.0
Sugarcane + Sesame	3.2	2.8	15.5	19.2	80.0	98.7	16.7	17.0	72.1	74.2	4220	8462.0
Sugarcane + Soybean	3.1	2.9	15.8	20.4	83.7	100.0	17.2	16.6	81.3	77.2	9280	9758.1
Sugarcane + Groundnut	3.5	3.5	18.9	21.0	90.5	119.1	19.7	20.0	87.6	85.8	16347	13261.3
LSD (0.05)	0.3	0.2	1.2	0.4	2.5	2.4	3.5	1.8	12.8	0.9	6401.8	1269.7

Discussion

Soil Physicochemical Dynamics and Nutrient Cycling

The initially low nutrient status of the Badeggi soil reflects a widespread condition across Sub-Saharan Africa, where continuous cultivation and limited organic matter inputs have resulted in progressive nutrient mining (Gana, 2013). The observed increases in soil organic carbon (SOC), total nitrogen (STN), and exchangeable cations following intercropping indicate a measurable improvement in soil fertility status, suggesting that diversified cropping systems can partially reverse this decline. Similar improvements in SOC and nitrogen under legume-based intercropping have been reported in Nigerian savanna systems

(Akpan *et al.*, 2023), reinforcing the suitability of such systems under local agro-ecological conditions.

The increase in soil pH toward near-neutral levels further supports enhanced nutrient availability, particularly for phosphorus and base cations, which are often limited under acidic conditions (Mamouda *et al.*, 2021). The substantial rise in effective cation exchange capacity (ECEC) also indicates improved nutrient retention, likely linked to increased organic matter content. This aligns with findings from Basumatary (2021), who reported that organic matter accumulation significantly enhances soil buffering capacity and nutrient-holding potential.

Although the increase in sand content

suggests a potential risk of nutrient leaching, the concurrent rise in SOC appears to mitigate this effect by improving aggregate stability and moisture retention. The higher SOC and STN observed in sugarcane + groundnut and sugarcane + soybean systems can be attributed to biological nitrogen fixation and residue incorporation, which enhance nutrient cycling. Comparable results have been documented in intercropping systems in India and China, where legume integration improved soil fertility through gradual mineralization and sustained nutrient release (Bassey *et al.*, 2019b; Yousra *et al.*, 2025). These findings highlight the role of legume-based systems in stabilizing soil fertility under intensive production.

Weed Suppression Mechanisms

The significant reduction in weed biomass observed under sugarcane–legume intercropping systems demonstrates the effectiveness of crop diversification as a biological weed management strategy. This suppression can be primarily attributed to resource competition and canopy-mediated shading, which reduce light availability at the soil surface and limit weed emergence. Similar observations have been reported in cereal–legume intercropping systems, where rapid canopy closure significantly reduced weed density and biomass (Khamare *et al.*, 2022).

In addition to physical suppression, the role of below-ground interactions may also be important. Legumes can alter soil microbial communities and nutrient dynamics, creating conditions less favorable for weed establishment. Some studies have also

suggested mild allelopathic effects in legume-based systems, although this mechanism may vary depending on species and environmental conditions (Bassey *et al.*, 2019a).

The relatively higher weed biomass observed in sole sugarcane and sugarcane + sesame treatments highlight the limitation of slower canopy development in these systems. This finding is consistent with previous studies in tropical agro-ecosystems, where wider row spacing and delayed crop establishment increase weed pressure. Overall, the results confirm that intercropping, particularly with fast-establishing legumes can serve as an effective and sustainable alternative to chemical weed control in sugarcane production systems.

Sugarcane Performance and Economic Efficiency

The improved germination, tillering, and growth performance of sugarcane under the groundnut intercrop indicate a strong facilitative interaction between the component crops. This is largely driven by enhanced nitrogen availability through biological nitrogen fixation and subsequent mineralization, which improves early crop vigor and stand establishment. Similar yield advantages of sugarcane–legume systems have been reported in both Nigerian and international studies (Pang *et al.*, 2022), suggesting that such interactions are consistent across agro-ecological zones.

The observed increases in stalk girth and brix content further indicate that intercropping did not compromise, but rather enhanced, industrial quality. This

may be linked to improved soil structure, nutrient availability, and water-use efficiency under legume integration, all of which contribute to better assimilate partitioning and sugar accumulation (Afolabi *et al.*, 2017). These findings are consistent with reports from India and Egypt, where sugarcane intercropped with legumes produced higher juice quality and cane yield compared to monocropping systems.

From an economic perspective, the superiority of the sugarcane + groundnut system (BCR = 2.14) highlights the practical relevance of intercropping for smallholder farmers. The increased profitability is not only a function of higher cane yield but also the additional income generated from the intercrop. This supports the concept of complementarity, where efficient resource sharing enhances overall system productivity. Similar economic advantages have been documented in intercropping studies across South Asia and Africa, where legume integration reduced input costs—particularly nitrogen fertilizers—while increasing total farm returns (Chogatapur *et al.*, 2017; Nadeem *et al.*, 2020).

Beyond plot-level productivity, these findings have broader implications for sustainable intensification in Nigeria. Intercropping offers a viable pathway to increase output per unit land area while improving soil health and reducing reliance on external inputs. This is particularly relevant in the Nigerian savanna, where land pressure, soil degradation, and input costs remain major constraints to

agricultural productivity.

Conclusion

This study demonstrates that intercropping industrial sugarcane with arable crops, particularly groundnut, is a highly viable strategy for the Nigeria Sudan Savannah. The practice significantly enhances soil fertility through the enrichment of SOC and STN, effectively suppresses weed competition via canopy shading, and improves both the yield and brix quality of the sugarcane.

From an economic perspective, the Sugarcane + Groundnut system offers a superior alternative to monocropping, providing a robust Benefit-Cost Ratio of 2.14. Adopting this sustainable approach can significantly contribute to narrowing the national sugar production gap and reducing dependency on imports. It is recommended that farmers and sugar estates in the Nigerian Savannah adopt the Sugarcane + Groundnut intercropping model

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OPTIMIZING ARBUSCULAR MYCORRHIZAL FUNGI INOCULANT: THE ROLE OF CARRIER MATERIALS IN MANAGING ANTHRACNOSE DISEASE IN TOMATO.

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ABSTRACT

Tomatoes are widely recognized for their economic importance and their vital role in supplying essential nutrients to humans. However, tomato cultivation faces several challenges, one of which is anthracnose disease, caused by Colletotrichum coccodes, which affects a range of hosts, including tomato, pepper, pumpkin, and papaya. This disease poses a significant constraint on tomato production, prompting the search for sustainable alternatives to chemical fungicides.

This review compiles existing research to critically evaluate the role of different carrier materials in modulating AMF performance and, consequently, in managing anthracnose disease by promoting plant growth, enhancing defense enzyme activity, and improving overall plant resilience. Arbuscular mycorrhizal fungi (AMF) inoculants have gained attention as an effective biocontrol strategy due to their ability to improve nutrient uptake and activate systemic defense mechanisms in tomato plants. However, biofertilizers have a limited shelf life, and microbial efficacy often diminishes during storage and application. Developing a suitable inoculant formulation is a complex, multi-step process that involves selecting one or more microbial strains and incorporating them into an appropriate carrier to ensure protection against environmental stress during storage and successful establishment in the soil. Carriers, can be organic (e.g., compost, biochar) or inorganic (e.g., sand, vermiculite), directly impact AMF survival and efficacy. Organic carriers enhance nutrient availability and microbial activity, whereas inorganic carriers provide stability and extend shelf life. An ideal carrier should offer high water-holding capacity, proper aeration, long-term viability, and compatibility with AMF. Ultimately, optimizing carrier materials is crucial for effectively integrating AMF inoculants into sustainable tomato production systems. This approach not only helps reduce disease incidence but also minimizes environmental impact, offering a promising alternative to chemical control methods.

Keywords: *Arbuscular mycorrhiza fungi, Carriers, Anthracnose disease, Tomato*

Background Information

Tomatoes (*Solanum lycopersicum* L.) are the most frequently cultivated and consumed vegetables in the world (Wlodarczyk, 2022).

They are regarded as a staple food crop for all sectors of the economy, regardless of whether

developed or underdeveloped. Tomato originated from Western South American specifically in Peru, Bolivia and Ecuador (Peralta *et al.*, 2008). Tomatoes were introduced to Africa during the 16th and 17th centuries through European colonization and trade.

They are considered part of a healthy diet because they are low in fat and contain no harmful cholesterol. Tomatoes have high levels of nutrients such as vitamin A, ascorbic acid, potassium, and folate (Chaudhary *et al.*, 2018). The ultimate significance of the vegetable crop is enunciated globally by the large area under cultivation of almost 4.2 million hectares yielding 100 million tons per year (Chandrasekaran *et al.*, 2021). Tomato crops occupied roughly 845 thousand ha in Nigeria in 2021, with a production of 3.6 million tons (FAO, 2021).

In spite of its significance, tomato cultivation faces numerous challenges, one of these is the anthracnose disease of tomato caused by (*Colletotrichum coccodes*) species on a diverse variety of hosts including pepper, pumpkin, papaya and tomato (Ridzuan *et al.*, 2018). *Colletotrichum coccodes* is a prevalent soil-borne disease that causes large economic losses of up to 50 % in some African countries (Ibrahim *et al.*, 2011). It is a hemi biotrophic pathogen that causes root rots and fruit decays in the field during rainy weather (Sanoubar and Barbanti, 2017), as well as during pre- and postharvest ripening and storage (Sonawane and Shinde, 2021). The typical lesions on ripe fruits are dark spherical with concentric circles ring, black spores, and depressed, resulting in lower marketable fruit quality

(Opeyemi *et al.*, 2018). Application of synthetic chemical is considered the most effective approach for controlling *Colletotrichum coccodes*. The use of chemical pesticides has a negative impact on the environment, human health, soil microbes and nontarget toxicity urging the exploration of sustainable alternatives (Hewedy *et al.*, 2020). Farmers are switching to ecofriendly biological agents (endophytic fungi) over agrochemicals due to consumer environmental awareness, natural resource depletion, and health concerns (Alori and Babalola, 2018). Arbuscular mycorrhizal fungi contribute to plant growth via the production of defense-related enzymes that inhibit or eliminate harmful microbe invasion (Adedayo and Babalola, 2023). Mycorrhizal fungi have been shown in studies to improve defence mechanisms against soil-borne diseases (Kumari *et al.*, 2019; Nguvo and Gao, 2019; Dreischoff, 2020). In this context, AMF are regarded as highly promising "biological fertilizers" and "biological pesticides" (Wilkes, 2021; Anand *et al.*, 2022; Weng *et al.*, 2022). Previous study showed that inoculating AMF significantly reduced the damage of anthracnose on tea seedlings by reducing the lesion area by 35.29 % compared to that of the control (Chen *et al.*, 2023). Research found that the AM fungus significantly reduced the content of malondialdehyde of plants and increased the content of proline, thus reducing the degree of disease stress in *Colletotrichum lentis* (common vetch) (Ding *et al.*, 2020). However, the success of AMF-based biofertilizers is highly dependent on the formulation process, especially on the

selection of carrier materials that protect microbial viability during storage and application (Khan *et al.*, 2023).

Tomato crop

Tomato is one of the most popularly grown vegetables worldwide serving as source of minerals and vitamins. Tomato contains huge number of phytochemicals, carotenoids, polyphenols and Vitamins. It remains second most important vegetable crop cultivated worldwide (Ilesanmi *et al.*, 2023). In Nigeria, about one million hectares of total land area is used for its cultivation and this crop makes up about 18 % of the average daily consumption of vegetables in Nigerian homes (Swamy, 2023). Nigeria ranks second to Egypt in Africa and 13th globally in tomato production (Nishizono *et al.*, 2023). Tomato fruits, aside from being tasty, are healthy as a good source of vitamins A and C. Vitamin A is important for bone growth, cell division and differentiation, for helping in the regulation of immune system and maintaining surface linings of eyes, respiratory, urinary and intestinal tracts. Vitamin C is important in forming collagen, a protein that gives structures to bones, cartilage, muscle and blood vessels. It contains lycopene the substance which gives the reddish colouration to tomato, flavonoid antioxidant together with carotenoids which protect the body cells and other structures in the human body (Theu, 2008; Labbo *et al.*, 2021).

Anthracnose and its impact on tomato crop

Anthracnose is a significant tomato disease, is brought on by fungi belonging to the

genus *Colletotrichum* (Yarmeeva *et al.*, 2023). Additionally, it causes lesions that damage the appearance and consumption of tropical fruits (Vilaplana *et al.*, 2018). Root rots and fruit deterioration in the field during wet seasons are caused by this hemi biotrophic pathogen (Sanoubar and Barbanti 2017). Infection can speed up fruit ripening, give the fruit an unfavourable appearance, and, in more severe cases, induce fruit rot. On green fruit, the symptoms are uncommon, but on ripe fruit, they are severe and manifest as tiny, sunken, circular spots that can grow up to half an inch in diameter. The centre of older spots later becomes blackish. In extreme situations, spots may proliferate and additional rotting organisms may infiltrate anthracnose lesions to totally decompose fruit that has been infected. Because anthracnose spores may survive in soil and plant detritus, they can splash onto fruit when it rains a lot or even when water is sprayed overhead. Up to 80 % and over 50 % of plant and fruit losses in nurseries and the field, respectively, can be attributed to anthracnose (Higuera *et al.*, 2019).

Arbuscular Mycorrhizal Fungi (AMF)

Mycorrhizal associations involve symbiotic relationships between fungi from various taxonomic groups and the majority of plant species. However, plants within the Brassicaceae family, such as cabbage and mustard, typically do not form these mutualistic interactions. This lack of association is partly due to the presence of glucosinolates in Brassicaceae species, which can inhibit the colonization of AMF (Sharma *et al.*, 2023). Other families that also exhibit limited or no association with

Juncaceae (rushes), Urticaceae (nettle family) and Chenopodiaceae (beet family), Colonization variation in plant roots has divided mycorrhizae, which are mainly classified into two categories: Endomycorrhizae (Phylum Glomeromycota) and Ectomycorrhizae (Phyla: Basidiomycota, Ascomycota, and Mucoromycota).

Endomycorrhizae are further divided into arbuscular, orchid, and ericoid types (Salmeron-Santiago *et al.*, 2022). Arbutoid considers ectendomycorrhizae because they have both ericoid and ectomycorrhizae features. Mycorrhizal fungi are obligate symbionts, they rely entirely on their hosts plant for access to carbon as carbohydrates and lipids (Keymer and Gutjahr, 2018). With respect to abundance, arbuscular mycorrhizal fungi colonize a huge number of plant species (80–90 %), and only 10 % of plants form ectomycorrhizae. Both types play a significant role in sustainable agriculture and forestry (Nadeem *et al.*, 2017).

Classification of AMF

Kingdom: Fungi

Phylum: *Glomeromycota*

Class: *Glomeromycetes*

Order: *Glomerales*

Family: *Glomeraceae*

Genera: Examples include *Glomus*, *Rhizophagus*, *Funneliformis*, *Claroideoglomus*, and *Acaulospora*.

AMF as a biocontrol strategy

AMF Improves Plant Nutrition

AMF improved the uptake of mineral nutrients and water by host plants. The study found that the AMF extra-root mycelia

widely distributed in the soil intertwined to form a huge mycelium network, thereby expanding the absorption range of the root system for water and nutrients, especially phosphate and nitrate, and for different plants at the same time. Water and nutrients are redistributed so that plants have another effective water and nutrient passage to a certain extent (De la Rosa-Mera *et al.*, 2011). AMF and pathogens compete for photosynthetic products from the root system of the host plant, and when photosynthetic products are first utilized by AMF, the opportunity for pathogen acquisition is reduced, thereby limiting the growth and reproduction of pathogens (Kuila, and Ghosh, 2022). Mycorrhizae compensate the loss of root biomass and function caused by pathogenic infection by enhancing the absorption of nutrients and water by plants, thereby indirectly reducing the damage caused by pathogenic microorganisms and improving the disease resistance of host plants (Ma *et al.*, 2023a). Inoculation of tomatoes under *Fusarium oxysporum* stress can promote the absorption of K, N, P, Ca, Mn, Zn, and other elements), increase chlorophyll and soluble sugar content, and increase the number of branches and leaves of the plant. Enhanced biological activity indirectly improves the plant's tolerance to pests and diseases (Poveda *et al.*, 2019; Wang *et al.*, 2021; Liang *et al.*, 2021). A study found that the growth of olives damaged by *M. incognita* and *M. javanica* significantly improved after inoculation with AMF, and the biomass increased by 88.9 % (Eliott *et al.*, 2021).

Enhance Plant Growth

Arbuscular mycorrhizal symbiosis shows great promise for sustainable agriculture by enhancing plant nutrition, promoting mineral cycling, and stimulating growth (Chahal *et al.*, 2020). This beneficial interaction increases the levels of chlorophyll, carotenoids, and phenolics (Baslam *et al.*, 2013), were early improvements in chlorophyll and growth boost overall plant vigor and reproductive health, leading to increased yields. Research has consistently demonstrated that applying AM inoculants enhances plant growth and productivity across various crops (Elbon and Whalen, 2015; Hijri, 2016; Lu *et al.*, 2015).

Moreover, AMF colonization improves food quality by increasing the content of antioxidants, flavonoids, and vitamins (Chaudhary *et al.*, 2018; Lu *et al.*, 2015). As such, AMF can be employed as an amendment to improve soil fertility, crop productivity, and yield quality, aiding in the revitalization of agro-ecosystems (Chen *et al.*, 2018). Incorporating AM inoculated farming, with its proven benefits for plant growth and product quality, can therefore be a key component of sustainable agricultural practices (Bardgett and van der Putten, 2014).

Activate Defence Mechanism

Arbuscular mycorrhizal fungi are the most common, largest biomass and the most significant beneficial fungal group in the mycorrhiza, with a specific antagonistic or inhibitory effect on soil-borne pathogens (Allsup *et al.*, 2021). Studies have shown that AMF can regulate the formation of secondary metabolites in host plants by changing the morphology, thickening of the cell walls through lignification, improving

the physical and chemical properties of the rhizosphere environment, competing with pathogens for photosynthetic products and infection space, and activating disease resistance and defence systems in plants (Aseel *et al.*, 2019). Compared with the control without AMF inoculation, the disease index and incidence of *Ralstonia solanacearum* inoculated with *Glomus rhizogenes* and *Glomus mossie* were reduced by 9.7 % and 49.8 %, respectively (Aguk *et al.*, 2018). AMF induce systemic resistance in plants by activating defence mechanisms that restrict pathogen colonization. They have been extensively utilized as a biological control strategy to manage various phytopathogenic fungi (Lin *et al.*, 2021). Overaccumulation of phenolic acids, amino acids, indoles, and various intermediates in the oxylipin pathway have been observed in the leaves of mycorrhized tomato plants upon infection by *Botrytis cinerea*, suggesting that these metabolic changes in the leaves also contribute to the overall mycorrhiza-induced resistance (Sánchez-bel *et al.*, 2016).

Challenges in AMF inoculant formulation

Shelf Life

The shelf life of inoculant formulation can significantly impact its efficiency. Microbial formulation having shorter shelf lives may require more frequent application, while longer shelf lives can reduce the need for frequent reapplication. Storage conditions and packaging play a crucial role in determining the shelf life of any formulated product, as they act as protective barriers against harmful factors like oxygen, moisture, light, microbial contamination, and high temperatures that could degrade the

product (Teixidó *et al.*, 2022). Formulating microbial products is essential for maintaining their stability during storage and ensuring effective delivery to the target site. Without proper formulation, up to 90 % of the applied inoculant may be lost during field application (Qiu *et al.*, 2019). An appropriate formulation creates a supportive microenvironment that helps minimize the rapid decline of introduced microorganisms in the soil (Bashan *et al.*, 2014).

Quality Control

Implementing strict quality control protocols during the manufacturing of microbial formulations is essential to maintain product consistency and effectiveness, as the presence of unwanted microorganisms can significantly compromise bioformulation performance. Research has highlighted concerns about contamination and the inclusion of unintended bacterial strains in commercial biofertilizers. For instance, Herrmann and Lesueur (2013) analyzed 65 commercial biofertilizer products and found that only 37% could be classified as "pure," while a notable 63 % were contaminated with one or more bacterial strains. Alarming, in 40% of these products, the intended microbial strains were absent altogether, and only contaminants were detected.

Robust regulatory oversight is crucial to mitigate these risks, enhance product reliability, and build user trust (Ghorui *et al.*, 2024). Such regulations help ensure uniform quality, composition, viability, and performance of biofertilizers across various batches and manufacturers. This includes the standardization of production procedures, verification of viable propagules, and

precise labeling of microbial content (Herrmann & Lesueur, 2013; Ghorui *et al.*, 2024).

Environmental Conditions

The formulation of AMF inoculation is significantly impacted by environmental factors, which also affect the effectiveness and outcome of AMF application in Agriculture. Soil temperature, pH, salinity, moisture and microbiota composition critically influence AMF colonization and performance (Ma *et al.*, 2023b). As a result, the AMF inoculant needs to be made to resist environmental stressors. Specific temperatures are necessary for the survival and proliferation of various AMF species, moderate temperatures between 20-25°C are ideal for most AMF species development and function (Gamalero and Glick, 2022). *Rhizophagus irregularis* has exhibit resistance to temperature fluctuation making them suitable for diverse climatic conditions (Puschel *et al.*, 2019).

Local adaptation of AMF strain is crucial in mitigating stressor like UV radiation and temperature fluctuations for optimal performance (Chaudary *et al.*, 2020). Locally adapted AMF strains optimize plant growth and biomass at varying environmental condition (Rua *et al.*, 2016).

Ultimately, choosing the right strain is essential since different strains have varied environmental requirements, hence satisfying certain environmental conditions is essential to optimizing the effectiveness of AMF inoculants (Rojas-Sanchez *et al.*, 2022).

(Rojas-Sanchez *et al.*, 2022)

Carrier

The selection of carrier materials in a formulation has a direct impact on the protection, delivery, and release of microorganisms. These substances must be chosen to boost the survival and activity of the microbes. For example, research by Barazetti *et al.* (2019) indicates that vermiculite proved to be the optimal carrier for AMF inoculation in soybean, regardless of phosphorus addition, though it had an adverse effect on corn. On the contrary, a peat-based inoculum enriched with phosphorus yielded the most favourable results on corn. Additionally, laminated vermiculite slides can create a conducive environment for AMF hyphae growth and persistence, thereby enhancing the number of infective propagules (Maria and Felinov, 2017).

Optimizing AMF using carrier materials

Carrier materials have been shown to enhance AMF spore germination and root colonization by creating a nutrient rich setting that supports both fungal development and its symbiotic relationship with plant roots. Research indicates that compost, when used as an organic carrier generally boosts AMF growth and sporulation (Cavagnaro, 2015). This beneficial effect likely stems from compost's high nutrients including humic acids, which are known to promote hyphal growth and spore production in AMF (Gryndler *et al.*, 2009; Yang *et al.*, 2018).

Over a year period, compost application significantly improved AMF root colonization, increased the density of extraradical hyphae, and raised spore numbers (Yang *et al.*, 2018). The effectiveness of compost as an organic

carrier is attributed to its rich microbial community, its capacity to retain moisture, and its high nutrient availability. However, field and greenhouse studies have reported either neutral or no negative effects of compost on AMF biomass (Cozzolino *et al.*, 2016). Similarly, Barazetti *et al.* (2019) showed that vermiculite can be used as a carrier for optimizing AMF inoculation. Their findings showed that in soybeans inoculated with *Rhizophagus clarus* and vermiculite led to greater root colonization, increased mycelial growth, and a higher number of propagules compared to treatments using standard fertilizer rates. Furthermore, laminated vermiculite slides have been found to create a favorable environment for AMF hyphal development and persistence, which increases the number of infective propagules (Maria & Felinov, 2017).

In recent years, nanomaterials is an emerging technology that is easy to apply and economically viable and could represent a promising alternative for optimising AMF inoculation. In recent years, nanomaterials have emerged as a novel, cost-effective, and user-friendly option for enhancing AMF inoculation. Research by Campaña and Arias (2020) showed that polyethylene oxide nanofibers had no adverse effect on AMF infectivity or plant growth-promoting indicators. In fact, inoculated bean plants experienced substantial increases of 200 %, 140 %, and 143 % in flower bud number, fresh biomass, and dry biomass, respectively.

Conclusions

Tomato is a vital vegetable crop globally and in Nigeria, valued not only for its nutritional and economic importance but

also for its contribution to daily diets. However, its production is heavily threatened by diseases such as anthracnose, which causes significant pre- and post-harvest losses. Arbuscular mycorrhiza fungi present a sustainable solution to this challenge, offering dual benefits of enhanced nutrient uptake, plant growth and improved plant resistance against pathogens. AMF function through multiple mechanisms, including improved water and nutrient absorption, competition with pathogens, and activation of plant defense systems. However, the effectiveness of AMF inoculants depends on various factors including formulation shelf life, quality control, environmental conditions, and the choice of carrier materials. Organic and inorganic carriers such as compost and vermiculite have shown promise in optimizing AMF efficiency, while innovative technologies like nanomaterials offer additional advantages in terms of application and economic viability. Harnessing these advances can significantly contribute to sustainable tomato production and effective disease management, particularly in regions like Nigeria where tomato plays a major dietary and economic role.

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CURRENT POTASSIUM DYNAMICS IN NIGERIAN SAVANNAH AGROECOSYSTEMS

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ABSTRACT

The Nigerian savannah agroecosystem plays a vital role in national agricultural productivity but faces persistent potassium (K) deficiency, threatening crop yields and soil sustainability. This review examines K dynamics in savannah soils, emphasizing soil properties, climatic influences, and management strategies affecting K availability. Findings reveal critically low exchangeable K levels due to sandy soils, intensive cropping, and inadequate nutrient replenishment. Over-reliance on muriate of potash (MOP) risks chloride toxicity, while climate change exacerbates K depletion through erratic rainfall and leaching. Integrated nutrient management, incorporating organic amendments (e.g., compost, biochar) and precision fertilization, is essential for improving soil health and K cycling. Key interventions such as soil testing, farmer education, and climate-resilient practices like residue retention and drought-tolerant crops are necessary to address these challenges. Regional research gaps, particularly in the Sahelian and northern Guinea savannah zones, must be bridged through interdisciplinary collaboration. Strengthening sustainable K management will enhance food security and ecological resilience in Nigeria's savannah regions.

Keywords: Potassium deficiency, Nigerian savannah, soil fertility, sustainable agriculture, climate resilience, nutrient management.

Introduction

Nigeria's ecological zones are broadly categorized into savannah and forest zones, based on climate, vegetation, and geography. The tropical savanna which comprises the Guinea, Sudan and Sahel Savannah characterize the central and northern part of the country (Mustapha *et al* 2021). The Sudan savannah, stretching from the Sokoto Plains through the northern High Plains to the Chad Basin, spans states such as Sokoto, Kaduna, Kano, and Borno, accounting for over 25% of Nigeria's land area. In contrast, the Sahel savannah, located in the extreme northwest and northeast, represents the

driest and most arid region, characterized by sparse

vegetation and frequent droughts. The Guinea savannah, however, is the most agriculturally productive and extensive vegetation zone, featuring a mosaic of trees and grasses that form a wooded savannah landscape (Adedibu *et al.*, 2022). Soil types across these regions vary significantly: the Guinea savannah is dominated by Luvisols, Acrisols, Ferralsols, and Lithosols; the

Arenosols and Regosols (Yeboah *et al.*, 2022).

The savannah region is a cornerstone of Nigeria's agricultural economy, supporting cultivation of staple crops such as maize (*Zea mays*), sorghum (*Sorghum bicolor*), millet (*Pennisetum glaucum*), and groundnuts (*Arachis hypogaea*), alongside livestock production (Osabo *et al.*, 2014; Barau *et al.*, 2019). Agricultural productivity in this region hinges on soil fertility, particularly the availability of essential macronutrients like phosphorus (P), nitrogen (N), and potassium (K). Among these, potassium (K) plays a pivotal role in sustaining soil health and crop resilience. It regulates critical physiological processes in plants, including enzyme activation, stomatal conductance, photosynthesis, and osmoregulation, while enhancing tolerance to abiotic stresses such as drought and salinity through ion homeostasis and antioxidant defense mechanisms (Hasanuzzaman *et al.*, 2018; Abdulrahman *et al.*, 2018). For example, potassium is particularly crucial for maize and rice production in the Guinea and Sudan savanna zones, improving grain yields and maintaining nutrient balance in soils (Shehu *et al.*, 2019; Agbo *et al.*, 2024).

Despite its importance, potassium availability in Nigerian savannah soils remains a critical concern. While total potassium reserves can be substantial (e.g., >25 cmol/kg in some soils; Ajiboye & Ogunwale, 2008), plant-available K is often critically low (0.06–1.35 cmol/kg) due to factors such as soil mineralogy, weathering processes, and poor retention capacity in

2021). Compounding this issue, fragmented data on spatial variability, coupled with a lack of region-specific potassium management strategies, hinder effective soil fertility interventions. This knowledge gap perpetuates yield gaps and economic losses, particularly in understudied regions like the Sahel and northern Guinea savannah (Adesanwo *et al.*, 2013). A comprehensive synthesis of existing research is therefore urgently needed to assess potassium dynamics, identify drivers of depletion, and propose context-specific solutions to enhance sustainable agriculture in Nigeria's savannah agroecosystems

Climatic and Soil Characteristics of the Nigerian Savannah

The Nigerian savannah experiences tropical climates with distinct wet and dry seasons. Rainfall varies across regions, with the Sudan savannah witnessing a decline from 981.5 mm to 656.1 mm, signaling increasing aridity (Butu & Emeribe, 2019). Soils, predominantly sandy loam and loamy sand, exhibit low fertility with deficient organic carbon and exchangeable K (Garba *et al.*, 2024; Mustapha & Surajo, 2023). Soil pH, a key factor in nutrient solubility, typically ranges from slightly acidic to neutral (4.0–7.0), affecting K retention and mobility (Neina, 2019).

Forms of Potassium in Soil

Potassium exists in four primary forms: water-soluble, exchangeable, non-exchangeable, and fixed K. The plant-available fraction is small, with most K sequestered in primary and secondary minerals like micas and feldspars (Zörb *et al.*, 2014; Leister *et al.*, 2009).

serves as the primary reservoir for crops (Kozak *et al.*, 2005). Soil texture and mineral composition dictate the fixation and release of K (Dhakshinamoorthy & Lalitha, 2013).

Understanding the dynamics that govern soil potassium levels and influence plants' ability to utilize these forms is crucial for optimizing potassium fertilization and ensuring an adequate nutrient supply for crops.

Although soil potassium reserves are generally large, the pool of plant-available potassium is much smaller compared to other forms of potassium (Zörb *et al.*, 2014; Leister *et al.*, 2009). Most potassium in soils (approximately 98% of total K) exists in unavailable forms, primarily in primary minerals such as micas and feldspars, and secondary minerals from the illite group (Dhakshinamoorthy & Lalitha, 2013). Non-exchangeable and fixed potassium constitute a substantial portion of total soil potassium, while water-soluble and exchangeable potassium levels are relatively low.

Research highlights the dynamic equilibrium between these forms. For instance, depletion of water-soluble and exchangeable potassium through plant uptake or leaching can trigger the release of non-exchangeable potassium into available pools (Afinnih *et al.*, 2014). Among these, exchangeable potassium adsorbed to soil colloids (e.g., clay and organic matter) serves as the primary reservoir of plant-available K (Kozak *et al.*, 2005). This equilibrium is strongly influenced by soil physicochemical properties such as texture, pH, and

and mobility (Lalitha & Dhakshinamoorthy, 2015).

Factors Influencing Potassium Availability

Potassium availability is governed by soil texture, mineral composition, pH, organic matter, and management practices (Oviasogie *et al.*, 2021). Fine-textured soils with high clay content retain K, while sandy soils are prone to leaching (Raheb & Heidari, 2012). Soil pH extremes limit K solubility and uptake (Jackson *et al.*, 2018). Organic matter enhances K retention and microbial activity, improving nutrient cycling (Patil *et al.*, 2019). Cropping systems also influence K dynamics, with intensive monocropping depleting soil reserves (Yahaya *et al.*, 2014).

The Role of Potassium in Crop Nutrition and Physiology

Potassium regulates osmoregulation, enzymatic activity, and stress tolerance in crops (Sardans & Peñuelas, 2021). It enhances drought resistance by controlling stomatal function and water retention (Hasanuzzaman *et al.*, 2018). Potassium also improves crop quality and post-harvest longevity (Zenda *et al.*, 2021). Sustainable K management ensures food security and enhances human nutrition by improving diet quality (Liang *et al.*, 2015).

Regional Studies on Potassium Levels in Nigerian Savannah Soils

Research on potassium (K) levels in Nigerian savannah soils has revealed considerable variability in both total and exchangeable K concentrations across different states and land-use systems. Several studies highlight the influence of soil parent material, weathering intensity, cropping practices, and nutrient retention

mechanisms on K availability in the region. Ajiboye & Ogunwale (2008) investigated potassium status in soils developed over talc in the Southern Guinea Savanna of Kogi State, assessing exchangeable, acid-extractable, total, and residual K fractions. Their findings showed that total K content exceeded 25 cmol/kg across all soil profiles, yet exchangeable K accounted for less than 1% of the total K, ranging from 0.20 to 0.50 cmol/kg. This aligns with Shehu *et al.* (2019), who reported mean exchangeable K levels of 0.22 cmol/kg, with a broader range of 0.06 to 1.35 cmol/kg in the Northern Guinea Savannah. Similarly, Affinnih *et al.* (2014) observed exchangeable K concentrations between 0.04 and 0.47 cmol/kg in selected soils of Kwara State, despite some locations possessing relatively high total K reserves. Their study highlighted that soils derived from basement complex rocks exhibited lower potassium availability due to increased weathering and reduced retention capacity, whereas soils formed on sandstone, such as those in Tsaragi, retained potassium more effectively. Intensive cropping and declining soil organic matter were identified as major contributors to potassium depletion, underscoring the need for improved nutrient management strategies in the savannah region.

Further regional disparities in K availability were noted in Jigawa State, where Abubakar *et al.* (2014) conducted potassium fractionation studies across different locations. Their findings revealed substantial variation, with water-soluble K ranging from 0.3 cmol/kg in Basirka to 11.36 cmol/kg in Birniwa, while non-exchangeable K varied

from 0.82 to 16.37 cmol/kg, peaking in Birniwa. Total K content similarly ranged from 0.82 cmol/kg in Basirka to 26.37 cmol/kg in Birniwa. The low K availability in Basirka and Roni was attributed to the dominance of low-activity clays like kaolinite, which limit K retention, as well as hydrological factors such as seasonal waterlogging, which exacerbate K leaching and diffusion. Additionally, low cation exchange capacity (CEC) and high concentrations of competing cations (Na, Mg, and Ca) further restricted exchangeable K retention on soil exchange sites.

Similar potassium deficiencies were reported in Gombe State, where Salem *et al.* (2016) documented exchangeable K levels ranging from 0.19 to 0.27 cmol/kg, with surface soils containing slightly higher concentrations than deeper layers. Despite location-specific variations, the overall K availability in the region was classified as medium, reinforcing the need for targeted soil fertility interventions.

In Kano State, Almu *et al.* (2021) assessed potassium distribution in surface soils (0–15 cm) at the Wudil research farm, located within the Sudan Savannah zone. Their findings revealed that all potassium fractions, including exchangeable K (0.15–0.27 cmol/kg), were generally low, indicating insufficient levels to sustain long-term plant growth. Poor fertility management, continuous cropping, and soil parent material were identified as key factors contributing to K depletion. Additionally, the study highlighted a negative correlation between sand fraction and potassium forms, suggesting that sandy soils in this region

due to reduced clay and silt content. These findings emphasize the urgent need for targeted soil fertility management strategies to address K deficiencies and improve nutrient availability in the Sudan Savannah zone.

Potassium Requirements of Major Savannah Crops

cereals; Among cereals, maize (*Zea mays*) exhibits the most pronounced response to potassium fertilization in Nigeria (Osemwota, 2008). Using the QUEFTS model, Shehu *et al.* (2019) estimated site-specific K requirements for maize: achieving 60% potential yield ($\sim 6 \text{ t ha}^{-1}$) demands 23.7 kg K per tonne of grain in the Northern Guinea Savanna and 30.4 kg K in the Sudan Savanna. These disparities reflect variations in soil texture, organic matter, and historical land use. Aliyu *et al.* (2022) corroborated these findings, reporting K requirements of 15–20.5 kg ha^{-1} across northern Nigeria and emphasizing the need for localized fertilizer regimes to address spatial heterogeneity in soil K availability.

Rice (*Oryza sativa*), another vital cereal, is cultivated in rainfed lowland, upland, and irrigated systems. Potassium enhances osmoregulation, enzyme activation, and stress resilience in rice, which are critical for grain filling and yield stability in the nutrient-poor, sandy soils of northern Nigeria's savannah. While nitrogen (N) is often the primary yield-limiting nutrient, potassium remains indispensable for optimizing N use efficiency and mitigating abiotic stresses such as drought and salinity (Chen *et al.*, 2024). For irrigated lowland rice, Kamai *et al.*, (2020) recommend 25–30

systems benefit from balanced N-K interactions, with 60–80 kg N ha^{-1} and 30 kg K ha^{-1} maximizing agronomic efficiency. For instance, Chen *et al.* (2024) demonstrated that co-application of 135–210 kg N ha^{-1} and 115–137 kg K ha^{-1} significantly improved dry matter accumulation, nutrient uptake, and grain quality in hybrid rice, underscoring K's role in amplifying N utilization.

For millet and sorghum, K responses are context-dependent. While traditionally considered less responsive to K inputs (Singh & Balasubramanian, 1983), intensive cropping systems with residue removal deplete soil reserves, necessitating supplementation. Bibinu *et al.* (2009) demonstrated that 30 kg K ha^{-1} , combined with NP fertilizers, improved yields under such conditions, underscoring the role of management practices in shaping K demand.

Legume Crops: Legumes, though less studied than cereals, show pronounced sensitivity to K availability. Adequate K enhances nodulation, nitrogen fixation efficiency, and grain quality in cowpea and soybean (Tening *et al.*, 1995). For instance, Uko *et al.* (2002) observed that soybean grown in southeastern Nigeria (a subzone of the savannah) achieved optimal yield at 45 kg $\text{K}_2\text{O ha}^{-1}$, with synergistic effects from combined N-K fertilization. This aligns with broader evidence that K strengthens stress resilience and seed development, critical traits in rainfed savannah systems.

The interaction between fertilization practices and potassium availability in cowpea (*Vigna unguiculata*) systems has been explored in differing agroecological and management contexts. In the northern

Guinea savanna of Nigeria, Ewansiha *et al.* (2015) conducted a maize-cowpea intercropping trial at Samaru, Zaria, where cowpea was sown six weeks after maize. Maize received a basal NPK (15:15:15) application at 60 kg N, P₂O₅, and K₂O ha⁻¹, followed by urea side-dressing (60 kg N ha⁻¹) at three weeks after planting (WAP). Cowpea, however, received only single superphosphate (SSP) at 30 kg P ha⁻¹ during planting, with no direct potassium fertilization. This reflects a common practice in the region where residual K from preceding maize crops or native soil K is presumed sufficient for legumes.

In contrast, Swaroop (2006), working on vegetable cowpea in a subtropical Indian context, demonstrated significant yield improvements with explicit K fertilization. Their study tested combinations of phosphorus (0–120 kg P ha⁻¹), potassium (0–120 kg K ha⁻¹), and *Rhizobium* inoculation. The highest green pod yield (a critical metric for vegetable cowpea) was achieved with 80 kg P ha⁻¹ + 120 kg K ha⁻¹ + 20 kg N ha⁻¹ + *Rhizobium* inoculation, while maximum root growth and residual soil P/K occurred at 120 kg P and 120 kg K ha⁻¹. Notably, synergistic effects between K and *Rhizobium* were observed: adequate K enhanced root development and nutrient uptake efficiency, while *Rhizobium* reduced dependence on synthetic N.

Potassium Fertilizer Use and Management

The most commonly used potassium fertilizers include muriate of potash (MOP; KCl), sulfate of potash (SOP; K₂SO₄), and potassium nitrate (KNO₃). In northern Nigeria's savannah agroecosystems, KCl

remains the dominant potassium fertilizer due to its affordability and alignment with government subsidy programs. Studies demonstrate its efficacy in boosting maize yields by up to 30% in nutrient-depleted soils (Tariq *et al.*, 2010). However, the long-term sustainability of KCl reliance is increasingly debated, as repeated applications risk chloride accumulation and soil salinization, despite leaching mechanisms that temporarily mitigate phytotoxicity (Tariq *et al.*, 2010). These risks underscore the need for integrated strategies that balance KCl's immediate benefits with practices that enhance soil resilience.

Sustainable potassium management is crucial for enhancing nutrient use efficiency and maintaining soil fertility. Integrated Soil Fertility Management (ISFM), which combines mineral fertilizers with organic amendments and site-specific practices, has proven effective in boosting soil potassium content, microbial activity, and long-term soil health (Vanlauwe *et al.*, 2010; Saini *et al.*, 2025). This approach not only improves nutrient availability but also promotes sustainable agricultural practices (Siddiki *et al.*, 2024).

Organic amendments such as compost, manure, and biochar serve as alternative potassium sources while improving soil structure and microbial activity. For example, Chada *et al.* (2020) reported that combined application of organic amendments, including biochar, increased available potassium by 8.54%, enhancing soil properties and crop yield. Similarly, Su *et al.* (2024) found that manure compost

exchangeable potassium to 233 mg kg⁻¹ and doubled tomato biomass compared to chemical fertilization. In Nigeria, Widowati and Asnah (2014) demonstrated that biochar reduced KCl requirements by 75% while increasing maize yield by 29%, highlighting its role in improving potassium use efficiency and farm profitability.

Crop residue retention further enhances potassium cycling, as potassium is readily released during decomposition. For instance, Madar *et al.* (2020) showed that retaining 6 Mg ha⁻¹ of residues in maize-wheat systems mobilized non-exchangeable potassium pools, increasing plant-available potassium by up to 59 kg ha⁻¹ through microbial activity. In Nigeria's savannah soils, Eze *et al.* (2023) confirmed that residue incorporation at 15 t ha⁻¹ significantly elevated exchangeable potassium (69–89%) and organic carbon, addressing the region's acute nutrient limitations. These practices not only sustain potassium cycling but also improve soil structure and moisture retention, offering smallholder farmers a low-cost, climate-resilient strategy to mitigate potassium depletion and enhance productivity. Collectively, these studies affirm that organic amendments and residue management holistically replenish potassium while reducing dependency on synthetic inputs.

Challenges in Managing Potassium in Savannah Soil

Despite the crucial role of potassium (K) in crop production, several challenges hinder its effective management in the Nigerian savanna. These challenges range from

uncertainties in K dynamics under changing environmental conditions.

Limited Soil Testing, Data Availability, and Research Gaps

Due to poor fertility status, especially in the savannah region of the country, Nigerian soils require tailored management approaches beyond generic fertilizer applications. A critical barrier to effective nutrient management is the limited adoption of soil testing for fertilizer recommendations (Abdulaheem *et al.*, 2022). Farmers frequently apply fertilizers without precise soil diagnostics, leading to mismatched nutrient inputs (e.g., prioritizing nitrogen in phosphorus- or potassium-deficient soils), which exacerbate deficiencies and diminish yield returns (Abay *et al.*, 2021). Compounding this issue, research on potassium dynamics in Nigerian savanna soils remains sparse compared to nitrogen (N) and phosphorus (P) studies, leaving gaps in understanding site-specific K cycling, leaching risks, and crop response thresholds. This knowledge deficit is exacerbated by the scarcity of affordable soil testing services and adaptive, context-specific guidelines, particularly in rural areas. Socioeconomic constraints such as farmers' reliance on low-cost urea and imbalanced N-P-K applications further hinder precision nutrient management. These challenges are amplified in Nigeria's heterogeneous savannah agroecosystems, where soil variability (e.g., K-leaching sands in the Sudan Savanna vs. clay-rich Northern Guinea Savanna soils) renders static

perpetuating yield gaps (Abdulraheem *et al.*, 2022).

Influence of Climate Change on Potassium Availability

Climate change exerts a dual pressure on potassium (K) availability in Nigeria's savannah soils through temperature variability and altered precipitation regimes. Rising temperatures accelerate organic matter decomposition and mineral weathering, which could transiently enhance K release in well-watered soils. However, in arid regions like the Sudan Savanna, where high temperatures (above 35°C) coincide with erratic rainfall, microbial activity critical for K solubilization is suppressed, exacerbating K deficits in low-clay, sandy soils (Guo *et al.*, 2024). Concurrently, intensified rainfall events, projected under climate change, increase K leaching in these porous soils, while prolonged droughts reduce soluble K pools by limiting root uptake and triggering plant K reallocation, such as retention in woody tissues (Sardans & Peñuelas, 2015). For instance, in Nigeria's Northern Guinea Savanna, heavier-textured soils may temporarily retain K during moderate rains, but extreme downpours overwhelm cation exchange capacities, displacing K to deeper, inaccessible layers. These dynamics are compounded by human activities, including overgrazing and unsustainable farming, which degrade vegetation cover and disrupt natural K cycling through reduced litter inputs and accelerated erosion, particularly on slopes where runoff strips topsoil K (Guo *et al.*, 2024). Together, these factors create a feedback loop where climate extremes and

land-use practices amplify K depletion, threatening the resilience of staple crops like maize and sorghum in nutrient-poor savannah agroecosystems.

Conclusion and Recommendations

Addressing K limitations requires improved soil testing, balanced fertilization, and climate-smart practices. Research should focus on K dynamics under climate extremes and crop-specific thresholds. Policy interventions must support smallholder access to soil diagnostics and sustainable K sources. Integrating organic amendments, precision fertilization, and farmer education will enhance productivity and resilience in Nigerian savannah agroecosystems

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ASSESSING THE ENVIRONMENTAL STRESS TOLERANCE OF SOYBEAN RHIZOBIA FOR IMPROVED BIOLOGICAL NITROGEN FIXATION IN THE NORTHERN GUINEA SAVANNA OF NIGERIA

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ABSTRACT

Microbial inoculants have long been recognized for their role in boosting agricultural productivity. Inoculants containing rhizobia, in particular, have enhanced biological nitrogen fixation in smallholder farming systems within Nigeria's northern Guinea savanna. When optimized, these inoculants can significantly increase grain legume yields while reducing dependence on chemical fertilizers. Beyond improving nitrogen fixation, it is crucial to evaluate inoculant strains for their resilience to environmental stress factors. This study assessed the tolerance of indigenous rhizobia to various environmental stresses, focusing on salinity, pH, temperature, heavy metals, and different carbon sources. Soil samples were collected from 9 locations in the northern Guinea savanna, and a greenhouse experiment was conducted using soybean as a trap crop. Rhizobia isolates were obtained from root nodules after inoculation on yeast mannitol agar. They were authenticated and screened for their nitrogen fixing capacity. A total of 64 isolates were assessed after which variations in colony morphology was recorded. Further characterizations were performed to assess tolerance to pH, salinity, temperature, heavy metals, and carbon sources. The observed colony morphology showed that 96.9% were mucoid indicating high exopolysaccharide production, potentially providing adaptive advantages. Nickel was identified as the most inhibitory heavy metal, as 90.4% of the isolates failed to grow in its presence. Among the carbohydrates tested, sucrose supported the highest growth, with 21.7% of isolates showing very high proliferation. Regarding temperature tolerance, the highest growth rate (27%) was observed at 37°C, which is close to the optimal temperature for rhizobia. A high or low pH either weakly supported growth or completely inhibited it, while moderate growth was observed (47%) at 1% NaCl. These findings highlight significant variations in the isolates' ability to withstand environmental stressors. Based on the results, these isolates, along with their nitrogen-fixing capabilities, have the potential to enhance biological nitrogen fixation in regions experiencing environmental stress.

Keywords: characterization, growth, isolates, tolerance

Introduction

Soybean (*Glycine max* L. Merr) is one of the world's most important legumes especially in

sub-Saharan Africa where its integration in the smallholder farming systems not only

improves human nutrition when incorporated into the diet but also soil

productivity (Mathenge *et al.*, 2019). The soybean plant is capable of symbiotic relationship with different rhizobia, including *Bradyrhizobium japonicum*, *Bradyrhizobium elkanii*, *Bradyrhizobium liaoningense* and *Sinorhizobium fredii* (Pule-Meulenberg *et al.*, 2011). As a result, it can contribute to the nitrogen economy of nutrient poor soils. Over 90% of arable land experiences some form of stress, leading to more than 50% of global crop losses (Yamal *et al.*, 2016; Torres-Gutiérrez *et al.*, 2017). Environmental stressors such as pH fluctuations, nutrient availability, temperature changes, and salinity significantly impact the growth, survival, and metabolic activity of soil microorganisms and plants, as well as their ability to form symbiotic relationships. In most cases, the microsymbiont is the more vulnerable partner (Torres-Gutiérrez *et al.*, 2017), herefore, selecting stress-tolerant strains of Rhizobium is crucial in challenging environmental conditions (Zahran, 1999; Torres-Gutiérrez *et al.*, 2017).

Soil is a reservoir of several heavy metals that are required in micro quantities to meet plants' nutritional needs (Goyal and Habtewold, 2023). Although Cu, Ni, Co, and Zn are required as micronutrients, at high concentrations they are toxic to plants and microorganisms. (Goyal *et al.*, 2021).

The tropics have been categorized to have potential salinity problem which could be detrimental to soil microbial populations (Zahran, 1999). It is estimated that 40% of the available land surface area is affected by salinity and desiccation, thereby severely limiting the productivity potential of crops.

effects of salinity, reducing thereby the availability of water and causing water deficiency or desiccation. (Goyal *et al.*, 2021). Certain agricultural practices and industrial pollution tend to make the soil acidic with a negative impact on crop productivity (Goyal *et al.*, 2021). Inoculation of grain legumes with rhizobia inoculants can improve biological nitrogen fixation, resulting in increased crop yield. However, the efficiency of the rhizobia inoculants used may be poor if the environmental conditions are not favourable.

Most research on rhizobia in the Nigerian savannah focuses on the symbiotic effectiveness of rhizobia with less focus on the effect of environmental variables on the symbiotic process. Thus, in vitro evaluation of strains under stress might be a useful method in finding rhizobial isolates adapted to different environments, where extreme variables such as temperatures and pH limit symbiotic nitrogen fixation (Rodrigues *et al.*, 2006). This study aimed at assessing the response of rhizobia to environmental stress conditions. The study will aid in selective screening of strains with tolerance to unfavourable environmental conditions in order to optimize the nitrogen fixation process.

Methodology **Soil Collection, Preparation and planting**

Soil samples were randomly collected at a depth of 0-20 cm from 9 locations within the northern guinea savanna of Nigeria. The samples were air-dried, sieved and transferred into 4kg capacity pots. Soybean variety TGx1835-10E was used as a trap crop and pots were irrigated as necessary for eight weeks. After eight weeks, plants were

harvested and the root nodules carefully detached and stored in silica gel for subsequent isolation. **Isolation and authentication of rhizobia**

Desiccated nodules were rehydrated by immersing in a clean beaker of cool water and leaving in the refrigerator to imbibe overnight after which surface sterilization was carried out according to Vincent, (1970). The nodules were crushed and streaked on yeast mannitol agar (YMA) plates. The plates were then incubated at 28°C for 10 days and daily observations were made for the appearance of typical colonies of rhizobia. Typical colonies were isolated and re-streaked on YMA and their characteristics observed. Presumptive isolates were authenticated by testing their capacity to form nodules on the initial host using plant infection method in Fitroton growth chamber (Somasegaran and Hoben, 1994). Isolates were stored on YMA slant in screw-cap tubes in the refrigerator at 4°C for subsequent characterizations.

Morphological characterization

Each isolate was characterized based on their physical appearance on yeast mannitol agar plates and on microscopic examination. The cultural characteristics/colony morphology examined included colour, elevation, margin, texture, gumminess and opacity according to Somasegaran and Hoben, (1994). Microscopic observation of isolates was also noted.

Tolerance evaluation

Carbohydrate utilization

The ability of strains to metabolize various substrates as sole carbon source was also assessed. Each carbohydrate was added as a substitute for mannitol to a final

concentration of 10 % (W/V). The following carbohydrate sources were assessed: L-arabinose, D-glucose, D-galactose, fructose, lactose and sucrose. Fructose, glucose, lactose and sucrose were autoclaved while arabinose and galactose were sterilized by filtration through Millipore membrane filter with pore size of 0.22 µm and then added to the sterilized liquefied basal medium before pouring the plates (Somasegaran and Hoben, 1994). Each isolate was tested on duplicate plates and the growth scored after incubation for seven days at a temperature of 28 °C (Boakye *et al.*, 2016).

Heavy metal tolerance

The isolates tolerance to heavy metals was tested in YMA supplemented with the following heavy metals: ZnCl₂ (50 µg ml⁻¹), NiSO₄ (100 µg ml⁻¹), HgCl₂ (10 µg ml⁻¹), Pb(CH₃COO)₂ (250 µg ml⁻¹) (Maâtallah *et al.*, 2002). Isolates were then scored according to their sensitivity to the heavy metals.

pH, salt and temperature tolerance

The isolates' tolerance to pH was assessed on YMA at two pH values of 4.0 and 9.0 using NaOH and HCl to adjust the pH of the medium. The ability of the isolates to tolerate sodium chloride (NaCl) was also assessed by growing on YMA at a concentration of 0.5% and 1% (w/v). The tolerance of the isolates to temperature was assessed at 4°C, 10°C, 37°C and 45°C. The growth was then scored accordingly after 7 days of incubation.

Results and Discussion

Growth characteristics

A total of 64 isolates were authenticated as rhizobia following the plant infection method. Most isolates showed poor or no absorption of Congo red. It was noted that while lack of or poor absorption of Congo red typically indicates rhizobia, partial absorption could also be a sign of rhizobia as reported by Kneen and LaRue, (1983), and Kawaka *et al.*, (2014). The isolates were either fast or slow growers, with fast growers being more dominant. This aligns with Ondieki *et al.*, (2017), but contrasts with Sanginga *et al.*, (1989), who found slow growers dominant in tropical soils. Microscopic examination revealed all isolates as Gram-negative, short, non-spore-forming rods, typical of rhizobia. Among the isolates, 59.4% of the isolates were fast growers while 40.6% were slow growers. A total of 89.1% were milky while 10.9% were whitish in appearance. The colony elevation was 10.9% raised and 89.1% flat. In terms of colony margin, 95.3% had entire margins while 4.7% were irregular. The texture showed 96.9% mucoid while 3.1% produced dry colonies. In terms of consistency, 46.9% were gummy while 53.1% were not. And for their reaction to light (opacity), 95.3% were translucent and 4.7% were opaque (Table 1). The variation in the morphological characteristics shows a wide diversity of indigenous rhizobia in the study locations as is evident from the different properties exhibited by individual strains. These properties are consistent with typical rhizobia characteristics accounted by previous reports (Somasegaran and Hoben, 1994); Elzanaty *et al.*, (2015); Jalloh *et al.*,

(2020); Qudratullah and Mohammad, (2020).

The high mucus production in most of the isolates was as a result of excess production of exopolysaccharides (EPS) which indicates the isolates' adaptability to various physiological stresses such as high temperatures, metal toxicity, low soil pH and salinity (Karthik *et al.*, 2017). EPS helps avert desiccation of the bacteria and aid in withstanding fluctuations in temperature, salinity, and acidity (Giongo *et al.*, 2010), thereby conferring a higher competitive advantage to the isolates compared to those that do not have the ability to produce EPS. Isolates well adapted to the local environmental and climatic conditions with a high capacity for BNF could be considered suitable candidates for the development of commercial rhizobia inoculants (Berrada *et al.*, 2012, Koskey *et al.*, 2018).

Carbohydrate utilization

A total of 64 isolates were characterized based on their carbohydrate utilization and all the isolates were able to utilize it at varying degrees (Table 2). The result showed that 5% of the isolates had weak growth in the presence of lactose, while 75% had moderate growth and 20% had high growth. For sucrose, 8.3% failed to grow while none had weak growth. Moderate growth was observed in 41.7% of the isolates, while 28.3% had high growth and 21.7% had very high growth. For fructose, 48.3% had moderate growth, 46.7% had high growth while 5% had very high growth. For glucose, 1.7% grew weakly, 78.3% grew moderately while 20% grew highly. For L-

Table 1. Summary of strains cell and colony morphology of soybean isolates

PROPERTIES	NO. OF STRAINS	PERCENTAGE (%)
MICROSCOPY		
G-rods	64	100
GROWTH RATE		
Fast	38	59.4
Slow	26	40.6
COLOUR		
Milky	57	89.1
Whitish	7	10.9
ELEVATION		
Flat	7	10.9
Raised	57	89.1
MARGIN		
Entire	61	95.3
Irregular	3	4.7
TEXTURE/MUCOSITY		
Mucoid	62	96.9
Dry	2	3.1
CONSISTENCY		
Gummy	30	46.9
Not gummy	34	53.1
OPACITY		
Translucent	61	95.3
Opaque	3	4.7
TOTAL	64	100

failed to grow while none of the isolates grew weakly, 53.3% grew moderately while 43.3% grew highly. For galactose, 1.7% failed to grow, none had weak growth, 68.3% had moderate growth while 30% had high growth. Sucrose and fructose emerged as the most supportive of high to very high growth, while glucose and lactose mainly supported moderate growth. The result is in agreement with the report of Maa'tallah *et al*, (2002) that rhizobia strains could utilize a broad range of carbohydrates. The ability of the isolates to utilize different carbon sources shows that rhizobia from the northern guinea savannah of Nigeria are metabolically versatile. It is expected that rhizobia should be capable of utilizing many different compounds since they are found in different and complex environments, such as the soil, the rhizosphere, or plant cells (Mazur *et al.*, 2013). Furthermore, it was reported that metabolic versatility may result in more

Table 2. Summary of carbohydrate utilization on soybean rhizobia isolates

Growth category	Lactose (%)	Sucrose	Fructose	Glucose	L-arabinose	Galactose
No growth	0	8.3	0	0	3.4	1.7
Weak growth	5	0	0	1.7	0	0
Moderate growth	75	41.7	48.3	78.3	53.3	68.3
High growth	20	28.3	46.7	20	43.3	30
Very high growth	0	21.7	5	0	0	0
TOTAL	100	100	100	100	100	100

successful competition for nodulation (Wielbo *et al.*, 2007).

Heavy metals tolerance

Among the isolates characterized for heavy metal tolerance (Table 3), 36% did not grow on Pb supplemented media, none had weak growth, but 52% had moderate growth while 12% had high growth. For Hg, 20.3% were susceptible and hence failed to grow, none had weak growth, 48.4% had moderate growth while 31.3% had high growth. For Zn, 20% were susceptible, none had weak growth, 44% had moderate growth while 36% had high growth. For Ni, growth was inhibited in 91%, none had weak growth, while 9% had moderate growth. Overall, while some of the isolates were resistant to some of the metals, some isolates failed to grow in the presence of these heavy metals.

The different level of tolerance to the various heavy metals shown by the isolates was similarly reported by Wani *et al.*, 2013. The high tolerance to mercury observed in this study was similarly reported by Maâtallah *et al.*, (2002) for chickpea rhizobia. The high sensitivity to Ni by most of the isolates could be as a result of cation (Ni^{2+}) build up in excess of the amount required for the biosynthesis of urease. Heavy metal- tolerant rhizobia deploy a number of strategies in order to mitigate oxidative stress caused by such heavy metals. Some of these strategies include but not limited to the presence of an efflux system, which reduces accumulation, has been a common strategy used by the rhizobia against several heavy metals (Goyal and Habtewold, 2023).

Table 3. Summary of the effect of heavy metals on soybean rhizobia isolates

Growth category	Pb (%)	Hg	Zn	Ni
No growth	35.9	20.3	20.3	90.6
Weak growth	0	0	0	0
Moderate growth	51.6	48.4	43.8	9.4
High growth	12.5	31.3	35.9	0
Very high growth	0	0	0	0
TOTAL	100	100	100	100

pH, salt and temperature tolerance

A total of 64 isolates were characterized for their tolerance to pH, salinity and temperature variations (Table 4). Some isolates were susceptible to varying conditions, some were highly tolerant. At pH 4, only 3% of the isolates failed to grow, while 67% had weak growth, 27% had moderate growth while only 3% had high growth. At pH 9, only 2% did not grow while 56% had weak growth, 33% had moderate growth while 9% had high growth. Regardless of situations where soil acidity is not a problem, it is very vital to have strains that are tolerant to low pH conditions. Faget *et al.*, (2013) reported that actively growing plants can excrete acidic compounds into immediate soil, thereby decreasing the pH of the root zone by as much as 2 pH units. pH tolerance may vary between species of rhizobia and also among strains within species (Hungria and Vargas, 2000) as was also observed in this study.

At 0.5% NaCl concentration, only 5% did not grow, while 62% had weak growth 33% had moderate growth while none of the isolates had high growth. At 1% NaCl concentration, only 5% did not grow, while 48% had weak growth, 47% moderate growth while none of the isolates had high growth. Several researchers have reported different variations in tolerance to NaCl under in-vitro conditions. In their findings, Jida and Assefa (2011) reported that 80% of isolates could not grow at 1% NaCl. This corroborates some of the findings from this study that isolates only had moderate and weak growth at this concentration. However, the result contradicts the findings of Ahmad and Abdelmageed (2005) who reported abundant growth at 1% NaCl with a decline

in growth with increase in concentration. The use of salt tolerant strains in these agro-ecologies improve the efficiency of BNF in areas with high salinity, as high salt has been reported to impair the early interactions of legume-rhizobia during nodule formation and development (Shoukry *et al.*, 2013).

At temperature of 45°C, only 3% did not grow, while 38% had weak growth, 50% had moderate growth while 9% had high growth. At temperature of 37°C, all isolates were able to grow at different levels. It was observed that 11% of the isolates had weak growth, while 63% had moderate growth and 27% of the isolates had high growth. At temperature of 10°C, only 6% of the isolates did not grow, while 91% had weak growth, 3% had moderate growth while none of the isolates had high growth. At temperature of 4°C, 70% of the isolates did not grow, while 27% had weak growth, 3% had moderate growth while none had high growth. The low growth observed for temperatures less than 28°C was not surprising as temperature of 28°C has been reported to be optimum for rhizobia growth. The results are in line with those obtained by Youseif *et al.*, (2014) who reported that rhizobia are able to grow at 37°C and also survive at 40°C and contrary to the study of (Chen *et al.*, 2002) that isolates from soybean are unable to grow at temperature of 45°C. The optimum growth temperature for most rhizobia is 25-30°C, however, they are often exposed to temperatures out of this range either in their symbiotic or saprophytic forms (Alexandre and Oliveira, 2013). From this study, the ability of isolates to thrive at the different exposure temperatures indicates the potential

Table 4. Summary of effect of pH, salt concentration and temperature on soybean rhizobia isolates

Growth category	pH 4	pH 9	0.5% NaCl	1% NaCl	45°C	37°C	10°C	4°C
	(%)							
No growth	3	2	5	5	3	0	6	70
Weak growth	67	56	62	48	38	11	91	27
Moderate growth	27	33	33	47	50	63	3	3
High growth	3	9	0	0	9	27	0	0
Very high growth	0	0	0	0	0	0	0	0
TOTAL	100	100	100	100	100	100	100	100

of native rhizobia to maintain their viability in terms of unfavourable temperature conditions.

Conclusion

In conclusion, the study of rhizobia isolates from the northern guinea savannah of Nigeria reveals significant diversity in their growth characteristics, morphological traits, and metabolic capabilities. The observation that both fast and slow growers can metabolize a wide range of carbon sources indicates that the metabolic versatility of these rhizobia is not dependent on their growth rate, further supporting their adaptability to varying environmental conditions. The ability of these isolates to produce exopolysaccharides (EPS) and adapt to physiological stresses such as high temperatures, metal toxicity, low pH, and salinity highlights their potential for survival and effectiveness in diverse and challenging environments. Their metabolic versatility not only underscores the adaptability of rhizobia in the northern guinea savannah but

also hints at their potential to enhance biological nitrogen fixation (BNF) under varied soil and environmental conditions. Therefore, these isolates could play a crucial role in improving legume productivity and soil fertility in the region. The variation in rhizobia tolerance to NaCl observed highlights the complexity of salt tolerance among isolates. This suggests that while the study areas may not currently face significant salinity issues, screening for salt tolerance remains important to optimize the nitrogen-fixing ability of effective strains. The study also concludes that rhizobia isolates exhibit varying levels of tolerance to heavy metals, with high tolerance to mercury possibly due to the protective role of exopolysaccharides (EPS) that prevent metal ions from entering cells. The study also highlights the sensitivity of most isolates to nickel, likely due to the accumulation of Ni^{2+} beyond the amount needed for urease biosynthesis. The observed tolerance or sensitivity to heavy

metals provides a basis for screening valuable strains for use in polluted sites. The study highlights the inhibitory effects of both high acidity and alkalinity, thereby underscoring the need for pH-tolerant strains to ensure successful symbiosis in varying soil conditions. The study concludes that the temperature tolerance of rhizobia is complex and can differ significantly between laboratory conditions and natural environments. This suggests that indigenous rhizobia strains might possess the ability to withstand a broader range of temperatures, thus enhancing their capacity for biological nitrogen fixation (BNF) even under stressful conditions.

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SOIL FERTILITY AND SUGARCANE (*SACCHARUM OFFICINARUM* L.) PRODUCTIVITY UNDER POSTHARVEST SUGARCANE STRAW AMOUNT AND WEED MANAGEMENT PRACTICES IN NIGERIA

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ABSTRACT

*Yield decline remains a persistent challenge for sugarcane (*Saccharum officinarum* L.) production in Nigeria. This study evaluated the impacts of post-harvest straw mulch rates and integrated weed management practices on soil fertility and crop productivity. Field trials were conducted during the 2016 and 2017 seasons at Badeggi, in the Southern Guinea Savanna of Nigeria. The treatments were arranged in a split-plot design with three replications, comprising four post-harvest straw rates (0, 3, 6, and 9 t ha⁻¹) and four weed management practices [weedy check, 5 monthly hoe weedings (MHW), pre-emergence (PE) Diuron (2 kg a.i. ha⁻¹) + post-emergence (POE) herbicide + 2 hoe weedings (2HW), and PE + POE herbicide only] as main plots, while two genotypes (*Bida local* and NCS 001) constituted the subplots. Results indicated that the application of 9 t ha⁻¹ post-harvest straw significantly ($p < 0.05$) maximized soil organic carbon, total nitrogen, phosphorus, and potassium levels, effectively reversing nutrient depletion. Furthermore, the synergy between 9 t ha⁻¹ straw mulch and the PE + POE + 2HW weed management strategy resulted in the highest cane yield for the industrial genotype, NCS 001. The study concludes that the integration of high-rate straw retention with combined chemical and mechanical weed control significantly enhances soil fertility and sustains the productivity of industrial sugarcane. This management framework is recommended for adoption in the Southern Guinea Savanna and similar tropical agro-ecologies to mitigate yield decline.*

Keywords: *Saccharum officinarum*, Crop Residue Management, Soil Fertility, Integrated Weed Management, Guinea Savanna, NCS 001.

Introduction

Sugarcane (*Saccharum officinarum* L.) is a premier industrial cash crop globally, serving as the primary raw material for sugar, molasses, livestock feed, ethanol, and bio-fuel (Alvaris, 2008; Junejo *et al.*, 2010). Currently, sugarcane accounts for approximately 80% of global sugar production, significantly overshadowing sugar beet (Busari & Misari, 2007). In addition to its industrial value, the crop

residues specifically post-harvest straw offers significant potential as a soil amendment and organic mulch to enhance field productivity (Gana, 2008).

Despite its economic importance, sugarcane production in sub-Saharan Africa, and specifically Nigeria, is severely hampered by a complex of biotic and abiotic constraints. Weed infestation remains one of the most detrimental factors, competing

aggressively with the crop for water, light, and essential nutrients (Takim & Amodu, 2013). Research indicates that unchecked weed competition can trigger a drastic yield reduction ranging from 40% to 67% (Ndarubu *et al.*, 2006; Kadam *et al.*, 2011), often leading to the total abandonment of fields by smallholder farmers.

Furthermore, the continuous cultivation of sugarcane without adequate organic recycling has led to a noticeable yield decline and the depletion of soil mineral reserves. There is, therefore, a critical need to develop integrated management strategies that combine chemical and mechanical weed control with sustainable residue retention.

By utilizing post-harvest straw as a "living mulch," farmers may be able to suppress weed emergence while simultaneously improving soil physicochemical properties. Consequently, this study was designed to evaluate the interactive effects of varying post-harvest straw rates and integrated weed management practices on the soil properties and yield performance of industrial and local sugarcane genotypes in the Southern Guinea Savanna of Nigeria.

Materials and Methods

Experimental Site

Field trials were conducted during the 2016 and 2017 rainy seasons at the upland sugarcane experimental field of the National Cereals Research Institute (NCRI), Badeggi (Lat. 9°45' N, Long. 6°07' E) in the Southern Guinea savanna agro-ecological zone of Nigeria. Total rainfall during the experimental period was 1504.1 mm in 2016 and 1045.4 mm in 2017. Mean air temperatures ranged from 35–38°C and 34–36°C across the two seasons, respectively.

Soil Sampling and Land Preparation

Prior to planting, composite soil samples were collected from ten random points at a depth of 0–15 cm using a soil auger to characterize the baseline physicochemical properties (Table 1). The site was manually cleared, followed by mechanized ploughing and harrowing.

Treatments and Experimental Design

The experiment utilized a split-plot design with three replications. The main plots consisted of a factorial combination of four post-harvest straw rates (0, 3, 6, and 9 t ha⁻¹) and four weed management practices [Weedy check, five monthly hoe weeding (5 MHW), Integrated control: Pre-emergence (PE) Diuron + Post-emergence (POE) 3-Maize force + Two hoe weeding (2HW) and Chemical control: PE Diuron + POE 3-Maize force. The subplots consisted of two sugarcane genotypes: Bida local (chewing) and NCS 001 (industrial). The gross plot size was 35 m² (7 m x 5 m), with a net plot area of 17.5 m² (3.5 x 5 m), comprising four rows of 5 m length.

Crop Establishment and Management

Healthy six-month-old stalks were cut into three-bud setts and planted. PE Diuron was applied a day after planting at 2.0 kg a.i. ha⁻¹, while POE 3-Maize force (179.2 g a.i. ha⁻¹) was applied at 5 weeks after planting (WAP) using a CP₃ knapsack sprayer (spray volume: 250 L ha⁻¹). Fertilizer was applied as NPK at a rate of 150:60:90 kg ha⁻¹, split into two equal doses at planting and 8–10 WAP. Weed identification followed the standards of Akobundu *et al.* (2016).

Data Analysis

All data generated were subjected to Analysis of Variance (ANOVA) using SAS version 9.0. Treatment means were separated using the Duncan's Multiple Range Test (DMRT) at a 5% level of probability ($p < 0.05$).

Results and Discussion

Baseline Soil Physical and Chemical Characteristics

The baseline soil properties for the 2016 and 2017 experimental sites at Badeggi are summarized in Table 1. The soil was classified as sandy loam across both sites. While the sand content remained high (722

to 765 g kg⁻¹), a significant reduction in clay content was observed in 2017 (79 g kg⁻¹) compared to 2016 (143 g kg⁻¹).

Initial fertility markers indicated a low-nutrient environment typical of the Sudan Savannah. However, the 2017 site exhibited higher baseline levels of organic carbon (3.45 g kg⁻¹) and total nitrogen (0.33 g kg⁻¹) compared to 2016. The acidic nature of the soil (pH 5.80 to 6.40) and the relatively low Effective Cation Exchange Capacity (ECEC) emphasized the need for organic amendments to improve nutrient retention and soil structure.

Table 1: Baseline soil physical and chemical properties of the Experimental sites at Badeggi

Parameters	2016	2017
Particle size distribution (g kg⁻¹)		
Sand	722	765
Silt	135	156
Clay	143	79
Textural class	Sandy loam	Sandy loam
Chemical properties		
pH (H ₂ O)	5.80	6.40
Organic Carbon (g kg ⁻¹)	2.37	3.45
Total Nitrogen (g kg ⁻¹)	0.06	0.33
Available Phosphorus (mg kg ⁻¹)	20.29	23.15
Exchangeable bases (cmol kg⁻¹)		
Ca ⁺⁺	2.48	4.18
Mg ⁺⁺	1.38	3.68
K ⁺	0.16	0.30
Na ⁺	0.09	0.22
Exchangeable acidity	1.03	1.07
ECEC	5.14	9.45

Analyzed at National Cereals Research Institute Laboratory

Influence of Genotype and Straw Mulching on Soil Properties

The chemical composition of the soil at harvest was significantly ($p < 0.05$) influenced by sugarcane genotypes, particularly regarding organic carbon and

total nitrogen (Table 2). Industrial sugarcane varieties demonstrated a superior capacity for nitrogen and carbon accumulation compared to local chewing cane, suggesting a more robust interaction with the soil rhizosphere.

The application of post-harvest straw mulch played a pivotal role in soil regeneration. Applying 9 t ha⁻¹ of straw mulch significantly ($p < 0.05$) maximized the levels of organic carbon, N, P, and K. Interestingly, these results were statistically comparable to the 6 and 3 t ha⁻¹ application rates, suggesting that even moderate mulching provides substantial benefits. This improvement is attributed to the decomposition of crop residues, which facilitates the gradual release of nutrients and enhances soil organic matter. These findings align with Singh *et al.* (2022) and Gatkal *et al.* (2024), who noted that straw retention is a critical strategy for improving the physicochemical properties of sugarcane-producing soils.

Impact of Weed Management on Soil Fertility

Weed management practices also exerted a significant ($p < 0.05$) influence on the post-harvest nutrient status (Table 2). The highest levels of organic carbon and macronutrients (N, P, and K) were recorded in plots treated with a combination of Pre-emergence and post-emergence herbicides. This suggests that effective weed control reduces the competition for soil nutrients, allowing for a

higher concentration of residual minerals and organic carbon to remain in the soil matrix after the sugarcane harvest. This observation is consistent with Chauhan and Abugho (2013), who noted that rigorous weed management prevents the "nutrient mining" effect caused by weed biomass, thereby preserving the soil's fertility status for the primary crop. Furthermore, Srivastava *et al.* (2024) demonstrated that integrated weed control significantly enhances the post-harvest residual nutrient pool by minimizing the off-take of N, P, and K by competitive weed species.

Genotypic Variations in Growth and Quality Traits

The growth and yield parameters were significantly ($p < 0.05$) influenced by sugarcane genotypes across both study years (Table 3). The industrial genotype (NCS 001) consistently recorded higher stalk height, brix content, and overall cane yield compared to the local chewing variety (Bida local). This superiority is largely attributed to the genetic potential of industrial canes to withstand drought conditions more effectively, facilitating faster establishment (Aroh *et al.*, 2020; Barajehfard *et al.*, 2026). In contrast, Bida local exhibited significantly ($p < 0.05$) higher stalk girth. As noted by Busari *et al.* (2005), chewing genotypes are characterized by robust, soft stems with high water content but lower sucrose levels. Conversely, industrial varieties like NCS 001 possess thinner, harder stems with higher sucrose concentrations (brix), which is a critical trait for industrial sugar processing (Khan *et al.*, 2018 and 2020).

Table 2: Effects of sugarcane genotypes and weed management practices on same soil properties at 12 MAP in 2016 and 2017 seasons

Treatments	Soil properties							
	Organic C (g kg ⁻¹)		Total N (g kg ⁻¹)		Available P (mg kg ⁻¹)		Potassium K (cmol kg ⁻¹)	
	2016	2017	2016	2017	2016	2017	2016	2017
Genotypes (G)								
Bida local	40.47	43.34	0.30	0.38	138.95	158.19	2.97	3.27
NCS 001	40.49	43.36	0.31	0.39	173.61	187.42	2.58	2.68
LSD (0.05)	0.005	0.007	0.02	0.005	12.16	11.37	0.13	0.11
Mulching (M) [t ha⁻¹]								
0	40.33	43.19	0.20	0.31	123.09	156.04	2.09	2.65
3	40.44	43.31	0.26	0.32	157.18	167.92	2.90	2.97
6	40.54	43.38	0.34	0.39	161.36	171.5b	2.93	3.01
9	40.63	43.54	0.43	0.51	183.48	195.75	3.16	3.28
LSD (0.05)	0.009	0.008	0.004	0.004	17.19	16.08	0.19	0.16
Weed management								
Weedy check	40.36	43.32	0.28	0.36	123.62	156.92	2.10	2.66
MHW	40.48	43.34	0.30	0.37	181.46	191.79	3.15	3.24
PE +POE+ 2HW	40.49	43.33	0.32	0.39	161.35	171.96	2.93	2.99
PE + POE	40.50	43.42	0.33	0.41	158.69	170.54	2.91	3.24
LSD (0.05)	0.01	0.006	0.005	0.004	17.19	16.08	0.19	0.16
Interaction	NS	NS	NS	NS	NS	NS	NS	NS

LSD- least significant difference, MHW-Monthly hoe weeding, PE- Pre-emergence (Diuron at 2 kg a.i/ha) herbicide, POE- Post-Emergence (3-Maize force at 179.2 g/ha) herbicide, NS- Not significant, MAP- Months after planting.

Impact of Post-harvest Straw Mulching

Straw mulching significantly ($p < 0.05$) improved all growth and quality metrics. The application of 9 t ha⁻¹ consistently produced the highest stalk height and girth, though results were statistically similar to the 3 t and 6 t ha⁻¹ rates. The positive response to mulching is attributed to improved soil water regimes, enhanced moisture retention, and increased soil organic matter (Yadav *et al.*, 2009; Fortes *et al.*, 2012).

Furthermore, the unburned surface mulch acts as a nutrient reservoir; as Cheong and Teeluck (2015) indicated, post-harvest straw can recycle up to 105 kg N ha⁻¹ annually, effectively supplementing mineral fertilizer needs. The observed increase in brix content under higher mulch rates further suggests that moisture conservation and weed suppression provide a more stable environment for sucrose accumulation (Thompson, 2005; Uwah & Iwo, 2011).

Table 3: Effects of sugarcane genotypes and weed management practices on growth and yield parameters of sugarcane

Treatment	Stalk	height	Stalk girth		Brix content		Number of		Millable stalks		Cane yield	
	(cm)		(cm)		(%)		Stool per plot		per stool		(t ha ⁻¹)	
	2016	2017	2016	2017	2016	2017	2016	2017	2016	2017	2016	2017
Genotypes (G)												
Bida local	146.4	172.5	3.05	3.27	16.49	16.74	9.17	17.63	3.01	3.29	52.12	57.24
NCS 001	178.6	201.9	2.63	2.68	18.28	18.29	11.75	22.17	5.51	5.33	82.27	66.18
LSD (0.05)	11.05	33.65	0.12	0.11	0.62	0.58	1.27	1.47	0.52	0.40	4.63	4.61
Weed management (W)												
Weedy check	148.5	168.7	2.37	2.66	16.60	16.30	8.17	14.67	3.63	3.75	57.33	54.91
5 MHW	181.5	209.1	3.15	3.24	18.15	18.38	11.79	20.83	4.63	4.63	77.54	61.29
PE +POE+ 2MHW	161.4	186.0	2.93	2.99	17.11	17.38	10.46	21.88	4.35	4.29	66.08	63.76
PE + POE	158.7	184.9	2.91	3.24	17.68	18.0	11.42	22.21	4.43	4.58	67.81	66.87
LSD (0.05)	15.63	20.03	0.17	0.16	1.29	0.82	1.79	2.09	0.73	0.57	8.36	5.23
Interaction												
G x W	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

LSD - least significant difference, MHW-Monthly hoe weeding, PE- Pre-emergence (Diuron at 2 kg a.i/ha) herbicide, POE- Post-Emergence (3-Maize force at 179.2 g/ha) herbicide, NS-Not significant

Weed Management and Yield Productivity

Yield-promoting attributes were significantly ($p < 0.05$) affected by weed management practices. The highest values for stalk height, girth, and brix were achieved through Monthly Hoe Weeding (MHW), which performed comparably to the chemical combination of Pre-emergence (PE) + Post-emergence (POE) herbicides. In 2017, the PE + POE herbicide application specifically maximized cane yield, aligning with findings by Singh *et al.* (2011) that weed-free environments are essential for achieving maximum stalk height and tonnage. Effective weed control eliminates competition for essential nutrients and light, allowing the crop to fully exploit its genetic potential (Zafar *et al.*, 2010).

Conclusion

This study establishes that integrating 9 t ha⁻¹ post-harvest straw mulch with a combined herbicide (PE + POE) and mechanical (two hoe weeding) strategy is the most effective approach for sustaining sugarcane productivity in the Nigerian Sudan Savannah. The high-rate mulching serves as a vital nutrient reservoir, significantly enhancing soil organic carbon and macronutrient (N, P, and K) availability while improving moisture retention. By minimizing weed-crop competition through this integrated management system, the improved soil physicochemical properties are effectively translated into superior growth and industrial yield. Therefore, it is recommended that producers in this agro-ecology transition from field burning to straw retention (6-9 t ha⁻¹) and adopt

integrated weed management to ensure long-term soil health and economic viability.

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NUTRIENT INPUTS AS DRIVERS OF SOIL ORGANIC MATTER MINERALIZATION AND TURNOVER

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ABSTRACT

Understanding the microbial metabolic mechanism of nutrient regulation of SOC is fundamental to the dynamic change and content of organic C. It is also helpful for effectively managing SOC and mitigating greenhouse gas emissions. This study investigated the nutrient regulation mechanisms of soil C cycling. To study the effects and mechanisms of different nutrient additions on straw decomposition, maize stover ($\delta^{13}\text{C}$ value of -11.2‰) was added to the soil ($\delta^{13}\text{C}$ value of -26.3‰), three levels of no addition (NPK_L), medium (NPK_M) and high nutrient addition (NPK_H) were set up, and 87 days of incubation experiments were carried out. The total organic C mineralization, straw mineralization, and extracellular enzyme activity of the soil were determined. The experimental results showed that nutrient addition significantly reduced the total soil mineralization and straw mineralization and affected the decomposition rate of the active (K_a) and slow (K_s) pools. There was a significant positive correlation between the activity of β -glucosidase, α -glucosidase, cellobiohydrolase, and β -xylosidase and CO_2 release, suggesting that microorganisms may break down SOC by releasing extracellular enzymes. In addition, the decomposition of maize stover under different nutrient conditions showed a "U-shaped" nutrient regulation pattern, and the decomposition rate of maize straw was the lowest under the medium nutrient addition treatment. The above results show that moderate nutrient addition can inhibit the activity of microbial extracellular enzymes, reduce the mining of nutrients by microorganisms, and thus regulate the decomposition rate of straw and SOC.

Keywords: Soil organic matter decomposition, Soil carbon dioxide efflux, Soil carbon turnover, Extracellular enzyme activity, Nutrients mining.

Introduction

The addition of nutrients regulates the mineralization and turnover of SOM. The rate at which SOM decomposes and transforms can be influenced by altering the nutrient supply and soil microbial activity and community (Bernard *et al.*, 2022). Adding organic fertilizers could greatly accelerate the breakdown and mineralization of SOM (Liu *et al.*, 2020). The addition of organic fertilizers can provide microorganisms with nutrients and C sources (Zheng *et al.*, 2020). Also, applying chemical fertilizers, e.g., inorganic N fertilizer, can speed up the decomposition of organic matter by increasing the microbial biomass and activity of enzymes (Fontaine *et al.*, 2011). On the other hand, overuse of chemical fertilizers may cause soil acidification and the decline of microbial biomass and activity, which can have a detrimental effect on the amount and quality of SOM (Kuz'yakov *et al.*, 2018).

Moreover, the biogeochemical soil processes, which range in size from smaller than a micron to the global level, are regulated by nutrients and chemicals within SOM (Kallenbach *et al.*, 2016). Straw is a plant C source that can increase or maintain SOC storage, shift SOM quality, and affect soil C dynamics (Chen *et al.*, 2019a; Lu *et al.*, 2019). Agricultural management, i.e., fertilization, regulates the C accumulation capacity by straw addition (Kumar *et al.*, 2018; Xu *et al.*, 2019a). The SOC mineralization and storage in soil are altered by adding organic C sources such as straw and nutrients (Fang *et al.*, 2018; Li *et al.*, 2018).

The length of time soil microorganisms live in soils is known as the "soil microbial mean residence time" (MRT), and it is essential for determining the soil C cycle (He and Xu, 2021). According to He and Xu (2021), the MRT is essential for regulating the microbe-mediated biogeochemical processes. According to Spohn *et al.* (2016a), understanding the microbial biogeographic pattern requires understanding the factors controlling MRT distribution. Increasing the C input or delaying microbial turnover can promote SOC storage, one of the most efficient strategies for halting climate change and improving agricultural sustainability (Schroeder *et al.*, 2020). Earlier studies reported that MRT was significantly influenced by the substrate's quality and availability, soil's pH and texture, moisture, temperature, and nutrient availability (Rousk and Bååth, 2011). Additionally, the availability of nutrients may significantly influence soil respiration, particularly in ecosystems where C is abundant but N is scarce (Guo *et al.*, 2019). According to some studies, N addition causes high heterotrophic respiration (Liu *et al.*, 2020). However, N was added in another study to account for the low heterotrophic respiration (Liu *et al.*, 2021). The idea of a "nutrient bank" operation that would mediate SOC decomposition and the release of nutrients through "microbial nutrient mining" was suggested (Zhu *et al.*, 2021). This mechanism frequently operates when nutrients are scarce. Following the addition of N, it was found that SOM decomposition decreased (Poeplau *et al.*, 2019).

There is no report about equivalent P mining mechanisms, while N mining is mostly observed in the leaf litter decomposition study. The basic stoichiometric decomposition theory explains the positive impact on SOC decay and, thus, possible adverse Influence on SOC stocks (Wei *et al.*, 2021). After the addition of P, elevated SOC mineralization was seen (Siles *et al.*, 2022). Adding P and K in long-term experiments remarkably decreased SOC stocks (Poeplau *et al.*, 2019). The chemical composition and stoichiometry of biomolecules are also related to C and N dynamics (Gillis and Price, 2016). Because SOM decay is influenced by the availability and ratio of soil nutrients, this influences soil C cycling (Poeplau *et al.*, 2019).

Due to the increased decomposition and microbial activity via stabilizing C-to-nutrients (e.g., N and P) stoichiometry (Fang *et al.*, 2019), adding nutrients through fertilization may lessen the C sequestration effects of incorporating straw into the soil (Das *et al.*, 2019). Soil microbes secrete the extracellular enzymes responsible for catalyzing the rate-limiting step in SOM decomposition (Fanin *et al.*, 2022). Additionally, because enzymes are N-rich molecules, the availability of nutrients prevents microbes from secreting them. As a result, they may respond to C availability and N availability by using N to produce hydrolytic enzymes (Feyissa *et al.*, 2022). The integration of microbial enzymes in a relationship with the input of nutrients in the decomposition still needs to be thoroughly understood, even though studies on the mechanisms and factors mediating the

secretion of enzymes are in progress (Bilyera and Kuzyakov, 2024).

The current study, therefore, set out to 1) ascertain the impact of nutrient addition on SOC dynamics, including maize straw decomposition and C turnover, and 2) ascertain the relationship between soil C dynamics and extracellular enzyme activities based on 87 days of soil incubation experiment with maize residue addition under a gradient of nutrients. The hypothesis was that nutrient addition would result in a decline in the rate of CO₂ emission from both SOC and straw C due to the removing nutrient limitation and less enzymes production.

Materials and methods

Soil sampling and substrate application

Soils from the top layer (0-15 cm) in Zhejiang University, Xihu District, Hangzhou, China (Longitude 120.081E, Latitude 30.309N) were collected in November, 2018 and sieved using a 2 mm sieve to homogenize samples. The area experiences a moderately warm but not oppressively warm with an average annual temperature of 23°C and mean annual precipitation of 1050.0 mm (Jeewani *et al.*, 2021). The samples secured were subdivided into three. The first undisturbed sample was used to estimate the water content and holding capacity (WHC). The second sample was for evaluating fundamental soil properties, and the third component of soil was kept at 4 °C before using it for the incubation experiment. According to Jeewani *et al.* (2020), having a sandy clay loam texture, the soil is classified as an Alfisol. Initial characteristics as mean values plus standard error (n = 3) include the

following: bulk density $1.3 (\pm 0.1) \text{ g cm}^{-3}$, pH $5.9 (\pm 0.6)$, total C $23.7 (\pm 3.0) \text{ g kg}^{-1}$, total N $1.7 (\pm 0.2) \text{ g kg}^{-1}$, C to N ratio $14.8 (\pm 2.1)$, and a $\delta^{13}\text{C}$ value of $-26.3 (\pm 1.2) \text{ ‰}$. Maize straw leftovers were gathered, dried at 60°C for 72 hours, ground finely ($< 2.00 \text{ mm}$), and stored in a tight container. The residue contained $442.1 (\pm 27.3) \text{ g C kg}^{-1}$, $5.4 (\pm 0.4) \text{ g N kg}^{-1}$, a $\delta^{13}\text{C}$ value of $-11.2 (\pm 0.7) \text{ ‰}$, and a C-to-N ratio of $81.9 (\pm 10.2)$. The amount of straw added to the soil was $2.2 \text{ g dry matter kg}^{-1}$, or 5000 kg ha^{-1} .

First soil chemical analysis

In a soil-water mixture (1:2.5 w: v), the pH of the soil was measured after the mixture was briefly shaken for one hour and then left to settle for an additional hour. We then used a digital pH meter (Delta 320; Mettler-Toledo Instruments Co. China) to determine the pH of the soil solution. The difference between fresh and dried soil at 105°C for 24 hours was used to estimate the soil water content. The total C and N in the soil were determined, as previously explained (Cheng *et al.*, 2011; Xiong *et al.*, 2024). In summary, dried soil samples were treated with 1 M HCl for 24 hours in aliquots (roughly 10 g). The soil's total C and N were measured using an element analyzer (Model Vario Macro CN, Elemental Analyzer System GmbH, Hanau, Germany).

Incubation experiment

The treatments include Soil only (Control), Soil + Maize residues (NPK_L), Soil + Maize residues + medium Level of nutrients (NPK_M), and Soil + Maize residues + high Level of nutrients (NPK_H). The nutrients were added at the rate of $53.3 \text{ mg N kg}^{-1}$ soil (120 kg ha^{-1}), $26.7 \text{ mg P kg}^{-1}$ soil (60 kg ha^{-1}), and $26.7 \text{ mg K kg}^{-1}$ soil (60 kg ha^{-1}) for

NPK_M and $88.8 \text{ mg N kg}^{-1}$ soil (200 kg ha^{-1}), $44.4 \text{ mg P kg}^{-1}$ and $44.4 \text{ mg K kg}^{-1}$ soil (100 kg ha^{-1}) for NPK_H , respectively. Ammonium sulfate $(\text{NH}_4)_2\text{SO}_4$ was used to supply N and P in the form of sodium phosphate (Na_2HPO_4), and potassium phosphate (KH_2PO_4). Potassium sulfate K_2SO_4 and potassium phosphate KH_2PO_4 were used to supply the K. Three replications and a fully randomized design were used to set up the four treatments.

A 1000 mL serum bottle with 10 mL water without CO_2 at the bottom was used to put a beaker containing 50 g (oven-dry equivalent weight) soil sample to sustain 100% relative humidity. To remove the CO_2 , we placed a wide-mouthed container in the jar and added 20 mL of 1 M NaOH . A total of twelve (12) treatment samples, each with an additional one as blank, were incubated at 25°C respectively, for 87 days. For CO_2 and its isotopic analysis, we replaced NaOH vials at days 1, 3, 7, 14, 28, 56, and 87. Similarly, the two pairs of soil samples (50 g) were incubated separately for extracellular enzyme analysis.

Estimation of soil CO_2 and $\delta^{13}\text{C}$ (‰)

By titrating 1 M NaOH with 0.5 M HCl using a TIM840 auto titrator (Radiometer Analytical Villeurbanne Cedex, France), the amount of C released as CO_2 during soil incubation was calculated (Luo *et al.*, 2018). Five milliliters of NaOH solution were transferred into five milliliters of a 1.5 M BaCl_2 solution to analyze the $\delta^{13}\text{C}$ (‰) of the NaOH -trapped CO_2 -C (Jeewani *et al.*, 2020; Luo *et al.*, 2018). The BaCO_3 precipitates were filtered, gently washed with water, and dried overnight. Thermo Scientific 24005300 tin capsules were used

to weigh the residues, and an elemental analyzer-isotope ratio mass spectrometer (Sercon Ltd, Crewe, UK) was used to estimate the $\delta^{13}\text{C}$ values.

Enzymes assay

Microbial extracellular enzyme activities were determined using high-throughput microplate assays (Jackson *et al.*, 2013; Sinsabaugh and Linkins, 1990). The activity of β -glucosidase and α -glucosidase was measured using pNP-glucopyranoside and pNP-D-glucopyranoside in 96 well microplate. The mixture contained 150 μL 5mM substrate in 50 mM acetate buffer (pH 5.4), and the blend was covered at room temperature for 0.5-2 hours. We added 10 μL 1M sodium hydroxide to slow the reaction and recorded the absorbance at 410 nm. Cellobiohydrolase and β -xylosidase activities were assayed using the same method (96 well microplate assay) using 2mM pNP- β -D-cellobioside and pNP- β -D-xyloside.

Statistical analysis and calculations

According to Amelung *et al.* (2008), Luo *et al.* (2011), and Yu *et al.* (2018), the percentage of $\text{CO}_2\text{-C}$ derived from maize residue (%) in the soil was calculated.

$$\text{Maize residue derived CO}_2\text{-C (\%)} = (\delta\text{T}^{13}\text{C} - \delta\text{S}^{13}\text{C}) / (\delta\text{M}^{13}\text{C} - \delta\text{S}^{13}\text{C}) \times 100 \quad (1)$$

The percentage of maize straw decomposed was calculated as

$$\text{Maize straw decomposed (\%)} = (\text{maize-derived CO}_2 / \text{Total C in maize straw}) \times 100 \quad (2)$$

Using Eq. (2), the percentage of $\text{CO}_2\text{-C}$ derived from SOC (%) in the total $\text{CO}_2\text{-C}$ was calculated.

$$\text{SOC derived CO}_2\text{-C (\%)} = (\delta\text{T}^{13}\text{C} - \delta\text{M}^{13}\text{C}) / (\delta\text{S}^{13}\text{C} - \delta\text{M}^{13}\text{C}) \times 100 \quad (3)$$

Where SOC (%) is the percentage of soil-derived C, $\delta\text{T}^{13}\text{C}$ is the $\delta^{13}\text{C}$ value of the total $\text{CO}_2\text{-C}$ emitted from the mixture of soil and maize residue; $\delta\text{S}^{13}\text{C}$ is the $\delta^{13}\text{C}$ of the initial soil without the maize residue addition, and $\delta\text{M}^{13}\text{C}$ is the $\delta^{13}\text{C}$ of the added maize residue.

The cumulative CO_2 efflux data were fitted to the double exponential model (Fernández *et al.*, 2014; Leng *et al.*, 2019). The MRT or mean residence time of SOC were calculated as $1/k$.

$$\text{C}_{(t)} = \text{C}_{(a)} \times (1 - e^{-k_a t}) + \text{C}_{(s)} \times (1 - e^{-k_s t}) \quad (4)$$

where $\text{C}_{(t)}$ is the cumulative $\text{CO}_2\text{-C}$ (%) of SOC) by time t , the size of the active C pool in the soil is denoted by $\text{C}_{(a)}$, the size of the slow C pool in the soil is denoted by $\text{C}_{(s)} = 100\% - \text{C}_{(a)}$, and the mineralization rate constant of active and slow C pool is denoted by k_a and k_s respectively.

A one-way analysis of variance (ANOVA) was performed using the Statistical Product and Service Solutions (SPSS) version 20.0 for Windows (SPSS Inc., Chicago, IL, USA) to test the main effects of nutrient level (between subjects). The variation between treatments was calculated using the least significant difference (LSD) at $p \leq 0.05$. Also, the relationship between maize straw decomposition and enzyme activities was determined using Pearson's correlation. At p

≤ 0.05 , we considered a correlation to be significant. Accurately forecasting the soil C dynamics is essential for nutrient cycling, C sequestration, and soil health assessment. In SPSS Modeler version 18, neural network analysis is utilized to determine the significance of predictors in SOC dynamics, like enzyme activities and decay rates.

Results

Effect of nutrient on cumulative C mineralization

The cumulative CO₂ efflux for NPK_L, NPK_M, and NPK_H after 87 days of incubation was 1468.3, 1369.1, and 1607.3 $\mu\text{g CO}_2\text{-C g}^{-1}$ soil, respectively (Figure 2.1). The outcomes

showed that cumulative CO₂ efflux is significantly impacted by nutrient addition.

Native soil and maize residue C mineralization

Maize residue (straw) and nutrient input had a significant impact on the mineralization of native SOC. The cumulative soil-derived CO₂ was 1077.78 $\mu\text{g CO}_2\text{-C g}^{-1}$ soil for NPK_L, 1011.96 $\mu\text{g CO}_2\text{-C g}^{-1}$ soil for NPK_M, and 1156.99 $\mu\text{g CO}_2\text{-C g}^{-1}$ soil for NPK_H, according to the trend of the soil-derived organic C after 87 days of incubation (Figure. 2.2).

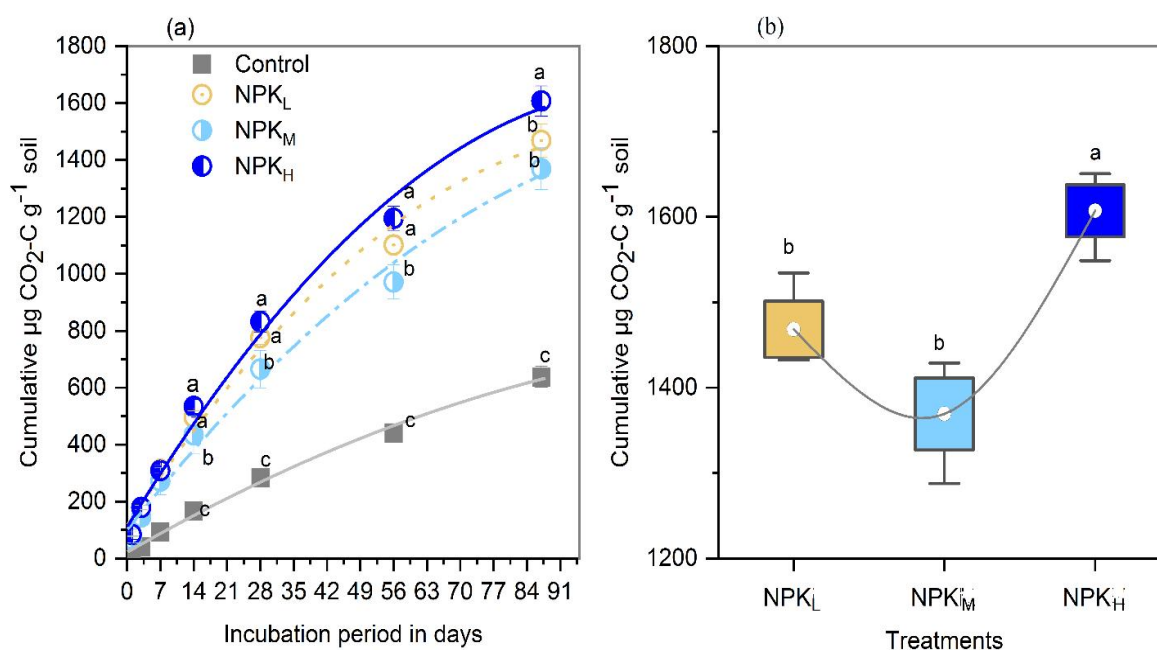


Figure 1. The cumulative C emission response to nutrient addition and maize residue (straw)

(a), Patterns of cumulative C emissions as a result of nutrient addition

(b). Treatments include soil alone (Control), soil plus leftover maize (NPK_L), soil plus leftover maize + medium nutrients (NPK_M), and soil plus leftover maize + high nutrients (NPK_H). Error bars designate standard error (n = 3), and solid lines represent a double-first-order nonlinear exponential fit curve for the observed data. Significant treatment differences can be seen in lowercase letters ($p \leq 0.05$).

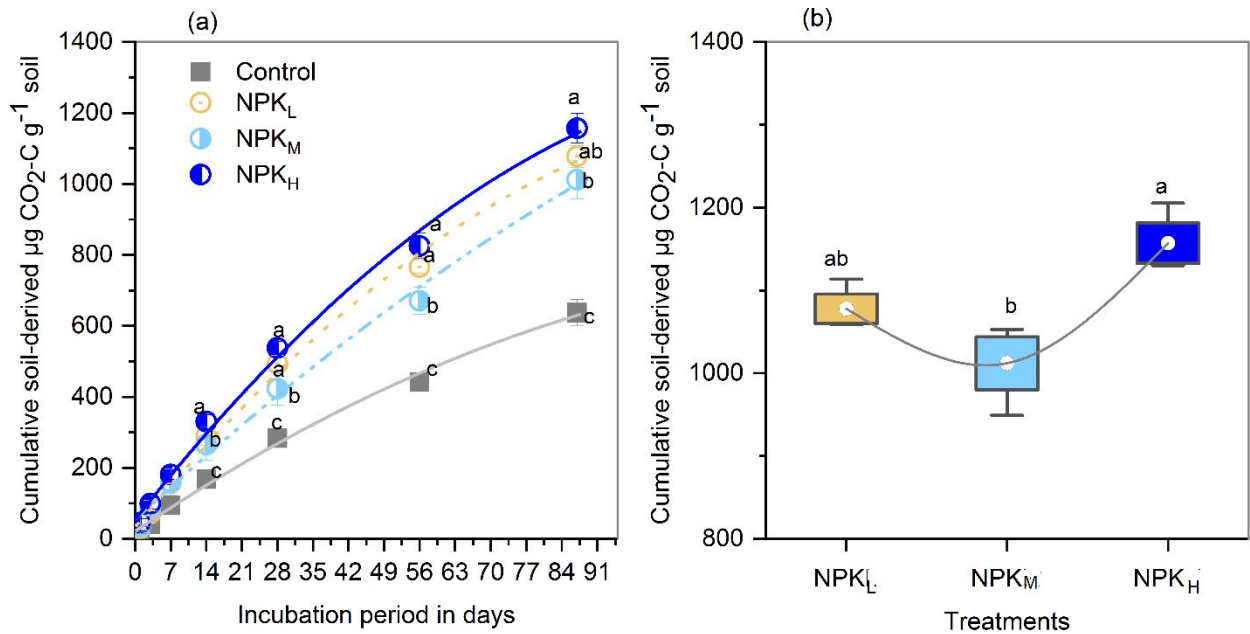


Figure. 2 The accumulated soil-derived CO₂ efflux in response to nutrient availability and maize residue (straw) (a). Patterns of cumulative soil-derived CO₂ in response to nutrient (b).

The main fertilizer treatment effects significantly affected the maize straw decomposition rate. After 87 days, the cumulative maize straw-derived CO₂ efflux for NPK_H, NPK_M, and NPK_L was 450.34 µg CO₂-C g⁻¹ soil, 357.17 µg CO₂-C g⁻¹ soil, and 390.53 µg CO₂-C g⁻¹ soil (Figure. 2.3).

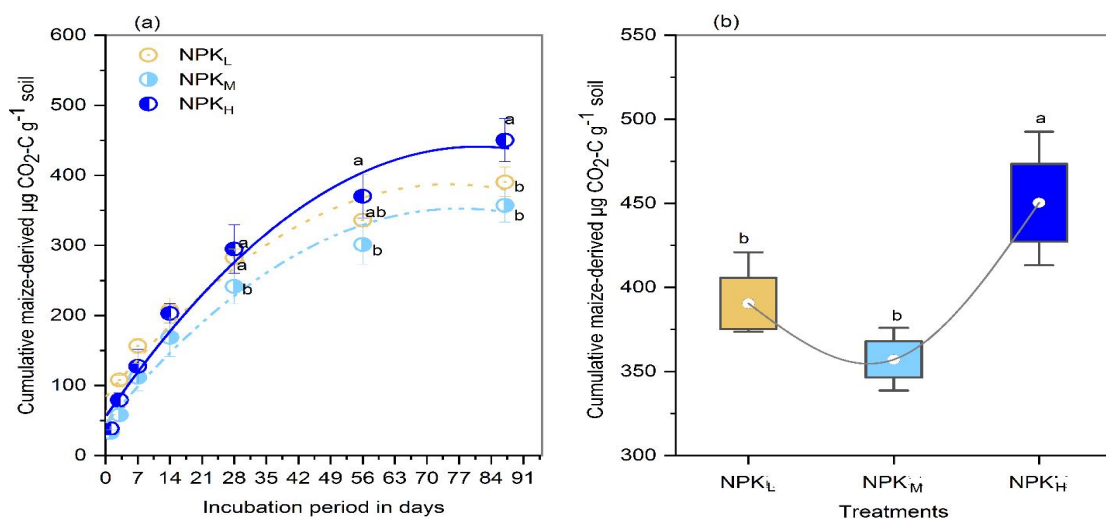


Figure 3 Cumulative maize straw-derived CO₂ in response to nutrient availability (a) Patterns of maize straw-derived CO₂ response to nutrient availability (b).

Cumulatively, the percent of decomposed values in NPK_H treatment (46.3%) followed maize straw C observed showed higher by NPK_L (40.15%). The lowest value,

36.72%, was observed in NPK_M treatment (Figure. 2.4b).

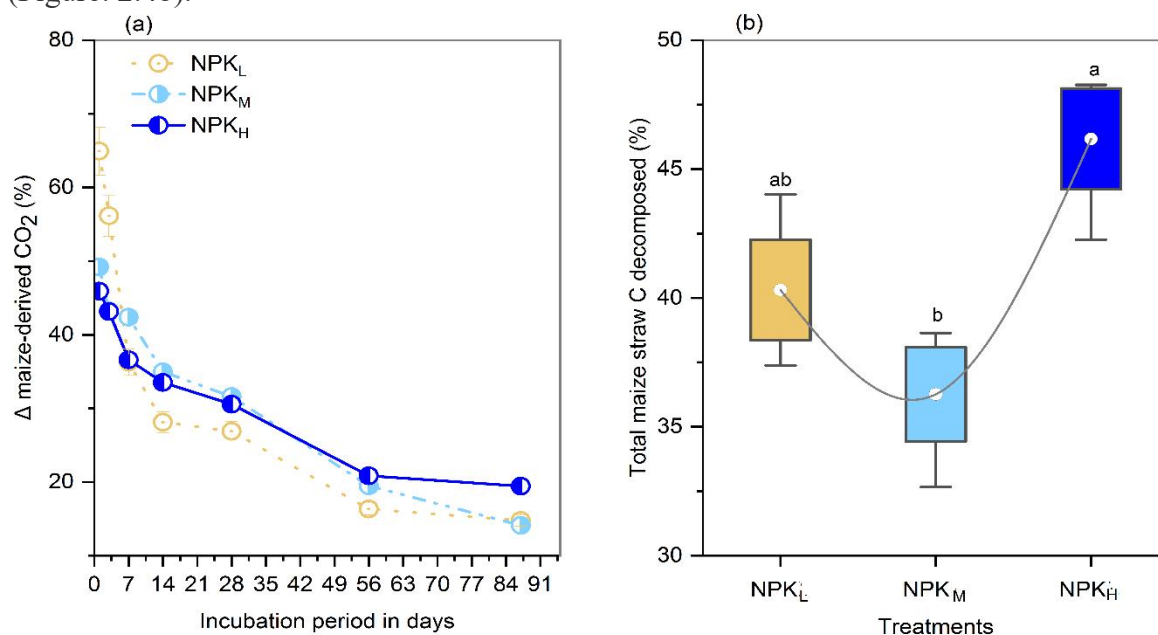


Figure 4 Dynamic change in maize straw-derived CO₂-C (%) (a) and Total maize straw C decomposed (%) under different nutrient treatments (b).

MRT of different C pools as regulated by nutrient addition

The turnover is the mean residence time (MRT). The effects of nutrient treatments on the MRT of the active soil C pool (MRT_a) and slow soil C pool (MRT_s)

Table 2.1 shows the impact of nutrient addition on the MRT of the active (MRT_a) and slow (MRT_s) C pools.

Treatment	k_a	$MRT_a = 1/k_a \times 87$ (days)	k_s	$MRT_s = 1/k_s$ (years)
Control	-	-	0.023a	43.7b
NPK _L	1.212a	71.8c	0.022a	45.9ab
NPK _M	0.54b	161.1b	0.022a	44.8b
NPK _H	0.479b	181.6a	0.021a	48.8a

Note: Control without the addition of straw/nutrients represented as (Control), maize residues + 0 nutrients addition (NPK_L), the addition of maize residue + nutrient at a medium concentration (NPK_M), and the addition of maize residue + nutrient at a high level (NPK_H). The k_a and k_s are active and slow C pool decomposition rates. A significant difference between treatments was denoted by lowercase letters (one-way ANOVA and LSD test; $p \leq 0.05$).

Extracellular enzyme activities

The activities of extracellular enzymes in the soil solution varied significantly between the

were significant ($p < 0.001$). The active C pool's mean MRT varied from 71.8 to 181.6 days (Table 2.1). However, the slow C pool's MRT varied from 43.7 to 48.8 years.

treatments. For the β -glucosidase enzyme, the activity was 0.91 $\mu\text{mol pNP hr}^{-1} \text{g}^{-1}$ soil in the control treatment, 2.76 $\mu\text{mol pNP hr}^{-1}$

g^{-1} soil in the NPK_L treatment, $2.45 \mu\text{mol pNP hr}^{-1} \text{g}^{-1}$ soil in the NPK_M treatment, and $2.65 \mu\text{mol pNP hr}^{-1} \text{g}^{-1}$ soil in the NPK_H treatment. The α -glucosidase activities were $0.64, 1.68, 1.60,$ and $1.58 \mu\text{mol pNP hr}^{-1} \text{g}^{-1}$ soil for the

control, NPK_L , NPK_M , and NPK_H treatments. The cellobiohydrolase activities were $0.62,$

$1.83, 1.72,$ and $1.77 \mu\text{mol pNP hr}^{-1} \text{g}^{-1}$ soil for the control, NPK_L , NPK_M , and NPK_H treatments. For the β -xylosidase enzyme, the activities were $1.72, 2.74, 2.46,$ and $2.69 \mu\text{mol pNP hr}^{-1} \text{g}^{-1}$ soil for the control, NPK_L , NPK_M , and NPK_H treatments, respectively (Figure 5). Overall, adding maize straw to the soil increased the rate of enzyme activities at all nutrient levels (Figure 5).

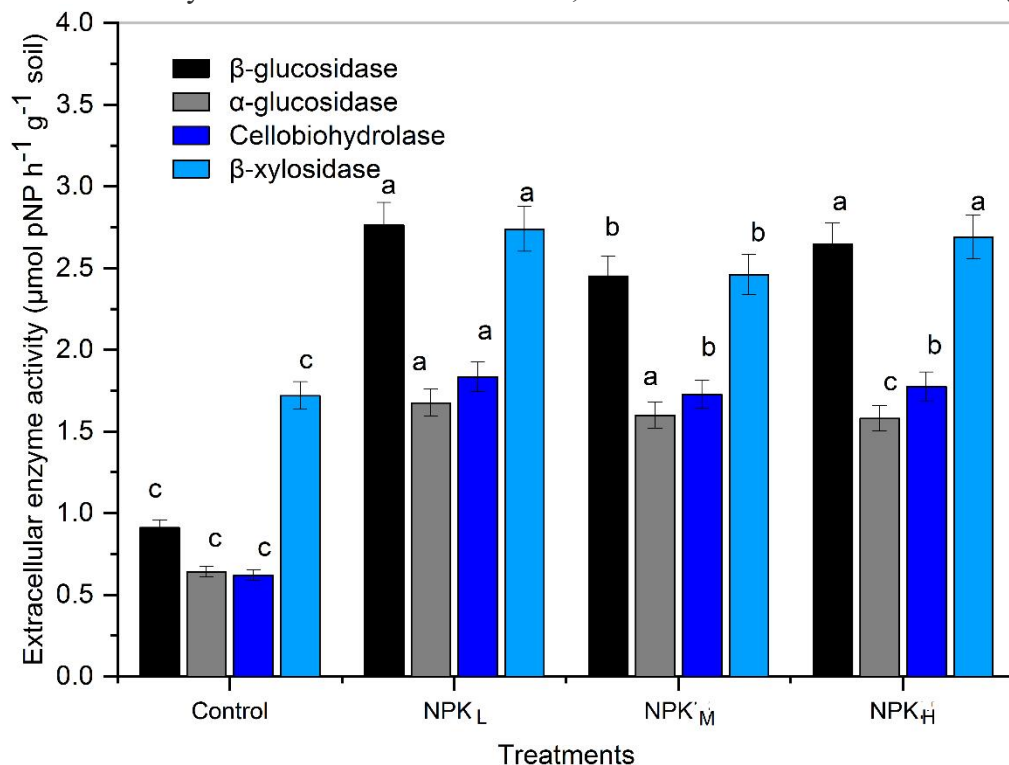


Figure 5 β -glucosidase (a), α -glucosidase (b), cellobiohydrolase (c), and β -xylosidase (d) activities as regulated by nutrient addition. Significant treatment differences can be seen in lowercase letters ($p \leq 0.05$).

The nutrient addition caused no significant effect on extracellular enzyme activity. Besides, the soil enzymes' activity positively correlated with total CO_2 efflux in both nutrient treatments (Figure. 2.6).

However, some negative relationship was observed, especially with the slow C pool's decay rate and maize residue-derived CO_2 (Figure. 6a).

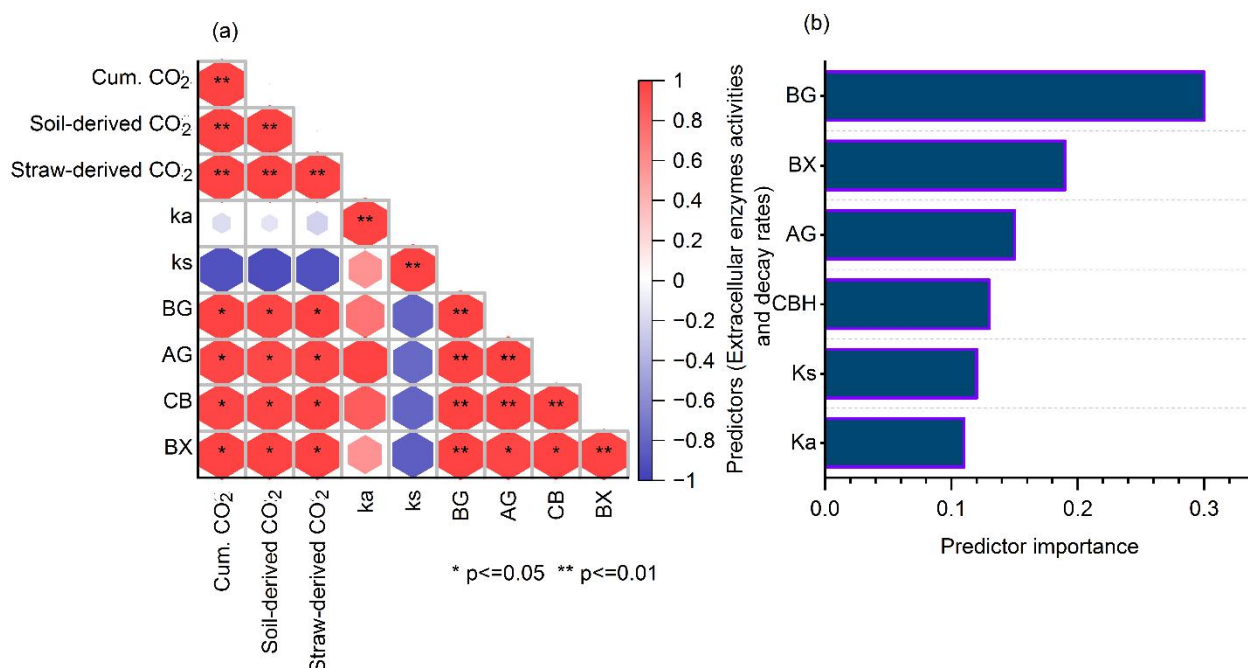


Figure 6 Pearson's correlation matrix between the extracellular enzyme activities of β -glucosidase (BG), α -glucosidase (AG), Cellobiohydrolase (CB) and β -xylosidase (BX), as well as cumulative CO₂ efflux, soil-derived CO₂, maize straw-derived CO₂, and decomposition rates of the active (k_a) and slow (k_s) C pools (a) and the effect of extracellular enzyme activities and decomposition rates on soil C mineralization and turnover based on neural network analysis (b).

Discussions

Nutrient control on SOC and straw residue C decomposition

The nutrient levels significantly influence the mineralization rate of soil C mineralization ($p < 0.01$) (Figure 2) and, similarly, residue C mineralization (Figure 3), which indicates that the addition of nutrients mediates the decomposition rate and hence may facilitate soil C sequestration. Moreover, in the long run, organic matter and nutrients (NPK) application acted as an energy barrier to SOM mineralization. They had significant potential for less corresponding to their total SOM decay. The cumulative soil-derived CO₂ was highest for NPK_H, followed by NPK_L and NPK_M. These results suggested that increased native SOC

mineralization is stimulated by higher nutrient input (NPK_H). The findings were consistent with other research (Zhou *et al.*, 2017) which found a higher nutrient availability correlated with increased mineralization of SOC. According to Beillouin *et al.* (2023), nutrient input can increase microbial activity, which will increase the breakdown of organic matter and the release of CO₂. Similarly, the highest cumulative CO₂ efflux derived from maize straw was highest for NPK_H, followed by NPK_L and NPK_M. This result implies that increased nutrient levels also intensify the breakdown of maize straw. These findings were in line with other studies that have demonstrated the beneficial effects of nutrient availability on residue

decomposition (Liu *et al.*, 2023). According to Zhou *et al.* (2020), nutrients can increase the microbial activity and enzymatic processes that break down straw, which increases the release of CO₂.

By giving microorganisms the resources they need to grow and function, nutrients can promote microbial activity and enzymatic processes. For instance, straw decomposition is frequently limited by nitrogen, an essential nutrient for microbial growth (Fang *et al.*, 2018). The addition of nutrients to straw can promote the development and activity of microorganisms, speeding up the breakdown process and causing the CO₂ release. Nutrients can also increase the synthesis and activity of the enzymes needed to break down straw. For instance, the synthesis of phosphatase enzymes, which is essential for the hydrolysis of organic phosphorus compounds in straw, depends on phosphorus (Mehnaz *et al.*, 2019). Thus, the production and activity of these enzymes can be increased by the addition of phosphorus and other nutrients, which will facilitate the straw breakdown.

Researchers have proposed that significant investment in enzymes can sometimes limit the activity of microbes in acquiring nutrients and energy from complex organic compounds in the soil (Kuzyakov *et al.*, 2019). To overcome this limitation, adding new organic can provide the energy necessary for microbial investment (Kuzyakov and Razavi, 2019). However, adding nutrients can also lead to increased microbial utilization and CO₂ efflux, which may be attributed to changes in the ratio of C to N (Fang *et al.*, 2018). Adding maize

residues supplies more C than N, increasing the C/N ratio and promoting microbial growth and activities (Zhao *et al.*, 2019). It is in line with the "nutrient bank" theory (Mehnaz *et al.*, 2019), which suggests that nutrient availability influences the mineralization of SOC and the release of nutrients through microbial nutrient mining. In our experiment, maize straw decomposition occurred faster initially than in later stages (Figure 2.4). Other studies have shown that applying organic residues can stimulate microbial activity by immobilizing inorganic N (Bastida *et al.*, 2019), indicating that N may be a limiting factor for microbial growth when crop residues are added.

The pattern of residue C mineralization shows that from the beginning of the incubation, the fast decomposition phase was from 1 to 14 days, and the slow decomposition stage was from 15 to 87 days (Figure 4). Previous research has shown that maize residues decompose more rapidly in the initial 14 days of incubation, followed by slower decay, potentially due to a decrease in the C/N ratio (Mincheva *et al.*, 2014). Similar studies have also observed reduced decomposition of residue C (Bandau *et al.*, 2017; Liu *et al.*, 2021). However, in the case of switchgrass addition supplemented with N, there was increased net CO₂ evolution (Sigua *et al.*, 2016). Thus, the ratio of C to N is a crucial factor influencing the decomposition of organic residues.

In summary, this finding shows that nutrient levels have a major impact on both the decomposition of maize straw residues and SOC dynamics. Increased nutrient input was found to accelerate the breakdown of maize

straw and the mineralization of native SOC, both of which increased CO₂ release. Notwithstanding, these results demonstrate how crucial of nutrient availability in the decomposition of native SOC and maize straw. A higher nutrient input induces the native SOC to mineralize more and the maize straw to break down more quickly, which increases CO₂ release. Thus, controlling nutrient inputs can be a viable technique for controlling the SOC dynamics in agricultural ecosystems.

Influence of nutrients on C turnover

The study's results demonstrated that the MRT of the active and slow soil C pools is considerably influenced by nutrient addition. In particular, the applied nutrient treatment affected the MRT of the active C pool. The MRT was longest for NPK_H (181.6 days), followed by NPK_M (161.1 days) and shortest for NPK_L (71.8 days). On the other hand, there was less variation in the MRT of the slow C pool among the nutrient treatments, indicating that these compounds are more recalcitrant or stable. The MRT for the NPK_H treatment was 48.8 years; for the NPK_M was 44.8 years and for NPK_L was 45.9 years; while it was 43.7 years for the control treatment. These findings suggest that, in comparison to the active C pool, the slow C pool's turnover may be less affected by nutrient addition. These results imply that nutrient addition may have an impact on the stability and turnover of the soil's active C pool. The reduced MRT seen after the NPK_L treatment suggests a faster turnover of the active C pool, maybe as a result of enhanced microbial activity and breakdown mechanisms. The longer MRT seen with the NPK_H treatment, on the other hand, may

indicate a slower turnover of the active C pool because of increased stabilization of C compounds and decreased microbial activity. These results are consistent with earlier research showing the impact of nutrient availability on soil C dynamics. For example, Kou *et al.* (2023) discovered that the interactive addition of N and P significantly changed the structure of the microbial community, increasing the activity of soil microbes (microbial biomass and soil respiration), which accelerated the turnover of the active C pool. Comparably, Zi *et al.* (2022) found that P fertilization increased the activity of microbial enzymes and microbial biomass (Huang *et al.*, 2021), hastening the breakdown of SOM and influencing the turnover of the active C pool. The addition of nutrients can act as a barrier to the activation energy of soil decomposition processes, possibly due to a decrease in the soil's C/N ratio caused by nutrient addition. This modification in soil nutrient status can reduce the activation energy required for C decomposition, leading to a reduced decomposition rate (Luo *et al.*, 2020). Additionally, the addition of straw (residue) and interactions with nutrients significantly affected the MRT, indicating that the availability of nutrients and stoichiometric flexibility regulate soil C turnover (Zhu *et al.*, 2018).

The effect of fertilization on MRT of the active C pool indicated that nutrient availability influences soil C turnover and stability. Thus, the addition of nutrients decreased the turnover rate and MRT of SOM by reducing soil nutrient mining, positively impacting soil C sequestration capacity.

Effect of nutrient addition on extracellular enzyme activity

This study found that adding nutrients to the soil with residue amendments decreased soil enzyme activities. This could be attributed to soil microorganisms having a lower demand for nutrients when readily available. The activities of certain extracellular enzymes, such as β -glucosidase, α -glucosidase, Cellobiohydrolase, and β -xylosidase, depend on nutrient availability (Lin *et al.*, 2019). This relationship between nutrients and enzyme activities is consistent with microbial metabolism's economic theories, which suggest that enzyme activity production declines when simple nutrients are present but increases with an abundance of complex nutrients (Meng *et al.*, 2020).

Positive relationships were also discovered between hydrolytic enzyme activities and soil C kinetics parameters (Figure 6a). The Michaelis-Menten relationship supported this positive correlation, indicating that substrate availability primarily regulates enzyme activity (Meng *et al.*, 2020). However, we also observed some negative relationships, particularly with the mineralization rate of the slow C pool and the CO₂ derived from maize residue. This could be due to the incubation process leading to a decrease in active soil C (Wilpiseski *et al.*, 2019) and an increase in stable C compounds (Meng *et al.*, 2020), resulting in negative correlations between enzyme activity and the kinetics of recalcitrant C in the soil. Other studies with similar findings were also reported (Luo *et al.*, 2019; Xu *et al.*, 2020), demonstrating a negative correlation between slow C pools and cellobiohydrolase and polyphenol

oxidase activities. Hence, soil enzyme activities were reduced when nutrients were added to the soil with residue amendments, suggesting that soil microorganisms require less nutrients when they are easily accessible. A neural network analysis was used to address the complex relationships and non-linear interactions related to soil C dynamics. The results showed that enzyme activity was a significant predictor of soil C dynamics (Figure 6b), which is in line with other studies (e.g., Zhang *et al.*, 2022). This research highlights how important enzymes are to the SOM breakdown, which is the main process that drives the C cycling in soil (Sulman *et al.*, 2014). The role of β -glucosidase in hydrolyzing cellulose, a significant source of soil C and a component of plant biomass, is well-established, which explains its prominence (Chakrawal *et al.*, 2020). Its strong predictive ability points to a major function in controlling C cycle. Likewise, the significance of β -xylosidase suggests that it plays a role in the degradation of hemicellulose, e.g., another essential plant component (Lyu *et al.*, 2019). Alpha-glucosidase may have less effect because it focuses on simpler sugars that are more widely available in the soil (Malik *et al.*, 2019).

The analysis also revealed the significance of the decay rate, with the slow k_s outperforming the active k_a . This finding highlights the importance of slower decomposition processes for long-term soil C storage. Hence, to preserve and expand stable soil C pools are essential for enhancing C accrual in ecosystem (Lal, 2018).

Conclusions

In conclusion, our incubation experiment demonstrated that nutrient addition regulates the mineralization rate of soil and maize straw C. The addition of straw promoted the production of microbial enzymes, leading to increased mineralization rates of both straw and SOC. The microbial nutrient mining theory suggests that soil microbes "mine" SOM to meet their nutrient requirements. This could potentially result in the loss of C from the soil. However, adding additional mineral nutrients inhibited the mineralization rate of soil and straw-derived C. This inhibition could be attributed to soil microorganisms' decreased demand for nutrients when nutrients are readily available, as the "nutrient bank" mechanism theory predicted. In general, the study highlights the role of nutrient addition in controlling the decomposition rate of soil and crop residue C.

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INFLUENCE OF PHOSPHATE FERTILIZER LEVELS ON THE GROWTH AND YIELD OF COWPEA IN MAKURDI

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Introduction

Cowpea (*Vigna unguiculata* (L.) Walp) is a critical indigenous food legume and a cornerstone of food security across sub-Saharan Africa (SSA), where it is cultivated on approximately 12.5 million hectares and feeds over 200 million people daily (FAOSTAT, 2023; Ojiewo *et al.*, 2020). Nigeria stands as the world's largest producer, with an annual output of 3.4 million tonnes, accounting for nearly half of Africa's production (Nwagboso, 2024; IITA, 2024).

Despite this vast production, the average grain yield in farmers' fields remains below 1 t ha⁻¹, a mere 25% of the 2.5–3.0 t ha⁻¹ routinely achieved under optimal on-station conditions where nutrient and water are not limiting (FAOSTAT, 2023; Kamara *et al.*, 2022). This significant yield gap is particularly pronounced in the southern Guinea savanna, including Makurdi (7° 44' N, 8° 32' E), where soils are inherently low in phosphorus (P) (Amapu *et al.*, 2021; Oikeh *et al.*, 2020).

Cowpea is an important component of sustainable agriculture due to its symbiotic nitrogen fixation with *Rhizobia* bacteria, which enriches the soil and benefits subsequent cereal crops (Nkurunziza *et al.*, 2025). However, this nitrogen fixation is a P-intensive process, with every kilogram of nitrogen fixed requiring approximately 0.25 kg of phosphorus (Bargaz *et al.*, 2022).

Consequently, P deficiency is the most common nutritional constraint limiting nodulation, vegetative growth, and ultimately, harvest index in farmers' fields (Kamara *et al.*, 2022; Ojiewo *et al.*, 2020).

Phosphorus is an essential macronutrient that profoundly influences cowpea's growth and yield. It promotes robust root development, initiates nodule formation, and enhances the efficiency of the rhizobium-legume symbiosis, thereby optimizing biological nitrogen fixation (Singh *et al.*, 2025; Haruna and Aliyu, 2011). Without adequate P, cowpea growth is severely limited once seed reserves are exhausted (Singh *et al.*, 2025). Despite this, cowpea in Nigeria is typically grown with minimal or no mineral P fertilizer, relying solely on low, naturally available soil nutrients (Nwagboso, 2024).

Recent high-yielding varieties, such as the dual-purpose, *Striga* and virus-resistant FUAM Pea 2, have the genetic potential to double yields to 2.8 t ha⁻¹ under optimal management (Aliyu *et al.*, 2022). However, current fertilizer recommendations for these modern genotypes are often outdated, based on studies from the 1990s using obsolete varieties that were less responsive to nutrients (Haruna and Aliyu, 2011; Osodeke, 2005). With a 300% increase in global phosphate prices since 2020 (World Bank, 2023), precise P-rate calibration is now an economic necessity as well as an agronomic one.

Objective of the Study

The study was carried out with the following objectives:

- i. To determine the effect of phosphate fertilizer on the growth of cowpea
- ii. To determine the effect of phosphate fertilizer on the yield of cowpea

MATERIALS AND METHODS

The field experiment was conducted during the 2024 cropping season at the Teaching and Research Farm of Joseph Sarwuan Tarka University, Makurdi, Benue State, Nigeria, located at Latitude 7° 44' N, Longitude 8° 32' E, and Altitude 97 m above sea level, within the Southern Guinea Savanna agro-ecological zone where the dominant soil type is an Alfisol. Before planting, a composite soil sample (0–15 cm depth) was collected randomly in a zigzag pattern, air-dried, sieved, and analyzed at the university's soil science laboratory to determine its physicochemical properties including soil texture, pH, organic carbon, total nitrogen, available phosphorus, and exchangeable cations. The experiment was laid out in a Randomized Complete Block Design (RCBD) with three replicates for four phosphate fertilizer levels (0, 27, 54, and 81 kg P₂O₅/ha), which were applied as Single Super Phosphate (SSP). The experimental site, measuring 12 m × 12 m, was manually cleared, with each 2 m × 2 m plot separated by a 0.5 m alley, and 1 m between replications. Cowpea seeds (cultivar FUAM Pea 2) were sown by hand at a depth of 2 cm with a spacing of 75 cm by 20 cm, with two seeds per hole, under rainfed conditions. Weeds were manually controlled. Phosphate fertilizer was applied via the band placement method three weeks

after planting. Pests, mainly cowpea aphids, were managed by spraying Cyperstar (cypermethrin 10 EC) at 100 mL per 20 L of water. Data were collected from five randomly selected plants from the central rows of each plot on the number of leaves, plant height (cm), and grain yield (kg/ha). All collected data were subjected to a one-way Analysis of Variance (ANOVA) using GENSTAT (2015), and the Least Significant Difference (LSD) test at a 5% probability level was used for mean separation.

RESULTS

INITIAL SOIL SAMPLING

The general chemical and physical properties of the surface soils used for the field experiments are presented in Table 1.

pH: The pH value indicates the acidity or alkalinity of the soil. A pH of 6.18 suggests that the soil is slightly acidic. pH is an essential parameter as it affects nutrient availability to plants and influences soil microbial activity. **Sand (%), Silt (%), Clay (%):** These values represent the soil texture. The soil is classified as sandy loam based on the given percentages. Soil texture influences the water-holding capacity, drainage, and nutrient-holding capacity of the soil. Sandy loam is generally considered good for plant growth as it provides a balance between drainage and water retention. **Organic Carbon (%):** Organic carbon is a measure of the amount of decomposed organic matter present in the soil. It is an essential component for soil fertility and nutrient cycling. The given value of 0.43% suggests a moderate level of organic carbon in the soil. **Total Nitrogen (%):** Nitrogen is a vital nutrient for plant growth and is necessary for various

biochemical processes. The given value of 0.036% represents the total nitrogen content in the soil. It helps assess the soil's fertility and potential for supporting plant growth. Phosphorus (mg kg⁻¹): Phosphorus is another crucial nutrient required for plant growth, especially for root development and flowering. The given value of 3.80 mg kg⁻¹ indicates the phosphorus content in the soil. It helps evaluate the soil's fertility and the need for phosphorus-based fertilization. K⁺ (cmol kg⁻¹), Ca²⁺ (cmol kg⁻¹ soil), Mg²⁺ (cmol kg⁻¹), Na⁺ (cmol kg⁻¹): These values represent the concentrations of essential cations (potassium, calcium, magnesium, and sodium) in the soil. These cations play important roles in nutrient uptake by plants and soil structure. The given values help assess the nutrient status of the soil and the availability of these cations to plants. TEB (cmol kg⁻¹), EA (cmol kg⁻¹), CEC (cmol kg⁻¹): TEB stands for Total Exchangeable Bases, EA represents Exchangeable Acidity, and CEC stands for Cation Exchange Capacity. These parameters are related to the soil's ability to hold and exchange nutrients. The given values help evaluate the soil's capacity to retain and supply nutrients to plants. BS (%): BS represents Base Saturation, which is the proportion of exchangeable bases (calcium, magnesium, potassium, and sodium) in relation to the CEC. The given value of 83.63% indicates the dominance of exchangeable bases in the soil, which is generally desirable for plant growth. The total annual rainfall at the experimental site was 604 mm with peak in August.

Table 1: physical and chemical properties of the soil before planting

Parameter	Value

Number of Leaves

Phosphorus acts as a growth catalyst in cowpea, substantially increasing the number of leaves at 6 weeks after sowing. Notably, plants receiving 80 kg P₂O₅/ha displayed the fullest foliage, a testament to phosphorus's power to fuel early vegetative development. This boost in leaf production translates into a larger photosynthetic surface, enabling the plant to fuel its growth engine more efficiently. Even moderate phosphorus doses (20–60 kg P₂O₅/ha) showed near-maximal leaf counts, while phosphorus-starved plants lagged behind, underscoring the nutrient's critical importance in canopy formation (Afolayan *et al.*, 2024).

Plant Height

Imagine a race where plant height is the winning criterion. In this competition, phosphorus acts as a potent performance enhancer. At 6 weeks after sowing, plants treated with 60 and 80 kg P₂O₅/ha surged ahead, growing significantly taller than their phosphorus-deficient peers. This boost stems from phosphorus's role in stimulating root vigor and nutrient uptake, fueling shoot elongation and overall plant vigor vital for maximizing yield (Okpara *et al.*, 2023).

100-Seed Weight

Seed weight is the currency of yield value, and phosphorus exerts a subtle yet positive influence here. Although differences in 100-seed weight were not statistically significant, a trend of increasing seed mass with higher phosphorus doses was observed, indicating improved nutrient translocation during grain filling. Phosphorus supports physiological

PH	6.18
Sand (%)	71.80
Silt (%)	13.0
Clay (%)	15.20
Textural Class	Sandy Loam
Organic Carbon (%)	0.43
Total Nitrogen (%)	0.036
Phosphorus(mg kg ⁻¹)	3.80
K ⁺ (cmol kg ⁻¹)	0.21
Ca ²⁺ (cmol kg ⁻¹ soil)	2.81
Mg ²⁺ (cmol kg ⁻¹)	2.52
Na ⁺ (cmol kg ⁻¹)	0.18
TEB (cmol kg ⁻¹)	5.72
EA (cmol kg ⁻¹)	1.12
CEC (cmol kg ⁻¹)	6.84
BS (%)	83.63

Key: pH= Alkalinity, K⁺=potassium, Ca=Calcium, Mg=Magnesium, TEB=Total Exchangeable Base, EA=Exchangeable Anions, CEC=Cations Exchange Capacity, BS=Base Saturation.

activities like ATP regeneration and lipid biosynthesis, contributing to plumper, heavier seeds (Emodi *et al.*, 2022).

Number of Grains per Plot

Phosphorus sprinkles a bit of magic on grain count too. Although the increase was not statistically significant, grain count per plot rose with increasing phosphorus application, peaking at 80 kg P₂O₅/ha. This pattern suggests enhanced reproductive success through improved flowering, pollination, and seed set, reinforcing phosphorus's role beyond vegetative growth (Ibeawuchi *et al.*, 2024).

Number of Pods per Plant

Phosphorus's fingerprint is evident on pod numbers, with the highest rate (80 kg

P₂O₅/ha) producing the most pods per plant and the control the fewest. Though variability prevented significant difference,

this trend reflects phosphorus's ability to foster flowering and fruiting, foundational for increased yield (Chukwu *et al.*, 2023).

Pod Length

A surprising twist emerges upon examining pod length: the 20 kg P₂O₅/ha treatment created the longest pods, while the heaviest phosphorus dose resulted in shorter pods. This likely signals a strategic resource allocation favoring seed filling over pod elongation at higher phosphorus levels, emphasizing moderation in fertilization strategies (Onwuchekwa and Nwankwo, 2021).

Grain Weight per Pod

When it comes to grain weight per pod, phosphorus draws a clear winning line. Increasing phosphorus rates steadily boosted grain weight from 0.320 g in controls to 0.587 g at 80 kg P₂O₅/ha, highlighting the nutrient's vital role during seed filling. Adequate phosphorus ensures that energy

and nutrients flow efficiently to developing seeds, culminating in heavier grains and improved yield quality (Okeke *et al.*, 2025).

Table 2: effect of phosphate fertilizer on growth of cowpea in Makurdi

P₂O₅	Number of Leaf			Plant Height		
	2 WAS	4 WAS	6 WAS	2 WAS	4 WAS	6 WAS
0	28.30	21.00	25.7	16.7	18.5	8.2
20	28.00	32.20	31.3	18.3	19.8	10.1
40	38.10	39.90	42.1	19.3	21.4	12.2
60	45.20	44.40	49.60	21.5	23.4	10.12
80	63.30	65.60	72.0	22.7	25.1	12.2
LSD (P≤0.05)	11.22	16.18	17.45	1.65	1.92	NS

Table 3: Effect on grain per plot, 100 grain weight and weight of grain, Number of Pods per Plot and Pod Length of cowpea

TREATMENT (kgt/ha)	No. of Pod Per Plant	Pod Length (cm)	Weight of Grain Per pod (g)	100 Grain Weight (g)	Weight of Grain per Plot (kg)
Control	5.30	15.5	0.320	16.54	2.50
20	5.93	25.7	0.373	17.01	2.75
40	6.90	16.1	0.467	17.55	2.81
60	7.65	16.8	0.500	17.95	2.97
80	8.79	19.1	0.587	18.61	4.27
LSD(P≤0.05)	0.842	0.57	0.230	0.646	0.287

Key: LSD=Least Significant Difference, WAP=Weeks After Planting, NS = Not Significant

Conclusion and Recommendations

This study clearly demonstrates that phosphorus fertilization plays a pivotal role in enhancing various growth and yield

parameters of cowpea. Application of phosphorus significantly increased the number of leaves, plant height, and grain weight per pod, all of which are integral to

improving overall crop productivity. Although some yield components such as 100-seed weight, number of grains per plot, and pods per plant showed positive trends with phosphorus application, they were not always statistically significant, reflecting the complex interaction of phosphorus with other environmental and genetic factors. The finding that moderate phosphorus rates (20–60 kg P₂O₅/ha) elicited near-optimal growth responses while very high application rates sometimes led to diminished pod length underscores the importance of balanced nutrient management.

Given these results, an application rate of approximately 40 to 60 kg P₂O₅/ha is recommended for optimal cowpea growth and yield in Nigerian agro-ecological zones, aligning with findings by various Nigerian researchers (Afolayan *et al.*, 2024; Omoigui *et al.*, 2020). This rate supports robust vegetative growth, effective reproductive development, and improved grain filling while avoiding potential nutrient imbalances or environmental inefficiencies associated with excessive phosphorus use. Encouragingly, adoption of phosphorus fertilization can be a game-changer for smallholder cowpea farmers in Nigeria, enhancing food security and economic returns.

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EFFECT OF SOIL PHOSPHORUS LEVELS ON SOYBEAN PERFORMANCE IN NIGERIAN SAVANNAS

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ABSTRACT

Soybean is an important leguminous crop with high nutritional, economic, and ecological values. However, the productivity of soybean can be highly constrained by soil phosphorus (P) availability. Since soybean is capable of biological nitrogen fixation, P remains a major growth limiting factor for its production. Field trials were conducted during the 2023 rainy season in two Nigerian agroecologies: Northern Guinea (Samaru) and Sudan (Minjibir) savannas, with differing levels of soil available P. The treatments included two biofertilizer formulations (A and B) applied with or without NPK fertilizer in a randomized complete block design with four replicates. There were three levels of biofertilizer -A (0, 10, and 20 L/ha), biofertilizer -B (0, 5, and 10 L/ha), and NPK mineral fertilizer (0%, 50% and 100% recommended rates). In Samaru with moderate soil P level (15.68 mg/kg), biofertilizer and NPK fertilizer application enhanced soybean growth and yield. The application of Biofertilizer -A at a rate of 20 L/ha, as well as NPK fertilizer at both 50% and 100% of recommended rates, significantly ($P \leq 0.05$) enhanced plant height. Additionally, soybean grain yield showed a significant ($P \leq 0.05$) increase with NPK fertilizer applied at 50% (2.8 t/ha) and 100% (3.2 t/ha) of the recommended rates compared to the control yield of 2 t/ha. However, in Minjibir where soil P was high (41.16 mg/kg), no responses were observed to the application of biofertilizer and NPK fertilizer. Neither biofertilizer-A, biofertilizer-B, nor NPK fertilizer, including their interactions, had a significant effect on soybean growth and yield. The findings of this study highlight the critical role of soil available P levels in determining soybean performance irrespective of additional inputs. Based on these results, it is recommended that future studies place adequate emphasis on soil P levels when cultivating soybean and other similar leguminous crops.

Keywords: Phosphorus; Soybean; Biofertilizer; NPK fertilizer; Soybean; Nigeria; Sustainable agriculture

Introduction

Phosphorus nutrition is among the major factors affecting leguminous crop production since these crops are capable of biological

nitrogen (N₂) fixation – BNF (Pérez-Fernández *et al.*, 2017). The application of phosphorus (P) results in increased benefits in terms of yield and quality as it plays key roles in cellular energy transfer, respiration, photosynthesis and BNF (Powers *et al.*,

2020). In fact, many reports of BNF-driven increase in crop productivity suggest that optimal P availability is important for optimal BNF (Míguez-Montero *et al.*, 2020). Soybean (*Glycine max* L.) is an important cash crop that is widely cultivated in Northern Nigeria, especially in the savannas (Kabiru *et al.*, 2024). It is an important source of vital dietary components (e.g. proteins, lipids and micronutrients) in human and animal nutrition (Yamada *et al.*, 2012; Bello, 2021). Similar to other leguminous crops, soil P levels affect the growth and productivity of soybean in Nigerian savannas. In soybean, P uptake and use efficiency is a major factor that drives enhanced BNF leading to increased biomass and grain yields (Bello, 2021).

Biofertilizers in the form of plant growth-promoting rhizobacteria (PGPR) may enhance plant growth by producing phytohormones and siderophores that stimulate plant growth and aid in the solubilization and biological fixation of nutrients such as nitrogen (N), P, and potassium (K) (Sethi and Adhikary, 2012). For example, *Azospirillum* spp. can improve root development to enhance water and nutrient use efficiency and converts unavailable forms of nutrients to forms easily utilized by plants (Fukami *et al.*, 2018). Large quantities of NPK fertilizers are usually applied to crops via soil application to improve crop growth and yield. However, long-term application of sole inorganic fertilizer may have deleterious effects on humans and the environment, hence, the need for alternative and sustainable nutrient management strategy. Therefore, this study was carried

out to test the individual effect of two different biofertilizers and their combined effects with NPK fertilizer on the growth and yield of soybean under varying soil P levels in Northern Guinea and Sudan savannas of Nigeria.

Materials and Methods

Site Description, Soil Sampling and Analysis

Field experiments were established at the Institute for Agricultural Research (IAR) farms at Samaru, Zaria, Kaduna State and Minjibir, Kano State during the 2023 wet season. The wet season trials started in June 2023 and ended in November 2023. In the Northern Guinea savanna (NGS), the mean annual temperature is 26.44 ± 0.33 °C and the average annual precipitation is 1204.14 ± 211.19 mm, respectively (Onyeneke *et al.*, 2020). In the Sudan savanna (SuS), the mean annual temperature and precipitation is 26.51 ± 0.41 °C and 571.31 ± 144.94 mm, respectively (Onyeneke *et al.*, 2020). Pre-planting soil samples were collected from the experimental fields at a depth of 0-20 cm for routine soil analyses. Routine soil analysis was carried out in the Department of Soil Science laboratories at IAR, Samaru, using standard procedures.

Land Preparation and Sowing

The fields were harrowed and ridged at 75 cm apart and soybean was sown at an intra-row spacing of 10 cm. The soybean variety sown in both Samaru and Minjibir was TGx 1951-3F. Three seeds of soybean were sown per hill and the seedlings were later thinned to two per hill at 2 weeks after sowing (2 WAS).

Treatment Application and Experimental Design

Biofertilizer-A is a formulation containing *Azotobacter* sp., *Azospirillum* sp., and *Bacillus licheniformis*, and biofertilizer-B contains *Azotobacter* sp., *Azospirillum* sp., *Bacillus subtilis* and *Bacillus megaterium*. A total of 27 treatments were evaluated comprising factorial combination of three concentrations (0, 10, and 20 L/ha) of biofertilizer-A, three concentrations (0, 5, 10 L/ha) of biofertilizer-B and three levels of mineral fertilizer (zero, half and full recommended rates). In Nigeria, the full and half recommended rates of NPK fertilizer for maize is 120:60:60 and 60:30:30, respectively. The treatments were arranged in a randomized complete block design (RCBD) with four replications. Each treatment was allocated on 4 ridges (75 cm) of 3 m length. Biofertilizer-A was applied as a foliar spray at seedling, vegetative, and fruiting stages and biofertilizer-B was applied at sowing.

Data Collection and Statistical Analysis

Crop agronomic data such as plant height, and number of branches per plant were collected during the growth period (at 8 WAS) and grain yield data were obtained at harvest. Collected data were subjected to analysis of variance (ANOVA) using the R program, version 4.1.2. Significantly different treatment means were separated using Duncan's Multiple Range Test (DMRT) at 5 % level of significance.

RESULTS AND DISCUSSION

Physical and chemical properties of the experimental soil

Interpretation of the soil results was based on the critical values for nutrients as given

by the Nigeria Federal Ministry of Agriculture and Natural Resources, FMANR (1990). In Samaru, the analytical values show that the soil texture was Loam and the pH in water was rated slightly acidic (pH 6.19), organic carbon (2.25 g/kg), and total N (0.75 g/kg) contents were interpreted to be very low while available P level was moderate (15.68 mg/kg). Exchangeable bases including Ca^{2+} (4.00 cmol/kg), Mg^{2+} (1.27 cmol/kg), Na^{+} (0.27 cmol/kg), and K^{+} (0.27 cmol/kg) were all classified as low. A similar trend was observed in Minjibir, except that the soil texture was loamy sand, available P level (41.16 mg/kg) was high, and soil pH (7.39) was slightly alkaline.

Effect of treatments on growth components and yield of soybean in Samaru

At 8 WAS, biofertilizer -A, biofertilizer-B and NPK fertilizer all significantly ($P \leq 0.05$) increased plant height (Table 2). The application of 20 l/ha biofertilizer -A significantly ($P \leq 0.05$) increased plant height by 6.30% and 5.66%, compared to 10 l/ha biofertilizer -A and the control (0 l/ha biofertilizer-A), respectively. The application of 5 l/ha biofertilizer -B significantly ($P \leq 0.05$) increased plant height by 4.45% compared to 10 l/ha biofertilizer -B. The full and half rates of NPK significantly ($P \leq 0.05$) increased plant height by 13.02% and 9.25%, respectively, compared to the control (no NPK). At 8 WAS, 20 l/ha biofertilizer -A significantly ($P \leq 0.05$) increased number of branches by 21.90% (with an average of 4 branches per plant) compared to 10 l/ha

Table 1. Physical and Chemical Properties of Experimental Soils

Soil property	Samaru	Minjibir

Sand (g/kg)	460	840
Silt (g/kg)	460	100
Clay (g/kg)	80	60
Textural class	Loam	Loam
Soil pH (H ₂ O) 1:2.5	6.19	7.39
Total N (g/kg)	0.73	0.17
Organic C (g/kg)	2.25	3.00
Available P (mg/kg)	15.68	41.16
Exchangeable bases (cmol/kg)		
Calcium (Ca)	4.00	3.60
Magnesium (Mg)	1.20	1.08
Potassium (K)	0.27	0.53
Sodium (Na)	0.25	0.47
Exch. acidity (H+Al) (cmol/kg)	0.80	0.60

Table 2. Effect of biofertilizer -A, biofertilizer -B, NPK fertilizer and their interactions on growth components and yield of soybean

Treatments	Plant height (cm)	Number of branches per plant	Grain yield (t/ha)
Biofertilizer -A (0 l/ha)	75b	3.39ab	2.5a
Biofertilizer -A (10 l/ha)	74.5b	2.92b	2.7a
Biofertilizer -A (20 l/ha)	79.2a	3.56a	2.8a
Biofertilizer -B (0 l/ha)	75.5ab	3.58a	2.6a
Biofertilizer -B (5 l/ha)	78.3a	3.17a	2.8a
Biofertilizer -B (10 l/ha)	75b	3.11a	2.6a
NPK (0-0-0 kg/ha)	70.98b	2.83b	2.0c
NPK (10-20-10 kg/ha)	77.54a	3.47a	2.8b
NPK (20-40-20 kg/ha)	80.22a	3.55a	3.2a
Interactions			
Biofertilizers -A * -B	NS	*	NS
Biofertilizer -A * NPK	NS	*	NS
Biofertilizer -A * NPK	NS	*	NS
Biofertilizers -A * -B * NPK	NS	NS	NS

Each value is a mean of 4 replicates and means within the same column and having similar letter(s) are not significantly ($P > 0.05$) different from each other. NS stands for not significant and * stands for significant at ($P \leq 0.05$).

Note: The data presented for plant height and number of branches (per plant) were taken 8 weeks after sowing. biofertilizer -A (with an average of 3 NPK (2.8 t/ha) and the control (2 t/ha). branches per plant). The grain yield of full Likewise, treatment interactions including rate of NPK was 3.2 t/ha and was biofertilizer -A x biofertilizer -B, significantly higher than that of half rate of biofertilizer -A x NPK, and biofertilizer -B x

NPK all significantly ($P \leq 0.05$) increased number of branches of growing soybean plants at 8 WAS.

Effect of treatments on growth components and yield of soybean in Minjibir

The results obtained from the individual and interaction effects of biofertilizer -A, biofertilizer -B, and NPK fertilizer on soybean growth and yield parameters are presented in Table 3.6. None of the treatments, either applied alone or in combination with each other, had significant effect on all the measured parameters (plant

height, number of branches and grain yield). This result can be ascribed to the fact that P, which is major constraint to soybean production, is not a limiting factor in the experimental soil. Phosphorus is a vital macronutrient in the growth and yield of soybean through its ability to aid important processes like assimilate partitioning during crop growth, biomass production, biological nitrogen fixation, and photosynthesis (Bello, 2021). The amount of available P (41.16 mg/kg) in the soybean field was found to be high and sufficient for soybean production without other P inputs.

Table 3 Effect of Biofertilizer -A, Biofertilizer -B, NPK fertilizer and their interactions on growth components and yield of soybean

Treatments	Plant height (cm)	Number of branches per plant	Grain yield (t/ha)
Biofertilizer -A (0 l/ha)	46.05a	7.61a	1.84a
Biofertilizer -A (10 l/ha)	46.63a	7.00a	1.76a
Biofertilizer -A (20 l/ha)	46.16a	7.00a	1.74a
Biofertilizer -B (0 l/ha)	45.61a	7.22a	1.70a
Biofertilizer -B (5 l/ha)	45.75a	7.19a	1.86a
Biofertilizer -B (10 l/ha)	47.48a	7.19a	1.78a
NPK (0-0-0 kg/ha)	45.36a	7.19a	1.77a
NPK (10-20-10 kg/ha)	47.35a	7.25a	1.85a
NPK (20-40-20 kg/ha)	46.13a	7.17a	1.72a
Interactions			
Biofertilizers -A * -B	NS	NS	NS
Biofertilizer -A * NPK	NS	NS	NS
Biofertilizer -A * NPK	NS	NS	NS
Biofertilizers -A * -B * NPK	NS	NS	NS

Each value is a mean of 4 replicates and means within the same column and having similar letter(s) are not significantly ($P > 0.05$) different from each other. NS stands for not significant and * stands for significant at ($P \leq 0.05$). **Note:** The data presented for plant height and number of branches (per plant) were taken 8 weeks after sowing.

Since soybean is capable of biological nitrogen fixation, nitrogen also seems not to be a limitation to soybean growth in this trial. Moreover, the availability of moderate level of soil P can also enhance legume's biological nitrogen fixation potential (Bello

et al., 2018). Thus, the impact of NPK application was not significant on soybean growth compared to control or biofertilizers -A and -B. Likewise, the biofertilizers only contained free-living or non-symbiotic nitrogen fixers (*Azotobacter* sp., and *Azospirillum* sp.) which can only fix a small amount of atmospheric nitrogen compared to the symbiotic nitrogen fixers (e.g., *Bradyrhizobium* spp) that the soybean roots may associate with in the rhizosphere. Studies have shown that the amount of atmospheric nitrogen fixed through non-symbiotic biological nitrogen fixation is usually insufficient to meet the needs of crops, and less efficient than symbiotic biological nitrogen fixation (Rosenblueth *et al.* 2018; Barros *et al.* 2020).

Conclusion

This study evaluated the effect of biofertilizers and NPK mineral fertilizer on soybean growth and yield in soils with varying levels of soil P in Northern Guinea and Sudan savannas. In Northern Guinea savanna (Samaru) with moderate soil P level (15.68 mg/kg), there was response to biofertilizers and NPK fertilizer application. Soybean growth and yield were significantly improved with the application of biofertilizers -A and -B as well as NPK mineral fertilizer. However, in Sudan savanna (Minjibir) with high soil P level (41.61 mg/kg), there was no response to biofertilizers and NPK fertilizer application. Although the fertility indices of the soils were generally low, the moderate to high soil P levels may have variable effects on the response of the soil to fertilizer application and other management practices such as microbial inoculation. Since most soils in

Nigeria are inherently low in fertility, soils with sufficient level of P are expected to enhance soybean growth and yield as P is the second most-limiting plant nutrient.

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EFFECT OF COW DUNG RATES ON THE GROWTH AND YIELD OF GROUNDNUT (*Arachis hypogaea* L.) IN GUSAU NORTHERN GUINEA SAVANNA OF NIGERIA

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ABSTRACT

Field experiments were conducted during the 2023 and 2024 rainy seasons at the Teaching and Research Farm of the Department of Agricultural Science Education, Federal College of Education (Technical), Gusau, to study the response of groundnut to different rates of cow dung. The treatments consisted of control (0 t ha⁻¹) and three rates of cow dung (10, 20 and 30 t ha⁻¹) laid out in a randomized complete block design replicated four times. The data collected include canopy height and spread, number of pods hill⁻¹, kernel and haulm yield, total biomass and harvest index. The data collected for the two seasons were pooled and subjected to analysis of variance (ANOVA) and means were separated using Duncan's new multiple range test. Results revealed that canopy height, spread at harvest, number of pods hill⁻¹, pod weight, kernel weight hill⁻¹, pod yield and kernel yield, haulm yield, shelling percentage were significantly ($P < 0.05$) higher in 2024 while total plant biomass was higher in 2023. Application of cow dung at the rate of 30 t ha⁻¹ significantly ($P < 0.05$) recorded the highest canopy height, spread at harvest, number of pods hill⁻¹, pod weight, kernel weight hill⁻¹ and kernel yield while application of cow dung at the rate of 20 t ha⁻¹ gave the highest pod yield. The results also showed significant ($P < 0.05$) effect of cropping season $\times$ cow dung interaction on pod weight hill⁻¹ pod yield and harvest index. Cow dung at the rate of 30 t ha⁻¹ in 2024 cropping season recorded the highest pod weight hill⁻¹ and pod yield, while cow dung at the rate of 10 t ha⁻¹ gave the highest harvest index in 2023 cropping season. Thus, it can be concluded that application of cow dung at the rate of 30 t ha⁻¹ increased yield of groundnut in the studied area.

Keywords: Groundnut; Cow dung; Rates; Growth; Yield.

Introduction

Groundnut (*Arachis hypogaea* L.) is a leafy annual legume crop belonging to the family fabaceae that produces its pod inside the soil (Ajeigbe *et al.*, 2014) and is cultivated in the semi-arid and subtropical regions of the world. It is the world's thirteenth most

important food crop, fourth most important source of edible oil and the third most important source of vegetable protein (Taru *et al.*, 2008). It is a self-pollinated, annual herbaceous plant growing 30 to 50 cm tall, groundnut is known by many other local names such as peanut, earthnut, monkey nut, pygmy nut and pignut. Despite its name and

appearance, groundnut is not a nut, but rather specie in the legume or “Bean” family, it is very rich in essential nutrients which are potential to provide health benefits (Janila and Mula, 2015). The crop is native to Central America and has never been found uncultivated (Vabi *et al.*, 2019). The World production figure of groundnut in 2019 was 48.8 million tonnes from 29.6 million hectares with average production of 1647 kg ha⁻¹ (FAO, 2021). The production of groundnut is concentrated in Asia and Africa, where the crop is grown mostly by smallholder farmers under rain-fed conditions with limited inputs. Nigeria is the third largest producer of groundnut in 2019 with annual production of 4.4 million tonnes after China 17.1 million tonnes and India 6.7 million tonnes (FAO, 2021). It is estimated that 3.9 million hectares were planted in 2019 with groundnut in Nigeria (FAO, 2021).

As an industrial cash and food crop, groundnut plays a significant role in the Nigerian economy, employing about 70% of the rural and urban population (Hakeem *et al.*, 2015). Groundnut is second to soybean among the food legume crops. Besides the mineral and vitamin contents, it contains 40% - 50% edible fat, 20-50% protein, 10-20% carbohydrates and other essential vitamins and minerals (Briend, 2001). It is used for human consumption, livestock feed, paint, polish, explosives and soap. (Amoke, 2019) Postulated that it is used as carrier for drugs like penicillin and adrenaline and that the oil is used medically as laxative and emollient. The researcher further indicated that groundnut production is influenced by differences in agro-ecological factors such as

rainfall, temperature and soil condition. The main agro-ecological zones for groundnut production in Nigeria are Sahel, Sudan, northern guinea and most of the southern guinea and derived savannah (Vabi *et al.*, 2019). Groundnut performs best in sandy loam soil rich in calcium and phosphorus for pod formation, in addition to adequate sunshine and well distributed rainfall (Hakeem *et al.*, 2015). The researchers also postulated that the cultivation of groundnut in Nigeria occurs in five major producing states, including Kano, Kaduna, Katsina, Borno and Sokoto. Despite the numerous uses of groundnut in Nigeria, yields across the country are low due to declining soil fertility, poor agronomic practices, irregular/inadequate rainfall and inability to identify high yielding varieties best suited to each agro-ecological zone (Audi *et al.*, 2013).

Nutrients' availability in soils is an essential factor for proper growth and development of plants (FAO, 2000). Organic manures mainly derived from the remains of plants and animals, which includes farm yard manure, animal manure, and compost plays a vital role in improving physical, chemical and biological properties of the soil. Among its function are increase in soil nutrients, improving soil structure, reducing erosion effect, temperature regulation and helps the soil to store more moisture; thus significantly improving soil fertility and, in addition, a necessary food for soil micro-organisms. Chandrasekarane *et al.* (2007) reported significant increase in stover yield in groundnut with the application of manure. Ahlawat (2004) reported application of 15 t ha⁻¹ to maximize haulm yield of groundnut.

Musa and Singh (2011) reported application of cow dung at the rate of 30 t ha⁻¹ increased herbage yield of groundnut. Among the common organic manure widely used by farmers is cow dung. Cow dung has been tested to increase plant growth (Tanimu *et al.*, 2013; Rahimabadi *et al.*, 2017). The increase in plant growth is due to its high nutrient contents and rapid decomposition. In the study area, there is a dearth of information concerning the appropriate rate of cow dung for increased yield of groundnut. The present study was therefore carried out to determine the best rate of cow dung for groundnut production in Gusau, Zamfara State, Nigeria.

Materials and Methods

Experimental site

Field experiments were conducted during the 2023 and 2024 rainy season at the Teaching and Research Farm of the Department of Agricultural Science Education, Federal College of Education (Technical), Gusau. The farm is located on latitude 12° 9' 46.25" N and longitude 6° 40' 28.22" E and at an altitude of about 495.98 m above sea level (asl). The total annual rainfall for 2023 and 2024 cropping seasons were 915.4 and 1156 mm, respectively (Zamfara Agricultural Development Project). The area is characterized by moderate rainfall. The relative humidity ranges from 12% in the dry season and a maximum of 96% during the rainy season. Temperature ranges from 25.8 to 42°C. The soil of the area is predominantly sandy loam, acidic and contains low nutrient and organic carbon, thus, had low CEC but high in base saturation (Table 1).

Treatments and Experiment Design

The treatments consisted of control (0 t ha⁻¹) and three rates of cow dung (10, 20 and 30 t ha⁻¹) laid out in a randomized complete block design replicated four times in each growing season.

Test crop, source of cow dung and its application

The test crop used was a popular local variety Buhu banza sourced from a farmer in the locality. Cow dung used was a more or less decomposed mixture of carbonaceous litter (straw) and excreta (cow faces and urine) sourced from the livestock shade of the Department of Agricultural Science Education, School of Secondary Education (Vocational), Federal College of Education (Technical), Gusau, Zamfara State, Nigeria. In each of the growing seasons, cow dung pellets were dried, crushed mechanically into powder before application and the equivalent weight of the cow dung rates as prescribed by the treatments (0, 10, 20 and 30 t ha⁻¹) were applied basally, incorporated (spreading and burying method) into the soil before ridging. The major nutrient (NPK) contents of the cow dung were presented in Table 2.

Field layout and crop management

In the two cropping seasons, the experimental area measuring 20.25 m × 13 m (263.25 m²) was cleared using cutlass and tilled using hoe and ridges at 75 cm inter-row spacing using work-bulls mounted with mouldboard ploughs. Four replicates made up of four plots each measuring 4.5m × 2.5m (11.25 m²) and separated from one another with a space of 0.75m marked out. Alley pathways of 1m separated one replicate from the other. The

Table 1: Physico-chemical characteristics of the soil at the experimental site in 2023 and 2024 cropping seasons

Soil properties	2023	2024
Particle size (g kg ⁻¹)		
Sand	67	68
Silt	21	21
Clay	12	11
Soil textural class	Sandy Loam	Sandy Loam
pH in H ₂ O	6.63	6.61
pH CaCl ₂	5.70	5.74
EC (dsm)	0.45	0.45
Organic carbon (g kg ⁻¹)	0.34	0.47
Total N (%)	0.08	0.05
Organic Matter (%)	0.59	0.81
Available phosphorus (mg kg ⁻¹)	21.39	20.58
Exchangeable bases (cmol kg ⁻¹)		
K	0.24	0.19
Ca	4.39	4.83
Mg	0.36	0.36
Na	0.43	0.43
Exchange acidity	0.80	0.80
CEC	6.75	7.05
Base Saturation (%)	80.94	83.90

Table 2: Chemical characteristics of the cow dung used in 2023 and 2024 cropping seasons

Nutrient elements (%)	2023	2024
N	1.12	1.37
P	0.74	0.90
K	0.86	1.39

total number of plots laid out in the entire experiment for each season were sixteen. Sowing was done on 7th July, 2023 and 23rd June, 2024 with four groundnut seeds hill⁻¹ at 5cm depth, using a spacing of 75 cm × 25 cm, thinned to two seedlings stand⁻¹ at 2 weeks after sowing (WAS). Two manual weeding were carried out at 2 and 4 WAS respectively to reduce the competition

between crop and weeds for soil resources. A manual mounding was carried out at 7 WAS in all plots. The aim was to favour the burying of young pods in formation and their development. All other recommended cultural practices were adopted uniformly according to groundnut crop requirements.

Data Collection

In each cropping season, eight middle stands in each row of the net plot were used as a sample population for data collection. Data were on canopy height, canopy spread at harvest, number of pods hill⁻¹, 100-kernel weight, pod weight, kernel weight hill⁻¹, pod yield, kernel yield, haulm yield, total plant biomass, shelling percentage and harvest index.

Statistical Analysis

The data collected for the two years were pooled and subjected to analysis of variance (ANOVA) using SAS (2004) computer software. Duncan's New Multiple Range Test (DNMRT) (Duncan, 1955) and Least Significant Difference (LSD) were adopted for means separation of the main effect of cow dung and the interaction effect for the cropping season and cow dung respectively.

Results and Discussion

Canopy height, spread at harvest, number of pods hill⁻¹ and 100-kernel weight

Effect of cropping season: Cropping season significantly ($P<0.05$) influenced canopy height, spread and number of pods hill⁻¹ of groundnut Table 3. The highest (37.50 cm, 84.60 cm and 60.62) canopy height, spread and number of pods hill⁻¹ were recorded in 2024 cropping season compared to (29.13 cm, 73.24 cm and 29.65 cm respectively) for 2023 cropping season.

Effect of cow dung rates: Canopy height, spread and number of pods hill⁻¹ of groundnut showed significant ($P<0.05$) response to cow dung compared with control Table 3. Application of cow dung at 30 t ha⁻¹ recorded the highest canopy height (35.78 cm), spread (84.66 cm) and number of pods hill⁻¹ (49.23 cm) but was at par with the

other rates (10 and 20 t ha⁻¹) while control recorded the least (30.51 cm, 71.54 cm and 36.30 canopy height, spread and number of pods hill⁻¹, respectively). However, the result revealed that canopy height in the control was statistically similar with those of 10 and 20 t ha⁻¹, but application of 20 t ha⁻¹ showed high canopy spread compared with the control and 10 t ha⁻¹, which were statistically the same. The increase in canopy height, spread and number of pods hill⁻¹ observed here could be attributed to the improved chemical (N, P, K, S, Ca, pH and CEC) and physical (structure, temperature and moisture) properties of the soil resulted from manure application (FAO, 2000; Lokanath and Parameshwarappa, 2006). The finding here is in harmony with the earlier report by Subrahmaniyan *et al.* (2000) who reported that increasing organic manure in the form of farm yard manure up to 15 t ha⁻¹ maximized the canopy height of groundnut.

Effects of interactions: No significant ($P>0.05$) interaction was observed between cropping season and cow dung rates on the canopy height, spread and number of pods hill⁻¹ of groundnut Table 3.

Pod weight, kernel weight hill⁻¹, pod yield and kernel yield

Effect of cropping season: Cropping season significantly ($P<0.05$) influenced pod weight, kernel weight hill⁻¹, pod yield and kernel yield of groundnut (Table 4). The highest pod weight, kernel weight hill⁻¹, pod yield and kernel yield were recorded (44.31 g hill⁻¹, 29.70 g hill⁻¹, 2.36 tons ha⁻¹ and 1.58 tons ha⁻¹) in 2024 cropping season compared with that of 2023 cropping season which had

Table 3: Influence of cropping season and cow dung rates on canopy height, spread (cm) at harvest, number of pods hill⁻¹ and 100-kernel weight (g) of groundnut in the studied area

Treatment	Canopy height at harvest	Canopy spread at harvest	Number of pods hill ⁻¹	100-kernel weight
Cropping Season (CS)				
2023	29.13b	73.24b	29.65b	61.42
2024	37.50a	84.60a	60.62a	61.43
Probability value	<.0001	0.0066	0.0014	0.9946
SE (±)	0.530	1.974	3.913	0.754
Cow dung (CD) (t ha⁻¹)				
0	30.51b	71.54b	36.30b	57.13
10	33.34ab	78.74ab	47.16a	62.84
20	33.64ab	80.74a	47.86a	63.73
30	35.78a	84.66a	49.23a	61.99
Probability value	0.0457	0.0261	0.0451	0.0541
SE (±)	1.1969	2.785	3.292	1.681
Mean	33.32	78.92	45.14	61.423
CV (%)	10.16	9.98	20.63	7.74
Interaction (CS×CD)				
Probability value	0.2265	0.3674	0.306	0.2779
SE (±)	1.693	3.939	4.655	2.378

Means in a column under each factor without letter do not differ significantly whereas means with dissimilar letter(s) differ significantly at P=0.05 using Duncan's new multiple range test (DNMRT), P≤0.05, P≤0.01, P≤0.001, P>0.05, represent level of significant at *, **, *** and ns = not significant

31.92 g hill⁻¹, 14.15 g hill⁻¹, 1.70 tons ha⁻¹ and 0.75 tons ha⁻¹ pod weight, kernel weight hill⁻¹, pod yield and kernel yield respectively.

Effect of cow dung rates:

Pod weight, kernel weight hill⁻¹, pod yield and kernel yield of groundnut showed significant (P<0.05) response to cow dung compared with the control (Table 4). Application of cow dung at 30 t ha⁻¹ recorded the highest (40.56 g hill⁻¹, 24.73 g hill⁻¹ and 1.32 tons ha⁻¹) pod weight, kernel weight hill⁻¹ and kernel yield, respectively but were at par with the other levels except

the control (0 t ha⁻¹) which recorded the least (28.92, 17.63, 1.5 and 0.94 for pod weight, kernel weight hill⁻¹, pod yield and kernel yield, respectively). Furthermore, plants that received a cow dung rate of 20 t ha⁻¹ recorded the highest (2.25 tons ha⁻¹) pod yield but was at par with the other levels except the control (0 t ha⁻¹) which produced the least (1.54 t ha⁻¹). On the other hand, the three rates of cow dung were at par and higher than the control on groundnut kernel weight, except that there was no significant difference between 10 t ha⁻¹ and the control.

Similar scenario was also observed on the kernel yield. This can be attributed to the fact that carbon content of the applied cow dung was appropriate, resulting in increased activities of beneficial micro-organism that improve soil fertility and avail nutrients for plants' use. This is similar to the findings of Enujeke (2013) who reported that the highest rate of organic manure gave a corresponding increase in fruit yield of cucumber. It is also synonymous with the findings of Iputu *et al.* (2019) who reported that the highest rate of manure gave a corresponding highest fruit weight of tomato. It is also consistent with the findings of Mehedi *et al.* (2012) and Fikadu-Lebeta and Refisa-Jabessa (2019) who reported that highest application rate of cow dung to carrot had better growth and marketable yield. It is also similar to the finding of Enujeke *et al.* (2022) who reported that 20 t ha⁻¹ of pig manure gave highest fruit yield of watermelon.

Effects of interactions: No significant ($P>0.05$) interaction was observed between cropping season and cow dung rates on kernel weight and kernel yield but there was significant ($P<0.05$) interaction on pod weight hill⁻¹ and pod yield of groundnut (Table 4).

Effects of interactions:

A Significant interaction was observed between cropping season and cow dung rates on pod weight hill⁻¹ and pod yield (Table 4b). Interaction revealed that addition of cow dung from 0-30 t ha⁻¹ did not result in increase in pod weight and pod yield in 2024 but at 0 t ha⁻¹ cow dung 2024 cropping season recorded more pod weight and pod yield than 2023. Addition of 10 t ha⁻¹ cow

dung resulted in more pod weight and pod yield in 2023 cropping season at par with 20 and 30 t ha⁻¹ on pod weight and different from 20 and 30 t ha⁻¹ on pod yield. At, 30 t ha⁻¹, 2024 cropping season recorded the highest (47.79 g and 2.55 t ha⁻¹) pod weight and pod yield, respectively while 0 t ha⁻¹ resulted in least pod weight and pod yield across the cropping seasons.

Growth and yield parameters of groundnut including canopy height, canopy spread, number of pods hill⁻¹, kernel weight hill⁻¹, kernel yield increased as cow dung application rate increased. This may be adduced to increased supply of nutrients, better utilization of carbon and synthesis of assimilates which as reported by Eifediya and Remison (2010) on growth characters of cucumber. It could also be attributed to mineralization of ammonia present in cow dung, leading to the release of nitrogen for enhancement of crop, vegetable growth. This is similar to the findings of Mehedi *et al.* (2012); Enujeke *et al.* (2022) who found an increase in vine length, number of leaves and branches of watermelon to possible release of nitrogen from mineralized ammonia present in cow dung. It is also identical to the report of Shao *et al.* (2023) who endorsed a synergetic application in fertilizer (DAP) and bioslurry to potato farmers for soil fertility management and enhanced crop productivity. This is also comparable to the report of Heydarzadeh *et al.* (2023) which endorsed that organic fertilizers such as vermi compost and poultry manure be used to substitute chemical fertilizers with a view to promoting

Table 4: Influence of cropping season and cow dung rates on pod weight, kernel weight hill⁻¹ (g), pod yield and kernel yield (t ha⁻¹) of groundnut in the studied area

Treatment	Pod weight	kernel weight	Pod yield	Kernel yield
Cropping Season (CS)				
2023	31.92b	14.15b	1.70b	0.75b
2024	44.31a	29.70a	2.36a	1.58a
Probability value	0.0093	0.0002	0.0092	0.0002
SE (±)	2.324	1.366	0.124	0.073
Cow dung (CD) (t ha ⁻¹)				
0	28.92b	17.63b	1.54b	0.94b
10	40.83a	21.65ab	2.18a	1.16ab
20	42.16a	23.69a	2.25a	1.26a
30	40.56a	24.73a	2.16a	1.32a
Probability value	0.0078	0.0144	0.0077	0.0148
SE (±)	2.650	1.459	0.142	0.078
Mean	38.12	21.92	2.03	1.17
CV (%)	19.66	18.83	19.69	18.87
Interaction (CS×CD)				
Probability value	0.0458	0.183	0.0467	0.1936
SE (±)	3.754	2.064	0.200	0.110

Means in a column under each factor without letter do not differ significantly whereas means with dissimilar letter(s) differ significantly at P=0.05 using Duncan's new multiple range test (DNMRT), P≤0.05, P≤0.01, P≤0.001, P>0.05, represent level of significant at *, **, *** and ns = not significant

Table 4b: Influence of cropping season and cow dung rates interaction on pod weight hill⁻¹ (g) and pod yield (t ha⁻¹) of groundnut in the studied area

Cropping Season (CS)	Cow dung (t ha ⁻¹)			
	Pod weight			
	0	10	20	30
2023	16.70c	39.95b	37.70b	33.33b
2024	41.13a	41.70a	46.63a	47.79a
LSD	7.87			
	Pod yield			
2023	0.89c	2.13a	2.01b	1.78b
2024	2.19a	2.23a	2.49a	2.55a
LSD	0.42			

Means followed by similar letter(s) across rows and columns do not differ significantly at 5% level of significance using least significant difference (LSD)

organic crops using rainfed and supplementary irrigation. Related report was furthered by Ranjan *et al.* (2023) which signposted that integrated use of chemical fertilizers and organic manures on a long-term basis improves soil fertility and crop productivity with the potential to enhance soil sustainability. It is consistent with the findings of Gudugi (2013); Thakur *et al.* (2002); Stevens *et al.* (2018); Tilley (2022) in which they reported an increased in vegetative growth of vegetables due to addition of nitrogen released from organic fertilizers. It also confirmed the report of Sow *et al.* (2023) which postulated that the application of animal manure to crops (organic farming) avoids the challenges and hazards connected with the continuous use of chemical fertilizers as well as aids to achieve sustainable agriculture.

Haulm yield, total plant biomass, shelling percentage and harvest index

Effect of cropping season: Cropping season significantly ($P<0.05$) influenced haulm yield, total plant biomass and shelling percentage of groundnut (Table 5). The highest (5.42 tons ha^{-1} and 66.67%) haulm yield and shelling percentage were recorded in 2024 cropping season, while the highest (5.28 tons ha^{-1}) total plant biomass was recorded in 2023 cropping season. The least (3.58 tons ha^{-1} and 46.40%) total plant biomass and shelling percentage were observed in 2023 cropping season, while the least (2.36 tons ha^{-1}) total plant biomass in 2024 cropping season.

Effect of cow dung rates: Haulm yield, total plant biomass and shelling percentage showed no significant ($P>0.05$) response to

cow dung (Table 5). Equally, no significant ($P>0.05$) interaction between year and cow dung levels was observed on haulm yield, total plant biomass and shelling percentage but there was significant ($P<0.05$) interaction on harvest index (Table 5b).

Effects of interactions: Significant interaction was observed between cropping season and cow dung rates on harvest index (Table 5b). Interaction revealed that cow dung at 0 t ha^{-1} , 2024 recorded the highest (31.96%) harvest index than 2023 cropping season, while cow dung at 10 t ha^{-1} , 2023 cropping season recorded the highest (35.38%) harvest index than 2024 cropping season. Addition of 20 and 30 t ha^{-1} cow dung gave similar harvest index in both years comparable with cow dung at 0 t ha^{-1} in 2024 cropping season.

Conclusion

The study was carried out to assess the response of groundnut to different rates of cow dung in Gusau, Zamfara State. The result of this work revealed significant effect of cow dung on the performance of groundnut. Application of cow dung at the rate of 30 t ha^{-1} recorded the highest canopy height, spread at harvest, number of pods hill^{-1} , pod weight, kernel weight hill^{-1} and kernel yield while application of cow dung at the rate of 20 t ha^{-1} gave the highest pod yield. From the findings of this study, application of cow dung at the rate of 30 t ha^{-1} could be used for increased yield of groundnut in Gusau, Zamfara State, Nigeria.

Table 5: Influence of cropping season and cow dung rates on haulm yield, total plant biomass (tons ha⁻¹), shelling percentage and harvest index (%) of groundnut in the studied area

Treatment	Haulm yield	Total plant biomass	Shelling percentage	Harvest index
Cropping Season (CS)				
2023	3.58b	5.28a	46.40b	31.58
2024	5.42a	2.36b	66.67a	30.70
Probability value	0.0002	<.0001	0.0003	0.6422
SE (±)	0.167	0.222	1.862	1.270
Cow dung (CD) (t ha⁻¹)				
0	3.90	3.11	58.00	26.90
10	4.91	4.11	53.48	31.45
20	4.66	4.11	55.54	33.01
30	4.53	3.97	59.12	33.21
Probability value	0.3539	0.1055	0.4266	0.0823
SE (±)	0.400	0.314	2.559	1.812
Mean	4.498	3.822	56.535	31.142
CV (%)	25.15	23.20	12.80	16.46
Interaction (CS×CD)				
Probability value	0.9659	0.2015	0.8021	0.0153
SE (±)	0.566	0.443	3.619	2.563

Means in a column under each factor without letter do not differ significantly whereas means with dissimilar letter(s) differ significantly at P=0.05 using Duncan's new multiple range test (DNMRT), P≤0.05, P≤0.001, P>0.05, represent level of significant at *, *** and ns = not significant

Table 5b: Influence of cropping season and cow dung rates interaction on harvest index (%) of groundnut in the studied area

Cropping Season (CS)	Cow dung (t ha ⁻¹)			
	0	10	20	30
2023	21.85c	35.38a	34.93a	34.18a
2024	31.96a	27.52b	31.09a	32.25a
LSD	5.38			

Means followed by similar letter(s) across rows and columns do not differ significantly at 5% level of significance using least significant difference (LSD)

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INFLUENCE OF COW DUNG MANURE AND NPK FERTILIZER ON YIELD AND PROFITABILITY OF CUCUMBER (*Cucumis sativus* L.) IN NORTHERN GUINEA SAVANNA, NIGERIA

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ABSTRACT

Cucumber (Cucumis sativus L.) is a high-value vegetable crop with significant nutritional and economic importance, yet its production in the Northern Guinea Savanna of Nigeria is constrained by declining soil fertility. This study examined growth, yield and profitability of cucumber under varying rates of NPK 15:15:15 fertilizer and cow dung manure. The experiment was conducted during the 2020 wet season at the Horticulture Section, Samaru College of Agriculture, Ahmadu Bello University, Zaria. Eight treatments were evaluated: control, NPK at 100, 150 and 200 kg ha⁻¹, cow dung at 10, 20 and 30 t ha⁻¹, and a combined application of NPK at 100 kg ha⁻¹ with cow dung at 15 t ha⁻¹. The experimental design adopted was a Randomized Complete Block Design (RCBD) replicated three times. Data were collected on vine length, number of leaves, number of branches, number of fruits, fresh fruit yield and profitability indices including gross revenue, total cost of production, net profit and benefit-cost ratio (BCR). Data were subjected to analysis of variance (ANOVA) and treatment means were separated using Duncan's Multiple Range Test (DMRT) at $p \leq 0.05$. Results showed that application of cow dung at 30 t ha⁻¹ produced the highest fresh fruit yield (39.33 t ha⁻¹), the highest net profit (₦1,297,500 ha⁻¹) and the best benefit-cost ratio (2.74), making it the most agronomically and economically superior treatment. The combined application of NPK 100 kg ha⁻¹ + cow dung 15 t ha⁻¹ ranked second in all profitability indices. This study recommends the application of cow dung at 30 t ha⁻¹, and where large quantities are unavailable, the integrated use of cow dung 15 t ha⁻¹ with NPK 15:15:15 at 100 kg ha⁻¹ as a cost-effective alternative for cucumber farmers in the Northern Guinea Savanna.

Keywords: *Cucumis sativus*, organic manure, soil fertility, Benefit-cost ratio, Zaria.

INTRODUCTION

Cucumber (*Cucumis sativus* L.) belongs to the family Cucurbitaceae and is one of the most widely cultivated vegetable crops in the world, ranking fourth in global vegetable production after tomato, onion and cabbage (Omotade and Babalola, 2019; Sodimu, 2020). In Nigeria, cucumber has gained remarkable commercial importance owing to

its rapid growth cycle, high market demand and suitability for both large-scale and smallholder production systems (Onuwa *et al.*, 2023). Beyond its dietary significance as a source of vitamins A, C and K, minerals and dietary fibre, cucumber is valued for its medicinal properties including diuretic effects, support for heart health, facilitation

of digestion, and management of skin conditions such as eczema (Shrivastava and Roy, 2013; Nweke and Nsoanya, 2015; Chakraborty and Rayalu, 2021).

The profitability of cucumber production in Nigeria has been widely documented. Onuwa *et al.* (2023) reported a gross farm income of ₦204,000 ha⁻¹ among smallholder cucumber farmers in Jos-South, Plateau State, while Adeoye and Balogun (2016) established cucumber as a venture with the highest benefit-cost ratio among vegetable crops. More recently, a cost-benefit analysis of cucumber production in Delta State, Nigeria established that cucumber farming was 87.8% profitable with a return of ₦0.85 on every ₦1 invested (IJRIAS, 2024). These outcomes, however, are significantly conditioned by soil fertility management strategies adopted by farmers.

Soils of the Northern Guinea Savanna, where this study was conducted, are inherently low in organic matter, total nitrogen and available phosphorus, owing to rapid mineralization, continuous cultivation and low clay content (FMARD, 2012; Tofa *et al.*, 2022). The declining soil fertility in this zone necessitates the use of external nutrient inputs to sustain crop productivity. Inorganic fertilizers such as NPK 15:15:15, while effective in providing readily available nutrients, have been associated with soil acidification, nutrient imbalance, environmental pollution and high cost that makes them inaccessible to resource-poor smallholders (Ojeniyi, 2000; Adeboye *et al.*, 2022). In contrast, organic manures, particularly cow dung, offer the dual benefit of supplying macro- and micro-nutrients while improving soil structure, water-

holding capacity and biological activity over the long term (Maritus and Vleic, 2001; Eleduma, 2023; Open Science and Technology, 2025).

Several studies have demonstrated the positive effects of organic and inorganic fertilizers on cucumber growth and yield in Nigerian agroecological zones (Eifediyi and Remison, 2010; Ikeh *et al.*, 2012; Sodimu, 2020; Eleduma, 2023). However, most of these studies focused predominantly on agronomic performance with little attention to economic profitability, which is a critical determinant of technology adoption at the farm level. Moreover, site-specific fertilizer management recommendations for the Northern Guinea Savanna remain limited, with most existing guidelines derived from distant ecological zones.

Against this background, this study was designed to: (i) evaluate the influence of different rates of cow dung manure and NPK 15:15:15 fertilizer on growth and yield of cucumber; (ii) assess the profitability of cucumber production under each fertilizer management treatment; and (iii) make appropriate fertility management recommendations to cucumber farmers in the Samaru metropolis and the wider Northern Guinea Savanna zone.

MATERIALS AND METHODS

Site Description and Climate

The field experiment was conducted during the 2020 wet season at the Horticulture Section of the Samaru College of Agriculture, Ahmadu Bello University, Zaria. The study site lies within latitudes 11°09'52" – 11°10'22" N and longitudes 07°38'05" – 07°38'22" E at an elevation of 684 – 697 m above sea level. The area is

situated within the Northern Guinea Savanna agro-ecological zone, characterized by a unimodal rainfall pattern with a long-term mean annual rainfall of approximately 1,011 $\pm$ 161 mm concentrated between May/June and September/October, and a mean daily temperature of 24°C (Oluwasemire and Alabi, 2004; Tofa *et al.*, 2022). Soils of the study area are predominantly sandy loam Alfisols with inherently low fertility status (Adeboye *et al.*, 2022).

Treatments and Experimental Design

Eight treatments were arranged in a Randomized Complete Block Design (RCBD) replicated three times, comprising: (i) Control (no fertilizer); (ii) NPK 15:15:15 at 100 kg ha⁻¹; (iii) NPK 15:15:15 at 150 kg ha⁻¹; (iv) NPK 15:15:15 at 200 kg ha⁻¹; (v) cow dung at 10 t ha⁻¹; (vi) cow dung at 20 t ha⁻¹; (vii) cow dung at 30 t ha⁻¹; and (viii) combined NPK 15:15:15 at 100 kg ha⁻¹ + cow dung at 15 t ha⁻¹. Each plot measured 3 m $\times$ 2 m with inter-row and intra-row spacings of 0.75 m and 0.5 m, respectively.

Land Preparation and Crop Management

The experimental site was cleared, ploughed, harrowed to fine tilth and ridged. Two seeds of the ‘Market-Moore’ variety were planted per hole and later thinned to one stand per hole. Cow dung was incorporated at the designated rates per plot and allowed to decompose for two weeks before planting. NPK 15:15:15 was applied at two weeks after planting (WAP) by the band placement method. Standard cultural practices, including weeding, insecticide application and trellising, were carried out as required. Trellising was performed using stakes to support the cucumber vine and keep fruits off the ground to prevent rotting.

Soil and Manure Characterization

Pre-planting soil samples were collected at 0–20 cm depth using a soil auger and composited. Soil and cow dung samples were air-dried, crushed, sieved through a 2-mm mesh, and analyzed for physical and chemical properties following standardized procedures described by Okalebo *et al.* (2002).

Data Collection

Data were collected on: vine length (cm), number of leaves per plant, number of branches per plant, number of fruits per plant, and fresh fruit yield (t ha⁻¹). All data were subjected to analysis of variance (ANOVA) using the Mixed Model Procedure of the Statistical Analysis System (SAS Institute, 2000), and treatment means were compared using Duncan’s Multiple Range Test (DMRT) at $p \leq 0.05$.

Profitability Analysis

Profitability of cucumber production under each treatment was estimated using a partial budget framework following the approach of Onuwa *et al.* (2023) and IJRIAS (2024). The following parameters were estimated:

$$\text{Gross Revenue (GR)} = \text{Fresh fruit yield (t ha}^{-1}\text{)} \times \text{Market price (₦/t)}$$

$$\text{Total Variable Input Cost} = \text{Cost of fertilizer or cow dung per hectare}$$

$$\text{Total Cost of Production (TCP)} = \text{Fixed costs} + \text{Variable input costs}$$

$$\text{Net Profit (NP)} = \text{Gross Revenue} - \text{Total Cost of Production}$$

$$\text{Benefit-Cost Ratio (BCR)} = \text{Gross Revenue} \div \text{Total Cost of Production}$$

The prevailing local market price for cucumber in Zaria was estimated at ₦35,000 per tonne during the 2020 cropping season. Fixed costs (land preparation, seeds, labour, irrigation and pesticides) were estimated at ₦78,000 ha⁻¹, consistent with farm budgeting approaches used for vegetable production in northern Nigeria (Abdulkadir *et al.*, 2020; Onuwa *et al.*, 2023). Cow dung was costed at ₦3,000 t⁻¹ and NPK 15:15:15 at ₦200 kg⁻¹.

The initial soil properties of the experimental site are presented in Table 1. The soil was sandy loam (80 g kg⁻¹ clay, 200 g kg⁻¹ silt, 720 g kg⁻¹ sand) with a slightly acidic pH (6.5 in water). Organic carbon content was 11.24 g kg⁻¹ and total nitrogen was 0.49 g kg⁻¹, both rated low according to FMARD (2012) standards. Available phosphorus (96.54 mg kg⁻¹) and exchangeable bases (K⁺: 0.11 cmol kg⁻¹; Ca²⁺: 1.79 cmol kg⁻¹; Mg²⁺: 0.74 cmol kg⁻¹) were at moderate levels. Cow dung total nitrogen was 0.98 g kg⁻¹ with available phosphorus of 1,133 mg kg⁻¹ and 0.3% potassium, confirming its high nutrient content relative to the native soil.

RESULTS

Characteristics of the Study Soil

Table 1: Initial soil properties at experimental site (Zaria, 2020 cropping season)

Parameter	Clay (g kg ⁻¹)	Silt (g kg ⁻¹)	Sand (g kg ⁻¹)	Textural class	pH (H ₂ O)	OC (g kg ⁻¹)	TN (g kg ⁻¹)	AP (mg kg ⁻¹)
Soil	80	200	720	Sandy Loam	6.5	11.24	0.49	96.54
Cow dung	n.d	n.d	n.d	n.d	n.d	n.d	0.98	1,133

OC = Organic Carbon; TN = Total Nitrogen; AP = Available Phosphorus; n.d = not determined

Effect of Treatments on Vine Length

Results presented in Table 2 indicate that vine length increased significantly ($p \leq 0.05$) with increasing rates of both NPK fertilizer and cow dung. The combined application of NPK at 100 kg ha⁻¹ with cow dung at 15 t ha⁻¹ produced the longest vines (139.97 cm), followed closely by cow dung at 30 t ha⁻¹ (129.73 cm). The control produced the shortest vines (42.30 cm). These findings are consistent with those of Sodimu (2020) who reported significantly longer vines under combined organic-inorganic fertilization in the Guinea Savanna of Kaduna State, and

with Eleduma (2023) who observed progressive increase in vine length with rising cattle manure rates in Ondo State.

Number of Leaves and Branches per Plant

Application of cow dung at 30 t ha⁻¹ resulted in the highest number of leaves (85.07) and branches (10.17) per plant, while the combined treatment produced 80.63 leaves and 8.87 branches. The control recorded the lowest values (23.53 leaves; 1.30 branches). The superiority of the high cow dung rate in promoting leaf area and branching can be

attributed to the sustained supply of macro-nutrients (N, P, K) and the improvement of soil physical properties that support vigorous vegetative development (Ewulo, 2005; Open Science and Technology, 2025). Similar outcomes were reported by Eifediyi and Remison (2010) and Ikeh *et al.* (2012), who noted that organic manure applications at high rates significantly enhanced leaf area index in cucumber.

Number of Fruits per Plant

The number of fruits per plant was significantly influenced by fertilizer and cow dung application. Cow dung at 30 t ha⁻¹ produced the highest number of fruits (10.04 per plant), followed by the combined treatment (8.63). The control recorded the least (2.67). This result agrees with Sodimu (2020) and is supported by findings from Awka, southeastern Nigeria, where integrated organic-inorganic treatments significantly increased cucumber fruit set compared to sole inorganic applications (Khalid *et al.*, 2014).

Fresh Fruit Yield

Significant differences ($p \leq 0.05$) were observed among treatments for fresh fruit yield per hectare (Table 2). The highest yield was recorded under cow dung at 30 t ha⁻¹ (39.33 t ha⁻¹), followed by the combined treatment (29.06 t ha⁻¹). The control produced the least yield (7.17 t ha⁻¹). Application of cow dung at 10 t ha⁻¹ (18.83 t ha⁻¹) already surpassed the highest NPK-only treatment (200 kg ha⁻¹; 14.67 t ha⁻¹), demonstrating the relative superiority of organic manure over mineral fertilizer at equivalent or lower cost. These yield levels are consistent with, or exceed, those reported

by Open Science and Technology (2025), who documented cucumber yields of 17.99–22.54 t ha⁻¹ under cow dung and NPK amendments in southeastern Nigeria.

Profitability Analysis

The profitability analysis results are presented in Table 3. All treatments recorded positive net profits, confirming that cucumber production is a viable enterprise across all fertility management options assessed in this study. This concurs with Onuwa *et al.* (2023) and IJRIAS (2024), who reported that cucumber farming is a profitable venture in Nigeria.

The control treatment, despite incurring only fixed costs (₦78,000 ha⁻¹), recorded the lowest gross revenue (₦250,950), net profit (₦172,950) and BCR (3.22), reflecting the limiting effect of unfertilized low-fertility savanna soils on crop productivity.

Among NPK-only treatments, NPK at 200 kg ha⁻¹ produced the highest net profit (₦435,450) and BCR (3.42), but this was considerably lower than all cow dung treatments. Cow dung at 30 t ha⁻¹ generated the highest gross revenue (₦1,376,550), net profit (₦1,207,550) and BCR (7.82), making it the most economically superior treatment. The combined NPK + cow dung treatment ranked second in profitability (₦944,600 net profit; BCR 5.45), suggesting that even at half the cow dung rate, integration with mineral fertilizer remains highly profitable.

The progressive increase in BCR with rising cow dung rates (1.96 at 10 t ha⁻¹ to 7.82 at 30 t ha⁻¹) underscores the economic advantage of high organic manure inputs in this environment. These findings align with

Table 2: Effect of NPK fertilizer and cow dung at different rates on growth and yield of cucumber (Zaria, 2020)

Treatment	Vine length (cm)	No. of leaves per plant	No. of branches per plant	No. of fruits per plant	Fresh fruit yield (t ha ⁻¹)
Control	42.30h	23.53h	1.30g	2.67h	7.17g
NPK at 100 kg ha ⁻¹	55.76g	34.70g	2.97f	3.85e	9.56f
NPK at 150 kg ha ⁻¹	74.57f	39.30f	3.87ef	4.15de	10.44f
NPK at 200 kg ha ⁻¹	82.67e	49.30e	4.30e	4.78d	14.67e
Cow dung at 10 t ha ⁻¹	104.97d	59.30d	6.30d	6.44c	18.83d
Cow dung at 20 t ha ⁻¹	116.07c	72.73c	7.30c	8.00b	25.22c
Cow dung at 30 t ha ⁻¹	129.73b	85.07a	10.17a	10.04a	39.33a
NPK 100 kg + CD 15 t ha ⁻¹	139.97a	80.63b	8.87b	8.63b	29.06b
SE (±)	1.2700	0.8405	0.3286	0.2831	0.548

Means followed by the same letter(s) in a column are not significantly different using DMRT at $p \leq 0.05$

Victor and Julius (2019) who reported high BCR values for organically managed cucumber farms in southwestern Nigeria, and with Adeoye and Balogun (2016) who identified cucumber production as having the highest BCR among vegetable crops when properly fertilized.

DISCUSSION

The soil of the experimental site was classified as sandy loam and characterized by low organic carbon and total nitrogen, consistent with the general fertility status of Northern Guinea Savanna soils reported by FMARD (2012) and Tofa *et al.* (2022). The

rapid decomposition of organic matter, high sand content, and history of continuous

cultivation in this zone collectively contribute to the depletion of soil nutrients, making external fertilizer inputs essential for profitable crop production.

The significant increases in all growth parameters — vine length, leaf number, branch number and fruit number — observed with increasing rates of cow dung or NPK fertilizer reflect the importance of adequate nutrient supply for cucumber vegetative and reproductive development. These findings are consistent with Sodimu (2020), Eleduma (2023), and the recent study by Open Science and Technology (2025) in southeastern Nigeria. The superior performance of cow dung treatments over NPK-only treatments may be attributed to the broader spectrum of nutrients supplied

by organic manure, including micronutrients, activity — factors that enhance nutrient as well as its positive effects on soil organic uptake efficiency (Ewulo, 2005; Adeboye *et al.*, 2022). matter, water retention and microbial

Table 3: Profitability analysis of cucumber production under NPK fertilizer and cow dung treatments (Zaria, 2020)

Treatment	Yield (t ha ⁻¹)	Gross Revenue (₦ ha ⁻¹)	Input Cost (₦ ha ⁻¹)	Total Cost (₦ ha ⁻¹)	Net Profit (₦ ha ⁻¹)	BCR
Control	7.17	₦250,950	₦0	₦78,000	₦172,950	3.22
NPK at 100 kg ha ⁻¹	9.56	₦334,600	₦20,000	₦98,000	₦236,600	3.42
NPK at 150 kg ha ⁻¹	10.44	₦365,400	₦30,000	₦108,000	₦257,400	3.38
NPK at 200 kg ha ⁻¹	14.67	₦513,450	₦40,000	₦118,000	₦395,450	4.35
Cow dung at 10 t ha ⁻¹	18.83	₦659,050	₦30,000	₦108,000	₦551,050	6.10
Cow dung at 20 t ha ⁻¹	25.22	₦882,700	₦60,000	₦138,000	₦744,700	6.40
Cow dung at 30 t ha ⁻¹	39.33	₦1,376,550	₦90,000	₦168,000	₦1,208,550	8.19
NPK 100 kg + CD 15 t ha ⁻¹	29.06	₦1,017,100	₦65,000	₦143,000	₦874,100	7.11

BCR = Benefit-Cost Ratio; CD = Cow Dung; Input Cost = cost of fertilizer or manure only; Total Cost = Fixed costs (₦78,000) + Input costs; Market price of cucumber = ₦35,000 t⁻¹

The outstanding fresh fruit yield recorded under cow dung at 30 t ha⁻¹ (39.33 t ha⁻¹) is substantially higher than the national average yield for cucumber in Nigeria, which ranges between 10 and 20 t ha⁻¹ under smallholder production conditions (IntechOpen, 2021). This yield level compares favourably with yields reported for organically managed cucumber in the humid tropics (Eleduma, 2023) and demonstrates the high yield potential achievable in the Northern Guinea Savanna with adequate organic matter inputs. The second-ranked combined treatment (29.06 t

ha⁻¹) confirms that an integrated approach using half the organic input supplemented with mineral fertilizer can still achieve impressive yields, consistent with findings of Nweke and Nsoanya (2013) on integrated manure-NPK management for grain crops. The profitability analysis established cow dung at 30 t ha⁻¹ as the most economically rewarding treatment, with the highest net profit and BCR. These results support the assertion of Onuwa *et al.* (2023) that soil fertility management is a key driver of cucumber farm profitability in Nigeria. However, the logistics and cost of sourcing

and transporting 30 t ha⁻¹ of cow dung may pose practical constraints for smallholder farmers, particularly in peri-urban settings where livestock density is declining. In such circumstances, the combined application of cow dung at 15 t ha⁻¹ with NPK 15:15:15 at 100 kg ha⁻¹ offers a highly profitable and practical compromise, achieving a BCR of 7.11 and net profit of ₦874,100 ha⁻¹. This finding is particularly relevant given the documented benefits of integrated soil fertility management (ISFM) in sustaining crop yields while reducing dependence on expensive mineral fertilizers (Maritus and Vleic, 2001; Adeboye *et al.*, 2022).

The performance of NPK 15:15:15 alone across all rates was significantly inferior to cow dung treatments for both yield and profitability. This is consistent with observations from IntechOpen (2021) and Sodimu (2020), who noted that inorganic fertilizers, while providing soluble nutrients, do not improve soil organic matter content or long-term soil health. The BCR of NPK treatments (3.22–4.35) was substantially lower than that of cow dung treatments (6.10–8.19), reinforcing the economic case for organic-based soil fertility management in this agroecological zone.

CONCLUSION AND RECOMMENDATIONS

This study demonstrated that the application of cow dung manure and NPK 15:15:15 fertilizer at varying rates significantly influenced the growth, yield and profitability of cucumber (*Cucumis sativus* L.) in the Northern Guinea Savanna of Nigeria. Cow dung at 30 t ha⁻¹ produced the highest vine length, leaf area, number of branches, fruit

number, fresh fruit yield (39.33 t ha⁻¹), and the best profitability indices (net profit: ₦1,208,550 ha⁻¹; BCR: 8.19), making it the most agronomically and economically superior treatment in this study.

Based on these findings, the following recommendations are made:

1. Farmers with adequate access to livestock manure should adopt cow dung at 30 t ha⁻¹ for cucumber production in the Northern Guinea Savanna, as it yields the greatest agronomic and economic returns.
2. Where 30 t ha⁻¹ of cow dung is logistically or economically impractical, the integrated application of cow dung at 15 t ha⁻¹ combined with NPK 15:15:15 at 100 kg ha⁻¹ is recommended as a cost-effective, high-yielding alternative.
3. Future research should investigate the residual effects of these treatments on soil properties and subsequent crops, long-term profitability over multiple seasons, and extension pathways for scaling up ISFM practices among smallholder cucumber farmers in northern Nigeria.

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EFFECT OF POULTRY MANURE ON SOIL CHEMICAL PROPERTIES AND MICROBIAL POPULATION UNDER COWPEA PRODUCTION AT MINNA, NIGER STATE

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ABSTRACT

A field experiment was carried out at Federal University of Technology, Minna, in the cropping season of 2024 to determine the effect of poultry manure on soil chemical properties and microbial population under cowpea production. The study was a 2 x 5 x 4 factorial experiment arranged in a Randomized Complete Block Design (RCBD). The treatments consisted of two sources of poultry manure (Deep Litter and Battery Cage Poultry systems) at 0, 5, 10, 15 and 20 t/ha replicated four times. The treatments were applied 2 weeks before planting to ensure proper breakdown of the organic material. The plots were leveled manually using hoe. The gross plot size was 4 m x 4 m (16 m²) each, while the net plot size was 2 m x 2 m (4 m²). Data obtained were subjected to Analysis of Variance at 5% level of probability using Statistix 8.0 statistical software. Duncan multiple range test (DMRT) was used to separate significant difference between means. Result obtained showed that there was no any significant interaction effect on Total Bacteria Count. However, there was a significant effect of source of poultry manure on Total Coliform Count. The deep litter source recorded the highest total coliform count of (186.60 x 10³ CFU/g). Also, apart from exchangeable Ca²⁺, selected soil chemical properties (pH, Organic Carbon, Na⁺, K⁺, Mg²⁺) contents were significantly affected by the interaction between poultry manure sources and level. Application of deep litter source of poultry manure especially at 10 t/ha that improved organic carbon K⁺ and Mg²⁺ content of soil is recommended for further studies. However, it is worthy to note that application of battery cage source of poultry manure significantly improved soil organic carbon and Na⁺ content especially at 20 t/ha.

Keywords: Poultry Manure, Deep Litter, Battery Cage.

INTRODUCTION

Cowpea (*Vigna unguiculata*), one of the important legume crop grown globally, plays a vital role in the livelihood of millions of smaller holder farmers who depend on it as a source of economic livelihood and nutritional well-being (Bolarinwa *et al.*, 2022). Cowpea is mainly grown for food, fodder, vegetable,

green manure, and cover crop. Apart from cowpea's nutritional component, the crop has high rates of symbiotic nitrogen fixation and improve soil fertility which can be achieved by litter accumulations that impacts organic matter positively. However, the quantity of organic matter accumulated under any cropping system may not be

stable over a period of time and may need i. external applications in the form of animal manures. Studies of Atugwu *et al.*, (2023), has shown that poultry manure may be a preferable source of animal manure used in crop production.

Poultry Manure have been used since earliest civilization for improving soil properties, it is primarily composed of Nitrogen (N), Phosphorus (P) and Potassium (K); it also contains calcium, magnesium, sulphur and some micronutrients (Atugwu *et al.*, 2023), which are critical for crop growth and soil fertility. The application of poultry manure has been shown to increase the organic matter content of soil, which in turn improves its structure, water-holding capacity, cation exchange capacity (CEC) and soil microbial properties (Minkina *et al.*, 2023).

The application of poultry manure introduces a substantial amount of organic matter into the soil, which serves as a substrate for microbial activity. This can lead to an increase in microbial biomass, diversity, and activity, all of which are beneficial for soil health and plant growth (Sant'Anna *et al.*, 2024).

Aim and Objectives of the Study

The aim of this experiment was to determine the effect of poultry manure sources and levels on selected soil microbial population and chemical properties in Minna, Niger state.

The objectives of the study were to:

- i. asses the effect of poultry manure sources and levels on selected soil microbial population (Total Bacteria Count and Total Coliform Count) in Minna.

determine the effect of poultry manure sources and levels on selected soil chemical properties (Soil pH, Organic Carbon, Calcium, Magnesium, Potassium and Sodium) in Minna.

MATERIALS AND METHODS

Description of Study Site

Location

The study was conducted at Federal University of Technology, Minna, Niger state. The experimental site is located beside the University Works Department on latitude 9°31'6"N to 9°31'50"N and Longitudes 6°26'26"E to 6°27'6"E.

Climate

Minna has a sub-humid climatic condition. The annual rainfall is 1,284mm, while the mean temperature is 37 °C, the dry season lasts for five (5) months occur from November to March, while the rainy season extends between May and October.

Geology and Soil

The soils of Minna developed from basement complex rocks ranging from shallow to very deep soils overlying deeply weathered gneisses and magnetite with some underlain by iron pan to varying depth (Lawal *et al.*, 2023). The soils are mostly sandy in texture

Vegetation

Minna is located in the Southern guinea savanna zone characterized by vast grassland with few scattered trees and shrubs. Crops are mostly grown under rain fed conditions. The crops include maize, rice, cowpea, soy bean and groundnut.

Treatments and Experimental Design

The study was 2 x 5 x 4 factorial experiment. The treatments consisted of two sources of poultry manure (Deep Litter and Battery

Cage Poultry systems) at 0, 5, 10, 15 and 20 t/ha replicated four times. The treatments was applied 2 weeks before sowing to ensure proper breakdown of the organic material.

The experiment was arranged in a Randomized Complete Block Design (RCBD)

Soil Sampling and Analysis

Soil samples were collected with an auger at a depth of 0 - 15cm from each plot at Physiological maturity (12 weeks after planting). A sub-sample (10 grams) of the soil sample was kept in the refrigerator for Microbial studies.

The soil samples were air dried, gently crushed and passed through 2mm sieve for determination of chemical properties following method described by International Institute of Tropical Agriculture (IITA, 2015) as follows:

Soil pH in 1:2.5 soil to water suspension with a glass electrode pH meter, soil organic carbon using the Walkley and Black wet oxidation method, exchangeable bases (Ca^{2+} , Mg^{2+} , K^{+} and Na^{+}) were extracted with 1N NH_4OAc . Ca^{2+} and Mg^{2+} in the soil extract were determined using atomic absorption spectrophotometer while K^{+} and Na^{+} were determined by flame photometry.

Land Preparation

The field was cleared and ploughed using a tractor. The plots were leveled manually using hoe. The gross plot size was 4 m x 4 m (16 m²) each, while the net plot size was 2 m x 2 m (4 m²).

Planting and Crop Management

Seeds (SAMPEA 20T, Early Maturing and Semi Erect) were planted at the rate of 3 seeds/hill and at a spacing of 75cm between

the rows and 25cm within the rows at a depth of 5cm according to (Dugje *et al.*, 2009). The plants were thinned to 1 plant/stand at 2 weeks after planting (WAP). All plot received a basal dose of N and P at a recommended rate of 10kg N/ha and 30kg P/ha. The nutrient were sourced from NPK 20:10:10 and SSP. 0.00083kg (0.83grams) of NPK20:10:10 fertilizer were applied per plant stand i.e 0.083kg (80grams) per plot at planting and 0.0026kg (2.6grams) of SSP was applied per plant stand i.e. 0.25kg (250 grams) per plot by band placement method. The same quantity of inorganic fertilizer was applied per plot irrespective of the different levels of treatment. Weeding was done manually first at 2 WAP, and secondly at 5 WAP to ensure a clean field. Insect pest was controlled using insecticide at 5 weeks after planting when flower bud initiation has started. This controlled thrips and early attack of *Maruca* pod borer and ensure good flowering. Pods were harvested at 12 WAP and sundried. The pods were threshed to separate the grains from the husk.

Microbial Population Analysis

The total microbial population was determined using the subsample (10g). The soil samples were plated on selective media (Nutrient Agar for Total Bacteria Count and MacConkey Agar for Total Coliform Bacteria) using New Plate Count Method described by Fujikawa & Tsubaki (2019) as follows: one grams of soil will be added to 9 ml of distilled water and 1 ml will be promptly transferred onto a Petridis using a syringe and kept at 37 °C for microbial growth.

Statistical Analysis of data

Data obtained were subjected to Analysis of Variance at 5% level of probability using Statistix 8.0 (Statistix, 2010) statistical software. Duncan multiple range test (DMRT) was used to separate significant difference between means.

Results and Discussions

Table 1 shows that the highest Total Bacteria Count (TBC) was recorded at 5 t/ha of poultry manure application and when the source was deep litter. Implying that 5 t/ha was a threshold value beyond and below which TBC declined. This response may be partly due to the soil organic carbon content (5.67 g/kg), this was the second highest but probably the most utilized (Smith and Wang, 2019). Total Coliform count on the other hand recorded its highest count at 10 t/ha (177.00×10^3 CFU/g) and when the source was deep litter 186.60×10^3 CFU/g probably due to its sensitivity to higher levels of coliform are bacteria of fecal origin (Agbede & Oyewumi, 2022).

Calcium (Ca^{2+}) content was not significantly affected by either sources or levels of poultry manure (Table 1). However values recorded were rated low to very low with the highest value of 2.38 Cmol/kg recorded at 10 t/ha and the lowest of 1.90 Cmol/kg at 5 t/ha. Averagely deep litter value of 1.94 Cmol/kg was lower compared to the value recorded under battery cage (2.18 Cmol/kg) and was probably due to the higher calcium content in the feed of layers kept under battery cage system (El-Sayed *et al.*, 2021). Averagely, pH values were higher under battery cage compared to deep litter implying that battery cage impacted the soil pH, increasing its pH towards Moderately acidic according to rating by (IITA, 2015)

pH (Table 2), also meaning that the pH under the battery cage was less acidic probably due to less humic, fluvic and other organic acids (El-Sayed *et al.*, 2021). the reverse was the case in the trend observed for Organic carbon where deep litter recorded the highest values of organic carbon (Table 3) because of litter inputs which is absent in battery cage and also suggest that decomposition of organic carbon was optimized under deep litter resulting in more release of organic acids (El-Sayed *et al.*, 2021).

Magnesium (Mg^{2+}) content of soil was significantly affected by interaction between poultry manure sources and levels (Table 4). Under battery cage, Mg^{2+} content of soil increased with level of application (0 – 10 t/ha) and dropped at 15 t/ha and increased at 20 t/ha. A similar trend was observed under deep litter except that Mg^{2+} content increased at 15 t/ha and later dropped at 20 t/ha. This is an indication that high Mg^{2+} content was sure to attain at 10 t/ha regardless of poultry manure sources (Hazelton & Murphy, 2025).

Potassium (K^+) content of the soil was significantly affected by the interaction between poultry manure sources and levels regardless of the treatment, soil K^+ content was very low. However the best soil K^+ content was recorded at 0 t/ha and 10 t/ha under battery cage and deep litter system respectively (Table 5). This is suggesting that soil K^+ content was only improved under deep litter especially at 10 t/ha application. The battery cage source did not improve the soil K^+ content. Although studies of Kidinda *et al.*, (2015) has shown that poultry manure

Table 1: Main Effect Poultry Manure Source and Levels on Selected Soil Microbial Population and Chemical Properties

LEVELS	TBC (10 ³ CFU/g)	TCC (10 ³ CFU/g)	pH (H ₂ O)	OC (g/kg)	Na ⁺ (Cmol/kg)	K ⁺ (Cmol/kg)	Ca ²⁺ (Cmol/kg)	Mg ²⁺ (Cmol/kg)
0 t/ha	178.00 ^a	153.00 ^a	6.08 ^b	5.02 ^b	0.115 ^a	0.163 ^{ab}	2.05 ^{ab}	2.45 ^b
5 t/ha	179.00 ^a	134.50 ^a	6.10 ^b	5.67 ^a	0.114 ^b	0.143 ^b	1.90 ^b	2.63 ^b
10 t/ha	174.25 ^a	177.00 ^a	6.12 ^b	5.85 ^a	0.123 ^a	0.183 ^a	2.38 ^a	3.30 ^a
15 t/ha	121.75 ^a	147.50 ^a	6.23 ^a	5.37 ^{ab}	0.123 ^a	0.148 ^b	1.88 ^b	3.20 ^a
20 t/ha	139.75 ^a	172.50 ^a	6.07 ^b	5.46 ^{ab}	0.122 ^{ab}	0.157 ^b	2.10 ^{ab}	2.75 ^b
Significance	NS	NS	*	NS	NS	*	NS	*
SOURCES								
Deep Litter	143.20 ^a	127.20 ^b	6.15 ^a	5.40 ^a	0.120 ^a	0.149 ^b	2.18 ^a	2.89 ^a
Battery Cage	173.90 ^a	186.60 ^a	6.09 ^b	5.55 ^a	0.119 ^a	0.169 ^a	1.94 ^a	2.84 ^a
Significance	NS	*	*	NS	NS	*	NS	NS
L*S	NS	NS	*	*	**	*	NS	**

Means with the same alphabet are not significant at $P > 0.05$. NS = Not Significant at $P > 0.05$. ** = highly Significant at $P < 0.01$.

Table 2: Interaction between Poultry Manure sources and levels on Soil pH

Levels	Poultry Manure Sources	
	Battery Cage	Deep Litter
0 t/ha	6.08	6.85
5 t/ha	6.08	6.11
10 t/ha	6.18	6.06
15 t/ha	6.32	6.15
20 t/ha	6.08	6.07
SE ±	0.029	

application increases soil K⁺ content, this study has clearly demonstrated that only poultry manure source of deep litter origin can achieve that. Soil Sodium (Na⁺) content as affected by sources and levels of poultry manure were rated low. Value under battery cage increased with the increase in

application but the trend under deep litter was irregular. Under batter cage the highest soil Na⁺ content was achieved at 20 t/ha followed by application of 10 t/ha implying that soil Na⁺ content was improved by each

Table 3: Interaction between Poultry Manure sources and levels on Soil Organic Carbon

	Poultry Manure Sources	
	Battery Cage	Deep Litter
Levels		
0 t/ha	5.04	5.00
5 t/ha	5.58	5.76
10 t/ha	5.22	6.48
15 t/ha	5.40	5.34
20 t/ha	5.77	5.16
SE $\pm$	0.202	

Table 4: Interaction between Poultry Manure sources and levels on Soil Mg²⁺

	Poultry Manure Sources	
	Battery Cage	Deep Litter
Levels		
0 t/ha	2.45	2.45
5 t/ha	2.45	2.80
10 t/ha	3.25	3.35
15 t/ha	2.95	3.45
20 t/ha	3.35	2.15
SE $\pm$	0.152	

Table 5: Interaction between Poultry Manure sources and levels on Soil K⁺

	Poultry Manure Sources	
	Battery Cage	Deep Litter
Levels		
0 t/ha	0.165	0.161
5 t/ha	0.150	0.135
10 t/ha	0.157	0.210
15 t/ha	0.129	0.167
20 t/ha	0.144	0.168
SE $\pm$	0.0093	

Table 6: Interaction between Poultry Manure sources and levels on Soil Na⁺

	Poultry Manure Sources	
	Battery Cage	Deep Litter
Levels		
0 t/ha	0.112	0.117
5 t/ha	0.113	0.115
10 t/ha	0.118	0.126
15 t/ha	0.117	0.127
20 t/ha	0.137	0.105
SE ±	0.0034	

application of battery cage manure. The reverse was the case under deep litter.

Conclusion

There was no any significant interaction effect on Total Bacteria Count However there was a significant effect of source of poultry manure of Total Coliform Count. The deep litter source recorded the highest total coliform count of (186.60 x 10³ CFU/g) Apart from exchangeable Ca²⁺, selected soil chemical properties (pH, Organic Carbon, Na⁺, K⁺, Mg²⁺) contents were significantly affected by the interaction between poultry manure sources and level.

Recommendation

Application of deep litter source of poultry manure especially at 10 t/ha that improved organic carbon K⁺ and Mg²⁺ content of soil is be recommended for further studies. However it is worthy to note that application of battery cage source of poultry manure significantly improved soil organic carbon and Na⁺ content especially at 20 t/ha

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INFLUENCE OF SHEA BUTTER RESIDUES ON SELECTED SOIL PHYSICAL AND CHEMICAL PROPERTIES IN BOSSO LGA OF NIGER STATE

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ABSTRACT

The study examined the impact of shea butter residues {Shea waste slurry (SWS) and Shea nut shell (SNS)} on selected soil physical and chemical properties. Random soil samples were collected from field measuring 3 m X 3 m away from shea butter processing point at a depth of 0-20 and 20-40 cm, while adjacent soil was used as the control at Bosso local government area of Niger State. Soil samples were analysed for certain soil properties according to standard laboratory methodology. Significant means were separated using LSD at 5 % level of probability. The predominant textural class of the dumpsites is Sandy Loam while the control is Clay Loam. The pH across the dump sites and control ranged from 5.2 to 6.9 indicating acidic to slightly acidic. However, at Point 1 (20-40 cm), the soil pH was alkaline (7.2). The pH values for the soils on dumpsites and control site showed significant ($p \leq 0.05$) increase with depths (0-20 cm and 20-40cm). The electrical conductivity on soil at all the points are ideal for plant growth though it differs from point to point with the control significantly ($P < 0.05$) lower than the dumpsites. The increase in OM, TN and AP accrue to shea waste residue on the dumpsite is an indication of the benefit of the residue as a source of soil fertility booster. The results for the heavy metals revealed that Fe, Cu and Zn on all the observed points are within the allowable limits in soil. On the other hand, Cd was within the allowable limits at control sites but exceeds the maximum allowable limits at all the points on shea butter residue dumpsite. However, Mn and Pb exceeded the maximum allowable limits for soil at both control and shea residue dumpsites. The study shows that shea butter residue has the potential of been used as soil nutrient enhancer, however there is need to reaffirm the heavy metal concentration of Shea butter residue dumpsite, so as to give a well guided suggestion with regards to its use as organic manure for crop production.

Key words: Shea butter residue, heavy metals, contaminant, waste recycling

INTRODUCTION

The shea butter tree (*Vitellaria paradoxa*) produces a local fruit with a green epicarp, a fleshy mesocarp (pulp) and a relatively hard shell (endocarp) which encloses the shea kernel. The shea nuts contain from 25 % up to 55 % edible fat (Akoma *et al.*; 2018). The Shea fruit according to Garti *et al.*, (2019) produces more solid shea butter as compared to other oil bearing fruits as it contains more stearic acid. The kernel, according to Honfo *et al.* (2014) contains 17.4% to 59.1% edible fat (shea butter) on a dry weight basis and the remaining product from which the butter is removed (shea cake), is an excellent ingredient for animal feed production. Niger state is becoming one of the main hub for shea butter in Nigeria (Adedeji *et al.*, 2024). Shea butter production is a way of life for most women and is traditionally acknowledged as 'women's work' by the local people as it is a key income source for them. Many of these women still use the traditional shea butter processing method they learnt from their elders' years ago, even though the method involves lengthy, arduous processes requiring large quantities of fuelwood and water which are often carried from long distances during shea butter processing season (Egbunonu *et al.*, 2019; Mohammed *et al.*, 2023; Katsekor *et al.*, 2024). Shea kernels are obtained after de-pulping which is the removal of the fleshy mesocarp after initial fermentation of the fruit through boiling or burying. After de-pulping, the nuts are boiled and sun dried. Sun drying

for 5-10 days reduces the moisture content to about 15-30 %. After sun drying, the nuts are de-husked through a number of ways

including trampling, pounding using a mortar and pestle and cracking between two stones. The dehusked nuts are also sun dried, stored, crushed into grits, roasted to aid oil extraction, milled or grind into paste, mixed with water and knead, cook emulsion, skim off the fats and cool to obtain shea butter (Ayodele, 2022; Choungo Nguekeng *et al.*, 202). Different wastes are generated and are either further used or disposed off and these include Shea nut shell (SNS) and shea waste slurry (SWS) (Abagale *et al.*, 2020). Shea nut shell as used in this study is the hard outer covering of the shea kernel, typically dark brown to black while shea waste-slurry is the semi-liquid by-product generated during shea butter processing which consists of a mixture of water, residual oil and fine organic particles from the shea nut. It is generally disposed off on open land which accumulate onto receiving soils. Jibreel *et al.* (2013) in Ghana realised that almost 46 % of the Shea butter processors disposed off the waste generated on open land which is the same practice we have in Nigeria. Plant wastes generally have a significant effect on soil properties (physical, chemical and biological) which favours plant growth and development (Hossain *et al.*, 2017). According to Jibreel *et al.* (2013), the intrinsic elements in shea waste might alter the structure and properties of receiving soils and affect crop development (Jibreel *et al.*, 2013). A study

by Abagale *et al.* (2020) in Ghana highlighted the positive potentials of Shea waste slurry on improving soil physical properties. This study therefore, examined the effect of shea butter processing residue on some selected soil properties.

MATERIALS AND METHODS

Study Area

The study area is located between Latitudes 9.583°N and 9.650°N and Longitudes 6.500°E and 6.583°E at an elevation of approximately 400 m above sea level within Bosso Local Government Area of Niger State. Soil samples were collected from the Shea Butter Processing Center, Kodo, Minna, Niger State. The area's mean annual maximum and minimum temperatures are 39.18 °C and 25.86 °C respectively, while the mean relative humidity and rainfall are 56.28% and 130.0 mm respectively. Bosso experiences two distinct central climate seasons: the rainy season (April to October) and the dry season (November to March). The vegetation of this area falls within the Guinea savanna zone. The soil is predominantly sandy loam, supporting both rain-fed and irrigated agriculture.

Soil Sampling and Analysis

A total of four sampling points were chosen for the study. Random soil samples were collected from field measuring 3 m X 3 m away from shea butter processing point at a depth of 0-20 and 20-40 cm, while adjacent soil, 100 m away from the dumpsite was used as the control at Bosso local government area of Niger State. At each collection points, soil samples were collected in 3 replicates to form one composite sample per point. The samples

were air dried, crushed and sieved with 2 mm sieve. Particle size distribution was determined using Bouyoucos hydrometer method (Klute, 1986). Soil pH was determined using the Potentiometric method (Thomas, 1996), while electrical conductivity was determined using the conductometry method in 1:2:5 soil/water ratio using electrical conductivity bridge (Rhoades, 1982). Organic carbon was determined using Walkley-Black wet oxidation method (Nelson and Sommers, 1982). Available phosphorus was determined using colorimetry method by Bray and Kurtz (1945). Exchangeable bases were extracted by ammonium acetate ($\text{NH}_4\text{CH}_3\text{CO}_2$); Na and K were read on flame photometer while Ca and Mg were determined by titration method (Thomas, 1982). Exchangeable acidity was extracted using 1M potassium chloride solution and determined by titration using sodium hydroxide. Trace elements were measured on Atomic Absorption Spectrophotometer (AAS) according to McLaughlin *et al.*, 2000.

Statistical Analysis

The collected data was subjected to analysis of variance (ANOVA). Significant differences among treatment means was determined using Student-Newman Keuls (SNK) test at a 5 % significance level using Minitab Version 17.

RESULTS AND DISCUSSION

The result of the physical properties of the soil under study is shown in Table 1. The bulk density mean value of the soil were found to be higher in the control. The values at 0-20 cm were 1.75 g cm⁻³, 1.68 g cm⁻³,

Table 1: Effect of Shea Butter Processing Residue on Soil Physical Properties

Dumpsites	Soil depth (cm)	Bulk Density (g cm ⁻³)	Soil Fractions (%)			Texture
			Sand	Silt	Clay	
Control	0-20	1.75	34.67	34.00	31.33	Clay Loam
	20-40	1.70	39.67	30.67	29.67	Clay Loam
Point 1	0-20	1.68	62.00	28.33	12.00	Sandy Loam
	20-40	1.65	54.67	26.00	17.00	Sandy Loam
Point 2	0-20	1.69	64.67	25.67	11.00	Sandy Loam
	20-40	1.71	57.33	23.67	19.00	Sandy Loam
Point 3	0-20	1.70	63.00	27.00	10.00	Sandy Loam
	20-40	1.70	52.00	17.00	31.00	Sandy Clay Loam
LSD		0.11	2.00	2.71	5.54	

1.69 g cm⁻³ and 1.70 g cm⁻³ for control, point 1, point 2 and point 3 and at 20-40 cm were 1.70 g cm⁻³, 1.65 g cm⁻³, 1.71 g cm⁻³ and 1.70 g cm⁻³ for control, point 1, point 2 and point 3 respectively. The reduction of bulk density on the dumpsite as compared to the control site may be attributed to the gradual increase in the organic matter content on the dumpsite. Organic matter decreases bulk density by increasing porosity and improving soil structure (Bashir *et al.*, 2021). Thus, the long term effect of shea butter residue on dumpsite may reduce the bulk density in the study area to the range suitable for cultivation (1.33 – 1.50 g cm⁻³). Abagale *et al.*, (2020) examined the effect of shea waste slurry on soil physical properties and reported that shea waste dumpsites influenced soil physical properties, resulting in lower bulk density values compared to control sites. The findings from the study conducted in peri-urban Tamale, Northern Ghana indicated that bulk densities ranged from 0.95 to 1.35 g cm⁻³ at the dumpsite, while the non-dumpsite exhibited higher bulk

densities ranging from 1.30 to 1.52 g cm⁻³. The study concluded that the application of shea waste slurry led to a reduction in soil bulk density, likely due to increased organic matter content from the waste (Abagale *et al.*, 2020).

The textural class of all the soils in the various points on the dumpsite were sandy loam except at point 3 (20-40 cm depth) which has sandy clay loam. **Sandy loam** tends to improve drainage and aeration, which benefits root development than clay loam (Weil *et al.*, 2017). However, the control has clay loam which has the tendency to hold nutrient but limits root development.

The chemical properties of soil on shea butter processing residue dumpsites is as shown on Table 2. A pH range of **5.5–6.5** is generally suitable for most crops (Agegnehu *et al.*, 2021). The results of the soil on shea waste dumpsite shows that the pH across the dump sites and control ranged from 5.2 to 6.9 indicating acidic to slightly acidic. However, at **Point 1 (20-40 cm)**, the soil pH was alkaline (7.2). The pH values for the

soils on dumpsites and control site showed significant ($p \leq 0.05$) increase with depths (0-20 cm and 20-40 cm). Control has the lowest electrical conductivity of 0.09 dS m^{-1} at 0-20 cm and 0.05 dS m^{-1} at 20-40 cm compared to that of the dumpsite which ranged from 0.12 to 0.49 dS m^{-1} . The electrical conductivity at the dumpsite is significantly ($p \leq 0.05$) higher than that of the control site but still within the ideal limit for plant growth. While high EC indicates increased availability of dissolved nutrients, excessively high EC can indicate salinity problems, which might hinder plant growth (Ehtaiwesh, 2022). Gulser *et al.*, (2010) reported that the addition of organic manure decreased soil pH and increased EC over different incubation periods. The study concluded that as nitrogen content increased with incubation in organically amended soils, corresponding changes in EC were observed. The reason for this increase may be because, the mineralization of organic wastes releases ions into the soil solution, which contributes to increased EC. When soil has less than 1 dS m^{-1} , it is considered non-saline and does not influence crops and soil microbial processes. But when the EC is greater than 1 dS m^{-1} , it is considered saline and it negatively affects plant growth and development. It also largely affects microbial processes such as nitrogen cycling (Ehtaiwesh, 2022).

The result of organic matter ranged from $3.26\text{--}48.84 \text{ g kg}^{-1}$ on the study sites. The organic matter content on 0-20 cm depth was significantly ($p \leq 0.05$) higher than the organic matter content on depth 20-40 cm at all the observed points. However, at 0-20 cm, the organic matter content on the dumpsite

was significantly ($p \leq 0.05$) higher than the control site. This may be due to breakdown of wastes in the dumpsites as a result of the activities of microorganisms. These observations are consistent with the study by Elenwo and Alloh (2018) which reported higher total organic matter levels at dumpsites compared to control plots, with concentrations decreasing as soil depth increases. the highest mean total organic matter was observed in the topsoil (0–15 cm) and the lowest at 30–45 cm depth. The authors concluded that the elevated organic matter at dumpsites was due to the accumulation and microbial decomposition of organic wastes. Similarly, research by Lemanowicz *et al.*, (2023) found that municipal waste deposition significantly influenced soil properties, leading to increased organic matter content in the upper soil layers. The study highlighted that waste decomposition enriches the soil with organic material, enhancing its fertility and structure.

Similarly, Total Nitrogen content was found to increase from mean value 2.63 g kg^{-1} on control (0-20 cm) to 3.17 g kg^{-1} and 4.70 g kg^{-1} on points 2 and 3 on dumpsites, Chude *et al.*, (2011) considered soils with $> 0.45 \text{ N}$ as high. Generally, the soils in all the observed points at both depths have high total Nitrogen content. High total nitrogen as found on dumpsites could be attributed to the presence of Shea waste on dumpsites. Available Phosphorus was shown to increase significantly as a result of the dumping of shea wastes ranging from high to very high (0-20 cm). At 20–40 cm, the dumpsites have values considered as

medium to high available phosphorus. While
on the control

Table 2: Chemical Properties of the soils on Shea Butter Processing Residue dumpsites

Dumpsites	Soil depth (cm)	pH in 0.01 M CaCl ₂	Electrical Conductivity (d Sm ⁻¹)	Organic Matter (g kg ⁻¹)	Total Nitrogen (g kg ⁻¹)	Available Phosphorous (mg kg ⁻¹)	Exchangeable Bases (Cmol kg ⁻¹)				CEC (Cmol kg ⁻¹)
							Ca	Mg	K	Na	
Control	0-20	6.10	0.09	16.96	2.63	6.52	9.13	0.97	2.52	2.17	18.53
	20-40	6.40	0.05	7.34	1.14	3.60	9.62	0.69	2.97	2.06	14.00
Point 1	0-20	6.90	0.37	19.72	2.40	78.72	10.24	0.98	3.04	2.13	18.57
	20-40	7.20	0.18	3.26	0.83	39.28	9.16	0.97	0.20	1.86	12.30
Point 2	0-20	5.50	0.49	34.64	4.70	47.68	9.11	0.90	3.00	2.31	17.60
	20-40	6.30	0.25	5.67	1.73	38.16	5.49	0.94	1.30	2.16	15.80
Point 3	0-20	5.20	0.13	48.84	3.17	35.67	9.78	0.96	2.51	2.14	17.40
	20-40	5.40	0.12	21.67	2.46	17.32	10.07	0.69	0.61	2.08	17
LSD		0.27*	0.8	1.73*	0.49	7.47	1.19*	0.46*	0.73*	0.2	1.01*

Table 3: Selected Trace Elements on Shea Butter Processing Residue dumpsites

Dumpsites	Soil depth (cm)	Mg kg ⁻¹					
		Fe	Mn	Cu	Zn	Pb	Cd
Control	0-20	94.70	82.1	0.50	6.84	1.26	0.35
	20-40	105.70	61.4	0.68	2.58	0.64	c
Point 1	0-20	62.50	63.60	0.13	28.73	1.19	3.28
	20-40	105.70	31.00	0.55	11.94	1.30	9.37
Point 2	0-20	214.30	51.70	1.33	35.84	3.06	3.27
	20-40	221.00	49.10	0.67	3.90	3.75	1.95
Point 3	0-20	274.40	84.10	4.32	35.62	0.12	53.74
	20-40	268.40	84.60	1.17	26.56	5.38	8.32
LSD		26.20	16.03	0.29	1.08	0.83	2.31
Maximum allowable limits		425.5	0.4	36	99.4	0.3	0.8

site, the results were observed to be low (6.52 mg kg^{-1}) at 0-20 cm and very low (3.60 mg kg^{-1}) at 20-40 cm. These findings show that shea waste could be an excellent material for soil fertility amendment.

The exchangeable acidity showed no significant differences between the means of the different points. The mean value of exchangeable bases are above their critical values of 4 Cmol kg^{-1} for Ca^{2+} , 0.5 Cmol kg^{-1} for Mg^{2+} , 0.5 Cmol kg^{-1} for K^{+} and 1.0 Cmol kg^{-1} for Na^{+} (Chude *et al.*, 2011). Except at point 1 (20-40 cm) where K was observed to be 0.2 Cmol kg^{-1} . Effective Cation Exchange Capacity (ECEC) ranged from 9.89 to $15.34 \text{ Cmol kg}^{-1}$ at 20-40 cm with dumpsite and control having lowest to highest values respectively. At 0-20 cm, ECEC ranged from 14.9 to $16.39 \text{ Cmol kg}^{-1}$ with control and dumpsites having lowest to highest respectively. As could be expected, the ECEC was higher in the dumpsite soil than the control; this shows that dumpsite can serve as source and sink of nutrients for plant growth. Magnesium increased non significantly on dumpsite than on control site, the values are all considered to be low. The potassium value also shows a similar trend, increasing non significantly with all the values considered very high.

The results in Table 3 shows the concentration of the selected trace elements on shea butter processing residue dumpsites. The concentration of the Mn and Pb on both dumpsites and control were found to exceed the maximum allowable limits set by FAO (FAO, 2004). The results indicated that the concentration of Fe, Cu and Zn on both dumpsites and control were found to be well below their critical limits indicating no contamination concerns. The critical limit for Cd is 0.8

mg kg^{-1} readings from the dumpsite exceed this limit.

The iron levels in the dumpsite ranged from 62.50 to $274.40 \text{ mg kg}^{-1}$ at 0–20 cm and 105.70 to $268.40 \text{ mg kg}^{-1}$ at 20–40 cm which is much lower below the Maximum Allowable Limit (MAL).

Mn concentration in the soil varied from 31.00 to 84.60 mg kg^{-1} , with higher levels recorded at Point 3 (84.10 mg kg^{-1} at 0–20 cm). The highest Cu in soil (4.32 mg kg^{-1}) was recorded at Point 3 (0–20 cm), which exceeds the MAL (0.4 mg kg^{-1}). Zn in the dumpsite soil ranged from 2.58 to 35.84 mg kg^{-1} , with the highest at Point 2 (0–20 cm) which is below the MAL (99.4 mg kg^{-1}). The highest Pb concentration is 5.38 mg kg^{-1} (Point 3, 20–40 cm), which is higher than in other points, Pb in all observed points is above the MAL (0.3 mg kg^{-1}). Cd in the dumpsite soil range from 1.95 to 53.74 mg kg^{-1} on dumpsites, with the highest value recorded at Point 3 (0–20 cm) all exceeding the MAL (0.8 mg kg^{-1}), indicating potential cadmium contamination at Point 3.

Iron and zinc values are below MAL in dumpsite soil, despite their high concentrations in the Shea waste. Copper remained below MAL, indicating low risk of contamination. Cadmium is critically high at dumpsites. While Manganese and Lead are above MAL at all points.

Conclusion

It was concluded from this study that the dumping of shea butter residues impact soil physical and chemical properties positively. Although, proper management is needed to maximize its benefits and minimize the toxic concentration of manganese, lead, cadmium and iron.

Recommendation

Based on the result obtained, the study recommends a field trial using shea butter processing residue as an organic amendment in different levels for soil amendment, growth and yield improvement of crops. Further studies need to be conducted to determine the heavy metals concentration in shea butter processing residues.

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OPTIMUM NITROGEN EFFICIENCY FOR RICE PRODUCTION IN THE TROPICS

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ABSTRACT

Because of inadequate nutrients, Malaysia's average rice production of 4.2 t/ha is regarded as low. Finding high yielding, extremely stable, blast-resistant, and nitrogen-efficient rice genotypes for commercial production in Malaysia was the primary goal of this study. Sixteen blast-resistant rice genotypes were evaluated in three rice granary areas (Tanjung Karang, Selangor; Kota Sarang Semut, Kedah and Seberang Perai, Penang) with five different nitrogen fertilizer levels over two planting seasons (Main and off seasons). Five nitrogen fertilizer levels:- 60, 80, 100, 120 (standard recommendation) and 140 kg N/ha were applied in each location and planting season. The experimental design was a split plot design with three replications, where the nitrogen fertilizer levels was assigned as main plot and rice genotypes as sub-plot. Nitrogen levels had highly significant effects on all the yields and vegetative traits. The nitrogen yield efficiency differed significantly with various levels of nitrogen applied. The optimum nitrogen levels for MADA, Seberang Perai and Tanjung Karang were 112, 125 and 105 kg N/ha with yield production of 9.53, 8.99 and 9.48 t/ha, respectively. The two superior optimum nitrogen levels with high yield across environments are MADA and Seberang Perai which are recommended for commercial cultivation in Malaysia.

Keywords:- Rice, Maximum nitrogen, Blast resistant, Germplasm, Nitrogen use efficiency.

Introduction

Nitrogen is the most important nutrient element in terms of rice plants. It promotes the life of rice plants. Many researchers have stated that in order to meet the global food demand for rice, production has to be increased by more than 50% worldwide by 2030 (Khush, 2023; Chukwu *et al.*, 2019).

It is a tremendous task for the development of high-yielding rice varieties with tolerance to biotic and abiotic stresses (Selvarag *et al.*, 2022). There is the need in maintaining a balanced optimum nitrogen value which has an important role in determining plant resistance or susceptibility to diseases (Fageria *et al.*, 2010). Moreover, improving nutrient use

efficiency (NUE) of crop plants leads to a substantial enhancement of the plant yields to satisfy growing food demand, while concurrently reducing the environmental impacts of agriculture which includes ammonia volatilization, run-off, leaching, nitrogen emission etc (Koorem *et al.*, 2014). The correct balance of nitrogen levels must be apply to avoid antagonistic interactions that could upset or suppress the uptake of other nutrients and affect the plant growth and development. Even when the fertilizer supply is satisfactory, the importance of increasing its use efficiency cannot be underestimated. Increasing yield potential, combine effort on plant breeding, physiology, agronomic and management practices are prerequisite for achieving set goals. The green revolution has shown the significant contribution of optimum nitrogen management for increasing rice yield (Zorilla *et al.*, 2012). Application of nitrogen fertilizer either in excess or less has a significant effect on growth, yield and grain quality of rice. Therefore, it is important to apply optimum rate of nitrogen fertilizer according to each variety, planting density and soil type requirement (Awan *et al.*, 2011; Wu *et al.*, 2013). Grain yield is influenced by many factors including the genotype, fertilizers, such as nitrogen, water management and location. Hence, selection of genotype should be based on fertilizer use efficiency For optimum crop growth and high yield proper doses or optimum levels of nitrogen rates are required. Maintaining an optimum nutrition is very important for rice species. It determine the resistant or susceptibility to plant diseases (Fageria *et al.*, 2010). Moreover, improving nutrient use efficiency of crop plants leads to a substantial enhancement of the plant yields to satisfying food demand while

concurrently reducing the environmental impact of agriculture (Lobell, 2007). There has been many studies on the optimum nitrogen uptake under soil based plants (Bloomfield *et al.*, 2014; Koorem *et al.*, 2014). However, in a soil base plant experiment, there exist a complex interaction between the rice plant, the soil and microbes which in one way or the other contribute to competitive effects and does not reflect on the nitrogen added to the rice plants. Nevertheless, within the soil medium there exist a complex interaction between ions within the soil particles (Conn *et al.*, 2013).

The present investigation is, therefore aimed at determining the optimum nitrogen rates for the production of rice at different locations

Materials and Methods

Plant materials, location and cultural practices

A set of thirteen advanced blast resistant varieties of rice and three checked varieties were used in this experiment. The field trial was conducted in Tanjung Karang, Selangor; Kota Sarang Semut, Kedah and Seberang Perai, Penang, in the 2020–2021 cropping seasons in Malaysia. The experimental design was Split plot design with three replications in a plot 35×28.5 m². The planting distant of $25\text{cm} \times 25\text{cm}$ spacing, the plot is $2\text{m} \times 1.5\text{m}$ unit for genotype in each replication. Optimum date for transplanting at the location was followed according to the farmer's schedule. Uniform fertilizer application was applied as prescribed by Malaysian Agricultural Research and Development Institute, MARDI. Nitrogen was applied at five (5) different rates of 60kgN , 80KgN , 100KgN , 120KgN and 140kg using Urea and N.P.K 15:15:15 compound fertilizer, first application was done at two weeks

after sowing (WAS), second at six WAS and the third at nine weeks after sowing. The field was mechanically ploughed in the normal cultivation practices. Soil samples from each experimental sites were taken randomly from different spot and bulked together to obtain a composite sample. This is to get a good plot for the planting of rice plants. Weeds were removed from the field by hand picking in order to have a weed-free area and spraying of herbicide for broadleaf, while in locations such as Tanjung Karang, the water level was used to control the weeds.

Data collection

The collection of data started at the time of crop maturity, five rice stands/plot/genotypes were sampled and recorded per each replication for all the genotypes. The following data were collected (Table 1)

Data analysis

All the data were analysed using analysis of variance (ANOVA) procedure in the statistical software package (SAS version 9.4).

Table 1 : List of quantitative traits collected

Growth trait	Abbreviation (unit)	Method of evaluation
Plant height	PHT (cm)	The average height from the base to the tip of the last leaf
Tillers per hill	NTH (no)	counting the number of tillers per hill
Panicle per hill	NPH (no)	counting the number of panicle per hill
Filled grain per panicle	FGPC (no)	counting the number of spikelets per panicle
Unfilled grain per panicle	UFGPC (no)	counting the number of unfilled spikelets per panicle
Percentage filled grain per panicle	PFGPC (%)	calculating the percentage filled grain
Panicle length	PLC (cm)	measuring the length from the node below the lowest branch on the panicle to the top of first superior spikelet
Grain length	GLTH (mm)	measuring the length of the grain
One thousand grain length	One TGWT (g)	weighing 1000 filled grain
Grain weight per plot	GWTPP (g)	weighing total number of grains per hill
Yield (kg per plot)	Kg/plot	weighing one kilogram per plot
Yield (t ha ⁻¹)	Tha (t/ha)	weighing tonnes per plot that is thrashed in 2×1.5 m ² excluding the border rows (kg/plot × 10,000/3 m ²)

Table 2: Means of agronomic nitrogen yield efficiency in individual environments

Genotype	MADA1	MADA2	SP1	SP2	TK1	TK2

1	80.29	91.94	112.23	94.21	88.09	96.75
2	78.01	100.3	87.97	107.82	94.52	87.48
3	95.83	96.5	95.59	101.56	98.9	106.72
4	95.23	96.37	104.93	93.67	83.26	101.11
5	108.97	87.94	87.42	88.76	74.47	81.02
6	88.49	90.89	90.96	116.05	99.6	86.14
7	95.6	93.75	98.47	107.87	90.19	84.72
8	87.53	102.84	106.81	107.73	83.98	105.42
9	91.29	74.2	87.5	107.32	90.5	101.05
10	96.05	69.04	97.03	113.62	82.47	106.29
11	82.69	66.92	114.02	100.24	80.81	100.08
12	85.26	80.93	92.46	110.53	98.9	111.19
13	78.96	87.28	96.56	98.92	82.33	112.08
14	93.07	98.83	74.29	108.79	93.02	106.68
15	100.34	97.07	100.2	117.97	93.7	117.45
16	90.88	96.69	71.4	99.53	81.42	109.25
MEAN	90.53	89.47	94.87	104.66	88.64	100.84
Std Dev	8.36	11.12	11.87	8.35	7.57	10.84
CV	25.4	25.38	32.48	17.63	29.57	28.23
Std Error	1.48	1.47	1.99	1.19	1.69	1.84
LSD	16.5	9.3	20.6	10.59	17.47	20.11

Note: MADA 1 and MADA 2 = MADA at planting season 1 and 2 respectively, SP1 and SP2 = SP at planting season 1 and 2 respectively, TK1 and TK2 = TK at planting season 1 and 2 respectively.

Results and Discussion

The analysis for the total mean per hectare of the agronomic nitrogen yield efficiency was presented in Table 2. Seberan Perai 2 environment produced the highest agronomic yield with the value of 104.66, followed by Tanjung Karan 2 with a value of 100.84. The lowest environment was Tanjung Karang 1 having a value of 88.64 agronomic nitrogen yield efficiency

A graph was drawn which comprises the mean of the yield of the 16 genotypes against the different nitrogen rates. The rice grain yield had a significant polynomial correlation with the amount of N applied at different nitrogen rates.

Optimum nitrogen Efficiency

The results of the optimum nitrogen yield efficiency was presented for each environments as shown below:-

MADA

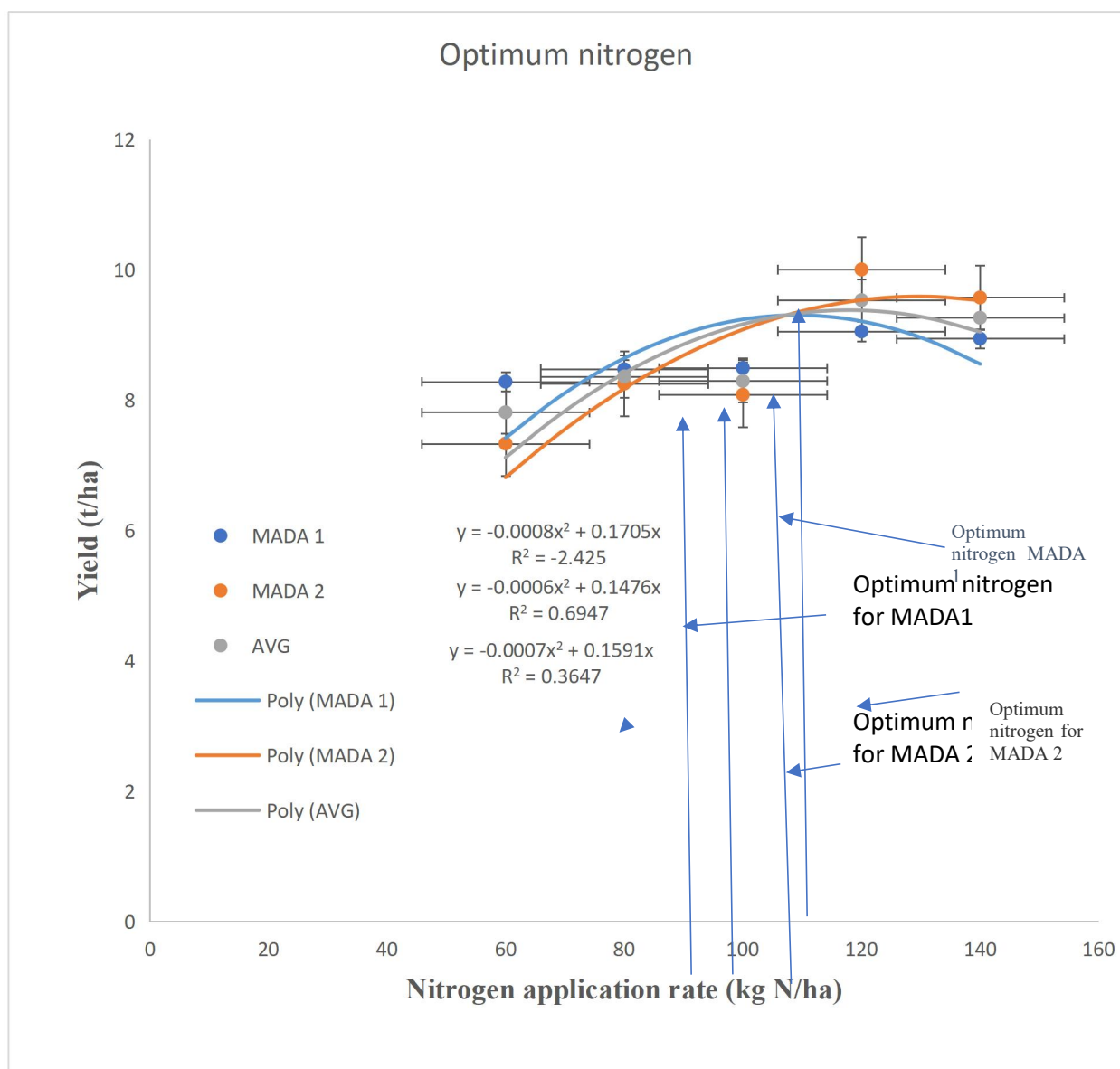


Figure 1 : Optimum nitrogen level at MADA

Sebarang Perai

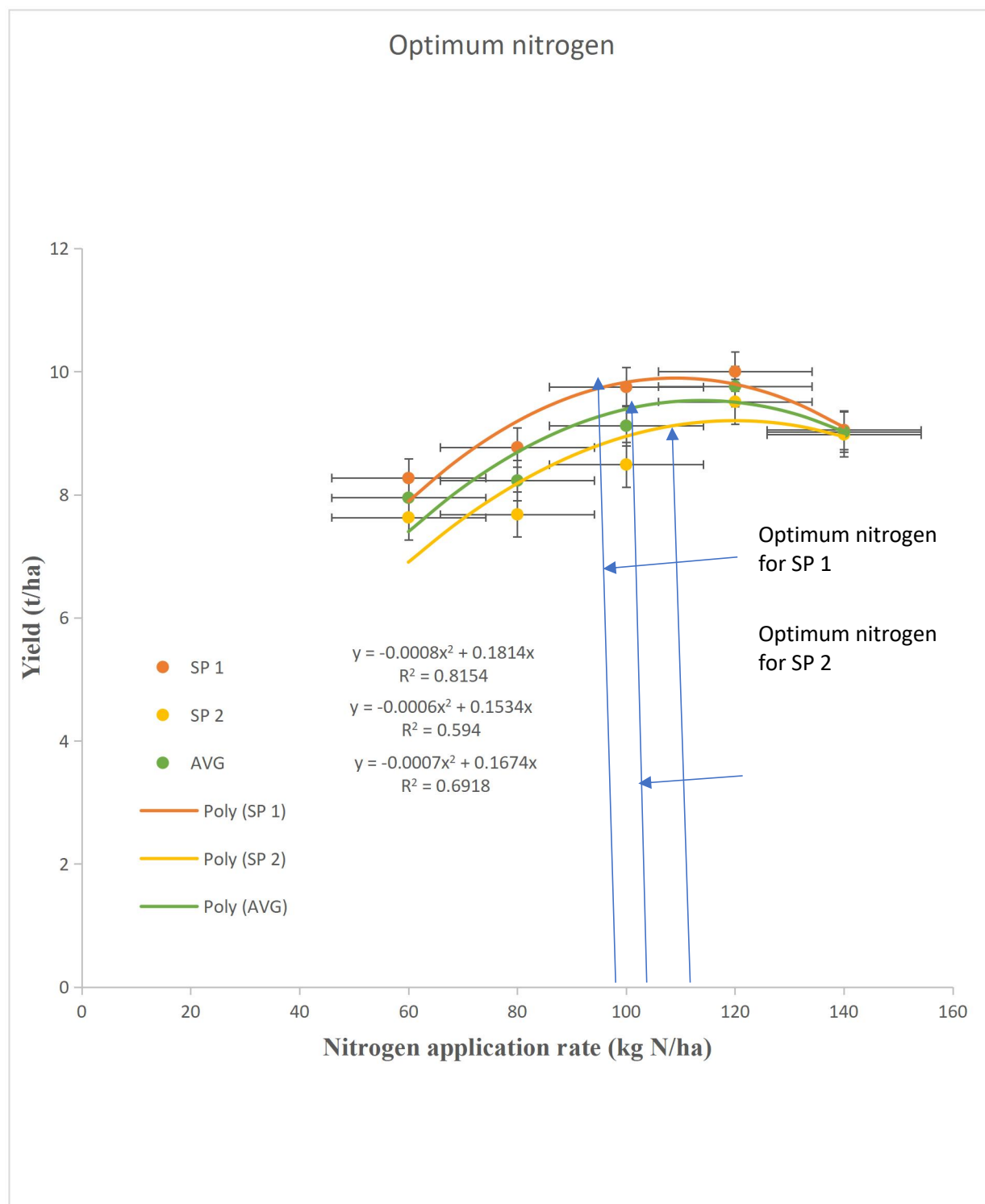


Figure 2 : Optimum nitrogen level at Sebarang Perai

Tanjung Karang

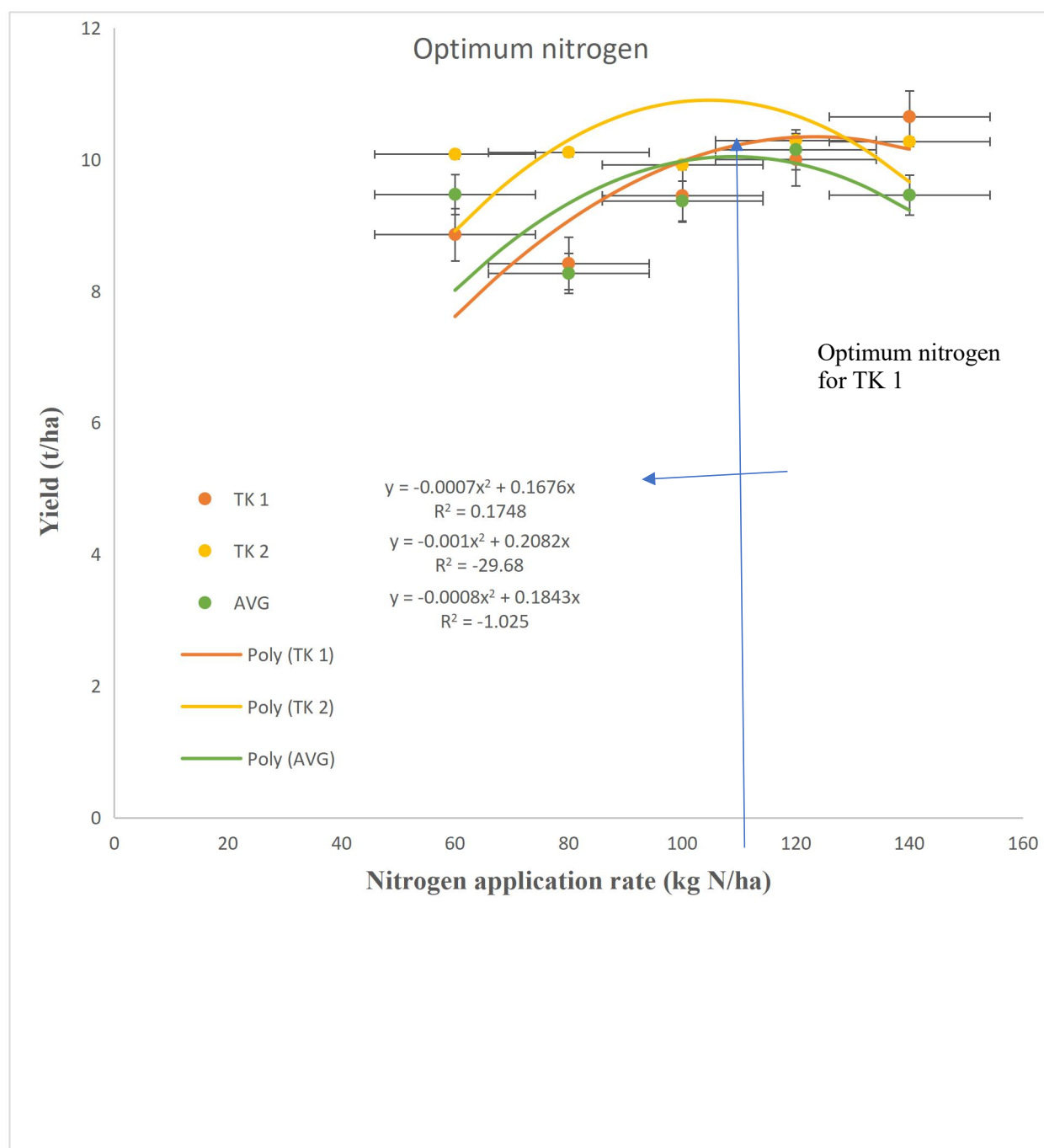


Figure3: Optimum nitrogen level at Tanjung Karang

In agriculture, soil fertility is a determining plant resistance or phenomenon of significant effect in rice susceptibility to disease. Moreover, study, most especially with agronomic improving agronomic nitrogen yield nitrogen efficiency. Maintaining a efficiency (ANYE) of crop plants leads to balanced nutrition has an important role in a substantial increase in the utilization of

the optimum nitrogen required for successful growth and yield of rice plants. Maintaining a balanced nutrition has an important role in determining plant resistance or susceptibility to disease (Fageria *et al.*, 2010). Moreover, improving agronomic nitrogen yield efficiency (ANYE) of crop plants leads to the enhancement of the plant rice to satisfy growing food demand, while concurrently reducing the environmental impacts of agriculture like ammonia volatilization, nitrogen emission, leaching, runoff etc. Soil degradation and nitrogen depletion becomes so serious to soil management, which gradually increased and become serious threats to agricultural productivity. Most of the areas used for production of rice especially MADA have recorded a significant increase in yield due to the nitrogen rates applied. In MADA 1, the optimum nitrogen level recorded was 104 kg N/ha rates which account for 10 kg /plot of rice yield. However, in MADA 2 the optimum nitrogen recorded was 121 kg N/ha revealing that more of the nitrogen level become prominent in enhancement of rice yields of about 9.05 kg /plot. However, when the two optimum nitrogen were averaged (MADA 1 and MADA 2), a significant optimum nitrogen is recorded to be 112.5 kg N/ha with a a yield of 9.53 kg/plot. In Seberang Perai environment there was also a significant increase in optimum nitrogen levels, there was a statistical difference in 115 kg N /ha optimum nitrogen level in Seberang Perai 1 with 9.85 kg/plot of yield while in Seberang Perai 2 it showed an optimum nitrogen level 125 kg/ha yield with the yield of 8.99 kg/plot. The average optimum nitrogen rates was 119.5 kg N/ha and the yield 9.42 kg/plot. In Tanjung Karang environment the optimum nitrogen

level were recorded, in Tanjung Karang 1 the optimum nitrogen level recorded was 105 kg N/ha giving the yield of 10.3 kg/plot. However, the optimum nitrogen level in Tanjung Karang 2 was around 127 kg N/ha. This give yield response of 10.5kg per plot, which is a good development. The average optimum nitrogen recorded was 116 kg N/ha with a yield of 9.48 kg/plot.

There is a need to maintain a balance of the optimum nitrogen rates for the production of rice at different locations. The correct balance of optimum nitrogen fertilizer rates were determined for each location in this study. However, the average optimum nitrogen rates observed was in MADA, having 112 kg N/ha average optimum nitrogen rate which give the yield of 9.53t/ha.

CONCLUSION

The yield of rice increased progressively with the increase of nitrogen rates upto 140 kg N/ha. Addition of nitrogen beyond that rate decreased yield of the rice. Higher levels of nitrogen application increase tallness and make the crop more ready to produce grains.

Agronomic N-use efficiency is the basis for economic and environmental efficiency, and more sustainable agricultural practices are required in farm management for improving crop yield performance and to reduce the environmental risks of farming. The optimum N fertilizer management is very important not only for economic purpose but also for environmental problems like ammonia volalization, nitrogen emission, leaching, runoff etc. An increase in the N application rate enhances rice yields, consequently resulting in the production of more food for people and providing more economic returns.

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ASSESSMENT OF MICRONUTRIENTS IN SOILS CONTAMINATED WITH HYDROCARBONS AND PLANTED TO COMMON REED PLANTS

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ABSTRACT

Hydrocarbon contamination is a widespread environmental issue, which can disrupt soil quality and nutrients availability. This experiment was a pot nursery one conducted to investigate the effects of soil contaminated with different hydrocarbons rates of application; 0mg/kg, 50mg/kg, 100mg/kg and 150mg/kg respectively and the impact of planted common reed (Phragmites australis), a plant known for its phytoremediation potential on the micro nutrients concentration. The experimental design was complete randomized design. The research focused on assessing the concentrations of essential micronutrients, including iron (Fe), zinc (Zn), copper (Cu), and manganese (Mn), within the hydrocarbon contaminated soil after the soil samples were analysed using standard procedures in the laboratory. Results indicated that the soil texture was sandy loam in nature and recorded a pH value that was in the range of slightly acidic to neutral (6.24-7.74) irrespective of hydrocarbon contamination level. Furthermore, a significant alteration in the micro nutrient levels in the soil was noted ($P < 0.05$) with a notable depletion of some of the nutrients particularly at 100mg/kg and 150mg/kg compared with control but within the range of literature standard compliance (1.18-3.01mg/kg for Fe, 1.02-1.95mg/kg for Cu, 0.13-0.74mg/kg for Mn and 0.18-0.22mg/kg for Mg respectively. This underscores the impact of hydrocarbon contamination on the soil nutrients availability and the potential of common reed plant as a tool for mitigating soil degradation; from the hydrocarbon contamination and enhancing soil quality restoration in the contaminated soil environments. This research contributes to the understanding of phytoremediation strategies and the role of common reed plants in quality restoration of micro nutrients in hydrocarbon-polluted soils.

Keywords: Micro nutrients; Environment, Hydrocarbon; Common reed; Soil quality

Introduction

Rapid industrialization, agricultural practices and inadequate waste management contribute to soil contamination by releasing pollutants such as heavy metals, persistent organic pollutants, and petroleum hydrocarbons, which can contaminate the surrounding environment (Abrahams, 2022). Furthermore, the use of chemical fertilizers, pesticides, and herbicides in agricultural practices also contributes to soil pollution posing a risk to human health and the environment.

Hydrocarbon contamination, the presence of petroleum-derived compounds in soil, is a widespread environmental concern, encompassing a diverse range of organic molecules originate from various sources including oil spills, leaks from pipelines and storage tanks, and improper disposal practices (Singh *et al.*, 2017). The prevalence of hydrocarbon contamination is alarming, affecting vast swathes of land globally, with estimates suggesting millions of hectares impacted (Meckenstock *et al.*, 2000) posing a significant threat to the health and functionality of soil and plant ecosystems. Micronutrients in soil are essential nutrients plants need in small quantities for healthy growth and development, they include B, Cl, Cu, Fe, Mn, Mo, Ni, and Zn. In addition, they play essential roles in plant growth and development, and their deficiencies can lead to stunted growth, reduced biomass production, and increased susceptibility to stress (Marschner, 2012). However, hydrocarbon contaminants can disrupt essential soil processes, hinder microbial

activity, and impact nutrient availability (Oyinlola *et al.*, 2019).

Common reed plant (*Phragmites australis*), is a plant that demonstrates remarkable tolerance to contaminated environments (Vymazal, 2007) including that of hydrocarbon. This adaptable plant boasts a surprising talent: flourishing in contaminated environments via its extensive root system that acts as a biofilter, absorbing pollutants like hydrocarbons from the soil and water. This tolerance, coupled with its ability to harbor contaminant-degrading microbes, makes it a potential champion for phytoremediation- the green technology of using plants to clean up contaminated sites. However, while common reed (*phragmites australis*) exhibits resilience in contaminated areas, little is known about the effects of hydrocarbons on soil micro nutrients. Moreover, the potential effects of hydrocarbon contamination on the soil's micro nutrient profile and their subsequent uptake by *phragmites australis* remain unclear. Thus, understanding the impact of hydrocarbon contamination on soil micronutrients is crucial. Furthermore, the ability of *Phragmites australis* to effectively remediate contaminated sites may be influenced by its micro nutrient status.

Many works were carried out on soil and water quality and hydrocarbon concentrations in Nigeria, for example, Abdallah *et al.*, (2022) and Sani *et al.*, (2022) investigated the impact of crude oil and irrigation water quality on various soil aspects respectively, including mineral nutrients. While it focused on macro-nutrients, it mentions potential interactive effects on micro nutrient availability due to microbial activity and plant uptake. Furthermore, Chukwuma (2023) explores how fertilizer affects hydrocarbon biodegradation in contaminated soils

highlighting how microbial communities dealing with hydrocarbons can influence nutrient availability in the soil. However, despite all these researches, none of them focused on the micro-nutrients concentration on soils contaminated with hydrocarbons and planted to common reed. Therefore, the main aim of the study is to assess micro-nutrients of soil contaminated with hydrocarbons and planted to common reed plants through the following objectives

1. To determine soil micro-nutrients levels in hydrocarbon-contaminated soil planted with common reeds plant.
- ii. Compare the assessed micro-nutrients with the literature standard for compliance.

Materials and Methods

Study Area Description

This research was conducted at Aliko Dangote University of Science and Technology, Wudil, Department of Forestry, Fisheries and Wildlife Nursery. Wudil is located on latitude 11.570317°N, 11.869425°N and longitude 8.779696°E, 8.936728°E of the Green which Meridian with the geological set up falling within the Northern Nigerian basement complex rocks (Olofin, 1987; and Olofin and Tanko, 2002) and the climate of the region is wet and dry seasons with the mean annual rainfall of about 850 mm (Olofin, 1987). The mean annual temperature in the area is about 26°C, however; the monthly mean temperature value ranges between 21°C during the coolest month of December/January and 31°C in the hottest months of April/May (Olofin, 1987).

Experimental Materials and Mode of Experiment

Soil, cow dung manure, common reed plant, diesel fuel as hydrocarbon model and source, weighing balance, plates, hand

trowel, hand gloves, and pots were used during the experiment. The experiment was an open-pot to simulate the natural environmental conditions of the research area. Five (5) healthy common reed plants were planted per experimental pot and thereafter contaminated with diesel fuel as a source of hydrocarbon at different rates; 50 mgkg⁻¹, 100 mgkg⁻¹, 150 mgkg⁻¹ and 0 mgkg⁻¹ as control having no contamination. The common reed plants were collected from healthy parent stocks growing in their natural environment to grow in fine river sand and cow dung manure sterilized and mixed at a ratio of 3:2 using a head pan, potted and set into a nursery in three replications.

Soil Sampling

Soil samples were collected from three different pots and their controls using random sampling technique. In each pot three representative soil samples from their composite were collected and bulked. All samples were kept for in a well labelled polythene bags for laboratory analyses. However, Note that twelve soil samples including the controls from the initial hydrocarbon concentration were collected and kept under shade to dry before and after the expiration of the experiment for laboratory analysis.

Experimental Design

Complete Randomized Design (CRD), with three contamination rates; (50mgkg⁻¹, 100mgkg⁻¹ and 150mgkg⁻¹ with control having no contamination as 0mgkg⁻¹) were applied to evaluate soil responses. CRD was chosen as it provided simplicity and flexibility in analyzing the effects of different contamination rates on hydrocarbon degradation and soil health.

2.5 Laboratory Analyses

Micro-nutrients (Fe, Mn, Zn, and Cu) were analysed by extraction method using

diethylenetriaminepenta acetic acid (DTPA) as described by Lindsay and Norvell (1978) and readings were made using the atomic absorption spectrophotometer (AAS) while soil pH and Mechanical Analysis were determined by pH meter and standard hydrometer method respectively as outlined by Gee and Bauder (1986).

Hydrocarbon Analysis

Soxhlet extraction was applied to measure the poly-cyclic aromatic hydrocarbons (PAH) as the model hydrocarbon in the soil samples. The extracted compounds were evaporated, purified, and gas chromatography was used to evaluate the hydrocarbon concentration (USEPA, 1984, and Christopher *et al.*, 1988).

Statistical Analysis

The obtained data were subjected to Analysis of Variance (ANOVA) using SAS statistical package and where means were separated, Least Significant Difference (LSD) was used under (5%) level of significance.

Results and Discussion

3.1 Experimental Soil Quality

The analyses of soil parameters in control soil before the start of the experiment and other soils after being contaminated with hydrocarbon fuel are presented in Table 1. Findings indicated that the pH recorded in both control and the contaminated soils (50mg/kg, 100mg/kg and 150mg/kg hydrocarbon contamination respectively) was within the range of 6.33-7.43 which is compliant to 6.5-8.5 permissible limit of agricultural soils (WHO, 2008) (Table 1). The soil textural class was sandy loam in nature and all the analysed micro-nutrients; Fe, Mg, Mn and Cu were relatively moderate to high micro-nutrients concentration in both the control and the contaminated soils and within the range of good agricultural soils (Table 3).

Considering the aforementioned contaminated soil characteristics, the soil quality was relatively good.

Comparison of Soil Properties and Micronutrients after Hydrocarbon Contamination

Comparison of soil pH

Table 1 indicated that the pH values were highly recorded in 150mgkg⁻¹ hydrocarbon contamination in comparison with other pH values and the difference was highly significant ($P < 0.05$) statistically and ranges between slightly acidic to neutral (Table 2). The plausible reason for the high concentration in the pH could be attributed to the high amount of the hydrocarbons compounds released in the 150mgkg⁻¹ contaminated soil pH samples which might have triggered the pH concentration (Sani *et al.*, 2022) leading to the observed high pH values and was in conformity with findings of Sani (2015) stated elsewhere.

Comparison of Fe

According to Table 1, Fe micro-nutrient recorded high values in 150mgkg⁻¹ hydrocarbon contaminated soil compared to other contaminations of 50gkg⁻¹ and 100gkg⁻¹ respectively, with very high statistical difference ($P < 0.05$) (Table 2). Moreover, the Fe concentration was within the range of low class of ranking of micro-nutrients (Table 3). The possible reason for the observed statistical low Fe concentration difference could be attributed to the reduction in microbial diversity impairing microorganisms' activities and population in the rhizosphere of common reed soil association leading to the observed low Fe values (Khan *et al.*, 2021; Zhang *et al.*, 2022).

Comparison of Cu

The result of copper indicates that 100mg/kg and 50mg/kg hydrocarbons contaminated soils recorded highest values

compared with control and 150mg/kg contaminated soils (Table 1). Though 100mg/kg and 50mg/kg were similar statistically (Table 2), the significant variation between them compared to 150mg/kg and control were highly significant ($P<0.05$). Furthermore, the Cu concentration level was according to Table 3 ranking of micro nutrients moderate in classification. The possible reason behind the statistical difference and the moderate Cu concentration could be ascribed to the contribution of common reed to the overall health of soil microbes which play a role in nutrient cycling including that of Cu promoting the breakdown of organic matter and release of nutrients including the Cu nutrient, leading to the observed moderate and sufficient Cu concentration (Mishra *et al*, 2023) and has been confirmed previously elsewhere (Bai *et al*, 2022).

Comparison of Mn

According to the Anova table, Table 2 shows that hydrocarbon contamination at the rate of 150mg/kg recorded highest Mn micro-nutrients values compared with control and other contamination rates. The differences in the concentration was very significant ($P<0.05$) statistically. Moreover, the micro-nutrient concentration of Mn in the ranking classification shows that the micro-nutrient was very low (<1) throughout the classification (Table 3). The plausible reason for this low concentration could be probably due to selectivity nature in demand of the microorganisms in the rhizosphere of common reed leading to higher demand of Mn compared with other nutrients as a source of carbon and energy making the concentration of the micro-nutrient very low as observed in Tables 1 and 2 (Sani,

2015) and was in conformity with other reported literature (Almukhtar *et al*, 2018).

Comparison of Mg

According to Table 1, the Mg concentration was highest in the 50mg/kg and 150mg/kg contamination rates respectively. Moreover, the difference in the concentration was highly significant ($P<0.05$) statistically compared with other levels of contamination (Table 2). In addition, the ranking in the classification of the micro nutrients classified the micro-nutrient as low, recording values in the range of 0.18-0.23 mg/kg (Tables 1 and 2). The responsible reason for the low concentration and the significant difference could be attributed to lower concentration in the nutrient as a result of high consumption by micro-organisms as a source of their energy that were very active and diverse in the common reed rhizosphere leading

to the observed low concentration (Sani *et al*, 2022) and has been confirmed elsewhere (Sani 2015).

Conclusion and Recommendation

The broad aim of this study was to evaluate the impact of hydrocarbons on soils micro-nutrients and the effect of planting common reed (*Phragmites australis*), a plant known for its phytoremediation potential. Findings indicated that the soil texture was sandy loam in nature and recorded a pH value that was in the range of slightly acidic to neutral (6.24-7.74) irrespective of hydrocarbon contamination level. Furthermore, a significant variation in the micronutrient levels in the soil was noted ($P<0.05$) with a notable depletion of some of the nutrients particularly at 100mg/kg and 150mg/kg compared with 50mg/kg and control but within the range of literature standard compliance (1.18-

3.01mg/kg for Fe, 1.02-1.95mg/kg for Cu, 0.13-0.74mg/kg for Mn and 0.18-0.22mg/kg for Mg respectively.

Table 1: Overall mean values of micro-nutrients in control soils before and after hydrocarbon fuel contamination at different level of application and planted to common reed plant

Soil parameters	Uncontaminated soils	Contaminated soils		
		A	B	C
pH (-)	6.24	7.64	7.24	7.74
Particle size				
Sand%	77.78	80.45	73.12	82.45
Silt%	16.55	16.56	15.22	11.22
Clay%	5.67	2.99	11.66	6.33
Micronutrients				
Fe (Mg/kg)		4.20	3.20	2.32
Mn (Mg/kg)		1.40	1.22	1.21
Cu (Mg/kg)		2.80	2.12	2.08
Mg (Mg/kg)		0.24	0.21	0.18

A, contaminated soil with hydrocarbon contamination at 50mg/kg, B contaminated with 100mg/kg hydrocarbon, C, contaminated with 150mg/kg hydrocarbon while uncontaminated soils are control with 0mg/kg hydrocarbon contamination and all were planted with common reed plants. Note that all the aforementioned soil parameters and HMs in the contaminated soils were analysed before planting *Jatropha* in the contaminated soils

Table 2: Overall Mean Comparison of Micro-nutrients Concentration in the Soil and their Corresponding Significant Differences after Hydrocarbon Contamination

HC	pH	Fe (mg/kg)	Cu (mg/kg)	Mn (g/kg)	Mg
(g/kg)					
0g/kg	6.24 ^c	1.18 ^d	1.02 ^c	0.13 ^d	0.18 ^b
50g/kg	7.64 ^{ab}	2.40 ^c	1.94 ^a	0.59 ^b	0.23 ^a
100g/kg	7.24 ^b	2.86 ^{ab}	1.95 ^a	0.49 ^c	0.19 ^b
150g/kg	7.74 ^a	3.01 ^a	1.54 ^b	0.74 ^a	0.22 ^a
SE±	0.059	0.666	0.200	0.013	0.013

Note, columns recording different letters are highly significant at 5% level of confidence while HC denotes hydrocarbon concentration

Table 3: Micro-nutrients rating (mg/kg) according to literature

Micro-nutrients	Low	Moderate	High
Fe	<4.5	4.5	>4.5
Cu	<0.2	0.2-1.0	>1.0
Mg	0-0.3	0.3-1.0	>1.0
Mn	<1.0	1-2.0	2.0-5.0

Modified from Adamu *et al.*, 2021

The study concludes that hydrocarbon micronutrient availability and pH, posing contamination significantly affects soil challenges to soil health and fertility. The

use of common reed (*Phragmites australis*) as part of a phytoremediation strategy demonstrated potential in mitigating these adverse effects caused by hydrocarbon contamination, enhancing the recovery of the critical micronutrients like Fe, Mn, Cu and Mg. The results suggest that targeted hydrocarbon contamination levels can improve nutrient balance and soil conditions in the contaminated environments because of complementary positive impact of the *phragmites australis*. Overall, the findings highlight the effectiveness of common reed in restoring soil quality in hydrocarbon-polluted areas and provide a basis for further research into sustainable remediation techniques

Concerning recommendation, application of higher hydrocarbon dosage for improving soil pH and increasing micronutrient availability, particularly for manganese (Mn) and magnesium (Mg), which showed significant responses to the hydrocarbon contamination is recommended. Furthermore, monitoring soil pH should be advocated regularly especially in regions where soil acidity or alkalinity may affect crop growth. The use of contamination dose that will enhance soil pH could be beneficial for improving overall soil health and nutrient uptake.

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INFLUENCE OF *JATROPHA CAUCUS* IN IMPROVING MICRONUTRIENTS CONCENTRATION STATUS IN SOILS OF KANO, SUDAN SAVANNAH ECOLOGICAL ZONE OF NIGERIA

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ABSTRACT

A nursery experiment was conducted at the Department of Forestry and Wild Life Management, Aliko Dangote University of Science and Technology, Wudil to assess the influence of *Jatropha curcas* plant on improving marginal quality of micronutrients status in degraded alfisols. The experiment was arranged in a complete randomized design (CRD) with 3 replications and control. Pre and post *Jatropha* planting soil samples were assessed for soil micronutrients in the *Jatropha* seeds and cuttings with and without organic amendment after analytical laboratory analysis. The treatments were seeds without organic amendment (SF), cuttings without organic amendment (CF), seeds with organic amendment SO, cuttings with organic amendment (CO) and control (O). Findings indicated that the soils were sandy loam in nature with pH within the range of 6.24-7.83. Furthermore, result revealed that all the treatments recorded high significant ($P < 0.05$) variation between them and the micronutrients with seeds and cuttings treatments with organic amendments (SO and CO) recording highest values (24.67mg/kg, 36.33mg/kg and 49.33mg/kg for SO in Mn, Zn, and Fe micronutrients respectively and 23.33mg/kg, 33mg/kg, and 42mg/kg for CO in Mn, Zn, and Fe micronutrients in that order) compared with control and other treatments. Overall, the research findings have shown that *Jatropha curcas* have the ability to reclaim degraded marginal soils quality and improve them effectively particularly if grown in cuttings and amended with organic amendments.

Keywords: *Jatropha curcas*, reclamation, marginal land, soil quality, organic carbon

Introduction

Geometric rise in the world population coupled with an increasing in spate of climate change and global warming pose a

threat to food security globally and cause severe stresses on the soil (Kamran *et al.*, 2021) ecology as the receiving environment. Anthropogenic activities such as over-cultivation and other agricultural intensified

practices, speedy urbanization, and rapid industrialization are also causing more serious environmental soil fertility and quality degradation (Kafle *et al.*, 2022) via soil micro-nutrients exhaustion.

In as much as the nutrients are required by the plant in small quantities, vital plant metabolism are impaired or limited without them, thus, leading to the plant growth failure and reduced yield because of poor soil fertility. Therefore, maintaining soil fertility of the micro-nutrients; iron (Fe), manganese(MN) Zn and copper (Cu) is very imperative, however, maintaining the fertility via the practice of leaving land to fallow for some years can no longer meet up with the demand for food crop production in West Africa due to high pressure on the limited arable lands. Soil fertility maintenance is very essential in achieving and maintaining high crop yields over a period of time which may require application of fertilizers (Ayoola and Makinde, 2014). However, continuous and exhaustive use of highly priced mineral fertilizers, for improving crop productivity in the past decades, had been obviously connected to this problem (Afe and Oluleye, 2017) and influences micro-nutrient imbalances, though the chemical fertilizers increase soil micro-nutrients as plants directly and indirectly assimilate them, but their much continuous application leads to environmental quality degradation (Akbariyeh *et al.*, 2018; Mahal *et al.*, 2019). Thus, a need to consider another source of fertilizer which is cheaper, biologically resourceful with no residual harmful effect and can replenish soil with the appropriate needed micro-nutrients capable of

improving soil fertility and quality such as *Jatropha curcas* plant becomes indispensable.

Jatropha curcas (henceforth denoted as *Jatropha*) is drought-resistant oil-bearing multipurpose shrub/small tree, belonging to the family of Euphorbiaceae (Baroi *et al.*, 2009; Mulpuri *et al.*, 2019). *Jatropha* which has been singled out to deliver benefits through both small and large- scale cultivation (Gilbert, 2011). Studies have revealed the potential of *Jatropha* for degraded land regeneration, as it does not compete substantially with arable crops for nutrients and thus reduce the cost of production, prevents erosion alongside energy provision, being a major source of biofuel (Openshaw, 2000).

The Sudano-Sahelian zone of Nigeria is characterized as semi-arid, experiencing several kinds of soil degradations through recurrent droughts and desertification, bush burning, bush fallowing, over-cultivation, synthetic fertilizer application and global warming leaving the soil exhausted of micro and macro nutrients, hence, non-fertile. The high cost and unavailability of inorganic fertilizer caused difficulty in formulating large scale agriculture (Olawuyi *et al.*, 2010). Some of the major constraints identified to be responsible for low production of arable crops therefore include poor soil fertility, high cost of fertilizer and recurrent pests invasion. More so, there is dearth of information on the use of potential agro-forestry plants such as *Jatropha curcas* to reclaim the marginal soils of Sudano-sahelian zone of Nigeria.

The previous researches on *jatropha curcas* were carried out focusing on the impact of

the plant in reclaiming marginal soils (Sani *et al.*, 2022) while some on accessing soil physical quality in Sudan Savannah alfisols (Shehu *et al.*, 2016). However only few if any concentrated their efforts on the impact of *Jatropha* on micro nutrient concentrate in the region.

The aim of this study is to evaluate the micronutrients of marginal soils planted to *Jatropha* in Kano state sudan savannah ecological zone of Nigeria. The objectives of the study are to:

1. Determine the concentration of micro nutrients present in marginal soils on which *J. curcas* is grown and those without *J. curcas*.
2. Evaluate the impact of the plant on the concentration of the micro nutrient.

Materials and Methods

Experimental study Area Description

The research was conducted at the university nursery unit of Forestry and Wild Life Management Department, Aliko Dangote University of Science and Technology, Wudil. The geographical location of the site is between N11°48'18" latitude and E8°51'40" longitude on altitude 488m above sea level. about 37.5 m above sea level. The annual rainfall ranges from 850 to 870 mm, while minimum and maximum temperature ranges between 26 and 33°C. The relative humidity of the region is always low and ranges between, 40 to 51.3% (Dambazau and Olofin, 2008).

Experimental Materials

Jatropha curcas (seed and cutting), organic manure (cow dung), experimental pots, marginal soils, ruler, digital scale, watering can, pen and record book. Collection of Experimental Materials

The seeds were collected from the nursery

unit of Forestry and Wild Life Management Department, Aliko Dangote University of Science and Technology while the soil samples were collected from marginal land area of Faragai village, Albasu LGA. Seeds and cuttings of *Jatropha curcas* were collected from a healthy mother tree and planted using both direct seeding and vegetative propagation (cuttings) in the nursery.

Soil Sampling Materials

Core sampler, helper, scraper, hammer, hand trowel, hoe, rubber band, plastic pot, plain yard and water

Collection and Preparation of Soil samples

Three disturbed random loose samples were collected using simple random technique from the place where the planting soils were taken. Also, 12 planting soils were fitted for the nursery experiment and three control soils were collected from three different farmlands. The soils to be used for planting were measured before filling the experimental pots as well as the quantity of organic fertilizer (in the case of organic amended treatments). The collected marginal soils to be used for planting were mixed with organic fertilizer in the ratio of 2:1 and well watered prior to sowing

Duration of the Experiment and Work schedule

The experiment lasted for good three months from March 15, 2023 to June 15, 2023 where the experimental materials have attained juvenility of growth capable of reclaiming the soils based on the research conducted by (Ofelia *et al.*, 2013). The plant was watered twice daily and then reduced to once when the plant exceeded two months

of growth, hand weeding was done as well as proper supervision of the experimental site during the whole period of the experiment.

Mode of Experiment

Jatropha curcas was planted in plastic pots. Before the onset of the experiment, the experimental soils were subjected to laboratory analysis. Also, after three months of planting, the soils were subjected to another laboratory analysis to justify the differences on the impacts of the plant on marginal soils quality improvement.

Experimental Treatment

The treatment was *Jatropha curcas* plant seed free of amendment (SF) T₁, cutting free of amendment (CF) T₂, seed with organic matter (SO) T₃ and cutting with organic matter (CO) T₄, tested on a free amended marginal soils and organic amended marginal soils. Where by T₀ is the control. The experimental pots was labeled according to their composition where each treatment was replicated three times given a total of twelve (12) samples. Lastly 3 control soils were used in the experiment.

Experimental Design

A Completely Randomized Design (CRD) was used with four (4) treatments and control, where each treatment was replicated thrice and the controls were collected from three different farm lands in the experiment.

Laboratory Analysis

Micronutrients (Fe, Mn, Zn, and Cu) were analysed by extraction method using diethylenetriaminepenta acetic acid (DTPA) as described by Lindsay and Norvell (1978) and readings were made using the atomic absorption spectrophotometer (AAS).

Statistical Analysis

Data obtained and collected was subjected to analysis of Variance (ANOVA) while Least Significant Difference was used to separate the means that were significant at 5% level of probability.

Results and Discussion

Experimental Soil Quality

Table 1 shows an overall soil micro nutrients quality before and after *Jatropha* planting of the study area. The soil pH was within the recommended permissible limit for arable crop production (6.5-8.5) advocated by WHO, 2008 regulatory agency. However, the micro nutrients concentration indicated the soil quality before *Jatropha* planting was marginal (Table 1) with very poor quality and very low fertility standard ((Kafle *et al.*, 2022)). However, the soil micro nutrients concentration after *Jatropha* planting became apparently increased with more than 100% increase in all the treatments; SF (seed free of organic amendment), CF (cuttings free of organic amendment), SO (seed with organic amendment), CO (cuttings with organic amendment) and O as control without any amendment and *Jatropha* planting (Tables 1, 2 and 3) respectively.

Effect of *Jatropha* planting on Soil Micro-nutrients Concentration

Comparison of Soil pH

The pH levels recorded, particularly the notable elevation in SO treatment (7.83) (Tables 1 and 2), was highly significant statistically ($P < 0.05$) compared to other treatments. This could be attributed to high pH closer to neutral which was favorable for microbial activity and nutrient cycling in the soil due to *Jatropha* planting. This microbial activity plays a crucial role in breaking down organic matter and releasing nutrients,

thus creating a more conducive environment for plant growth and correlated well with findings of Lee *et al.* (2021). Moreover, the consistent pH levels across all treatments indicate a relatively stable soil environment; however, the heightened pH in SO treatment reflects the potential for improved nutrient mobilization as a result of the *Jatropha* plant, further supporting the need for combining organic amendments and *Jatropha* in agricultural practices.

Comparison of other micronutrients

Table 2 indicates that (SO) treatment demonstrated a significant enhancement ($P<0.05$) in the availability of key nutrients including manganese, zinc, and iron (Tables 1 and 2), these nutrients are crucial for various physiological processes in plants, and their elevated concentrations in SO treatment suggest that organic amendments with *Jatropha* plant can effectively address nutritional deficiencies in the soil. This aligns well with previous research conducted by Smith *et al.* (2020), who reported that the application of organic matter, particularly in the form of organic manure and *Jatropha* plant, can effectively improve manganese thereby facilitating better plant growth and productivity.

Furthermore, the study's observation of high significant level of zinc in SO treatment ($P<0.05$) bolstered findings from Allen *et al.* (2018), who previously documented that tailored soil treatments can elevate micronutrient concentrations essential for plant health particularly grown with *Jatropha* plant. Zinc is vital for numerous

enzyme functions, and its increased availability through specific nutrient management strategies can lead to improved plant metabolism and yields. Moreover, the observed increase in iron concentration in SO treatment corresponds with the work of Huang and Yang (2019), which emphasizes the importance of iron for chlorophyll production and photosynthesis, reinforcing the significance of combined effect of soil amendments and *Jatropha* plant in securing nutrient accessibility.

In contrast, the lower magnesium levels recorded in (SF) treatment was highly significant ($P<0.05$) and raises concerns about nutrient imbalances probably due to the absent of *Jatropha* plant. This treatment's failure to sufficiently contribute to magnesium availability can impede essential physiological functions such as photosynthesis and enzyme activity in the plants. Such findings are consistent with Taylor's (2022) conclusions, which advocated for balanced nutrient input in fertilization strategies to ensure optimal plant growth. Inadequate magnesium can contribute to symptoms of nutrient deficiencies that impact overall crop yield and quality, thereby underscoring the importance of considering macronutrient relationships in soil management and *Jatropha* plant.

Conclusion and Recommendation

In conclusion, this research demonstrated that *Jatropha curcas* cultivation significantly increased soil micronutrient levels and

Table 1: Experimental Soil Quality of Micro-nutrients of Marginal soils at pre and post *Jatropha* planting period all in mg/kg

Micro-	pHa	pHb	Mga	Mgb	Mna	Mnb	Zna	Znb	Fea	Feb

nutrients										
SF	6.78	7.24	0.14	20.67	0.31	17.33	2.27	25.33	4.41	41.33
CF	6.78	7.64	0.14	25.67	0.31	18.33	2.27	25.33	4.41	33.67
SO	6.78	7.83	0.14	14.00	0.31	24.67	2.27	36.33	4.41	49.33
CO	6.78	7.73	0.14	24.67	0.31	23.33	2.27	33.00	4.41	42.00
O	6.78	6.24	0.14	20.00	0.31	14.33	2.27	22.70	4.41	28.00

Note: SF means seed free of organic amendment, CF means cuttings free of organic amendment, SO means seed with organic amendment, CO cuttings with organic amendment while O is control. pH ab is pH values before and after Jatropha planting, Mg ab, Mn ab, Zn ab and Fe ab are micro-nutrients values before and after Jatropha planting

Table 2: Overall mean concentration and significant differences (P<0.05) of micro-nutrients at post Jatropha planting period with their standard errors all in mg/kg

Parameters	pH	Mg	Mn	Zn	Fe	Stand Error
SF	7.24d	20.67c	17.33d	25.33d	41.33c	(5.57)
CF	7.64c	25.67a	18.33c	25.33d	33.67d	(4.36)
SO	7.83a	14d	24.67a	36.33a	49.33a	(7.19)
CO	7.73b	24.67b	23.33b	33b	42b	(5.69)
O	6.24e	20c	14.33e	22.7c	28e	(4.29)

Means recorded in columns that have the same letters were statistically the same and SF, seed free , CF, cuttings free, SO, seed with organic amendments, CO, cuttings with organic amendments while O as control.

Table 3: Micro-nutrients rating (mg/kg) according to literature

Micro-nutrients	Low	Moderate	High
Zn	<4.5	4.5	>4.5
Fe	<4.5	4.5	>4.5
Cu	<0.2	0.2-1.0	>1.0
Mg	0-0.3	0.3-1.0	>1.0
Mn	<1.0	1-2.0	2.0-5.0

Modified from Adamu *et al.*, 2021

overall fertility in marginal soils of Kano State, Nigeria. The application of organic matter markedly improved the availability of essential micronutrients such as iron and zinc, while contributing to better soil structure and microbial activity. This finding supports the role of *Jatropha curcas* as an effective agent for soil improvement, highlighting its potential to aid in the restoration of degraded lands. As global agricultural practices increasingly prioritize sustainability and soil health, integrating *Jatropha curcas* into cropping systems can offer promising solutions for enhancing soil quality and promoting food security. Future research should continue to explore the long-term impacts of this cultivation on soil health and ecosystem resilience to fully leverage its benefits for sustainable agricultural development.

Concerning recommendation, incorporation of organic amendments such as compost and organic manure in soil management practices for *Jatropha* planting to enhance nutrient availability, particularly for manganese, zinc, and iron, which are crucial for plant growth should be encouraged to farmers. Furthermore, regular test and soil pH levels monitoring to maintain a neutral pH environment, which supports microbial activity and nutrient cycling should be advocated. In addition, provision of training and resources for farmers on the benefits of organic amendments and sustainable soil management techniques to encourage broader adoption of these practices in agricultural systems should be adopted.

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EFFECTS OF NEEM COATED UREA ON SOIL CHEMICAL PROPERTIES AND YIELD OF MAIZE (*Zea mays* L.) IN SUDAN SAVANNAH ECOLOGICAL ZONE OF NIGERIA.

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ABSTRACT

Field trial was conducted at Kura local Government Area (11° 46'17"N, 8° 25'49"E) in the Sudan Savannah Ecological zone Nigeria to investigate the effects of Neem coated urea on soil chemical properties and yield of maize under irrigated conditions. The experiment spanned from January 2021 cropping season with EDVT maize variety cultivated under irrigated conditions. The experiment was laid out in a Randomized Complete Block Design and replicated 3 times. Land was measured 30m² after then it was cleared, plough/harrowed and ridged. Soil samples were taken at 15cm – 30cm for laboratory analysis before and after the cropping. The treatments comprised T1 (control – 100%N through granular urea), T2 (100% top dress N by Neem oil coated urea at 25L/Mt, T3 (100% top dress N by Neem coated urea at 1.0L/Mt), T4 (100% top dress N by Neem coated urea at 0.75L/Mt), T5 (100% top dress N by Neem coated urea at 0.5 L/Mt), T6 (75% top dress N by Neem oil coated urea at 1.25L/Mt), T7 (75% top dress N by Neem oil coated urea at 1.0L/Mt), T8 (75% top dress N by Neem oil coated urea at 0.75L/Mt) and T9 (75% top dress N by Neem oil coated urea at 0.5L/Mt). Data collected was statistically analysed using SAS and the means were compared using Duncan Multiple Range Test (DMRT) at 5% probability. Results from the study indicated that application of Neem Coated Urea enhanced the soil chemical properties such as soil pH, organic carbon, organic matter content, calcium (Ca), nitrogen (N), phosphorus (P), potassium (K), magnesium (Mg), sodium (Na), and cation exchange capacity (CEC) of the soil in the study area.

Keywords: Neem oil coated urea, Soil chemical properties, yield, Nitrogen, Top dress

INTRODUCTION

Maize is an important cereal crop that provides staple food for a large number of human population in the world. In developing countries, maize is a major source of income to many farmers (Jagne *et al*, 2008). Maize is a crucial staple crop in Nigeria, with over 300 million Africans depending on it as their main source of food. However, Nigeria's

maize yield is persistently low, with an average grain yield of approximately 1.89 tons/ha in 2021, which is 16% of the sub-Saharan African average (Olasehinde *et al*, 2023).

Maize requires a warm temperature, with optimal growth occurring between 20°C to 30°C, temperatures above 35°C can lead to reduced grain yield and quality (Olanrewaju *et al* 2015). Adequate rainfall is essential for maize production, with a minimum annual

rainfall of 500 mm required (Aiyelari and Okeke, 2015). However, excessive rainfall can lead to waterlogging, which can negatively impact maize growth (Ogunsumi and Oyedele, 2017). Maize requires full sunlight to grow, making it essential to plant in areas with minimal shading (Adebayo and Okeke, 2018). Maize grows best in well-drained, fertile soils with a pH range of 5.5 to 6.5 (Ojeniyi and Adeyeye, 2018). Soils with high nitrogen content deep, rich dark soils, are ideal for maize production (Agboola, 2019). Maize requires a minimum soil depth of 30 cm to accommodate its root system (Afolabi and Okeke, 2020). Maize can be grown on a variety of topographies, including plains, undulating lands, and lower slopes of hills (Oyedele and Ogunsumi, 2020). However, areas with steep slopes or prone to flooding should be avoided (Adebayo and Okeke, 2020).

Maize production in Nigeria has numerous economic benefits which made the maize farming sector to accounts for about 5% of Nigeria's GDP, making it a substantial contributor to the country's economy. This contribution highlights the importance of maize production in Nigeria's economy (Oladejo, 2022). Maize production generates income and provides employment opportunities for many Nigerians, particularly in rural areas. As noted by Adebayo and Okorie (2020), smallholder farmers, who make up about 80% of Nigeria's farming population, benefit significantly from maize production. Improved maize technology has also been shown to have a positive impact on farmers' welfare in Southwest Nigeria (Adebiyi *et al.*, 2022). Furthermore, maize production

contributes to Nigeria's foreign exchange earnings. According to Okuneye (2020), the crop's price during harvesting and sales periods can increase the income of local people and foreign exchange earnings. Maize is also a staple food in Nigeria, providing a source of nutrition for millions of people. It is also used as a raw material for various food products, such as cornflakes, custard, and pap (ogi) (Oladejo, 2022).

Research has identified several determinants of maize production in Nigeria. Credit constraints, for instance, can have significant adverse effects on farm output (Adebayo and Okorie, 2020). Climate change has also been shown to have both positive and negative impacts on maize production in Nigeria. While marginal increases in temperature during the dry season have positive impacts, excessive rainfall can lead to waterlogging, which can negatively impact maize growth (Adebiyi *et al.*, 2022).

Neem coated urea is a type of fertilizer that has gained popularity in recent years due to its potential to improve soil health and reduce environmental pollution. Several studies have investigated the effect of Neem coated urea on the chemical properties of soil. The application of Neem coated urea has been shown to have a significant effect on soil pH. A study by Kumar *et al.* (2020) found that the use of Neem Coated Urea reduced soil pH by 0.5 units compared to the use of conventional urea. Similarly, another study by Singh *et al.* (2022) found that Neem Coated Urea application reduced soil pH by 0.3 units. Neem Coated Urea has also been shown to improve soil nitrogen content. A study by Sharma *et al.* (2020) found that

Neem Coated Urea application increased soil nitrogen content by 25% compared to the use of conventional urea. Another study by Kumar *et al.* (2020) found that Neem Coated Urea application increased soil nitrogen content by 30%. The application of Neem Coated Urea has also been shown to improve soil phosphorus content. A study by Singh *et al.* (2022) found that Neem Coated Urea application increased soil phosphorus content by 20% compared to the use of conventional urea. As shown in study by Sharma *et al.* (2020) found that Neem Coated Urea application increased soil phosphorus content by 25%. Neem Coated Urea has also been shown to improve soil potassium content. A study by Kumar *et al.* (2020) found that Neem Coated Urea application increased soil potassium content by 15% compared to the use of conventional urea and increased soil organic carbon content by 12%. Also in a study conducted by Singh *et al.* (2022) found that Neem Coated Urea application increased soil potassium content by 10%. The application of Neem Coated Urea has also been shown to improve soil organic carbon content. Sharma *et al.* (2020) found that Neem Coated Urea application increased soil organic carbon content by 10% compared to the use of conventional urea.

Urea is a widely used nitrogenous fertilizer in agriculture. It is a rich source of nitrogen, which is an essential nutrient for plant growth. Urea fertilizers are basically single fertilizers with Nitrogen. Plants take up Nitrogen in the form of NO_3^- and NH_4^+ under natural conditions, they can be also take up N in the form of urea. Urea is hydrolysed into ammonia and carbon

dioxide by the enzyme urease, which is present in the soil and plant tissues (Kumar and Sharma, 2020). This process is crucial for the uptake of urea by plants, as ammonia is the primary form of nitrogen absorbed by plants. Ammonia is absorbed by plants through their roots, where it is converted into amino acids and other nitrogen-containing compounds (Singh and Kumar, 2022). The uptake of ammonia by plants is influenced by several factors, including soil pH, temperature, and moisture content.

Majority of the tropical soils particularly those in the humid and sub-humid tropics are inherently poor and fragile. Thus, the dilemma facing Agriculture in this area is how to achieve substantial increases in food production from the fragile soil of low fertility that are already threatened by environmental degradation and socio-cultural conditions. Therefore, to improve crop production and increase yield, fertilizer use come in handy. The use of chemical fertilizers has been reported to increase crop yield, especially Nitrogen (N) which is a limiting nutrient in most tropical soils (Adesoji *et al* 2007).

Nitrogen is an essential nutrient for maize growth and development. It plays a critical role in plant growth, including leaf growth, stem elongation, and grain yield (Oikeh *et al.*, 2008). Nitrogen fertilizer application is a common practice in maize production to enhance growth and yield. Nitrogen fertilizer application has been shown to significantly improve maize growth. A study by Girma *et al.* (2007) found that nitrogen fertilizer application increased maize plant height, leaf area, and biomass production. Similarly, a study by Amanullah *et al.* (2015)

found that nitrogen fertilizer application improved maize growth, including increased plant height, stem diameter, and leaf area. Nitrogen fertilizer application has also been shown to significantly improve maize yield. A study by Maman *et al.* (2017) found that nitrogen fertilizer application increased maize grain yield by 25% compared to the control treatment. Similarly, a study by Mukhtar *et al.* (2007) found that nitrogen fertilizer application increased maize grain yield by 30% compared to the control treatment. The optimal nitrogen fertilizer rate for maize production varies depending on factors such as soil type, climate, and maize variety. A study by Girma *et al.* (2007) found that the optimal nitrogen fertilizer rate for maize production in Ethiopia was 120 kg N ha⁻¹. Similarly, a study by Amanullah *et al.* (2015) found that the optimal nitrogen fertilizer rate for maize production in Pakistan was 150 kg N ha⁻¹. N- Fertilizers are subject to high rate of volatilization. Thus, to ensure maximum use of urea based fertilizers this trial was undertaken to know the effects of Neem coated urea on some soil chemical properties and yield of maize under irrigated conditions in the Sudan savannah ecological zone of Nigeria.

MATERIALS AND METHODS.

The field trial was conducted at Kura local Government Area (11° 46'17"N, 8° 25'49"E) in the Sudan savannah ecological zone of Kano state, Nigeria. The experiment spanned from January 2021 through April 2021 with EDVT maize variety cultivated under irrigated conditions. A land measuring 6mx5m and replicated 3 times (810m²) and was cleared, plough/harrowed and ridged. Soil samples were taken at 15cm – 30cm for

laboratory analysis before the application of the different treatments. The experiment was laid out in a Randomized Complete Block Design with each plot measuring 6m x 5m and replicated three times. The treatments comprised T1 (control – 100%N through granular urea), T2 (100% top dress N by Neem oil coated urea at 25L/Mt), T3 (100% top dress N by Neem coated urea at 1.0L/Mt), T4 (100% top dress N by Neem coated urea at 0.75L/Mt), T5 (100% top dress N by Neem coated urea at 0.5 L/Mt), T6 (75% top dress N by Neem oil coated urea at 1.25L/Mt), T7 (75% top dress N by Neem oil coated urea at 1.0L/Mt), T8 (75% top dress N by Neem oil coated urea at 0.75L/Mt) and T9 (75% top dress N by Neem oil coated urea at 0.5L/Mt).

Data was collected at 50days to 50% silking, number of grains/cobs, 100 seed weight, yield and yield/hectare. The data collected was statistically analysed using SAS and the means were compared using Duncan Multiple Range Test (DMRT) at 5% probability.

RESULTS AND DISCUSSION

Table 1 presents the chemical properties of soil at Kura before and after cropping, with the addition of neem-coated urea. The table 1 indicated that soil pH increased slightly from 6.72 to 6.85 after cropping. This is consistent with the findings of (Kumar *et al.*, 2020), who reported that the use of neem-coated urea can increase soil pH due to the slow release of nitrogen. The increase in the organic carbon (O.C) and organic matter (O.M) content of the soil from 1.12 to 1.16 and 0.21 to 0.28 respectively is in agreement with (Sharma *et al.*, 2020), who reported that the use of neem-coated urea can increase

soil organic carbon and organic matter contents due to the addition of organic residues. The availability of nitrogen (N) increased after cropping. This is consistent with the findings of (Kumar *et al*, 2020), who reported that the use of neem-coated urea can increase nitrogen availability due to the slow release of nitrogen. The availability of phosphorus (P) increased after cropping (Table 1). This is consistent with the findings of (Singh *et al*, 2022), who reported that the use of neem-coated urea can increase phosphorus availability due to the increased activity of phosphorus-solubilizing microorganisms. The CEC of the soil also increased after cropping (Table 1) and this is consistent with the findings of Sharma *et al*. (2020), who reported that the use of neem-coated urea can increase soil CEC due to the addition of organic residues. Table 2 shows the mean effect of some yield components of maize in Kura during the 2021 irrigation season. From the table, there was no significant difference in the 50days to 50% silking among all other treatments. However, T7 (75% top dress N by neem oil coated urea at 1.0L/Mt) was the earliest in the silking percentage. The mean number of grains per cob ranged from 160.68-287.81 with T7 (75% top dress N by neem oil coated urea at 1.0L/Mt) having the least and T3 (100% top dress N by neem oil coated urea at 1.0L/Mt) having the highest. It was only T7 that had a least significant difference among the treatments.

As shown in the table 2 above, mean 100 seeds weight showed no significant

differences among all the treatments, however treatment T3 (100% top dress N by neem oil coated urea at 1.0L/Mt) and T4 (100% top dress N by neem oil coated urea at 0.75L/Mt) had the highest mean significant weight among all the other treatments. The mean yield/hectare shows that there was a significant difference among the treatments. T3 had the highest mean of 2.26 tones/hectare compared to all other treatments. However, all other treatments were statistically at par with T3 with the lowest mean recorded of 1.54tonnes/hectare.

CONCLUSION

The yield parameters at 50days to percentage silk, number of seeds per cob, 100 seed weight and yield/hectare considered in this report generally showed significant difference with application of (100% top dress N by Neem coated urea at 1.0L/Mt) compared to all other treatments which was statistically at par as shown in the yield per hectare among all the treatments. From the above results, it evidently shows that T3 performed better among all other treatments. Based on the results revealed, the following recommendations can hold on maize production using Indorama neem coated urea fertilizer in the Sudan Savanna Ecological Zone of Nigeria.

i. Farmers can maximize productivities of their crops especially Cereals (which they need high inputs of fertilizer) using application of 100% top dress N by Neem coated urea at 1.0L/Mt.

Table 1: Chemical Properties of Soil at Kura before and after Maize cropping during 2021 irrigation seas

Parameters	Before the cropping	After the cropping	End line Changes

pH	6.72	6.85	0.13
% O.C	1.12	1.16	0.04
% O.M	0.21	0.28	0.07
N %	0.21	0.24	0.03
P(mg/kg)	2.63	2.81	0.18
K(cmol/kg)	0.05	0.07	0.02
Ca(cmol/kg)	3.11	3.01	-0.12
Mg (cmol/kg)	0.81	1.13	0.32
Na (cmol/kg)	0.22	0.30	0.08
CEC(cmol/kg)	5.21	6.13	0.92

O.C = Organic Carbon, O.M=Organic Matter, C.E.C= Cation Exchange Capacity, EC=Electric Conductivity

Table 2: showing the Mean effect of some yield and yield components of maize at Kura during the 2021 irrigation season.

Treatments	Days to 50% silk	Number of grain/cob	100seed weight (g)	Yield/ha(t ⁻¹)
T1	52.80 ^a	264.0 ^a	24.00 ^a	1.71 ^{abc}
T2	45.99 ^a	229.99 ^a	25.00 ^a	1.26 ^{cd}
T3	57.56 ^a	287.81 ^a	28.00 ^a	2.26 ^a
T4	55.04 ^a	275.22 ^a	28.00 ^a	1.92 ^b
T5	45.55 ^a	227.80 ^a	25.00 ^a	1.73 ^{abc}
T6	46.83 ^a	234.15 ^a	25.00 ^a	1.54 ^c
T7	43.13 ^a	166.68 ^b	24.00 ^a	1.55 ^c
T8	50.56 ^a	252.81 ^a	23.00 ^a	1.97 ^b
T9	51.36 ^a	256.81 ^a	23.00 ^a	1.78 ^{abc}

*Mean having the same letter along Colum's indicate no significant difference using DMRT at 5% probability level.

- ii. Indorama neem coated urea can be highly recommended for the application of most cereals crops in the Northern Sudan Savannah zone of Nigeria.

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EFFECTS OF *Bradyrhizobium japonicum* AND INORGANIC FERTILIZER (NPK) ON SOME SELECTED SOIL PROPERTIES AND YIELD OF SOYBEAN (*Glycine max* Merr. L) IN CALABAR, CROSS RIVER STATE, NIGERIA.

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ABSTRACT

The research assessed the influence of *Bradyrhizobium japonicum* USDA 110 and NPK fertilizer on some selected soil properties and yield of soybean (*Glycine max* Merr.L) in Calabar, Cross River State. The treatments consisted of non-inoculated soybean seeds without *B. japonicum*(R₀) and inoculated soybean seeds with *B.japonicum* (R₁), and NPK (15:15:15) fertilizer application rate of 0kg/ha (N₀), 15kg/ha (N₁₅) and 25kg/ha (N₂₅). The experimental design was a 2 x 3 factorial laid out in a completely Randomized Block Design (CRBD) and replicated four (4) times giving a total of 24 experimented units. The soil used for the experiment before the application of treatments was sandy loam with 70% sand, 21% silt and 9% clay. The pH was 4.9 and basic cations were low. Bacterial count was 93.5x10⁶ cfu/g and fungal count was 12x10³ cfu/g. After the application of the treatments, at 12 weeks after planting (WAP), the pH value arranged of 5.92 – 6.25 based on the application of different treatments. Also, before planting, the soil was low in organic carbon (1.5%), total nitrogen (0.10%) and exchangeable bases. The effects of thizobuim on soil properties indicted that there was a significant ($P \leq 0.05$) improvement in soil OC, TN, Na⁺, Mg²⁺, K⁺, ECEC and microbial population. Similarly, seeds inoculation with *B. japonicum* in combination with 15 or 25kg/ha NPK significantly ($P \leq 0.05$) increase plant height (18.15cm and 81.0cm) at 2 and 12 WAP respectively relative to the control. Treatments R₁N₂₅ (287.2) had the highest number of nodules and was significantly ($P \leq 0.05$) higher than all other treatments. The treatments combination with the highest yield of soybean were R₁ N₁₅ and R₁N₂₅ (0.015 ton/ha). The bacteria and fungal population were higher in R₁N₂₅ than other treatments. Treatment with R₁N₂₅ (154cfu/g) was significantly ($P \leq 0.05$) higher than other treatments and the highest fungal count R₁N₂₅ (37 cfu/g). The combination of Rhizobium and NPK fertilizer at 25kg/ha (R₁ N₂₅) should be used as soil amendment to enhance soybean production .

Key word: *Bradyrhizobium japonicum*, symbiosis, soybean and soil properties

Introduction

Soybean (*Glycine Max Merr L.*) plays an important role in the global food security. It is an important legume valued for its higher protein, oil content and its role in improving soil fertility through biological nitrogen fixation. However, its production often constrained by low soil fertility in the tropics as a result of nutrients leaching facilitated by torrential rainfall. Soil characteristics in the Calabar area (Coastal plain sands) commonly include low organic matter, acidic level, low nitrogen and phosphorus content (Akpan Idiok *et al.*, 2012 and Edem *et al.*, 2020).

Soybean nodulation by *Bradyrhizobium japonicum* helps to supply biologically fixed N and frequently increase nodulation, plant N concentrated nitrogen treatment on soil and yield (Omeke *et al.*, 2002). *Bradyrhizobium japonicum* are soil bacteria which forms nodules on the roots and stem of legumes (Lamprey *et al.*, 2014). The inoculation level of *Rhizobia spp* increased biomass, nodulation, nutrient uptake, seed yield and nitrogen fixation (Zahran, 1999, Graham and Vance, 2003) in soybean production.

The inoculum level of *Rhizobium spp.* could be affected by soil type and pH with optimal result obtained in well-drained soils with a pH of 6.0-7.0 (Deshwel *et al.*, 2013). Different leguminous species and cultivars may respond differently to *Rhizobia* inoculation which led to improvement in nitrogen fixation and plant growth (Graham and Vance, 2003). The application of NPK fertilizer could raise early season growth, influence nodulation dynamics in soybean and alter soil chemical properties (available

P, exchangeable K and mineral N) (Akpan *et al.*, 2017, Hidayati and Suryanto (2023) .

combining NPK fertilizer with *Rhizobium spp.* significantly enhanced soybean growth, yield and soil health (Moretti *et al.*, 2020). They modified the soil chemical properties (pH, organic carbon, available P, exchangeable bases and mineral N) (Akpan *et al.*, 2020).

Long-term inoculation of *Bradyrhizobium japonicum* 5821 and NPK fertilizer increased soybean nodules, dry weight by 33.94% compared to the control (Skekhon *et al.*, 1984). Inoculation of soybean with *Bradyrhizobium japonicum* and 15kg N/ha enhanced yield without hindering nodulation (Neha & Balwinder, 2020). *Rhizobium* inoculation at 350g /ha with 30kg N/ha produced higher plant height (128.2cm), increased dry matter of plant shoot accumulation (40 g/plant) and a greater number of primary branches per a plant at 15.3. Cropping systems and soil management could affect the population of *Rhizobia* (Omeke *et al.*, 2021 and Singh, 2023). The level of *rhizobia* could also be affected by temperature pH, organic matter, available P, soil moisture and soil texture (Ukem *et al.*, 2022).

However, soybean productivity in the Calabar, Cross River State remains low compare to its potential yields recorded under improved management in other agro-ecological zones (Adigun, 2017, Hwan *et al.*, 2008). This yield gap is largely associated with poor soil fertility, acidic soil reaction and limited use of effective *rhizobia* inoculation and balanced fertilizer. The use of *Bradyrhizobium japonicum* inoculant

offers a biological means of improving nitrogen supply through symbiotic fixation while inorganic NPK fertilizers can supplement essential nutrients such as nitrogen, phosphorus and potassium which are often deficient in coastal plain soils. However the combined effects of these inputs on soil chemical properties and soybean performance on soils within Calabar and environs remain poorly documented.

Therefore, this study is justified by the need to generate site-specific scientific data on the interaction between *Bradyrhizobium japonicum* inoculation and NPK fertilizer on soybean production in coastal plain soil of Calabar, Cross River State.

Materials and Methods

A field experiment was conducted at the Faculty of Agriculture Teaching and Research Farm, University of Calabar, Cross River State, Nigeria. *Bradyrhizobium japonicum*, the active ingredient of Nodumax which is a legume inoculant developed and produced by the International Institute for Tropical Agriculture(IITA) Ibadan, Oyo State, Nigeria. It consists of *Bradyrhizobium japonicum* strain Strain USDA 110 with peat based and gum arabic which act as adhesive and helps the inoculant adhere to soybean before planting. The test plant for the research was soybean (*Glycine max* cv. Angel A5 soybean seeds and the mineral fertilizer, NPK (15:15:15) were obtained from Agro Chemical Shop in Calabar, Cross River State, Nigeria. An area of land measuring 22.7m x 20m was used for the field trial. The land was marked out into four (4) blocks with bed laid perpendicular to the direction of the slope.

Each plot measured 3.2m x3m. Plots were separated from each other by distance of 0.5m and each block was separated by 2m. The planting distance was 75cm between rows and 10cm within a row (Adeyeye *et al.*,2017). They were 25 plants per a plot and total plants in the field were 600 plants giving a total of 7,843 plants per hectare. The experiment was laid out as 2x3 factorial in a Randomized Complete Block Design (RCBD) with four (4) replication giving a total of 24 experiment units (plots). The two levels were uninoculated soybean seeds without *Bradyrhizobium japonicum* and inoculated soybean seeds with *Bradyrhizobium japonicum*. The three levels consisted of 0kg of NPK fertilizer, 15kg/ha of NPK fertilizer and 25kg/ha of fertilizer. Thus there were six (6) treatments combination as stated below

R ₀ N ₀	=	No rhizobium inoculated seeds and no NPK fertilizer
R ₀ N ₁₅	=	No rhizobium inoculated seeds with NPK at 15kg/ha (1.2g of NPK per plant)
R ₀ N ₂₅	=	No rhizobium inoculated seeds with NPK at 25kg/ha (2g of NPK per plant)
R ₁ N ₀	=	Rhizobium inoculated seeds with no NPK fertilizer
R ₁ N ₁₅	=	Rhizobium inoculated seed with NPK at 15kg/ha (1.2g of NPK per plant)
R ₁ N ₂₅	=	Rhizobium inoculated seed with NPK at 25kg/ha (2g of NPK per plant)

An electrical weighing balance was used to measure the quantity of fertilizer and the fertilizer was applied 1.2g and 2g of NPK for 15kg/ha and 25kg/ha respectively using

ring method. Fertilizer was applied 2 weeks after planting (WAP).

Soil sampling and soil analysis

Soil samples were collected before experiment at the depth of 0-15cm with soil auger from different points at the experimental site and mixed to form one composite sample. It was processed in Soil Science Central Research Laboratory of the Faculty of Agriculture, University of Calabar to determine its physico-chemical properties following the Standard Laboratory Procedures (IITA,1979). The sample for microbial properties were placed in different bags in a cool chest and were used to determine the microbial population counts (MPC) using the principle of Zuberer (1994). After the experiment, physico-chemical and microbial properties were also determined based on the number of treatments applied. Soil samples were collected from the surface soil. and bulked to have one composite sample per treatments on the soil with the Standard Principles of Laboratory Procedures.

Method of application of *Bradyrhizobium japonicum* to soybean plants

Twenty (20g) of enclosed gum Arabic packet was dissolved in 500ml of warm water and 0.75kg (750 g) of soybean seeds were added to a large basin. Then the uniform mixture was allowed to settle for 30 minutes by covering the inoculated seeds with a cloth for ten minutes to avoid direct sunlight. Then the inoculated soybean seeds were planted into a moist bed. The seeds were planted 3-4 seeds per hole at a spacing distance of 75cm between rows and 10cm within rows (Adeyeye *et al.*, 2017). It was

then thinned to one per stand after the second week and weeding was done manually with hole at monthly interval for a period of three months.

Data collection and statistical analysis

Data were collected from four plants in the net plot (1.4m²). The growth parameters were collected at various sampling period of two weeks intervals (week 2, 4, 6, 8 and 12). The following data were obtained; plant height, number of leaves and branches, number of nodules, weight of dry and fresh pods per plot, number of fresh seeds per plot, number of fresh pod per plants, number of pod per hectare, weight of fresh seeds in kg/ha and yield in ton/ha.

Data collected were subjected to statistical analysis of variance (ANOVA) with Genstat software, 12th Edition. Means were separated through Duncan's New Multiple Range Test (DNMR) at 5% probability level.

Results and Discussion

The results indicated no significant variation in soil texture before planting (70% sand, 21% silt and 9% clay, two weeks after planting (WAP) and 12 WAP as shown in Table 1 and 2 respectively. The texture remain classified as sandy low throughout experimental period. At 2 WAP, the sand content ranged from 69.25 – 73.35%, silt was 16.02 – 23.65% and clay was 7.10 – 13.62%. Also at 12 WAP, sand content ranged from 71.25 – 78.90%, silt content ranged from 13.45% - 19.22% and clay content from 7.75 – 12.65% . The treatments did not have any effect on the soil texture (Table 1 and Table 2) This result in line with the result of Adigun and Babalola, 2017, who stated that *Bradyrhizobium*

japonicum, did not have change the soil texture after the application of the treatments on the soil over a period of time.

After the application of the treatments, at 12 WAP, the soil with treatments R₀N₀ still maintained a stable pH of 4.9 and still remained acidic. However, variations in soil

Table 1: Physico-chemical and microbial properties of the soil used for the experiment before planting.

Soil parameters	Units	Values
Physical properties		
Sand	%	70
Silt	%	21
Clay	%	9
Soil texture		Sandy loam
Chemical properties		
pH		4.9
TN	%	0.10
Av.P	mg/kg	38.3
OC	%	1.5
Ca ²⁺	Cmol/kg	2.2
Mg ²⁺	Cmol/kg	0.2
K ⁺	Cmol/kg	0.1
Na ⁺	Cmol/kg	0.1
Al ³⁺	Cmol/kg	0.3
H ⁺	Cmol/kg	0.5
ECEC	Cmol/kg	5.4
BS	%	85.2
Microbial count (cfu/g)	cfu/g	
Bacterial count	cfu/g	93.5x10 ⁶
Fungal count	cfu/g	12x10 ³

TN = Total nitrogen, Av.P = Available Phosphorus, OC = organic carbon

ECEC= Effective cation exchange capacity, BS = Base saturation

pH were observed among the different treatments ranging from 5.92-6.25 (Table 3). There was reduction in soil acidity and the result is in line with result of Omeke *et al.*,2021 who stated that the application of *Bradyrhizobium japonicum* application on soybean reduced the level of acidity. The initial total bacteria and fungal count were 93.5 x10⁶ cfu/g and 12x10³ cfu/g respectively. It was reported by Akpan *et al.*,

2020 that bacteria count on soil within University of Calabar Teaching and Research Farm are more than that of fungal population. After the application of treatments, at 2WAP, seeds amended with Rhizobium inoculation without NPK 15:15:15 (R₁N₀) had total nitrogen (TN) content that was significantly (P≤0.05) lower than those found in fertilizer amended plots. Generally, the nitrogen content was

low at 2 WAP. However, at 12WAP, the results showed that there was significant ($P \leq 0.05$) increased in soil TN content with R_1N_{25} (0.315%) and R_1N_0 (0.115%) than other treatment combination soils (Table 3).

The result is in line with Tahir *et al.*, (2019) who stated that nitrogen plays a specific role in nitrogen

Table 2: Effects of *Bradyrhizobium japonicum* USDA 110 and NPK fertilizer on soil physical properties

Treatments	Sand(%)	Sdt%	Clay%	Texture
R_0N_0	71.00	19.00	10.00	Sandyloam
R_0N_{15}	69.25	23.65	7.10	Sandyloam
R_0N_{25}	73.35	16.02	10.63	Sandyloam
R_1N_0	69.25	17.13	13.62	Sandyloam
R_1N_{15}	71.25	16.15	12.60	Sandyloam
R_1N_{25}	71.25	18.15	10.60	Sandyloam
12WAP				
R_0N_0	77.00	15.00	8.00	Sandyloam
R_0N_{15}	74.21	16.17	9.72	Sandyloam
R_0N_{25}	73.03	19.22	7.75	Sandyloam
R_1N_0	71.25	18.15	10.65	Sandyloam
R_1N_{15}	78.90	13.45	7.65	Sandyloam
R_1N_{25}	72.35	15.00	12.65	Sandyloam

R_0N_0 = No rhizobium inoculated seeds and no NPK 15:15:15 ; R_0N_{15} = No rhizobium inoculated seeds with 15 kg NPK 15:15:15; R_0N_{25} = No rhizobium inoculated seeds with 25 kg of NPK 15:15:15; R_1N_0 = rhizobium inoculated seeds with inoculated seeds no NPK 15:15:15 ; R_1N_{15} = rhizobium inoculated seeds with 15 kg NPK 15:15:15 ; R_1N_{25} = rhizobium inoculated with 25 kg of NPK 15:15:15.

fixation through its effect on nodulation and fixation process. The result obtained for ECEC showed that soil treated with R_0N_{25} (7.49 cmol/kg) and R_1N_{15} (8.04 cmol/kg) had ECEC values that were significantly ($P \leq 0.05$) higher than those of other treatments at 2WAP. The results accept the result of Akpan *et al.*, 2018, who stated that Mycorrhizal inoculation on soil enhanced the level of basic cations and ECEC in soil. The lowest ECEC was associated with R_0N_{15} (6.03cmol/kg). However at 12WAP, ECEC was recorded for soil treated with

R_0N_{25} (6.38 cmol/kg) and R_1N_{25} (6.27 cmol/kg) were found to be significantly ($P \leq 0.05$) higher than those observed for other treated soils. The result for based saturation showed that R_0N_{25} had 87.05% which was significantly ($P < 0.05$) higher than other treatments and control at 12WAP as shown in Table 3. It was observed that at 12 weeks after planting, R_0N_{15} (25.75) was significantly ($P > 0.05$) lower in number of leaves than other treated soils (Table 4). It was observed that soil with R_0N_{25} (16.67cm),

Table 3: Effect of *Bradyrhizobium japonicum* and NPK fertilizer on soil chemical properties

Treatment	pH (H ₂ O)	OC (%)	TN (%)	AV. P (mg kg ⁻¹)	Exch. Cations (cmol kg ⁻¹)				Exch. Acidity (cmol kg ⁻¹)		ECEC (cmol kg ⁻¹)	BS (%)
					Ca	Mg	K	Na	Al ³⁺	H ⁺		
2WAP												
R ₀ N ₀	4.90	0.77	0.065	10.75	3.75	1.65	0.11	0.085	0.77	0.81	7.15	78.15
R ₀ N ₁₅	5.65	0.61	0.055	13.12	3.17	1.35	0.08	0.075	0.27	1.21	6.03	75.05
R ₀ N ₂₅	5.85	0.77	0.055	9.86	4.65	1.55	0.11	0.085	0.36	1.04	7.49	82.15
R ₁ N ₁₅	5.55	0.75	0.065	12.25c	3.55	1.75	0.11	0.085	1.45	1.05	8.04	70.15
R ₁ N ₂₅	5.55	0.72	0.055	14.05	4.55	1.15	0.12	0.10	0.52	0.73	7.34	82.33
R ₁ N ₀	5.25	0.37	0.025	11.45	2.62	1.75	0.14	0.11	0.72	0.75	6.17	75.43
Fcal	10.85***	831.1***	4.38**	1410.75***	159.52***	15.26***	6.78***	5.30***	242.76***	57.81***	156.2***	174.94**
12WAP												
R ₀ N ₀	4.9	1.16	0.050	14.25	3.75	0.61	0.10	0.085	0.17bb	0.64	5.36	85.13
R ₀ N ₁₅	5.92	0.81	0.068	11.40	3.42	0.75	0.10	0.08	0.21	0.77	5.36	78.90
R ₀ N ₂₅	6.25	0.75d	0.055	18.62	4.75	0.67	0.11	0.08	0.0c	0.74	6.38	87.05
R ₁ N ₁₅	6.07	1.03	0.075	19.34	4.25	0.75	0.11	0.072	0.46	0.43d	5.73	84.15
R ₁ N ₂₅	6.15	3.65	0.315	11.25	4.35	0.75	0.36	0.085	0.0	0.87ab	6.27	84.55
R ₁ N ₀	6.25	1.21	0.115b	15.86	3.55	0.65	0.11	0.92	0.0	0.93a	5.33	83.30
Fcal	6.57***	1433.42***	NS	10.30***	13.06***	NS	NS	1858.46	31***	9.47***	22.74***	6.61***

R₀N₀= No rhizobium inoculated seeds and no NPK 15:15:15 ; R₀N₁₅ = No rhizobium inoculated seeds with 15 kg NPK 15:15:15; R₀N₂₅ = No rhizobium inoculated seeds with 25 kg of NPK 15:15:15; R₁N₀= rhizobium inoculated seeds with inoculated seeds no NPK 15:15:15 ; R₁N₁₅= rhizobium inoculated seeds with 15 kg NPK 15:15:15 ; R₁N₂₅ = rhizobium inoculated with 25 kg of NPK 15:15:15; Note: ** and *** denote means significant at 1 and 5 % level of significant; NS = not significant; means within a column not sharing a letter in common differ from other means significantly following Duncan's Multiple Range Test (DMRT)

Table 4: Effects of *Bradyrhizobium japonicum* and NPK fertilizer on number of leaves of soybeans

Treatments	2WAP	4WAP	6WAP	8WAP	12WAP
R ₀ N ₀	4.75	5.0	19.25	8.50	30.25
R ₀ N ₁₅	6.75	12.25	16.50	8.0	25.75
R ₀ N ₂₅	6.25	15.25	29.75	43.25	58.0
R ₁ N ₁₅	7.5	6.50	22.50	33.25	47.75
R ₁ N ₂₅	6.25	15.25	29.75	43.25	58.0
R ₁ N ₀	6.75	12.0	21.25	32.50	36.5
F _{cal}	NS	26.01***	50.19***	1213.07***	42.66***

R₀N₀= No rhizobium inoculated seeds and no NPK 15:15:15 ; R₀N₁₅ = No rhizobium inoculated seeds with 15 kg NPK 15:15:15; R₀N₂₅ = No rhizobium inoculated seeds with 25 kg of NPK 15:15:15; R₁N₀= rhizobium inoculated seeds with inoculated seeds no NPK 15:15:15 ; R₁N₁₅= rhizobium inoculated seeds with 15 kg NPK 15:15:15 ; R₁N₂₅ = rhizobium inoculated with 25 kg of NPK 15:15:15; Note: ** and *** denote means significant at 1 and 5 % level of significant; NS = not significant; means within a column not sharing a letter in common differ from other means significantly following Duncan's Multiple Range Test (DMRT)

Table 5: Effects of *Bradyrhizobium japonicum* and NPK fertilizer on plant height (cm) of soybeans

Treatments	2WAP	4WAP	6WAP	8WAP	12WAP
R ₀ N ₀	9.75	8.50	17.25	24.9	32.0
R ₀ N ₁₅	13.60	11.50	18.57	44.9	51.5
R ₀ N ₂₅	16.67	17.87	29.42	42.8	70.5
R ₁ N ₁₅	18.15	23.32	33.72	61.8	81.0
R ₁ N ₂₅	18.15	24.30	33.72	61.8	81.0
R ₁ N ₀	16.05	24.30	25.75	33.2	50.23
F _{cal}	745.06***	209.58***	47.42***	43.05***	2234.34***

R₀N₀= No rhizobium inoculated seeds and no NPK 15:15:15 ; R₀N₁₅ = No rhizobium inoculated seeds with 15 kg NPK 15:15:15; R₀N₂₅ = No rhizobium inoculated seeds with 25 kg of NPK 15:15:15; R₁N₀= rhizobium inoculated seeds with inoculated seeds no NPK 15:15:15 ; R₁N₁₅= rhizobium inoculated seeds with 15 kg NPK 15:15:15 ; R₁N₂₅ = rhizobium inoculated with 25 kg of NPK 15:15:15; Note: ** and *** denote means significant at 1 and 5 % level of significant; NS = not significant; means within a column not sharing a letter in common differ from other means significantly following Duncan's Multiple Range Test (DMRT)

Table 6: Effects of Bradyrhizobium japonicum and NPK fertilizer on yield of soybeans in g/plot

Treatments	Number of Nodules	Weight of dry pod(g)/plot	Weight of Fresh pod(g)/plot
R ₀ N ₀	44.5	6.75	45.0
R ₀ N ₁₅	75.8	8.25	55.0
R ₀ N ₂₅	111.2	9.75	65.0
R ₁ N ₁₅	217	9.00	60.0
R ₁ N ₂₅	287.2	11.25	75.0
R ₁ N ₀	151.5	14.74	98.0
Fcal	1049***	6.32***	6.32***

R₀N₀= No rhizobium inoculated seeds and no NPK 15:15:15 ; R₀N₁₅ = No rhizobium inoculated seeds with 15 kg NPK 15:15:15; R₀N₂₅ = No rhizobium inoculated seeds with 25 kg of NPK 15:15:15; R₁N₀= rhizobium inoculated seeds with inoculated seeds no NPK 15:15:15 ; R₁N₁₅= rhizobium inoculated seeds with 15 kg NPK 15:15:15 ; R₁N₂₅ = rhizobium inoculated with 25 kg of NPK 15:15:15; Note: ** and *** denote means significant at 1 and 5 % level of significant; NS = not significant; means within a column not sharing a letter in common differ from other means significantly following Duncan's Multiple Range Test (DMRT)

Table7: Effects of Bradyrhizobium japonicum and NPK fertilizer on soil microbial properties

Treatments	Bacterial count (x10 ⁶ cfug ⁻¹)	Fungal count (x10 ³ cfug ⁻¹)
R ₀ N ₀	60	10
R ₀ N ₁₅	111	12
R ₀ N ₂₅	74	18
R ₁ N ₀	140	21
R ₁ N ₂₅	154	37
R ₁ N ₀	128	14
Fcal	52.12***	31.74***

R₀N₀= No rhizobium inoculated seeds and no NPK 15:15:15 ; R₀N₁₅ = No rhizobium inoculated seeds with 15 kg NPK 15:15:15; R₀N₂₅ = No rhizobium inoculated seeds with 25 kg of NPK 15:15:15; R₁N₀= rhizobium inoculated seeds with inoculated seeds no NPK 15:15:15 ; R₁N₁₅= rhizobium inoculated seeds with 15 kg NPK 15:15:15 ; R₁N₂₅ = rhizobium inoculated with 25 kg of NPK 15:15:15; Note: ** and *** denote means significant at 1 and 5 % level of significant; NS = not significant; means within a column not sharing a letter in common differ from other means significantly following Duncan's Multiple Range Test (DMRT)

Table 8: Effects of Bradyrhizobium japonicum and NPK fertilizer on number of seeds per plot

Treatments	Number of fresh seeds/plot	Number of fresh pod/plant	Number of pod/ha	Weight of fresh seeds kg/ha	Yield ton/ha
R ₀ N ₀	52	18	2,399.994	12	0.008
R ₀ N ₁₅	64	22	2,933.326	13	0.013
R ₀ N ₂₅	76	26	3,466.658	14	0.014
R ₁ N ₁₅	61	24	3,199.992	15	0.015
R ₁ N ₂₅	98	39	5,199.987	15	0.015
R ₁ N ₀	81	30	3,999.990	13	0.013
Feal	1.58***	3.33***	3.31***	1.58***	1.58***

R₀N₀= No rhizobium inoculated seeds and no NPK 15:15:15 ; R₀N₁₅ = No rhizobium inoculated seeds with 15 kg NPK 15:15:15; R₀N₂₅ = No rhizobium inoculated seeds with 25 kg of NPK 15:15:15; R₁N₀= rhizobium inoculated seeds with inoculated seeds no NPK 15:15:15 ; R₁N₁₅= rhizobium inoculated seeds with 15 kg NPK 15:15:15 ; R₁N₂₅ = rhizobium inoculated with 25 kg of NPK 15:15:15; Note: ** and *** denote means significant at 1 and 5 % level of significant; NS = not significant; means within a column not sharing a letter in common differ from other means significantly following Duncan's Multiple Range Test (DMRT)

R₁N₁₅ (18.15cm), R₁N₂₅ (18.15cm), R₀N₂₅ (16.05cm) and R₀N₁₅(13.60) produced plants that were significantly ($P \leq 0.05$) taller than R₀N₀ (9.7cm) at 2WAP as shown in Table 5. However, at 12WAP, it was observed that soil treated with R₁N₁₅ (81.0 cm) and R₁N₂₅ (81.0 cm) had plants that were significantly ($P \leq 0.05$) taller than plants in other treatments soils.

It was observed that the highest weight of dry pod and fresh pod were recorded in R₁N₀ (14.7g) and R₁N₀ (98.0g) respectively as shown in Table 6. It was also shown from the result that R₁N₁₅ (287.2) was significantly ($P < 0.05$) higher in number of nodules than other treatments as shown in Table 6.

The microbial population was presented in Table 7 which showed that bacteria were higher than fungi before and after the experiment indicated that soil with

R₁N₂₅(154 cfu/g)>, R₁N₁₅ (140 cfu/g)> R₁N₀ (128 cfu/g)> R₀N₁₅ (111 cfu/g) > R₀N₂₅ (74) cfu/g > R₀N₀ (60 cfu/g) in bacterial count and fungal count R₁N₁₅ and R₁N₂₅ had the same count but were statistically ($P \leq 0.05$) higher than other treatments with the range of 10-21 cfu/g at 12 WAP.

The highest number of fresh seeds per a plot was R₁N₂₅ (98) and the highest number of pod per plant was also R₁N₂₅ (39) as shown in Table 8. This result is in line with the result of Adedeye *et al.*, 2017 who stated that inoculated plants with rhizobium produced more grains at 35% higher than the uninoculated ones.

At 12 WAP, it was observed that inoculation *Rhizobium* combined with 15kg/ha NPK and 25kg/ha NPK produced plants with significantly ($P \leq 0.05$) heavier seeds (15kg/ha) relative to other treatments and significantly ($P \leq 0.05$) higher in weight of

fresh seeds compared to control (R_0N_0) at 8kg/ha as shown in Table 8. Treatment R_1N_{25} had the highest number of fresh seeds/pod and significantly ($P \leq 0.05$) higher than all other treatments, and control, R_0N_0 (52) as shown in Table 8. The result is in line with the result of Moretti *et al.*, 2020. It was also shown that R_1N_{15} and R_1N_{25} had the highest yield with 0.015 ton/ha of soybean and was significantly ($P \leq 0.05$) higher than all other treatments and control, R_0N_0 (0.012 ton/ha).

Conclusion and Recommendation

Conclusion

The research has shown efficacy of seeds inoculated with *Bradyrhizobium japonicum* combined with 15 kg/ha and 25kgN/ha produced and served as a good organic amendment for the growth and yield of soybean (*Glycine max* Merr.L). The treatments also enhanced nutrients such as nitrogen, phosphorous and basic cations in soil. They improved the bacterial population from 93.5×10^6 cfu/g to the range of 74-150 cfu/g at 12WAP. The applied treatments also help in the reduction of acidity from 4.9 (initial level) to the range of 5.9 - 6.25 at 12WAP. The best treatments were found in rhizobium inoculated seeds with 15kg NPK 15:15:15 (R_1N_{15}) and rhizobium inoculated seeds with 25kg NPK 15:15:15 (R_1N_{25}).

Hence, the application of rhizobium can substitute NPK fertilizer in degraded soil developed from coastal plain sands of humid tropical Rainforest of Calabar, Nigeria.

Recommendation

Treatment combination of *Bradyrhizobium japonicum* and NPK 15:15:15 at 25kg/ha (R_1N_{25}) should be used as an amendment in order to enhance soybean (*Glycine max*)

production in coastal plain soils because they help to reduce the soil acidity level. They also improve the contents of basic cations, seed yield in (tons/ha) and microbial population in the soil which shows high rate of organic matter decomposition, transformation and enhancement of nutrients within the soil.

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DETERMINATION OF TIME AND METHOD OF APPLICATION OF PHOSPHORUS FERTILIZATION ON PERFORMANCE OF GREEN BEANS (*PHASEOLUS VULGARIS* L.) AT AFAKA, NIGERIA

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ABSTRACT

A Field Experiment was conducted at the Experimental Farm of Federal College of Forestry Mechanization, Afaka, Kaduna in northern Guinea savanna ecological zone of Nigeria. Afaka is located at Latitude, 10° N¹ 35¹, longitude 07° E 21¹ and altitude 632M above the sea level. The research was conducted during the onset of the raining season of 2024 to assess the effect of Time and Method of Application of Phosphorus Fertilization on performance of Green beans (*Phaseolus vulgaris* L.) at Afaka. The treatments consisted of three times of Phosphorus application, 0, 2 and 4 weeks after sowing (WAS) and three methods of Phosphorus application, drill, ring and side placement. The experiment was laid out in randomized complete block design (RCBD). The growth and yield parameter collected included number of leaves and stem girth, which was replicated three times could be applied for better growth and yield performance in northern Guinea savanna zone, since these treatments were observed to have done better than the other treatments used in the experimental study. Four weeks phosphorus application and ring placement method at 9 WAS produced the highest weight of pod per plot, while at 7 WAS, this same treatment produced the highest number of nodule, weight of dry biomass, weight of pods, and 100 seed weight. The result from the experiment showed that four weeks phosphorus application and ring placement method at 9 WAS produced the highest weight of pod per plot while at 7 WAS, the same treatment produced the highest number of nodule per plant at the same sampling period.

Keywords: Green beans, fertilizer use, soil fertility, Northern savanna zone.

INTRODUCTION

Green bean is a member of the legume family and has the first rank in the world according to FAO Stat (2013). Green beans (*Phaseolus vulgaris* L.) are one of the main staple crops known world-wide and in Africa, particularly in Nigeria (Mushagalusa, *et al* 2016; Upenji *et al*, 2020). According to FAO (2023), Green bean is widely cultivated across all cropping systems and contributes to significantly improve soil fertility (Kirba, *et al* 2020; Merga, 2020). For a long time,

they became rare and expensive and this vegetable only became wide spread in the 19th century.

MATERIALS AND METHODS

Experimental Site, Treatments, Design and Cultural Practice

Field experiment was conducted at the Crop Production Department Farm of the Federal College of Forestry Mechanization, Afaka, Kaduna in the Northern Guinea Savannah Agro-Ecological Zone of Nigeria. The

experiment was carried out during onset of the rainy season of 2024.

Treatments consisted of three times of application and three methods of fertilization application which gave nine treatments combination that was replicated three times. The plot size is 3.0m x 3.0m. The spacing between plots was 60cm, while spacing between replications was 60cm. The experimental site was ploughed, harrowed and made into plot sizes and labelled according to treatment specification. The phosphorus fertilizer was applied at the rate of 26kg P_2O_5 /ha and this was done at planting and two weeks after planting according to the treatment specifications while NPK (20;10;10) at 200 kg N /ha was applied at five weeks after planting which was uniformly applied across all the plots. The three methods of fertilizer application methods used are, side row placement also known as band placement or side dressing. This involves placing fertilizer in a band beside the row of crops. This method aims to position the fertilizer near the root zone of the plants, making it readily available for uptake while minimizing losses due to volatilization. Side row placement is often done at planting or during the early growth stages of the crop when nutrient demand is high. The fertilizer was applied in a narrow band typically 5-10cm to the side of the seed row and 2.5-5cm below the soil surface. This ensure that the fertilizer is close enough for the roots to access but not in direct contact with the seeds, which can cause seed burn. The second is the ring method or ring placement or ring application, this involves applying fertilizer in a circular pattern around the base of the plant. The method of

application involves measuring the drip line, this is the outermost circumference of the plant's canopy. Fertilizer should be applied along this line since it corresponds to the areas where the plant's feeder roots are most active. The fertilizer should be lightly worked into the top soil with a hoe, especially when using the granular fertilizer. This helps to prevent runoff and ensures the nutrients reach the root zone. The third method is the drilling method of fertilizer application, this involves placing the fertilizer directly into the soil at specific depths and locations typically alongside or below the seeds at planting time. This method is useful where precise nutrient placement is critical for optimal plant growth. The fertilizer is placed in narrow bands alongside or below the seeds. This involves placing the fertilizer 2.5-5cm below and to the side of the seed row. Test Crop is green bean seed and the variety used was Blue Lake 274 bush green bean variety. The planting was carried out on the ridge in a hole of about 3.0 cm deep in the soil. Weeding was manually done using a hoe every three weeks interval until maturation. Five tagged plants within the net plot were observed and data were collected on the following parameters. Number of leaves was done by counting the number of leaves of five randomly selected plants per plot at 3 5, and 7 weeks after planting and the average was taken and recorded. Stem diameter/girth per plant was determined by using a measuring tape to measure the diameter at the base of the stem, perpendicular to the ground. Number of nodule and nodule was at 7 weeks after planting and roots were separated from soil and the nodules detached

from the roots of sampled plants. This was then washed and cleared of soil particles and the detached nodules were counted and the numbers recorded. The nodules were kept in an envelope and oven dried at 65°C, weighed and recorded. The nodules were weighed fresh, recorded and placed in an envelope which was labelled and dried. Weight of pod per plot was weighed and recorded every 2-3 days during harvesting of the pods and added after the harvesting had been completed. A 100 seed weight (g) per plot was determined by counting the 100 seed of the green beans that has been unshelled manually and weighing through by using a sensitive weighing balance and recorded. Weight of dry biomass per plot from above ground matter of the harvested plants was enveloped and labelled at harvest oven dried at 65°C and recorded.

Pre-experimental Soil Sampling and Analysis

Physical and chemical properties of the soil profile within the depth of 0-20cm of the experimental site was taken for analysis.

Soil samples was randomly taken from the depth stated above using soil auger this was then bulked, air dried and sieved through a 2 mm sieve. A sub-sample of the composite soil was taken for analysis to obtain the physical and chemical properties of the soil.

Statistical Analysis

The data collected were subjected to analysis of variance (ANOVA) described by (Snedecor and Cochran, (1967). The difference among the means was compared using Duncan Multiple Range Test (DMRT), Duncan (1955).

RESULT AND DISCUSSION

Characterization of the Study site

The results obtained from the physical and chemical properties of the pre-cropping soil are shown in Table 1. The soil is sandy loam in texture, high in organic carbon (3.8 g kg⁻¹), total N (0.2 g kg⁻¹), Available phosphorus (22.75 mg kg⁻¹) with low exchangeable base cations as Calcium (Ca), Potassium (K), Magnesium (Mg) and Nitrogen (N).

Table 1: Chemical and physical properties of the soils used for the study

Parameters	Values
pH (H ₂ O) 1:2.5	6.4
Electrical conductivity (dsm ⁻¹)	0.15
Total nitrogen (g kg ⁻¹)	0.2
Organic Carbon (g kg ⁻¹)	38
Available phosphorus (mgkg ⁻¹)	22.78
Calcium (g kg ⁻¹)	0.71
Magnesium (cmol kg ⁻¹)	0.26
Sodium (cmolkg ⁻¹)	0.05
Potassium (cmolkg ⁻¹)	0.03
Exchangeable acidity (cmolkg ⁻¹)	0.5

The determination of time and method of phosphorus fertilization on performance of Green beans (*Phaseolus vulgaris* L.)

Number of leaves per plant

Table 2 shows that increasing the time of phosphorus fertilization from 0 up to 4 weeks had not significantly increased number of leaves at all the sampling periods except at 5 and 7 WAS. When the applied phosphorus fertilizer produced the highest number of leaves at 2 weeks of phosphorus fertilization which was statistically similar with 4 weeks phosphorus fertilization at 5 WAS period of sampling. At 7 WAS, 4 weeks phosphorus fertilization resulted in the highest number of leaves at this sampling period which was also statistically similar with 2 weeks phosphorus fertilization. Applying phosphorus (P) at 4 weeks enhances the number of leaves per plant due to its critical role in early plant development and growth (John *et al.*, 2013). The method of fertilization had significantly increased the number of leaves at the sampling period of 5 and 7 WAS. The ring placement method of fertilizer application produced the highest number of leaves at 5 and 7 WAS which was statistically at par with the drilling method of fertilizer application. At 7 WAS, the drilling method of fertilizer application gave the highest number of leaves which was statistically at par to the ring method of fertilizer application and lowest number of leaves was obtained from the treatment with the side placement at the 7 WAS sampling period. The ring method of fertilization application ensures gradual phosphorus availability leading to continuous leaf production and expansion, (Benton, 2012).

Stem girth

Table 3 shows that increasing the time of phosphorus fertilization from 0 up to 4 weeks had not significantly increased stem girth per plant at any of the sampling periods except at 5 WAS. When the 4 weeks

phosphorus fertilization produced the widest stem girth was statistically similar with 2 weeks phosphorus fertilization. Applying phosphorus at 4 weeks enhanced stem girth per plant due to its role in DNA, RNA and ATP synthesis which drive cell division and enlargement. This contributes to a more robust stem structure in plant metabolism, (Alam *et al.*, 2022). At this same sampling period of 5 WAS, the ring placement method of fertilizer application had significantly increased the stem girth and gave the widest and which was statistically similar with the drilling method of fertilizer application. The side placement method of fertilizer application gave the narrowest stem girth at the sampling period. The ring method places phosphorus around the plant, promoting even root expansion and better nutrient uptake, (Adiaha *et al.*, 2016 and Yeboah *et al.*, 2020).

Table 3 shows that increasing the time of phosphorus fertilization from 0 to 4 weeks and the method of fertilizer application had both significantly influenced the number of nodules per plant at 8 WAS sampling period. Two weeks phosphorus fertilization produced highest number of nodules per plant at the sampling period which was statistically similar with 4 weeks phosphorus fertilization. Applying phosphorus at 4 weeks influences the number of nodules per plant because P is essential for root development, biological nitrogen fixation and symbiotic relationship with nitrogen fixing bacteria, (Ngari *et al.*, 2023).

The methods of fertilizer application had also significantly increased the number of nodules per plant at the same sampling period. The ring method of fertilizer application produced highest number of nodules per plant which was statistically at par with the drilling method of fertilizer application obtained at the period of sampling. The ring method

Table 2: Determination of methods of application of phosphorus on number of leaves per plant at Afaka during 2024 planting season.

Treatment	Number of leaves per plant		
	3 WAS	5 WAS	7 WAS
Time of application			
4	5.22	35.11ab	90.44a
2	5.11	38.78a	89.11ab
0	5.11	34.11b	83.33b
SE±	0.231	1.016	1.771
Method of application			
Drilling	5.44	36.22ab	90.67a
Ring placement	5.01	38.33a	90.56a
Side placement	5.01	33.44b	81.67b
SE±	0.231		
Interaction	0.401	1.771	3.067
T*M	NS	*	*

Table 3: Determination of Time and Method of Application of phosphorus fertilization on Performance of green beans on stem girth per plant sat Afaka at 2024 planting season

Treatment	Stem girth per plant		
	3 WAS	5 WAS	7 WAS
Time of application			
4	1.27	2.21a	2.32
2	1.23	2.12ab	2.21
0	1.2	2.07b	2.2
SE±	0.033	0.033	0.034
Method of Application			
Drilling	1.21	2.12	2.24ab
Ring placement	1.26	2.11	2.31a
Side placement	1.23	2.17	2.18b
SE±	0.033	0.033	0.034
Interaction	0.067	0.056	0.0598
T*M	NS	*	*

promotes root elongation and branching creating more infection sites for nitrogen-fixing bacteria and this leads to nodule initiation, nitrogen fixation and higher nodule number, (Hansel *et al.*, 2022).

Weight of pod per plant

Table 4 shows that increasing the time of phosphorus fertilization from 0 to 4 weeks and the method of fertilizer application had both significantly influenced the weight of pod per plant at 9 WAS sampling period. The method of fertilizer application significantly influenced the weight of pods per plant. The drilling method of application was observed to have produced the highest weight of pods which was statistically at par with the ring method of fertilizer application at the sampling period of 9 WAS. The ring method of fertilizer application optimized P supply which improved pod formation, seed development, heavier well filled pod which increases dry pod weight, (Ngari *et al.*, 2023).

Weight of dry biomass per plot

Table 4 shows that increasing the time of phosphorus fertilization from 0 to 4 weeks and the method of fertilizer application had both significantly influenced the weight of dry biomass per plot at 9 WAS sampling period. Four weeks phosphorus fertilization produced the highest weight of dry biomass which was statistically similar with the two weeks phosphorus fertilization produced at the sampling period. Applying Phosphorus at 4 weeks ensures the plant has sufficient nutrients during its rapid vegetative phase, leading to higher biomass production, (Broughton *et al.*, 2003). The methods of fertilizer application had also significantly increased the weight of dry biomass at 9 WAS sampling period. The drilling method of fertilization produced the highest weight of dry biomass which was statistically similar with the ring placement method of fertilization at the period of sampling but significantly different from the side placement which had the lowest weight of

dry biomass. The better root system from ring application improves nutrient absorption, leading to increased vegetative growth, more leaves and stronger stem result in higher total biomass accumulation, (Broughton *et al.*, 2003).

Root dry weight per plot

Table 4 shows that increasing the time of phosphorus fertilization from the control up to 4 weeks and the method of fertilizer application had both significantly influenced the root dry weight per plot at 9 WAS sampling period. Four weeks phosphorus fertilization produced the highest weight root dry weight per plot at the sampling period. Applying Phosphorus at 4 weeks influences root development because phosphorus plays a key role in energy transfer, and overall plant metabolism, (Hanse *et al.*, 2022). The methods of fertilizer application had also significantly increased the root dry weight at the same sampling period of 9 WAS. The ring method of fertilizer application produced the highest weight of the root dry weight which was statistically at par with the drilling method of fertilizer application at the same period of sampling. The ring method ensures phosphorus is available around the plant rather concentrated in one spot. This encourages root growth, roots grow outward toward the P increasing uptake efficiency, (Hansel *et al.*, 2022).

100 seed weight per plot

Table 5 shows that increasing the time of phosphorus fertilization from the control up to 4 weeks and the method of fertilizer application had significantly influenced the 100 seed weight per plot at 9 WAS sampling period. Two weeks phosphorus fertilization produced the highest weight of 100 seed weight per plot at the sampling period was statistically at par with 4 weeks phosphorus fertilization at 9 WAS. Applying Phosphorus at 4 weeks influences 100 seed weight because P plays a crucial role in seed

development, grain-filing and overall plant productivity, (Ibrahim *et al.*, 2019). The methods of fertilizer application had also significantly increased the 100 seed weight

Table 4. Determination of Time and Methods of Application of Phosphorus fertilization on number of nodules per plant, Weight of dry biomass plot and Weight of pod per plot at harvest at Afaka during the 2024 planting season

Table 6. Determination of Time and Methods of Application of Phosphorus fertilization

	Number of nodules per plant	Weight of pod per plot	Weight of dry biomass plot
Time of application	7 WAS	9 WAS	9 WAS
4	14.21a	68.44	31.11a
2	12.11ab	67.19	29.67ab
0	10.31b	66.88	24.61b
SE±	0.925	1.669	1.728
Method of application			
Drilling	13.67a	68.35a	32.48a
Ring placement	15.01a	72.81a	29.56ab
Side placement	7.44b	61.35b	23.34b
SE±	0.925	1.669	1.728
Interaction	1.603	2.891	2.993
	*		*

on Performance of Green beans on number of 100 seed weight per pot at harvest at Afaka at 2024 planting season

	100 seed weight per plot 10 WAS
Time of application	
4	23.33a
2	23.46a
0	18.46b
SE±	0.370
Method of application	
Drilling	21.08b
Ring placement	23.04a
Side placement	21.13b
SE±	0.370
Interaction	0.642
T*M	*

per plot at the same sampling period of 9 WAS. The ring placement method of fertilizer application produced the highest weight of 100 seed weight per plot which was significantly different from drill and side placement which had the lowest weight. The efficient phosphorus uptake from the ring method enhances carbohydrate and

protein synthesis leading to well-filled, heavier seeds. It also prolongs the grain filling period ensuring seeds reach their full weight potential, (Hansel *et al.*, 2022).

Conclusion

Four weeks phosphorus application and ring placement method at 9 WAS produced the highest weight of pod per plot, while at 7 WAS, this same treatment produced the widest stem girth, highest weight of root and number of nodule per plant at the same sampling period. The revealed that Four weeks phosphorus application and ring placement method gave better performance on growth and yield of green beans production in the study area.

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EFFECT OF POULTRY MANURE ON THE GROWTH OF COWPEA IN MINNA SOUTHERN GUINEA SAVANNA ZONE OF NIGERIA

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ABSTRACT

A field experiment was carried out in the cropping season of 2024 to investigate the effects of different rates and sources of poultry manure on the growth of cowpea at minna southern guinea savanna zone of Nigeria. Two sources of poultry manure were used; deep litter and battery cage. With five levels of treatments (0, 5, 10, 15 and 20 t. ha⁻¹) were established in Randomized Complete Block Design with four replicates. Results revealed that plant height significantly increased with increasing poultry manure (PM) rate. Plants from deep litter at 20 tons produces the tallest plant at 4, 6 and 8 weeks.

Keywords: poultry Manure, Cowpea, deep litter, battery cage, Minna

INTRODUCTION

Cowpea (*Vigna unguiculata* L. Walp) is an important leguminous crop grown for its protein-rich grains and as a cover crop to improve soil fertility. In Nigeria, particularly in the Southern Guinea Savanna zone, cowpea is a major component of smallholder farming systems due to its adaptability to diverse environmental conditions (Singh *et al.*, 2011). However, poor soil fertility remains a major constraint to cowpea production in this region, necessitating the use of organic and inorganic soil amendments to enhance productivity (Akanbi *et al.*, 2010).

Poultry manure has gained attention as a sustainable soil amendment due to its high nitrogen, phosphorus, and potassium (NPK) content, which improves soil structure, microbial activity, and nutrient availability

(Azeez & Van Averbek, 2010). Studies have shown that the application of poultry manure enhances cowpea growth, increases nodulation, and boosts grain yield compared to unfertilized soils (Oladiran & Oso, 2021). Poultry manure has been extensively studied for its impact on the growth and yield of cowpea (*Vigna unguiculata*), particularly in various regions of Nigeria. While specific studies focusing on Minna in the southern Guinea savanna zone are limited, research from similar agro-ecological zones provides valuable insights.

This study investigates the effects of poultry manure application on the growth of cowpea in Minna, located in the Southern Guinea Savanna of Nigeria. The study aims to determine the optimal poultry manure rate for cowpea growth. The findings will contribute to sustainable agricultural practices, reducing dependency on synthetic fertilizers while enhancing food security in the region.

MATERIAL AND METHODS

Location

This study was conducted opposite School of Agriculture and Agricultural Technology (SAAT) complex, Federal University of Technology, Minna Niger state. The experimental site is located on latitude 9°31'6"N to 9°31'50"N and Longitudes 6°26'26"E to 6°27'6"E. The study area has a distinct wet and dry season. The wet season typically last from April to October, with the highest rainfall occurring in August and dry season which lasts for five (5) months occurs from November to March. The annual rainfall is 1284mm.

Sources of Materials

Poultry manure source were obtained from Niger State Ministry of Agriculture (Livestock, Poultry Unit). Cowpea variety Sampea 20T was obtained from Ahmadu Bello University (ABU) Zaria. Fertilizers and pesticides were obtained from a retail shop in Minna.

Treatments and Experimental Design

Treatments were two poultry manure sources (deep litter and battery cage) and five poultry manure application levels (0, 5, 10, 15 and 20 t ha⁻¹ respectively) replicated 4x and fitted to a Randomized Complete Block Design (RCBD).

Planting and Agronomic Practices

Cowpea seeds were planted at the rate of 3 seeds/hill and at a spacing of 75cm between the rows and 25cm within the rows at a depth of 5cm on each 4m by 4m bed. After germination, the seeds were thinned to 1 plant per hill. Weeding was done twice by hoeing 2 and 5 weeks after planting to keep the field weed free. Cypermethrin insecticide was applied at 5 weeks.

Data Collection

At 4,6, and 8 weeks respectively, five plants were randomly selected for the measurement of plant height.

Statistical Analysis

Data collected were subjected to Analysis of Variance (ANOVA) at 5% level of probability using Statistix 8.0 statistical software (Statistix, 2005). Duncan Multiple Range Test (DMRT) was used to separate the difference between the means.

RESULTS AND DISCUSSION

Results

Effect of poultry manure sources and levels on plant height at 4, 6 and 8 weeks after planting

Plant height at 4 weeks after planting were significantly affected by levels of poultry manure ($P < 0.01$), Application of 20 t ha⁻¹ of poultry manure produced the highest plant height of 39.48 cm, followed by the application of 15 t ha⁻¹ (36.68 cm). The least plant height of 22.33 cm was produced by plants fertilized with 0 t ha⁻¹ of poultry manure. Plant height at 4 weeks after planting was also significantly affected by sources of poultry manure ($P < 0.05$). Application of deep liter source of poultry manure produced the highest plant of 33.11 cm which was significantly higher than the height of 32.18 cm produced as a result of the application of battery cage source of poultry manure.

Plant height at 6 weeks after planting was significantly affected by poultry manure levels ($P < 0.01$). The highest plant height of 54.24 cm was recorded with the application of 20 t ha⁻¹ of poultry manure, followed by 15 t ha⁻¹, which resulted in a height of 47.88 cm. The shortest plants, measuring 34.51 cm,

were observed in the absence of poultry manure (0 t ha^{-1}). Additionally, plant height at six weeks was significantly affected by different poultry manure sources ($P < 0.01$). The deep litter poultry manure source yielded the tallest plants at 44.33 cm, which was significantly greater than the 42.66 cm recorded with the battery cage manure source.

Plant height at 8 weeks after planting was significantly affected by poultry manure application rates ($P < 0.01$). The tallest plants, reaching 77.01 cm, were obtained with 20 t ha^{-1} of poultry manure, followed by 15 t ha^{-1} , which resulted in a height of 71.91 cm. The shortest plants, measuring 58.23 cm, were recorded in the absence of poultry manure (0 t ha^{-1}). Furthermore, plant height at eight weeks was also significantly affected by the source of poultry manure ($P < 0.01$). The application of deep litter poultry manure resulted in the greatest plant height of 68.63 cm, which was significantly higher than the 66.43 cm achieved with battery cage poultry manure.

Discussion

Initial soil physical and chemical analysis shows that the experimental soil was loamy sand which is ideal for Cowpea cultivation (IITA, 2024). The organic carbon content, available phosphorus was low. This is typical of cultivated soils of the savanna and it is usually as a result of cultivation (Yakubu and Jaiyeoba, 2020).

Poultry manure levels significantly affected plant height at 4, 6 and 8 weeks to show that the effect of application should not be ignored. The absence of poultry manure produced the shortest plants across sampling

dates (4, 6 and 8 WAP) (fig 1, 2 & 3) implying that the nutrient responsible for plant height improvement notably nitrogen was of low concentration. The increase in height of Cowpea plants as a result of poultry manure application was probably due to the addition of organic nitrogen contained in the poultry manure. According to Smith & Brown 2020 poultry manure contains 3.5 % N, 2.0 % K and 1.5 % P_2O_5 . The results also demonstrated that the plant grew taller with increase in the application and age of the plants (fig 1, 2 & 3) signifying that the supply of the nutrient content in the manure especially nitrogen increased with application and age of plants. In other words, the nutrient responsible for height appreciation were readily released with increase in application and age of plants (Chaudhry and Nosheen, 2014). Deep litter source of poultry manure recorded the tallest plants compared to battery cage regardless of age of plants. This is surprising and unexpected owing to the fact that the litter in deep litter source should immobilize nitrogen, hence reducing supply of nitrogen to the plants for height improvement. This however would depend on the kind of litter and this is also demonstrating that the litter used in the deep litter has a narrow C:N ratio and resulted in nitrogen mineralization rather than immobilization. In conclusion plant height of Cowpea significantly increased with increase in application of poultry manure up to 20 t ha^{-1} . The deep litter source on the other hand produced the most significant height increase compared to battery cage source of poultry manure.

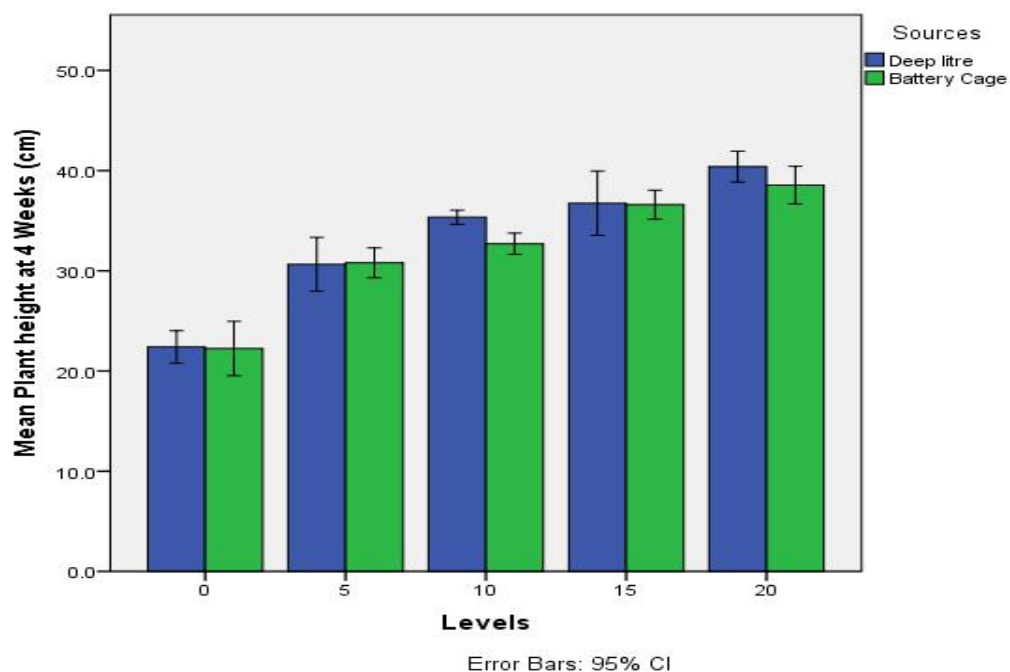


Fig 1 effect of poultry manure on plant height at 4 weeks after planting

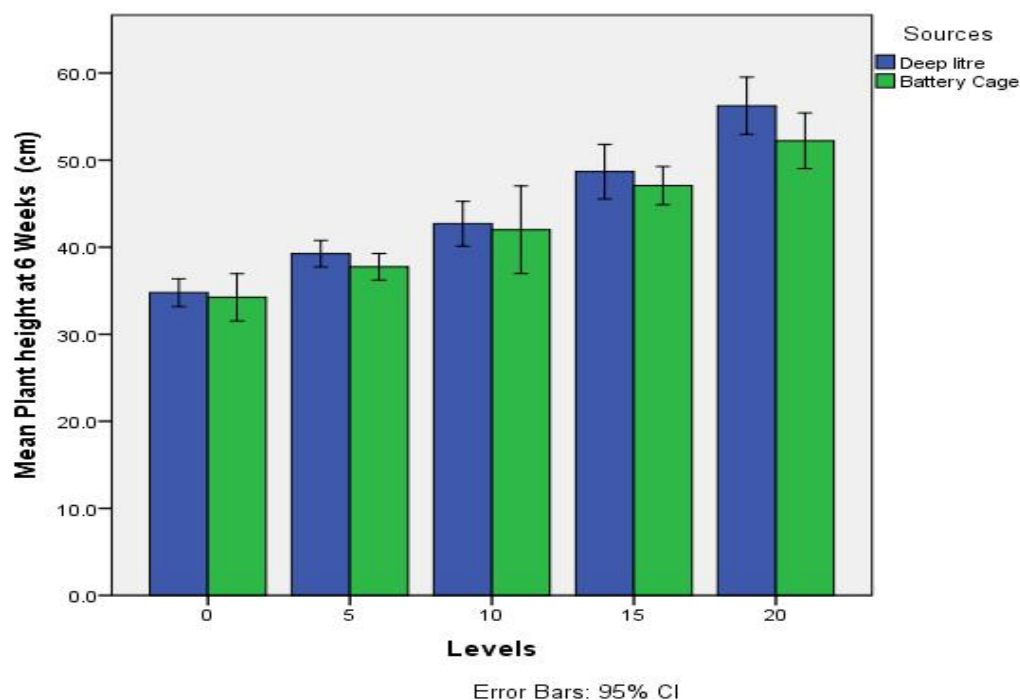


Fig 2 effect of poultry manure on plant height at 6 weeks after planting

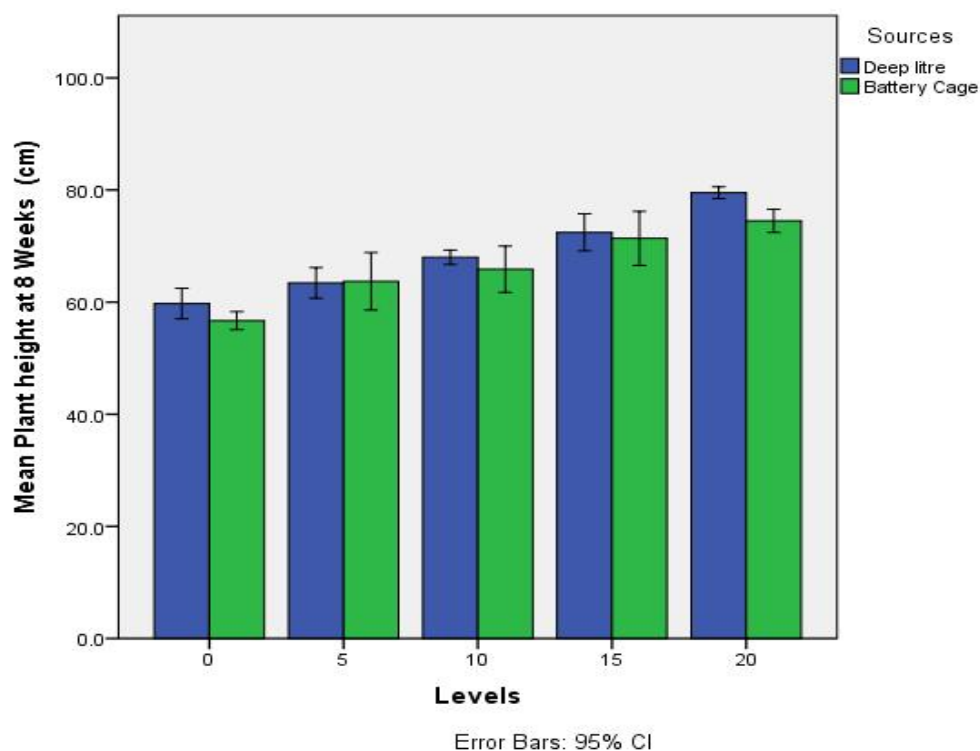


Fig 3: Effect of poultry manure on plant height at 4 weeks after planting

Table 1. Main effect of levels of poultry manure and source on plant height at 4, 6, and 8 WAP

	4 WAP(cm)	6 WAP (cm)	8 WAP (cm)
Levels (t ha ⁻¹)			
0	22.33 ^e	34.51 ^e	58.23 ^e
5	30.73 ^d	38.50 ^d	63.56 ^d
10	34.03 ^c	42.35 ^c	66.94 ^c
15	36.68 ^b	47.88 ^b	71.91 ^b
2	39.48 ^a	47.88 ^a	77.01 ^a
Significance level	**	**	**
Source (s)			
DL	33.11 ^a	44.33 ^a	68.63 ^a
BC	32.18 ^b	42.66 ^b	66.43 ^b
Significance level	*	**	**
Level x Source	NS	NS	NS

Deep litter (DL), Battery cage (BC), Not significant (NS), * (P≤0.05), ** (P≤0.01), WAP (Weeks after planting)

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TEMPORAL ANALYSIS OF SOIL FERTILITY STATUS FOR CROP CULTIVATION IN SHINKAFI VILLAGE, KATSINA STATE, NIGERIA

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ABSTRACT

Almost all the needs of man are derived from soil. Temporal analysis from 2011 to 2024 was conducted on soil fertility status for crop cultivation in Shinkafi village, Katsina State, Nigeria. Composite soil sampling method for the collection of soil samples between the depths of 0-15cm was adopted. The soil samples were collected from farmlands under crop cultivation and in the village as control and analysed for PSD, pH, Oc, N, P, K, Ca, Mg and CEC physical and chemical properties. The result revealed as added the soil properties the results show that clay was 13.85%, pH 7.10, OC 1.90% total N 0.90%, P 2.19ppm, K 0.77cmol/kg, Ca 8.01cmol/kg, Mg 3.57cmol/kg and CEC 2.89cmol/kg in the area. Analysis of variation (ANOVA) show that there was no variation among the soil samples. The study shows that values of sample D with regards to clay 16.04% and Mg 4.02cmol/kg are higher compared to other areas. Therefore, the findings of this study indicate that, the soil fertility is at low level and it has clearly shown the influence of anthropogenic activities. The results of this study are greater compared to average clay 1.34%, Oc 0.90%, total N 0.006%, K 0.92cmol/kg, Ca 3.68cmol/kg and Mg 3.16cmol/kg of the year 2011. This clearly shows that there was influence of anthropogenic activities which resulted increase in values of soil properties. Therefore, the area is recommended for other land use and cultivation of some crops on other part of the area. These include millet, tomato, sorghum and vegetables. Thus, because the values of soil fertility for crop cultivation are very low compared to requirements, integration of organic and inorganic fertilizers and improvement in traditional fertility management should be maintained to increase rice production to meet the people's demand for sustainable development.

Key Words: Soil, Fertility, Crop, Shinkafi village and Katsina.

INTRODUCTION

There are various types of soil in Nigeria, each one existing in its own unique ecosystem and possessing unique fertility status (Olorunfemi *et al.*, 2018; Muhammad, Buhari & Mohammed, 2023). It is common knowledge that soils with a high fertility level

also have a high concentration of nutrients (Hodges, 2010). As far as the nation is concerned, the requirement for food security has brought with it a commensurate need to harness the fertility of the soil as it has demonstrated the ability to be used throughout the entire year (Reijneveld *et al.*,

2019). Due to crop cultivation year after year, soils are depleted of their fertility status, therefore for a succeeding crops to survive successfully in the same environment, depleted nutrients must be supplemented (Nesme, 2011; Dewangana *et al.*, 2023). Fertile soils can provide enough nutrients to the crop throughout the growing season. As a result, higher yields per unit area are easier to achieve in fertile soils than in low-fertility soils (Van and Rabbinge, 2017).

Soil fertility is the capacity of the soil to produce the crop desired. Fertility is the potential of soil to supply nutrient elements in amounts, forms and proportion required for maximum plants growth (Ahmed, 2019; Ufot, 2012; Yusuf, 2015). Soil is a medium for plant growth and whose characteristic have resulted from forces of climate and living organisms acting upon parent materials (rock) as modified by relief over period of time. The essential elements as soil fertility indices for rice and their chemical symbols are nitrogen (N), phosphorus (P), potassium (K), organic matter (OM), pH and cation exchange capacity (CEC) (Ahmed, 2019; Yusuf, 2016). In addition micronutrients and soil particles (clay fraction) also are of paramount important. These soil properties determine the capacity of soil supply nutrients to plants. This capacity to provide nutrients to crop plants is in part influenced by the physical properties of soils and is one component of soil fertility (Ahmed and Yusuf, 2020). Desirable soil physical properties and the capacity of the soil to provide nutrients for growing crops are both soil quality indicators.

Despite the limited ability of smallholder farmers to manage most of these factors (Ogbena *et al.*, 2016). The extensive expertise they have acquired in the cultivation of land, it is evident that farmers should assume a crucial role in the stabilization of agricultural land management. There also appears to be a potential prejudice among soil scientists and other experts towards the knowledge possessed by farmers regarding soil fertility. Nevertheless, it has been observed that small-scale farmers possess a considerable aptitude for discerning variations in fertility levels among different types of agricultural areas (Domchang *et al.*, 2014). According to Nesme *et al.* (2011), there exists a potential prejudice among soil scientists and other experts towards the knowledge of soil fertility possessed by farmers. Nevertheless, there is a significant lack of knowledge regarding farmers' perspectives on, fertilization recommendations, soil function, soil health, and soil fertility in general (Abdulkadir and Nuhu, 2020).

Researches on the fertility of the soil had been conducted in Nigeria and other African countries by the use of scientific methods for evaluating soil. These studies have produced a variety of findings (Fanuel *et al.*, 2017). However the scientific methods are not always consistent with how farmers perceived the fertility of the soil. Petrescu-Mag (2020) also assert that a comprehensive examination of soil functions necessitates the inclusion of farmers. It's against this background that this study analyses the perception of cereals farmers on soil fertility management practices. This is imperative to comprehend the level of information

possessed by farmers regarding soil quality and health to facilitate the effective dissemination of suitable technology for on-farm evaluations.

The research of soil fertility status of Shinkafi village in the year 2011, revealed the soil properties including average clay of 1.34%, pH of 7.09, Oc of 0.94%, N of 0.006%, P of 13.15ppm, Ca of 3.68cmol/kg, K of 0.92cmol/kg, Mg of 3.16cmol/kg, and CEC of 10.70cmol/kg were found to be at lower level compared to fertility requirements for crop cultivation (Ahmed, 2011). This study investigated the temporal analysis of soil fertility status of the area in the year 2024 to ascertain the changes occurred within the period of time for measures to be for sustainable crop production or seek other alternative for economic development.

2.1 MATERIALS AND METHOD

2.1.1 Field Work

Fieldwork (survey) was carried out on the study area to identify farmlands that cultivate crops for many years. It also involved physical characteristics of the study area. These include soil and land use types, soil management, vegetation etc. Composite samples were drawn from quadrant of 12m² in which five samples at the depth of 0 to 15cm were collected randomly within the quadrant and bulked as one composite sample. In this regard, according to Yusuf (2017) five samples

were collected within the 12m² and bulked as composite representative of the area. The Composite samples collected were air dried, put in cotton yard bags, labelled A, B, C and D appropriately and stored.

The soil samples were collected on 19th May, 2024 after harvest. They were taken to the soil laboratory of Umaru Musa Yar'adua University, Katsina for further analyses of soil physical and chemical properties. Geographic Positioning System (GPS) was used to locate the sampled location.

2.1.2 Laboratory Analysis

The samples were analysed for fertility indicators for the following; clay, EC, soil pH, total nitrogen, exchangeable bases (K, Na⁺, Ca⁺⁺ and Mg⁺⁺), available phosphorus and nitrogen (Lamofor *et al.*, 1990; Ibitoye, 2008; Eno *et al.*, 2009; Estefan, Sommer and Ryan, 2013; Garba, 2014). Statistical analysis for coefficient of variation and analysis of variation (ANOVA) were used. The procedures for the analysis are stated in Table 2.1.

3.1 STUDY AREA

Shinkafi village is located in Katsina local government area at the north end of Katsina State along Kaita road, between latitude 12°55'N – 13°08'N and longitude 7°32'E – 7°42'E (Katsina State Ministry of Lands, Survey and Environment, 2018).

Table 2.1: Methods of Determining Physical and chemical Properties of Soil Samples

Physicochemical Parameters	Methods Adopted
PSD& AWHC (%)	1:25 water ratio Hydrometer
Soil pH	pH meter (1:25 water ratio)
Total nitrogen (%)	Micro kjeldahl
Phosphorus(ppm)	Spectrophotometry (centrifuge) and calculation
Organic carbon (%)	Walkley black (dichromate solution), leaching, titration and calculation
Exchangeable bases(cmol/kg)	Bray 1 (NH ₄ OAC, Na ⁺ & K ⁺ by flame photometer and Ca ⁺⁺ & Mg ⁺⁺ by atomic absorption, AAS)
CEC(cmol/kg)	Calculated by the sum of exchangeable bases
Electrical Conductivity (%)	Leaching and Electrical Conductivity Meter

Source: Adapted from Eno *et al.* (2009); Ahmed (2019)

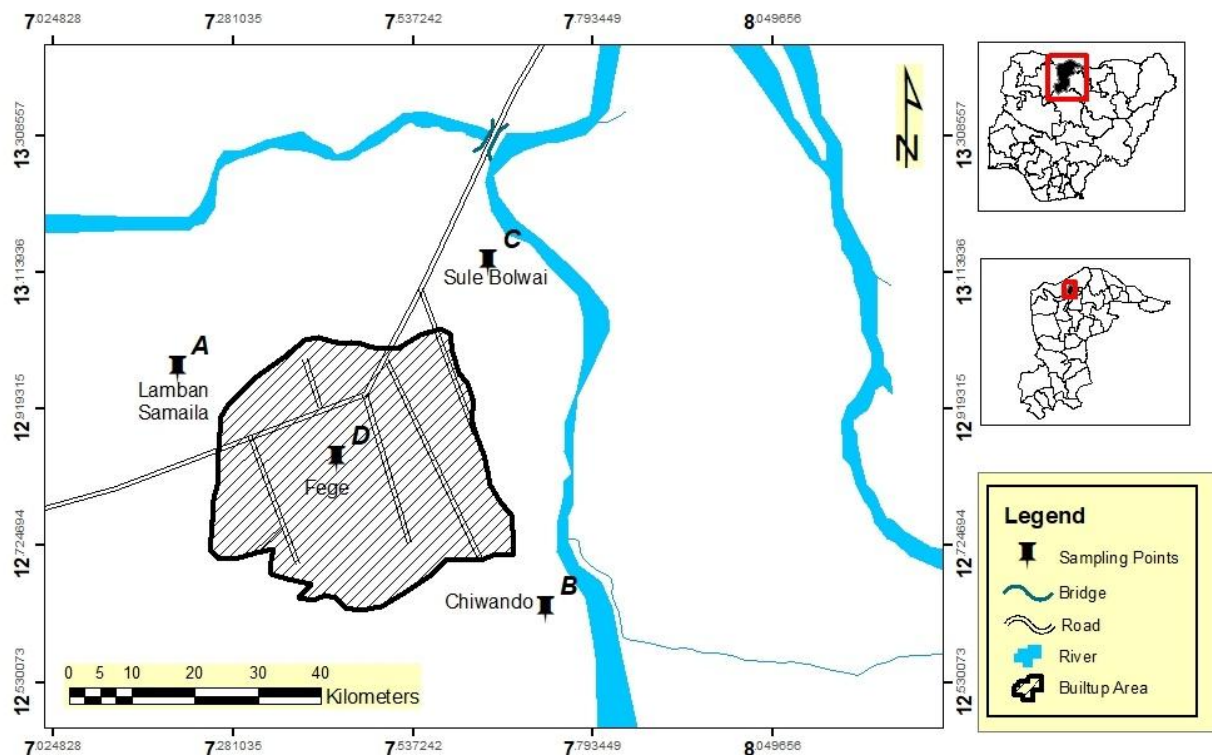


Figure 1: Map of Shinkafi Village showing Sampling Points

Sources: Drawn at GIS Lab, Geography Department, BUK (2025)

The rainy season of area is between the month of May to September and it has its peak in the month of August. The rainfall ranges from 4 to 5 months and recorded 550mm – 800mm annually, based on

average of 10 years from 2000 to 2009. It is characterized by conventional rainfall (dry and wet climate) followed by long dry season of 6 – 7 months (Meteorological Unit, Umaru Musa Yar'adua International Airport

Katsina, 2020). The mean maximum temperature of the area is 40°C in the month of April and May. At the peak of rainy season, average maximum temperature is 42°C and in December average temperature is 19°C (Meteorological Unit, Umaru Musa Yar'adua International Airport Katsina, 2020).

Relative humidity denotes the amount of water vapour in the atmosphere (air) compared to what the air can hold when fully saturated. The minimum relative humidity of the area is 15% in December to January and maximum as 90% around July to September, (Meteorological Unit, Umaru Musa Yar'adua International Airport Katsina, 2020). Soils are the mixture of rock

particles loosened by weathering, mineral salts and dead vegetation matter. In the northern part of Katsina State, the soils are largely sandy in nature and are fine in texture. The soils of the area are sandy in nature (Chude, 2012). Figure 1 showing map of the study area.

The most cultivated food crops are sorghum, maize, millet, white beans, rice and vegetables. The domesticated animals including goat, sheep and cow use to feed on the leaves and cane of the crops after harvest (Chude, 2012; Ahmed, 2014; 2019).

4.1 RESULTS AND DISCUSSION

The results of soil physical and chemical properties in the study area are presented in Table 4.

Table 4: Soil Physicochemical Properties in Shinkafi Village at the Year 2024

Sample ID	pH	OC %	N %	P ppm	Ex. Bases (Cmol/kg)				CEC Cmol/kg	PSD (%)			EC %
					Na	K	Ca	Mg		Clay	Silt	Sand	
A	6.80	1.63	0.81	1.85	5.22	0.26	8.11	3.44	2.16	12.64	3.28	82.08	1.23
B	6.90	1.81	0.72	2.15	5.13	0.28	7.32	3.15	3.04	12.64	3.28	84.08	1.21
C	7.02	2.01	1.05	2.31	4.78	1.24	8.44	3.66	3.31	14.08	3.28	82.64	1.67
D	7.40	2.16	1.02	2.45	5.36	1.30	8.16	4.02	3.06	16.04	3.28	80.64	1.53
Average	7.03	1.90	0.90	2.19	5.12	0.77	8.01	3.57	2.90	13.85	3.28	82.36	1.41
SD	0.14	0.23	0.12	1.02	1.65	0.13	2.34	0.98	0.86	3.72	0.76	3.67	0.08
CV %	1.99	12.11	13.33	46.58	32.23	16.88	29.21	27.45	29.65	26.86	23.17	4.45	5.67

Key: A-Lambun Sama'ila, B-Chiwando, C-Sule Balwai, D-Fagge (Inside Shinkafi)

Source: Field Work and Laboratory Analysis (2024)

From Table 4.1, the high value of clay fraction of 16.04% is recorded at Fagge (inside Shinkafi village and the lowest of 12.64% at Lambun Sama'ila and Chiwando area. The lowest pH level of 6.80 and higher pH of 7.40, were found to be at Lambun Sama'ila and Fagge areas and are almost neutral in nature. This corresponds with the findings of Chude, Jayeoba and Berding (2012), which shows soil pH values below 4.5 are strongly acidic and values of average pH of 7.03, the soil is at very low in fertility

levels. They added that soil pH levels of 6.1-6.5 are slightly acidic and soils are very fertile. Therefore, the pH levels in the study area in this regard are classified as very low fertile.

The result shows average Oc of 1.9%, N of 0.90%, P of 2.15ppm, K of 0.77cmol/kg and Ca of 8.01cmol/kg at the study area. The values are very low compared to result of soils at Musawa area (Ahmed, 2014). Thus, Esu *et al* (2014) suggested that lower values

of soil nutrients has influence low values in clay fraction in the soils. Therefore, soil nutrient values in this regard are below the plants requirement as pointed by Yusuf (2015).

The values of soil have increased compared to the values of soil in the year 2011. This could be seen as a result of human activities in the area. This include settlement by building houses and developmental project. This can led to the changes in soil properties

as indicated by Yusuf (2017) that soil change in addition to other soil from different location with different parent materials. The values of coefficient of variation are found to be below 50% which shows there is no variation among the soil samples. The coefficient of variation recorded pH of 1.41%, N of 19.01%, and clay fraction of 16.42% which are below 50% and shows that there is no variation among the soil samples.

Table 5: Soil Properties in Shinkafi Village in the Year 2011

Sample ID	pH	OC %	N %	P ppm	Ex. Bases (Cmol/kg)				CEC Cmol/kg	PSD (%)			EC uc/cm
					Na	K	Ca	Mg		Clay	Silt	Sand	
A	6.96	0.44	0.004	10.50	2.10	1.10	2.70	2.94	8.30	2.76	4.00	93.24	365
B	7.24	0.70	0.005	11.70	2.20	0.78	3.10	2.40	9.10	0.50	6.26	93.24	237
C	7.08	0.78	0.006	13.20	2.40	0.40	3.20	2.30	11.20	0.35	5.41	94.24	381
D	7.08	1.82	0.010	17.20	3.20	1.38	5.70	5.00	14.35	1.76	6.00	92.24	203
Average	7.09	0.94	0.006	13.15	2.48	0.92	3.68	3.16	10.70	1.34	5.42	93.24	296.5
SD	0.10	0.53	0.002	2.50	0.43	0.37	1.18	1.09	2.34	0.98	0.89	0.71	77.65
CV%1.41	56.33	33.33	19.01	17.34	40.21	32.07	34.43	21.87	73.13	16.42	0.76	26.14	

Key: A-Lambun Sama'ila, B-Chiwando, C-Sule Balwai, D-Fagge (Inside Shinkafi)

Source: Field Work and Laboratory Analysis (2011)

From Table 5, the average clay fraction recorded 1.34%, which is very low compared to plant requirements. According Ahmed (2019), clay fraction is one of the yard sticks of measuring soil fertility and should be about 30% and above. The macronutrients are at very low level and below the requirements for rice cultivation. These include average soil Oc of 0.94%, N of 0.006%, K of 0.92cmol/kg and P of 13,15ppm. It has been observed that soil pH has impact on soil macronutrients. The result shows pH of 6.96, pH of 7.24 and pH of 7.08 at Lambun Sama'ila, Chiwando and Sule Balwai areas (Table 5). Soil pH is like the temperature of an element and thus

could be used to diagnose what is likely to be disease problem of the soil or plant growth. A good and overall nutrients (availability) are found at mean pH of 6.5 and field crop prefer a pH of 6 or higher (Yusf and Tukur, 2012; Yusuf, 2017). According to Ahmed (2019) the pH scale range from 0 to 14, a neutral state is indicated at pH 7.0, values below 7.0 are acidic and above 7.0 are basic.

5.1 CONCLUSION AND RECOMMENDATIONS

The high value of clay fraction of 16.04% was recorded at Fagge (inside Shinkafi village and the lowest of 12.64% at Lambun Sama'ila and Chiwando area. The lowest pH level of 6.80 and higher pH of 7.40, were

found to be at Lambun Sama'ila and Fagge areas and are almost neutral in nature. The result shows average Oc of 1.9%, N of 0.90%, P of 2.15ppm, K of 0.77cmol/kg and Ca of 8.01cmol/kg at the study area. The values of soil have increased compared to the values of soil in the year 2011. This could be as a result of human activities in the area. This include settlement by building houses and developmental project.

Considering the above findings, it can be concluded that the soil values of 2024 are higher compared to the soil values of 2011 and the soil is at low level in fertility for crop cultivation. Therefore, measures should be taken in order to improve soil fertility for crop cultivation.

1. The soil pH level is found to be almost neutral. The use of chemical fertilizer is recommended to stabilise the levels of pH.
2. The major soil properties including P and K are found to be at very low levels compared to the crop requirements. The use of chemical fertilizer is recommended to normalise their level in the soil for intensive crop production in the area.
3. The soil nutrients including P and K were found to be at lower level. The use of chemical fertilizer is recommended to balance the issue.
4. The areas including Lambun Sama'ila Chiwando are recommended for other land uses. This is because the areas are almost occupied by building houses and other developmental project. The Sule Balwai area is recommended to cultivate cropd including millet, sorghum and beans.

5. The major soil properties including Oc, N, P and K are found to be at very low levels compared to the crop requirements. Integration of organic and inorganic fertilizer is recommended. Thus, plants need these soil properties in large quantity to meet the requirements for growth and development.

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SECTION THREE: SOIL PHYSICS AND CONSERVATION

APPLICATION OF ORGANIC AMENDMENTS: A PROMISING APPROACH IN LAND DEGRADATION REVERSAL

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ABSTRACT

Land degradation is one of the protracted global challenges associated with crop production declination, soil quality deterioration, and ecosystem malfunction. Unraveling proper understanding on the effectiveness of the use of organic materials in tackling these challenges is imperative and that is what this review set out to achieve. The motivation was born out of the reported fact about the safety, cost-effectiveness and durable effects of organic amendments on soil system relative to inorganic. This review extensively examined the effects of organic amendments on key land/soil quality indices dwelling on the hypothesis that their improvement indicates land degradation mitigation/restoration potential. In achieving that, reputable databases, including but not restricted to Science Direct, Elsevier, Google Scholar, Academia, and Web of Science were consulted for articles sourcing using relevant key terms. Summary of the review indicates that sole or combined application of cow dung, poultry litter, biochar, and compost, curtail and reverse land degradation, mostly through enhancement of soil qualities (physical, chemical, biological). The review, further established a positive link between such effects with crop growth and yield characteristics. The paper also noted the role of quality, quantity, and pyrolysis temperature on the restoration effectiveness of the different organic materials. Drawbacks associated with the application of each organic materials were pointed out and insufficiently explored areas were recommended for further studies. As a contribution, this review promotes advancement of organic-based approach in addressing land degradation and crop productivity shortfall.

Keywords: Land degradation, mitigation, organic amendment, soil quality, growth and yield characteristics

INTRODUCTION

Land is a vital non-renewable resource that is constantly being degraded by natural (climatic change and related factors), and anthropogenic (land misuse and soil management) factors (Lal, 2015; Sangita & Sharma, 2021). Land degradation is a global concern that threatens ecosystem services, biodiversity, and food security (Anālayo *et al.*, 2023; Jayaraman *et al.*, 2024). Almost half of the world's arable land is currently at

a different stage of land degradation due to a combination of physical, chemical, and biological processes that decline soil quality and productivity (Müller *et al.*, 2023; Umoru, 2023; Jayaraman *et al.*, 2024). This problem extends to Africa and Asia continents where land is a natural agricultural resource, supporting 70% of subsistence farming (Umore, 2023). It is estimated that 46 - 80% of the Africa's arable land is degraded, with 30 - 60 kg

nutrients loss per hectare per year (African Group of Negotiators Experts Support [AGENES], 2020). The wide range informs that there is a huge spatial variability in terms of land degree and susceptibility to degradation process which mainly depends on the nature of the soil, types of agroecological zones and human activities level.

In Nigeria, the soils of the savanna agroecosystem are inherently poor in fertility status, cation exchange capacity (CEC), fragile in soil structure, and low in activity clays and organic matter content (Jones & Wild, 1975). Further, they are dominantly sandy in nature which aggravate nutrients leaching away from the rooting depth of most crop (Tanko, 2018).

In reversing the trend, the Sustainable Development Goal (SDG 15.3) focuses on combating land degradation by promoting land restoration efforts aimed at ensuring the sustainable utilization of land resources. This initiative is crucial for the conservation of ecosystem services, biodiversity sustainability and agricultural productivity. To effectively address the challenges of land degradation, it is vital to understand the roles of organic amendments (such as cow dung, poultry litter, biochar, and compost). To that end, this review intends to advocate the use of organic amendments with or without the use of inorganic materials in improving the soil quality of degraded land. Literature was searched using variety reputable databases, including but not restricted to Science Direct, Elsevier, Google Scholar, Academia, ResearchGate, Agora, Semantic Scholars, and Web of Science.

CONCEPT OF LAND DEGRADATION

Land Degradation

Land degradation (LD) is broadly defined as the reduction or loss of biological and economic productivity and complexity of cropland, range, pasture, forest, and woodlands as a result of a variety of pressures, including land use and management practices (United Nations Statistical Division [UNSD], 2018). Within the soil Science context, land degradation is more related to the gradual decline in soil quality that affects a particular soil's ability to maintain net primary productivity (United Nation Environment Programme [UNEP], 1992). According to the World Soil Charter, the process of LD overridingly results from human actions that partially or entirely modifies soil properties (Food and Agriculture Organization of the United Nations [FAO], 2015a), to disrupts the ecological balance and lowers soil fertility and biodiversity strength (Teng and Zhou, 2020). The LD development manifest through soil erosion, desertification, salinization, acidification, contamination, land destruction and fertility loss (Teng & Zhou, 2020; Zaitsev *et al.*, 2022).

Three sub-indicators namely (a) land cover and land cover changes, (b) land productivity and (c) carbon stocks (above and below ground) (Andrew *et al.*, 2014; Ban *et al.*, 2015; Oehri *et al.*, 2017; Hengl *et al.*, 2017; Cowie *et al.*, 2018; Stumpf *et al.*, 2018) are being used to assess land degradation in Sustainable Development Goal Indicator 15.3.1. These indicators were initially proposed as proxies to monitor key factors and driving variables

that reflect the capacity of the land to deliver ecosystem services within the land degradation neutrality framework (Fu *et al.*, 2015; Orr *et al.*, 2017). Since most cases of land degradation are context-specific which is challenging for a single indicator to fully express the complexity of the state and condition of LD, the use of three factors is more effective (Gilbey *et al.*, 2019).

Causes of Land Degradation

Land degradation represents a multifaceted issue that unfolds due to human and natural influences (Bunning *et al.*, 2016). The factors and mechanisms contributing to land degradation as well as its effects on ecosystem services evolved over time (Cherlet *et al.*, 2018). Natural factors encompass those that defined the ecosystem's inherent ability to produce biomass, deliver goods and services, maintain ground cover, regulate water availability, and support biodiversity. Certain natural elements also play a role in the processes of LD, such as terrain slope and erodibility (the susceptibility of soil to erosion) (Jayaraman *et al.*, 2024). Soil erosion mainly instigated by natural forces like water and wind, which significantly depletes the topsoil layer that is essential for agricultural productivity (Farooq *et al.*, 2023). Other natural factors that are often influenced by human activities are forest fires, landslides, floods, and droughts (Nachtergaele *et al.*, 2012).

On the other hand, the primary human activities contributing to LD encompass a range of practices (Jayaraman *et al.*, 2024), changes in land use, deforestation, bush burning, over use of agrochemicals, total removal of crop residues and cultivation of

marginal lands. The consequences are more experienced in agricultural sector (Zucca *et al.*, 2022). Other noticeable, human driving factors include urban and industrial expansions (Zalesny *et al.*, 2021). The interplay between the natural and human factors complicates efforts towards addressing LD menace.

EFFECT OF LAND DEGRADATION ON SOIL PROPERTIES AND CROP PRODUCTION

Effect of Land Degradation on Soil Physical Properties

Land degradation has a significant effect on soil physical properties such as negative consequences for water and nutrient use efficiency as well as the overall soil productivity (Abdulmalik & Zewide, 2021). Deterioration or loss of soil physical properties leads to soil compaction, fine particle leaching, increased soil bulk density and penetration resistance (Yadav *et al.*, 2019; Hartati *et al.*, 2021). Moreover, compaction reflects compressive forces that reduce soil pore space, hydraulic conductivity and/or surface soil infiltration rates due to sealing, which in turn increase overland flow and the potential for erosion (Donovan & Monaghan, 2021). The combined effects of reduced vegetation cover and deteriorating of soil physical attributes such as macroporosity, permeability, infiltration, pore volume and function, bulk density, and structural aggregation, render the land unproductive by affecting soil functions (Monaghan *et al.*, 2017; Abdalla *et al.*, 2018).

Agricultural expansion and overgrazing are globally recognized as key contributors to accelerated soil degradation and surface

erosion, with direct consequences for land productivity (Donovan & Monaghan, 2021). Additionally, soils which are depleted in organic matter content, aggregates are more likely to slake into smaller sub-units during wetting, resulting in a soil structure that is more likely to erode which limit water infiltration and the emergence of seedlings (Tisdall & Oades, 1982; Matano *et al.*, 2015; Blanco-Canqui & Ruis, 2018). Notably, deteriorating soil physical quality reduces soil function in terms of soil physical attributes which had negative consequence on soil physical productivity especially water and nutrients retention.

Effect of Land Degradation on Soil Chemical Properties

Land degradation results in several negative effects on chemical soil properties including a decrease in soil pH, leaching of soluble salts and nutrients, accumulation of weathered salt, loss of soil organic carbon, reduction in nitrogen content and phosphorus availability, removal of exchangeable bases, decreased cation exchange capacity and depletion in soil fertility resistance (Yadav *et al.*, 2019; Hartati *et al.*, 2021). Degradation of soil chemical properties caused by both natural and human factors resulted in long-term consequences for ecosystems and agricultural productivity (Donovan & Monaghan, 2021). Natural processes of chemical degradation, such as the formation of pedogenic calcium carbonate and subsoil sodicity, could impair soil hydraulic properties and reduce crop productivity (Pal, 2017).

Furthermore, the buffering ability of soil, the degree to which the decline of soil

organic matter concentrations has changed the pH level (Page *et al.*, 2020), and lowering cation exchange capacity which in turn reduces nutrient retention by deteriorating soil quality (Sithole & Magwaza, 2019), are some soil chemical properties affected during land degradation. Therefore, nutrient depletion (Yadav *et al.*, 2019), soil acidity and toxicity of high concentrations of Al and Mn in the root zone served as a serious problem in sub-humid and humid regions (Eswarn *et al.*, 1997). Soil salinity and erosion problems are not only deteriorate the quality and quantity of crop production but also severely affect the lands which may not be used for further cultivation (Yadav *et al.*, 2019). Remarkably, deteriorating soil chemical quality reduces soil function in terms of soil chemical attributes which had negative consequences on soil chemical productivity, especially soil pH, organic matter content and cation exchange capacity.

Effect of Land Degradation on Soil Biological Properties

Land degradation has a significant effect on the biological properties of soil which includes a decline in organic matter content due to the removal of vegetation from topsoil, decline in microbial population, total and biomass carbon, biomass N, P, and S, and soil respiration rate resulted to decline in land biodiversity (Sims, 1990; Yadav *et al.*, 2019). Furthermore, due to the deterioration of soil quality lowers microbial activity and soil fauna population (Land Dgradation Assessment in Drylands [LADA], 2011), which also lead to decline in C turnover and nutrient availability, the

activity of numerous soil enzymes involved in the cycle of C, N, P, and S is reduced, killing off soil fauna and reducing the land biodiversity process (LADA, 2011;Yadav *et al.*, 2019).

In addition, biodegradation of organic compounds by soil micro-organisms involves a process known as mineralization whereby microorganisms convert the organic molecules to obtain carbon and energy for growth and multiplication, releasing the inorganic forms of N, P, S or other elements and also biodegradation process also depends on soil nature and microbial population. Land degradation processes erode top soil and sheltering of microorganisms which results in a reduction in the biodegradation process (Yadav *et al.*, 2019). Additionally, all of the soil's physical, chemical, and biological characteristics are crucial for the survival of soil fauna and microorganisms for the improvement of soil productivity (Yadav *et al.*, 2019). Conspicuously, the deteriorating biological quality of soil in terms of biological attributes of soil may hinder the biological function of soil, especially on beneficial soil microbes and enzymatic activities, as well as mineralization of organic matter.

Effect of Land Degradation on Crop Production

Land degradation is the main threat to soil and crop productivity (Utuk & Daniel, 2015). Changes in agricultural land to non-agricultural land, deforestation, desertification, erosion, salinization, waterlogging and organic matter depletion

lead to land deterioration which affect crop growth and yield (Guo *et al.*, 2013; Muhammad *et al.*, 2020). Land degradation has negatively affected the overall maize production (growth parameters such as: plant height, leaf area index, and number of leaves) due to the loss of surface soil rich in organic material, thereby affecting nutrient availability for plants and hinders the crop growth (Adewuyi & Baduku, 2012).

Soil quality deterioration has also a significant impact on various yields parameters of maize which affects grain yields, harvest index, seed test weight, biological yield, cob length, cob weight, cob diameter, and the number of cobs (Tanimu *et al.*, 2007;Yigermal *et al.*, 2021). The loss of nutrients from degraded land, in addition to the type and growth stages of seedlings also played a role in determining yield and yield-related traits of transplanted maize (Zhang *et al.*, 2018), leading to terminal moisture stress and grain yield loss (Huang & Rozelle, 1995). Drought and waterlogging during the maize growing season severely affected both the growth or vegetative and yield stages which led to reductions of crop performance (Djaman *et al.*, 2013). Remarkably, the deterioration of soil quality reduces the growth and yield of crops due to insufficient of water and nutrient required by the crop to achieve and maintain its high potential in terms of produce.

CONCEPT OF LAND DEGRADATION RESTORATION

Apart from the organic farming approach various strategies and practices have been implementing to address land degradation including agroecology practices, sustainable farming techniques,

conservation agriculture and initiatives for afforestation, as well as soil and water conservation techniques (Jayaraman *et al.*, 2024). Furthermore, the organic farming approach emphasizes on sustainable practices such as the use of animal manures, crop rotation, and biological pest control (Jayaraman *et al.*, 2024). Jointly, these practices contribute to the improvement of soil quality thereby reducing the adverse environmental effects typically associated with conventional agricultural practices (Raj *et al.*, 2024). Remarkably, the increase in soil organic carbon (SOC) sequestration is regarded as a viable approach to restore land degradation and improve crop productivity.

Notability, soil amendment has been reported as any substance which is applied to soil in order to enhance its physical qualities, including water retention, permeability, water infiltration, drainage, aeration and structure as well as chemical and biological qualities and overall soil productivity (Davis & Whiting, 2013; Muzyamba *et al.*, 2021). Organic (compost, wood chips, biochar, animal manure, straw, husk, and sewage manure) and inorganic (mineral) amendments are two fundamental categories of soil amendments (Davis & Whiting, 2013).

Organic amendments are extremely rich in organic matter, macro and microelements, act as substrates for microbial growth and in turn improve soil fertility. On the other hand, inorganic (mineral) amendments include minerals that contribute to soil fertility e.g gypsum, frequently used to lower soil pH by combining high sodium salts with lime or limestone and lowering

the pH of the soil (Davis & Whiting, 2013). Notably, Kadiri *et al.*, (2021); Sisouvanh *et al.*, (2021) reported that organic amendments play a crucial role in agroecosystems processes by enhancing soil quality. This could be attained through improved soil organic matter content, carbon sequestration (Li *et al.*, 2019), nutrient availability, water retention, aggregate stability, and substantial crop yield increases (Jiang *et al.*, 2018).

In spite of the multifaceted positive effects of the listed organic amendments, literatures have pointed out some critical drawbacks associated with their application. Findings by Muhereza *et al.*, (2013), indicated that the spread of pest, huge tonnage requirement and high cost associated with their transportation and application make their application less friendly. While about one-third of farmers noted increased weed devastation from cow dung application, others (33%) were concerned with the possibility of human disease transmission due to lack of good hygiene of the cow dung materials (Muhereza *et al.*, 2013). Poor handling techniques and low-quality of animal feed are partly responsible for low nutrient-richness of cow dung thereby reducing its potential as an alternative fertilizer source. Grannt, (2023) added that poorly handled manure is a breeding hub of pathogens and parasites and may contain active heavy metals that affect crop growth and development. Although Kumar *et al.* (2013) have alluded that proper treatment and good storage system curtail pathogens development, yet most farmers lack accessibility to machines and expertise

necessarily required for hygienic treatment. They further cited observed presence of *Salmonella*, *Yersinia enterocolitica*, and *Cryptosporidium* in cow and poultry dungs. Contamination of groundwater was similarly reported and attributed to the excessive $\text{NO}_3\text{-N}$ in poultry manure (Heathman *et al.*, 1994; Hoover *et al.*, 2019). Notably, it is realized that proper handling and storage of organic materials provide more productive and cost-effective in restoring soil deterioration and crop sustainability compared to the improper use of manure or inorganic fertilizer alone.

Agricultural soils are increasingly being enhanced with organic amendments serving as alternatives or supplements to inorganic fertilizers (Urta *et al.*, 2020). Various soil amendments, including compost, charcoal, and livestock manure, are employed to improve soil fertility, physicochemical properties and soil biota, thereby nurturing crop growth and productivity (Clements & Bihn, 2019). The incorporation of organic amendments into the soil contributes to the improvement in soil porosity, availability of water for crops, cation exchange capacity and essential plant nutrients (Cercioglu, 2017; Mitran *et al.*, 2017; Zhao *et al.*, 2021). Among organic fertilizers poultry manure is noted for its high nutrient concentration which is vital for crop development (Dang *et al.*, 2021). Research has consistently indicated that the proper application of poultry manure significantly improves the physical, chemical, and biological properties of soil (Agbede *et al.*, 2017; Hoover *et al.*, 2019). Additionally, cow dung is recognized for providing substantial plant nutrients and enhancing

physicochemical characteristics (Ozlu *et al.*, 2019). Recently, the application of biochar as soil amendment in agricultural settings has gained support in addressing land degradation (Bohara *et al.*, 2019). Furthermore, the use of composted organic residues has been shown to improve aggregate stability, water retention, hydraulic conductivity, and water penetration in agricultural soils, ultimately benefiting crop production (Mujdeci *et al.*, 2017; Oueriemmi *et al.*, 2021).

Recent research highlighted the significance of long-term amendments, like compost, biochar, beside cow dung and poultry manure (Dawaki *et al.*, 2019), due to more of recalcitrant carbon, effectiveness and long-lasting effect in restoring degraded lands and ensuring sustainable agricultural production for future generation.

ORGANIC APPROACH ON SOIL PROPERTIES

Organic Approach on Soil Physical Properties

In previous studies, the application of soil amendment has significantly affected the soil physical properties. For example Cercioglu (2017) worked on maize production in the western Anatolian region of Turkey, he reported that the application of organic amendments such as chicken manure, bio-humus, and composted tobacco waste improved soil physical properties such as improved in porosity, structure stability index and field capacity. Similarly, in Anambra State in southeast, Nigeria application of poultry manure, cassava peel, pig waste, and rice husk at a rate of 20 t ha^{-1} decreased bulk density, improved total porosity and moisture content of the

amended than unamended soil by which poultry manure had the highest improvement among the amendments for sole maize, sole cowpea, and maize-cowpea intercrop (Onunwa *et al.*, 2021). Poultry manure had the highest contribution compared to pig manure and cow dung (Nweke & Igwe, 2021). Use of poultry manure at 2 t ha⁻¹ was significantly increased the water-stable soil aggregates as the highest compared to the lowest in control (only inorganic fertilizers). The order of increasing soil aggregates among the organic amendments: poultry manure > rice straw > cow dung > vermicompost (Rahman *et al.*, 2022).

Angst *et al.* (2017) & Ibrahim *et al.* (2021) observed that an organic additive with a higher concentration of recalcitrant material (lignin, lipids, cellulose, etc.) had slower decomposition rates and longer-lasting effects on aggregate stability. According to earlier researches, biochar amendment application to soil was useful in regulating soil thermal properties, decreased soil bulk density, increased soil water holding capacity, soil porosity and soil aeration with beneficial effect on roots proliferation (Baiamonte *et al.*, 2019; Karim *et al.*, 2020; Chang *et al.*, 2021). However, the literature assessment conducted by Blanco-canqui. (2017) also revealed that, in a few instances biochar application at rates <10 Mg ha⁻¹ may not significantly reduce bulk (Usowicz *et al.*, 2016; Xiao *et al.*, 2016). Pratiwi & Shinogi, (2016) found that biochar application even at rates as high as 2% by weight (which is equivalent to about 50 Mg ha⁻¹ of biochar did not affect bulk density.

Numerous researches examined the impact of biochar on soil hydraulic characteristics (Abdo, 2021; Liang *et al.*, 2021; Chen *et al.*, 2021) the results have been inconsistent, ranging from a reduction to no desirable effect (Atkinson, 2018; Wang *et al.*, 2021). In addition, Are *et al.*, (2018) noted that the saturated hydraulic conductivity after the addition of poultry manure biochar was lower (9.2 mm/hr) than for other organic amendments (16.5–18.2 mm/hr). Biochar improved aggregate stability, as the biochar contents increased with increasing biochar dosage in all soil aggregate fractions except the microaggregate fraction (Sun *et al.*, 2021). Soil structural index increased by 147% at fbc = 0.091, indicated the effectiveness of this biochar fraction in enhancing aggregate stability (Baiamonte *et al.*, 2019; Chen *et al.*, 2021). Remarkably, the effectiveness used of biochar depend on the nature of biochar in addressing soil quality.

Additionally, research had shown that compost is one of the organic amendments, used to avail suitable soil physical condition, such as improved aggregate stability, hydraulic conductivity, penetration resistant, and water retention capacity for plant root development resulting in increased agricultural production (Mujdeci *et al.*, 2017; Şeker & Manirakiza, 2020). Cow dung and compost had more surface area, which encouraged the circulation of essential soil nutrients, reduces water logging, and enhances crop development (Darusman *et al.*, 2018). Improved or increased in water stable aggregates under the veticompost treatment was 3.4 to 26.7% greater than for the other

treatments. The comparison of the soil physical quality indices indicated positive effects from the amendments on the soil physical properties in the order: unamended control < poultry biochar < poultry tea < non-composted poultry manure < vermicompost (Are *et al.*, 2018). Generally, the effectiveness of organic amendments in addressing the land deterioration on soil physical properties depend on the recalcitrant nature of the organic materials and soil managements.

Organic Approach on Soil Chemical Properties

The effect of soil amendments on chemical properties was reported in many studies however, the outcomes vary based on the management and climatic condition (Mi *et al.*, 2018; Ahmadu *et al.*, 2020) due to specific and distinctive characteristics, rates of addition and composition of the amendments (Arif *et al.*, 2016). Mi *et al.*, (2018) reported that the use of spent mushroom compost, green manure, cattle manure, and rice straw are the four common organic materials widely used by local farmers in southern China. Application of cattle manure to the soil surface led to increased soil pH, cation exchange capacity and lower exchangeable acidity and Al^{3+} concentrations compared to applying NPK alone. Eche *et al.* (2013) reported that the application of cow dung alone or in combination with sole urea fertilizer at the rate of 90 kg N ha⁻¹ increased soil pH, organic carbon, total nitrogen, and cation exchange capacity by 2, 55, 17 and 26 % respectively as compared to sole urea. Similarly, application of different rate of cattle manure slightly increased soil pH value of about 5.20% and

total nitrogen by 133.33%, likewise, percentage of organic carbon, Ca and Mg and the highest was recorded from soil supplied with 20 t ha⁻¹ however, available P, Na and K was slightly decreased across the different level of application respectively (Eleduma *et al.*, 2020; Dang *et al.*, 2021).

Denton *et al.*, (2020) reported that the application of poultry manure, cassava-based compost, and vermicompost had increased the soil organic carbon content by 24.1, 18.2, and 22.3% respectively. Application of biochar made from cow dung, a combination of cow dung + urea, and poultry droppings improved soil pH, organic matter, total nitrogen, and available phosphorus compared with the unamended soil (NPK-15:15:15) (Ndzeshala *et al.*, 2023). Similar, trends were observed for sole maize production in which the poultry manure at 20 t ha⁻¹ had significant effect on exchangeable Al^{3+} and Na^{+} ; organic carbon, soil pH, available phosphorus and CEC but had no significant effect as compared to the control (Onunwa *et al.*, 2021). Application of organic amendments at 2 t ha⁻¹ positively appeared for the increasing C contents and C sequestration in the soils which revealed that the vermicompost was far more effective in terms of C sequestration, followed by poultry manure, cow dung and rice straw as compared with only inorganic fertilizers (Rahman *et al.*, 2022).

Moreover, biochar has attracted much attention as a soil amendment which has a slow decomposition rate and its application to soils can sequester SOC compared to non-amended soils for example, 1.4 times higher total soil C was found in hardwood biochar amended soils compared to non-

amended soils (Lentz & Ippolito, 2012). Sun *et al.*, (2021) reported that four biochar doses were tested: control (without biochar), biochar at 15.75, 31.5, and 47.25 t ha⁻¹ which increased the pH, EC, and CEC and the pH, EC and CEC increased simultaneously with increasing biochar dose but decrease the levels of exchangeable H⁺ and Al³⁺. Moreover, biochar derived from wood, solid digestate and biochar derived from solid digestate in which all the biochars increased pH and EC compared to the soil, while only biochar derived from solid digestate, and solid digestate showed significant increase in secondary macro- and micronutrient-element content (Ca, Mg, Na, Fe, Mn, and Zn) (Calamai *et al.*, 2020).

Furthermore, application of compost into soil provides better nutrient input compared to raw manure from the perspective of C sequestration for example, four years after application about 36% of applied compost remained in the soil as sequestered C, as compared to only 25% of applied raw manure (Eghball & Ginting, 2003; Shrestha *et al.*, 2018). Oueriemmi *et al.*, (2021) reported that municipal solid waste compost, sewage sludge compost and farmyard manure were tested at rates of 0, 20, 40 and 60 t ha⁻¹ in which application of the amendments improved organic matter, cation exchange capacity and available P, Ca, Mg and K in the soil. Moreover, compost and biochar applied alone or in combination significantly increased soil pH, total organic carbon, available phosphorus, mineral nitrogen, reduced exchangeable acidity, and increased effective cation exchange capacity in both soils (Mensah &

Frimpong, 2018). The combination of compost and biochar as compared to compost amendments alone resulted in decreased contents of available K, P and NO₃⁻N in all soils except for available K in sandy soil in Thailand and NO₃⁻ N for clayey soil in Vietnam (Doan *et al.*, 2021). Generally, the effectiveness of organic amendments in addressing the land deterioration on soil chemical properties depend on the recalcitrant nature of the organic materials and soil managements.

Organic Approach on Soil Biological Properties

Soil amendments had significant effect on biological properties which had been widely documented in the literature therefore, soil fauna and flora play a key role for the functioning of the soil ecosystem. However, the level of transformation and other biotic processes depends mainly on the existence (Yanarda *et al.*, 2017; Aytenew & Bore, 2020). Addition of organic amendments to soils promotes the growth of microorganisms, which stimulates soil respiration and nutrient cycling and the synthesis of various phytohormones and low molecular mass compounds and enzymes that benefit plant growth (Lakhdar *et al.*, 2008; Oueriemmi *et al.*, 2021). Soil enzymes such as dehydrogenase, acid phosphatase and β-glucosidase showed a significant increase with the inclusion of organic amendments in fertilizer schedule (Mangalassery *et al.*, 2019). Moreover, the diversity and richness of bacteria and eukaryotic were lower in the synthetic than in the organic amendments. The addition of organic amendments promoted the growth of Acidobacteria and Gemmatimonadetes

bacteria. On the contrary, members of Actinobacteria and Proteobacteria were more abundant in the soil treated with synthetic fertilizer (Cesarano *et al.*, 2017). Consequently, the use of organic amendments contributed immensely in improving soil quality thereby providing food as a source of energy to the soil microbes in addressing the soil deterioration.

ORGANIC APPROACH ON CROP PRODUCTION

Organic Approach on Crop Growth Characteristics

Organic amendments play vital roles in crop production depending on the amendment's nutrient content composition and rate applied. Khatun *et al.* (2019) reported 86.67% germination percentage in both cow dung and vermicompost treated soil, while the control soil with no amendment had the lowest germination percentage of 66.67%. The growth attributes of maize plant (DMR-ESR-Y) increased significantly with increasing rates of cattle manure, applications rate of 20 t ha⁻¹ gave the highest vegetative growth attributes such as leaf area index (403.04) was recorded at 20 t ha⁻¹ which was higher than 15 t ha⁻¹ (381.13), 10 t ha⁻¹ (379.91), 5 t ha⁻¹ (378.07) and 0 t ha⁻¹ (313.62). Likewise, stem girth, plant height and number of the leaves which were wider in girth, taller in height and higher in number of leaves per plant respectively at 20 t ha⁻¹ than the other levels of manure and control (Eleduma *et al.*, 2020).

Ahmadu *et al.* (2020) reported that maize plants treated with poultry manure and cattle manure were taller than control plants

on plant height in which the tallest and thickest plants were observed on plots treated with poultry manure. Application of 1/2 recommend rate of fertilizer + 2 t ha⁻¹ poultry manure gives higher plant height, leaf area index, dry matter accumulation, and number of functional leaves of sweet corn (*Zea mays saccharata* L.) (Jan *et al.*, 2023). Asfaw, (2022) reported that the vegetative growth of maize variety, 'Bahir Mashila' were lower in untreated soil indicating that poultry-cleaned sites offer the highest number of leaves per plant, thick stem and highest leaf area index. However, sweet maize (*Zea mays saccharata* L.) spaced at 40 cm x 25 cm with 20 t ha⁻¹ of chicken manure resulted in the highest leaf area index, stem girth in both years of the study (Berdjour *et al.*, 2020; Effa *et al.*, 2021, 2022). Similarly, growth parameters were increased from four soil organic amendments viz: cassava peel, poultry manure, pig waste, and rice husk at the rate of 20 t ha⁻¹ while the poultry manure gives highest (Berdjour *et al.*, 2020; Onunwa *et al.*, 2021; Effa *et al.*, 2021, 2022).

Tanure *et al.* (2019) also noted that the addition of biochar (0, 5, 10, 20, 40, and 60 g of biochar per kg of soil) increased plant growth indicators such as height, stem diameter, leaf area, and shoot and root production responded even at the lowest biochar dose. Furthermore, enriched paddy straw compost improved growth of parameters such as plant height and chlorophyll content in sweet corn (Pangaribuan *et al.*, 2017; Rosa *et al.*, 2020). Application of chemical fertilizer (nitrogen fertilizer = 350 kg ha⁻¹, phosphate

fertilizer = 125 kg ha⁻¹, potassium fertilizer = 125 kg ha⁻¹) of maize and corn cob (compost) organic amendment at a rate of 2.5, 5, 7.5, 10 or 12.5 t ha⁻¹ of which the rate of 12.5 t ha⁻¹ had an effective increased in leaf area index, root length, levels of chlorophyll a and chlorophyll b (Budiastut *et al.*, 2023). Generally, the used of organic materials in addressing land deterioration aid in improving crop growth by providing nutrients required by crop to attain higher potential of crop growth.

Organic Approach on Crop Yield Characteristics

Numerous studies have shown that organic amendments significantly play vital roles on crop production. The crop response may be due to the fertilizing effect of the amendment, some effect related to the carbon or biological components of the amendment, or a combination of both (Doan *et al.*, 2015; Hijbeek *et al.*, 2017; Schjønning *et al.*, 2018; Celestina *et al.*, 2019) For example, Anees *et al.* (2016) reported that the maximum plant height of maize at maturity (218.67 cm), ear length (20.47 cm), number of grains per ear (372), 1000- grain weight (260.33 g), biological yield (18.58 t ha⁻¹), grain yield (7.35 t ha⁻¹), harvest index (39.56) and grain protein contents (9.64%) were recorded where 8 t ha⁻¹ Poultry Manure + 15 kg ha⁻¹ Humic Acid + 6.25 kg ha⁻¹ Micronutrient (Zn, Fe, Cu, Mn) were applied. Application of recommended NPK, rate for wheat along with either cow dung or poultry manure at 5 t ha⁻¹ exhibited the highest in all growth and yield parameters of wheat (BARI Gom 26) (Azad *et al.*, 2022). Application of manure of 2 t ha⁻¹ gives the highest yield such as

weight of cob with cornhusk (454,82 g) weight of cob without cornhusk (319,78 g), length of cob (23 cm) and the diameter of cob (51,79 mm) (Muchtar *et al.*, 2020).

Research highlights the significant effect of poultry manure on maize yield quality. The MMRI maize variety showed greater yield compared to the Pearl variety in terms of cob length, cob diameter, cob weight, number of grains per cob, grain yield, and biological yield (Rasool *et al.*, 2023). Furthermore, maize variety ‘Bahir Mashila’ exhibited lower vegetative growth in untreated soil, while poultry-manured sites achieved the highest grain yield of 5.7 t/ha. In comparison, horse manure produced a yield of 4.2 t/ha, sheep manure yielded 3.9 t/ha, and untreated soil recorded the lowest yield at 2.8 t/ha (Asfaw, 2022). Likewise, maize varieties such as ‘SUWAN-1-SR,’ ‘Oba 98,’ and the ‘Uselu’ local variety treated with poultry and cattle manure showed similar kernel numbers per row and 1,000-grain weights, both significantly higher than untreated plants. Grain yields were also higher in plants fertilized with poultry manure (2.11 t/ha) and NPK (2.22 t/ha) compared to control treatments (Ahmadu *et al.*, 2020). Moreover, the application of poultry manure at a rate of 20 t/ha significantly increased dry matter and green cob yields (Effa *et al.*, 2021).

According to Calamai *et al.* (2020) the solid digestate had the best maize performance (biomass dry weight, seed number, and weight per ear) while using biochar derived from solid digestate, while plant growth in biochars derived from wood had reduced results. Maize grown in soil amended with digestate-enriched

biochar showed a higher biomass yield compared to the control and non-enriched biochar treatments but was slightly lower than yields lower yield (20%–25%) from chemical fertilizer treatments (Kizito *et al.*, 2019). Moreover, application of 20 t ha⁻¹ of compost + NPK fertilizer gives the highest fresh weight of cob without husk 79.26 g increased by 51.54% when compared with the lowest yield on 52.30 g fertilizer without fertilizer of sweet corn (Ulm *et al.*, 2019; Situmeang *et al.*, 2019). Additionally, tofu dregs compost positively influenced cob length, plant height, and leaf count at 60 days after planting (Rosa *et al.*, 2020).

The application of 5 t/ha of biochar and compost increased grain yield by 46.29% and biological yield by 13.4% compared to untreated control (Zahra *et al.*, 2021). Composted and non-composted manures, along with biochar, produced higher maize grain yields (1.48–1.73 t/ha) for *Zea mays* var. DMR-ESR-Y compared to unamended controls (0.87 t/ha) (Are *et al.*, 2018; Denton *et al.*, 2020). Additionally, compost and mulch improved cob weight and biomass by 30% and 18%, respectively, while compost applied at 20 t/ha achieved similar growth and yield results to NPK fertilizer (15-15-15) at 200 kg/ha (Zaki *et al.*, 2018). Generally, the used of organic materials in addressing land deterioration aid in improving crop growth by providing nutrients required by crop to attain higher potential of crop yields.

CONCLUSION

RECOMMENDATION

Land degradation is also one of the global mainstay problems of crop production and food security which affects the function of

ecosystem. This phenomenon occurs through anthropogenic and natural activities which lead to the deterioration of soil quality. Compared to the use of the conventional system of farming by which the application of inorganic material alone could not be sustainable. Therefore, the use of organic amendments with or without the use of inorganic amendments could serve as an additional sustainable approach to restore land degradation thereby reducing the excess or overuse of inorganic or chemical fertilizer in addition to the enhancement of soil properties and crop production. The use of inorganic material alone could lead to hazardous and harmful to the ecosystem functionality. Notably, it has been observed that, lack of adequate nutrient and composite analyses of organic amendments prior to the experiment constitute difficulty for justifying the observed effects and variation among different results. Equally effect of preparation procedures and application methods of such organic amendments have received unsatisfactory attention. It is crucial to close these gaps of for a proper understanding of the subject matter. The use of proper organic approach offers a significant, sustainable and cost-effective alternative by reducing the environmental effect. However, further studies are required to optimize the use of organic materials with or without the use of inorganic amendments in restoring land degradation and sustainable crop production thereby sustaining food security. The further studies should also explore the use of organic materials that are more nutritive and effective in terms of

recalcitrant carbon which mainly depends on the quality, quantity, feedstocks and temperature at which the organic material pyrolyzed in case of biochar, which aids in improving the soil quality at large. Overall, this review study contributes to the growing field of organic approach thereby providing insights into the development of sustainable and cost-effective in addressing land degradation and crop productivity.

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INFILTRATION CHARACTERISTICS OF *FADAMA* SOIL UNDER TWO SOIL MANAGEMENT PRACTICES IN SOUTHERN KADUNA PLAIN, NIGERIA

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ABSTRACT

An accurate measurement of infiltration is important to assess soil water storage in the root zone, predict soil erodibility, and assess soils susceptibility to erosion. It is also important in the design of irrigation system and general planning of soil and water conservation activities. The study reviewed and evaluated our understanding of infiltration process and factors affecting infiltration rate in inundated (Fadama) soil. The field water infiltration data generated were based on double ring infiltrometer test conducted for 4 hours at two Fadama irrigation area located in Southern Kaduna Plain, Nigeria. Measurements were made at two sites in each of the two Fadama irrigation area based on land management practices (Cultivated/fallow) giving a total of four experimental sites. The results of the measured infiltration rates revealed that site 2 (Kuda/fallow) gave the highest average final infiltration rate of 69mm/hr followed by site 1 (Kuda/cultivated) 52mm/hr and then site 3 (Kukum-daji/cultivated) 35mm/hr while site 4 (Kukum-daji/fallow) recorded the least of 18mm/hr. Result from the study reveals that among the factors affecting infiltration, texture, management practice and bulk density are the most important and that cultivation greatly reduces soil infiltration rate when compared to the same soil under fallow. Based on the result of the study, it is recommended that all the four Fadama sites will be suitable for both surface and drip irrigation however, sites three and four will be more suitable for drip irrigation than sites one and two. Also, regression analyses were performed on various functions between final infiltration rate and the selected soil properties (hydraulic conductivity, bulk density, and field capacity). Regression equation (4.7) gives the best fit with R value of 0.999 and is recommended for use to predict infiltration rates for the sites studied.

Keywords: Infiltration, Characteristics, Inundated, Soils, Management

INTRODUCTION

Wetlands or inundated lands (*Fadama*) are seasonally flooded low-lying lands occurring along water courses, or on valley bottoms and which usually have high water table (Adeniran and Babatunde, 2010).

Quantitative data sourced from Water Resources Consultants of the World Bank Agricultural Development Projects (ADP) in Nigeria shows that about 3.5 million hectares of Nigeria's landmass are *Fadama* lands out of which only 2 million hectares can be put under small-scale irrigation (Adeniran and Babatunde, 2010).

In watershed modeling, a major hindrance to predicting surface runoff is the uncertainty in characterizing soil infiltration. The difficulty of predicting infiltration is due to the variation of infiltration-related soil physical properties from site to site in the field (Mudiare and Adewumi, 2000). Watershed and streams constitute important natural resource of every nation. Careful water resources management is therefore essential for stable and efficient agriculture and reduction of natural disasters. In Nigeria, efforts are being directed towards soil and water conservation activities such as irrigation, flood, and erosion control (Arab, 2009). The realistic planning of these activities requires adequate information on the rate at which different soils will take water under different conditions. Therefore, information on the infiltration characteristics of *Fadama* irrigated soils in southern Kaduna plain becomes important.

LITERATURE REVIEW

Infiltration may be defined as the process whereby water enters the soil through its surface. Kirkham (2014) has suggested that one way of regarding the infiltration process is to consider it as the consequence of the hydraulic conductivity and gradient at the soil surface (Ahmed, 1982).

Whether one's concern is agricultural or hydrological, the crucial role of the infiltration process is clear and important. In view of this, it is imperative that our understanding of this process be reviewed and evaluated.

Infiltration Process

The water added to the soil in rainfall or irrigation can either be intercepted by vegetation, infiltrate, accumulate over the

surface depressions, or form surface runoff. The infiltrated water itself is partitioned eventually into evapotranspiration and seepage, with some of the latter water emerging as stream flow and the rest reaching the water table as ground water recharge.

The infiltration rate may be limited in two ways. Firstly, it cannot exceed the rate at which water is added to the surface (that is, rainfall intensity) and secondly, it is limited by the rate at which water can enter and move through the soil (USDOA, 2019).

Factors Affecting Infiltration

The process of infiltration can be affected by some factors such as those related to the type of soil which includes: texture, structure, porosity, organic matter content, clay type; and those related to water which includes: raindrop size and energy, surface condition and the amount of protection against the raindrop impact, soil moisture content and degree of saturation, duration and intensity of water application, soil moisture retention capacity and hydraulic conductivity (Israel, 2021).

Raindrops, on striking the ground, have a tendency of sealing the soil surface. This sealing results in a decrease in infiltration rate. It was found that the momentum of drops hitting a naturally crusted soil significantly affect the infiltration rate and that increase in drop size resulted in a decrease in infiltration rate (Carmi *et al.*, 2018). Antecedent soil moisture content (ASMC) had insignificant effect on infiltration processes for clay soil but exerted a considerable influence on infiltration for clay loam and loamy sand soils; this implies that infiltration models for

loamy soils must consider the effects of ASMC (Lan Ma *et al.*, 2020).

Vegetation and crop residue (mulch) increase the infiltration rates of soils. Vegetation absorbs the raindrop impact, prevents crust formation, and promotes microbial activity and soil structure. Plant roots when they decay, leave large conducting pores (Kirkham, 2014). Detailed reports on effect of vegetation and raindrop impact on bare soil could be found elsewhere (Bridge and Bell, 1994; Loch, 1994 etc.).

Cultivation often affects infiltration because of its effects on the conducting pores in soils. Connolly *et al* (1997) reported that change in soil infiltration characteristics with cultivation can result in reduced soil water storage, increased runoff and erosion, and reduced crop production. Cultivation may either increase or decrease infiltration depending on the soil surface after cultivation. Practices that leave the surface rough with many pockets are likely to have more infiltration than smooth heavily worked surface.

Christiansen (1944) evaluated the effect of entrapped air and escape on movement of water through soils. It was found that in closed columns, water compressed the air below the advancing moisture front and gravitational movement ceased. The front continued to move by aid of capillary forces and the air pressure continued to rise until finally, there was sufficient pressure to affect an upward release of air through the pore holding capillary water.

There are a range of factors affecting infiltration but are not all present in each

soil at a given time. Also, the effects of some overshadow those of others. In this study, only some selected physical characteristics of the soil are considered.

These are: -

- (i) Soil texture; (ii) Bulk density; (iii) Field capacity; (iv) Hydraulic conductivity; and (v) Soil structure

MATERIALS AND METHOD

Description of Experimental Area

The experiments were carried out in southern Kaduna plain at two (2) *Fadama* irrigated areas Namely: Kuda and Kukum-Daji in Kachia and Kaura Local Government (LGA) of Kaduna State, respectively.

Southern Kaduna plain lies within Southern Guinea Savannah Ecological Zone, and it is bounded by longitudes 7°00' to 9°00'E and latitudes 9°00' to 10°15'N and lies within Kaduna State with smaller areas in Niger State, Plateau State, and the Federal Capital Territory. The altitude ranges between 500 to 1000m above sea level and the mean annual rainfall ranges from 1300mm to 1700mm while the length of the rainy days' ranges between 190-200 days starting from April to October (Kowal and Knabe, 1972).

Site selection

Two *Fadama* irrigation areas in Southern Kaduna plain were selected based on the economic activities and income generation. In each of the selected areas, two (2) sites were selected based on the land management practice (i.e., cultivated or fallow) making a total of four (4) experimental sites (i.e., two sites on each *Fadama* irrigation area) as shown in Table 3.1.

Table 3.1: Details of the selected *Fadama* irrigation experimental sites.

Sites	Size (ha)	Soil Series	Fadama Irrigation Area	Management Practice
1	19	48	Kuda	Cultivated
2	19	48	Kuda	Fallow
3	13	230	Kukum-Daji	Cultivated
4	13	230	Kukum-Daji	Fallow

Soil series description

SOIL SERIES 48

Series parameter: Deep, poorly drained ground water gleys, fine textured, weak, and moderate structures on basalt, lacking sufficient coarse material for designated coarse material layer. Typical profile description for Soil series 48 and 230 are presented in Table 3.2 and 3.3, respectively.

SOIL SERIES 230

Series parameter: Deep, poorly drained, fine textured, groundwater gleys, having dominantly strong structure in the B horizon, developed on basement complex and lacking sufficient coarse material for designated coarse material horizon.

Table 3.2: Typical Profile Description for Soil Series 48

Horizon	Depth (cm)	Profile Morphology			
		Predominant Color	Texture	Structure	Consistence/Moisture
1	0 – 11	10YR 4/3 brown/deep brown	Sandy-loam	w. m. sab*	Hard/dry
2	11 – 36	10YR 5/4 yellowish brown	Sandy-loam	w. m. sab*	Very hard/dry
3	36 – 66	10YR 5/4 yellowish brown	Sandy-loam	md. m. sab*	Very hard/dry
4	66 – 96	2.5YR 5/2 greyish brown	Sandy-loam	md. m. sab*	Very hard/dry
5	96 – 160	10YR 6/1 light grey/grey	Clay	w. m. sab*	Very hard/dry

Source: Soil Survey Report by Land Resources Development of Central Nigeria (1977)

w- Weak; m- medium size; md-Moderate; sab- Sub-angular blocky; *

Table 3.3: Typical Profile Description for Soil Series 230

Horizon	Depth (cm)	Profile Morphology			
		Predominant Color	Texture	Structure	Consistence/Moisture
1	0 – 24	10YR 4/3 brown/deep brown	Loam	s. c/m. pr/sab*	Soft/dry

2	24 – 41	10YR 4/2 dark greyish brown	Clay- loam	s. m/f. pr/sab *	Hard/dry
3	41 – 92	10YR 4/2 dark greyish brown	Clay	s. c/m. pr*	Extremely hard/dry
4	92 – 157	2.5YR 5/1 grey	Gravel y clay	s. vs.. pr*	Moist

Source: Soil Survey Report by Land Resources Development of Central Nigeria (1977)

m- Medium size; s- Strong; c-Coarse; f- Fine; vs.- Very coarse; pr- Prismatic; sab- Sub-angular blocky;

Infiltration Measurement and Soil Sampling

Infiltration measurements were made using double ring infiltrometer (inner and outer diameter: 300mm and 400mm respectively). Water level readings were taken in the inner ring with the aid of a plastic rule attached to a float at 3-minute intervals for the first 15minutes, 5-minute intervals for the next 15minutes, 10-minute intervals for the next 30minutes, 15-minute intervals for the next 45minutes, 30-minute intervals for the next 90minutes and finally 15-minute intervals for the last 45minutes. Each replicate was allowed time duration of 240 minutes (4 hours).

A total of twenty-four infiltration measurements were made in all the four

experimental sites giving six replicates on each site.

Soil samples were taken from each site for determining the following: initial moisture content, bulk density, soil texture and hydraulic conductivity.

RESULT AND DISCUSSION

Measured Infiltration Rates

The measured infiltration rates data is given in Appendix I (Table 3.3, 3.4, 3.5 and 3.6 for site 1, 2, 3 and 4, respectively) while the average infiltration rate curves for sites 1, 2, 3 and 4 were presented in figure. 4.1. The infiltration curves have a general shape, starting from extremely high values, reducing sharply to almost half the initial values within the first 20 minutes, continued to decrease gradually until

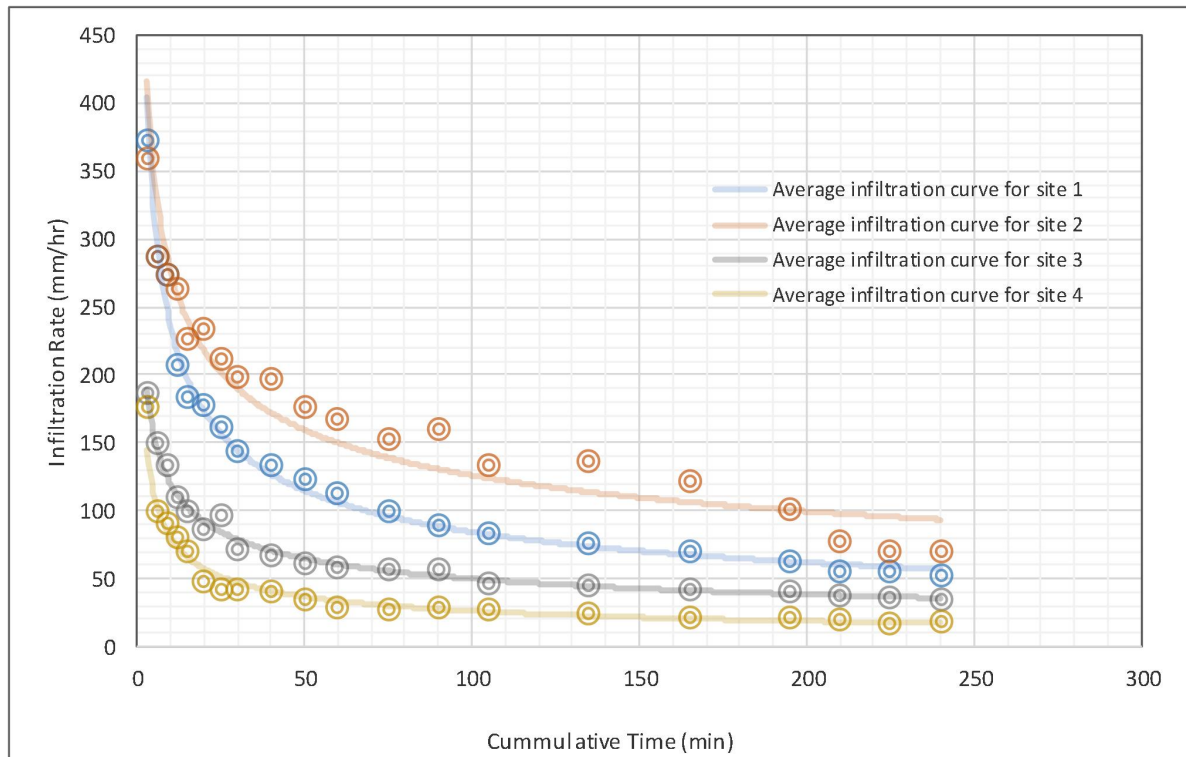


Figure 4.1: Average infiltration Rate Curves

a constant value is reached. Most of the runs attained this constant value within the first 4 hours. It has been observed that not all the runs reduce steadily (Appendix I). Sometimes a run was reducing then it rose again. This could be understood clearly by looking at the data in Table 3.3 (site 1) replicate 3 & 5, and Table 3.4 (site 2) replicate 1, 3 and 4. This was not expected but could be explained by the heterogeneity of the soil. Another likely reason might be due to entrapped air as reported and explained by many researchers (Christiansen, 1944; and Ahmed, 1982). Water may compress the air below the advancing moisture front and gravitational movement ceased. The front continues to rise until finally, there was sufficient pressure to cause an upward release of air through the pore holding capillary water.

Once this happened, gravitational movement continues again resulting in a subsequent increase in infiltration rate. Another possibility is the presence of animal burrows, crabs' holes, or cracks within the soil. In some cases, refilling the infiltrometer cause an increase in water head which eventually result in a slight increase in the rate of infiltration. The effect of head, though slight, certainly contributed to this rise and fall in infiltration rates. Errors in reading and timing may have a significant contribution. During the experiments, water level readings were taken to the nearest millimeter, and it is therefore possible to truncate some readings and exaggerate others due to parallax. With the above explanations, one would say that water level in the infiltrometer, entrapped air, and errors in reading and timing

affected the accuracy of a cylinder infiltrometer.

Table 4.1 shows the average final infiltration rates, the soil series, and the land management for each site. Cultivated soils have lower infiltration rates than fallow soils but ironically, a close look at sites 3 and 4 reveals that the reverse is the case. Site 4 being fallow for a long time, develops a hard capping which resulted to low infiltration rate. This shows that the effect

of hard capping can over-shadow the effect of fallow, that is, a fallow area with hard capping can have lower infiltration rates than the same soil under cultivation. It is important to note that the infinite numbers of factors affecting infiltration are not all present in a given soil at a given time. Furthermore, the effects of some over-shadow those of others. This study reveals that the effect of hard capping can over-shadow the effect of fallow.

Table 4.1: Effect of land management on infiltration

Site	Soil series	Management practice	Average final infiltration rate (mm/hr)
1	48	Cultivated	52
2	48	Fallow	69
3	230	Cultivated	35
4	230	Fallow	18

Measured Infiltration and Soil Physical Properties

Regression and correlation analyses were performed to explain the relationship between final infiltration rate and the selected soil properties (hydraulic conductivity, bulk density, and field capacity). The details of selected soil properties for the four sites is presented in Table 4.2.

The result of the correlation analysis between final infiltration rate and field capacity, bulk density, and hydraulic conductivity indicated that surface bulk density has a higher correlation coefficient ($R = 0.907$) than bulk density at 30cm ($R = 0.758$) and that at 50cm ($R = 0.674$) down the profile. Also, surface field capacity gave R value of 0.947 while that at 30cm and 50cm down the profile gave R values of

0.854 and 0.786, respectively. This shows that both bulk density and field capacity are important in affecting infiltration for the type of soil studied and that infiltration is greatly affected by the soil condition at the surface and/or near the surface (because of the decrease in R value as you go down the profile). Surface hydraulic conductivity gave R value of 0.778 while that at 30cm and 50cm are 0.965 and 0.080, respectively. This shows an extremely poor correlation between final infiltration rate and hydraulic conductivity at 50cm down the profile. Although there is not any definite pattern to indicate as to whether the correlation coefficients are increasing or decreasing as you go down the profile but one fact that remain clear is that the correlation between final infiltration rate and

Table 4.2: Details of selected soil properties and correlation coefficient

Site	Field Capacity (FC) in % by weight			Bulk density (BD) in g/cm ³			Hydraulic Conductivity (mm/hr)		
	At the surface	At 30cm depth	At 50cm depth	At the surface	At 30cm depth	At 50cm depth	At the surface	At 30cm depth	At 50cm depth
1	65.4	53.4	54.3	0.78	0.97	0.96	2.4	1.3	2.4
2	65.7	49.6	45.2	0.83	1.05	1.11	2.4	0.8	2.7
3	36.6	27.8	28.9	1.16	1.27	1.26	1.8	5.2	5.2
4	22.9	27.8	26.9	1.27	1.23	1.26	2.0	7.4	1.4
R	0.947	0.854	0.786	0.907	0.758	0.674	0.778	0.965	0.080

hydraulic conductivity at the surface and 30cm down the profile are far higher than that at 50cm. This is clear evidence that infiltration is greatly affected by the soil conditions at or near the surface.

Regression analyses were carried out on various functions (Eqs. 4.1, 4.2, 4.3, and 4.4) between final infiltration rate and the selected soil properties (hydraulic conductivity, bulk density, and field capacity).

$$f = \alpha_0 + \alpha_1 B_s + \alpha_2 H_s + \alpha_3 F_s \dots \dots \dots (4.1)$$

$$f = \alpha_0 + \alpha_1 B_{30} + \alpha_2 H_{30} + \alpha_3 F_{30} \dots \dots \dots (4.2)$$

$$f = \alpha_0 + \alpha_1 B_{50} + \alpha_2 H_{50} + \alpha_3 F_{50} \dots \dots \dots (4.3)$$

$$f = \alpha_0 + \alpha_1 B_a + \alpha_2 H_a + \alpha_3 F_a \dots \dots \dots (4.4)$$

Where: - f = Infiltration rate (mm/hr); B_s = surface bulk density (g/cm³); B_{30} = bulk density at 30cm depth (g/cm³); B_{50} = bulk density at 50cm depth (g/cm³); H_s = surface hydraulic conductivity (mm/hr); H_{30} = hydraulic conductivity at 30cm depth (mm/hr); H_{50} = hydraulic conductivity at 50cm depth (mm/hr); F_s = surface field capacity (% by weight); F_{30} = field capacity at 30cm depth (% by weight); F_{50}

= field capacity at 50cm depth (% by weight); B_a = average profile bulk density (g/cm³); H_a = average profile hydraulic conductivity (mm/hr); F_a = average profile field capacity (% by weight); $\alpha_0, \alpha_1, \alpha_2, \alpha_3, m, n$ = constants

A constant R^2 values of 0.999 were obtained for Eqn. 4.1, 4.2, 4.3 and 4.4. This indicates that all the four equations gave a good relationship between measured infiltration rate and the selected soil properties, but Eq. 4.1 gives the best due to the fact it has the highest correlation coefficient (R). Thus, infiltration rate of soil is greatly affected by the soil properties at or near the surface. The constants of Eq. 4.1 are shown in Eq. 4.7.

$$f = -545 + 321B_s + 29.3H_s + 4.22F_s \dots \dots \dots (4.7)$$

Equation 4.7 can be used to predict infiltration rate for the site studied. However, it needs to be tested for other soil types and sites to ascertain its general applicability.

Conclusion and Recommendation

Conclusion

From the study reported herein, the following conclusions were made:

- i. Among the factors affecting infiltration, texture, management practice and bulk density are the most important. Light-textured soils were found to have higher infiltration rates than heavier textured soils.
- ii. Cultivation reduces soil infiltration rate when compared to the same soil under fallow. However, hard capping can overshadow the effect of fallow; a soil with hard capping can have lower infiltration rate than a cultivated soil, primarily because the hard capping is destroyed by tillage.
- iii. The study also established the fact that infiltration rate of soil is governed mainly by condition at or near the soil surface.

Recommendations

Based on the result of the study, it is recommended that:

- i. All the four Fadama sites will be suitable for both surface and drip irrigation. However, sites three and four will be more suitable for drip irrigation than sites one and two.
- ii. Also, Equation 4.7 is recommended for use to predict infiltration rates for the sites studied.
- iii. Finally, it is recommended that similar research and data documentation on infiltration rates should be carried out anywhere in the country until the data is sufficient for complete watershed modeling and hydrologic classification of Nigerian soils. This is possible through effective coordination among researchers and between researchers and water resources authorities in the country.

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Table: 3.3

SITE NUMBER 1			SOIL SERIES 48				CULTIVATED							
INITIAL SOIL MOISTURE CONTENT = 18% BY WEIGHT														
CUM. TIME (min)	REPLICATE 1		REPLICATE 2		REPLICATE 3		REPLICATE 4		REPLICATE 5		REPLICATE 6		AVERAGE	
	CUM.	INF.	CUM.	INF.	CUM.	INF.	CUM.	INF.	CUM.	INF.	CUM.	INF.	CUM.	INF.
	INF.	RATE	INF.	RATE	INF.	RATE	INF.	RATE	INF.	RATE	INF.	RATE	INF.	RATE
														(mm/hr)
3	21	420	18	360	21	420	11	220	21	420	20	400	18.7	373.3
6	38	340	30	240	32	220	20	180	40	380	38	360	33	286.7
9	56	360	42	240	49	340	28	160	54	280	51	260	46.7	273.3
12	66	200	53	220	59	200	35	140	66	240	63	240	57	206.7
15	76	200	61	160	68	180	41	120	77	220	74	220	66.2	183.3
20	90	168	74	156	81	156	52	132	97	240	92	216	81	178
25	102	144	88	168	92	132	60	96	113	192	112	240	94.5	162
30	115	156	100	144	103	132	68	96	127	168	126	168	106.5	144
40	140	150	124	144	121	108	82	84	152	150	153	162	128.7	133
50	159	114	145	126	136	90	97	90	179	162	179	156	149.2	123
60	176	102	166	126	153	102	111	84	201	132	201	132	168	113
75	201	100	199	132	175	88	128	68	229	112	225	96	192.8	99.3
90	223	88	223	96	193	72	146	72	257	112	248	92	215	88.7
105	241	72	247	96	212	76	164	72	280	92	270	88	235.7	82.7
135	279	76	294	94	247	70	198	68	309	58	316	92	273.8	76.3
165	307	56	338	88	276	58	231	66	352	86	351	70	309.2	70.7
195	334	54	372	68	306	60	263	64	386	68	383	64	340.7	63
210	345	44	388	64	317	44	278	60	401	60	398	60	354.5	55.3
225	355	40	403	60	329	48	293	60	417	64	413	60	368.3	55.3
240	364	36	418	60	338	36	307	60	432	60	429	64	381.3	52

Table 3.5 **SITE NUMBER 3** **SOIL SERIES 230** **CULTIVATED**

INITIAL MOISTURE CONTENT = 9% BY WEIGHT

Table 3.4

SITE NUMBER 2			SOIL SERIES 4				FALLOW							
INITIAL MOISTURE CONTENT = 9% BY WEIGHT														
CUM. TIME (min)	REPLICATE 1		REPLICATE 2		REPLICATE 3		REPLICATE 4		REPLICATE 5		REPLICATE 6		AVERAGE	
	CUM.	INF.	CUM.	INF.	CUM.	INF.	CUM.	INF.	CUM.	INF.	CUM.	INF.	CUM.	INF.
	INF.	RATE	INF.	RATE	INF.	RATE	INF.	RATE	INF.	RATE	INF.	RATE	INF.	INF. RATE (mm/hr)
3	22	440	12	240	21	420	21	420	20	400	12	240	18	360
6	43	420	20	160	37	320	38	340	34	280	22	200	32.3	286.7
9	64	420	27	140	51	280	56	360	48	280	30	160	46	273.3
12	84	400	39	240	64	260	72	320	59	220	37	140	59.2	263.3
15	103	380	46	140	71	140	88	320	71	240	44	140	70.5	226.7
20	134	372	56	120	89	216	115	324	91	240	55	132	90	234
25	166	384	65	108	105	192	135	240	111	240	64	108	107.7	212
30	197	372	73	96	120	180	153	216	129	216	73	108	124.2	198
40	255	348	89	96	148	168	200	282	162	198	88	90	157	197
50	309	324	106	102	175	162	230	180	193	186	106	108	186.5	177
60	348	234	120	84	203	168	273	258	220	162	122	96	214.3	167
75	401	212	139	76	237	136	334	244	260	160	144	88	252.5	152.7
90	468	268	155	64	277	160	394	240	299	156	162	72	292.5	160
105	529	244	178	92	313	144	437	172	317	72	182	80	326	134
135	622	186	211	66	383	140	535	196	397	160	218	72	394.3	136.7
165	702	160	244	66	452	138	628	186	453	112	254	72	455.5	122.3
195	776	148	273	58	501	98	708	160	489	72	290	72	506.2	101.3
210	804	112	287	56	522	84	726	72	507	72	308	72	525.7	78
225	822	72	301	56	542	72	744	72	525	72	326	72	543	69.3
240	840	72	315	56	558	72	762	72	543	72	344	72	560.3	69.3

Cum. (min)	TIME	Replication 1		Replication 2		Replication 3		Replication 4		Replication 5		Replication 6			RATE (mm/hr)
		Cum. INF.	RATE	Cum. INF.	RATE	Cum. INF.	RATE	Cum.INF.	RATE	Cum. INF.	RATE	Cum. INF.	RATE	Cum. INF.	
3		10	200	7	140	10	200	10	200	11	220	8	160	9.3	186.7
6		21	220	13	120	16	120	18	160	18	140	15	140	16.8	150
9		29	160	19	120	20	80	27	180	26	160	20	100	23.5	133.3
12		35	120	24	100	24	80	35	160	31	100	25	100	29	110
15		42	140	29	100	27	60	42	140	34	60	30	100	34	100
20		49	84	35	72	32	60	51	108	43	108	37	84	41.2	86
25		56	84	47	144	38	72	60	108	52	108	42	60	49.2	96
30		62	72	54	84	41	36	68	96	59	84	47	60	55.2	72
40		72	60	66	72	50	54	84	96	71	72	55	48	66.3	67
50		81	54	78	72	58	48	99	90	83	72	60	30	76.5	61
60		87	36	92	84	66	48	111	92	94	66	67	42	86.2	58
75		102	60	108	64	79	52	126	60	110	64	76	36	100.2	56
90		121	76	124	64	92	52	141	60	125	60	84	32	114.5	57.3
105		129	32	137	52	106	56	151	56	139	56	91	28	125.5	46.7
135		149	40	159	44	131	50	179	56	163	48	108	34	148.2	45.3
165		169	40	185	52	152	42	201	44	185	44	124	32	169.3	42.3
195		191	44	209	48	172	40	222	42	207	44	138	28	189.8	41
210		201	40	220	44	181	36	232	40	217	40	144	24	199.2	37.3
225		211	40	229	36	190	36	242	40	227	40	150	24	208.2	36
240		221	40	237	32	199	36	252	40	237	40				

Table: 3.6

SITE NUMBER 4 SOIL SERIES 230 FALLOW

INITIAL MOISTURE CONTENT = 9% BY WEIGHT

	REPLICATE 1		REPLICATE 2		REPLICATE 3		REPLICATE 4		REPLICATE 5		REPLICATE 6		AVERAGE	
CUM.	CUM.	INF.	CUM.	INF.	CUM.	INF.	CUM.	INF.	CUM.	INF.	CUM.	INF.	CUM.	INF.
TIME (min)	INF.	RATE	INF.	RATE	INF.	RATE	INF.	RATE	INF.	RATE	INF.	RATE	INF.	RATE (mm/hr)
3	7	140	13	260	11	220	3	60	12	240	7	140	8.8	176.7
6	12	100	19	120	20	180	5	40	17	100	10	60	13.8	100
9	16	80	24	100	30	200	7	40	20	60	13	60	18.3	90
12	19	60	28	80	38	160	9	40	24	80	16	60	22.3	80
15	21	40	33	100	45	140	11	40	26	40	19	60	25.8	70
20	24	36	38	60	52	84	13	24	30	48	22	36	29.8	48
25	27	36	44	72	58	72	15	24	31	12	25	36	33.3	42
30	29	34	48	48	64	72	17	24	35	88	28	36	36.8	42
40	34	30	57	54	75	66	20	18	41	36	34	36	43.5	40
50	39	30	64	42	86	66	23	18	46	30	38	24	49.3	35
60	43	34	69	30	96	60	25	12	49	18	43	30	54.2	29
75	47	16	76	28	111	60	29	16	53	16	49	24	60.8	26.7
90	52	20	85	36	125	56	33	16	57	16	55	24	67.8	28
105	57	20	94	36	137	48	37	16	61	16	61	24	74.5	26.7
135	67	20	110	32	159	44	42	10	69	16	72	22	86.5	24
165	75	16	126	32	180	42	48	12	75	12	81	18	97.5	22
195	83	16	140	28	200	40	54	12	81	12	93	24	108.5	22
210	87	16	146	24	206	24	57	12	84	12	100	28	113.3	19.3
225	91	16	151	20	211	20	60	12	87	12	105	20	117.5	16.7
240	96	20	156	20	216	20	63	12	90	12	111	24	122	18

ASSESSMENT OF CONTAMINANT IN A PORTION OF UNIVERSITY OF MAIDUGURI FARM: IMPACT OF APPLICATION OF UNTREATED URBAN WASTEWATER

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ABSTRACT

This study assessed the contamination levels of contaminant Zinc (Zn), Copper (Cu) and Lead (Pb) in surface and subsurface soils at a portion of the University of Maiduguri farm, with a focus on the impact of untreated urban wastewater application. A total of 72 soil samples were collected using Expert GPS-based grid sampling techniques. Comprehensive soil characterization was conducted to evaluate soil quality and determine the concentrations and spatial distribution of the selected heavy metals. The results revealed that heavy metal concentrations were higher in subsurface soils than in surface soils. The concentrations of Zn, Cu, and Pb exceeded established threshold levels in both surface and subsurface soils. A strong positive correlation was observed among the heavy metals, alongside varying degrees of association with soil chemical properties. Correlation analyses indicated relationships ranging from weak positive to moderate and negative correlations among soil properties at both surface and subsurface. The mean levels of Calcium (Ca^{2+}), Magnesium (Mg^{2+}), Potassium (K^+) and Sodium (Na^+) in the soil were generally low to moderate, with low to moderate, indicating at both surface and subsurface. Similarly, for Organic Carbon (%O.C), Organic Matter (O.M), Carbon to Nitrogen ratio (C:N), exchangeable acidity (E.A), Cation Exchange Capacity (CEC), Effective Cation Exchange Capacity (ECEC), Percent Base Saturation (PBS) were also generally low to moderate and the soil texture is Sandy loam at both surface and subsurface. The surface soil pH ranged from 3.6 to 5.7. The subsurface soil pH ranged from 3.4 to 5.0, indicating an acidic in both surface and subsurface. These findings highlight the extent of heavy metal contamination in the study area is due to untreated urban wastewater application to the soil and emphasize the need for continuous monitoring and soil health assessment to mitigate potential environmental and agricultural risks.

Introduction

Population growth in industrialized societies has led to a significant increase in wastewater and sewage sludge production, posing serious environmental challenges (Shahbazi *et al.*, 2017). One of the widely practiced methods of managing sewage

sludge is its application as an organic fertilizer in agricultural fields. This practice has gained global recognition as a sustainable farm environmental management strategy, as it enhances soil fertility and crop production (Asgari

Lajayer *et al.*, 2019). However, the disposal and utilization of sewage sludge require careful planning due to the presence of hazardous heavy metals and pathogenic organisms, which can pose significant risks to soil and water resources (Sidhu *et al.*, 2024). While sewage sludge contains essential nutrients that promote plant growth, its improper disposal can lead to severe environmental consequences. Heavy metals such as lead (Pb), nickel (Ni), chromium (Cr), arsenic (As), cadmium (Cd), copper (Cu), molybdenum (Mo), and zinc (Zn) are often present in sewage sludge and can accumulate in agricultural soils, ultimately entering the food chain and threatening human health (Cheraghi *et al.*, 2015).

Heavy metal contamination has emerged as a global concern due to its persistence in the environment and toxic effects on living organisms (Díaz *et al.*, 2024). Even at trace levels, heavy metals can have detrimental effects on human health, causing chronic illnesses and disrupting ecosystems (Tran *et al.*, 2024). The contamination of water bodies, soil, and air with heavy metal ions (HMIs) contributes to ecosystem degradation and increases health risks, as these metals are non-biodegradable and can bioaccumulate over time (Dhokpande *et al.*, 2024). Heavy metals are characterized by their high density, atomic weight, and electrical conductivity, making them valuable for industrial applications but also major contributors to environmental pollution (Alias *et al.*, 2020). Industrial expansion and urbanization have exacerbated heavy metal contamination, leading to widespread environmental issues,

including soil degradation, bioaccumulation in crops, and groundwater pollution (Ilango *et al.*, 2025). The unregulated disposal of industrial and municipal wastes has further intensified these problems, raising concerns about soil fertility and food safety (Somadas *et al.*, 2025).

Agricultural soils contaminated with heavy metals pose significant risks to food security and human health due to bioaccumulation in the food chain (Song *et al.*, 2017). Crops cultivated in polluted soils can absorb heavy metals, leading to their presence in commonly consumed agricultural products such as grains, vegetables, fruits, and seafood (Ahmad *et al.*, 2025). Given the potential risks associated with sewage water application, it is crucial to assess the extent of heavy metal contamination in agricultural soils. This study aims to evaluate the levels of heavy metals in the University of Maiduguri farm, where sewage water has been consistently dumped, to determine its impact on soil quality, crop safety, and environmental health.

Materials and methods

Study area

The study was conducted at University of Maiduguri Farm located in Jere, local government of Borno State, Nigeria. The area falls between latitude 13.214° to 13.220°N and longitude 11.790° to 11.792°E. of Borno State (Bababe *et al.*, 2024). It is characterized by biannual mean rainfall and temperatures of 650mm and 32oC respectively. The months of March and April are the hottest periods of the year, with monthly temperatures ranging between 30oC and 40oC. The volcanic and basement

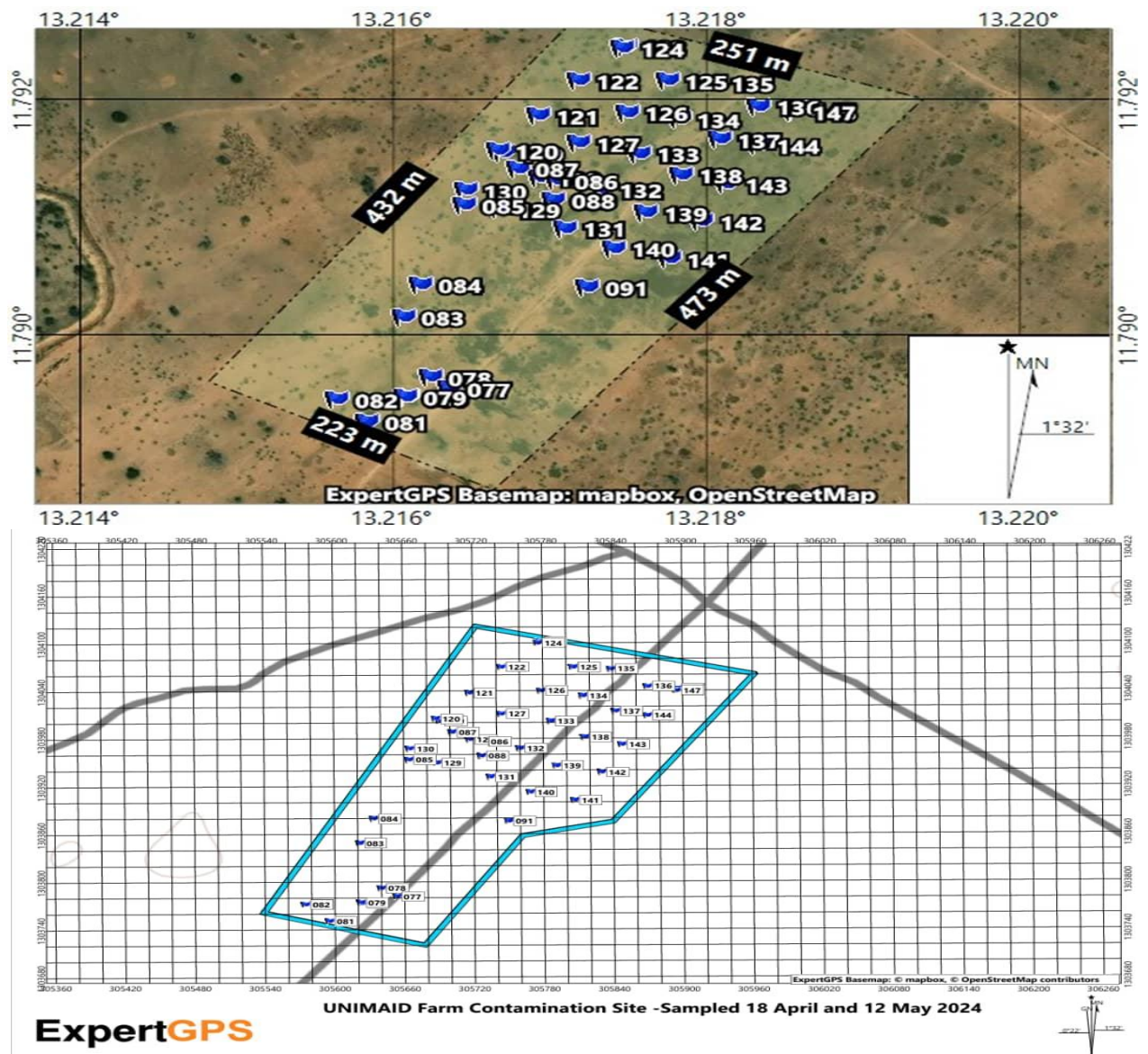


Figure 1

complex areas of the region have fertile clayey loamy soils in valley bottoms, but skeletal soils and rock outcrops occur along gentle and steep slopes (van Herk, 2012). The vegetation accommodated plants such as *Mangifera indica*, *Acacia nilotica*, *Acacia senegal*, *Acacia seyal*, *Azadirachta indica*, *Ziziphus* spp. and *Balanites aegyptiaca* (van Herk, 2012).

Site Selection and Soil Sampling

The methodology consisted of primary recognition and pre-assessment site visits for defining dislodgement site. A systematic method was used for soil sampling in key area of dislodgement in 2024. The soil samples were obtained at a constant depth 0 - 30 cm at 15 intervals following a grid layout design. Approximately 0.5 kg of composite samples were collected from each sampling points and placed in polythene

bags. For the determination of soil physicochemical properties.

Laboratory analysis

The soil samples were analyzed for some selected chemical and physical properties using standard laboratory analytical methods described in methods of soil analysis. The chemical properties include pH, Electrical Conductivity (EC), %organic carbon (Walkley, and Black, 1934), total nitrogen (N) Bremner (1996), available phosphorus (P) Bray 1 method, Exchangeable bases (potassium, sodium, magnesium and calcium) (Jackson 1999), Exchangeable acidity and particle size analysis was analysed using the hydrometric method (Bouyoucos, 1962) copper Cu, zinc Zn and lead Pb determine using ASS.

Results

The soil of the University of Maiduguri farm is strongly acidic, with pH values of 5.5 (H₂O) and 4.6 (CaCl₂). It has low electrical

Correlations among soil chemical properties

The correlation analysis of soil chemical properties at a depth of 0–15 cm reveals significant relationships affecting soil fertility and management. Heavy metals such as digest Zn, Pb, and Cu exhibit very strong positive correlations, indicating they tend to increase together. pH positively correlates with organic carbon (%O.C) and nitrogen (%N), suggesting higher pH supports organic matter and nitrogen availability. %N and %O.C also show a strong relationship, while calcium negatively correlates with the C:N ratio, implying better nutrient availability at

conductivity (0.2–0.3 dS/m), indicating the absence of salt-related issues. The exchangeable acidity is very low, making the soil suitable for agriculture, the exchangeable cations analysis showed low calcium (4.08 cmol/kg), high magnesium (5.53 cmol/kg), and relatively high sodium (1.64 cmol/kg) and potassium (0.87 cmol/kg). The CEC (12.12 cmol/kg) and ECEC (12.89 cmol/kg) indicate moderate nutrient-holding capacity. Total nitrogen (0.19%) is at a medium level, while organic carbon (0.25%) and organic matter (0.43%) are low. The soil has high available phosphorus (19.54 mg/kg), though its availability can be affected by organic matter and pH. The soil texture is classified as loam, with 40.02% sand, 41.95% silt, and 18.03% clay, showing higher sand and silt content than clay.

Correlations among soil chemical properties

higher calcium levels. Magnesium, however, negatively correlates with %O.C, indicating potential organic carbon depletion. Cation exchange capacity (CEC) is strongly linked to effective CEC (ECEC) and moderately correlated with magnesium and potassium, reflecting its role in nutrient retention. Soil texture analysis shows a moderate correlation between clay and silt, while sand exhibits weak associations with other properties. Additionally, percent base saturation (PBS) negatively correlates with ECEC and CEC, highlighting its impact on soil exchange properties. Overall, these correlations provide valuable insights into soil chemistry,

Table 1: physicochemical properties of the soil

Parameter	Value

pH (H ₂ O)	5.5
pH (CaCl ₂)	4.6
EC (dsm ⁻¹)	0.2
EC (dsm ⁻¹)	0.3
E.A cmol/kg soil	0.77
Ca ²⁺	4.08
Mg ²⁺	5.53
K ⁺	0.87
Na ²⁺	1.67
CEC	12.12
ECEC	12.89
%N	0.19
%O.C	0.25
O.M	0.43
P (mg/kg)	19.54
PBS	93.83
Sand	40.02
Silt	41.95
Clay	18.05
Textural class	Loam

helping to inform sustainable soil management practices.

The correlation analysis of soil chemical properties at a subsurface depth of 15–30 cm reveals strong relationships among heavy metals, with digest Zn and digest Pb (0.99) and digest Pb and digest Cu (1.00) showing near-perfect correlations, indicating potential contamination risks. Calcium and potassium exhibit a negative correlation (-0.74), suggesting competition for plant uptake, while sodium positively correlates with potassium (0.76), highlighting their interrelationship. Nitrogen (%N) positively correlates with potassium (0.64) and organic matter (0.81), reinforcing the role of organic content in nitrogen

availability, while its negative correlation with the C:N ratio (-0.70) suggests increased nitrogen availability from organic sources. Cation exchange capacity (CEC) and effective CEC (ECEC) are highly correlated (0.99), showing effective cation retention, though CEC negatively correlates with %N (-0.54) and exchangeable acidity (-0.62), indicating possible limitations in nitrogen retention. Soil texture analysis reveals a strong negative correlation between clay and percent base saturation (PBS) (-0.97), implying that higher clay content may reduce base saturation and affect fertility. Sand shows weak correlations with most

Table: 2 Correlation between some selected soil chemical properties at surface soil 0-15cm

	pH	D Zn	D Pb	D Cu	Ca ⁺²	Mg ⁺²	K ⁺	Na ⁺	P	%N	%O.C	O.M	C:N	E.A	CEC	ECEC	PBS	Sand	Silt	Clay
pH	1.00																			
Digest Zn	0.32	1.00																		
Digest Pb	0.30	0.99	1.00																	
Digest Cu	0.29	0.98	1.00	1.00																
Ca ⁺²	0.18	0.03	0.04	0.04	1.00															
Mg ⁺²	-0.36	-0.10	-0.11	-0.11	-0.65	1.00														
K ⁺	-0.51	-0.04	-0.01	0.01	-0.01	0.32	1.00													
Na ⁺	-0.39	-0.11	-0.11	-0.01	-0.93	0.50	0.12	1.00												
P	-0.33	-0.29	-0.30	-0.32	0.22	-0.22	-0.45	-0.16	1.00											
%N	0.53	0.31	0.30	0.29	-0.39	0.01	-0.09	0.17	-0.39	1.00										
%O.C	0.75	0.39	0.39	0.39	0.31	-0.53	-0.03	-0.42	-0.52	0.67	1.00									
O.M	0.75	0.39	0.39	0.39	0.31	-0.53	-0.04	-0.42	-0.52	0.67	1.00	1.00								
C:N	0.02	-0.05	-0.08	-0.09	-0.82	0.39	-0.51	0.69	0.23	0.39	-0.32	-0.31	1.00							
E.A	0.52	0.26	0.24	0.25	0.04	0.26	0.04	-0.21	-0.76	0.10	0.36	0.36	-0.25	1.00						
CEC	-0.49	-0.11	-0.11	-0.09	0.04	0.66	0.75	-0.07	-0.24	-0.33	-0.35	-0.35	-0.40	0.27	1.00					
ECEC	-0.26	-0.02	-0.02	-0.00	0.05	0.66	0.67	-0.12	-0.45	-0.26	-0.19	-0.19	-0.43	0.55	0.95	1.00				
PBS	-0.65	-0.29	-0.28	-0.29	-0.03	-0.12	0.11	0.19	0.75	-0.19	-0.47	-0.46	0.18	-0.98	-0.06	-0.36	1.00			
Sand	-0.02	0.01	0.04	0.04	0.01	-0.01	-0.06	0.00	0.13	-0.06	-0.09	-0.09	0.05	-0.09	-0.02	-0.05	0.09	1.00		
Silt																	-			
Clay	0.04	-0.03	-0.07	-0.07	-0.02	-0.05	0.06	0.03	-0.16	0.10	0.14	0.14	-0.05	0.08	-0.03	-0.01	0.09	-0.97	1.00	
	-0.09	0.10	0.13	0.13	0.06	0.21	-0.05	-0.11	0.21	-0.19	-0.25	-0.25	0.03	0.01	0.22	0.19	0.05	0.45	0.64	1.00

Table: 3 Correlation between some selected soil chemical properties at sub-surface soil 15-30cm

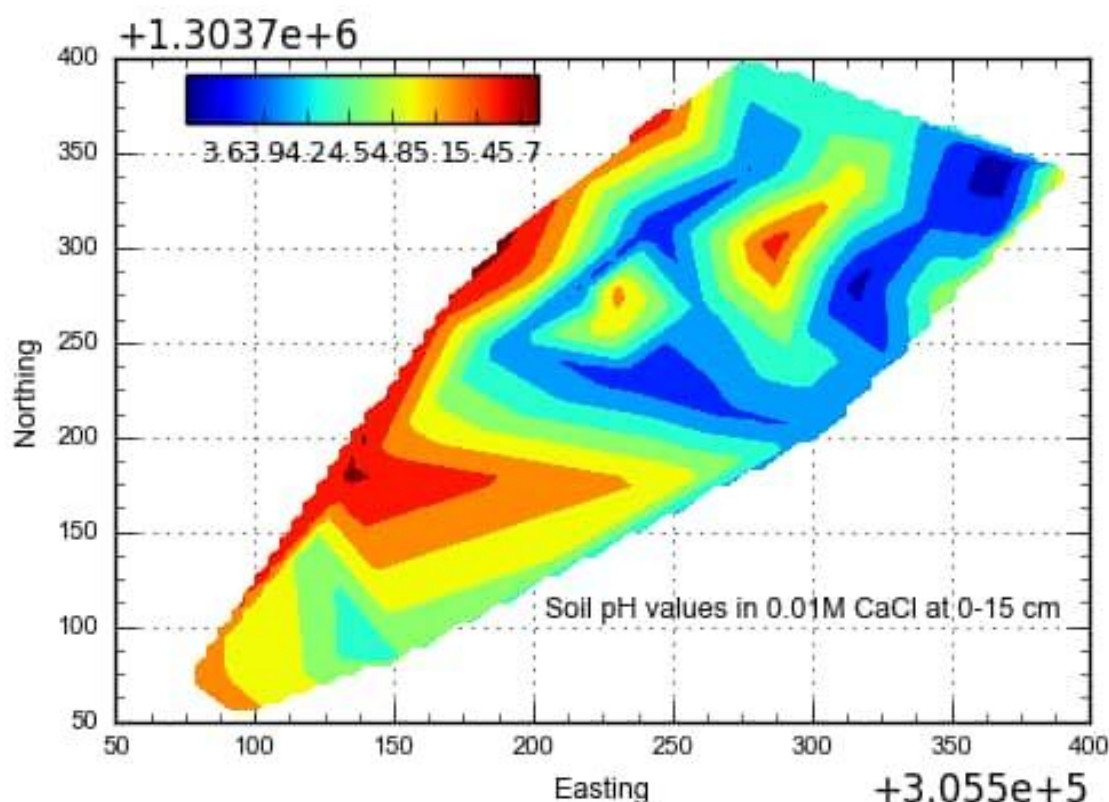
	pH	Digest Zn	Digest Pb	Digest Cu	Ca ⁺²	Mg ⁺²	K ⁺	Na ⁺	P	%N	%O.C	O.M	C:N	E.A	CEC	ECEC	PBS	Sand	Silt	Clay
pH	1.00																			
Digest Zn	-0.04	1.00																		
Digest Pb	-0.03	0.99	1.00																	
Digest Cu	-0.03	0.98	1.00	1.00																
Ca ⁺²	-0.55	0.15	0.16	0.15	1.00															
Mg ⁺²	-0.60	0.06	0.07	0.07	0.16	1.00														
K ⁺	0.74	-0.19	-0.19	-0.19	-0.74	-0.65	1.00													
Na ⁺	0.71	-0.04	-0.04	-0.03	-0.38	-0.77	0.76	1.00												
P	0.80	-0.10	-0.10	-0.08	-0.59	-0.57	0.82	0.90	1.00											
%N	0.63	-0.12	-0.13	-0.14	-0.24	-0.90	0.64	0.56	0.51	1.00										
%O.C	-0.33	-0.10	-0.11	-0.12	-0.06	0.55	-0.28	-0.82	-0.57	-0.19	1.00									
O.M	-0.33	-0.10	-0.11	-0.12	-0.06	0.55	-0.27	-0.81	-0.57	-0.18	1.00	1.00								
C:N	-0.60	0.01	0.01	0.00	0.12	0.93	-0.60	-0.91	-0.70	-0.72	0.81	0.81	1.00							
E.A	-0.62	-0.04	-0.04	-0.05	0.13	0.65	-0.46	-0.89	-0.83	-0.49	0.84	0.84	0.85	1.00						
CEC	-0.61	0.09	0.09	0.10	0.19	0.99	-0.66	-0.69	-0.54	-0.96	0.42	0.41	0.87	0.59	1.00					
ECEC	-0.66	0.07	0.07	0.08	0.19	0.99	-0.66	-0.78	-0.64	-0.93	0.53	0.53	0.92	0.71	0.99	1.00				
PBS	0.54	0.06	0.07	0.09	-0.10	-0.46	0.34	0.83	0.79	0.28	-0.84	-0.85	-0.73	-0.97	-0.38	-0.53	1.00			
Sand	-0.01	-0.11	-0.16	-0.18	0.21	-0.13	-0.08	-0.07	-0.16	0.13	0.02	0.02	-0.06	0.06	-0.14	-0.11	-0.11	1.00		
Silt	0.13	-0.14	-0.11	-0.08	-0.08	-0.11	0.13	0.17	0.18	0.10	-0.12	-0.12	-0.14	-0.17	-0.10	-0.12	0.16	-0.08	1.00	
Clay	-0.11	0.19	0.19	0.17	-0.06	0.17	-0.06	-0.10	-0.06	-0.16	0.09	0.09	0.16	0.11	0.17	-0.07	-0.51	-0.81	1.00	1.00

properties, whereas silt has moderate relationships, indicating its moderate influence on soil chemistry. Lastly, pH positively correlates with sodium (0.71) and phosphorus (0.80), suggesting improved nutrient availability in alkaline conditions. These findings emphasize the importance of soil management strategies to maintain fertility and mitigate potential contamination.

Soil pH distribution

The distribution maps of soil pH at different depths reveal that surface soil pH ranges from 3.6 to 5.7, while subsurface soil pH is slightly lower, ranging from 3.4 to 5.0. The strong acidity in the surface layer may be influenced by organic matter decomposition, microbial activity, and environmental

factors like rainfall and temperature. In contrast, the lower pH in the subsurface layer could result from leaching processes or variations in parent material composition. Since pH adjusted to CaCl_2 0.01M affects metal solubility, lower pH levels increase metal mobility, while higher pH reduces their concentration in soil solution. The acidic conditions ($\text{pH} < 6.0$) can significantly impact nutrient availability, making it harder for crops to absorb essential elements like nitrogen, phosphorus, and potassium, which may hinder agricultural productivity. Proper soil management, including liming, may be necessary to improve fertility and optimize crop growth.



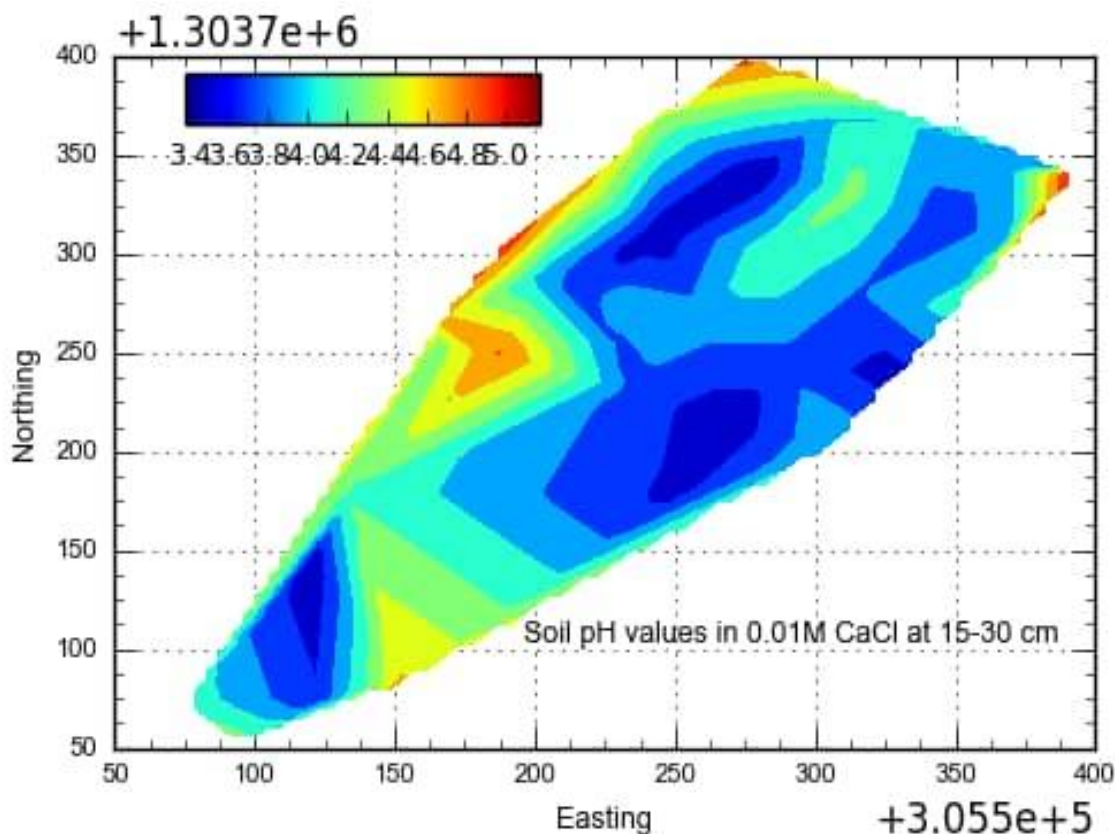
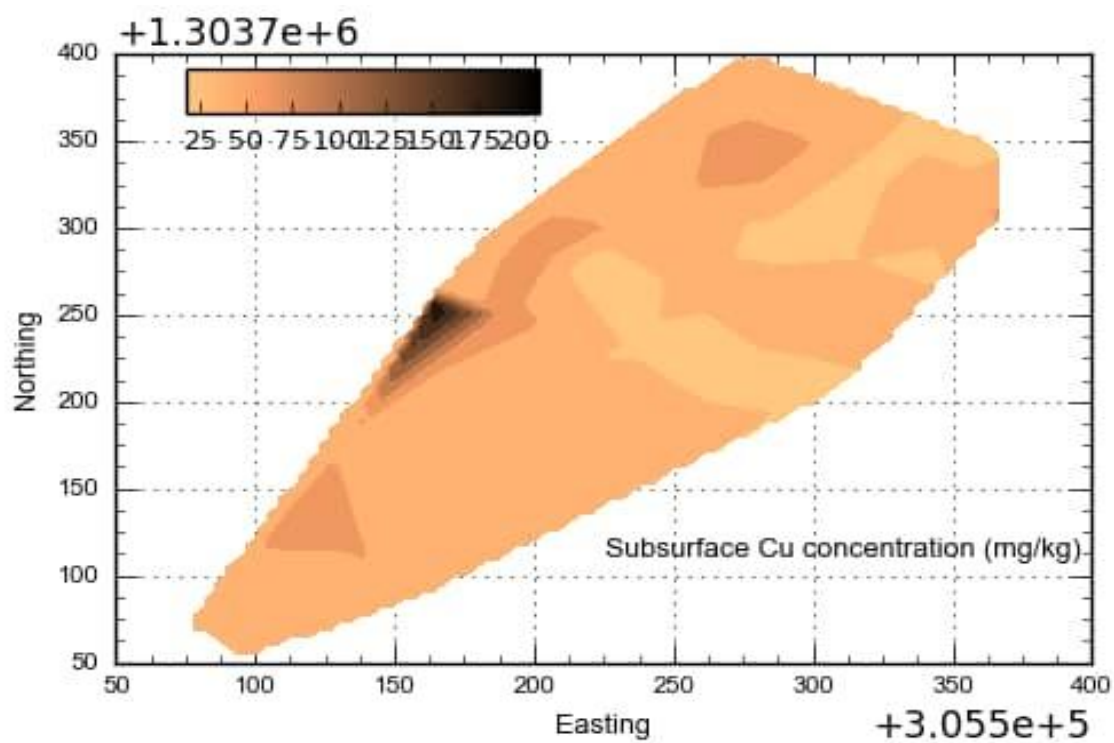
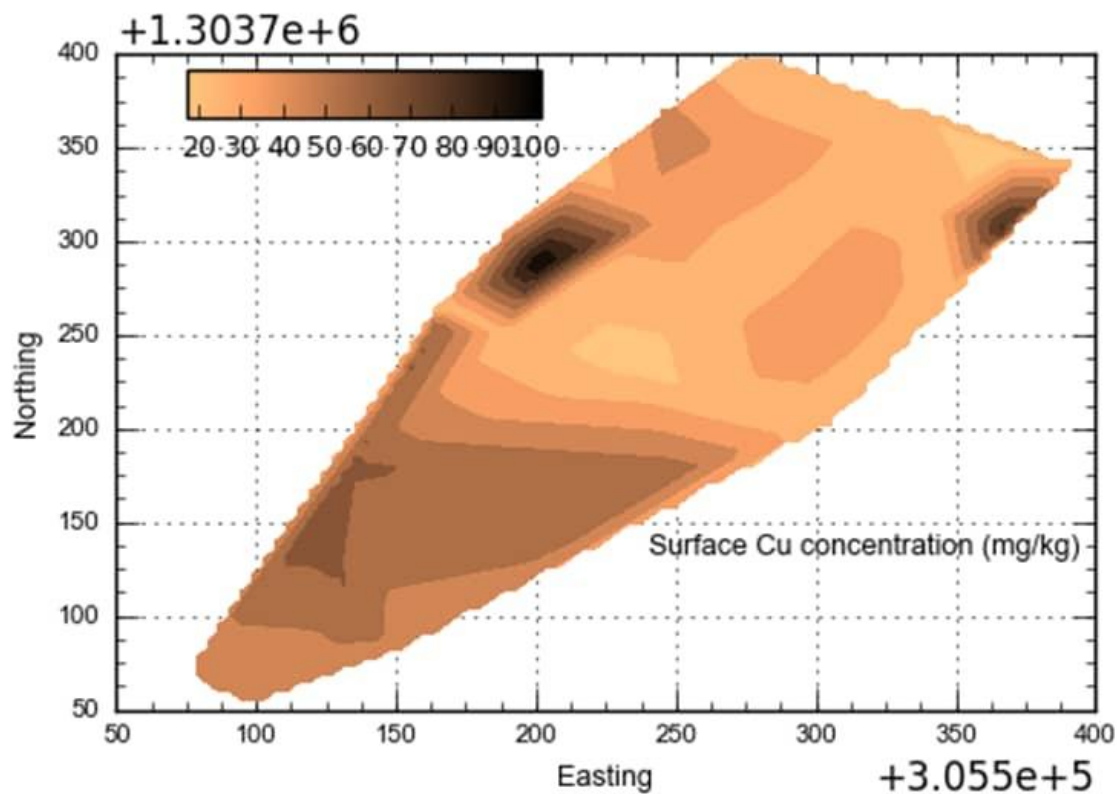
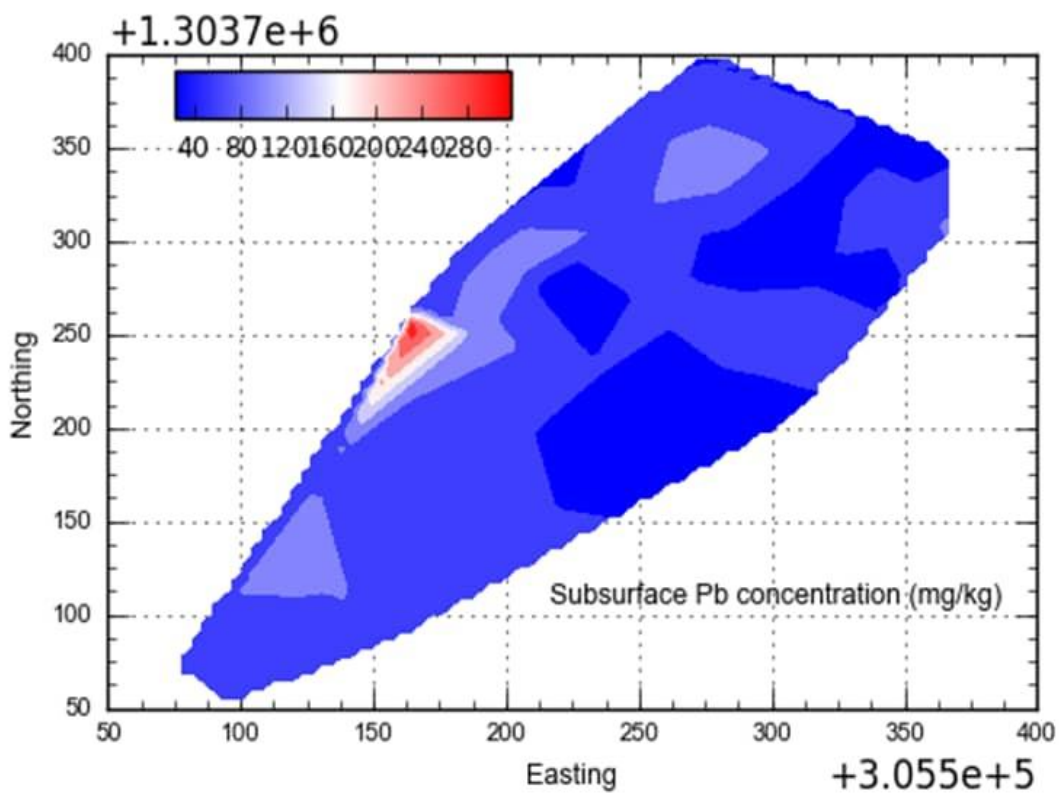
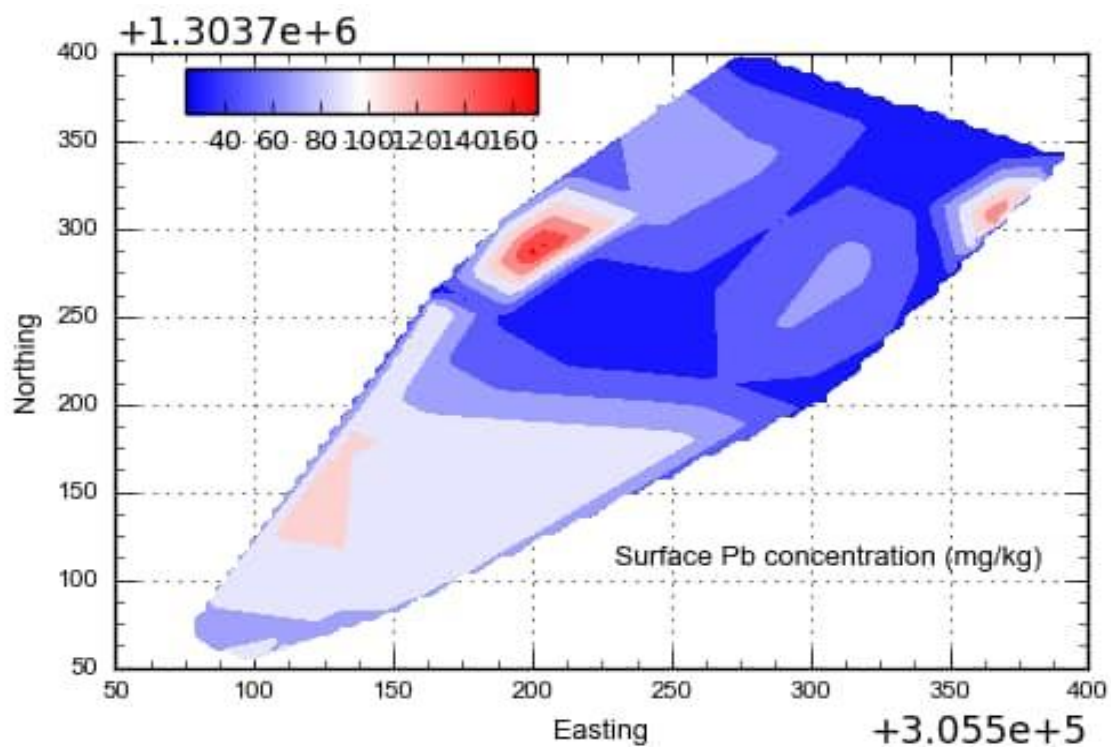


Figure: 2

The distribution of heavy metals in soil, particularly Copper (Cu), Lead (Pb) and Zinc (Zn), reveals distinct patterns between surface and subsurface layers, with subsurface concentrations generally being higher. Surface Cu concentrations appear localized, whereas subsurface levels are more widespread, indicating leaching influenced by soil permeability, organic matter, and water movement. Despite Pb's strong binding tendency to soil particles, its significant accumulation in subsurface layers suggests possible anthropogenic

contamination or enhanced mobility due to environmental factors like rainfall, irrigation, and chemical interactions. Additionally, Zinc (Zn) follows a similar trend, with its subsurface concentration reaching up to 270 mg/kg, while Cu and Pb reach 200 mg/kg and 280 mg/kg, respectively. These findings suggest that leaching plays a major role in the downward migration of heavy metals, facilitated by soil texture, water infiltration, and organic matter interactions, ultimately impacting soil health and posing ecological risks.





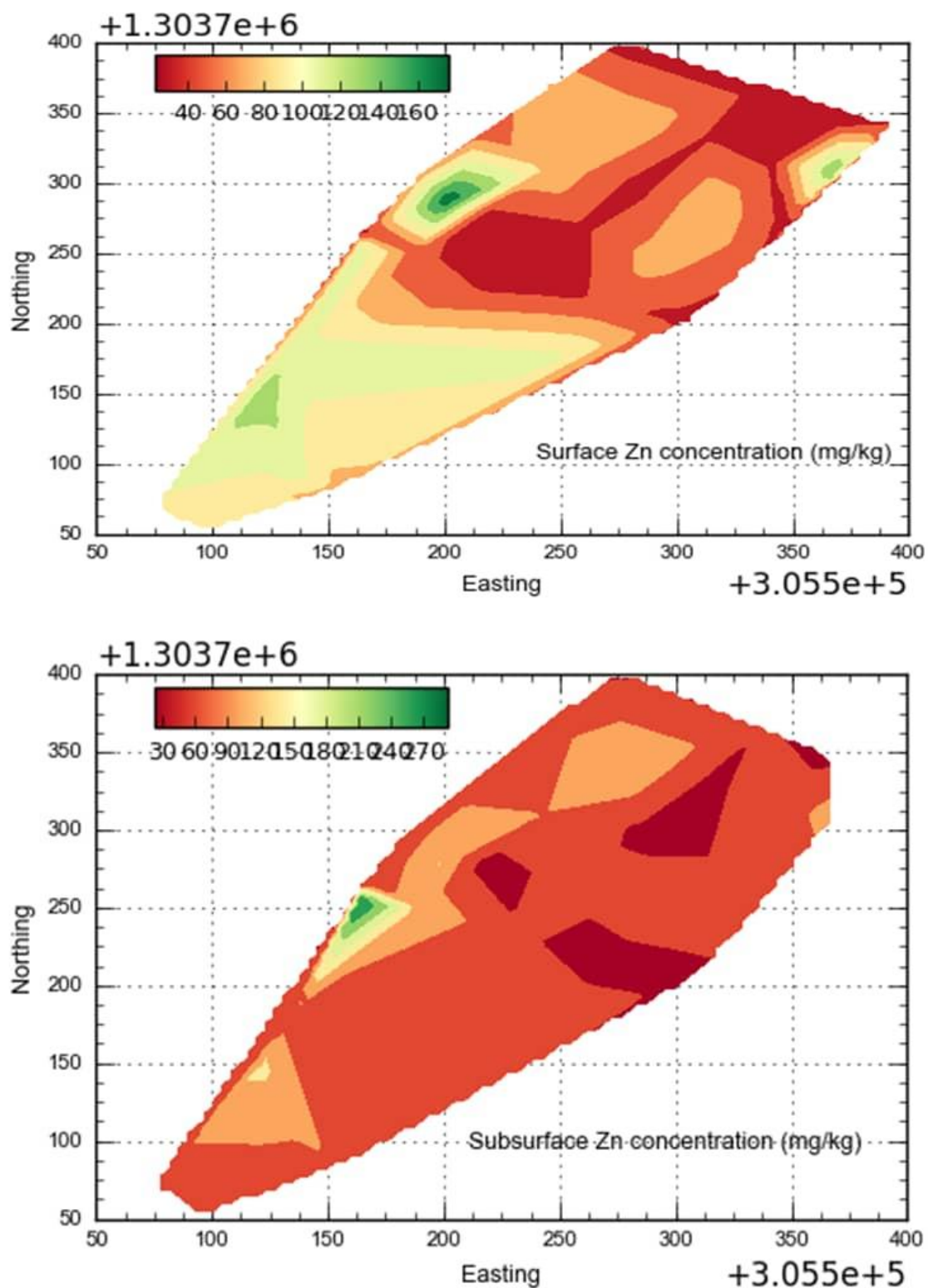


Figure 3

Discussion

The findings by (Abad *et al.*, 2014) and (Ayoubi *et al.*, 2011) showed similar trend in the correlation coefficients for similar studied soil properties all degree of correlations depending on the soil depths. The use of sewage sludge as an organic fertilizer is a widely adopted environmental management practice in agricultural lands around the world. This study aims to monitor the concentrations of heavy metals in soil, as these elements can pose risks to both animal and human health if they enter the food chain through the soil-plant system as reported by Liu *et al.* (2014). Similar findings were obtained by Yunta *et al.* (2024), who reported that the concentration of heavy metals increases with frequent application of sewage sludge to soil over time. They also found that acidity levels decrease, affecting both surface and subsurface soil. Likewise, Gao *et al.* (2024) observed rising pollution levels for Zn, Cu, and Cd with repeated sewage sludge application. Additionally, Hg contamination progressed from no contamination to moderate contamination and eventually to moderate-to-high contamination. However, the overall pollution level remained within safe limits. Xie *et al.* (2024) also reported similar results, stating that alkalizing treatments further stimulated sewage sludge mineralization, increasing soil pH and exchangeable calcium (Ca). This, in turn, enhanced Ca availability for plants, suggesting that sewage sludge is preferable for use in acidic soils. However, cationic micronutrients were minimally affected by sewage sludge application and its treatments. A review of previous studies indicates a common trend: the extractable

fraction of heavy metals in soil tends to increase with sewage sludge application. However, in most cases, the concentrations remain below the threshold values for contaminated soil (Hernández *et al.*, 2024). Contrary to these findings, our results suggest that soil treated with sewage sludge is not acidic; meaning that metal absorption by plants is not restricted. These findings align with those of Romanos *et al.* (2021), who concluded that pH values were not a limiting factor in their study.

Conclusion

The study concludes that untreated wastewater disposal is the primary cause of heavy metal contamination in the University of Maiduguri farm, significantly degrading soil quality and altering its chemical properties. This contamination poses risks to both agriculture and human health, as heavy metals can be absorbed by plants and enters the food chain, raising serious concerns about the consumption of contaminated crops. To mitigate these risks, implementing effective waste management strategies and remedial measures is crucial for protecting soil health and public well-being. Additionally, further research is recommended to assess contamination levels more comprehensively and explore sustainable solutions for restoring soil integrity in affected agricultural areas.

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GROWTH AND PERFORMANCE OF SELECTED RICE (*Oryza sativa* L.) VARIETIES AS AFFECTED BY IRRIGATION WITH SALINE WATER IN SUDAN SAVANNA, NIGERIA

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ABSTRACT

Salinity is a major environmental constraint affecting plant growth, nutrient uptake, and overall crop performance. This study evaluated the growth and physiological responses of four rice (*Oryza sativa* L.) varieties (FARO-16, FARO-44, WAS-SIPI, and NERICA-2) under three salinity levels (0.2, 0.4, and 0.8 dS/m) in a screen-house experiment. The experiment was laid out in a Completely Randomized Design (CRD) with three replications. Data were collected on plant height, leaf area, biomass accumulation, and nutrient uptake. Results showed that FARO-16 and NERICA-2 recorded the highest plant height (73.26 cm) and leaf area (466.9 cm²) at 8 weeks after sowing (WAS), while 0.4 dS/m salinity led to optimal plant growth. The highest nitrogen (N) uptake (3.803%) was recorded in NERICA-2, whereas JAMILA had the highest potassium (K) content (17.88 mg/kg). These findings suggest that FARO-16 and NERICA-2 are relatively salt-tolerant and suitable for cultivation under mild saline conditions.

Key Words: Rice seed, Growth, Performance and Saline water

INTRODUCTION

Salinity is a major abiotic stress limiting plant growth and productivity (Todaka *et al.*, 2012). It affects multiple physiological processes, including water uptake, ion balance, and nutrient absorption (Munns, Schachtman, & Condon, 1995). High salt concentrations disrupt plant metabolism, leading to reduced photosynthesis, respiration, and protein synthesis (Meloni *et al.*, 2003; Pal, Mansour, & Salama, 2004).

Rice is highly sensitive to salinity, particularly at the young seedling stage, which impacts plant density and overall crop performance (Lutts *et al.*, 1995; Heenan, Lewin, & Caffery, 1988). Salinity stress leads to reductions in plant height, biomass accumulation, and yield (Mahammod, Latif, & Khan, 2009).

Selecting salt-tolerant rice varieties is essential to mitigate these negative effects.

Salinity-induced stress results in water deficits, ion toxicity, and nutrient imbalances, ultimately reducing plant growth and yield (Parida, Das, & Mohanty, 2004). Global projections indicate that salt-affected soils are expanding, particularly in irrigated areas, with an estimated 50% of arable land expected to be salinized by 2050 (Jamil *et al.*, 2011).

In Nigeria, salinity has been reported as a growing concern in irrigation schemes, affecting rice productivity (Ibrahim *et al.*, 2018). Identifying rice varieties that can withstand saline conditions is crucial for maintaining agricultural sustainability.

Rice is a staple food in Nigeria, with over 90% of production coming from smallholder farmers (Nigeria Agribusiness).

Developing salt-tolerant rice varieties will help improve yield stability in affected areas. Salt-tolerant cultivars can maintain fresh and dry biomass under saline stress, ensuring sustainable rice production (Amirjani, 2010; Pattanagul & Thitsaksakul, 2008).

MATERIALS AND METHODS

Study Area

The study was conducted in the Soil Science Laboratory and Screen House of the Faculty of Agriculture, Bayero University, Kano, located in the Sudan Savanna region of Nigeria. Kano State is situated between latitudes 10°03'N and 12°04'N and longitudes 7°04'E and 9°03'E. It shares boundaries with Katsina State to the northwest, Kaduna State to the southwest, Jigawa State to the northeast, and Bauchi State to the southeast (Murtala *et al.*, 2015).

Climate

Kano experiences four distinct seasons: Rani (warm and dry), Damina (wet and warm), Kaka (cool and dry), and Bazara (hot and dry), which are influenced by the movement of the Intertropical Discontinuity (ITD) zone. The mean annual rainfall is approximately 884 mm, with variations ranging from 600 mm in the north to 1,200 mm in the southern part of the state. August is typically the wettest month, characterized by frequent rainstorms and high sediment generation. The mean annual temperature ranges from 26°C to 32°C, with a high diurnal temperature variation of 13.1°C and relative humidity levels fluctuating between 17% and 90% (Murtala *et al.*, 2015).

Soils

The predominant soil texture in the study area is sandy loam. The soil has been

classified as Typic Kandiusalf (Malgwi, 2001) following the USDA Soil Taxonomy, and as Gleyic Solonetz, Haplic Solonetz, and Calcic Luvisols under the FAO-UNESCO Soil Classification System.

Vegetation and Land Use

The natural vegetation consists mainly of shrubs and grasses, interspersed with scattered trees such as Neem (*Azadirachta indica*) and *Acacia* spp. The local population is predominantly engaged in agriculture and trade, cultivating rainfed crops such as millet, sorghum, groundnut, maize, cowpea, and rice, alongside livestock rearing of cattle, goats, and sheep.

Experimental Design and Treatments

Screen House (Pot) Experiment: Based on the laboratory screening, five selected varieties were further tested under controlled saline irrigation in a pot experiment.

Following the germination test, five rice varieties (Faro-16, Faro-44, Jamila, NERICA-2, and WAS-SIPI) and three salt concentration levels (0.2 dS m⁻¹, 0.4 dS m⁻¹, and 0.8 dS m⁻¹) were selected for further testing in a pot experiment.

Experimental Setup:

Plastic pots (15.5 cm diameter, 25 cm depth) with four drainage perforations at the base were filled with 10 kg of topsoil collected from the Bayero University Teaching and Research Farm. The experiment was conducted using a completely randomized design (CRD) with three replications.

Pre-Planting Soil Analysis

Soil samples were collected, air-dried, and passed through a 2 mm sieve before analysis. The following parameters were determined using standard laboratory methods: Particle size distribution:

Bouyoucos hydrometer method (Gee & Bauder, 1986). Soil pH: 1:2.5 soil-water suspension using a glass electrode pH meter. Electrical conductivity (EC): 1:2.5 soil-water extract. Organic carbon: Walkley and Black (1965) wet oxidation method. Exchangeable cations (Ca^{2+} , Mg^{2+} , Na^{+} , K^{+}): Neutral ammonium acetate extraction; Ca^{2+} and Mg^{2+} determined by EDTA titration, Na^{+} and K^{+} by flame photometry. Available phosphorus: Bray and Kurtz (1945) method. Cation exchange capacity (CEC): Summation of exchangeable bases and exchangeable acidity. Base saturation (%): Total exchangeable bases divided by CEC $\times$ 100.

Irrigation Water Requirement

Soil moisture retention characteristics were determined using the pressure membrane apparatus (Model 0750 Series). The field capacity (FC) was 15.3%, while the permanent wilting point (PWP) was 11.1%. Based on these values, plants were irrigated at 50% available water capacity (13.2%), equivalent to 1,320 mL of water per pot at five-day intervals.

Agronomic Practices

Weeding: Manually removed as needed. Tagging: Seven plants per pot were tagged for data collection.

Growth and Yield Parameters

Plant height: Measured at 2, 4, 6, and 8 weeks after sowing (WAS) using a meter ruler. Leaf area: Measured using a Leaf Area Meter (Model NMJ-A/B) at 2, 4, 6, and 8 WAS. Root length: Plants were uprooted, and root length was measured using a meter ruler. Fresh weight: Plants were harvested at 8 WAS, and fresh biomass was recorded using an electronic

balance. Dry weight: Samples were oven-dried at 70°C for 48 hours and weighed.

Soil Salinity and Nutrient Uptake Analysis

Soil pH and EC were monitored every two weeks to assess salt accumulation. Nitrogen uptake: Determined by the Macro-Kjeldahl method. Phosphorus uptake: Determined by the Bray No. 1 method. Potassium uptake: Analyzed using Atomic Absorption Spectrophotometry (AAS, Agilent 200 series, 240fs AA).

Data Analysis

All data were subjected to analysis of variance (ANOVA) at $p \leq 0.05$ using GenStat statistical software. Mean separation was performed using Least Significant Difference (LSD).

Results and Discussion

Effect of Irrigation with Saline Water on pH and EC of the Irrigated Soil.

Table 1 presents the effects of saline irrigation on soil pH and electrical conductivity (EC) at different time intervals (2, 4, 6, and 8 WAS). Both parameters increased consistently with rising salt concentrations. The highest EC (0.8 dS m^{-1}) resulted in the greatest increase in pH (6.30). However, no significant differences in pH were observed between sampling weeks.

Soil pH and Electrical Conductivity (EC) Under Saline water Irrigation

Soil pH and EC play a critical role in nutrient availability. Saline soils typically exhibit pH levels below 8.5, but excessive Na^{+} and Cl^{-} concentrations alter soil structure and ionic balance, affecting nutrient absorption (Alam, 1999). In low-rainfall areas, poor leaching contributes to alkaline soil conditions,

Table 1. Effect of irrigation with saline water on PH and EC of the irrigated soil

Salt Conc (dS/m)	2WAS	4WAS	6WAS	8WAS	2WAS	4WAS	6WAS	8WAS
Ctrl (0)	6.00	6.00	6.00	6.00 ^c	0.051 ^d	0.042 ^d	0.049 ^d	0.045 ^d
0.4	6.13	6.18	6.22	6.26 ^b	0.112 ^c	0.770 ^c	1.089 ^c	1.078 ^c
0.6	6.25	6.27	6.28	6.29 ^a	0.134 ^b	0.995 ^b	1.464 ^b	1.753 ^b
0.8	6.27	6.29	6.29	6.30 ^a	0.173 ^a	1.224 ^a	1.724 ^a	1.977 ^a
SE±	0.0994	0.1031	0.096	0.0714	0.01320	0.0545	0.0566	0.682

Means followed by the same letters within the same column and row are not significantly different at 95% confidence level of probability using Duncan's Multiples Test.

Table 2. Effect of Variety and Salt Water Irrigation on Plant Height and Leaf Area of Rice

Treatment	Plant Height (mm)				Leaf Area (cm ²)			
	2WAS	4WAS	6WAS	8WAS	2WAS	4WAS	6WAS	8WAS
Varieties								
Faro-16	23.25 ^c	36.80 ^c	44.76 ^{cd}	53.20 ^c	117.1 ^a	234.2 ^a	468.4 ^a	546.9 ^a
Faro-44	26.62 ^b	44.61 ^a	63.63 ^b	70.36 ^b	106.2 ^b	212.5 ^b	425.0 ^b	462.5 ^{bc}
Jamila	22.87 ^{cd}	34.37 ^d	43.06 ^{cd}	50.81 ^{cd}	104.6 ^b	209.2 ^b	418.3 ^b	438.6 ^c
NERICA-2	30.35 ^a	44.15 ^b	65.18 ^a	73.26 ^a	108.1 ^b	216.2 ^b	432.4 ^b	488.9 ^b
Wassipi	21.44 ^d	36.49 ^c	46.19 ^c	48.74 ^d	87.6 ^c	175.2 ^c	350.4 ^c	372.0 ^d
SE±	0.524	0.856	1.436	1.340	2.37	4.66	9.33	12.39
Salt Conc (dS/m)								
Ctrl (0)	27.74 ^a	43.12 ^a	59.22 ^a	68.08 ^a	113.6 ^a	227.2 ^b	454.3 ^a	472.8 ^a
0.4	24.40 ^b	38.83 ^b	50.97 ^{bc}	59.41 ^b	104.7 ^b	269.4 ^a	418.8 ^b	421.2 ^b
0.6	25.67 ^b	39.18 ^b	53.11 ^b	59.36 ^b	103.1 ^b	263.5 ^a	407.1 ^b	410.9 ^{bc}
0.8	21.82 ^c	36.01 ^c	46.45 ^d	50.25 ^c	97.5 ^c	197.8 ^c	396.5 ^c	400.1 ^c
SE±	0.469	0.766	1.284	1.199	12.2	4.17	8.34	11.08
Interaction								
Varieties x								
Salt conc	NS	NS	NS	NS	NS	NS	*	NS

Means followed by the same letters within the same column and row are not significantly different at 95% level confidence of probability using Duncan's Means Separation.

further restricting nutrient availability (Provin and Pitt, 2001).

At a salinity level of 0.6 dS m⁻¹, ionic imbalances were evident, with reduced Ca²⁺, K⁺, and Mg²⁺ uptake due to

competition with Na⁺ ions (Nishimura *et al.*, 2011). Elevated EC levels in salt-treated soils caused significant reductions in germination, shoot length, root length, and

dry weight, aligning with previous studies on salinity stress in rice (Yuda *et al.*, 2014). Effect of Variety and Salt Water Irrigation on Plant Height and Leaf Area of Rice.

Table 2 illustrates the effects of variety and salinity on plant height and leaf area. Nerica-2 consistently achieved the tallest plants and largest leaf areas, followed by FARO-44, FARO-16, Jamila, and WAS-SIPI. At 8 WAS, Nerica-2 reached a height of 73.326 cm, whereas WAS-SIPI was the shortest (48.74 cm). Similarly, FARO-16 exhibited the highest leaf area (546.9 cm²), while WAS-SIPI had the lowest (372.0 cm²).

Plant Height and Leaf Area Development of rice Under Saline water Irrigation

Plant height varied significantly across salinity treatments, with reductions observed at increasing salinity levels. At 0% salinity, rice plants reached an optimal height of 88 cm, with a 12.8% increase over 40 days (Akinbode, 2014). However, at 1.5% salinity, significant reductions were evident, aligning with previous studies that

reported decreased rice density and yield under saline conditions (Razzaq *et al.*, 2020).

By 8 weeks after seeding (8WAS), salinity levels exceeding 0.8 dS m⁻¹ caused substantial height 3reductions, with plants at 5% salinity reaching only 48–50 cm, indicating a one-third reduction compared to the control. Salt accumulation disrupts plant metabolism, leading to leaf tissue damage, reduced nutrient uptake, and physiological stress (Munns and Tester, 2008). Additionally, high Na⁺ levels impair photosynthetic efficiency, reducing biomass accumulation and overall productivity (Yang and Guo, 2018).

Interaction Effect of variety and Salt Concentration of irrigation water on Leaf Area at 6 WAS

Table 3 demonstrates the interaction effects of salinity on leaf area. The findings indicate a significant interaction at 6 WAS, suggesting that salt concentration plays a crucial role in influencing leaf expansion.

Table 3. Interaction Effect of salt concentration on Leaf Area of rice at 6WAS

Salt Conc (dSm ⁻¹)	Varieties				
	Faro-16	Faro-44	Nerica-2	Jamila	WAS-SIPI
Control (0)	517.3d	471.1cd	454.6bcd	455.5bcd	373.1abc
0.4	472.6cd	430.1bcd	444.5bcd	431.8bcd	314.8a
0.6	456.6bcd	382.0abc	424.0bcd	412.5abcd	360.2ab
0.8	427.0bcd	416.8abcd	406.4abc	373.6abc	353.ab

Means followed by the same letters within the same column and row are not significantly different at 95% level confidence of probability using Duncan's Means Separation.

Effect of Variety and Salt Water Irrigation on Fresh, Dry, and Root

Biomass of rice.

Table 4 presents data on biomass accumulation. Nerica-2 exhibited the highest fresh biomass (60.63 g) and dry biomass (19.38 g), while FARO-44 had the lowest values (56.99 g and 16.74 g, respectively). Similarly,

root biomass was highest in WAS-SIPI (17.48 g) and lowest in FARO-44 (16.66 g). Fresh biomass was highest at 0.6 dS m⁻¹ (59.64 g) and lowest at 0 dS m⁻¹ (56.65 g), indicating that mild salinity may promote biomass production.

Table 4. Effect of Variety and Salt Water irrigation on Fresh weight, Dry weight and Root weight of Rice Biomass

Treatment	Fresh above ground Biomass weight (g)	Dry above ground biomass weight (g)	Fresh Root weight (g)
Varieties			
Faro-16	57.87 ^b	17.15 ^c	16.83
Faro-44	56.99 ^c	16.74 ^{cd}	16.66
Jamila	57.71 ^b	16.19 ^{cd}	16.58
Nerica-2	60.63 ^a	19.38 ^a	16.92
WAS-SIPI	57.09 ^b	18.41 ^b	17.48
SE±	1.076	0.684	0.581
Salt Conc dS/m			
Crtl (0)	57.39 ^b	17.46 ^{ab}	17.05
0.4	56.65 ^c	18.51 ^a	17.06
0.6	59.64 ^a	17.88 ^{ab}	16.69
0.8	58.56 ^a	16.45 ^b	16.77
SE±	0.962	0.612	0.520
C.V	*	*	NS

Means followed by the same letters within the same column and row are not significantly different at 95% level confidence of probability using Duncan's Means Separation.

Table 5 Interaction Effect of Variety and Salt Water irrigation on Fresh weight of rice.

Salt Conc (dSm ⁻¹)	Varieties				
	Faro-16	Faro-44	Nerica-2	Jamila	WAS-SIPI
Control (0)	57.13ab	60.20ab	55.57ab	58.17ab	55.87ab
0.4	61.67ab	56.33ab	57.27ab	57.47ab	50.50a
0.6	61.47ab	54.67ab	65.47b	55.40ab	61.20ab
0.8	51.20a	56.77ab	64.23b	59.80ab	60.80ab

Means followed by the same letters within the same column and row are not significantly different at 95% level confidence of probability using Duncan's Means Separation

Table 6. Interaction Effect of Variety and Salt Water irrigation on Dry weight of rice

Salt Conc (dSm ⁻¹)	Varieties				
	Faro-16	Faro-44	Nerica-2	Jamila	WAS-SIPI
Control (0)	20.43a	17.67a	16.90a	15.57a	16.73a
0.4	19.70a	18.70a	17.77a	16.40a	19.97a
0.6	18.13a	16.30a	17.90a	16.33a	20.73a
0.8	19.23a	14.30a	16.03a	16.47a	16.20a

Means followed by the same letters within the same column and row are not significantly different at 95% level confidence of probability using Duncan's Means Separation.

Interaction Effect of Variety and Salt Water Irrigation on Fresh and Dry Biomass of rice. Tables 5 and 6 reveal significant interactions between variety and salinity levels on fresh and dry biomass. These findings emphasize the complexity of plant responses to saline irrigation, with some variety–salinity combinations demonstrating better adaptability.

Effect of Saline Irrigation on Early Biomass Development and Nutrient Uptake in Rice
Fresh and Dry Above-Ground Biomass Weight & Root Biomass Weight

Salinity stress significantly influenced biomass accumulation at early growth stages, with reductions observed at increasing salinity levels (Table 7). At 0.4, 0.6, and 0.8 dS m⁻¹, biomass declined by 1.1%, 15.4%, and 18.2%, respectively, compared to the control. Root fresh weight initially increased at 0.4 dS m⁻¹ but declined at higher salinity levels, suggesting that moderate salinity may stimulate root growth before reaching a threshold where toxicity limits expansion (Kaya *et al.*, 2005).

Similarly, salinity affected root biomass dynamics, with the lowest root fresh weight recorded at 0.4 dS m⁻¹ and a subsequent

increase at 0.8 dS m⁻¹ due to increased root number but reduced root growth (Alshammary *et al.*, 2004). The impact of salinity on early biomass development suggests that rice seedlings experience increased sensitivity at this stage, affecting stand establishment and subsequent productivity (Zeng and Shannon, 2000).

Effect of Variety and Irrigation with Saline Water on Nutrient Content of Rice.

Table 7 summarizes the effects of variety and salinity on nitrogen (N), phosphorus (P), and potassium (K) content. Nerica-2 had the highest nitrogen content (3.803%), while Jamila recorded the highest phosphorus (0.801 mg/kg) and potassium (1.789 mg/kg) levels. Salinity influenced nutrient uptake, with nitrogen content increasing as salt concentration rose from 3.565% (control) to 3.771% (0.8 dS m⁻¹), while potassium peaked at 0.4 dS m⁻¹.

Table 7. Effect of Variety and Irrigation with Salt Water on Nutrient Content of Rice

Treatment	Total N	%	P (mg/kg)	K (mg/kg)
Varieties				
Faro-16	3.640 ^{ab}		0.794	1.590 ^{ab}
Faro-44	3.710 ^{ab}		0.785	1.640 ^{ab}
Jamila	3.523 ^b		0.801	1.789 ^a
Nerica-2	3.803 ^a		0.792	1.549 ^{ab}
WAS-SIPI	3.593 ^b		0.776	1.474 ^b
SE	0.0765		0.0304	0.0919
Salt Conc dS/m				
Ctrl (0)	3.565 ^b		0.794	1.488 ^{ab}
0.4	3.659 ^{ab}		0.809	1.714 ^a
0.6	3.621 ^{ab}		0.752	1.533 ^{ab}
0.8	3.771 ^a		0.821	1.488 ^{ab}
SE	0.0631		0.0272	0.0822
Varieties x Salt Conc	NS		NS	NS

Means followed by the same letters within the same column and row are not significantly different at 95% confidence level of probability using Duncan's multiple Range Test

Nutrient Uptake Under Saline Conditions

Salinity disrupts nutrient absorption by increasing Na⁺ and Cl⁻ accumulation, which can lead to nutrient imbalances and toxicity (Nishimura *et al.*, 2011). High Na⁺ levels interfere with potassium (K⁺) uptake,

a key nutrient in plant growth and stress tolerance (Jung *et al.*, 2009). Under saline conditions, nitrogen (N) uptake may also be reduced (Abdelgadir *et al.*, 2005), while phosphorus (P), zinc (Zn), and iron (Fe)

availability decline due to altered soil chemistry (Garcia *et al.*, 2010).

As salinity increases, the Na^+/K^+ and $\text{Na}^+/\text{Ca}^{2+}$ ratios rise, leading to ionic competition that reduces K^+ , Ca^{2+} , and Mn^{2+} absorption, ultimately impairing plant growth (Razzaque *et al.*, 2011). The accumulation of Na^+ and Cl^- in plant tissues can also induce osmotic stress, limiting water uptake and leading to physiological drought conditions that negatively affect seedling development (Siringam *et al.*, 2011).

These findings highlight the critical role of nutrient regulation in salt-affected soils and emphasize the importance of managing salinity at early growth stages to enhance rice establishment and productivity.

Effect of Salinity on Plant Height, Leaf Area, Biomass, and Nutrient Uptake Biomass Accumulation Across Growth Stages

Salinity-induced reductions in biomass were particularly pronounced at early growth stages. The lowest biomass values (36.09 g) were recorded during tillering, while the highest (53.02 g) occurred at ripening. This suggests that young rice plants are more sensitive to salinity, with the most affected stages being tillering, panicle initiation, and panicle emergence (Munns, 2002).

Shoot biomass was less affected than reproductive structures, except in young seedlings where salinity stress reduced biomass accumulation significantly (Khatun and Flowers, 1995). Under extreme salinity (8 dS m^{-1}), the lowest biomass (26.84 g/pot) was recorded, highlighting the severe impact of salt stress on plant growth and development (Dai *et al.*, 2009).

Impact of Salinity on Nutrient Uptake at Advanced Growth Stages

Salt stress-induced nutrient imbalances were evident in mature rice plants. As salinity increased, Na^+ and Cl^- accumulation intensified, limiting K^+ , Ca^{2+} , and Mn^{2+} uptake and disrupting metabolic functions (Razzaque *et al.*, 2011). This led to osmotic stress, reduced photosynthesis, and physiological drought, all of which contributed to lower grain yield and biomass production (Siringam *et al.*, 2011). Salinity stress also decreased nitrogen uptake and altered ion exchange, affecting plant health and productivity (Chakrabarti and Mukherji, 2003). However, some studies suggest that moderate salinity may increase N and K uptake, depending on soil conditions and rice genotype (Laghari *et al.*, 2010; Saha *et al.*, 2014). The extent of nutrient disruption depends on the plant's ability to regulate K^+ absorption and exclude Na^+ toxicity (Jung *et al.*, 2009).

The findings indicate that salinity significantly reduces plant height, biomass, and nutrient uptake, particularly at levels exceeding 0.8 dS m^{-1} . The impact of salinity varies across growth stages, with young seedlings exhibiting higher sensitivity than mature plants. Managing salinity through improved irrigation strategies and soil amendments can mitigate adverse effects and sustain rice productivity in saline-prone regions.

Summary

This study assessed the effect of saline irrigation on the vegetative growth, biomass production, and nutrient uptake of different rice varieties. The results showed that

increasing salinity levels significantly reduced plant height, leaf area, biomass accumulation, and overall growth performance. High salinity led to reduced nutrient uptake, particularly of potassium (K⁺) and calcium (Ca²⁺), while increasing sodium (Na⁺) accumulation. The adverse effects of salinity were more pronounced at later growth stages, leading to significant reductions in yield-related parameters.

Conclusion

Saline irrigation negatively affects rice growth by inducing physiological stress, reducing nutrient availability, and limiting biomass accumulation. The findings suggest that prolonged exposure to saline conditions can lead to significant yield losses due to disrupted nutrient uptake and increased ion toxicity. The study reinforces the need for adopting salt management strategies and selecting salt-tolerant varieties to sustain rice production in saline environments.

Recommendations.

1. Adoption of Salt-Tolerant Rice Varieties: Farmers should cultivate salt-tolerant varieties to minimize yield losses under saline irrigation.
2. Irrigation Management: Improved irrigation strategies, such as alternate wetting and drying, can help reduce salt accumulation in the root zone.
3. Nutrient Supplementation: The application of potassium and calcium amendments can help counteract the negative effects of sodium accumulation.
4. Soil Amendments: The use of organic matter, gypsum, and biochar can improve soil structure and reduce salinity stress.
5. Further Studies: More research is needed to explore molecular and physiological

adaptations of rice under saline conditions to develop targeted interventions.

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GERMINATION RESPONSE OF SELECTED RICE (*ORYZA SATIVA* L.) VARIETIES TO SALINE IRRIGATION IN SUDAN SAVANNA OF NIGERIA

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ABSTRACT

Salinity stress is a major constraint limiting agricultural productivity in arid and semi-arid regions, particularly affecting crop germination and establishment. This study evaluated the germination response of eight rice (*Oryza sativa* L.) varieties (FARO-15, FARO-16, FARO-44, JAMILA, IRGA, NERICA-1, NERICA-2, and WAS-SIPI) under five salinity levels (0–1.0 dS/m) in a laboratory experiment. Seeds were placed in petri dishes and irrigated with saline solutions in a Completely Randomized Design (CRD) with three replications. Germination percentage, plumule length, and radicle length were recorded. Results indicated that salinity had a significant negative impact on germination, with higher salinity levels reducing germination percentage and seedling vigor. However, FARO-16 and NERICA-2 exhibited higher tolerance, maintaining germination rates above 90% at 0.6 dS/m salinity. These findings suggest that FARO-16 and NERICA-2 could be recommended for cultivation in moderately saline environments.

Keywords: Germination percentage, Salinity levels, Germination rates

INTRODUCTION

Salinity stress is a major environmental constraint in arid, semi-arid, and coastal regions, limiting the agricultural productivity of many crops, especially cereals (Lluchi & Grattan, 2007). It affects nearly 20% of the cultivated and irrigated areas worldwide (Zheng, Shannon, & Lesch, 2001). In rice production, the first exposure to salinity stress usually occurs at the germination stage, particularly in direct sowing and transplanting systems (Ibrahim & Kazzim, 2008).

Salinity affects germination by increasing osmotic pressure, reducing water absorption, and exerting toxic effects due to excessive sodium and chloride ions (Abu-Elkhaeir & Mekki, 2007). High salt concentrations limit seed germination, delay emergence, and reduce germination percentage (Ashraf &

Harris, 2004). The sensitivity of rice to salinity varies across growth stages, with germination being more tolerant than seedling and vegetative stages (Zeng & Shannon, 2000; Lutts, Kinet, & Bouharmont, 1995). However, increased salinity levels still negatively impact germination rates and seedling vigor.

Rice is particularly vulnerable at the young seedling stage, which affects stand establishment in salt-affected fields (Lutts *et al.*, 1996). Identifying salt-tolerant varieties at the germination stage is essential for improving crop production in saline environments.

Soil salinity is a growing problem worldwide, significantly reducing crop productivity (FAO, 2006). In rice, high salinity levels inhibit seed germination and seedling emergence due to osmotic stress

and ion toxicity (Grieve & Suarez, 1997). While cereal crops exhibit varying degrees of salt tolerance, rice is among the most sensitive (Munns & Tester, 2008).

Salinity has become a major concern in Nigerian rice irrigation schemes, such as the Kano River Irrigation Project (KRIP), where smallholder farmers cultivate rice for their livelihoods (Ibrahim *et al.*, 2018). Developing salt-tolerant rice varieties can help farmers sustain production under saline conditions.

Rice production in Nigeria is dominated by smallholder farmers using traditional irrigation systems (Hassan, Onwunali, & Ibrahim, 2020). The yield gap in rice production can be reduced by introducing salt-tolerant, high-yielding varieties adapted to saline environments (Efisue *et al.*, 2008). Identifying and promoting salt-tolerant rice cultivars will help ensure food security and improve livelihoods in salt-affected areas.

MATERIALS AND METHODS

Study Area

The study was conducted in the Soil Science Laboratory and Screen House of the Faculty of Agriculture, Bayero University, Kano, located in the Sudan Savanna region of Nigeria. Kano State is situated between latitudes 10°03'N and 12°04'N and longitudes 7°04'E and 9°03'E. It shares boundaries with Katsina State to the northwest, Kaduna State to the southwest, Jigawa State to the northeast, and Bauchi State to the southeast (Murtala *et al.*, 2015).

Climate

Kano experiences four distinct seasons: Rani (warm and dry), Damina (wet and warm), Kaka (cool and dry), and Bazara (hot and dry), which are influenced by the movement of the Intertropical Discontinuity

(ITD) zone. The mean annual rainfall is approximately 884 mm, with variations ranging from 600 mm in the north to 1,200 mm in the southern part of the state. August is typically the wettest month, characterized by frequent rainstorms and high sediment generation. The mean annual temperature ranges from 26°C to 32°C, with a high diurnal temperature variation of 13.1°C and relative humidity levels fluctuating between 17% and 90% (Murtala *et al.*, 2015).

Soils

The predominant soil texture in the study area is sandy loam. The soil has been classified as Typic Kandiusalf (Malgwi, 2001) following the USDA Soil Taxonomy, and as Gleyic Solonetz, Haplic Solonetz, and Calcic Luvisols under the FAO-UNESCO Soil Classification System.

Vegetation and Land Use

The natural vegetation consists mainly of shrubs and grasses, interspersed with scattered trees such as Neem (*Azadirachta indica*) and *Acacia* spp. The local population is predominantly engaged in agriculture and trade, cultivating rainfed crops such as millet, sorghum, groundnut, maize, cowpea, and rice, alongside livestock rearing of cattle, goats, and sheep.

Preparation of Saline Irrigation Water

Saline irrigation water was prepared by dissolving laboratory-grade NaCl in 1 liter of distilled water. The electrical conductivity (EC) of the solutions was measured in $\mu\text{S cm}^{-1}$ and converted to dS m^{-1} by dividing by 1,000. A standard calibration curve was developed to determine the amount of NaCl required to achieve the desired salinity levels. Table 1 presents the corresponding salt concentrations prepared for the experiment.

Experimental Design and Treatments

Laboratory Experiment: This phase evaluated the germination response of eight rice varieties under varying saline conditions.

Germination Test

Uniform seeds of eight rice varieties (Faro-15, Faro-16, Faro-44, IRGA, Jamila, NERICA-1, NERICA-2, and WAS-SIPI) were selected. A germination test was conducted using 9 cm diameter sterile glass Petri dishes lined with Whatman No. 1 filter paper. The seeds were exposed to five salinity levels (0.2 dS m^{-1} , 0.4 dS m^{-1} , 0.6 dS m^{-1} , 0.8 dS m^{-1} , 1.0 dS m^{-1}) and a control (0 dS m^{-1}).

The experiment followed a factorial design arranged in a completely randomized design (CRD) with three replications, resulting in 120 experimental units.

Data Analysis

All data were subjected to analysis of variance (ANOVA) at $p \leq 0.05$ using GenStat statistical software. Mean separation was performed using Least Significant Difference (LSD).

Results and Discussion

Effect of Salt Concentration and Variety on Germination Percentage of Rice.

The germination percentage of rice varieties under different salt concentrations is presented in Table 1. The results indicate that at lower salinity levels (0.2 and 0.4 dS m^{-1}), germination percentages remained high and relatively consistent. However, at 1.0 dS m^{-1} , germination percentage declined to 78.50%, demonstrating the negative impact of increased salinity.

Among the varieties, WAS-SIPI (94.06%), FARO-44 (90.13%), FARO-16 (88.60%), and JAMILA (75.46%) exhibited varying

degrees of salt tolerance. Germination percentages exceeded 90% at 0.2 and 0.4 dS m^{-1} across all varieties, indicating their ability to germinate well under mild saline conditions. At 0.6 dS m^{-1} , NERICA-2 and FARO-16 maintained over 90% germination, suggesting higher tolerance compared to other varieties. However, germination percentages dropped below 90% at 0.8 dS m^{-1} for most varieties, except for FARO-16.

These findings highlight the detrimental effect of salinity on rice germination, with increasing salt concentration leading to significant reductions in germination percentages. The interaction between salinity levels and variety influences the overall response, emphasizing the importance of varietal selection under saline conditions.

Effect of Salt Concentration and Variety on Plumule and Radicle Length of Rice.

The effects of salt concentration on plumule and radicle length are shown in Table 2. Plumule length generally declined as salinity increased. Interestingly, at 0.4 dS m^{-1} , WAS-SIPI exhibited a 20% increase in plumule length, whereas other varieties experienced reductions. This suggests that mild salinity may stimulate growth in specific varieties.

Plumule length declined from 65% to 48% as salinity increased from 0.4 to 0.6 dS m^{-1} . At higher salinity levels (0.8 – 1.0 dS m^{-1}), the differences among varieties became less pronounced due to substantial growth reductions. However, WAS-SIPI, FARO-44, NERICA-2, and JAMILA maintained relatively higher plumule lengths.

Radicle length displayed an inverse relationship with salinity, with higher salt

concentrations causing more pronounced reductions. At 1.0 dS m⁻¹, radicle length was significantly reduced across all varieties, indicating their susceptibility to salt stress. Varietal differences were observed, with Nerica-1, IRGA, and FARO-15 showing the greatest reductions between 0.4 and 0.8 dS m⁻¹. In contrast, WAS-SIPI, FARO-44, NERICA-2, JAMILA, and FARO-16 exhibited smaller reductions (24–40%) at 0.8 dS m⁻¹.

Interaction Effects Between Variety and Salt Concentration of irrigation water on Plumule Length at 3 WAS.

Table 3 presents the interaction effects between salt concentration and variety on plumule length at 3 weeks after sowing (WAS). The results indicate a significant interaction ($p \leq 0.05$), suggesting that both salinity and variety influenced seedling growth. Faro-16 exhibited superior plumule growth, while Nerica-1 and Nerica-2 performed poorly. This reinforces the negative correlation between salinity and seedling development.

Table 1. Effect of salt concentration and variety on Germination Percentage of Rice Varieties

Variety	Salinity levels (d S m ⁻¹)				
	0.2	0.4	0.6	0.8	1.0
	Germination				
FAR0 15	96.1% ^a	93.0% ^a	88.75% ^b	72.93% ^c	45.82% ^e
FARO 16	95.7% ^a	97.00% ^a	91.64% ^a	88.60% ^a	68.42% ^a
FARO 44	96.9% ^a	94.64% ^{ab}	84.38% ^{cd}	76.84% ^{bc}	55.34% ^d
NERICA-2	94.5% ^{ab}	93.45% ^{ab}	87.00% ^b	85.14% ^{ab}	64.38% ^b
WAS-SIPI	94.9% ^{ab}	96.76% ^b	90.88% ^a	78.63% ^b	60.51% ^c
IRGA	90.6% ^{ab}	94.34% ^a	90.00% ^a	76.75% ^{bc}	37.84% ^d
JAMILA	90.89% ^{ab}	93.45% ^{ab}	85.88% ^c	51.86% ^e	45.16% ^e
NERICA-1	88.95% ^b	90.42% ^b	89.25% ^a	64.23% ^d	40.84% ^f

Means followed by different letters within the same column and row are significantly different at 95% confidence level ($p < 0.05$) of Duncan's Multiple Test.

Table 3. Effect of Salt concentration and varieties on Plumule and Radicle length of Rice

Treatment	Plumule Length (mm)			Radicle Length (mm)		
	1WAS	2WAS	3WAS	1WAS	2WAS	3WAS
Varieties						
Faro 15	10.49 ^b	13.43 ^a	12.17 ^{cd}	9.15 ^d	11.55 ^{bc}	11.67 ^d
Faro 16	12.60 ^a	13.11 ^a	16.11 ^a	10.06 ^c	12.39 ^b	14.57 ^b
Faro 44	11.40 ^a	12.96 ^{ab}	10.99 ^d	13.03 ^a	13.19 ^a	12.43 ^c
IRGA	10.86 ^b	12.25 ^{ab}	11.70 ^{ab}	13.15 ^a	13.48 ^a	11.74 ^d
Jamila	11.69 ^a	13.94 ^a	13.25 ^c	12.29 ^b	12.50 ^b	13.58 ^{bc}
NERICA 1	9.15 ^c	10.98 ^b	10.71 ^d	11.91 ^{bc}	12.05 ^b	9.91 ^c
NERICA 2	11.52 ^a	13.91 ^a	15.01 ^b	11.40 ^{bc}	13.40 ^a	16.54 ^a
WAS-SIPI	11.20 ^{ab}	13.29 ^a	14.78 ^{bc}	10.14 ^c	13.05 ^a	13.85 ^{bc}
SE±	0.446	0.472	0.544	0.535	0.6	0.612
Salt Concentration (ds/m)						
0.2	15.30 ^a	16.32 ^a	16.79 ^a	14.30 ^a	14.41 ^a	16.84 ^a
0.4	13.88 ^b	14.25 ^b	14.10 ^b	11.68 ^b	12.92 ^b	13.92 ^b
0.6	12.51 ^c	13.40 ^{bc}	13.78 ^c	10.79 ^c	12.93 ^b	13.23 ^b
0.8	11.26 ^d	12.58 ^c	11.47 ^d	11.92 ^b	12.70 ^b	11.22 ^c
1.0	9.48 ^c	9.51 ^d	8.02 ^c	10.44 ^c	9.78 ^c	8.33 ^d
SE±	0.373	0.42	0.437	0.423	0.474	0.483
INTERACTION						
Variety x Salt Concentration						
	NS	NS	*	NS	NS	*

Means followed by the same letters within the same column are not significantly different at 95%.

Interaction Effects Between Salt Concentration and Variety on Radicle Length at 3 WAS.

Table 4 highlights the interaction effects between salt concentration and variety on radicle length. The analysis of variance revealed significant differences ($p < 0.05$),

confirming that both salt levels and variety affect root development. Certain variety–salinity combinations exhibited enhanced root growth, while others were more sensitive to increased salinity.

Table 4. Interaction Effect of salt concentration and variety on plumule length at 3 WAS

Salt	VARIETIES							
Conc (dSm ⁻¹)	FARO-15	FARO-16	FARO-44	IRGA	JAMILA	NERICA-2	NERICA-1	WAS-SIPI
0.2	14.13ab	15.80a	15.67a	13.10abc	15.83a	17.07a	13.97ab	16.80a
0.4	11.70abc	15.03a	13.97ab	12.03abc	14.33ab	15.57a	12.67abc	15.77a
0.6	12.63abc	14.33ab	14.87a	12.50abc	13.77ab	15.00a	10.13abc	14.83a
0.8	11.20abc	12.17abc	14.87a	11.80abc	12.27abc	13.13abc	7.48bc	15.20a
1.0	11.07abc	11.97abc	12.62abc	10.13abc	12.27abc	12.23abc	6.73c	14.83a

Means followed by different letters are significantly different at 95% confidence level of interval ($p < 0.05$) using Duncan's Multiple Test.

Table 5. Interaction Effect of salt concentration and variety on Radicle length at 3 WAS

Salt	VARIETIES							
Conc. (dSm ⁻¹)	FARO15	FARO16	FARO44	IRGA	JAMILA	NERICA2	NERICA1	WAS-SIPI
0.2	12.83abc	15.73a	15.17a	12.37abc	14.63a	15.80a	13.00abc	15.70a
0.4	12.33abc	15.00a	13.63abc	12.00abc	13.97ab	14.47a	12.63abc	15.43a
0.6	12.83abc	13.97ab	14.10ab	11.90abc	12.85abc	15.00a	10.83abc	14.40a
0.8	11.70abc	11.57abc	14.60a	10.43abc	12.73abc	12.87abc	7.41bc	14.70a
1.0	10.53abc	11.13abc	12.80abc	10.50abc	12.25abc	12.03abc	6.81c	15.47a

Means followed by different letters are significantly different at 95% confidence interval ($p < 0.05$) using Duncan's Multiple Test

Discussion

The germination responses of various rice varieties to different levels of salinity were investigated. At a salinity level of 8 dS m⁻¹, germination was entirely inhibited across all varieties (Grieve and Suarez, 1997). The percentage of germination displayed a clear correlation with salt concentration, with germination percentages declining

significantly as salinity increased (Reddy and Vaid, 1983; Mondal *et al.*, 1988). In a non-saline condition, germination percentages for all varieties exceeded 90%. When exposed to a salinity level of 5 dS m⁻¹, NERICA 2 and FARO-16 exhibited a higher germination percentage of over 90%, statistically comparable to three other varieties: FARO-15, FARO-44, and NERICA-2 (Masood *et al.*, 2006). Conversely, the remaining three varieties,

namely IRGA, NERICA-1, and JAMILA, displayed germination percentages ranging from 80% to 90% (Parida and Das, 2005). This trend of decreasing germination percentages persisted at a salinity level of 6 dS m⁻¹. A significant differentiation among varieties was observed at a salinity level of 4 dS m⁻¹ (Khan *et al.*, 2008). Notably high germination percentages were achieved by FARO-16 and NERICA-2. Variability in salinity tolerance during germination has been documented by several researchers (Reddy and Vaid, 1983; Mondal *et al.*, 1988; Masood *et al.*, 2006). Salinity adversely affects germination due to reduced seed germination rates, primarily attributed to osmotic effects resulting from salinity (Grieve and Suarez, 1997). The inhibitory impact of salinity on plant growth is attributed to both osmotic and ionic influences on soil solution (Parida and Das, 2005; Khan *et al.*, 2008). Elevated soil salinity significantly hampers both seed germination and seedling growth, resulting from a combination of high osmotic potential and specific ion toxicity (Grieve and Suarez, 1997). Excessive Na⁺ accumulation in saline soils leads to decreased water potential, impeding water extraction by plants due to osmotic stress (Misra *et al.*, 2005). Plumule length of all rice varieties decreased under salt treatments in comparison to the control, with an overall trend of decreasing length as salinity increased (Javed and Khan, 1995). An exception was observed with a 20% increase in plumule length at a salt concentration of 4 dS m⁻¹, except for the WAS-SIPI variety which experienced a 24% reduction. Within salinity levels of up to 8 dS m⁻¹, FARO 16 exhibited the most

favourable performance, followed by NERICA-2 and NERICA-1, whereas IRGA and JAMILA demonstrated the least growth. At these salt concentrations, plumule length increased by around 32% to 40% for varieties NERICA-1, NERICA-2, FARO-16, FARO-44, and JAMILA; other varieties experienced growth between 41% and 49%. With higher salinity levels at 0.4 dS m⁻¹ and 0.6 dS m⁻¹, reduction percentages ranged from 48% to 65%. Notably, FARO-15 and FARO-16 produced significantly higher plumule lengths at 3 weeks after sowing (3WAS) under these salt concentration levels, yet their lengths only amounted to 52% and 61% of the control. At the high salt concentrations, differences in plumule lengths were less discernible due to substantial reductions in height across all varieties except NERICA-2, NERICA-1, and WAS-SIPI. The decline in seedling height is a common phenomenon observed in various crop plants grown under saline conditions (Javed and Khan, 1995). These results reveal that plumule length declines with salinity, with plumule length showing a consistent decline as salt treatments increased. Based on the results, it's evident that increasing salinity levels have a negative impact on germination percentages and plumule length for most rice varieties. Some varieties, like NERICA-2 and FARO-16, showed better tolerance to salinity, maintaining higher germination percentages and plumule lengths under certain conditions.

Summary

This study investigated the impact of saline irrigation on the germination and early growth of different rice varieties under controlled conditions. The findings revealed

that increasing salinity levels significantly affected seed germination, reducing germination percentage, speed, and uniformity. Varietal differences were observed, with some rice varieties demonstrating higher tolerance to salinity than others. The study also highlighted that soil salinity altered the electrical conductivity (EC) and pH of the growing medium, influencing nutrient availability and uptake during early seedling development.

Conclusion

Salinity stress negatively affects the germination of rice by inducing osmotic and ionic stress, delaying emergence, and reducing seedling vigor. The study confirmed that even low salinity levels could impact early growth, with severe effects observed at higher salinity concentrations. Among the varieties tested, some showed better adaptability, indicating the potential for selecting salt-tolerant varieties for cultivation in saline-prone environments. The results emphasize the importance of understanding varietal differences to mitigate yield losses in saline conditions.

Recommendations

1. Selection of Salt-Tolerant Varieties: Future breeding programs should focus on enhancing the salt tolerance of rice varieties to improve germination and early growth.
2. Management Practices: Farmers in saline-prone areas should consider seed priming techniques to enhance germination under saline conditions.
3. Soil and Water Monitoring: Regular monitoring of soil EC and pH is

essential to assess salinity levels and guide irrigation management.

4. Further Research: Additional studies should evaluate the physiological and molecular responses of rice to salinity stress to develop effective mitigation strategies.

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ORGANIC AMENDMENTS APPLICATION: A PROMISING APPROACH IN LAND DEGRADATION REVERSAL

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ABSTRACT

Land degradation is one of the protracted global challenges associated with crop production declination, soil quality deterioration, and ecosystem malfunction. Unraveling proper understanding on the effectiveness of the use of organic materials in tackling these challenges is imperative and that is what this review set out to achieve. The motivation was born out of the reported fact about the safety, cost-effectiveness and durable effects of organic amendments on soil system relative to inorganic. This review extensively examined the effects of organic amendments on key land/soil quality indices dwelling on the hypothesis that their improvement indicates land degradation mitigation/restoration potential. In achieving that, reputable databases, including but not restricted to Science Direct, Elsevier, Google Scholar, Academia, and Web of Science were consulted for articles sourcing using relevant key terms. Summary of the review indicates that sole or combined application of cow dung, poultry litter, biochar, and compost, curtail and reverse land degradation, mostly through enhancement of soil qualities (physical, chemical, biological). The review, further established a positive link between such effects with crop growth and yield characteristics. The paper also noted the role of quality, quantity, and pyrolysis temperature on the restoration effectiveness of the different organic materials. Drawbacks associated with the application of each organic materials were pointed out and insufficiently explored areas were recommended for further studies. As a contribution, this review promotes advancement of organic-based approach in addressing land degradation and crop productivity shortfall.

Keywords; *Land degradation, mitigation, organic amendment, soil quality, growth and yield characteristics*

INTRODUCTION

Land is a vital non-renewable resource that is constantly being degraded by natural (climatic change and related factors), and anthropogenic (land misuse and soil management) factors (Lal, 2015; Sangita & Sharma, 2021). Land degradation is a global concern that threatens ecosystem services, biodiversity, and food security (Anālayo *et*

al., 2023; Jayaraman *et al.*, 2024). Almost half of the world's arable land is currently at a different stage of land degradation due to a combination of physical, chemical, and biological processes that decline soil quality and productivity (Müller *et al.*, 2023; Umoru, 2023; Jayaraman *et al.*, 2024). This problem extends to Africa and Asia continents where land is a natural

agricultural resource, supporting 70% of subsistence farming (Umoru, 2023). It is estimated that 46 - 80% of the Africa's arable land is degraded, with 30 - 60 kg nutrients loss per hectare per year (African Group of Negotiators Experts Support [AGENES], 2020). The wide range informs that there is a huge spatial variability in terms of land degree and susceptibility to degradation process which mainly depends on the nature of the soil, types of agroecological zones and human activities level.

In Nigeria, the soils of the savanna agroecosystem are inherently poor in fertility status, cation exchange capacity (CEC), fragile in soil structure, and low in activity clays and organic matter content (Jones & Wild, 1975). Further, they are dominantly sandy in nature which aggravate nutrients leaching away from the rooting depth of most crop (Tanko, 2018).

In reversing the trend, the Sustainable Development Goal (SDG 15.3) focuses on combating land degradation by promoting land restoration efforts aimed at ensuring the sustainable utilization of land resources. This initiative is crucial for the conservation of ecosystem services, biodiversity sustainability and agricultural productivity. To effectively address the challenges of land degradation, it is vital to understand the roles of organic amendments (such as cow dung, poultry litter, biochar, and compost). To that end, this review intends to advocate the use of organic amendments with or without the use of inorganic materials in improving the soil quality of degraded land. Literature was searched using variety reputable databases, including but not restricted to Science Direct, Elsevier,

Google Scholar, Academia, ResearchGate, Agora, Semantic Scholars, and Web of Science.

CONCEPT OF LAND DEGRADATION

2.1 Land Degradation

Land degradation (LD) is broadly defined as the reduction or loss of biological and economic productivity and complexity of cropland, range, pasture, forest, and woodlands as a result of a variety of pressures, including land use and management practices (United Nations Statistical Division [UNSD], 2018). Within the soil Science context, land degradation is more related to the gradual decline in soil quality that affects a particular soil's ability to maintain net primary productivity (United Nation Environment Programme [UNEP], 1992). According to the World Soil Charter, the process of LD overridingly results from human actions that partially or entirely modifies soil properties (Food and Agriculture Organization of the United Nations [FAO], 2015a), to disrupts the ecological balance and lowers soil fertility and biodiversity strength (Teng and Zhou, 2020). The LD development manifest through soil erosion, desertification, salinization, acidification, contamination, land destruction and fertility loss (Teng & Zhou, 2020; Zaitsev *et al.*, 2022).

Three sub-indicators namely (a) land cover and land cover changes, (b) land productivity and (c) carbon stocks (above and below ground) (Andrew *et al.*, 2014; Ban *et al.*, 2015; Oehri *et al.*, 2017; Hengl *et al.*, 2017; Cowie *et al.*, 2018; Stumpf *et al.*, 2018) are being used to assess land degradation in Sustainable Development Goal Indicator 15.3.1. These indicators were initially proposed as proxies to

monitor key factors and driving variables that reflect the capacity of the land to deliver ecosystem services within the land degradation neutrality framework (Fu *et al.*, 2015; Orr *et al.*, 2017). Since most cases of land degradation are context-specific which is challenging for a single indicator to fully express the complexity of the state and condition of LD, the use of three factors is more effective (Gilbey *et al.*, 2019).

Causes of Land Degradation

Land degradation represents a multifaceted issue that unfolds due to human and natural influences (Bunning *et al.*, 2016). The factors and mechanisms contributing to land degradation as well as its effects on ecosystem services evolved over time (Cherlet *et al.*, 2018). Natural factors encompass those that defined the ecosystem's inherent ability to produce biomass, deliver goods and services, maintain ground cover, regulate water availability, and support biodiversity. Certain natural elements also play a role in the processes of LD, such as terrain slope and erodibility (the susceptibility of soil to erosion) (Jayaraman *et al.*, 2024). Soil erosion mainly instigated by natural forces like water and wind, which significantly depletes the topsoil layer that is essential for agricultural productivity (Farooq *et al.*, 2023). Other natural factors that are often influenced by human activities are forest fires, landslides, floods, and droughts (Nachtergaele *et al.*, 2012).

On the other hand, the primary human activities contributing to LD encompass a range of practices (Jayaraman *et al.*, 2024), changes in land use, deforestation, bush burning, over use of agrochemicals, total removal of crop residues and cultivation of

marginal lands. The consequences are more experienced in agricultural sector (Zucca *et al.*, 2022). Other noticeable, human driving factors include urban and industrial expansions (Zalesny *et al.*, 2021). The interplay between the natural and human factors complicates efforts towards addressing LD menace.

EFFECT OF LAND DEGRADATION ON SOIL PROPERTIES AND CROP PRODUCTION

Effect of Land Degradation on Soil Physical Properties

Land degradation has a significant effect on soil physical properties such as negative consequences for water and nutrient use efficiency as well as the overall soil productivity (Abdulmalik & Zewide, 2021). Deterioration or loss of soil physical properties leads to soil compaction, fine particle leaching, increased soil bulk density and penetration resistance (Yadav *et al.*, 2019; Hartati *et al.*, 2021). Moreover, compaction reflects compressive forces that reduce soil pore space, hydraulic conductivity and/or surface soil infiltration rates due to sealing, which in turn increase overland flow and the potential for erosion (Donovan & Monaghan, 2021). The combined effects of reduced vegetation cover and deteriorating of soil physical attributes such as macroporosity, permeability, infiltration, pore volume and function, bulk density, and structural aggregation, render the land unproductive by affecting soil functions (Monaghan *et al.*, 2017; Abdalla *et al.*, 2018).

Agricultural expansion and overgrazing are globally recognized as key contributors to accelerated soil degradation and surface erosion, with direct consequences for land

productivity (Donovan & Monaghan, 2021). Additionally, soils which are depleted in organic matter content, aggregates are more likely to slake into smaller sub-units during wetting, resulting in a soil structure that is more likely to erode which limit water infiltration and the emergence of seedlings (Tisdall & Oades, 1982; Matano *et al.*, 2015; Blanco-Canqui & Ruis, 2018). Notably, deteriorating soil physical quality reduces soil function in terms of soil physical attributes which had negative consequence on soil physical productivity especially water and nutrients retention.

Effect of Land Degradation on Soil Chemical Properties

Land degradation results in several negative effects on chemical soil properties including a decrease in soil pH, leaching of soluble salts and nutrients, accumulation of weathered salt, loss of soil organic carbon, reduction in nitrogen content and phosphorus availability, removal of exchangeable bases, decreased cation exchange capacity and depletion in soil fertility resistance (Yadav *et al.*, 2019; Hartati *et al.*, 2021). Degradation of soil chemical properties caused by both natural and human factors resulted in long-term consequences for ecosystems and agricultural productivity (Donovan & Monaghan, 2021). Natural processes of chemical degradation, such as the formation of pedogenic calcium carbonate and subsoil sodicity, could impair soil hydraulic properties and reduce crop productivity (Pal, 2017).

Furthermore, the buffering ability of soil, the degree to which the decline of soil organic matter concentrations has changed the pH level (Page *et al.*, 2020), and

lowering cation exchange capacity which in turn reduces nutrient retention by deteriorating soil quality (Sithole & Magwaza, 2019), are some soil chemical properties affected during land degradation. Therefore, nutrient depletion (Yadav *et al.*, 2019), soil acidity and toxicity of high concentrations of Al and Mn in the root zone served as a serious problem in sub-humid and humid regions (Eswarn *et al.*, 1997). Soil salinity and erosion problems are not only deteriorate the quality and quantity of crop production but also severely affect the lands which may not be used for further cultivation (Yadav *et al.*, 2019). Remarkably, deteriorating soil chemical quality reduces soil function in terms of soil chemical attributes which had negative consequences on soil chemical productivity, especially soil pH, organic matter content and cation exchange capacity.

Effect of Land Degradation on Soil Biological Properties

Land degradation has a significant effect on the biological properties of soil which includes a decline in organic matter content due to the removal of vegetation from topsoil, decline in microbial population, total and biomass carbon, biomass N, P, and S, and soil respiration rate resulted to decline in land biodiversity (Sims, 1990; Yadav *et al.*, 2019). Furthermore, due to the deterioration of soil quality lowers microbial activity and soil fauna population (Land Dgradation Assessment in Drylands [LADA], 2011), which also lead to decline in C turnover and nutrient availability, the activity of numerous soil enzymes involved in the cycle of C, N, P, and S is reduced, killing off soil fauna and reducing the land

biodiversity process (LADA, 2011;Yadav *et al.*, 2019).

In addition, biodegradation of organic compounds by soil micro-organisms involves a process known as mineralization whereby microorganisms convert the organic molecules to obtain carbon and energy for growth and multiplication, releasing the inorganic forms of N, P, S or other elements and also biodegradation process also depends on soil nature and microbial population. Land degradation processes erode top soil and sheltering of microorganisms which results in a reduction in the biodegradation process (Yadav *et al.*, 2019). Additionally, all of the soil's physical, chemical, and biological characteristics are crucial for the survival of soil fauna and microorganisms for the improvement of soil productivity (Yadav *et al.*, 2019). Conspicuously, the deteriorating biological quality of soil in terms of biological attributes of soil may hinder the biological function of soil, especially on beneficial soil microbes and enzymatic activities, as well as mineralization of organic matter.

3.4 Effect of Land Degradation on Crop Production

Land degradation is the main threat to soil and crop productivity (Utuk & Daniel, 2015). Changes in agricultural land to non-agricultural land, deforestation, desertification, erosion, salinization, waterlogging and organic matter depletion lead to land deterioration which affect crop growth and yield (Guo *et al.*, 2013; Muhammad *et al.*, 2020). Land degradation has negatively affected the overall maize production (growth parameters such as: plant height, leaf area index, and number of

leaves) due to the loss of surface soil rich in organic material, thereby affecting nutrient availability for plants and hinders the crop growth (Adewuyi & Baduku, 2012).

Soil quality deterioration has also a significant impact on various yields parameters of maize which affects grain yields, harvest index, seed test weight, biological yield, cob length, cob weight, cob diameter, and the number of cobs (Tanimu *et al.*, 2007;Yigermal *et al.*, 2021). The loss of nutrients from degraded land, in addition to the type and growth stages of seedlings also played a role in determining yield and yield-related traits of transplanted maize (Zhang *et al.*, 2018), leading to terminal moisture stress and grain yield loss (Huang & Rozelle, 1995). Drought and waterlogging during the maize growing season severely affected both the growth or vegetative and yield stages which led to reductions of crop performance (Djaman *et al.*, 2013). Remarkably, the deterioration of soil quality reduces the growth and yield of crops due to insufficient of water and nutrient required by the crop to achieve and maintain its high potential in terms of produce.

4.0 CONCEPT OF LAND DEGRADATION RESTORATION

Apart from the organic farming approach various strategies and practices have been implementing to address land degradation including agroecology practices, sustainable farming techniques, conservation agriculture and initiatives for afforestation, as well as soil and water conservation techniques (Jayaraman *et al.*, 2024). Furthermore, the organic farming approach emphasizes on sustainable practices such as the use of animal manures, crop rotation,

and biological pest control (Jayaraman *et al.*, 2024). Jointly, these practices contribute to the improvement of soil quality thereby reducing the adverse environmental effects typically associated with conventional agricultural practices (Raj *et al.*, 2024). Remarkably, the increase in soil organic carbon (SOC) sequestration is regarded as a viable approach to restore land degradation and improve crop productivity.

Notably, soil amendment has been reported as any substance which is applied to soil in order to enhance its physical qualities, including water retention, permeability, water infiltration, drainage, aeration and structure as well as chemical and biological qualities and overall soil productivity (Davis & Whiting, 2013; Muzyamba *et al.*, 2021). Organic (compost, wood chips, biochar, animal manure, straw, husk, and sewage manure) and inorganic (mineral) amendments are two fundamental categories of soil amendments (Davis & Whiting, 2013).

Organic amendments are extremely rich in organic matter, macro and microelements, act as substrates for microbial growth and in turn improve soil fertility. On the other hand, inorganic (mineral) amendments include minerals that contribute to soil fertility e.g gypsum, frequently used to lower soil pH by combining high sodium salts with lime or limestone and lowering the pH of the soil (Davis & Whiting, 2013). Notably, Kadiri *et al.*, (2021); Sisouvanh *et al.*, (2021) reported that organic amendments play a crucial role in agroecosystems processes by enhancing soil quality. This could be attained through improved soil organic matter content,

carbon sequestration (Li *et al.*, 2019), nutrient availability, water retention, aggregate stability, and substantial crop yield increases (Jiang *et al.*, 2018).

In spite of the multifaceted positive effects of the listed organic amendments, literatures have pointed out some critical drawbacks associated with their application. Findings by Muhereza *et al.*, (2013), indicated that the spread of pest, huge tonnage requirement and high cost associated with their transportation and application make their application less friendly. While about one-third of farmers noted increased weed devastation from cow dung application, others (33%) were concerned with the possibility of human disease transmission due to lack of good hygiene of the cow dung materials (Muhereza *et al.*, 2013). Poor handling techniques and low-quality of animal feed are partly responsible for low nutrient-richness of cow dung thereby reducing its potential as an alternative fertilizer source. Grannt, (2023) added that poorly handled manure is a breeding hub of pathogens and parasites and may contain active heavy metals that affect crop growth and development. Although Kumar *et al.* (2013) have alluded that proper treatment and good storage system curtail pathogens development, yet most farmers lack accessibility to machines and expertise necessarily required for hygienic treatment. They further cited observed presence of *Salmonella*, *Yersinia enterocolitica*, and *Cryptosporidium* in cow and poultry dungs. Contamination of groundwater was similarly reported and attributed to the excessive NO₃-N in poultry manure (Heathman *et al.*, 1994; Hoover *et al.*,

2019). Notably, it is realized that proper handling and storage of organic materials provide more productive and cost-effective in restoring soil deterioration and crop sustainability compared to the improper use of manure or inorganic fertilizer alone.

Agricultural soils are increasingly being enhanced with organic amendments serving as alternatives or supplements to inorganic fertilizers (Urta *et al.*, 2020). Various soil amendments, including compost, charcoal, and livestock manure, are employed to improve soil fertility, physicochemical properties and soil biota, thereby nurturing crop growth and productivity (Clements & Bihn, 2019). The incorporation of organic amendments into the soil contributes to the improvement in soil porosity, availability of water for crops, cation exchange capacity and essential plant nutrients (Cercioglu, 2017; Mitran *et al.*, 2017; Zhao *et al.*, 2021). Among organic fertilizers poultry manure is noted for its high nutrient concentration which is vital for crop development (Dang *et al.*, 2021). Research has consistently indicated that the proper application of poultry manure significantly improves the physical, chemical, and biological properties of soil (Agbede *et al.*, 2017; Hoover *et al.*, 2019). Additionally, cow dung is recognized for providing substantial plant nutrients and enhancing physicochemical characteristics (Ozlu *et al.*, 2019). Recently, the application of biochar as soil amendment in agricultural settings has gained support in addressing land degradation (Bohara *et al.*, 2019). Furthermore, the use of composted organic residues has been shown to improve aggregate stability, water retention, hydraulic conductivity, and water

penetration in agricultural soils, ultimately benefiting crop production (Mujdeci *et al.*, 2017; Oueriemmi *et al.*, 2021).

Recent research highlighted the significance of long-term amendments, like compost, biochar, beside cow dung and poultry manure (Dawaki *et al.*, 2019), due to more of recalcitrant carbon, effectiveness and long-lasting effect in restoring degraded lands and ensuring sustainable agricultural production for future generation.

10 ORGANIC APPROACH ON SOIL PROPERTIES

5.1 Organic Approach on Soil Physical Properties

In previous studies, the application of soil amendment has significantly affected the soil physical properties. For example Cercioglu (2017) worked on maize production in the western Anatolian region of Turkey, he reported that the application of organic amendments such as chicken manure, bio-humus, and composted tobacco waste improved soil physical properties such as improved in porosity, structure stability index and field capacity. Similarly, in Anambra State in southeast, Nigeria application of poultry manure, cassava peel, pig waste, and rice husk at a rate of 20 t ha⁻¹ decreased bulk density, improved total porosity and moisture content of the amended than unamended soil by which poultry manure had the highest improvement among the amendments for sole maize, sole cowpea, and maize-cowpea intercrop (Onunwa *et al.*, 2021). Poultry manure had the highest contribution compared to pig manure and cow dung (Nweke & Igwe, 2021). Use of poultry manure at 2 t ha⁻¹ was significantly increased the water-stable soil aggregates as

the highest compared to the lowest in control (only inorganic fertilizers). The order of increasing soil aggregates among the organic amendments: poultry manure > rice straw > cow dung > vermicompost (Rahman *et al.*, 2022).

Angst *et al.* (2017) & Ibrahim *et al.* (2021) observed that an organic additive with a higher concentration of recalcitrant material (lignin, lipids, cellulose, etc.) had slower decomposition rates and longer-lasting effects on aggregate stability. According to earlier researches, biochar amendment application to soil was useful in regulating soil thermal properties, decreased soil bulk density, increased soil water holding capacity, soil porosity and soil aeration with beneficial effect on roots proliferation (Baiamonte *et al.*, 2019; Karim *et al.*, 2020; Chang *et al.*, 2021). However, the literature assessment conducted by Blanco-canqui. (2017) also revealed that, in a few instances biochar application at rates <10 Mg ha⁻¹ may not significantly reduce bulk (Usowicz *et al.*, 2016; Xiao *et al.*, 2016). Pratiwi & Shinogi, (2016) found that biochar application even at rates as high as 2% by weight (which is equivalent to about 50 Mg ha⁻¹ of biochar did not affect bulk density.

Numerous researches examined the impact of biochar on soil hydraulic characteristics (Abdo, 2021; Liang *et al.*, 2021; Chen *et al.*, 2021) the results have been inconsistent, ranging from a reduction to no desirable effect (Atkinson, 2018; Wang *et al.*, 2021). In addition, Are *et al.*, (2018) noted that the saturated hydraulic conductivity after the addition of poultry manure biochar was lower (9.2 mm/hr) than for other organic amendments (16.5–18.2 mm/hr). Biochar improved aggregate stability, as the biochar

contents increased with increasing biochar dosage in all soil aggregate fractions except the microaggregate fraction (Sun *et al.*, 2021). Soil structural index increased by 147% at fbc = 0.091, indicated the effectiveness of this biochar fraction in enhancing aggregate stability (Baiamonte *et al.*, 2019; Chen *et al.*, 2021). Remarkably, the effectiveness used of biochar depend on the nature of biochar in addressing soil quality.

Additionally, research had shown that compost is one of the organic amendments, used to avail suitable soil physical condition, such as improved aggregate stability, hydraulic conductivity, penetration resistant, and water retention capacity for plant root development resulting in increased agricultural production (Mujdeci *et al.*, 2017; Şeker & Manirakiza, 2020). Cow dung and compost had more surface area, which encouraged the circulation of essential soil nutrients, reduces water logging, and enhances crop development (Darusman *et al.*, 2018). Improved or increased in water stable aggregates under the veticompost treatment was 3.4 to 26.7% greater than for the other treatments. The comparison of the soil physical quality indices indicated positive effects from the amendments on the soil physical properties in the order: unamended control < poultry biochar < poultry tea < non-composted poultry manure < veticompost (Are *et al.*, 2018). Generally, the effectiveness of organic amendments in addressing the land deterioration on soil physical properties depend on the recalcitrant nature of the organic materials and soil managements.

2 Organic Approach on Soil Chemical Properties

The effect of soil amendments on chemical properties was reported in many studies however, the outcomes vary based on the management and climatic condition (Mi *et al.*, 2018; Ahmadu *et al.*, 2020) due to specific and distinctive characteristics, rates of addition and composition of the amendments (Arif *et al.*, 2016). Mi *et al.*, (2018) reported that the use of spent mushroom compost, green manure, cattle manure, and rice straw are the four common organic materials widely used by local farmers in southern China. Application of cattle manure to the soil surface led to increased soil pH, cation exchange capacity and lower exchangeable acidity and Al^{3+} concentrations compared to applying NPK alone. Eche *et al.* (2013) reported that the application of cow dung alone or in combination with sole urea fertilizer at the rate of 90 kg N ha^{-1} increased soil pH, organic carbon, total nitrogen, and cation exchange capacity by 2, 55, 17 and 26 % respectively as compared to sole urea. Similarly, application of different rate of cattle manure slightly increased soil pH value of about 5.20% and total nitrogen by 133.33%, likewise, percentage of organic carbon, Ca and Mg and the highest was recorded from soil supplied with 20 t ha^{-1} however, available P, Na and K was slightly decreased across the different level of application respectively (Eleduma *et al.*, 2020; Dang *et al.*, 2021).

Denton *et al.*, (2020) reported that the application of poultry manure, cassava-based compost, and vermicompost had increased the soil organic carbon content by 24.1, 18.2, and 22.3% respectively. Application of biochar made from cow dung, a combination of cow dung + urea,

and poultry droppings improved soil pH, organic matter, total nitrogen, and available phosphorus compared with the unamended soil (NPK-15:15:15) (Ndzeshala *et al.*, 2023). Similar, trends were observed for sole maize production in which the poultry manure at 20 t ha^{-1} had significant effect on exchangeable Al^{3+} and Na^{+} ; organic carbon, soil pH, available phosphorus and CEC but had no significant effect as compared to the control (Onunwa *et al.*, 2021). Application of organic amendments at 2 t ha^{-1} positively appeared for the increasing C contents and C sequestration in the soils which revealed that the vermicompost was far more effective in terms of C sequestration, followed by poultry manure, cow dung and rice straw as compared with only inorganic fertilizers (Rahman *et al.*, 2022).

Moreover, biochar has attracted much attention as a soil amendment which has a slow decomposition rate and its application to soils can sequester SOC compared to non-amended soils for example, 1.4 times higher total soil C was found in hardwood biochar amended soils compared to non-amended soils (Lentz & Ippolito, 2012). Sun *et al.*, (2021) reported that four biochar doses were tested: control (without biochar), biochar at 15.75, 31.5, and 47.25 t ha^{-1} which increased the pH, EC, and CEC and the pH, EC and CEC increased simultaneously with increasing biochar dose but decrease the levels of exchangeable H^{+} and Al^{3+} . Moreover, biochar derived from wood, solid digestate and biochar derived from solid digestate in which all the biochars increased pH and EC compared to the soil, while only biochar derived from solid digestate, and solid digestate showed significant increase in

secondary macro- and micronutrient-element content (Ca, Mg, Na, Fe, Mn, and Zn) (Calamai *et al.*, 2020).

Furthermore, application of compost into soil provides better nutrient input compared to raw manure from the perspective of C sequestration for example, four years after application about 36% of applied compost remained in the soil as sequestered C, as compared to only 25% of applied raw manure (Eghball & Ginting, 2003; Shrestha *et al.*, 2018). Oueriemmi *et al.*, (2021) reported that municipal solid waste compost, sewage sludge compost and farmyard manure were tested at rates of 0, 20, 40 and 60 t ha⁻¹ in which application of the amendments improved organic matter, cation exchange capacity and available P, Ca, Mg and K in the soil. Moreover, compost and biochar applied alone or in combination significantly increased soil pH, total organic carbon, available phosphorus, mineral nitrogen, reduced exchangeable acidity, and increased effective cation exchange capacity in both soils (Mensah & Frimpong, 2018). The combination of compost and biochar as compared to compost amendments alone resulted in decreased contents of available K, P and NO₃⁻N in all soils except for available K in sandy soil in Thailand and NO₃⁻ N for clayey soil in Vietnam (Doan *et al.*, 2021). Generally, the effectiveness of organic amendments in addressing the land deterioration on soil chemical properties depend on the recalcitrant nature of the organic materials and soil managements.

5.3 Organic Approach on Soil Biological Properties

Soil amendments had significant effect on biological properties which had been

widely documented in the literature therefore, soil fauna and flora play a key role for the functioning of the soil ecosystem. However, the level of transformation and other biotic processes depends mainly on the existence (Yanarda *et al.*, 2017; Aytenew & Bore, 2020). Addition of organic amendments to soils promotes the growth of microorganisms, which stimulates soil respiration and nutrient cycling and the synthesis of various phytohormones and low molecular mass compounds and enzymes that benefit plant growth (Lakhdar *et al.*, 2008; Oueriemmi *et al.*, 2021). Soil enzymes such as dehydrogenase, acid phosphatase and β -glucosidase showed a significant increase with the inclusion of organic amendments in fertilizer schedule (Mangalassery *et al.*, 2019). Moreover, the diversity and richness of bacteria and eukaryotic were lower in the synthetic than in the organic amendments. The addition of organic amendments promoted the growth of Acidobacteria and Gemmatimonadetes bacteria. On the contrary, members of Actinobacteria and Proteobacteria were more abundant in the soil treated with synthetic fertilizer (Cesarano *et al.*, 2017). Consequently, the use of organic amendments contributed immensely in improving soil quality thereby providing food as a source of energy to the soil microbes in addressing the soil deterioration.

6 ORGANIC APPROACH ON CROP PRODUCTION

6.1 Organic Approach on Crop Growth Characteristics

Organic amendments play vital roles in crop production depending on the amendment's nutrient contain composition

and rate applied. Khatun *et al.* (2019) reported 86.67% germination percentage in both cow dung and vermicompost treated soil, while the control soil with no amendment had the lowest germination percentage of 66.67%. The growth attributes of maize plant (DMR-ESR-Y) increased significantly increases with increasing rates of cattle manure, applications rate of 20 t ha⁻¹ gave the highest vegetative growth attributes such as leaf area index (403.04) was recorded at 20 t ha⁻¹ which was higher than 15 t ha⁻¹ (381.13), 10 t ha⁻¹ (379.91), 5 t ha⁻¹ (378.07) and 0 t ha⁻¹ (313.62). Likewise, stem girth, plant height and number of the leaves which were wider in girth, taller in height and higher in number of leaves per plant respectively at 20 t ha⁻¹ than the other levels of manure and control (Eleduma *et al.*, 2020).

Ahmadu *et al.* (2020) reported that maize plants treated with poultry manure and cattle manure were taller than control plants on plant height in which the tallest and thickest plants were observed on plots treated with poultry manure. Application of 1/2 recommend rate of fertilizer + 2 t ha⁻¹ poultry manure gives higher plant height, leaf area index, dry matter accumulation, and number of functional leaves of sweet corn (*Zea mays saccharata* L.) (Jan *et al.*, 2023). Asfaw, (2022) reported that the vegetative growth of maize variety, 'Bahir Mashila' were lower in untreated soil indicating that poultry-cleaned sites offer the highest number of leaves per plant, thick stem and highest leaf area index. However, sweet maize (*Zea mays saccharata* L.) spaced at 40 cm x 25 cm with 20 t ha⁻¹ of chicken manure resulted in

the highest leaf area index, stem girth in both years of the study (Berdjour *et al.*, 2020; Effa *et al.*, 2021, 2022). Similarly, growth parameters were increased from four soil organic amendments viz: cassava peel, poultry manure, pig waste, and rice husk at the rate of 20 t ha⁻¹ while the poultry manure gives highest (Berdjour *et al.*, 2020; Onunwa *et al.*, 2021; Effa *et al.*, 2021, 2022).

Tanure *et al.* (2019) also noted that the addition of biochar (0, 5, 10, 20, 40, and 60 g of biochar per kg of soil) increased plant growth indicators such as height, stem diameter, leaf area, and shoot and root production responded even at the lowest biochar dose. Furthermore, enriched paddy straw compost improved growth of parameters such as plant height and chlorophyll content in sweet corn (Pangaribuan *et al.*, 2017; Rosa *et al.*, 2020). Application of chemical fertilizer (nitrogen fertilizer = 350 kg ha⁻¹, phosphate fertilizer = 125 kg ha⁻¹, potassium fertilizer = 125 kg ha⁻¹) of maize and corn cob (compost) organic amendment at a rate of 2.5, 5, 7.5, 10 or 12.5 t ha⁻¹ of which the rate of 12.5 t ha⁻¹ had an effective increased in leaf area index, root length, levels of chlorophyll a and chlorophyll b (Budiastut *et al.*, 2023). Generally, the used of organic materials in addressing land deterioration aid in improving crop growth by providing nutrients required by crop to attain higher potential of crop growth.

2 Organic Approach on Crop Yield Characteristics

Numerous studies have shown that organic amendments significantly play vital roles on crop production. The crop response may be due to the fertilizing effect of the

amendment, some effect related to the carbon or biological components of the amendment, or a combination of both (Doan *et al.*, 2015; Hijbeek *et al.*, 2017; Schjønning *et al.*, 2018; Celestina *et al.*, 2019). For example, Anees *et al.* (2016) reported that the maximum plant height of maize at maturity (218.67 cm), ear length (20.47 cm), number of grains per ear (372), 1000-grain weight (260.33 g), biological yield (18.58 t ha⁻¹), grain yield (7.35 t ha⁻¹), harvest index (39.56) and grain protein contents (9.64%) were recorded where 8 t ha⁻¹ Poultry Manure + 15 kg ha⁻¹ Humic Acid + 6.25 kg ha⁻¹ Micronutrient (Zn, Fe, Cu, Mn) were applied. Application of recommended NPK, rate for wheat along with either cow dung or poultry manure at 5 t ha⁻¹ exhibited the highest in all growth and yield parameters of wheat (BARI Gom 26) (Azad *et al.*, 2022). Application of manure of 2 t ha⁻¹ gives the highest yield such as weight of cob with cornhusk (454,82 g), weight of cob without cornhusk (319,78 g), length of cob (23 cm) and the diameter of cob (51,79 mm) (Mughtar *et al.*, 2020).

Research highlights the significant effect of poultry manure on maize yield quality. The MMRI maize variety showed greater yield compared to the Pearl variety in terms of cob length, cob diameter, cob weight, number of grains per cob, grain yield, and biological yield (Rasool *et al.*, 2023). Furthermore, maize variety 'Bahir Mashila' exhibited lower vegetative growth in untreated soil, while poultry-manured sites achieved the highest grain yield of 5.7 t/ha. In comparison, horse manure produced a yield of 4.2 t/ha, sheep manure yielded 3.9 t/ha, and untreated soil recorded the lowest yield at 2.8 t/ha (Asfaw, 2022). Likewise,

maize varieties such as 'SUWAN-1-SR,' 'Oba 98,' and the 'Uselu' local variety treated with poultry and cattle manure showed similar kernel numbers per row and 1,000-grain weights, both significantly higher than untreated plants. Grain yields were also higher in plants fertilized with poultry manure (2.11 t/ha) and NPK (2.22 t/ha) compared to control treatments (Ahmadu *et al.*, 2020). Moreover, the application of poultry manure at a rate of 20 t/ha significantly increased dry matter and green cob yields (Effa *et al.*, 2021).

According to Calamai *et al.* (2020) the solid digestate had the best maize performance (biomass dry weight, seed number, and weight per ear) while using biochar derived from solid digestate, while plant growth in biochars derived from wood had reduced results. Maize grown in soil amended with digestate-enriched biochar showed a higher biomass yield compared to the control and non-enriched biochar treatments but was slightly lower than yields lower yield (20%–25%) from chemical fertilizer treatments (Kizito *et al.*, 2019). Moreover, application of 20 t ha⁻¹ of compost + NPK fertilizer gives the highest fresh weight of cob without husk 79.26 g increased by 51.54% when compared with the lowest yield on 52.30 g fertilizer without fertilizer of sweet corn (Ulm *et al.*, 2019; Situmeang *et al.*, 2019). Additionally, tofu dregs compost positively influenced cob length, plant height, and leaf count at 60 days after planting (Rosa *et al.*, 2020).

The application of 5 t/ha of biochar and compost increased grain yield by 46.29% and biological yield by 13.4% compared to untreated control (Zahra *et al.*, 2021). Composted and non-composted manures,

along with biochar, produced higher maize grain yields (1.48–1.73 t/ha) for *Zea mays* var. DMR-ESR-Y compared to unamended controls (0.87 t/ha) (Are *et al.*, 2018; Denton *et al.*, 2020). Additionally, compost and mulch improved cob weight and biomass by 30% and 18%, respectively, while compost applied at 20 t/ha achieved similar growth and yield results to NPK fertilizer (15-15-15) at 200 kg/ha (Zaki *et al.*, 2018). Generally, the used of organic materials in addressing land deterioration aid in improving crop growth by providing nutrients required by crop to attain higher potential of crop yields.

7.0 CONCLUSION AND RECOMMENDATION

Land degradation is also one of the global mainstay problems of crop production and food security which affects the function of ecosystem. This phenomenon occurs through anthropogenic and natural activities which lead to the deterioration of soil quality. Compared to the use of the conventional system of farming by which the application of inorganic material alone could not be sustainable. Therefore, the use of organic amendments with or without the use of inorganic amendments could serve as an additional sustainable approach to restore land degradation thereby reducing the excess or overuse of inorganic or chemical fertilizer in addition to the enhancement of soil properties and crop production. The use of inorganic material alone could lead to hazardous and harmful to the ecosystem functionality. Notably, it has been observed that, lack of adequate nutrient and composite analyses of organic amendments prior to the experiment constitute difficulty for justifying the

observed effects and variation among different results. Equally effect of preparation procedures and application methods of such organic amendments have received unsatisfactory attention. It is crucial to close these gaps of for a proper understanding of the subject matter. The use of proper organic approach offers a significant, sustainable and cost-effective alternative by reducing the environmental effect. However, further studies are required to optimize the use of organic materials with or without the use of inorganic amendments in restoring land degradation and sustainable crop production thereby sustaining food security. The further studies should also explore the use of organic materials that are more nutritive and effective in terms of recalcitrant carbon which mainly depends on the quality, quantity, feedstocks and temperature at which the organic material pyrolyzed in case of biochar, which aids in improving the soil quality at large. Overall, this review study contributes to the growing field of organic approach thereby providing insights into the development of sustainable and cost-effective in addressing land degradation and crop productivity.

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ASSESSMENT OF EFFLUENT DISCHARGED RIVER OLUWA FOR AGRICULTURAL IRRIGATION AT OKITIPUPA

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ABSTRACT

The study was carried out to investigate the suitability of effluent discharged river oluwa as an agricultural irrigation water. Irrigation water quality refers to water suitability for agricultural purpose. Good water quality has the possibilities to allow maximum yield of crops under good soil and water administration practices. Oluwa River water which they are using for irrigation purposes by the rural communities was evaluated for its quality. Samples were taken before discharge of effluent, point of discharge, 2km and 4 km up and downstream from the discharge point. At each sampling location, six (6) samples were collected to ensure accuracy by replication. A total of thirty six samples (36) were collected and their Temperature, pH, COD, BOD, Na, O&G, Cl, and TSS were analyzed for irrigation water quality. Descriptive statistics was carried out on the data. The results obtained were compared with UNEP standards. A paired sample t-test was also carried out to test for any significant difference in the mean value of parameters from L1 to L6. Based on the findings of the research, Temperature, pH, COD, BOD, Na, O&G, Cl, and TSS. Data obtained were subjected to statistical analyses of variance (ANOVA). Significant variations exist in most of the chemical variables among the sampled sections. Comparison of the investigated parameters at the various sections of the river with the standard limit of effluent guideline of UNEP showed that the river is polluted but can be used for irrigation with good management practices. However, it was recommended that the Okitipupa oil palm mill should treat their effluent before discharge to encourage farming and fishing activities in the area.

Keywords: Okitipupa Oil Palm Mill, Effluent, river oluwa, Irrigation. Quality, physiochemical properties, UNEP

INTRODUCTION

In Nigeria, the interim water quality criterion in temperature for different water uses is: the protection of aquatic life, it is 20 - 33°C (4 mg O₂/l), for irrigation water it is 20 - 25°C (2mg O₂/l) and for recreational water it is 20 - 33°C (2 mg O₂/l) (FEPA1991). Water plays a vital role in human life and is an essential natural

resource that plays an important role in supporting irrigation and economic growth. The consequence of climate change, speedy growth of population coupled with extension of urbanization and industrialization combined with improper sanitation management have leads to the increase in the river water contamination

(Tsado *et al.*, 2014; Al-Isawi *et al.*, 2016). The knowledge of irrigation water quality is important to soil conservation and maximum agricultural productivity. Surface water quality is the physical, biological and chemical characterization of surface water, which measures its suitability for human and animal consumption, irrigation and other uses. The quality of water body is assessed using several physical, chemical and biological parameters, in fact, values of these parameters are harmful to crop if they exceed certain threshold values (APHA 2005). According to FAO statistics, 20% of the land is irrigated but produces 40% of the crops Tiri *et al.* (2018). Irrigation water quality refers to water suitability for agricultural purpose. Good water quality has the possibilities to allow maximum yield of crops under good soil and water administration practices.

Agricultural water sources must be of good quality before it is acceptable for a given use (Wong, 2010). Pertaining irrigation, several scientists have advocated and expounded that water quality parameters for evaluating irrigation water quality include salinity hazard, water infiltration rates (sodium hazard), pH, carbonate and bicarbonates, and specific ion toxicities (Bauder *et al.*, 2011), and concluded that irrigation water quality is evaluated based upon total salt content, sodium and specific ion toxicities. Thus, assessing the composition of the effluent waters is very imperative, and helps in ascertaining the suitability of the effluent for irrigation purpose.

For any Irrigated agriculture to be effective and efficient, the assessment of the water quality is one of the most important aspects,

because water quality has direct effect on crop growth and development as well as soil itself. For instance, Bouksila *et al.* (2013) documented that human activities that involved urbanization, agricultural activities, over use of fertilizers or chemicals, inadequate management of land use and sewage disposal have directly or indirectly affected the quality of water and makes it unsuitable for irrigation as a result of excess salts and other pollutants being present in the water. Hence, continuous application of irrigation water without effective irrigation water quality assessment gives rise to salts and other pollutants accumulation in the soil which will generally affect the growth and development of crops.

Food produce processing industries generate large quantities of effluent with a high Biochemical Oxygen Demand (BOD) which when discharged untreated into water courses and soil, adversely affects aquatic life, domestic water supply and land uses (Awotoye *et al.*, 2011). Oil palm cultivation and processing, like other agricultural and industrial activities, also raises environmental issues. Palm oil processing is carried out using large quantities of water in mills where oil is extracted from the palm fruits. During the extraction process, about 50% of the water results in palm oil mill effluent. It is estimated that for every 1 tonne of crude palm oil produced, 5-7.5 tonnes of water end up as palm oil mill effluent (POME) (Okwute, O.L, N.R Isu, 2007; Wu *et al.*, 2009 and Aliyu *et al.* 2012). In major oil palm producing nations like Indonesia and Malaysia, production of crude palm oil results in an annual production of up to 3 billion pounds of palm

oil mill effluent, and these effluents generally contain materials which has concentrations, above threshold values (Wu *et al.*, 2009), and are injurious to the environment. In Nigeria, current efforts in the oil palm sector, is aimed at increasing/improving oil palm production through value chain activities, one of which is rehabilitation of oil palm mills and establishment of new ones aimed at generating income for the nation. When this is achieved, no doubt POME production will increase and this calls for attention.

It has however been noted that the primary means of disposing effluent is through river systems near the industries and often fish and other aquatic organisms get killed and local people are denied of the availability of local water sources for domestic uses and fishing (Ezemonye *et al.*, 2008) and this need to be addressed. These effluents have a great deal of influence on the pollution of the water body, and can alter the physical, chemical and biological nature of the receiving water body (Kanu *et al.* 2011). The Okitipupa palm oil company is located near river Oluwa and their effluent is discharged into this river. The discharge of the effluent of Okitipupa oil palm company to Oluwa River in Okitipua Local Government Area, Ondo State, Nigeria, has been noted to constitute some environmental nuisance as revealed by high values of pollution characteristics (Aiyesanmi *et al.*, 1997). These pollutants if not attended to constitute public health hazards (Arimoro *et al.*, 2007).

Water pollution by effluent has therefore become a question of considerable public and scientific concern in the light of evidence of their extreme toxicity to human

health and to biological ecosystems (Katsuro *et al.*, 2004). Water contaminated by effluent from various sources is associated with heavy disease burden (Okoh, 2007) and this could influence the current shorter life expectancy in the developing countries compared with developed nation (WHO, 2002).

Many studies were carried out on industrial effluents (Olayinka and Alo 2004; Essoka and Ummaru, 2006; Ebiyare and Luv, 2010; Abdulmumini *et al.*, 2015; Amoo *et al.*, 2018) particularly on their quality. In Northern Sudan Savannah Ecological Zone however, few concerted efforts on the evaluation and assessment of industrial effluents particularly from tannery and textile industries were made (Akan *et al.*, 2009; Danazumi and Bichi, 2010; Abdulmumini *et al.*, 2015), while some focused on underground water and mixture of the industrial effluents (Isa and Jimoh, 2015; Amoo *et al.*, 2018; Sani *et al.*, 2020). Yet, despite these numerous investigations, there is a gap in knowledge and understanding as very little information is available about the irrigation quality assessments of these effluents to justify their application as irrigation amendments in agricultural irrigation using international standards. In other parts of the world, standards for irrigation water are in place while in Nigeria, such standards are yet to be set. For the purpose of this study, UNEP standard for discharge of effluents in to the environment will be used for assessing compliance of irrigation quality standards. This is against the background that water is an environmental factor. Therefore, the aim of this paper was to evaluate irrigation water quality of industrial effluents in

Okitipupa and assess whether they comply with permissible irrigation quality standards.

The Study area

Okitipupa oil palm company is located in Okitipupa Local Government Area of Ondo State. The LGA lies between Longitudes $4^{\circ} 3''$ and $6^{\circ} 00''$ East of Greenwich Meridian and latitudes $5^{\circ} 45''$ and $8^{\circ} 15''$ North of the Equator. The LGA has a land area of about 638 sq km. The Local Government is in the high forest Zone of rain forest, although the shifting cultivation

system of the people has turned the high forest into shrubs and herbs zone. The humidity is relatively high and the annual rainfall is about 2000mm. Apart from River Oluwa, which runs through the state, the local government is blessed with rivers and streams such as river Akeun, Omiju, Chen, among others. Some of which flow into the Atlantic Ocean. They all support fish farming and production of oil palm among other crops.

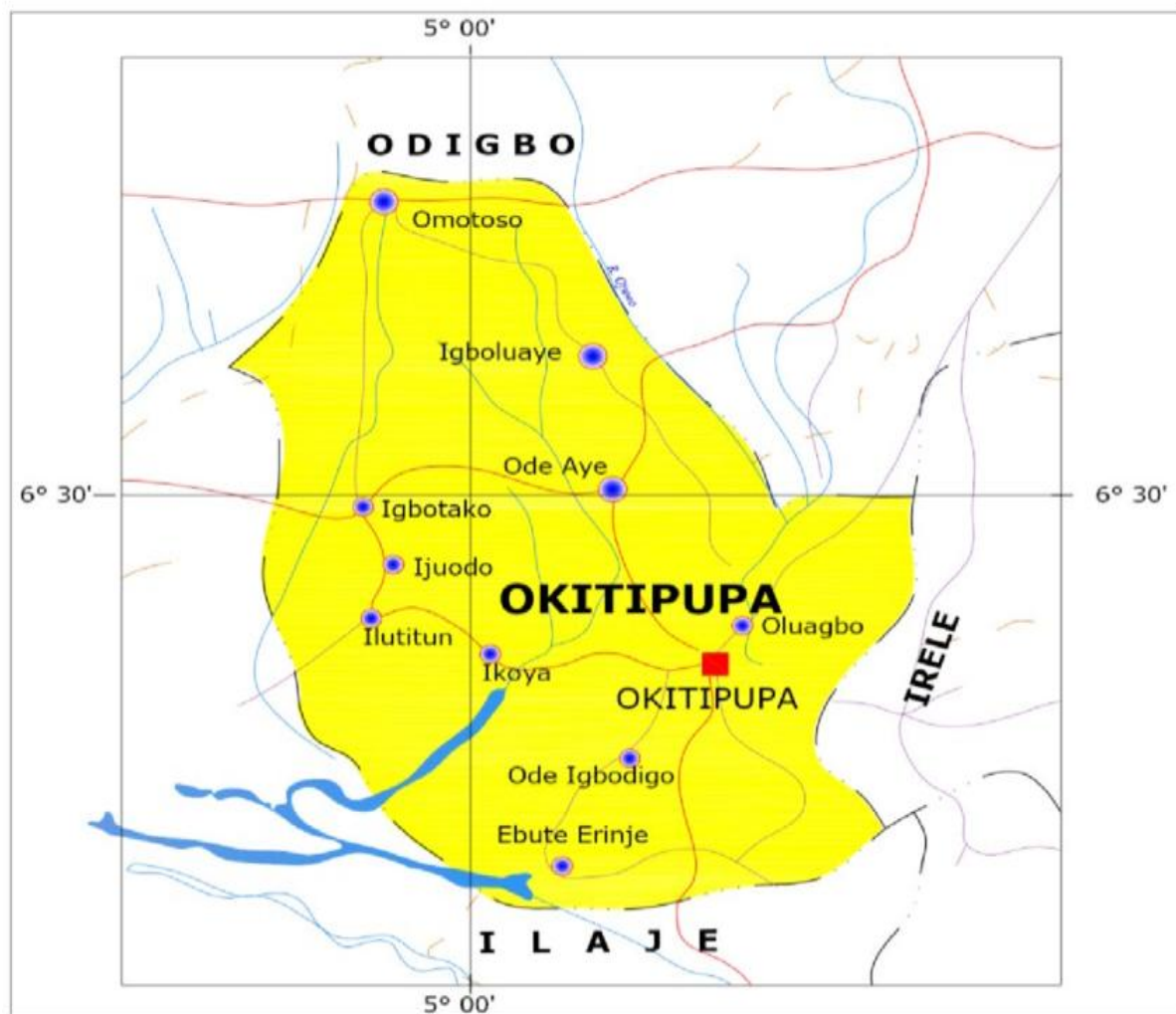


Figure 1 : Map of Okitipupa Local Government Area
Source: Adewale and Braimo (2021)



Figure 2. Effect of untreated effluent on River Oluwa
Source: Iyere-Usiahon (2020)

RESULT AND DISCUSSION

From the tests conducted, the results indicated that there was no significant difference in temperature upstream and downstream Oluwa river. The p -value of (.0001) as shown on table 1. However, the temperature at L1 is as high as 98°C and the samples showed a t -statistic of -2.469 which is smaller than the significant t value of .057 and points to the fact that standards were not met. Although the result of this study deviates from the findings of (Oparaocha *et al*, 2011) who reported that the highest water temperature in various water bodies in Nigeria was 28 °C, but is very similar to those of a study conducted in England (80 - 84 °C) (Milkiyas, 2011) (Wilson and Woral, 2021). The effluent thus causes water pollution since it does not meet effluent discharge standards for edible oil. Temperature influences pH, alkalinity and dissolves oxygen in water. The rates of biological and chemical reaction depend to a large extent on temperature, also growth of microorganisms, taste and odour,

corrosiveness may increase with increase in temperature.

The pH concentration of any irrigation water quality is evaluated based on acidity or basicity of that irrigation water and is expressed as pH (< 7.0 acidic; > 7.0 basic). When the pH concentration in irrigation water is acidic (<5), some nutrients such as sodium are usually more soluble in the effluent, subsequently, leading to high sodium absorption ratio (SAR), high electrical conductivity (EC) and salinity concentrations. In addition, this leads to poor soil texture and structure (Bauder *et al.*, 2011). Result shows that the pH of the water samples ranged from 5.91 to 7.01, indicating that the water sources were slightly acidic and this increased acidity could be attributed to the presence of acidic metabolites. The low pH values of the water samples may be an indication of low CO₂ content of the water bodies (Edema *et al.*, 2010). The result of this study is in confirmation with that of Duke *et al*, 2018 on the study of microbiological quality assessment and

Table 1: RESULT OF ANALYSIS OF VARIANCE OF SAMPLES AT DIFFERENT VARIATIONS

PARAMETER	P- Value	F-value	EFFLUENT		UPSTREAM		DOWNSTREAM	
			Raw (A)	TREATED (B)	4KM (C)	2km (D)	2KM (E)	4 KM (F)
Temperature	0.0001	267.508	98.1667	46.65	29.2	29.1833	32.15	32.3833
pH	0.001	20.49	5.0617	5.6667	7.0667	6.9167	5.9167	6.1833
COD	0.0001	26.177	360.1883	255.5983	77.28	80.305	248.9717	220.6533
BOD	0.0001	45.71	137.3167	113.6983	70.4	79.3783	93.7267	100.7117
Chloride	0.243	1.428	245.2667	148.59	68.4633	65.24	132.395	338.97
Sodium	0.0001	25.346	353.02	211.3767	96.6333	109.173	223.5467	221.8333
Oil and Grease	0.0001	98.747	3912.5	2711.5	185.5	147.333	1053.3333	1061.1667
Total Soluble Solid	0.001	23.99	281.1667	267.325	96.585	60.9	249.815	202.5683
Total Nitrogen	0.0001	352.396	682.8333	514.3333	173.327	179.378	185.68	178.2967

TABLE 2: Compliance test with the UNEP recommended standards for discharge of effluence into river

Parameter	UNEP Standard	One Sample T -Test						Sig.		
		Mean	Std. Deviation	Mean	MD	95% Confidence Interval of the Difference		t	Df	(2-tailed)
						Lower	Upper			
Temp	35	46.65	6.75596	2.75811	11.65	4.5601	18.7399	4.224	5	0.008
pH	5 TO 9	5.669	.66232 .27039	0.27039	-3.33333	-4.0284	-2.6383	-12.328	5	0
COD	120	255.5983	41.85443	17.087	135.59833	91.6748	179.5219	7.936	5	0.001
BOD	40	113.6983	5.06631	2.06831	73.69833	68.3816	79.0151	35.632	5	0
Chloride	750	148.59	14.03365	5.72922	-601.41	-616.1374	-586.6826	-104	5	0
Sodium	200	211.3767	49.60023	20.24921	11.37667	-40.6756	63.4289	0.562	5	0.598
Oil and Grease	10	2711.5	786.7299	321.1811	2701.5	1875.8776	3527.1224	8.411	5	0
TSS	35	267.325	24.18136	9.872	232.325	206.9482	257.7018	23.534	5	0
Total Nitrogen	50	514.3333	66.51516	27.1547	464.33333	394.53	534.1367	17.1	5	0

physicochemical analysis of selected major streams and rivers in Calabar Municipality,

Sodium (Na^+) content is another major indicator when evaluating irrigation water quality. The result of this study shows that sodium was lowest at location 3 (96.6333 mg/L) and highest at location 1 (353.1 mg/L). However, the range and mean values were less than 400 mg/L. Salifu *et al.* (2017), indicating no restriction of use. Irrigation water with high sodium (Na^+) content could cause the displacement of exchangeable cations, such as Ca^{2+} and Mg^{2+} , from the soil clay minerals, which would be replaced by Na^+ . Matthess *et al.* (1982) stated that soils saturated by sodium peptize can lose their permeability, leading to decrease in fertility and their suitability for cultivation. Heavy metals and bacterial pollution are common in most streams flowing through urban areas in Sub-Saharan Africa (Zhang *et al.*, 2016) while human exposure to these contaminants is enhanced through use of polluted stream water for irrigation farming (Qureshi *et al.*, 2016). The danger of bioaccumulation of pollutants and the risk of ill-health is increased through consumption of crop commodities irrigated with contaminated water (Singh and Kumar, 2017; Kim *et al.*, 2015).

Chemical Oxygen Demand (COD) is a measure of the amount of oxygen needed to oxidize all organic chemicals in a wastewater before it is discharged into water bodies (Islam *et al.*, 2018) while BOD in wastewater is a measure of the oxygen needed to aerobically digest organic compounds by biological microorganisms (Mallika *et al.*, 2017; Kitilulu, 2020). The COD for the six sampling points ranged between 77.28

(4km upstream) and 360.1883 Mg/L (raw effluent) (Table 1). The significantly high levels of COD in L1 indicated that it was not properly treated before being discharged into river Oluwa. Lower amounts of BOD signifies improved efficiency of wastewater treatment plants. In this study, the discharge from Palm oil mill treatment plant had comparatively high levels of BOD (70.4 - 137.3167mg/l) implying its low efficiency in eliminating bioorganic waste. Organic chemicals were further washed into the stream from the farms alongside it. Despite this, dilution of effluent as the water flowed downstream lowered the concentrations of COD and BOD gradually from Point E to F. The COD and BOD had significant variations among the six sampling points ($P \leq 0.05$). The high quantities of COD and BOD in all the sampling points were an indication that the river in Okitipupa was not suitable for irrigation due to excessive amounts of organic chemicals. These organic chemicals pollute soils and are further absorbed by plants and transmitted to humans. The COD and BOD in Oluwa River were relatively high compared to those found in other streams in Nigeria; Imabholo stream, Ankpa, (Ocheje *et al.*, 2019); Overall, the use of this stream water for irrigation poses serious health risks to the farmers as well as residents of Okitipupa especially the Ebutte people who are the main users of the stream for their agricultural and domestic purposes.

Chloride

From the tests conducted, the results indicated that there was no significant difference in chloride upstream and downstream. This implies that on many occasions, wastewater from the mill had no considerable impact on the chloride of

the river water downstream. After effluent treatment, the effluent was discharged into the river with chloride mean value of 148.59mg/L. When the t-test was done, it gave a t value of -104.4449 and a significant t value of .0001. This is an indication that the parameter complies with the UNEP set standard for discharge of edible oil effluent since t sig is higher than the t value. Chloride is an essential micronutrient as a cofactor in the oxidation of water in photosynthesis and as an activator of enzymes. It is readily taken up by plants. Chloride also serves in the plant as a charge balance during cation transport, and contributes to cell hydration and turgor maintenance. In the soil, chloride balances the positive charge of the soluble cations Na, Ca, Mg, and potassium. Treated effluent water, which is increasingly used for agricultural irrigation, contains higher chloride levels than the potable water from which it is derived (Khalkafi, 2011). High concentrations of chloride in the irrigation water or the soil are toxic to plants and may affect plant function and reduce productivity. The chloride anion is very stable and will not leave the soil system unless it is leached by an excess of good quality irrigation water, or removed from the soil by exported vegetative plant parts. Continuous long-term utilization of recycled water for irrigation may therefore increase the chloride content of the soil, and without proper leaching it will deteriorate soil fertility, and under extreme conditions may render the soil unproductive.

Oil and Grease

The t-statistic of 8.411 was recorded in the test for O & G compliance and found to be extremely higher than the significant

t value of 0.00. This is an indicator that there is a significant variation between the mean values of O & G and UNEP standard, which implies that the actual measured values are higher than the UNEP standard. Therefore, the effluent cause water pollution since it does not meet effluent discharge standards into the environment and the treatment does not comply with the set standards. The oil and grease content of the water under study ranged from (147.33 and 1065.1 mg/l) indicating high level of oil pollution in most sampling locations. Oil and grease can have negative effects on plants and soil in water used for irrigation. When oil and grease are present in irrigation water, they can form a film on the surface of the soil that reduces soil aeration and water infiltration. This can lead to reduced plant growth and yield, as well as increased susceptibility to disease and pests (Hseu and chen, 2012). Oil and grease in water used for irrigation decreases the capillary action of water in the soil and reduces the soil's ability to significantly transmit water to the roots of plants (Travis *et al*, 2008). Oil and grease can directly harm plants by blocking stomata, the small openings on the surface of leaves that are responsible for gas exchange. When stomata are blocked, plants cannot take in the carbon dioxide they need for photosynthesis and release the oxygen they produce, this can cause reduced growth and even death of plants, the use of oil-water separators and filtration systems in industrial processes could address this menace (Islam *et al*, 2015). There are so far no maximum guideline limits set by regulatory agencies such as the FAO for oil and grease in irrigation water. However, the levels of oil and grease recorded in this study could have toxic effects on soil

microorganisms that are important for nutrient cycling. These microorganisms can be killed or their populations reduced when exposed to oil and grease in irrigation water, leading to decreased soil fertility and plant growth (Jiang *et al*, 2017 and Ashie *et al*, 2024).

Total Soluble Solid (TSS)

Total suspended solids (TSS) in the samples had a mean value of 60 mg/l at location L4 to 281.1667 mg/l at location L1 as in Table 1. In another study, Aliyu, Balogun (2017) reported a TSS level ranging 10.3–90.6 mg/L from Kwara state in Nigeria and Asher *et al*, 2024 recorded 26mg/l and 49mg/l in Kumasi Ghana in in water used for irrigation, the two reports are lower than the levels recorded in this study. A high TSS can influence the level of water turbidity directly, affect soil structure by increasing soil density and reducing soil porosity, as a result of this, percolation and infiltration rates of soil are reduced which significantly reduces the uptake of water by plants (Wulber and Clarke, 2021; Malakooti and Tabrizi, 2012). TSS can also affect the movement of water from the soil to the root of plants (osmotic potential) in soil, this occurs by causing a clogging in the roots of plants (Mahajan and Gupta, 2014). The t-statistic of 23.534 is extremely higher than the significant t - value of 0.00. This is an indicator that there is a significant variation between the mean values of TSS and UNEP standard, which implies that the actual measured values are higher than the standard. Therefore, the effluent cause water pollution since it does not meet effluent discharge standards into the environment.

Total Nitrogen (TN)

Variation in the TN from different sampling points of the study area was investigated and the value found to vary from one sample to another. The level of compliance with the UNEP standard for discharge of edible oil effluent was based on TN pollution loading at the treated effluent point was carried out by t- test at 95% confidence level. The result shows that the t-statistics is 17.1 while the t - significance is .0001. This indicates a non compliance by the Okitipupa Oil Palm Mill and therefore adds to the pollution level of river Oluwa.

CONCLUSION

Discharge of untreated POME into streams increases water parameters such as temperature, pH, total alkalinity, total dissolved solids, total suspended solids, sodium, potassium, chloride, , dissolved oxygen and biological oxygen demand in a river or water body receiving POME (Ogunsan and Akintan, 2020; Awotoya *et al* (2011). The high concentrations of COD and BOD in Oluwa river above WHO limits for irrigation water are a pointer to heavy organic load discharge. The sources of organic wastes need to be monitored, tracked and prevented. In addition, this study concludes that POME from Okitipupa Oil Palm Mill need to be treated before being discharged into the river if river Oluwa will continue its traditional function of providing water for farming and other domestic purposes.

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ASSESSMENT OF SOIL HYDRAULIC PROPERTIES IN JIBIA IRRIGATION PROJECT, KATSINA STATE, NIGERIA

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ABSTRACT

Soil hydraulic properties are vital for understanding water movement in soil, including moisture retention, infiltration rates, and hydraulic conductivity. These properties are particularly important in arid and semi-arid regions, such as Jibia, Nigeria, where water scarcity presents significant challenges to irrigation and crop growth. This study aimed to evaluate the hydraulic properties within the Jibia Irrigation Project in Katsina State, a Sudano-Sahelian region of Nigeria. A grid soil sampling method was used to collect 144 samples, and the data were analyzed using descriptive statistics and correlation analysis. The results revealed a predominance of sandy-textured soils (ranging from loamy sand to sandy), with an average moisture content at field capacity (FC) of 0.332%, permanent wilting point (PWP) of 0.222%, and available water (AW) of 0.192%. These low moisture content levels, coupled with high hydraulic conductivity, indicate the need for irrigation strategies tailored to minimize water loss, prevent soil degradation, and optimize crop yields. Recommendations include implementing more frequent irrigation cycles, applying soil amendments, and using mulching to enhance soil moisture retention and improve overall water use efficiency. This study offers valuable insights for developing sustainable irrigation practices and advancing long-term agricultural development in arid and semi-arid regions.

Keywords: Hydraulic, Irrigation, Moisture, Semi-arid and Soil degradation

Introduction

Soil hydraulic properties are critical for understanding how water moves through and is stored in soil. These properties include soil moisture retention, infiltration rate, and hydraulic conductivity. Soil moisture retention refers

to the soil's capacity to hold water, which is essential for providing a consistent water supply to plants. The infiltration rate measures how quickly water can enter the soil, while hydraulic conductivity indicates the ease with which water can move through soil pores. These factors

collectively influence irrigation efficiency and crop growth (Hillel, 2004). In arid and semi-arid regions like Jibia, efficient water management is vital due to limited and unpredictable rainfall. Such regions are prone to water scarcity, soil erosion, and salinization. Understanding soil hydraulic properties can help mitigate these issues by optimizing irrigation practices to reduce water loss through runoff and deep percolation. Properly managed irrigation can prevent soil degradation and improve water use efficiency, crucial for sustaining agricultural productivity in these environments (Abdulkadir *et al.*, 2020; Rhoades *et al.*, 1992). The Jibia Irrigation Project, located in Katsina State, Nigeria, was established to enhance agricultural activities in an area with scarce water resources. The project includes constructing dams and canals to provide a reliable irrigation water supply, aiming to boost food production, improve farmers' livelihoods, and promote economic development in the region (Othman & Ibrahim, 2012). However, the project's success largely depends on understanding the soil's hydraulic properties to ensure effective water management and prevent issues such as waterlogging or insufficient water supply to crops. Several factors influence soil hydraulic properties, including soil texture, structure, organic matter content, and compaction. Soil texture, defined by the proportion of sand, silt, and clay particles, significantly affects water movement and retention. Sandy soils, with larger particles, generally have high infiltration rates but low water retention, making them less effective for water storage. Conversely, clayey soils, with smaller particles, have lower infiltration rates but higher water

retention capacities, which can lead to waterlogging if not properly managed (Abdulkadir *et al.*, 2022; Rawls *et al.*, 1992). Soil structure, or the arrangement of soil particles into aggregates, also impacts pore space and water movement. Well-structured soils with stable aggregates typically exhibit better water infiltration and retention properties. Organic matter plays a crucial role in enhancing soil structure by binding soil particles together and increasing porosity. Compaction, often caused by heavy machinery or livestock, reduces pore space and impedes water movement, leading to poor drainage and increased runoff (Abdulkadir *et al.*, 2024; Dawaki *et al.*, 2019; Noma and Sani 2008; Letey, 1991). Accurate assessment of soil hydraulic properties is essential for developing effective irrigation schedules that align with the soil's capacity to absorb and retain water. This reduces water wastage, prevents soil degradation, and minimizes the risk of salinization. Proper management of these properties can lead to significant improvements in crop yields and water use efficiency. For instance, Iqbal *et al.* (2014) found that enhancing soil quality through organic amendments increased water retention and crop productivity in sandy loam soils. The aim of the study is to assess soil hydraulic properties in Jibia irrigation project

MATERIALS AND METHODS

Study Area

The study was carried out in Sector F1 of the Jibia Irrigation Project located in Jibia Local Government Area (Latitudes 13°04'18" N - 13°10'27" N and longitudes 07°15'06" E - 07°18'15" E). Jibia Local Government Area is bordered by Katsina and Batsari Local

Governments Areas (LGAs) to the South, Kaita LGA to the East, and Zurmi LGA in Zamfara State to the West and Maradi State in the Niger Republic to the North. The landscape is nearly level to gently undulating with 0 - 2% slope and averaging 442 meters above sea level (FDLAR, 1990). The study area is within the semi-arid region which falls within the Sahel savannah zone of Nigeria with a mean annual temperature and precipitation of about 25 °C and 600 -700 mm, respectively. Rainfall pattern is seasonal and occurs between the months of June and September with the peak rainfall occurring in the month of August. The dry season last between October and May (KTARDA, 2010; Sani *et al.*; 2019).

Vegetation and Land Use

The vegetation in this area is of the Sudan savannah, characterized by scattered trees across a vast grassland. These trees, such as the baobab with its large trunk and broad canopy, include various acacia species like *Acacia nilotica*, *Acacia albida*, and *Acacia seyal*. Other common trees include Neem (*Azadirachta indica*) and different types of scattered shrubs, including *plastima*. Most of these trees are xylophytic, meaning they have adapted to resist drought conditions. They achieve this through features like deep roots, leathery or small leaves, and spines that help reduce water loss through transpiration (Shittu, 1999, Sani *et al.*; 2019). The local population predominantly engages in farming, cultivating rain-fed crops such as millet, sorghum, groundnut, cowpea, and sesame, as well as irrigated crops like wheat, cowpea, maize, groundnut, cassava, and

various vegetables. They also raise livestock, including cattle, goats, sheep, and poultry (KTARDA, 2010; Sani *et al.*; 2022; Sokoto Rima River Basin Development Authority (SRRBDA), 2013).

The Jibia irrigation project aims to develop 3,450 hectares of land for irrigation, featuring approximately 192 kilometers of concrete irrigation canals that distribute water to sub-canals and irrigation plots. The project also includes 114 kilometers of drainage channels, 50 kilometers of service roads, and 110 kilometers of farmland, divided into six sectors (hydrological boundaries F1-F6). The study area, Sector F1, encompasses 206 hectares of land (SRRBDA, 1991; Sani *et al.*; 2023).

Soil Sampling

Reconnaissance Survey A reconnaissance survey was conducted in the study area to establish the location and extent of the sampling area as well as to establish the sampling points. The Google Earth satellite imagery was used to demarcate the extent of the sampling area. The Global Positioning System (GPS) device was used to ground-truth the study area. The area was georeferenced using the ArcGIS 10.3.1 GIS software. Grid sampling technique was used. Grids were drawn at 150 meters intervals and a total of One hundred and forty-four (144) soil samples were collected at grid intersection points which were identified with the help of a handheld GPS device (Figure 1). At each sampling point, disturbed and undisturbed soil samples were collected. Collected samples were air dried, crushed gently and sieved through 2 mm mesh

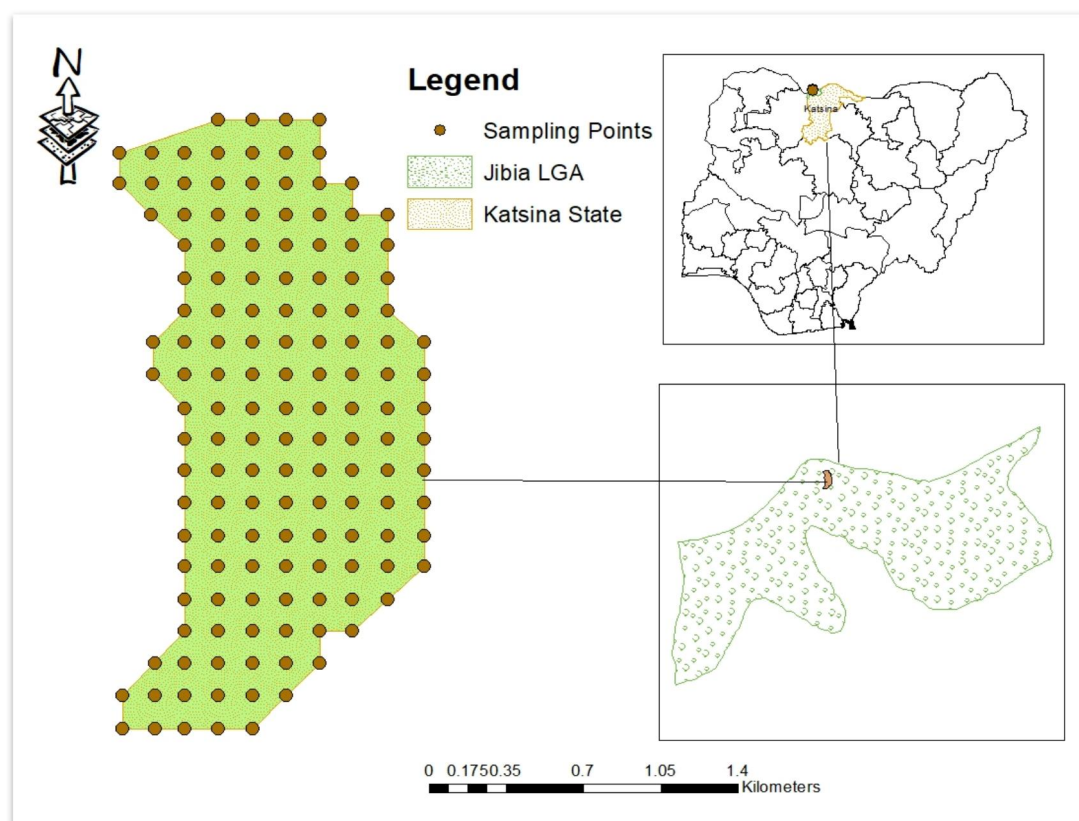


Figure 1: Map of Katsina state showing the study area.

Table 1: Soil Hydraulic Properties in Jibia Irrigation Project

Variable	Mean	Minimum	Maximum	SD	CV (%)	Skewness	Kurtosis
SAND (%)	82.79	34	98	13.011	15.72	-1.699	2.739
SILT (%)	11.21	0.56	41.28	8.309	74.1	1.492	2.096
CLAY (%)	5.998	0.72	50.72	6.536	109	3.346	15.68
FC (%)	0.332	0.0452	4.013	0.386	116.5	6.502	56.12
PWP (%)	0.222	0.0126	3.927	0.351	158.1	8.405	84.5
AWHC (%)	2.192	0.13	17.88	2.700	123.2	3.45	13.78
$K_s \times 10^3$ (mmhr ⁻¹)	1275.72	162.28	17898.75	2619.62	205.3	4.45	22.10

Key: SD = Standard deviation; CV = Coefficient of variations; FC = Field Capacity,
PWP = Permanent Wilting Point; AWHC = Available Water Holding Capacity;
Ks= Saturated Hydraulic Conductivity:

size and the fine earth separates were then properly labeled and stored for analyses in the laboratory.

Data Analyses

Data analyses were performed using descriptive statistics. The Measured variables were analyzed to obtain Mean, Median, Range, Maximum, Minimum, Variance, and Coefficient of variation using SPSS 16.0 (IBM-SPSS, 2017).

RESULT AND DISCUSSION

Table 1 above shows the soil hydraulic properties in Jibia irrigation project and is discussed below:

The soil hydraulic properties of the Jibia Irrigation Project reveal a diverse range of soil textures and water retention capabilities. The percentage of clay in the soil exhibits significant variability, with a mean of 5.99% and a standard deviation of 6.54%. This high variability, evidenced by the coefficient of variation of 109.00%, indicates heterogeneous soil composition. Such heterogeneity is common in irrigation projects, as seen in the study by Zhang *et al.* (2018), which reported similar variability in clay content in an irrigated agricultural region, where clay percentages ranged from 5% to 45%, significantly affecting soil water retention properties.

The sand content in the Jibia soils is notably high, with a mean of 82.79% and a moderate coefficient of variation (15.72%). This predominance of sandy soils suggests rapid drainage and low water-holding capacity, which is consistent with findings by Smith *et al.* (2019) who observed that high sand content in soils leads to increased hydraulic conductivity but reduced available water for crops. The study found that soils with over 70% sand content had hydraulic conductivities exceeding 1500 mm/hr, aligning with the Jibia data where

the hydraulic conductivity (HC) mean is 1620 mm/hr.

Silt content in the Jibia soils shows moderate variability with a mean of 11.21% and a standard deviation of 8.309% and high coefficient of variation of 74.1 %. This is comparable to results from a study by Jones *et al.* (2020), where silt content ranged from 10% to 40% in an irrigation project, influencing the soil's physical structure and nutrient availability. The balance of sand and silt in Jibia's soils suggests a loamy texture that can support diverse crop types but may require careful management to maintain soil structure and fertility.

Field capacity

Water content at field capacity (FC) of the soil was found to have a mean of 0.332%, with a value range of 0.045 to 4.013%. The parameter is highly variable with high coefficients of variation of 116.5%. Skewness and kurtosis values were both positive as 6.502 and 56.12 respectively.

Permanent wilting point

The mean value of water content of the soil at permanent wilting point (PWP) was found to be 0.222%, with values ranging from 0.0126 to 3.927% respectively. The analysis revealed a high coefficient of variation of 158.1%. The Skewness and kurtosis values were both positive as 8.405 and 84.5 respectively

Permanent wilting point (PWP) and field capacity (FC) also demonstrate variability, with means of 0.23 and 0.332 respectively. The high standard deviation and coefficients of variation for these parameters (87.62 and 116.5% respectively) indicate diverse soil water retention characteristics across the project area. Similar findings were reported by Liu *et al.* (2020), who found that soils in semi-arid irrigation projects exhibited

wide ranges in PWP and FC due to variability in soil texture and organic matter content.

Available water holding capacity

The Available water holding capacity (AWHC) of the soils of the study area was found to have a mean of 2.192% and ranged between 0.13% and 17.88%. The data revealed a high coefficient of variation of 123.1%. Both Skewness and kurtosis values were positive with 3.45 and 13.78 respectively.

Available water holding capacity (AWHC) of any soil is predominantly dependent on its texture and structure, and the OM content. The soil water storage capacity knowledge is an important water management tool since it allows the determination of how much water to apply at one time and how long to wait between each irrigation schedule (Taiwo *et al.*, 2016). The available water (AW) content of the Jibia soils is quite low, with a mean of 0.11 and a high coefficient of variation (122.90%). This indicates that the water retention capacity is limited, likely due to the high sand content. Comparable results were observed by Ahmed *et al.* (2017), who reported that sandy soils in arid regions often have low AW values, necessitating frequent irrigation to maintain crop health. The study found that soils with AW values below 0.15 require irrigation intervals of less than 7 days to prevent water stress in crops. Similarly, the relative decreased water holding capacity in other areas of the field could be associated with the high sand content and low organic matter. The effect is largely indirect. Tillage break down aggregates thereby decreasing the number of large pores. This will cause a decrease in infiltration rate and percolation. Compaction causes an increase in the

number of very small pores increasing the unavailable water and water holding capacity of the soil decreases (USDA-NCRS, 2018). This agrees with the findings of Leelamanie (2010) who states that water content of soil samples are greatly affected by soil textural classes. The high soil temperature in the study site and the consequent drying of the soils might have been responsible for the low water holding capacity. This finding agrees with the observation of Doerr *et al.* (2006) who stated that the greater drying of soils is making them less able to retain water. The Low available water holding capacity observed might be as a result of low organic carbon and compaction which increase the bulk density with a consequent reduction in total pore volume.

Saturated hydraulic conductivity

The saturated hydraulic conductivity (Ks) was found to range between 162.3×10^{-3} mmhr⁻¹ and 17898.75×10^{-3} mmhr⁻¹ with a mean of 162.3×10^{-3} mmhr⁻¹. The parameter showed a high coefficient of variation of 205.3%. Saturated hydraulic conductivity (Ks) had the highest CV of all the measured soil properties in the study area. Skewness and kurtosis values were positive with 4.45 and 22.10 respectively. Hydraulic conductivity (HC) values in Jibia show extreme variability, with the highest recorded value at 17899 mm/hr and a mean of 1620 mm/hr. The skewness (3.69) and kurtosis (14.02) values indicate a non-normal distribution, with a few extremely high values skewing the mean. This pattern is similar to findings by Brown *et al.* (2018), who reported high variability in HC in irrigation projects, attributing it to the presence of preferential flow paths and soil heterogeneity. HC also exhibit the

highest variability of all the measured parameters with High CV of 205.3%.

Saturated hydraulic conductivity, K_s was the most variable of all the properties measured with a coefficient of variations (CV) of 205.3%. Saturated hydraulic conductivity is one of the most variable soil properties because it is associated with soil texture, structure and other factors such as topography, vegetation, climate and land use (Deb and Shukla, 2012, Rabbi *et. al.*, 2014; Jabro *et. al.*, 2011; Schaap *et. al.*, 2001). It is a challenging soil hydraulic property to describe because it can change many orders of magnitude over short distances. This observation also correlates with the work of Biggar and Nielson (1976); Shukla *et. al.* (2004) and Ramzan *et. al.* (2016).

The soil hydraulic properties of the Jibia Irrigation Project exhibit significant variability, particularly in terms of clay and sand content, hydraulic conductivity, and water retention characteristics. These findings are consistent with other studies (Abu and Malgwi, 2011) in similar environments, emphasizing the need for tailored irrigation and soil management practices to optimize agricultural productivity. The variability in soil properties necessitates site-specific management strategies to enhance water use efficiency and crop performance.

Conclusion

The soil hydraulic properties of the Jibia Irrigation Project exhibit significant variability, with high sand content indicating rapid drainage and low water-holding capacity. The variability in clay and silt content points to heterogeneous soil composition, affecting water retention. Low available water content and extreme variability in hydraulic conductivity

necessitate tailored irrigation practices. These findings emphasize the need for specific soil management strategies such as the use of organic materials for mulching to conserve soil moisture to optimize agricultural productivity in the region.

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EVALUATION OF SOME SOIL HYDRO-PHYSICAL PROPERTIES IN KASHERE AND PINDIGA AREAS OF GOMBE STATE, NIGERIA.

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ABSTRACT

The study was conducted in Kashere and Pindiga of Areas of Akko L.G.A., Gombe State, Nigeria, to examine some soil hydro-physical and structural properties across the three slope positions. Four (4) profile pits were sunken at the upper, middle and lower slope position of the two study areas. Soil samples were collected, then air dried, crushed gently and stored in well labeled polyethene bags. The processed soils were then taken to the laboratory for analysis following the standard procedure to the determination of the physical, structural properties and organic carbon contents. Infiltration test were carried out using double ring infiltrometer method. The results indicated that the soils were deep to very deep with dominant sub-angular blocky structure in all the profiles. The study revealed that the sand contents was the dominant fraction for Kashere and Pindiga ranged from 47.2-97.2%, while the soil textural classes were found to be sandy loam, loamy sand, and sandy clay loam. The B.D ranged from 1.34-1.91 g/cm³, P.D ranged from 2.35-2.83 g/cm³, T.P ranged from 28.5-51.43%, W.H.C ranged from 29.45-48.9% while the S.O.C ranged from 3.59-16.17.76 g/kg, for Kashere and Pindiga, respectively. The steady state infiltration rate of Kashere and Pindiga soils range from 1.2-28.8 cm/hr. The soil structure across the slope positions ranges from weak, moderate to strong fine sub angular blocky. It is important to adopt soil and water conservative practices such as mulching, cover cropping, addition of organic manures and amendments to increase soil quality and crop productivity in the study locations.

Keywords: Soil, Hydro-physical, Kashere and Pindiga.

INTRODUCTION

Soil, water and food are fundamental to human life (FAO, 2009); furthermore soil is considered the most vital natural resources on earth. This is because it hosts both animate and inanimate beings and over three quarters of the world's man-made developments are being carried out on land but this resource is being degraded due to the impact of soil

erosion (Iliyasu, *et al.*, 2019 and Okin, 2005). Despite the significance of soil to life it is most neglected commodity on this planet (Suraj *et al.*, 2019). Soil comprises of minerals, organic matter, nutrients, moisture and micro-organisms that supports the ecosystem (Sebastian *et al.*, 2014). Temporal changes in soil physical and hydraulic properties have been the subject of much research to quantify the effects of different management practices,

land uses and topo-sequences on soil quality within the growing seasons. The impact of these factors resulted in to variability of these soil properties spatially and temporally (Shahid, 2012, Oshunsanya, 2013, Regues *et al.*, 2017 and Zebarth *et al.*, 1989).

The spatial and temporal changes in soil physical, hydraulic and chemical properties have been subject to much research to quantify and assess the impacts of different land management systems within and after the growing season (Sahid, 2012, Iliya, 2023, Biliyaminu, 2024 and Malata, 2024). This leads to variability in soil physical and hydraulic properties in space and time. The management of soil water requires a reliable estimate of soil physical and hydraulic properties for effective prediction and control of water dynamics in an agricultural field or land scape (Oshunsanya, 2010, Idris, 2021 and Iliya, 2023).

Soil physical properties such as soil texture, structure, pore space, and soil hydraulic properties: bulk density, available water, permanent wilting point, water at field capacity and water retention capacity, saturated hydraulic conductivity are essential to be studied. This property affects soil and water productivity or water use efficiency (Wagna *et al.*, 2001). Cultivation practices and land use change affects the physical and hydraulic soil properties causing damage on soil aeration, soil water dynamics (Emily and Marcos, 2019).

Soil degradation is the loss of soil qualities and nowadays, the term “soil degradation” is frequently discussed in the field of environmental protection. Soil erosion is one of the most crucial problems that cause soil degradation and

losses. In certain regions of the world water and wind erosion can especially be identified (Hlavčová, 2011, Nampak *et al.*, 2018 and Rizeei *et al.*, 2016). The current rate of agricultural land degradation worldwide by soil erosion and other factors is leading to an irreplaceable soil loss in productivity on about 6 million hectare of fertile land a year (Suraj, *et al.*, 2019). The consequences and effects of land degradation and conversion of natural ecosystem to agricultural land can increase runoff and decrease evapotranspiration (Roost *et al.*, 2008) and alteration of ground water research water research (Le Maitre *et al.*, 1999).

Kashere and Pindiga communities are villages under Akko Local government of Gombe State, the land surface terrain were sloppy and undulating, the soils in the area were observed and characterized to be loose and friable soil (sandy, sandy clay loam and loamy sand soils) predominantly with some clay occurring in some part of the environment this could be one of the possible contribution to the high infiltration capacity low runoff coefficient and incidence of soil erosion challenges because loose soils lack aggregate stability with surface compaction cases (Iliya, 2023 and Idris, 2021). Therefore, the objective of this study were to determine some hydro-physical properties in these areas across the three slope positions. The information of soil hydro-physical characteristics may be useful in land use planning to mitigate the problem of poor plant growth, low crop yield, high cost of irrigation and soil management strategies such as soil erosion control, rain water harvesting for better watershed management in the study areas.

MATERIALS AND METHODS

The study area

The studies were carried out at some selected catchment areas of Kashere and Pindiga locations. Kashere and Pindiga are the two separate study locations located in Akko Local government area of Gombe State. It is part of the Northern Guinea Savanana ecological zone in North eastern Nigeria. The Kashere study site is located within latitude 10.65120°N to 11.5321°N of the equator to longitude 6.79663°E to 6.764419°E of Greenwich meridian while Pindiga study site is located within latitude 10.083364°N to 11.33565°N of the equator to longitude 6.65830°E to 6.750585°E of Greenwich meridian (UTM 32N). The Geology of the study areas is developed on basement complex rocks with adjoining sedimentary

rocks formation (Ikusemoran *et al.*, 2018). The areas records about three to four months of rainfall and its is concentrated in the months of July, August and September with the average rainfall of 951mm per annum (UBRBDA, 2018). The mean annual temperature ranged from 30 to 37 °C, while March, April and May were observed to be the dry hot months of the year. During the rainy season, the temperature drops considerably due to the cloud cover between July and August as well as during the Harmattan periods of November to February (UBRBDA, 2018). Relative humidity has the same pattern being 94% in August and drops to less than 10% during harmattan period (Balzerek *et al.*, 2003 and Lazarus, 2017).

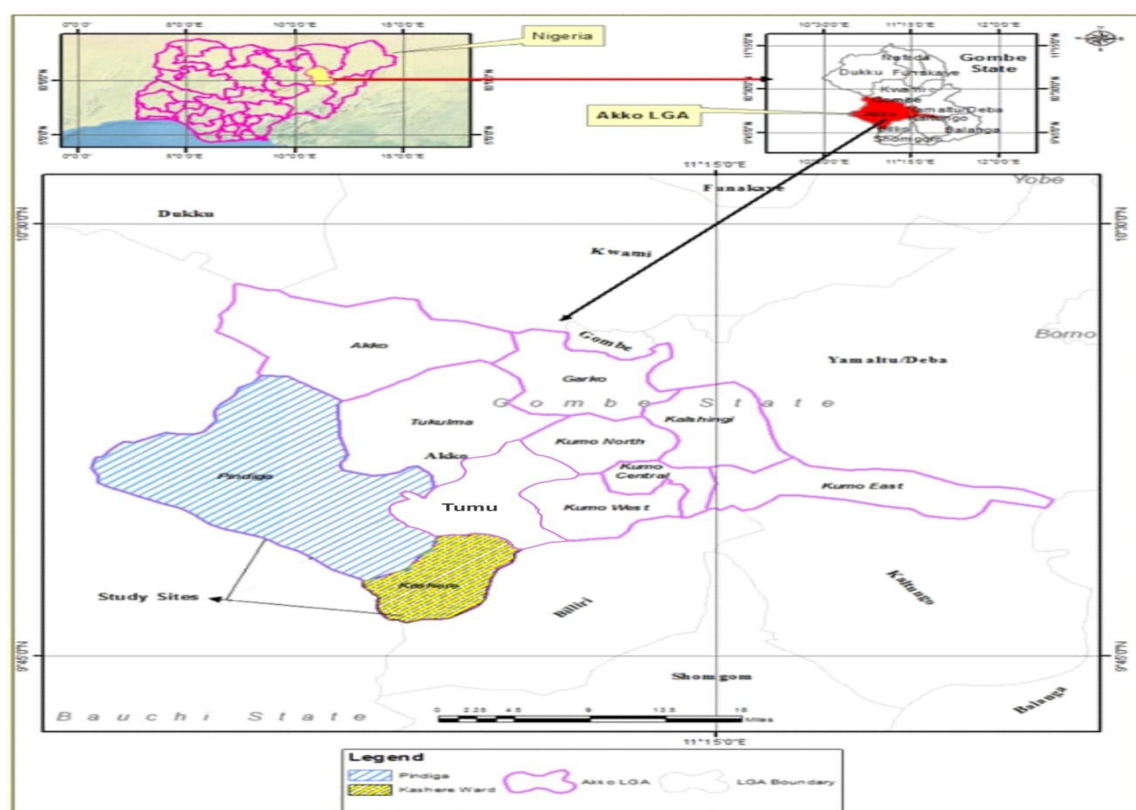


Figure 3.1: Map of Akko L.G.A showing the study locations (Kashere and Pindiga)

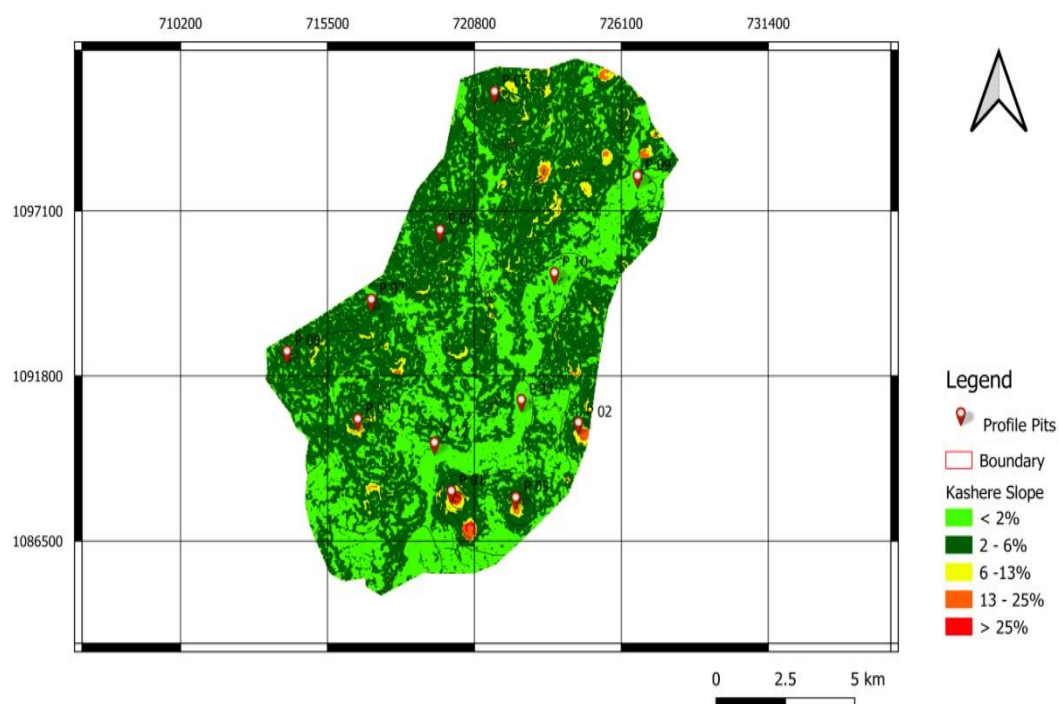


Figure 3.2: Topographic map of Kashere

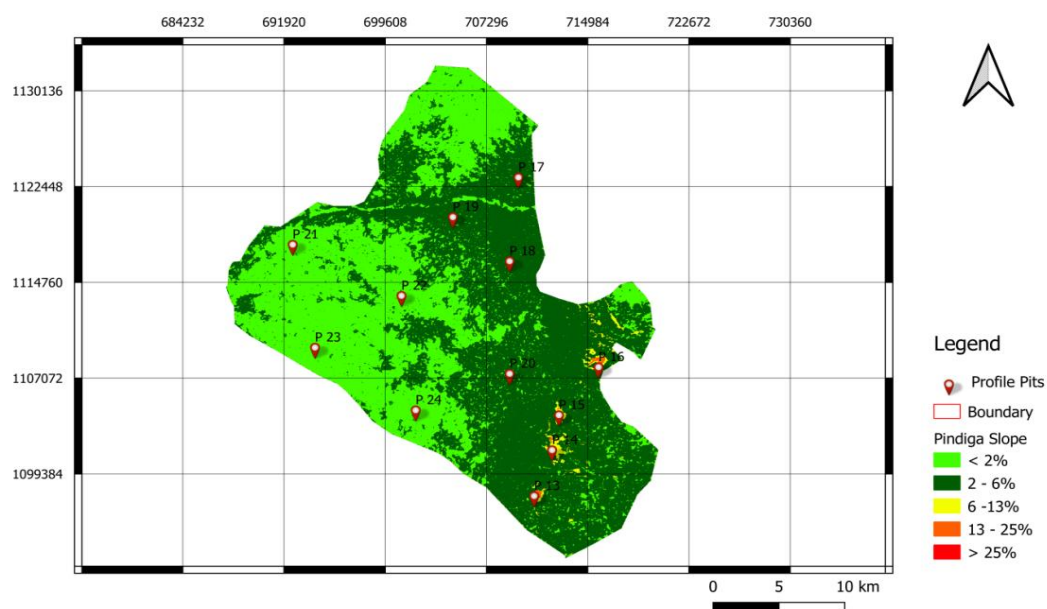


Figure 3.3: Topographic map of Pindiga

Soil sampling and handling

A reconnaissance soil survey was conducted at the study sites aided by topographic maps, hand held G.P.S and vital information's at hand. The soils samples were randomly collected from the selected catchment areas at Kashere and Pindiga communities based on their slope positions and the distinct soil horizons. In this study lower slope position, middle slope position and upper slope position consist of areas with the slope of 0-2%, 2-6% and 6-13% respectively. A total of 24 profile pits with the dimensions of 2m long, 1.5m wide and 1.5 m deep were sunken and representative soil samples were collected as aided by slope and watershed maps. All the sunken pits were described according to the method outlined by United State Department of Agriculture (USDA) Soil Survey Staff (1999). Soil samples were collected based on the pedogenic horizons identified. Soil samples were collected from each experimental site and sealed in a clean polyethene bags, labeled and then brought to Soil Science Department Laboratory, Moddibo Adama University, Yola for laboratory test and determinations of soil properties such as soil structure, texture, bulk density, particle density, total porosity, water holding capacity and organic carbon content.

In the laboratory, each sample was separately air dried ground and passed through a 2.0 mm sieve for laboratory analysis as described by (Agbenin, 1995). The particle sizes were determined using the Bouyoucous hydrometer method as described by Jaiswal (2003). The soil bulk densities were determined by collecting undisturbed soil samples using core sampler. The collected moist undisturbed soil was oven dried at 105°C to a constant

weight. The volume of the soil core was estimated from the internal radius and height of the core. The mass of the oven dried soil core was divided by its volume to obtain the bulk density of the soil in g/cm³ as described by Jaiswal, (2003). The percentage soil porosity was determined by subtracting the ratio of bulk density and particle density from one and multiplying by 100 as described by Jaiswal, (2003). The water holding capacity was determined by filter paper method as described in Zhang *et al.*, (1999) and Haiquiang, *et al.*, (2019). The water content at field capacity was determined using core samples as describe as described by Zhang *et al.*, (1999) and Haiquiang, *et al.*, (2019). Permanent wilting point was determined as described by Utter Pradesh Public service commission, UPPSC-AE, (2004). The plant available water was determined as described by Dumitru *et al.*, (2011).

Soil organic carbon content were determined in bulk soil and in the various aggregate fractions separated during the wet sieving by the dichromate oxidation method (Nelson and Summers 1982). Soil structures were described according to procedures in the USDA Soil Survey Manual (Soil Survey Staff, 2010; Soil Survey Division Staff, 1993). The Infiltration capacity of the soils of the study area was determined using double ring infiltrometer methods as described by Anderson and Ingram, (1993) which reflects the permeability class of the soil.

Data analysis

The data generated from the laboratory analysis were subjected to simple descriptive statistics which include range

and mean as described by (Harry and Steven, 1995). Coefficient of variation was used to compare means as described by Wilding (1985) ratings.

Table 2.1: Rating for coefficient of variability

CV values	Variability Ratings
< 15%,	Low
15% to 35%,	Moderate
>35%,	High

Source: Wilding, (1985).

RESULTS AND DISCUSSION

Physical properties of the soil in the study areas

The mean value of sand content (Tables 3.1 and 3.2) on the upper (6-13%) slope positions of Kashere and Pindiga at the surface and subsurface horizons were observed to range from 47.2-91.2% and 65.2-95.2%, respectively. Also, at the middle (2-6%) slope positions of Kashere and Pindiga the mean sand content (Table 3.3 and 3.4) for the surface and subsurface horizons ranged from 79.2-97.2% and 47.2-85.2% respectively. The mean value of sand content (Tables 3.5 and 3.6) at the 0-2% slope position for the surface and subsurface horizons at the lower slope positions of Kashere and Pindiga were observed range from 51.2-79.20% and 65.1-95.2%, respectively.

The sand particle is the dominant fraction in all the horizons of the studied soils. The predominance of sand particles in arid and semi arid climates is not uncommon because many of the soils were found to be of Aeolian deposits blown from across several thousand kilometers (Imadojemu *et al.*, 2017, Onweremadu, *et al.*, 2011, Salem *et al.*, 2020 and Idris *et al.*, 2023).

The mean value of silt content on the upper (6-13%) slope positions of Kashere and Pindiga (Tables 3.1 and 3.2) at the surface and subsurface horizons were observed to range from 4.0-32% and 8.0-24%, respectively. The silt contents in the soils are lower than sand content. Also, at the middle (2-6%) slope positions of Kashere and Pindiga the mean silt content (Table 3.3 and 3.4) for the surface and subsurface horizons ranged from 1.0-10% and 12-22%, respectively. The mean value of silt content (Table 3.5 and 3.6) at the 0-2% slope positions for the surface and subsurface horizons at the lower slope positions of Kashere and Pindiga were observed to range from 4.8-30.8% and 2.0-8.0%, respectively. Similar result of low silt content were also reported by Idris *et al.*, (2023) and Osondu and Lekwa (2016). However, Salem *et al.*, 2020, Askira *et al.*, (2019); and Zata *et al.*, (2020) all reported high silt content in their respective studies. The mean value of clay content, on the upper (6-13%) slope positions of Kashere and Pindiga (Tables 3.1 and 3.2 above) at the surface and subsurface horizons were observed to range from 4.8-40.8% and 4.8-30.8%, respectively.

Table 3.1: Some soil properties at the upper slope positions of Kashere.

Pedon and UTM Coordinates	H.D (cm)	Soil Texture			TC	B.D (g/cm ³)	P.D (g/cm ³)	T.P (%)	W.H.C (%)	P.W.P (%)	P.A.W (%)	F.C (%)	O.C (g/kg)	Soil Structure
		% Sand	% Silt	% Clay										
Pedon 1	0-34	79.20	12.00	8.800	LS	1.68	2.67	37.07	39.50	5.20	12.1	17.3	16.76	wfsbk
<i>Lat: 718726</i>	34-50	63.20	14.00	22.80	SCL	1.53	2.67	42.69	45.90	4.90	12.9	17.8	12.47	mfsbk
<i>Long:1088267</i>	50-76	51.20	8.000	40.80	SC	1.43	2.50	42.80	50.00	10.2	13.6	23.8	15.36	mfsbk
<i>Elev:369m</i>	76-105	47.20	32.00	20.80	L	1.42	2.67	46.75	46.70	6.80	11.5	18.3	12.27	sfsbk
Pedon 2	0-36	81.20	12.00	6.800	LS	1.65	2.67	38.13	37.90	4.90	11.6	16.5	12.57	mfsbk
<i>Lat:724342⁰</i>	36-67	71.20	16.00	12.80	SL	1.53	2.67	42.63	42.20	5.10	12.1	17.2	12.67	wfsbk
<i>Long:1090026⁰</i>	67-120	73.20	14.00	12.80	SL	1.54	2.50	38.40	42.00	5.40	11.4	16.8	13.07	wfsbk
<i>Elev:367m</i>	120-135	57.20	12.00	30.80	SCL	1.38	2.67	48.25	48.00	4.80	12.7	17.5	12.77	sfsbk
Pedon3	0-29	79.20	14.00	6.800	LS	1.64	2.67	38.50	38.10	5.10	13.3	18.4	9.980	mfsbk
<i>Lat:722567⁰</i>	29-50	63.20	14.00	22.80	SCL	1.43	2.67	46.38	45.90	5.40	14.2	19.6	12.27	mfsbk
<i>Long:1088232⁰</i>	50-77	67.20	12.00	20.80	SCL	1.45	2.50	42.00	45.10	5.80	12.5	18.3	11.77	mfsbk
<i>Elev: 370m</i>	77-110	53.20	10.00	36.80	SC	1.34	2.76	51.43	49.30	7.30	14.1	21.4	7.780	sfsbk
Pedon 4	0-28	91.20	4.00	4.800	S	1.72	2.50	31.20	35.30	6.30	4.30	10.6	9.780	mfsbk
<i>Lat:717268⁰</i>	28-45	51.20	18.00	30.80	SCL	1.36	2.50	45.60	48.50	7.10	13.4	20.5	11.37	mfsbk
<i>Long:1090083⁰</i>	45-73	49.20	16.00	34.80	SCL	1.34	2.50	46.60	49.30	7.30	12.2	19.5	13.27	sfsbk
<i>Elev:405m</i>														

Source: Field work (2021). Note: HD: Horizon Depth, BD: Bulk Density, PD: Particle Density, T.P: Total Porosity, T.C: Textural Classes, W.H.C: Water Holding Capacity, O.C: Organic Carbon, mfsbk = medium fine sub-angular blocky, wfsbk = weak fine sub-angular blocky and sfsbk strong fine sub-angular blocky

Table 3.2: Some soil properties at the upper slope of Pindiga.

Pedon and UTM Coordinates	H.D (cm)	Soil Texture			T.C	B.D (g/cm ³)	P.D (g/cm ³)	T.P (%)	W.H.C (%)	P.W.P (%)	P.A.W (%)	F.C (%)	O.C (g/kg)	Soil Structure
		%Sand	%Silt	%Clay										
Pedon 13	0-29	73.20	14.0	12.80	SL	1.74	2.55	31.76	42.00	5.1	11.7	16.8	7.380	mfsbk
Lat: 714972	29-106	61.20	14.0	24.80	SCL	1.68	2.57	34.63	46.60	3.4	11.9	15.3	11.97	wfsbk
Long: 1098674														
Elev: 476m														
Pedon 14	0-35	81.20	12.0	6.800	LS	1.65	2.67	38.13	37.90	3.20	12.3	15.5	14.56	wfsbk
Lat: 713217	35-110	79.20	8.00	12.80	SL	1.55	2.67	41.88	41.60	5.70	12.2	17.9	12.17	mfsbk
Long: 1099825														
Elev: 465m														
Pedon 15	0-29	79.20	16.0	4.800	LS	1.60	2.67	40.07	36.10	7.20	10.6	17.8	8.980	wfsbk
Lat: 713605	29-42	75.20	12.0	12.80	SL	1.54	2.76	44.20	41.90	8.30	11.1	19.4	11.77	mfsbk
Long: 1105302	42-105	65.20	12.0	22.80	SCL	1.44	2.58	44.18	45.80	3.40	10.7	14.1	13.37	sfsbk
Elev: 463m														
Pedon 16	0-35	83.20	10.0	6.800	LS	1.65	2.86	42.25	37.80	2.80	10.8	13.4	12.57	wfsbk
Lat: 715549	35-61	69.20	8.00	22.80	SCL	1.50	2.67	43.82	45.50	2.20	11.5	13.7	15.16	mfsbk
Long: 1108834	61-120	45.20	24.0	30.80	SCL	1.40	2.50	44.00	48.90	7.20	9.30	16.5	10.57	mfsbk
Elev: 458m														

Source: Field work (2021). Note: H.D: Horizon Depth, B.D: Bulk Density, P.D: Particle Density, T.P: Total Porosity, T.C: Textural Classes, W.H.C: Water Holding Capacity, O.C: Organic Carbon, mfsbk = medium fine sub-angular blocky, wfsbk = weak fine sub-angular blocky and sfsbk strong fine sub-angular blocky

Table 3.3: Some soil properties at the middle slope positions of Kashere

Pedon	UTM Coordinates	H.D (cm)	Soil Textural Class			T.C	B.D (g/cm ³)	P.D (g/cm ³)	T.P (%)	W.H.C (%)	P.W.P (%)	P.A.W (%)	F.C (%)	O.C (g/kg)	Soil Structure
			%Sand	%Silt	%Clay										
Pedon 5 <i>Lat: 720978</i> <i>Long: 1098875</i> <i>Elev: 361m</i>		0-25	79.20	8.00	12.80	SL	1.73	2.50	30.80	41.60	8.30	10.2	18.5	12.07	wfsbk
		25-63	81.20	10.0	8.800	LS	1.61	2.67	39.70	39.40	8.07	8.63	16.7	12.27	mfsbk
Pedon 6 <i>Lat: 717242</i> <i>Long: 1095160</i> <i>Elev: 361m</i>		0-35	89.20	6.00	4.800	S	1.71	2.67	35.88	35.00	4.20	5.40	9.60	18.25	sfsbk
		35-47	87.20	6.00	6.800	LS	1.66	2.67	37.75	37.50	3.20	10.3	13.5	15.26	mfsbk
		47-68	97.20	1.00	1.800	S	1.87	2.67	29.88	29.40	2.70	4.80	7.50	12.07	wfbk
Pedon 7 <i>Lat: 717280⁰</i> <i>Long: 1094323⁰</i> <i>Elev: 357m</i>		0-32	87.20	6.00	6.800	LS	1.67	2.67	37.75	37.50	8.10	4.40	12.5	12.77	mfsbk
		32-46	91.20	2.00	6.800	LS	1.66	2.67	37.75	37.20	3.80	6.90	10.7	14.56	mfsbk
		46-70	91.20	2.00	6.800	S	1.66	2.35	29.45	37.20	3.20	5.30	8.50	10.77	wfsbk
Pedon 8 <i>Lat: 714627</i> <i>Long: 1093520</i> <i>Elev: 361m</i>		0-27	87.20	8.00	4.800	LS	1.71	2.67	35.88	35.60	5.20	5.40	10.6	12.07	sfsbk
		27-51	85.20	8.00	6.800	LS	1.65	2.67	38.13	37.60	3.20	8.20	11.4	15.16	mfsbk
		51-72	84.20	4.00	12.80	S	1.72	2.50	31.20	35.30	3.20	9.10	12.3	9.180	sfsbk

Source: Field work (2021). Note: H.D: Horizon Depth, B.D: Bulk Density, P.D: Particle Density, T.P: Total Porosity, T.C: Textural Classes, W.H.C: Water Holding Capacity, O.C: Organic Carbon, mfsbk = medium fine sub-angular blocky, wfsbk = weak fine sub-angular blocky and sfsbk strong fine sub-angular blocky

Table 3.4: Some soil properties at the middle slope positions of Pindiga

Pedon and UTM Coordinates	H.D (cm)	Soil Texture			T.C	B.D (g/cm)	P.D (g/cm ³)	T. P (%)	W.H.C (%)	P.W.P (%)	P.A.W (%)	F.C (%)	O.C (g/K)	Soil Structure
		% Sand	% Silt	% Clay										
Pedon 17	0-32	71.20	20.0	8.800	SL	1.80	2.50	28.00	40.10	5.10	11.4	16.5	10.87	wfbsk
Lat: 709946	32-74	55.20	22.0	22.80	SCL	1.75	2.53	30.83	46.50	3.70	10.6	14.3	14.16	wfsbk
Long: 1122421	74-98	47.20	16.0	36.80	SC	1.60	2.42	33.88	49.80				14.76	mfsbk
Elev: 463m										3.90	12.5	16.4		
Pedon 18	0-26	77.20	8.00	14.80	SL	1.52	2.50	39.20	42.50	5.70	9.50	15.2	18.85	sfsbk
Lat: 708994	26-98	61.20	12.0	26.80	SL	1.41	2.50	43.60	47.00	8.70	11.8	20.5	13.37	mfsbk
Long: 1116505														
Elev: 497m														
Pedon 19	0-39	85.20	12.0	2.800	LS	1.78	2.67	33.25	32.70	4.90	6.80	11.7	13.67	wfbsk
Lat: 705529	39-66	79.20	10.00	10.80	SL	1.57	2.67	41.13	40.60	3.20	10.2	13.4	8.580	sfsbk
Long: 1117425	66-107	60.20	15.00	24.80	SCL	1.41	2.67	47.13	46.60	3.70	11.5	15.2	13.27	sfsbk
Elev: 450m														
Pedon 20	0-25	85.20	8.000	6.800	LS	1.65	2.50	34.00	37.60	9.70	9.50	19.2	3.59	mfsbk
Lat: 709063	25-61	73.20	12.00	14.80	SL	1.52	2.67	43.00	42.80	5.70	11.0	16.7	14.16	mfsbk
Long: 1107084	61-116	53.20	12.00	34.80	SCL	1.35	2.50	46.00	49.00	5.80	14.1	19.9	10.17	sfsbk
Elev: 452m														

Source: Field work (2021). Note: H.D: Horizon Depth, BD: Bulk Density, P.D: Particle Density, T.P: Total Porosity, T.C: Textural Classes, W.H.C: Water Holding Capacity, O.C: Organic Carbon, mfsbk = medium fine sub-angular blocky, wfsbk = weak fine sub-angular blocky and sfsbk strong fine sub-angular blocky

Table 3.5: Some soil properties at the lower slope positions of Kashere.

Pedon UTM Coordinates	and	HD (cm)	Soil Texture			T.C	BD (g/cm ³)	PD (g/cm)	T.P (%)	W.H.C (%)	P.W.P (%)	P.A.W (%)	F.C (%)	O.C (g/K)	Soil Structure
			%Sand	%Silt	%Clay										
Pedon 9		0-30	71.20	14.0	14.00	SL	1.70	2.50	32.00	43.00	3.90	12.5	16.4	11.57	Wfsbk
<i>Lat:727301</i>		30-68	57.20	14.0	28.80	SCL	1.56	2.50	37.60	44.40	4.10	10.6	15.3	13.77	mfsbk
<i>Long:1098059</i>		68-110	59.20	12.0	28.80	SCL	1.39	2.50	44.40	47.50	7.30	11.3	18.6	13.97	sfsbk
<i>Elev: 350m</i>															
Pedon 10		0-28	73.20	16.0	10.80	SL	1.56	2.67	41.50	41.10	3.90	11.6	15.5	15.26	Mfsbk
<i>Lat:726125</i>		28-105	51.20	18.0	30.80	SCL	1.37	2.67	48.63	48.50	4.90	12.5	17.4	17.76	Sfsbk
<i>Lon:1094371</i>															
<i>Elev: 358m</i>															
Pedon 11		0-25	79.20	16.0	4.800	LS	1.69	2.86	40.85	36.10	6.00	11.6	17.6	13.67	Mfsbk
<i>Lat:721496</i>		25-48	67.20	24.0	8.800	SL	1.58	2.76	42.73	40.40	5.40	10.2	15.6	12.77	mfsbk
<i>Long:1091329</i>		48-105	65.20	20.0	14.80	SL	1.50	2.50	40.00	43.40	5.00	9.60	14.6	15.76	mfsbk
<i>Elev:329m</i>															
Pedon 12		0-20	75.20	16.0	8.800	SL	1.60	2.67	40.00	39.80	6.30	8.90	15.2	17.36	Mfsbk
<i>Lat:718148</i>		20-50	67.20	18.0	14.80	SCL	1.50	2.50	40.00	43.30	3.10	13.5	16.6	15.36	mfsbk
<i>Long:1090208</i>		50-85	63.20	10.0	26.80	SCL	1.41	2.67	47.13	46.80	6.90	12.6	19.5	16.66	sfsbk
<i>Elev:338m</i>		85-107	53.20	16.0	30.80	SCL	1.37	2.50	45.20	48.30				12.87	sfsbk

Source: Field work (2021). Note: HD: Horizon depth, BD: Bulk density, PD: Particle density, T.P: Total Porosity, T.C: Textural classes, W.H.C: Water holding capacity , O.C: Organic carbon, mfsbk = medium fine sub-angular blocky, wfsbk = weak fine sub-angular blocky and sfsbk strong fine sub-angular blocky

Table 3.6: Some soil properties at the lower slope positions of Pindiga

Pedon and UTM Coordinates	HD (cm)	Soil Texture			BD (g/cm ³)	TC	PD (g/cm ³)	Porosity (%)	W.H.C (%)	P.W.P (%)	P.A.W (%)	F.C (%)	O.C (g/kg)	Soil Structure
		%Sand	% Silt	% Clay										
Pedon 21 <i>Lat: 692341</i> <i>Long: 1117498</i> <i>Elev:349m</i>	0-20	67.20	4.00	28.80	1.91	SCL	2.67	28.46	46.90	3.10	9.50	12.6	13.57	wfsbk
	20-90	65.20	6.00	28.80	1.68	SCL	2.55	34.12	47.10	3.40	10.3	13.7	8.480	mfsbk
Pedon 22 <i>Lat:701370</i> <i>Long:1112 918</i> <i>Elev:338m</i>	0-33	87.20	8.00	4.800	1.71	LS	2.67	35.88	35.60	4.20	12.3	16.5	16.16	wfsbk
	33-64	85.20	8.00	6.800	1.65	LS	2.83	42.25	37.60	7.20	10.3	17.5	10.57	wfsbk
	64-109	85.20	6.00	8.800	1.61	LS	2.58	37.61	39.10	5.50	9.80	15.3	6.880	mfsbk
Pedon 23 <i>Lat:694870</i> <i>Long:1109722</i> <i>Elev:352m</i>	0-32	87.20	6.00	6.800	1.66	LS	2.67	37.75	37.50	3.69	8.91	12.6	13.27	wfsbk
	32-63	87.20	4.00	8.800	1.62	LS	2.67	39.25	38.90	4.30	9.40	13.7	11.87	wfsbk
	63-109	75.20	6.00	18.80	1.48	SL	2.50	40.80	44.00	6.20	10.3	16.5	14.66	sfsbk
Pedon 24 <i>Lat:702676</i> <i>Long: 1109621</i> <i>Elev:339m</i>	0-43	95.20	2.00	2.800	1.80	S	2.58	30.25	32.00	3.19	7.41	10.6	12.17	wfsbk
	43-66	87.20	4.00	8.800	1.62	LS	2.67	39.25	38.90	2.90	9.40	12.3	10.57	mfsbk
	66-115	83.20	6.00	10.80	1.58	LS	2.67	40.75	40.40	3.30	12.3	15.6	12.47	mfsbk

Source: Field work, (2021). Note: HD: Horizon Depth, BD: Bulk Density, PD: Particle Density, T.C: Textural Classes, W.H.C: Water Holding Capacity O.C: Organic Carbon, mfsbk = medium fine sub-angular blocky, wfsbk = weak fine sub-angular blocky and sfsbk strong fine sub-angular blocky

Also, at the middle (2-6%) slope positions of Kashere and Pindiga the mean clay content (Table 3.3 and 3.4) for the surface and subsurface horizons ranged from 1.8-12.8% and 2.8-36.8%, respectively. The mean value of clay content (Table 3.5 and 3.6) at the 0-2% slope position for the surface and subsurface horizons at the lower slope positions of Kashere and Pindiga were observed to range from 4.8-30.8% and 2.8-28.8%, respectively. Generally, clay content was found to be low when compared to the sand content. The lower clay content of the surface soil could be a characteristic of soils formed on basement complex rocks in the study area from which the soils were formed (Kparmwang, 1993; and Salem *et al.*, 2023 and Brady and Weil, 2017)

The soil textural classes were found to be sandy loam, loamy sand, and sandy clay loam. There was general non uniformity in soil texture in the soil horizons of each studied pedon. Similar results were obtained by Salem *et al.*, 2020 and Idris *et al.*, 2023). The mean value of soil bulk density, on the upper (6-13%) slope positions of Kashere and Pindiga (Table 3.1 and 3.2 above) at the surface and subsurface horizons were observed to range from 1.34-1.72g/cm³ and 1.4-1.74g/cm³, respectively. Also, at the middle (2-6%) slope positions of Kashere and Pindiga the mean soil bulk density (Table 3.3 and 3.4 above) for the surface and subsurface horizons ranged from 1.61-1.87g/cm³ and 1.35-1.75g/cm³, respectively. The mean value of soil bulk density (Table 3.5 and 3.6 above) at the 0-2% slope positions for the surface and subsurface horizons at the lower slope of Kashere and Pindiga were observed to

range from 1.37-1.80g/cm³ and 1.48-1.91g/cm³, respectively. It was reported that critical levels of bulk density for clay and sand are 1.0-1.69g/cm³ and 1.2-1.8 g/cm³ with potential root restriction occurring at $\leq 1.4 \text{ g/cm}^3$ and $\geq 1.6 \text{ g/cm}^3$ respectively, (Hagan *et al.*, 2010).

However, the values obtained in this study are generally considered to be safe for root penetration because penetration might be hindered in soils having bulk density value $>1.75 \text{ g/cm}^3$ (Esu, 2005 and Ashenefi *et al.*, 2010 and Donahue *et al.* (1990) pointed out that good plant growth is best at bulk densities below 1.40g/cm³ for clay and 1.60g/cm³ for sandy soil. This range of values for bulk density observed in this study are rated low as per Malgwi (2007) rating scale. The values of bulk density obtained in this study are within the range reported earlier by Salem *et al.* (2020) who recorded values of 1.19 to 1.66g/cm³ while working on the soil of Teaching and Research farm of the Federal University of Kashere, Gombe State

The mean value of soil particle density, on the upper (6-13%) slope positions of Kashere and Pindiga (Tables 3.1 and 3.2 above) at the surface and subsurface horizons were observed to range from 2.5-2.76g/cm³ and 2.50-2.86g/cm³, respectively. Also, at the middle (2-6%) slope positions of Kashere and Pindiga the mean soil particle density (Tables 3.3 and 3.4 above) for the surface and subsurface horizons ranged from 2.35-2.67g/cm³ and 2.42-2.67g/cm³, respectively. The mean value of soil particle density (Tables 3.5 and 3.6 above) at the 0-2% slope position for the surface and subsurface horizons at the lower slope positions of Kashere and

Pindiga were observed to range from 2.5-2.83g/cm³ and 2.5-2.83g/cm³, respectively. This range of values is rated low as per Malgwi (2007) rating scale. Ayolagha and Opene, (2012) reported that particle density values recorded in this study indicates that perhaps quartz, feldspars, mica, and other colloidal silicate clays which have densities between the range of 2.50-2.70g/cm³ make-up the major portion of the materials in the studied soils.

The mean value of total porosity (T.P) on the upper (6-13%) slope positions of Kashere and Pindiga (Tables 3.1 and 3.2 above) at the surface and subsurface horizons were observed to range from 31.2-51.43% and 31.76-44.2%, respectively. Also, at the middle (2-6%) slope positions of Kashere and Pindiga the mean total porosity (Tables 3.3 and 3.4) for the surface and subsurface horizons ranged from 29.45-39.7% and 28.5-42.25%, respectively. The mean value of total porosity (Tables 3.5 and 3.6 above) at the 0-2% slope position for the surface and subsurface horizons at the lower slope positions of Kashere were observed to range from 32-48.63% and 32-47.1%, respectively.

The mean value of water holding capacity (W.H.C), on the upper (6-13%) slope positions of Kashere and Pindiga (Tables 3.1 and 3.2 above) at the surface and subsurface horizons were observed to range from 35.3-50% and 41.6-48.9%, respectively. Also, at the middle (2-6%) slope positions of Kashere and Pindiga the mean water holding capacity (Tables 3.3 and 3.4) for the surface and subsurface horizons ranged from 29.45-39.7% and 32.7-49.8%, respectively. Percentage porosity of all the studied soils fall below the ideal porosity value (>50%) for healthy root growth the range obtained

were rated low to medium by Dumitru *et al.*, (2011). Also Malgwi, (2007) stated that the recorded range of total porosity values across the locations are regarded as low.

The mean value of water holding capacity (Tables 3.5 and 3.5 above) at the 0-2% slope position for the surface and subsurface horizons at the lower slope positions of Kashere and Pindiga were observed to range from 36.1-48.5% and 32--47.1%, respectively. Similarly, Maduakar (1991) found out those sand textured and loamy sand textured soils of sudano sahelian region of Nigeria retained moisture ranging from 13-15% and 23-30%, respectively.

The mean value of water contents at permanent wilting point (P.W.P), plant available water (P.A.W) and field capacity (F.C) on the upper (6-13%) slope positions of Kashere and Pindiga (Tables 3.1 and 3.2 above) at the surface and subsurface horizons were observed to range from 4.8-10.2%, 4.30-14.2% and 10.6-23.8% respectively. Also, the mean value of water contents at permanent wilting point(P.W.P), plant available water (P.A.W) and field capacity (F.C) on the middle (2-6%) slope positions of Kashere and Pindiga (Tables 3.1 and 3.2 above) at the surface and subsurface horizons were observed to range from 2.7-8.3%, 4.4-10.3% and 7.5-18.5% respectively. Furthermore, the mean value of water contents at permanent wilting point(P.W.P), plant available water (P.A.W) and field capacity (F.C) on the lower (0-2%) slope positions of Kashere and Pindiga (Tables 3.1 and 3.2 above) at the surface and subsurface horizons were observed to range from 3.1-7.2%, 8.9-13.5% and 12.3-19.5% respectively. From the study the P.A.W is rated low to high

and is typical for sandy textured soils such as coarse sand, fine sand, loamy sand, sandy loam and sandy clay loam with P.A.W which ranges 5-20% as characterized by (NRCCA, 2010).

Similarly, Bamanga *et al.*, (2024) reported that the water contents at field capacity and permanent wilting points were moderate in all the farm locations except at Gindin Dorowa in Wukari farm lands where F.C and P.W.P were low (18.65% and 7.45%) meanwhile the P.A.W was high except at except at Gindin Dorowa where F.C and P.W.P were low (11.18% - 11.20%).

Soil organic carbon across the slope positions of Kashere and Pindiga

The mean value of soil organic carbon, on the upper (6-13%) slope positions of Kashere and Pindiga (Tables 3.1 and 3.2 above) at the surface and subsurface horizons were observed to range from 9.78-16.76g/kg and 7.38-14.56g/kg, respectively. Also, at the middle (2-6%) slope positions of Kashere and Pindiga the mean soil organic carbon (Tables 3.3 and 3.4) for the surface and subsurface horizons ranged from 9.18-18.25g/kg and 3.59-18.85g/kg, respectively. The mean value of soil organic carbon (Table 3.5 above) at the 0-2% slope position for the surface and subsurface horizons at the lower slope positions of Kashere and Pindiga were observed to range from 11.57-17.76g/kg and 6.88-16.16g/kg, respectively. This range of values for soil organic carbon for all the soils studied across this slope positions was rated low to high according to Malgwi (2007) rating scale.

This finding is in line with earlier report by Jolimar *et al.* (2012); Raji, (2016) who obtained high soil organic carbon in their respective studies. However, Abagyeh *et*

al. (2017); Salem *et al.* (2018); Askira *et al.* (2019) all obtained low soil organic carbon content for soils in the Savanna zones of Nigeria. The low level of soil organic carbon in these soils could be attributed to low organic matter returns and other human factors such as crop residues removal, burning and mineralization.

Soil structure across the slope positions of Kashere and Pindiga

The soil structure across the slope positions ranges from weak, moderate to strong fine sub angular blocky. The soil structure mostly varies with soil depth this could be due to variation in soil texture, bulk density and soil porosity down the profile depth. Similarly, Sarah (2024) reported that the soil structure at the upper, middle and lower slope positions are mostly strong fine sub-angular blocky, weak fine sub-angular blocky and moderate fine sub-angular block structure. Similarly, Idris (2023) found out that soil structure in the mapping units, varied from weak fine sub-angular blocky, moderate sub-angular blocky to strong sub-angular blocky. The strong sub-angular blocky structure is often found in B-horizons due to higher clay content (Singer and Munns, 1999).

Infiltration capacity of soils of Kashere and Pindiga across the slope positions.

The steady state infiltration rate (Table 3.7 below) of Kashere soils at the lower (0-2%) slope was found range from 1.2 to 19.5cm/hr, while that of Pindiga (Table 3.7 below) ranged from 3.3 to 28.8cm/hr. The cumulative infiltration for Kashere and Pindiga Soils at steady state ranges from 3.4 to 78 cm and 9.0 to 76cm, respectively. Also, the steady state infiltration rates of Kashere soils at the middle (2-6%) slope (Table 3.7 below)

were found range from 2.1 to 28.8 cm/hr, while that of Pindiga ranged from 3.0 to 15.6 cm/hr (Table 3.8 below). The cumulative infiltration for Kashere and Pindiga Soils at steady state ranges from 5.0 to 91cm and 3.8 to 52.6 cm, respectively. Furthermore, the steady state infiltration rates of Kashere soils at the upper (6-13%) slope position (Table 3.7 below) were found range from 2.4 to 16.5

cm/hr, while that of Pindiga (Table 3.7 below) ranged from 6.0 to 18.3 cm/hr. The cumulative infiltration for Kashere and Pindiga soils at steady state ranges from 3.4 to 78 cm and 9 to 76 cm. Idris (2021) also, reported that that Kashere, Pindiga, and Tumu areas, recorded infiltration rates (IR) of 4.2, 5.2 and 3.4 cm/hr, respectively.

Table 3.7: Infiltration capacity of Kashere and Pindiga Soils.

Study Locations	Kashere			Pindiga	
Sampling Points/ Replications	Kashere Soils I.C	Kashere Soils C.I	Sampling Points/ Replications	Pindiga Soils I.C	Pindiga Soils C.I
	(cm/hr)	(cm)		(cm/hr)	(cm)
Upper Slope Positions (6-13%)					
1 R1	2.40	3.40	13R1	6.00	9.00
2 R2	16.5	78.2	14 R2	13.5	76.0
3 R3	13.2	38.4	15 R3	18.3	41.2
4 R4	16.5	36.9	16 R4	8.70	24.5
<i>SD</i>	6.68	30.63	<i>SD</i>	5.424	28.735
<i>Mean</i>	12.15	38.98	<i>Mean</i>	11.625	37.675
<i>CV (%)</i>	55.0	78.58	<i>CV (%)</i>	46.66	76.273
Middle Slope Positions (2-6%)					
5 R1	2.10	5.00	17 R1	3.00	3.80
6R1	28.8	91.4	18 R1	10.5	30.2
7R3	14.4	35.4	19 R3	15.6	52.6
8R4	16.5	41.1	20 R4	12.9	40.7
<i>SD</i>	10.93	35.82	<i>SD</i>	5.417	20.801
<i>Mean</i>	15.45	43.23	<i>Mean</i>	10.5	31.825
<i>CV (%)</i>	70.77	82.86	<i>CV (%)</i>	51.59	65.377
Lower Slope Positions (0-2%)					
9R1	1.20	4.00	21R1	3.30	4.80
10R2	6.60	20.3	22R2	28.8	81.2
11 R3	19.5	50.3	23 R3	13.5	65.5
12R4	15.0	38.2	24 R4	24.3	81.1
<i>SD</i>	8.22	20.30	<i>SD</i>	11.425	36.33
<i>Mean</i>	10.6	28.2	<i>Mean</i>	17.475	58.15
<i>CV (%)</i>	77.5	71.99	<i>CV (%)</i>	65.378	62.47

Source: Field work (2021). Note I.C.: Infiltration capacity and C.I: Cumulative infiltration

Similarly, Sarah, (2024) reported that the mean steady infiltration capacity of the soils at the upper, middle and lower

positions slope of Kashere ranges from 2.73 to 4.87cm/hr, 2.73 to 5.84 cm/hr and 2.08 to 2.91cm/hr with the mean

values of 3.85 cm/hr, 4.47cm/hr and 2.50 cm/hr, respectively.

Conclusion

Based on the findings of the study, the result indicated that Kashere and Pindiga soils are predominantly sandy in texture, with weak, moderate to strong sub-angular block structures. The soils of the study area were also found to be of moderate to high infiltration capacity. The soils have high surface bulk density that decreases with increase in soil depth. The soils also were having low to moderate water holding capacities. Percentage porosity of all the studied soils fall below the ideal porosity value (>50%) for healthy root growth the range obtained were rated low to medium.

The soil water at P.W.P, P.A.W and F.C were found to be predominantly low to moderate in the studied soils.

Recommendations.

It is important to adopt soil and water conservative practices such as mulching, cover cropping, addition of organic manures and amendments to increase soil quality and crop productivity in the stud locations.

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DETERMINATION OF ERODIBILITY FACTOR (K-VALUE) IN KASHERE AND PINDIGA AREAS OF GOMBE STATE, NIGERIA.

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ABSTRACT

The study was conducted in Kashere and Pindiga of Areas of Akko L.G.A, Gombe State, Nigeria, to examine some soil hydro-physical properties and also to evaluate soil erodibility factors across the three slope positions. Four (4) profile pits were sunken at the upper, middle and lower slope position of the two study areas. Soil samples were collected, then air dried, crushed gently and stored in well labeled polyethene bags. The processed soils were then taken to the laboratory for analysis following the standard procedure to the determination of the physical, structural properties and organic carbon contents. Infiltration test were carried out using double ring infiltrometer method. The results indicated that the soils were predominantly of sub-angular blocky structure in all the profiles. The study revealed that the sand, silt and clay contents at the surface of Kashere and Pindiga soils ranges 67.2-95.2%, 2.00-20.0%, 4.80-14.0%, respectively. The soil organic matter content of Kashere and Pindiga ranges from 0.69-3.25%. The steady state infiltration rate of Kashere and Pindiga soils range from 1.2-28.8 cm/hr. The soil structure across the slope positions ranges from weak, moderate to strong fine sub angular blocky. The K-factor at the 6-13% slope of Kashere and Pindiga were rated low to moderate, it ranges from 0.0438 to 0.1558 ton MJ⁻¹ hmm⁻¹ and 0.09556 to 0.13459 tons MJ⁻¹ hmm⁻¹, respectively. Also, the K-factor at the 2-6% slopes of Kashere and Pindiga were rated low to moderate, it ranges from 0.0526- 0.1366 and 0.0772-0.22829 tons MJ⁻¹ hmm⁻¹. Furthermore, the K-factor at the 0-2% slope of Kashere and Pindiga were rated low to high, it ranges from 0.011784-0.20321 and 0.03006-0.10042 tons MJ⁻¹ hmm⁻¹. High variability of K-factor was obtained across the slope positions of Kashere (CV=37.7%) and Pindiga (CV=37.1%) It is important to adopt soil conservative practices such as mulching, cover cropping, addition of organic manures and amendments to reduce the susceptibility of these soils to erosion events.

Keywords: Soil Erodibility, Erosion, Kashere and Pindiga.

INTRODUCTION

Soil, water and food are fundamental to human life (FAO, 2009); furthermore, soil is considered the most vital natural resources on earth. This is because it

hosts both animate and inanimate beings and

over three quarters of the world's man-made developments are being carried out on land but this resource is been

degraded due to the impact of soil erosion (Iliyasu, *et al.*, 2019 and Okin, 2005). Despite the significance of soil to life it is most neglected commodity on this planet (Suraj *et al.*, 2019). Soil comprises of minerals, organic matter, nutrients, moisture and micro-organisms that supports the ecosystem (Sebastian *et al.*, 2014). Temporal changes in soil physical and hydraulic properties have been the subject of much research to quantify the effects of different management practices, land uses and topo-sequences on soil quality within the growing seasons. The impact of these factors resulted in to variability of these soil properties spatially and temporally (Shahid, 2012, Oshunsanya, 2013, Regues *et al.*, 2017 and Zebarth *et al.*, 1989).

Soil degradation is the loss of soil qualities and nowadays, the term “soil degradation” is frequently discussed in the field of environmental protection. Soil erosion is one of the most crucial problems that cause soil degradation and losses. In certain regions of the world water and wind erosion can especially be identified (Hlavčová, 2011, Nampak *et al.*, 2018 and Rizeei *et al.*, 2016). The current rate of agricultural land degradation worldwide by soil erosion and other factors is leading to an irreplaceable soil loss in productivity on about 6 million hectare of fertile land a year (Suraj, *et al.*, 2019). Soil erosion is a natural phenomenon which involves the removal and transportation of soil materials through the action of erosive agent such as water, wind, gravity and human disturbances (Gunawa *et al.*, 2013, Okafor *et al.*, 2018, Novora *et al.*, 2006, Ekpo *et al.*, 2021). Water erosion is a continual process; it results in

thinning the soil profile, loosening fine soil particles and nutrients, and degrading the soil structure and texture. It can also cause significant changes in a water regime. (Nasco, *et al.*, 2019). Soil loss by erosion is considered a global issue due to its on- site and off site effects on the environment and its resulting effects on the socio-economic of the populace (Schoonover and Crim, 2015, Adimasu *et al.*, 2014, Angassa, (2014), Ajibade *et al.*, 2020 and Kalhoro *et al.*, 2017). The washing away of the top layer of the soil is carried out in layers and goes deep as it progresses there by reducing the soil depth and exposing the root of the plant, which has resulted in poor crop yield, damage of farm lands, siltation and pollution of nearby surface water (Schoonova and Crim, 2015 and Okafor *et al.*, 2018). Land use and soil depth have effects on soil properties (Fetene and Amara, 2018, Ajibola *et al.*, 2018, Biliyamnu, 2023, Malata, 2023, Bappa, 2023).

Soil erodibility denoted by K is an important index in the soil erosion model used in evaluating how susceptible is soil to erosion (Wischmeier and Smith, 1978, Zhang *et al.*, 2008, Shi *et al.*, 2012). Soil erodibility is the ability of the soil to resist detachment and transportation by an erosive event or it represents soil susceptibility to suffer detachment by hydric erosion processes (Shi *et al.*, 2012, Abidan *et al.*, 2017 and Suraj *et al.*, 2019).

Climate, environmental and management parameters combined together to cause soil erosion. Considering the revised universal soil loss equation (RUSLE)/universal soil loss equation (USLE) empirical model, the climate and environmental variables are

represented by rainfall erosivity (R), soil erodibility (K), and slope length and steepness (LS), while the management C and land management P factor. (Ajibade *et al.*, 2020, Kalhoro *et al.*, 2017 and Wischmeier and Smith, 1978 Ekpo, *et al.*, 2021). The correct study and estimation of soil erodibility is essential in understanding soil detachment, transport and deposition and its prediction to evaluate land quality for production and conservational purpose. The physical and chemical properties of soil have been known to affect soil stability which is an important property governing erodibility (Zimmermann *et al.*, 2013 and Reichert *et al.*, 2001). Kashere and Pindiga communities are villages under Akko Local government of Gombe State, the land surface terrain were sloppy and undulating, the soils in the area were observed and characterized to be loose and friable soil (sandy, sandy clay loam and loamy sand soils) predominantly with some clay occurring in some part of the environment this could be one of the possible contribution to the high incidence of soil erosion challenges because loose soils lack aggregate stability and when there is surface compaction this may lead to higher runoff water movements (Iliya, 2023 and Idris, 2021). Therefore, the objective of this study were to determine some hydro-physical properties and evaluate the soil erodibility factor (K) in these areas across the three slope positions. The information of soil erodibility characteristics may be useful in land use planning and soil management strategies such as soil erosion control and

watershed management in the study areas.

MATERIALS AND METHODS

The study area

The studies were carried out at some selected catchment areas of Kashere and Pindiga locations. Kashere and Pindiga are the two separate study locations located in Akko Local government area of Gombe State. It is part of the Northern Guinea Savanana ecological zone in North eastern Nigeria. The Kashere study site is located within latitude 10°51'20"N to 11°53'21"N of the equator to longitude 6°79'63"E to 7°64'41"E of Greenwich meridian while Pindiga study site is located within latitude 10°08'33'64"N to 11°33'56"N of the equator to longitude 6°65'830"E to 7°50'585"E of Greenwich meridian (UTM 32N). The Geology of the study areas is developed on basement complex rocks with adjoining sedimentary rocks formation (Ikusemoran *et al.*, 2018). The areas records about three to four months of rainfall and its is concentrated in the months of July, August and September with the average rainfall of 951mm per annum (UBRBDA, 2018). The mean annual temperature ranged from 30 to 37 °C, while March, April and May were observed to be the dry hot months of the year. During the rainy season, the temperature drops considerably due to the cloud cover between July and August as well as during the Harmattan periods of November to February (UBRBDA, 2018). Relative humidity has the same pattern being 94% in August and drops to less than 10% during harmattan period (Balzerek *et al.*, 2003 and Lazarus, 2017).

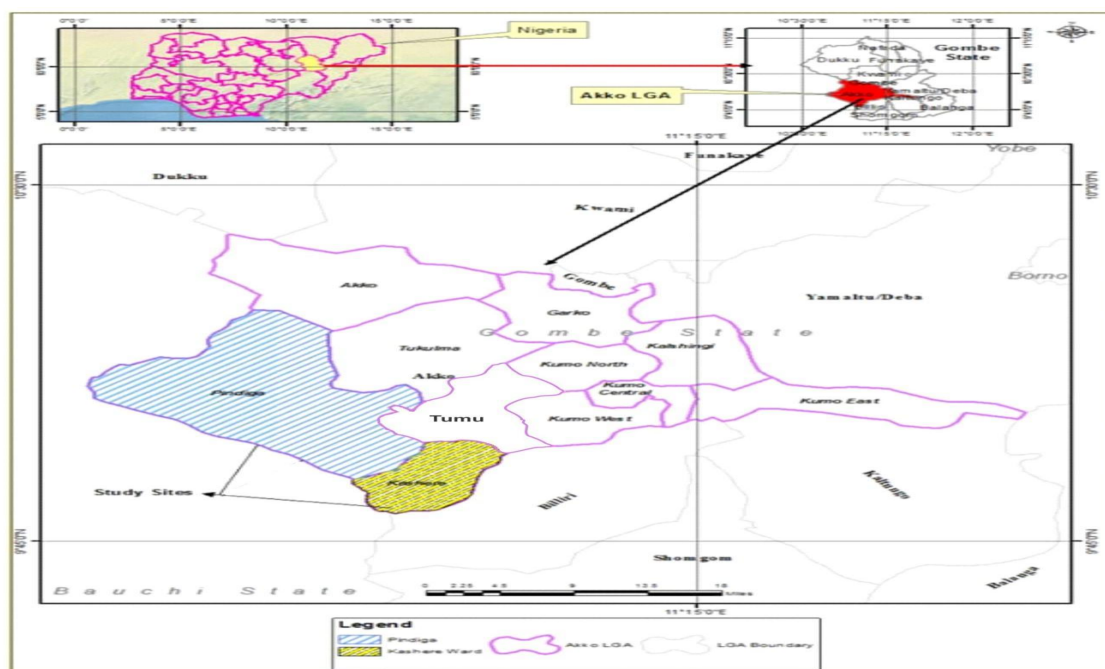


Figure 3.1: Map of Akko L.G.A showing the study locations (Kashere and Pindiga)

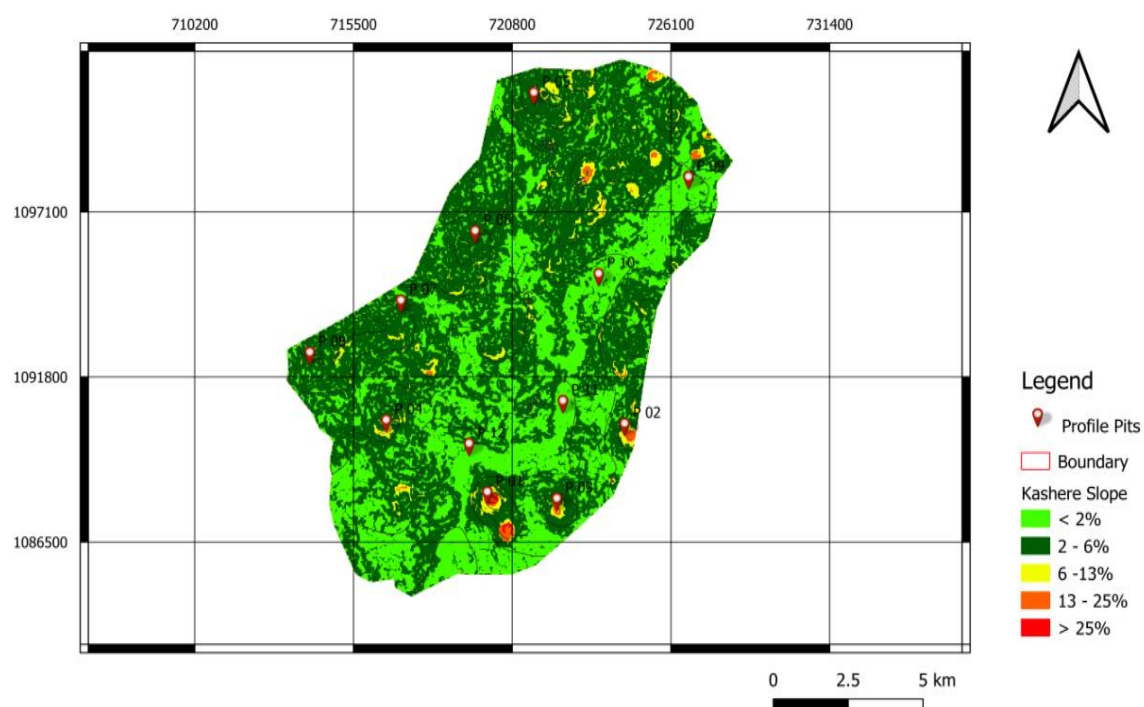


Figure 3.2: Topographic map of Kashere

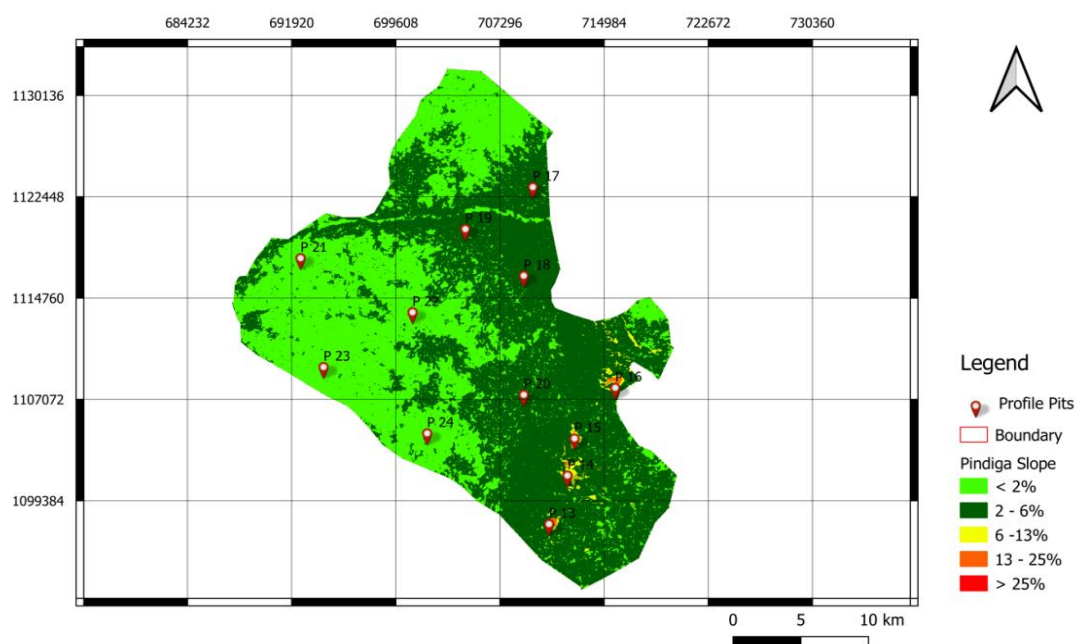


Figure 3.3: Topographic map of Pindiga

Soil sampling and handling

A reconnaissance soil survey was conducted at the study sites aided by topographic maps, hand held G.P.S and vital information's at hand. The soils samples were randomly collected from the selected catchment areas at Kashere and Pindiga communities based on their slope positions and the distinct soil horizons. In this study lower slope position, middle slope position and upper slope position consist of areas with the slope of 0-2%, 2-6% and 6-13% respectively. A total of 24 profile pits with the dimensions of 2m long, 1.5m wide and 1.5 m deep were sunken and representative soil samples were collected as aided by slope and watershed maps. However, only the soil data from the surface horizons from each sunken profile was utilized for soil erodibility factor evaluation. All the sunken pits were described according to

the method outlined by United State Department of Agriculture (USDA) Soil Survey Staff (1999). Soil samples were collected based on the pedogenic horizons identified. Soil samples were collected from each experimental site and sealed in a clean polyethene bags, labeled and then brought to Soil Science Department Laboratory, Moddibo Adama University, Yola for laboratory test and determinations of soil properties such as soil structure, texture, bulk density, particle density, total porosity, water holding capacity and organic carbon content. In the laboratory, each sample was separately air dried ground and passed through a 2.0 mm sieve for laboratory analysis as described by (Agbenin, 1995). The particle sizes were determined using the Bouyoucos hydrometer method as described by Jaiswal (2003). The water holding

capacity was determined by filter paper method as described in Iliya, (2023). Soil organic carbon content were determined in bulk soil and in the various aggregate fractions separated during the wet sieving by the dichromate oxidation method (Nelson and Summers 1982). Soil structures were described according to procedures in the USDA Soil Survey Manual (Soil Survey Staff, 2010; Soil Survey Division Staff, 1993).

The Infiltration capacity of the soils of the study area was determined using double ring infiltrometer methods as described by Anderson and Ingram, (1993) which reflects the permeability class of the soil. The Soil erodibility factor (K) was determined on both the treatment and control plots using the formula below as described by Wischemier *et al.*, (1971) was used as adopted by Rosool *et al* (2014).

$$K = [2.173 \times 10^{-6} \times M^{1.14} \times (12-a) + 3.25 \times 10^{-2} (b-2) + 2.5 \times 10^{-2} (c-3)]$$

$$M = (\% \text{ Silt} + \% \text{ Very fine Sand}) \times (100 - \% \text{ Clay})$$

Where, M= Particle size parameter, a = percent organic matter content, b= soil structure code use in soil classification and c= the profile permeability class.

Data analysis

The data generated from the laboratory analysis were subjected to simple descriptive statistics which include range and mean as described by (Harry and Steven, 1995). Coefficient of variation was used to compare means as described

by Wilding (1985) ratings. Correlation analysis was used to determine the relationships between the evaluated soil erodibility factor and properties using statistical packaged for social sciences (SPSS) version 23.

Table 2.1: Ratings for coefficient of variability

CV values	Variability Ratings
< 15%,	Low
15% to 35%,	Moderate
>35%,	High

Source: Wilding, (1985).

Table 2.2: Soil structural class index

Soil structure	Structural code ratings
Very fine granular (<1mm)	1
Fine granular (1-2 mm)	2
Medium or coarse granular soil (2-5 mm)	3
Massive (Blocky, platy, columnar and prismatic)	4

Source; Udoumoh *et al.*, (2018)

Table 2.3: Soil permeability classification

Permeability type (cm/hr)	Permeability code ratings
Very Slow infiltration (< 0.125 cm/hr)	6
Slow (0.125 to 0.5 cm/hr)	5
Slow to moderate (0.5 to 2.0 cm/hr)	4
Moderate (2.0 to 6.25 cm/hr)	3
Moderate of rapid or high (6.25 to 12.5cm/hr)	2
Rapid or high (> 12.5cm/hr)	1

Source: Wischemeier and Smith, (1978).

Table 2.4: Standard erodibility Indices

Group	K-Factor	Nature of Soil
I	0 to 0.1	Permeable out wash well drained soil slowing permeable substrater
II	0.11 to 0.17	Well grained soils in sandy gravel material
III	0.18 to 0.28	Well grained soils in sandy gravel fee material
IV	0.29 to 0.48	Poorly graded moderately fine and fine textured soils
V	0.49 to 0.64	Poorly graded silts or very fine sandy soil, well and moderately grained soils

Source: Wischemeier and Smith, (1978).

Table 2.5: Soil erodibility ratings

K-Factor	Soil erodibility rating	Effect rating
0 .02 to 0.1	Low	Low
0.11 to 0.17	Moderate	Moderate
0.18 to 0.28	High	High/severe

Source: Okafor *et al*, (2017).

Table 3.1: Surface Soil Properties and Erodibility Factor in Kashere Locations.

Pedon No	S.O. M	SAND	SILT	CLAY	Soil Structure	Steady State Infiltration rates	Soil Erodibility (K- Factor)
	(%)	(%)	(%)	(%)		(cm/hr)	(tons MJ ⁻¹ hmm ⁻¹)
Upper slope position, (6 to 13%) slope							
1R1	2.88	79.2	12.0	8.80	Weak fine sub angular blocky	Moderate (2.40)	0.1558
2R2	2.17	81.2	12.0	6.80	Moderate fine sub angular blocky	High (16.5)	0.0985
3R3	1.72	79.2	14.0	6.80	Moderate fine sub angular blocky	High (13.2)	0.1183
4R4	1.69	91.2	4.00	4.80	Moderate fine sub angular blocky	High (16.5)	0.0438
Mean	2.12	82.7	11.1	6.80		12.15	0.1041
CV(%)	26.4	6.71	39.9	23.9		55.00	44.90
Middle slope position, (2 to 6%) slope							
5R1	2.08	79.2	8.80	12.8	Weak fine sub angular blocky	Moderate (2.10)	0.1366
6R2	3.15	89.2	6.00	4.80	Strong fine sub angular blocky	High (28.8)	0.0526
7R3	2.20	87.2	6.00	6.80	Moderate fine sub angular blocky		
						High (14.4)	0.0553
8R4	2.08	87.2	8.00	4.80	Strong fine sub angular blocky	High (16.5)	0.0710
Mean	2.38	85.7	7.20	7.30		15.5	0.0789
CV(%)	21.9	5.17	19.7	51.9		70.0	49.80
Lower slope position, (0 to 2%) slope							
9R1	1.99	71.2	14.0	14.0	Weak fine sub angular blocky	Slow to Moderate (1.20)	0.20321
10R2	2.63	73.2	16.0	10.8	Moderate fine sub angular blocky	Modete to high (6.60)	0.15152
11R3	2.36	79.2	16.0	4.80	Moderate fine sub angular blocky	High (19.5)	0.13007
12R4	2.99	75.2	16.0	8.80	Moderate fine sub angular blocky	High (15.00)	0.11784
Mean	2.49	74.7	15.5	9.60		10.6	0.15066
CV(%)	16.9	4.58	6.45	40.1		77.5	25.02

Source: Field Work, (2021).

Table 3.2: Surface Soil Properties and Erodibility Factor in Pindiga Locations

Pedon No	S.O.M	SAND	SILT	CLAY	Soil Structure	Steady State Infiltration rates	Soil Erodibility (K -factor)
	(%)	(%)	(%)	(%)		(cm/hr)	(tons MJ ⁻¹ hmm ⁻¹)
Upper slope position, (6 to 13%) slope							
13R1	1.26	73.2	14.0	12.8	Moderate fine sub angular blocky	High (6.0)	0.13459
14R2	2.51	81.2	12.0	6.80	Weak fine sub angular blocky	High (13.5)	0.09556
15R2	1.55	79.2	16.0	4.80	Weak fine sub angular blocky	High (18.7)	0.11661
16R4	2.17	83.2	10.0	6.80	Weak fine sub angular blocky	High (8.70)	0.11612
Mean	1.87	79.2	13.0	7.80		11.7	0.11572
CV(%)	30.47	5.46	19.9	44.4		47.8	13.8
Middle slope position, (2 to 6%) slope							
17R1	1.76	71.2	20.0	8.8	Weak fine sub angular blocky	Moderate (3.0)	0.22829
18R2	3.25	77.2	8.00	14.8	Strong fine sub angular blocky	High (10.5)	0.09184
19R3	2.36	85.2	12.00	2.8	Weak fine sub angular blocky	High (15.6)	0.10099
20R4	0.62	85.2	8.00	6.8	Moderate fine sub angular blocky	High (12.9)	0.0772
Mean	1.99	79.7	12.0	8.30		10.5	0.14037
CV(%)	55.4	8.55	47.2	60.2		51.2	54.4
Lower slope position, (0 to 2%) slope							
21R1	2.34	67.2	4.00	28.8	Weak fine sub angular blocky	Moderate (3.30)	0.10042
22R2	2.79	87.2	8.00	4.80	Weak fine sub angular blocky	High (28.8)	0.06740
23R3	2.29	87.2	6.00	6.80	Weak fine sub angular blocky	High (13.5)	0.05495
24R4	1.05	95.2	2.00	2.80	Weak fine sub angular blocky	High (24.3)	0.03006
Mean	2.12	84.2	5.00	10.8		17.5	0.06321
CV(%)	35.4	14.2	51.6	112		62.6	46.0

Source: Author's field survey, (2021)

RESULTS AND DISCUSSION

Surface Soil Organic Matter Content at Kashere and Pindiga

The mean the value of surface soil organic matter content (Table 3.1 below) of Kashere soils at the upper, middle and lower slope position were found to be ranging from 1.69-2.88%, 2.20-3.15% and 1.99-2.99%, respectively. The coefficient of variability of S.O.M at the upper, middle and lower slope positions were found to be 26.4%, 21.9% and 16.9% which shows low to moderate variability across the upper, middle and lower slope positions. While the soil organic matter content (S.O.M) (Table 3.2 below) at the upper, middle and lower slope position of Pindiga ranges from 1.26-2.51%, 0.62-3.25% and 1.05-2.79%, respectively. The coefficient of variability of S.O.M at the upper, middle and lower slope positions were 30.47%, 55.4% and 35.4%, respectively which shows moderate to high variability across the upper, middle and lower slope positions. Similarly, Sarah (2024) reported that the S.OM content of Kashere soils at the 6-13%, 2-6% and 0-2% slope positions ranges from 1.09-3.26%, 2.13-3.39% and 2.44-2.97%, respectively with the coefficient of variability of 40.7%, 20.6% and 9.32%, respectively. This range of values for soil organic carbon for all the soils studied across this slope positions was rated low to high according to Malgwi (2007) rating scale. This finding is in line with earlier report by Jolimar *et al.* (2012); Raji, (2016) who obtained high soil organic carbon in their respective studies. However, Abagyeh *et al.* (2017); Salem *et al.* (2018); Askira *et al.* (2019)

all obtained low soil organic carbon content for soils in the Savanna zones of Nigeria. The low level of soil organic carbon in these soils could be attributed to low organic matter returns and other human factors such as crop residues removal, burning and mineralization.

Physical properties of the soil in the study areas

The mean the value of surface sand content (Table 3.1 above) of Kashere soils at the upper, middle and lower slope position were found to be ranging from 79.2-91.2%, 79.2-89.2% and 71.2-79.2%, respectively. The coefficient of variability of sand content at the upper, middle and lower slope positions were found to be 6.71%, 5.17% and 4.58% which shows low variability across the upper, middle and lower slope positions. While the sand content (Table 3.2 above) at the upper, middle and lower slope position of Pindiga ranges from 73.2-83.2%, 71.2-85.2% and 67.2-95.2%, respectively. The coefficient of variability of sand content at the upper, middle and lower slope positions were 5.04%, 8.55.4% and 14.2%, respectively which shows low variability across the upper, middle and lower slope positions. The sand particle is the dominant fraction in all the horizons of the studied soils. The predominance of sand particles in arid and semi arid climates is not uncommon because many of the soils were found to be of Aeolian deposits blown from across several thousand kilometers (Imadojemu *et al.*, 2017, Onweremadu, *et al.*, 2011, Salem *et al.*, 2020 and Idris *et al.*, 2023).

The mean the value of surface silt content (Table 3.1 above) of Kashere

soils at the upper, middle and lower slope position were found to be ranging from 4.0-14%, 6.0-8.8% and 14-15.5%, respectively. The coefficient of variability of silt content at the upper, middle and lower slope positions were found to be 39.9%, 19.7% and 6.45% which shows moderate to high variability across the upper, middle and lower slope positions. While the silt content (Table 3.2 above) at the upper, middle and lower slope position of Pindiga ranges from 10-16%, 8.0-20% and 2.0-8.0%, respectively. The coefficient of variability of silt content at the upper, middle and lower slope positions were 19.9%, 47.2% and 51.6%, respectively which shows moderate to high variability across the upper, middle and lower slope positions. Similar result of low silt content were also reported by Idris *et al.*, (2023) and Osondu and Lekwa (2016). However, Salem *et al.*, 2020, Askira *et al.*, (2019); and Zata *et al.*, (2020) all reported high silt content in their respective studies.

The mean the value of surface clay content (Table 3.1 above) of Kashere soils at the upper, middle and lower slope position were found to be ranging from 4.80-8.80%, 4.80-12.8% and 4.80-14.0%, respectively. The coefficient of variability of clay content at the upper, middle and lower slope positions were found to be 23.9%, 51.9% and 40.1% which shows moderate to high variability across the upper, middle and lower slope positions. While the clay content (Table 3.2 above) at the upper, middle and lower slope position of Pindiga ranges from 4.80-12.8%, 4.80-12.8% and 4.80-14%, respectively. The coefficient of variability of silt content at the upper, middle and lower slope positions were

44.4%, 60.2% and 112%, respectively which shows high variability across the upper, middle and lower slope positions. Generally, clay content was found to be low when compared to the sand content. The lower clay content of the surface soil could be a characteristic of soils formed on basement complex rocks in the study area from which the soils were formed (Kparmwang, 1993; and Salem *et al.*, 2023 and Brady and Weil, 2017).

The soil textural classes (Table 3.1 and 3.2 above) were found to be sandy loam, loamy sand, and sandy clay loam. There was general non uniformity in soil texture in the soil horizons of each studied pedon. Similar results were obtained by Salem *et al.*, 2020 and Idris *et al.*, 2023).

Soil structure across the slope positions of Kashere and Pindiga

The soil structure across the slope positions (Table 3.1 and 3.2 above) ranges from weak, moderate to strong fine sub angular blocky. The soil structure mostly varies with soil depth this could be due to variation in soil texture, bulk density and soil porosity down the profile depth. Similarly, Sarah (2024) reported that the soil structure at the upper, middle and lower slope positions are mostly strong fine sub-angular blocky, weak fine sub-angular blocky and moderate fine sub-angular block structure. Similarly, Idris (2023) found out that soil structure in the mapping units, varied from weak fine sub-angular blocky, moderate sub-angular blocky to strong sub-angular blocky. The strong sub-angular blocky structure is often found in B-horizons due to higher clay content (Singer and Munns, 1999).

Soil erodibility factor (K) across the slope positions of Kashere and Pindiga

The soil erodibility (Table 3.1 above) at the upper slope of Kashere (6-13%) was rated low to moderate and it ranges from 0.0438 to 0.1558 tons MJ⁻¹ hmm⁻¹ with the mean value of 0.1041 tons MJ⁻¹ hmm⁻¹. There was high variability in the value of K factor (CV=44.9%) for Kashere soils at the 6-13% slope position this could be due to the high variability of the soils infiltration capacity (CV =55.0%) and silt content (CV=39.9%), followed by moderate variability in clay (CV =23.9%) and organic matter (26.4%). Similarly, at the Pindiga location, the soil erodibility (Table 3.2 above) at the upper slope (6-13%) was also found to be rated low to moderate and it ranges from 0.09556 to 0.13459 tons MJ⁻¹ hmm⁻¹ with the mean value of 0.11572 tons MJ⁻¹ hmm⁻¹. There was slight variability in the value of K factor (CV=13.8%) for Pindiga soils at the 6-13% slope position this could be due to the slight variability in sand content (CV=5.46%), moderate variability in silt (CV=19.9%) and organic matter content (CV=30.45%) even though there was high variability in clay content (CV=44.4%) and soil infiltration capacity (CV= 47.8%)

Also, the soil erodibility (Table 3.1 above) at the middle slope of Kashere (2-6%) was rated low to moderate and it ranges from 0.0526 to 0.1366 tons MJ⁻¹ hmm⁻¹ with the mean value of 0.0789 tons MJ⁻¹ hmm⁻¹. There was high variability in the value of K for soils at the 2-6% slope position of Kashere (CV =49.8%) this could be due to the high variability of the soils infiltration capacity (CV =70.0%) and clay content (CV=51.9%), followed by moderate

variability in organic matter (CV=21.9%). Similarly, at the Pindiga location, the soil erodibility (Table 3.2 above) at the middle slope (2-6%) was also found to be rated low to high and it ranges from 0.0772 to 0.22829 tons MJ⁻¹ hmm⁻¹ with the mean value of 0.14037 tons MJ⁻¹ hmm⁻¹. There was high variability in the value of K for soils at the 2-6% slope position of Pindiga (CV =54.4%) this could be due to the high variability of the soils infiltration capacity (CV =51.2%), Silt (CV=47.2%), clay (CV=60.2%) and Organic matter (CV=55.4%) contents, despite the slight variability sand (CV=8.55%) content.

Furthermore, the soil erodibility at the lower slope of Kashere (0-2%) was rated low to high and it ranges from 0.011784 to 0.20321 tons MJ⁻¹ hmm⁻¹ with the mean value of 0.015666 tons MJ⁻¹ hmm⁻¹. There was moderate variability in the value of K for soils at the 0-2% slope position (CV =25.02%) this could be due to the high variability of the soils infiltration capacity and clay content (CV=77.5%), followed by moderate variability in organic matter (16.9%). Similarly, at the Pindiga location, the soil erodibility (Table 3.2) at the lower slope (0-2%) was also found to be rated low and it ranges from 0.03006 to 0.10042 tons MJ⁻¹ hmm⁻¹ with the mean value of 0.06321 tons MJ⁻¹ hmm⁻¹. There was high variability (Table 3.5) between the K factor values across the three slope positions of Kashere (CV=327%). However, At the Pindiga study location the middle slope position have the highest value of soil erodibility (0.14037 tons MJ⁻¹ hmm⁻¹), followed by the upper slope position (0.11572 tons MJ⁻¹ hmm⁻¹) and

Table 3.5: Variability of surface soil properties and erodibility factor across the slope positions of Kashere and Pindiga

Source: Field Work, (2021)

S/No	Slope Positions	S.O.M	SAND	SILT	CLAY	Soil Structure	Steady State Infiltration rates	Soil Erodibility (K- Factor)
		(%)	(%)	(%)	(%)		(cm/hr)	(tons MJ ⁻¹ hmm ⁻¹)
Kashere Locations								
1	Upper	2.12	82.7	11.1	6.80	Weak to moderate fine sub angular blocky	12.1	0.1041
2	Middle	2.38	85.7	7.20	7.30	Strong, weak to moderate fine sub angular blocky	15.5	0.0789
3	Lower	2.49	74.7	15.5	9.60	Weak to moderate fine sub angular blocky	11.8	0.15066
	Mean	2.33	81.0	11.3	7.90		12.1	0.0915
	CV (%)	8.15	7.02	36.7	18.9		16.9	32.70
Pindiga Locations								
4	Upper	1.87	79.2	13.0	7.80	Weak to moderate fine sub angular blocky	11.7	0.11572
5	Middle	1.99	79.7	12.0	8.30	Strong, weak to moderate fine sub angular blocky	10.5	0.14037
6	Lower	2.12	84.2	5.00	10.8	Weak fine sub angular blocky	17.5	0.06321
	Mean	1.99	81.2	10.0	8.90		13.2	0.1064
	CV (%)	6.28	3.19	43.6	18.1		27.9	37.10

the lower slope position have the least value of $0.06321 \text{ tons MJ}^{-1} \text{ hmm}^{-1}$. Okafor *et al.*, (2018) also reported that the soil erodibility factor of soils of Imo State ranges from 0.023 to 0.067 and that the soils were of sandy texture with moderate infiltration capacity.

Similarly, Ekpo *et al.*, (2021) reported that the soil erodibility indices of the soils obtained from the different geologic formation across of Akwa Ibom State. In Alluvium geologic formation, the *K factor* ranged from 0.141 to 0.159 $\text{tons MJ}^{-1} \text{ hmm}^{-1}$ with an average of $0.150 \text{ tons MJ}^{-1} \text{ hmm}^{-1}$ across the depths. In Ameki, *K factor* ranges from 0.103 to 0.171 $\text{tons MJ}^{-1} \text{ hmm}^{-1}$ with an average of $0.131 \text{ tons MJ}^{-1} \text{ hmm}^{-1}$ across the depths. In Benin, The value of *K* obtained across the depths varies from 0.103 to 0.170 $\text{tons MJ}^{-1} \text{ hmm}^{-1}$ with an average of $0.130 \text{ tons MJ}^{-1} \text{ hmm}^{-1}$ across the depths. In Imo, the value of *K* ranges from 0.135 to 0.155 $\text{tons MJ}^{-1} \text{ hmm}^{-1}$ with an average of $0.147 \text{ tons MJ}^{-1} \text{ hmm}^{-1}$ across the depth. In Ogwashi, *K* ranges from 0.115 to 0.144 $\text{tons MJ}^{-1} \text{ hmm}^{-1}$ with an average of $0.127 \text{ tons MJ}^{-1} \text{ hmm}^{-1}$ across the depth. Furthermore, Suraj *et al.*, (2019) reported that the average *K* factor in Coimbatore district is $0.0174 \pm 0.005881 \text{ t.ha.h.ha}^{-1} \text{ MJ}^{-1}, \text{ mm}^{-1}$ and in most of the study area it ranges from 0.01 to $0.03 \text{ t.ha.h.ha}^{-1} \text{ MJ}^{-1}, \text{ mm}^{-1}$. The average value of *K* observed in this slope position falls under group II (Well grained soils in sandy gravel material) as categorized by Wischmire and Smith (1978).

The steady state infiltration rates of Kashere soils at the upper (6-13%) slope position (Table 3.3 below) were found range from 2.4 to 16.5 cm/hr, while that of Pindiga (Table 3.4 below) ranged from 6.0 to 18.3 cm/hr. The cumulative infiltration for Kashere and Pindiga soils at steady state ranges from 3.4 to 78 cm and 9 to 76 cm,

Also, the steady state infiltration rates of Kashere soils at the middle (2-6%) slope (Table 3.3 below) were found range from 2.1 to 28.8 cm/hr, while that of Pindiga ranged from 3.0 to 15.6 cm/hr (Table 3.4 below). The cumulative infiltration for Kashere and Pindiga Soils at steady state ranges from 5.0 to 91cm and 3.8 to 52.6 cm, respectively. Furthermore, the steady state infiltration rate (Table 3.3 below) of Kashere soils at the lower (0-2%) slope was found range from 1.2 to 19.5cm/hr, while that of Pindiga (Table 3.8 below) ranged from 3.3 to 28.8cm/hr. respectively. The cumulative infiltration for Kashere and Pindiga Soils at steady state ranges from 4.0 to 38.2 cm and 4.8 to 81.2 cm, respectively. Idris (2021) also, reported that that Kashere, Pindiga, and Tumu areas, recorded infiltration rates (IR) of 4.2, 5.2 and 3.4 cm/hr, respectively. The soils in infiltration rate in Kashere were characterized to be of moderate to high infiltration rate. There was high variability in the values of steady infiltration rates at both Kashere and Pindiga locations and slope positions (CV= 35%).

Similarly, Sarah, (2024) reported that the mean steady infiltration capacity of the soils at the upper, middle and lower

Infiltration capacity of soils of Kashere and Pindiga across the slope positions.

Table 3.3: Infiltration capacity of Kashere soils.

Sampling Points/Replications	Infiltration Capacity (cm/hr)	Cumulative Infiltration (cm)
Upper Slope Positions (6-13%)		
1 R1	2.40	3.40
2 R2	16.5	78.2
3 R3	13.2	38.4
4 R4	16.5	36.9
<i>SD</i>	6.68	30.63
<i>Mean</i>	12.15	38.98
<i>CV (%)</i>	55.0	78.58
Middle Slope Positions (2-6%)		
5 R1	2.10	5.00
6R1	28.8	91.4
7R3	14.4	35.4
8R4	16.5	41.1
<i>SD</i>	10.93	35.82
<i>Mean</i>	15.45	43.23
<i>CV (%)</i>	70.77	82.86
Lower Slope Positions (0-2%)		
9R1	1.20	4.00
10R2	6.60	20.3
11 R3	19.5	50.3
12R4	15.0	38.2
<i>SD</i>	8.22	20.30
<i>Mean</i>	10.6	28.2
<i>CV (%)</i>	77.5	71.99

Source: Field work (2021).

Table 3.4: Infiltration capacity of Pindiga soils.

Sampling Points/Replications	Infiltration Capacity (cm/hr)	Cumulative Infiltration (cm)
Upper Slope Positions (6-13%)		
13R1	6.00	9.00
14 R2	13.5	76.0
15 R3	18.3	41.2
16 R4	8.70	24.5
<i>SD</i>	<i>5.424</i>	<i>28.735</i>
<i>Mean</i>	<i>11.625</i>	<i>37.675</i>
<i>CV (%)</i>	<i>46.66</i>	<i>76.273</i>
Middle Slope Positions (2-6%)		
17 R1	3.00	3.80
18 R1	10.5	30.2
19 R3	15.6	52.6
20 R4	12.9	40.7
<i>SD</i>	<i>5.417</i>	<i>20.801</i>
<i>Mean</i>	<i>10.5</i>	<i>31.825</i>
<i>CV (%)</i>	<i>51.59</i>	<i>65.377</i>
Lower Slope Positions (0-2%)		
21R1	3.30	4.80
22R2	28.8	81.2
23 R3	13.5	65.5
24 R4	24.3	81.1
<i>SD</i>	<i>11.425</i>	<i>36.33</i>
<i>Mean</i>	<i>17.475</i>	<i>58.15</i>
<i>CV (%)</i>	<i>65.378</i>	<i>62.47</i>

Source: Field work (2021).

Table 3.6: Correlation between surface soil properties and soil erodibility of Kashere.

	Sand	Silt	Clay	Structure	I.R	K-Factor	Slope	B.D	S.O.M
Sand	1								
Silt	-.882** .000	1							
Clay	-.768** .004	.381 .222	1						
Structure	.591* .043	-.288 .364	-.767** .004	1					
IR	.650* .022	-.306 .334	-.854** .000	.865** .000	1				
K-Factor	-.931** .000	.755** .005	.799** .002	-.729** .007	-.767** .004	1			
Slope	-.532 .075	.497 .100	.372 .234	.000 1.000	-.082 .801	.408 .188	1		
B.D	.537 .072	-.657* .020	-.169 .600	-.049 .881	.098 .761	-.257 .419	-.291 .359	1	
S.O.M	-.133 .681	.233 .465	-.013 .967	.171 .595	.217 .499	.054 .867	.333 .290	-.315 .318	1

Source: Field Work, (2021). **. Correlation is significant at the 0.01 level (2-tailed) and *. Correlation is significant at the 0.05 level (2-tailed).

positions slope of Kashere ranges from 2.73 to 4.87cm/hr, 2.73 to 5.84 cm/hr and 2.08 to 2.91cm/hr with the mean values of 3.85 cm/hr, 4.47cm/hr and 2.50 cm/hr, respectively.

Table 3.6 below shows that K-factor and sand content, K-factor and silt content, K-factor and clay content were found to be highly positively significantly correlated with the r values of 0.931**, 0.755** and 0.799**, respectively). Also, K-factor and soil structure, K-factor and soil infiltration capacity (I.R) were found to be highly significantly negatively correlated with the r values of -0.729**, and -0.866**, respectively. This means that K-factor was highly dependent on texture of the soils. No correlation was found between organic matter content and soil erodibility.

Correlation between Soil Properties and K-factor

Correlation between Soil Properties and K-factor at Kashere

Similar result was obtained by Suraj *et al.*, (2019) who found out that there was no significant correlation between soil erodibility and organic, matter content of the soil. Also, Wischmeire and Mannering (1969) found similar results. The result of this study indicates that the use of soil physical and hydraulic properties for K-factor determinations have strong influence than solely relying on soil organic matter content, slope position. Suraj *et al.*, (2019) reported similar findings that there was need to perform water erosion vulnerability analysis based on soil properties but not organic matter contents alone. Sand and silt contents, Sand and clay contents were found to be highly significantly negatively correlated with the r values of -0.882** and -0.768**, respectively. Also, sand and soil structure,

sand and infiltration capacity were found to be significantly positively corrected with the r values of 0.591* and 0.650*, respectively. Soil structure and clay, soil structure and Infiltration capacity (I.R) were found to be highly negatively and positively significantly correlated with the r values of -0.767** and 0.865**, respectively. Infiltration capacity and clay content of the soils were found to be highly significantly negatively correlated with the r value of -0.854**. However, Suraj *et al.*, (2019) and Perez –Rodríguez *et al.*, (2007) reported that the highest vulnerability of soil to water erosion occurred where the soils contained predominantly contained silts.

Correlation between Soil Properties and K-factor at Pindiga

Table 3.7 below shows that K-factor and sand content, K-factor and silt content, K-factor and I.R were found to be highly negatively significantly correlated with the r values of -0.717**, -0.657**, respectively. Also, K-factor and sit content were found to be highly significantly positively correlated with the r value of 0.846**. This means that K-factor was highly dependent on texture and Infiltration capacity of the soils. As earlier reported in Kashere study area (Table 3.12 above) no correlation was found between organic matter content and soil erodibility. Similar result was obtained by Suraj *et al.*, (2019) who found out that there was no correlation between soil erodibility and organic, matter content of the soil. Also, Wischmeire and Mannering (1969) found similar results. The result of this study indicates that the use of soil physical and hydraulic properties for

Table 3.7: Correlation Between Surface Soil Properties and Soil Erodibility of Pindiga Area.

	Sand	Silt	Clay	Structure	I.R	K-factor	Slope	B.D	S.OM
Sand	1								
Silt	-.435	1							
	.157								
Clay	-.773**	-.233	1						
	.003	.466							
Structure	-.274	.373	.026	1					
	.389	.233	.937						
I.R	.803**	-.310	-.640*	-.250	1				
	.002	.327	.025	.433					
K-factor	-.717**	.846**	.175	.469	-.657*	1			
	.009	.001	.586	.124	.020				
Slope	.273	-.643*	.177	-.164	.311	-.454	1		
	.390	.024	.581	.611	.325	.138			
B.D	-.226	-.149	.349	.523	-.194	.159	.443	1	
	.479	.644	.266	.081	.546	.621	.149		
S.O.M	.041	-.251	.144	-.267	.188	-.194	.308	-.107	
	.900	.431	.656	.402	.559	.546	.331	.741	1

Source: Field Work, (2021). ** Correlation is significant at the 0.01 level (2-tailed) and * Correlation is significant at the 0.05 level (2-tailed).

K-factor determinations have strong influence than solely relying on soil organic matter content, slope position. Sand content and clay were found to be highly negatively significantly correlated with the r values of -0.773**. Sand content and IR were found to be positively significantly correlated with the r values of 0.803*. Furthermore, Silt content and slope was found to be negatively significantly correlated with the r value of -0.643*.

CONCLUSION

Based on the findings of the study, the result indicated that Kashere and Pindiga soils are predominantly sandy in texture, with weak, moderate to strong sub-angular block structures. The soils of the study area were also found to be of moderate to high infiltration capacity. Furthermore, the soil erodibility at the two study area were found to be rated low to high and there was high variability of the values of K-factor across the slope or physiographic positions of Kashere and Pindiga. Soil texture, I.R and soil structure were also found to have strong influenced of the soil erodibility factor in the two study areas.

Recommendations.

It is recommended that to adopt soil conservative practices such as mulching, cover cropping, addition of organic manures and amendments to reduce the susceptibility of these soils to erosion events.

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BARE SOIL VULNERABILITY TO WIND EROSION IN THE SEMI-ARID REGION, A CASE STUDY OF AGRICULTURAL FIELD IN MAIDUGURI – NIGERIA

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ABSTRACT

Wind-induced soil erosion significantly impacts agricultural productivity and land sustainability, particularly in semi-arid regions. This study examines wind-driven soil erosion in Maiduguri, Nigeria, using eight Big Spring Number Eight (BSNE) sediment traps across a 2-hactare field to measure sediment transport. Natural wind erosion buffers (crop residues, moisture, surface roughness) were removed to assess initial soil erodibility. Wind speed monitoring with anemometers at 10 cm, 100 cm, and 150 cm revealed maximum speeds of 19.9 m/s and an average of 8.4 m/s, predominantly from the northeast (NE), shifting to the southwest (SW) in May and June with maximum speeds over 14 m/s. Sediment flux measured from January to June revealed monthly mass flux values of 0.34 g/cm², 0.61 g/cm², 0.35 g/cm², 1.77 g/cm², and 5.21 g/cm² for January to May, highest in May 2022. Flux decreased with height: 4.44 g/cm², 0.39 g/cm², and 0.12 g/cm² at 5 cm, 35 cm, and 55 cm, respectively. Transport rates increased in May to (84.403 g/cm² at 0–5 cm, 166.028 g/cm² at 5–35 cm, and 181.240 g/cm² at 5–55 cm) and were lowest in January (5.923 g/cm², 8.555 g/cm², and 8.929 g/cm² across the same heights). Sediment size analysis showed coarser particles at lower heights (0.50–0.106 mm dominated at 74.2% at 5 cm), while finer particles (<0.038 mm) were observed at 35 cm and 55 cm. The Mean Weight Diameter (MWD) of saltating particles increased from 0.18 mm in January to 0.24 mm in May (average 0.20 mm). A negative correlation was observed between maximum wind speed and MWD, with higher wind speeds transporting finer particles. Organic carbon and total nitrogen concentrations in transported sediment (e.g., 0.40% and 0.043% at 5 cm; 0.655% and 0.105% at 35–55 cm) were higher than initial field levels, contributing to nutrient depletion in the soil (organic carbon reduced to 0.18%). The implications of wind erosion in arid and semi-arid agricultural fields are discussed.

Key words: Wind erosion, Big Spring Number Eight, sediment transport rates, nutrient dynamics, mean weight diameter.

INTRODUCTION

Soil erosion, driven by agents such as water and wind, results in significant soil displacement and loss. Wind erosion, in particular, involves the detachment and transport of dry, loose soil particles by wind, leading to surface abrasion (Mustafa, 2007). In the Sahelian region of West Africa, wind erosion is a critical issue due

to land degradation, which depletes soil fertility and threatens agricultural productivity (Sterk and Haigis, 1998). Quantifying soil and nutrient loss, especially during the early rainy season when soils are most vulnerable, is essential for developing effective mitigation strategies (Middleton *et al.*, 2017; IPCC, 2019). In Nigeria, wind erosion has not

received the same level of attention as other forms of erosion, such as flooding and gully erosion (Odjuge, 2007). Despite its recognition as a natural phenomenon in arid and semi-arid regions (Ofomata, 2017), the rates of soil loss due to wind erosion remain poorly quantified, particularly in cultivated and rangeland areas (Mortimore, 1989). Dryland ecosystems, characterized by nutrient-poor sandy or sandy loam soils, are highly susceptible to wind erosion, especially during periods of low vegetation cover and strong winds (Biielders *et al.*, 2001).

Wind erosion is influenced by two primary factors: wind erosivity, which refers to the wind's capacity to lift and transport soil particles, and soil erodibility, which reflects the soil's susceptibility to detachment and transport (Shao, 2000). These factors are closely linked to wind velocity, with even gentle breezes (3.4–5.4 m/s) capable of initiating particle movement (Sterk, 1997). In the Niger Sahel, wind speeds exceeding 11 m/s can trigger significant soil transport, negatively impacting crop yields (Sterk, 1997). Understanding saltation, the primary mechanism of sand drift, is crucial for describing aeolian transport processes (Raupch and Lu, 2004). Threshold wind velocities for erosion vary depending on climatic and soil conditions. For instance, the Revised Wind Erosion Equation (RWEQ) uses a threshold of 5.0 m/s, while the Wind Erosion Prediction System (WEPS) employs 8.0 m/s (Fryrear *et al.*, 1998; Wagner, 2004). In Maiduguri, northeastern Nigeria, average wind speeds range from 7.9 to 11.4 m/s, with peak speeds occurring from March to June (Amadi and Udo, 2015). Despite these conditions, no studies have quantified soil loss due to wind erosion in Nigerian agricultural fields (Mortimore, 1989). Wind erosion processes, including creep, saltation,

and suspension, occur primarily at or near the soil surface. Saltation, the dominant mode, drives sand drift and dust lifting through particle bombardment (Jarrah *et al.*, 2020).

This study aims to address the knowledge gap by investigating wind erosion dynamics in northeastern Nigeria, focusing on soil particle flux at different heights and sampling intervals. By employing affordable and effective field instruments, the research seeks to provide insights into the mechanisms of aeolian transport and inform strategies for mitigating wind erosion in semi-arid regions.

MATERIALS AND METHODS

Study Area

The study was conducted during the dry season at the University of Maiduguri, Borno State, northeastern Nigeria. The experimental site, located adjacent to the School of Postgraduate Studies, has geographic coordinates: Zone 33P, X (East): 304138.68, Y (North): 1306933.09, latitude 11° 81' 71" N, and longitude 13° 20' 21" E. The region experiences an average annual rainfall of 650 mm and an average temperature of 32°C, with sandy loam soils (69% sand, 18% silt, 12% clay) susceptible to wind erosion.

Experimental Design

A 2-hectare plot was cleared and leveled to a slope of <2% using a grader machine, whereby all natural buffers to wind erosion were removed (crop residues, moisture and surface roughness) to establish the initial erodibility of the soil.

Evaluation of Soil Erodibility

The material at the top (0–5 cm) of the soil is defined as erodible fraction by the wind (**EF**). Erodible fraction (**EF**) is the percentage of particles smaller than 0.84 mm and are considered to be sensitive soil particles that can be carried by the wind (Chepil, 1942). **EF** is used by the wind

erosion equations WEQ (Woodruff & Siddoway, 1965) and RWEQ (Fryrear *et al.*, 2000) as a potential erosion index. The effect of percentage clay and organic matter on aggregate formation, which reduced all kinds of erosion in the soil and keep it at tolerance values, is defined as the relative stability index (***RSI***) (Avecilla *et al.*, 2015).

Fabrication of Sediment Catchers

Big Spring Number Eight (BSNE)

BSNE samplers are passive devices (Fryrear, 1986; Mariano *et al.*, 2011) designed to collect soil particles that naturally enter the inlet as wind erodes the soil surface. These devices are categorized as quasi-isokinetic samplers (Goossens *et al.*, 2000). For this study, the BSNE sediment traps were constructed following the guidelines of Meselhy and Wassif (2021) and based on the design used by Zabihi *et al.* (2018) as shown in Fig. 2 and 3.

Installation of Field Instruments

Eight BSNE sediment stalks (poles), were loaded with three trays at 5, 35 and 55 cm heights, as recommended by Ellis *et al.* (2019). Three anemometers were installed to measure wind speed and direction at 10 cm, 100 cm and 150 cm heights. Wind speed and wind directions were recorded daily to obtain daily average wind speed (ms^{-2}). These anemometers were used to estimate the aerodynamic roughness and wind threshold velocity. Digital and mercury thermometers were installed in the field to monitor daily average air temperature through January to June, 2022.

Samples Collection and Analytical Methods

Eight vertical BSNE stalks with traps at height (5 cm, 35 cm and 55 cm) were exposed to sediment flow for a period of one month. The collected materials were weighed (to nearest 0.001 g) and divided by the inlet area using equation 3 to obtain

mass flux values (g/cm^2). The value of q_0 is the value of extrapolated saltating/suspended sediments mass transport at the surface. The value of q_0 and b was obtained by a non-linear regression analysis (using Curve Expert 2.7.3) to the data from the field.

$$q_{z \text{ exp}} = q_0 e^{\beta z} \dots\dots\dots (1)$$

where the sediment mass transported at a given height above the ground surface (2) is represented by q_z (g/cm^2) and q_0 (g/cm^2) denotes the extrapolated saltatng sediment mass transported at the surface. The vertical decay rate is represented by β ($1/\text{cm}$). this allows calculating the total mass transport (Q_{total} in g/m) is determined by utilizing the data fitted parameters q_0 and β as found in equation 5.

The total mass transport was calculated by integrating equation as follows (Zobeck *et al.* 2003).

$$Q_{\text{total}} = \int_0^{55} q_z dz \frac{q_0}{\beta} \dots\dots\dots (2)$$

Where Q_{total} (g/cm/month) is the total mass transport by saltation and suspension. It is assumed that saltating/suspended particles start moving immediately above the surface ($z = 0$) m to a maximum height of 55 cm (and beyond).

Computation of Mass Flux and Sediment Transport Rates

The BSNE sediment traps were emptied every month (January – June, 2022) to measure the trapped sediments using digital balance (0.001 g) at the desired heights. The measured sediments were used to determine the sediment mass flux of saltation, suspension and creep. Sediment

mass flux ($q_z, \text{g/cm}^2$) at each trap height ($z=0, 5, 35$ and 55 cm) was calculated by Eqn. 3.

$$q_z = \frac{m}{A} \dots\dots\dots (3)$$

where;

m = sediment weight (g) caught by each trap at a given height,

A = inlet area (cm^2) of the traps, 10 cm^2 , and 50 cm^2 , respectively.

Because of the total sediment flux under consideration, the rate of soil creeping away from the surface in BSNE was estimated using empirical equation to predict q_0 . Therefore, the vertical flux distribution for BSNE stalks $q_{z \text{ exp.}} (\text{g/cm}^2)$ was calculated using the exponential equation (Eqn. 1) with every measured mass flux.

Physical Characteristics of Sediments

The BSNE samplers were emptied monthly, and the collected samples were weighed and subjected to dry aggregates and particles was determined by passing the samples through a series of sieves with mesh sizes of 0.84 mm , 0.50 mm , 0.106 mm , 0.053 mm , 0.038 mm , and $<0.038 \text{ mm}$.

$$\text{MWD} = \sum_{i=1}^n x_i w_i \dots\dots\dots (4)$$

Where;

MWD = mean weight diameter of the soil aggregates; X_i = mean diameter of the soil aggregate class (mm); W_i = weight of the aggregates in the size range as a fraction of the total dry weight of the sample; i = weight of respective sieve size; and n = number of aggregate size ranges.

Chemical Characteristics of Sediments

Collected sediments were analyzed for percent organic carbon (% O.C.), percentage total nitrogen (%N) and available phosphorus (P).

RESULTS AND DISCUSSION

Physicochemical Characteristics of soil of the Study Area in (Table 1)

The experimental site in Table 1. exhibited sandy loam texture with high particle density, low water-holding capacity, and low to very low permeability, consistent with typical Maiduguri soils. Permeability, explaining Maiduguri's erosion susceptibility due to high silt content. At $0\text{--}5 \text{ cm}$ depth, the soil was sandy clay loam (SCL) with 57.10% sand (enhancing drainage but reducing nutrient retention), 20.70% silt (moderate nutrient retention), and 22.20% clay (improving nutrient retention but potentially hindering drainage). The pH was slightly acidic (6.01), favorable for nutrient availability, while low electrical conductivity (0.23 dS/m) indicated minimal salinity stress.

Erodibility of Soils

Table 2 evaluates soil erodibility using four key indices Stability Index (SI), Erodible Fraction 1 (EF1), Erodible Fraction 2 (EF2), and Relative Stability Index (RSI) across three sample points (SPS, SLC, SSS) taken from the $0\text{--}5 \text{ cm}$ soil depth, a critical zone for surface erosion. Measured Indices: Stability Index (SI): Lower values (e.g., SPS: 0.12 , SLC: 0.14) suggest stable soils; the sharp rise in SSS (1.84) signals severe destabilization, likely due to human activity or environmental stress. Erodible Fraction 1 (EF1): High values ($\sim 48\text{--}49\%$ across all samples) imply a persistent pool of easily dislodged particles, reflecting inherent erosion risk. Erodible Fraction 2 (EF2): Declined from 36.49% (SLC) to 13.77% (SSS), suggesting loss of moderately erodible particles due to erosion or aggregation. Relative Stability Index (RSI): Dropped from 9.102 (SPS) to 3.996 (SSS), confirming reduced resistance to erosion post-intervention. Statistical Summary: High variability in SPS (0.7 ± 0.9) and EF2 (26.16 ± 11.5) points to uneven soil

responses. EF1 (48.69 ± 0.6) shows consistent erodibility, emphasizing a systemic vulnerability.

Wind Speed and Direction

The average wind speed across all months was 7.4 ± 0.8 m/s in Table 3, indicating relatively consistent wind conditions throughout the year. The highest mean wind speed was observed in April 2022 (8.4 m/s), while the lowest was in June 2022a (6.2 m/s). The highest wind speed recorded in any month was 19.9 m/s in April 2022, which stands out as an outlier compared to the overall average maximum wind speed of 14.7 ± 2.6 m/s. This suggests that April experienced particularly strong wind events. The lowest wind speed recorded was 1.0 m/s in March 2022, with an overall average minimum wind speed of 1.9 ± 1.2 m/s.

Monthly Mass Flux Analysis

The mass flux in Table 4. showed significant variation across months, with May recording the highest flux (5.214 g/cm^2) and January the lowest (0.335 g/cm^2). The recorded mean mass flux values for the different stalk ($21 \text{ m} = 1.645$, $35 \text{ m} = 1.930$, $50 \text{ m} = 1.673$, $100 \text{ m} = 1.459$, $152 \text{ m} = 2.157$, $171 \text{ m} = 1.830$, $185 \text{ m} = 1.716$) all share the same statistical notation ('a') at $\alpha = 0.05$, indicating no statistically significant differences between mass flux values per stalk. This suggests that the mass flux is similar across these stalks, indicating that the variation in sediment transport is not influenced by the poles (stalks).

Monthly Mean Sediment Mass Fraction and Mean Weight Diameter (MWD)

The largest mass fractions are consistently observed in the 0.50–0.106 mm sieve size class, particularly in the months of May and June. This suggests the predominance of coarser sediments during these months. The result in Table 5, also highlights the vertical

variation in sediment size distribution, where the heights of 5 cm predominantly capture finer particles ($<0.038 \text{ mm}$), whereas the 35 cm and 55 cm heights show an increased presence of coarser particles as shown in Fig. 4. The strong correlation between mass fraction and MWD is a confirmation that the sizes are changing in MWD. This stratification can be attributed to the effects of wind and gravitational forces on particle suspension (Katra, 2020).

Monthly Sediment Transport Rates

Table 6. showed a clear increase with height, peaking at the 35 – 55 cm range. This suggests a progressive intensification in the transport capacity as the height increases, which can be attributed to the dynamics of wind flow and the suspension of particles in the air column. At lower heights, such as near the surface, sediment particles may settle more quickly due to gravitational forces, leading to relatively lower transport rates (McCave, 2008).

Maximum Transport Rate ($Q_{\max}$) and Critical Field Length (S)

The estimation of maximum transport rates ($Q_{\max}$) and critical field lengths (S) in Table 7, are gotten from regression equation of least square fit of transport rates and fetch distance which provides information on the dynamics of sediment transport. Results indicated an initial increase in transport rate until the critical fetch distance S, followed by a subsequent decrease in sediment transport with farther fetch distance (from NEB). The highest in May indicates that the transport capacity of the wind reaches its maximum during this period. The increase in critical field length during these months suggests that as wind speed intensifies, it requires a longer distance to fully mobilize and carry the particles, likely due to the enhanced suspension of larger or heavier particles. The longer critical field lengths in April

and May reflect the greater energy required for the wind to lift and transport sediment over larger distances, which is consistent with the observed peak in Q_{max} .

Sediment Nutrient Dynamics

Table 8. highlighted the concentration of total nitrogen in the saltation layer is 0.03%, organic carbon is 0.4 %, available phosphorus was 0.18 ppm and in the suspended layer, N is 0.1%, O.C is 0.6% and P is 0.14 ppm. Percentage of both N and O.C increases with height except P concentration that slightly decrease with height and the concentrations of the saltated and suspended soil is higher than the original soil, indicating loss of essential nutrients due to aeolian transport processes.

Statistical Analysis

Data were subjected to analysis of variance, Duncan multiple range test ($P > 0.05$) and Curve Expert. Correlation analysis was carried out to determine the relationships between and among the measured parameters.

CONCLUSION

This study comprehensively analyzed wind erosion, sediment and nutrient dynamics from January to June 2022. Findings highlight the significant impact of seasonal variations and wind patterns on mass flux, sediment transport rates, and soil fertility. The highest mass flux and sediment transport rates occurred in May and June, with June 2022 experiencing the most severe erosion and substantial losses of organic carbon and nitrogen, underscoring wind erosion's adverse effects on soil quality. Wind direction played a crucial role, with Northeast winds causing greater soil loss than Southwest winds, particularly during the dry season. The study emphasizes the urgent need for effective soil erosion management strategies in erosion-prone regions. It also calls for further research on wind erosion's impact

on soil quality and improved predictive models. These findings provide valuable insights into wind erosion dynamics and its environmental consequences, serving as a foundation for future research and mitigation efforts.

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Table 2: Erodibility status of the soils

S.P 0-5cm	%SI	%EF1	%EF2	%RSI
S.P.S	0.12	48.59	28.23	9.102
S.L.C	0.14	48.11	36.49	6.66
S.S.S	1.84	49.38	13.77	3.996
Mean ± SD	0.7 ± 0.9	48.69 ± 0.6	26.16 ± 11.5	6.5 ± 2.55

S.P.: Sample point; S.P.S: Soil profile sample; S.L.C: Soil sample at land clearing; S.S.S: Soil sample after the study; SI: Stability index; EF1: Erodible fraction; EF2: Erodible fraction 2; RSI: Relative stability index; S1: Soil profile sample; S2: Soil sample at the commencement of the study; S3: Soil sample after the study.

Table 3: Monthly average daily wind speed and predominant wind direction showing maximum, minimum and mean wind speed for Jan. 2022 – Jun. 2022.

Month	Mean (m/s)	Max. (m/s)	Min. (m/s)	Direction
Jan.22	6.8	15.2	1.3	45°
Feb.22	8.2	15.4	1.3	45°
Mar.22	7.0	13.4	1.0	45°
Apr.22	8.4	19.9	1.6	45°
May22	6.9	14.1	1.8	220°
Jun.22a	6.2	12.7	2.0	220°
Jun.22b	8.1	11.9	4.5	220°
Mean ± SD	7.4 ± 0.8	14.7 ± 2.6	1.9 ± 1.2	

Table 1: Physico-Chemical Properties of Soil at the study site

Depth (cm)	Particle size Analysis (%)			T. Class	pH (H ₂ O)	EC (dS/cm)	OC (%)	N	P (mg/kg)	Exchangeable bases (cmol/kg)				CEC (cmol/kg)
	Sand	Silt	Clay							Ca ²⁺	Mg ²⁺	K ⁺	Na ⁺	
0–5	57.10	20.70	22.20	SCL	6.01	0.23	0.41	0.14	1.75	10.60	9.40	0.20	0.78	20.98
5-18	57.10	20.70	22.20	SCL	5.02	0.23	0.20	0.07	5.60	9.80	10.60	0.79	0.87	22.06
18-51	59.60	18.20	22.20	SCL	5.50	0.20	0.23	0.10	5.60	7.40	12.00	0.55	0.83	20.78
51-109	57.10	18.20	24.70	SCL	5.51	0.19	0.10	0.03	1.40	7.00	16.60	0.52	0.78	24.90
109-152	52.10	25.70	22.20	SCL	5.67	0.23	0.06	0.03	1.40	14.80	14.80	0.63	0.32	30.55
152-200	44.60	23.20	32.20	CL	5.98	0.19	0.08	0.04	1.05	8.00	14.00	0.54	0.23	22.77
Mean	54.60	21.12	24.28	-	5.62	0.21	0.18	0.07	2.80	9.60	12.90	0.54	0.64	23.67

Table 4: Means of monthly mass flux for sediment sampling periods and heights and distance between the sampling traps for BSNE.

Sampling period	Mass Flux (g/cm ²)				Distance (m)	
	Sediment Trap					
	Height (cm)					
	5	35	55	Mean	Stalk	Mean
Jan.22	0.910 ^a	0.069 ^a	0.027 ^a	0.335 ^a	21	1.645 ^a
Feb.22	1.679 ^a	0.092 ^a	0.054 ^a	0.608 ^a	35	1.930 ^a
Mar.22	0.917 ^a	0.077 ^a	0.048 ^a	0.347 ^a	50	1.673 ^a
Apr.22	4.797 ^b	0.390 ^b	0.112 ^b	1.766 ^b	100	1.459 ^a
May.22	13.915 ^c	1.344 ^c	0.382 ^b	5.214 ^c	152	2.157 ^a
Jun.22a	4.537 ^b	0.628 ^b	0.188 ^b	1.784 ^b	171	1.830 ^a
Jun.22b	5.814 ^b	0.876 ^b	0.372 ^b	2.354 ^b	185	1.716 ^a
Mean	4.653	0.497	0.169	1.773		1.773

Means followed by different letters along the columns are significantly different at $\alpha = 0.05$.

Table 5: Monthly mean sediment mass fraction and monthly mean weight diameter (MWD) analyzed from field data from Jan. – June, 2022.

Sampling Period	Mass Fraction				MWD
	0.50-0.106 mm	0.106-0.053 mm	0.053-0.038 mm	< 0.038 Mm	
5cm					
Jan.22	0.473 ^a	0.356 ^{cd}	0.289 ^b	0.434 ^c	0.178 ^a
Feb.22	0.475 ^a	0.373 ^d	0.259 ^b	0.458 ^c	0.179 ^a
Mar.22	0.450 ^a	0.366 ^d	0.259 ^b	0.469 ^c	0.172 ^a
Apr.22	0.568 ^b	0.326 ^c	0.275 ^b	0.427 ^c	0.202 ^b
May.22	0.742 ^d	0.213 ^a	0.389 ^c	0.293 ^b	0.244 ^b
Jun.22a	0.632 ^c	0.297 ^b	0.046 ^a	0.025 ^a	0.218 ^b
Jun.22b	0.651 ^c	0.286 ^b	0.041 ^a	0.022 ^a	0.222 ^b
Mean	0.570	0.317	0.223	0.304	0.202
35cm					
Jan.22	0.00	0.00	0.340 ^a	0.660 ^d	0.028 ^a
Feb.22	0.00	0.00	0.337 ^a	0.663 ^d	0.028 ^a
Mar.22	0.00	0.00	0.312 ^a	0.688 ^d	0.027 ^a
Apr.22	0.00	0.00	0.385 ^b	0.614 ^c	0.029 ^a
May.22	0.00	0.00	0.574 ^c	0.426 ^b	0.035 ^{bc}
Jun.22a	0.00	0.00	0.560 ^c	0.440 ^b	0.034 ^b
Jun.22b	0.00	0.00	0.766 ^d	0.234 ^a	0.040 ^c
Mean	0.00	0.00	0.468	0.532	0.032
55cm					
Jan.22	0.00	0.00	0.409 ^c	0.591 ^c	0.030 ^b

Feb.22 0.00 0.00 0.342^a 0.658^{de} 0.028^a

Table 6: Monthly Sediment Transport Rates of Soil Samples trapped by BSNE (20 Jan. 2022 to 18 June 2022) computed from the monthly mean Mass Flux data given in Table 4

Periodical Observation of Wind Erosion Events	Sediment Transport Rate, q_r (g/cm) at trap height intervals			Exponential Regression Parameters			Mass Transport ($Q_{total} = \int_0^b q_z dz = \frac{q_0}{b}$) Qtotal (g/cm) $= a/\beta$
	0 – 5 cm	5 – 35 cm	35 – 55 cm	A	B	r^2	
Jan.2022	5.923	8.555	0.374	1.5095	-0.1013	0.999	14.906
Feb.2022	10.698	16.882	0.922	2.6781	-0.0934	0.999	28.672
Mar.2022	5.610	10.583	0.882	1.3562	-0.0784	0.998	17.296
Apr.2022	29.702	53.146	3.924	7.2531	-0.0877	0.999	82.702
May.2022	84.403	166.028	15.212	20.2412	-0.0749	0.999	270.240
14/Jun.22	26.840	59.542	7.083	6.2951	-0.0655	0.999	96.108
17/Jun.22	33.995	79.764	10.666	7.8931	-0.0613	0.999	128.762
Mar.22	0.00		0.00	0.349 ^a		0.651 ^{de}	0.029 ^a
Apr.22	0.00		0.00	0.368 ^b		0.632 ^d	0.029 ^a
May.22	0.00		0.00	0.562 ^d		0.438 ^b	0.034 ^b
Jun.22a	0.00		0.00	0.608 ^e		0.392 ^a	0.035 ^{bc}
Jun.22b	0.00		0.00	0.588 ^d		0.412 ^b	0.035 ^{bc}
Mean	0.00		0.00	0.461		0.539	0.032

Means followed by different letters along the columns are significantly different at $\alpha = 0.05$.

Table 7: Maximum transport rate (Qmax) and critical field length (S) estimated from non-linear exponential equation with given r² values on the monthly transport rate data from the study area (Fryrear *et al.*, 2000).

Trap height (cm)	Qmax	S	R ²
Jan.22			
0 – 5	0.9373	81.52	0.924
5 – 35	1.0889	44.11	0.828
35 – 55	1.0889	47.49	0.433
Feb.22			
0 – 5	2.1086	113.12	0.772
5 – 35	2.172	93.5	0.698
35 – 55	0.0557	31.889	0.662
Mar.22			
0 – 5	1.192	115.48	0.839
5 – 35	1.971	100.58	0.829
35 – 55	0.097	32.17	0.436
Apr.22			
0 – 5	6.918	125.28	0.864
5 – 35	11.334	113.24	0.885
35 – 55	0.774	110.28	0.891
May.22			
0 – 5	24.375	24.375	0.828
5 – 35	16.299	23.296	0.951
35 – 55	1.416	31.89	0.882
Jun.22a			
0 – 5	3.696	61.72	0.698
5 – 35	6.604	56.59	0.941
35 – 55	1.032	48.16	0.565
Jun.22b			
0 – 5	3.414	3.90	0.328
5 – 35	9.872	33.68	0.606
35 – 55	0.741	32.26	0.565

Table 8: Periodic distribution of total N, % O.C and available P (ppm) in the BSNE trapped sediments in comparison to the values in the soil before and after the study

Periods	Total N %	O.C %	Available P PPM
BSNE			
5 cm			
Jan/Feb	0.05	0.47	0.24
March/April	0.035	0.32	0.17
May/June	0.035	0.18	0.14
35 – 55 cm			
Jan/Feb	0.14	0.90	0.11
March/April	0.07	0.41	0.14
May/June	0.035	0.14	0.19
Field Sample			
Before	0.035	0.30	0.11
After	0.035	0.18	0.13

Table 9: Correlation analysis of wind erosion parameters

	Avg. Wind Speed (m/s)	Max. Wind Speed (m/s)	Wind Direction (deg)	Avg Temp (degC)	Mass Flux (g/cm ²)	Mass Transport (Q total)	Critical Fetch Length (m)	Qmax (kg/m)	MWD (mm)	MF0.5- 0.106(mm)	MF0.106- 0.05(mm)	MF0.05- 0.038(mm)	MF> 0.038 (mm)
Average Wind Speed (m/s)	1												
Max. Wind Speed (m/s)	0.50	1											
Wind Direction (deg)	-0.21	-0.390	1 **										
Avg Temp (degC)	-0.16	0.150	0.812 *	1									
Mass Flux (g/cm ²)	-0.13	-0.430	0.509 **	0.338 **	1								
Mass Transport (Q total)	-0.11 **	-0.090 *	0.953	0.630	0.532	1							
Critical Fetch L (m)	0.71 *	0.530	-0.479 **	-0.154 *	-0.122	0.532	1						
Qmax (kg/m)	0.56	0.127 **	0.673	0.504	0.420 **	-0.625	-0.200	1					
MWD (mm)	-0.41	-0.640	0.123	0.079	0.714 **	0.130	0.373	0.162	1				
MF0.5-0.106(mm)	0.22	0.260 **	0.129	0.085	0.743	0.136	0.362 *	0.163	0.999 **	1			
MF0.106-0.05(mm)	0.24	0.620 *	-0.116 **	-0.079	0.377	-0.124 **	0.573 **	0.000	0.917	0.898	1 *		
MF0.05-0.038(mm)	0.00	0.540 **	0.689 *	0.384	-0.009 **	0.782 **	-0.837	0.472	-0.446 **	-0.449 **	-0.583**	1	
MF>0.038(mm)	0.41	0.610	-0.573	-0.323	-0.702 *	-0.645	0.125 *	-0.483	-0.792 **	-0.783 **	-0.650 **	-0.183 *	1
Trap height (cm)	0.194	0.000	0.000	0.002	-0.532	-0.276	-0.582	0.215	-0.891	-0.896	-0.896	0.517	0.651

Pearson correlation coefficient (r) between two variables, ranging from -1 to 1, where: 1 = Perfect positive correlation, -1 = Perfect negative correlation 0 = No correlation. **. Correlation is significant at the 0.01 level (2-tailed). *. Correlation is significant at the 0.05 level (2-tailed).

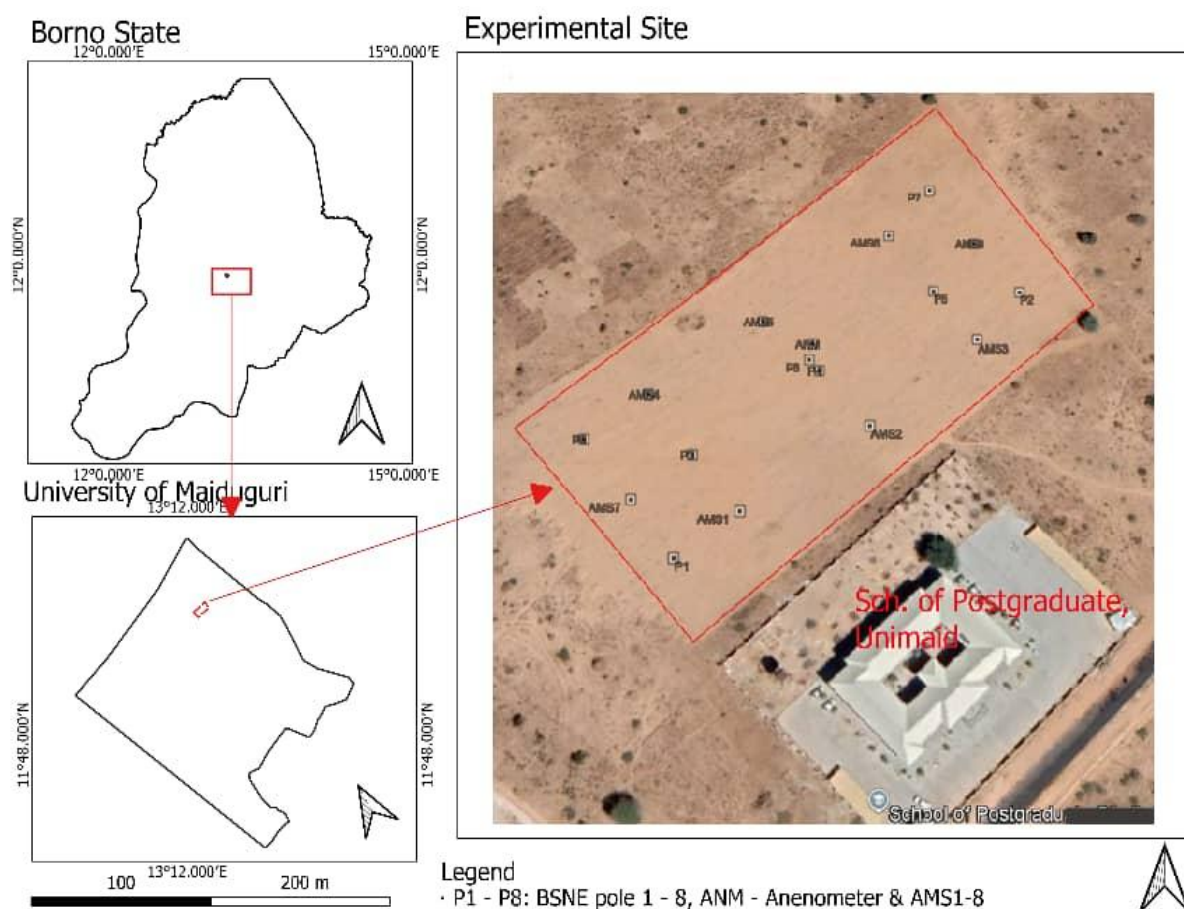


Figure 1: Map of Borno State Showing the location and site of the study

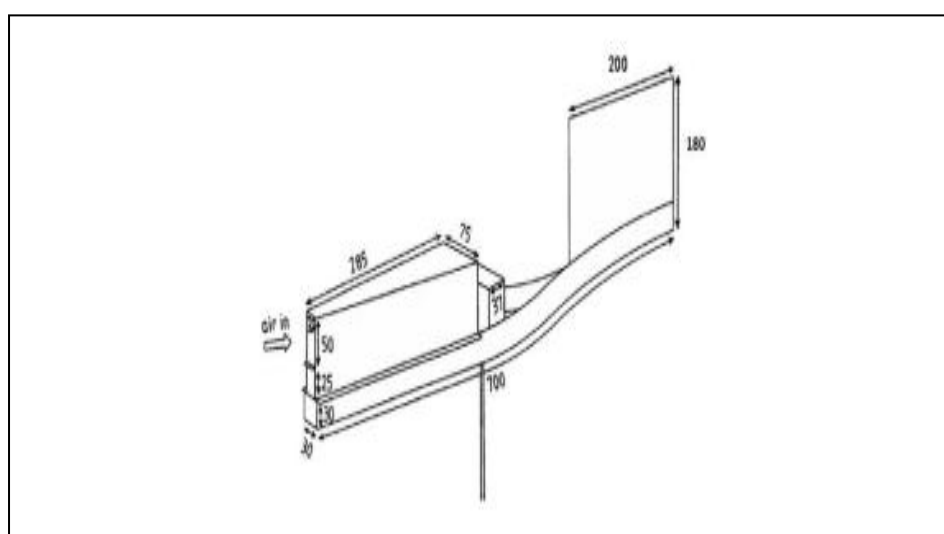


Figure 2: Dimensional diagram of the BSNE fabricated in this study. Adopted from Zahibi et al. (2018)



Figure 3: A Fabricated BSNE stalk loaded with sediment catchers at 5 cm, 35 cm and 55 cm height installed at the experimental site

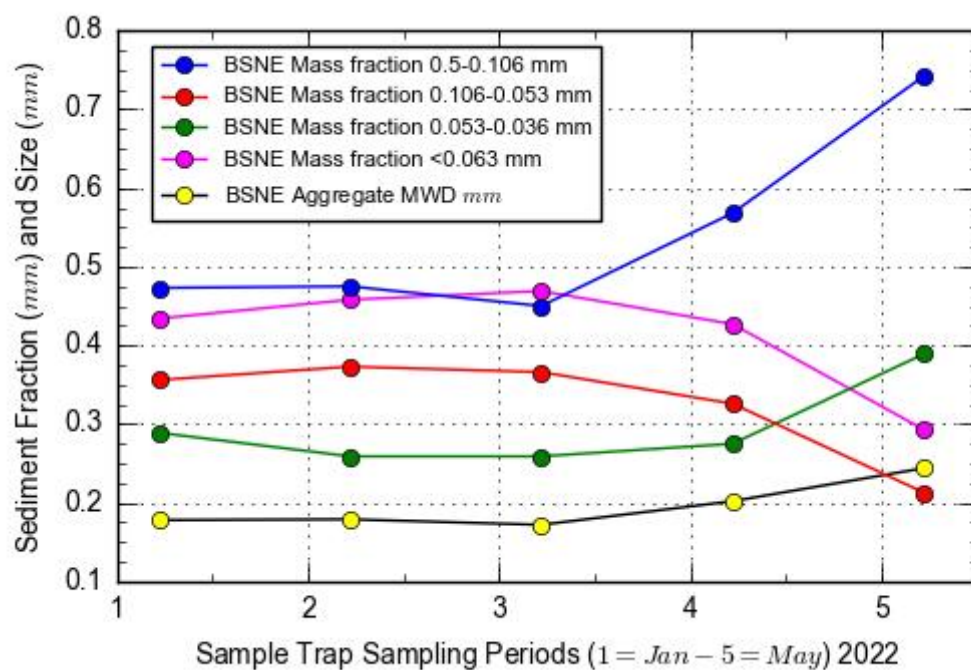


Figure 4: Monthly distribution of aggregate mass fraction of sediment and size distribution of aggregates during the study period

EFFECT OF IRRIGATION DEFICIT AND N-FERTILIZER ON NITROGEN USE EFFICIENCY AND YIELD OF WHEAT (*TRITICUM AESTIVUM* L) IN SUDAN SAVANNA ZONES OF NIGERIA

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ABSTRACT

Understanding the management of irrigation water in relation to nutrients requirements is one of the most significant factor for sustainable crop production. This research aimed at evaluate the effect of irrigation deficit and N-fertilizer on nitrogen Use efficiency and yield of wheat (*Triticum aestivum* L). The experimental trial was conducted during the 2016/2017 dry season at the Irrigation Research Station, Institute for Agricultural Research (IAR) Kadawa, Kano State, Nigeria. The experiment comprised of twelve (12) treatment combinations, viz: three levels of irrigation water application (100%, 70%, and 40% weekly reference evapotranspiration (ET_0)) and four levels of N-fertilizer treatment coded as F_1 (0 kg ha^{-1}), F_2 (50 kg ha^{-1}); F_3 (100 kg ha^{-1}); F_4 (150 kg ha^{-1}). The treatments were laid out in randomized complete block design with split-split plot arrangement. Data obtained was tested for normality and subjected to analysis of variance (ANOVA) by general linear model and means that were statistically different at 5% level of significance were separated by Turkey Honesty test using SAS software. The highest crop water use efficiency (CWUE) was obtained at I_{40} with 4.75 kg m^{-3} , followed by 2.84 and 2.59 kg m^{-3} at I_{100} and I_{70} respectively. Thus, I_{40} deficit treatment saved 18.86% amount of water compare to full irrigation treatment; I_{100} . For N-fertilizer application, F_4 had highest CWUE comparatively greater than F_1 by 10.7%. Yield obtained under varying irrigation regimes ranged from 1033.09 to 1328.3 kg ha^{-1} . The least yield value was obtained from I_{40} while the highest was obtained from I_{100} . It is recommended that I_{100} (1328.3) with F_4 (150 kg of N ha^{-1}) be practiced for promising yield output of wheat in the study area.

Key words: Irrigation Deficit, Nitrogen Use efficiency, Wheat, Sudan Savanna.

INTRODUCTION

Deficit irrigation is a scheduling method under which irrigation is purposefully carried out not to fully meet water requirements of the crop, and plants are allowed to extract soil moisture beyond readily available water in plant root zone

(Steduto, *et al.*, 2012). It can be practiced either by skipping regular irrigation events at selected growth stages (Ayana, 2011) or by irrigating at regular intervals (for example, 7-day) throughout the crop growing season. Alternatively, by applying less water than crop water

requirement either at all or some selected growth stages of the crop (Igbadun *et al.*, 2011; Ramalan *et al.*, 2010). Deficit irrigation means the application of water below full crop-water requirements (Fererres and Soriano, 2007). In another way, it is the practice of deliberately under irrigating the crop to reduce water consumption while minimizing adverse effects of extreme water stress on yield (Dagdelen *et al.*, 2006). The deficit irrigation is also becoming more important in recent years as there is continuous decrease in availability of fresh water that can be used for agricultural production (Cai and Rosegrant, 2003). If implemented correctly, the major benefit of deficit irrigation is improved plant water use without significant loss of yield (Grant *et al.*, 2011), but plant quality may also be enhanced (e.g. fruit with higher sugar, compact ornamental plants) and greater control over growth can be achieved.

Nitrogen is the most limiting crop nutrient for most non-legume production systems (Zotarelli *et al.* 2007). After irrigation, nitrogenous fertilizer is the second most important input (Lenka *et al.*, 2009) for wheat crop growth and development. There are many reports that nitrogenous fertilizer enhances water productivity (Pandey *et al.*, 2001), but the efficacy of nitrogenous fertilizer depends on the availability of soil moisture. Lopez-Bellido, *et al.*, (2001) reported that NUE indices were significantly affected by crop rotation and N fertilizer rate. Mahler *et al.*, (1994) indicated that research is required to increase NUE and profitability in semi-arid condition, and to develop sustainable farming systems in response to continually increasing economic and environmental pressures. Supply of adequate amounts of

N and its management is one of the most important factors influencing the yield of not only wheat but other crops as well. Good management of nitrogen fertilizer in wheat crop production is important to obtain higher yields and profit. Nitrogen fertilization practices can provide a sufficient N supply for plants to achieve the potential yield allowed by the actual climatic conditions (Lemaire, *et al.*, 2008). Technological quality of grain depends mainly on grain protein content that is influenced by crop nitrogen fertilization with respect to both application time and the amount of N (Daniel and Tribo 2002).

MATERIALS AND METHODS

Experimental Site

The study was conducted at the Irrigation Research Station of the Institute for Agricultural Research (IAR) Zaria, Nigeria (Lat. 11° 38' N and long. 8° 25' E and altitude of 500m above sea level), Sudan savannah zone of Nigeria. The rainfall pattern is uni-modal with at least 6 months of dry season. Onset of rainfall is in May-June while September is the wettest month in the area. Temperature ranges between 27.8°C - 30.4°C. The soil was characterized as Inceptisol and dominantly loamy sand in texture (Table 1) (Odunze, 2017).

Treatments and Experimental Design

The treatments consisted of three irrigation regimes 100% ET_o, (full irrigation) 70% ET_o and 40% ET_o), and four N fertilizer rates N₀P₀K₀ kg/ha (control), N₅₀P₅₀K₅₀ kg/ha (half recommended rate of N), N₁₀₀P₅₀K₅₀ (recommended rate), and N₁₅₀P₅₀K₅₀ (more than recommended rate), which were laid out in randomized complete block design (RCBD) with split-split plot arrangement.

Soil Sampling and Analyses

Disturbed and undisturbed soil samples were collected from the experimental site at 0 – 15 cm, 15 – 30 cm, using Simple Random Sampling method prior to sowing and after harvest using core sampler and auger. The auger samples collected at random points across the entire were bulked to form composite samples, representing the entire field. Soil samples were also collected from each plot and replicated to represent each individual treatment. Standard procedures were followed to prepare and store the samples which were later subjected to various laboratory analyses.

Soil Analytical Methods

Soil physical and chemical properties were determined as follows; particle size distribution by Bouyocous hydrometer method (Gee and Bauder, 1986), dry bulk density (P_b) by core method (Black and Hartge, 1986), soil moisture content, using pressure plate extractors as described by (Klute, 1986), saturated hydraulic conductivity (K_{sat}) by constant head permeameter method (Klute and Dirksen, 1986), total porosity (TP) by using the mathematical expression of (Danielson and Sutherland, 1986) as follows;

$$TP = 1 - \frac{\rho_b}{\rho_p} \quad \text{Equation 1}$$

Where:

ρ_b = bulk density

ρ_p = particle density

Total nitrogen (TN) was determined by micro Kjeldahl digestion method (Bremner and Mulvaney 1982), organic carbon (OC) by Walkley – Black wet oxidation method

(Nelson and Sommers 1982), available phosphorous (Av.P) by Bray-1 method

(Bray and Kurtz, 1945), exchangeable K by flame photometer (Black, 1965)

Field Operations

The field was cleared, ploughed, harrowed, leveled, and basins and water channels were constructed. Gross plot size was 12m x 13m (156m²), net plot was 4m²; 1m² lee- way was left between blocks and 0.5m² between plots. Atilla Gan Atilla wheat seeds used for the study were treated with Apron star 42 WS (20% w/w thiamethoxam, 20% w/w metalaxyl-M and 2% w/w difenoconazole) at a rate of 10g to 4kg of seed before sowing. Seeds were sown by drilling at 20 cm inter row spacing at 3 cm depth and at the rate of 100kg ha⁻¹. Irrigations were done for two weeks prior to proper establishment, after which water deficits were imposed. At two weeks to harvest, irrigation was withheld to allow for seed hardening and ripening. NPK 15: 15: 15 and urea (46% N) were used to supply 100 – 50– 50 kg ha⁻¹ through split application by broadcasting method. Weeds were controlled by hoeing at 3 and 6 weeks after sowing (WAS). The crop was manually harvested at physiological maturity when the peduncles have turned brown using sickles. The crop was cut at ground level and sun-dried for 4 days. Threshing and winnowing were achieved mechanically using multipurpose thresher, Handria®44D to collect grain yield.

Reference evapotranspiration was estimated using weather data from IAR meteorological station. Actual crop evapotranspiration was calculated from measured soil moisture content collected using theta probe (Michael, 1978) as:

$$E_t = \left[\frac{M_1 - M_2}{100} \right] \rho_b \quad \text{Equation 2}$$

Where

ETa = actual crop evapotranspiration mm day⁻¹

$M1$ = volumetric moisture content (cm³cm⁻³) at the first sampling (2 days after irrigation),

$M2$ = gravimetric moisture content (g g⁻¹) at the second sampling (7 days after irrigation)

Di = root zone depth

ℓb = bulk density of the soil

Irrigation Water Use Efficiency

Irrigation water use efficiency ($IWUE$) of wheat was calculated as the ratio of total grain yield (kg ha⁻¹) to actual water used by the crop mathematically as;

$$IWUE = \frac{Y}{Eta - Etd} \quad \text{Equation 3}$$

Where,

Y = total yield (kg ha⁻¹).

ETa = Evapotranspiration of the irrigated crop (mm day⁻¹).

Etd = Evapotranspiration of the dry crop (mm day⁻¹).

Soil moisture was monitored in each plot a day after and on the day of application before the next irrigation to enable quantification of seasonal crop water use.

Nitrogen Use Efficiency (NUE)

The NUE ; (kg of grain kg⁻¹ of N applied) was determined using the following equation.

$$NUE = \frac{YN - YO}{FN} \quad (\text{kg of grain kg}^{-1} \text{ of N applied}) \quad \text{Equation 4}$$

Where;

Y = grain yield of N- Fertilized plot (kg ha⁻¹) N

Y = grain yield of control plot (kg ha⁻¹) and O

F = amount of fertilized N (kg ha⁻¹) N

Statistical Analyses

Data obtained from all the measured parameters were subjected to analysis of variance (ANOVA) using General Linear Model (GLM), by SAS, 2009 statistical package and treatment means with significant differences at 5% probability level were separated using Tukey's Honesty Significant Difference (HSD) test. T-test was also carried out using GENSTAT Ed.14 to compare properties of surface and sub-surface depths of the field.

RESULTS AND DISCUSSION

Soil Physical and Chemical Properties of the Experimental Site

Mean values of the physical and chemical properties of the experimental soils at 0 – 15 and 15 – 30 cm depths are shown in Table 1. The result of the particle size distribution across the two depths showed that 0-15cm has more sand (855g) compared to the 15 – 30 cm, which recorded (830g). In contrast, clay was higher at sub – surface layer (60g) as compared to plough layer (40 g). This indicates clay migration from surface to the sub – surface, known as illuviation pedogenic processes. Both soil layers were loamy sand. Idris *et al.* (2018) also found increased clay content with increasing depth up to 90 cm in Hadejia – Nguru wetland soil of Sudan savannah. There was significant difference between the two depths with 0 – 15 cm recording highest mean in most of the tested chemical properties. Soil pH in water and CaCl₂ differed by - 7.24% and - 3.05% in the surface soil compared to the sub – surface, which may be ascribed to leaching away of sesquioxides and their subsequent deposition in the sub – surface layer in processes such as calcification Michael and Dunns, (2000). Organic carbon, TN and Av.P were greater in the sub – surface

by 20.14%, 17.10% and 22.29% respectively. This may be attributed to more organic matter content obtained in the sub – surface layer due to physical and chemical protection by soil aggregates and colloids. The three parameters may have behaved in similarly because they were derived from a common source as opined by Brady and Weil (1999) and Silmara *et al.*, (2008) who stated that more than 58% of organic matter is formed by carbon. Exchangeable K values were slightly lower in the surface by 1.5%. Bulk density ranged from 1.47 and 1.57 mg m⁻³ in the surface and sub – surface.

Effect of Irrigation Deficit, and Nitrogen Rate on Selected Soil Physical Properties

Results obtained from the study on the effect of irrigation deficit and N rate on soil physical properties are presented in Table 2. The Table shows that soil *BD* ranged from 1.49-1.58 Mg/m³ for the three irrigation levels; indicating high *BD*, considering the soil textural class as reported by Reynolds, *et al.*(2009), Brady and Weil, 1999) and Miller and Donahue, (1992). Among the irrigation treatment levels, I₇₀ and I₁₀₀ treatments plot recorded the highest *BD*. However, treatment plot supplied with 60% deficit, i.e. I₄₀ had the lowest *BD* value. This may be due to high organic matter (OM) decomposition owing to high microbial activities at higher moisture content. However, treatment plot supplied with 100% ETo (I₁₀₀) got the highest value (49.12%). There was no significant difference among the N levels in soil bulk density, hydraulic conductivity and total porosity. This may be true, since nitrogen application does not have direct effect on any of the properties tested above and perhaps, the indirect effect possibly on OM

accumulation that will in turn affect *BD*, and consequently porosity and *K_{sat}* may require long time to manifest.

Soil Water Content at Various Matric Potential

Results of soil moisture retention at various matric potentials as affected by irrigation deficit and N fertilizer levels are presented in Table 3. The results showed that there was no significant difference in water content at the various matric potentials among irrigation levels, and fertilizer treatment levels. Water content at 0, 10 and 33 kPa across all the treatments ranged between 0.47 to 0.36; 0.35 to 0.32; 0.29 to 0.25 respectively which did not differ significantly among the rates of both *DI* and N fertilizer. This may be attributed to climatic situation and aggregation homogeneity of the area (Miller and Donahue, 1992).

Wheat Grain Yield and Agronomic Nitrogen Use Efficiency

Table 4 shows mean values of grain yield of wheat and *NUE* as influenced by irrigation deficit and fertilizer treatments. The yield ranged from 1033.09 - 1328.3 kg ha⁻¹ for irrigation treatment. The results indicated that the crop cultivated in treatment plot with I₁₀₀ produced significantly higher yield than in the other treatment plots, followed by the crop in treatment plot with I₇₀, while the lowest yield was recorded in treatment plot with I₄₀. However, there was no significant difference in the yield obtained under I₇₀ and I₄₀. This may be connected to the porous nature of the soil, which responded to higher water supplied by I₁₀₀ that virtually translated to more uptake and grain yield formation. Abu and Malgwi, (2011). There results obtained by Pandey *et al.* (2000) showed that when deficit irrigation was imposed during the

vegetative period, grain yield reduced from 7 to 11%. Kabir *et al.* (2009) and Ali *et al.* (2007) also noted similar effects of deficit irrigation on grain yield while working on wheat in Bangladesh.

Tilahun, *et al.* (2008) concluded that split application of N, one third rate at planting and the remaining two third at mid-tillering, provided optimum wheat yield. Haile, *et al.* (2012) and Yohannes, (2014) pointed out that there was a significantly higher grain yield, N utilization efficiency and N use efficiency for grain yield when N was applied $\frac{1}{4}$ at sowing, $\frac{1}{2}$ at mid-tillering, and $\frac{1}{4}$ at anthesis.

Significant difference ($p \leq 0.05$) was also found in yield among the fertilizer levels which ranged from 995.5 kg/ha⁻¹ to 1242.31 kg ha⁻¹. Treatments plot with application of F₄ had higher grain yield than that of F₃, F₂ and F₁ by 1.5%, 15.8% and 24.8%, respectively. This may be attributed to the nutrient deficiency of soil as observed in Table 4.1, thus require high dose of fertilizer.

The results obtained from the study on agronomic nitrogen use efficiency (ANUE) under different irrigation treatments are presented in Table 4.4. The highest ANUE was observed in I₁₀₀ irrigation treatment plot (2.218 kg grain/kg N), followed by that of I₇₀ (0.739 N kg grain/kg N) while the lowest ANUE is recorded I₄₀ irrigation treatment plot (0.727 N kg grain/kg N). This results confirmed the findings of Ashraf *et al.* (2016), which showed better maize growth, grain formation and more efficient water and nitrogen usage in treatments with application of higher

amount irrigation water under semi-arid climate.

CONCLUSION AND RECOMMENDATION

The study inferred that full irrigation (I₁₀₀) treatment resulted in high yield by 7.88 % and 8.68 % than I₇₀ and I₄₀ deficit treatments respectively. Also the combination of N fertilizer and Irrigation deficit (ID) has significant positive effects on yield, WUE, NUE and N uptake and utilization of wheat.

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Table 1 Physical and Chemical Properties of the Experimental Site

Soil properties	Soil Depth	
	0-15cm	15-30cm

pH (H ₂ O)	5.80 ^b	6.80 ^a
pH (CaCl ₂)	4.89 ^a	5.20 ^a
Organic Carbon (g kg ⁻¹)	0.54 ^a	0.36 ^b
Total Nitrogen (g kg ⁻¹)	0.06 ^a	0.04 ^b
Available phosphorus (mg kg ⁻¹)	7.79 ^a	4.99 ^b
Exchangeable K (Cmol kg ⁻¹)	0.19 ^a	0.16 ^b
Sand (%)	855 ^a	830 ^b
Silt (%)	105	110
Clay (%)	40 ^b	60 ^a
Textural class	Loamy sand	Loamy sand
Bulk density (mg m ⁻³)	1.47 ^b	1.57 ^a

Means with the same letter are not statistically different at 5% level of probability

Table 2. Effects of Irrigation deficit, fertilizer levels on selected soil physical properties

Factor	<i>BD</i>	<i>Pt</i>	<i>Ksat</i>
Levels / interaction	(Mg m ³)	(%)	(cm /sec)
Irrigation Level (I)			
I ₁₀₀	1.52	49.12	2.67
I ₇₀	1.59	48.34	2.65
I ₄₀	1.49	48.03	2.65
SE ±	0.643	0.009	0.289
Fertilizer Level (F) (kg/ha)			
F1	1.52	47.54	2.79
F2	1.49	49.55	2.72
F3	1.51	48.32	2.80
F4	1.56	48.24	2.31
SE ±	0.897	0.010	0.334

BD, soil bulk density; TP, total porosity; K sat, saturated hydraulic conductivity; I₁₀₀, water application depth of 100%; I₇₀, water application depth of 70%; I₄₀, water application depth of 40%; and F1 = 0 kg/ha; F2 = 50 kg/ha; F3 100 kg/ha; F4= 150 kg/ha SE standard error, NS = not significant *

Table 3 Effects of irrigation deficit and N fertilizer rate on soil water retention

Water content (cm ³ /cm ³) at various matric potentials (kPa)							
Factor	0	10	33	100	500	1000	1500
Levels/interaction							
Irrigation Levels (I)							
I ₁₀₀	0.47	0.35	0.28	0.25	0.22	0.19	0.06
I ₇₀	0.36	0.30	0.25	0.20	0.15	0.10	0.04
I ₄₀	0.39	0.34	0.28	0.24	0.18	0.13	0.04
SE ±	0.009	0.009	0.008	0.008	0.008	0.009	0.018
Fertilizer Levels (F)							
F1	0.41	0.32	0.27	0.21	0.17	0.13	0.05
F2	0.41	0.34	0.29	0.24	0.19	0.15	0.03
F3	0.40	0.33	0.27	0.22	0.18	0.14	0.04
F4	0.41	0.34	0.28	0.24	0.19	0.18	0.03
SE ±	0.011	0.011	0.009	0.009	0.009	0.002	0.002
Interactions							
I x F	NS	NS	NS	NS	NS	NS	NS

I₁₀₀, water application depth of 100%; I₇₀, water application depth of 70%; I₄₀, water application depth of 40%; and F1=0 kg ha⁻¹, F2=50 kg ha⁻¹, F3=100 kg ha⁻¹, F4= 150 kg ha⁻¹. Means with the same letter within each factor are not significantly different at 5% level of probability using Tukey's Honestly significant Difference (HSD) test.

Table 4. Means of Wheat yield and Nitrogen use Efficiency as influenced by Irrigation Deficit and N fertilizer Levels.

Factor	Yield	ANUE
Levels/ interaction	(kg ha ⁻¹)	(kg grain kg ⁻¹ N)
Irrigation Level (I)		
I ₁₀₀	1328.3 ^a	2.218 ^a
I ₇₀	1058.93 ^b	0.739 ^b
I ₄₀	1033.09 ^b	0.727 ^c
SE ±	137.039	0.018
Fertilizer Level (F)		
F1	995.5 ^d	0.00 ^d
F2	1072.7 ^c	1.544 ^c
F3	1223.9 ^b	2.284 ^a
F4	1242.31 ^a	1.692 ^b
SE ±	158.249	0.018
Interactions		
I x F	NS	NS

I₁₀₀, water application depth of 100%; I₇₀, water application depth of 70%; I₄₀, water application depth of 40%; and F1=0 kg ha⁻¹, F2=50 kg ha⁻¹, F3=100 kg ha⁻¹, F4= 150 kg ha⁻¹. Means with the same letter within each factor are not significantly different at 5% level of probability using Tukey's Honestly significant Difference (HSD) test. SE = standard error NS = not significant * = significant at p ≤ 0.05

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INFLUENCE OF MULCHING AND PLANT DENSITY ON SOIL TEMPERATURE IN SAMARU, NORTHERN GUINEA SAVANNA

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ABSTRACT

Field experiment was conducted during the 2021 wet season at the teaching and research farm of the Institute for Agricultural Research (IAR), Ahmadu Bello University, Zaria to determine the Influence of Mulching and Plant Density on Soil Temperature in Samaru, Northern Guinea Savanna a region characterized by low soil temperatures and relatively higher rainfall than the Sudan and Sahel savanna. The treatments include three mulching materials (plastic, sawdust and control) and three plant densities (44,444, 53,333 and 66,666 plants ha⁻¹) These were combined factorially and laid out in a randomized complete block design (RCBD) in three replicates. It should be noted that soil temperature is a critical factor influencing plant growth and productivity, nutrient availability, and microbial activity in the soil. Soil temperature readings were taken at 30cm depth. The result revealed that mulching and plant density significantly affect soil temperature, though the effects vary over time. At 3 and 4 weeks, saw dust mulch had the highest soil temperatures compared to plastic mulch and control plots. While plastic mulch led to higher soil temperatures in most of the remaining weeks. Control plots had an average of 27.0°C across the trial period, saw dust mulch (M1) is slightly higher with an average of 27.3°C while plastic mulch (M2) gave the highest soil temperature values of 28.0°C. However, Plant density also influenced soil temperature, with highest density of 66,666 plants/ha (P3), resulting in higher temperatures. The lowest plant density (44,444 plants/ha) produced an average of 27.0°C soil temperature in the entire experimental period. P2 (53,333 plants/ha) impacted soil temperature slightly higher than P1 with an average of 27.3°C P3 (66,666 plants/ha) had the highest average soil temperature values of 28.0°C. There was no significant interaction between mulching and plant density, indicating their effects on soil temperature are independent of each other.

Keywords: Mulching, Density, and Soil temperature

Introduction

There is general consensus that the global climate has changed rapidly, and the global mean surface temperature has

increased by 0.74°C between 1906 and 2005 IPCC

(2007). Apart from studies on atmospheric temperature continuously published partly

due to global warming, more focus on variation of soil temperature and its factors has emerged recently Jacobs *et al.*, (2011). Soil temperature which is the function of heat flux in the soil as well as heat exchanges between the soil and the atmosphere (Elias *et al.*, 2004) varies from horizon to horizon whereas surface soil temperature varies from hour to hour in a day and month to month during the year this is the usual pattern of soil temperature variations the quantum of which depends upon soil cover (mulch and vegetation/plant density), geographical location, season and nature of soil Biswas and Mukherjee (2005). Soil temperature varies seasonally and daily which may result from changes in radiant energy and energy changes taking place through soil surface Chiemeka (2010).

Soil temperature plays an important role as an environmental factor that significantly impacts plant growth and major activities taking place in the soil such as influencing microbial and enzymatic activities, organic matter accumulation/decomposition and mineralization processes, water and nutrient availability to plants and microbes, soil aeration, humidity, fertilizer efficiency, pesticide degradation etc. (Onwuka and Mang 2018). Soil temperature under field conditions can be altered by suitable cultural practices such as mulching, increased plant population/vegetation, irrigation, drainage and tillage. Plastic mulches are commonly used to modify soil temperature, control weed, conserve water etc. Soil temperatures under black plastic at day time can be as much as 5°F higher at 2-inch depth and 3 °F higher at a 4-inch depth than bare soil at the same depths. Similarly, soil temperatures during the day

time under clear plastic can reach 8-14 °F higher at 2-inch depth and 6-14 °F higher at 4-inch depth than bare soil at the same depths due to a greater (85 to 95%) solar radiation transmittance Shylla and Rona (2005). Filipović *et al.*, (2016) reported that a black film mulching treatment resulted in higher soil temperature and yield than a transparent film mulching treatment. In addition, Liu *et al.* (2016) found that their 2 years' field experiment on the effects of plastic film color on soil temperature and maize yield had different results in that first-year black film mulching treatments had higher soil temperature and maize yield than transparent film mulching treatments, but in second year results were opposite to those of the first year. Hence, the reported effects of mulching often differ and sometimes contradict between studies, likely due to differences in the climatic conditions (rainfall and temperature), soil characteristics and crop species. As such, the effects of plastic film mulch on soil temperature and crop yield warrant further study.

Organic mulches also influence soil temperature by improving soil water holding capacity and soil color, which in turn increase heat conduction/retention within the soil.

The Northern Guinea Savanna experiences a distinct wet season with cooler air and soil temperatures in mid-season which can affect soil microorganisms and crop production that relies on warmer soil for optimal performance and growth. The use of organic mulch during the growing season would be a simple solution to raise soil temperature and conserve moisture but most of the crop residues are fed to livestock or used as building materials.

MATERIALS AND METHOD

Experimental site

The study was conducted at the Experimental Farm of the Institute for Agricultural Research (IAR), Samaru in the Northern Guinea Savannah of Nigeria. Samaru is located at the geographic coordinates of latitude 11° 11'N and

longitude 07° 38'E, with an altitude of 686 m above sea level. The Mean annual rainfall of the study area is reported to be 1015.9 mm; the mean maximum air temperature is 29.7°C while the mean minimum air temperature is 13.3°C (Yamusa and Abdulkadir 2020).

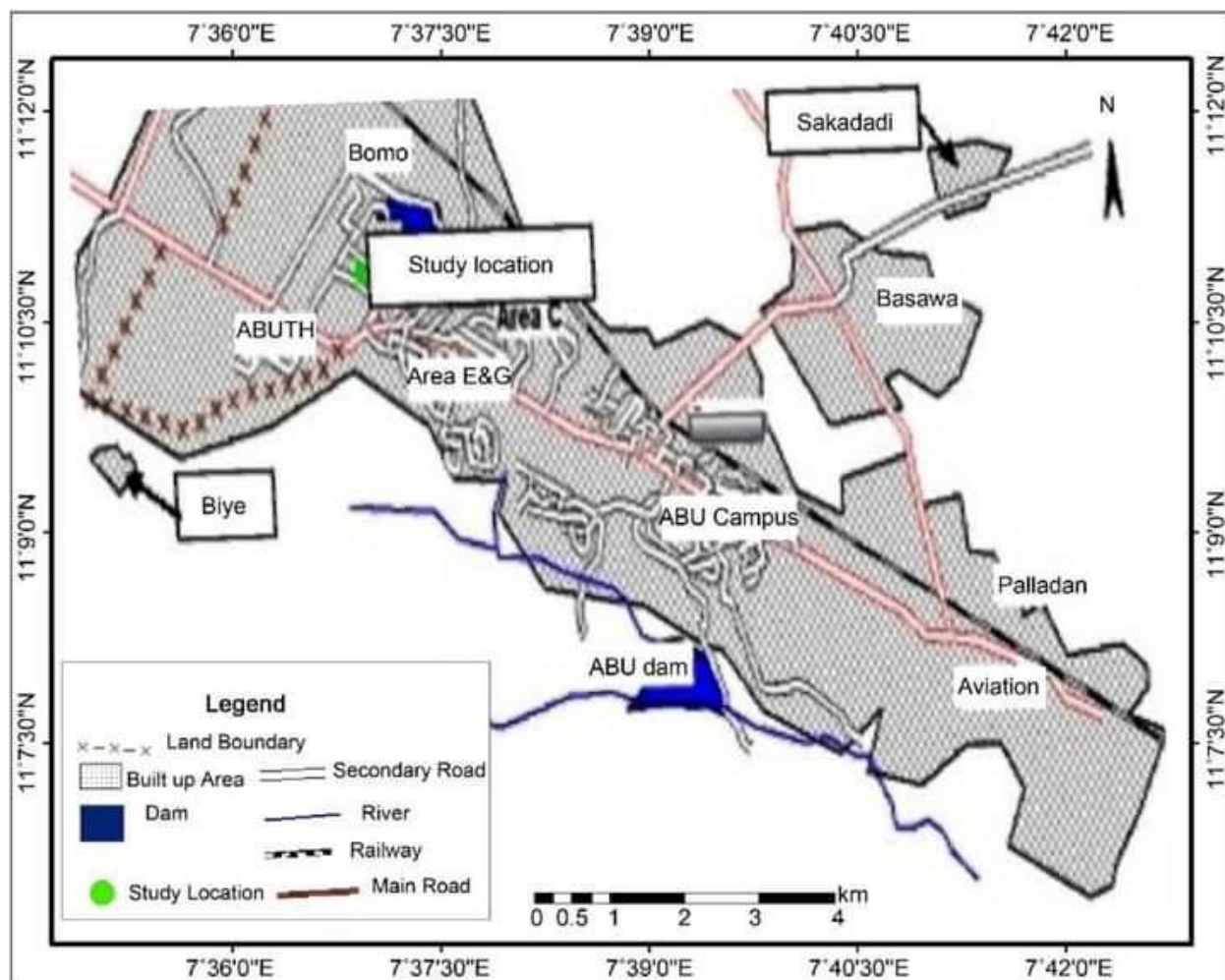


Figure 3: Map of the study Area

Treatments and Experimental Design

The treatment combinations consist of three mulching treatments; plastic mulch, saw dust and no mulch (control) and three levels of plant densities 44,444, 53,333 and 66,666 plants/ha. The treatment combinations were laid out in a Randomized Complete Block Design (RCBD) and replicated 3 times.

Data Collected

Soil temperature readings were taken from 18 randomly selected plots (six from each replication and two for each treatment) at a depth of 30 cm on weekly basis using earth thermometer and recorded in degree Celsius (°C). To take the reading, a soil thermometer is inserted into a 30 cm depth that was made and kept specifically for

taking soil temperature readings throughout the experiment, after inserting the thermometer it is usually left for 1 minute before the reading is taken. All readings were taken at 14:00hrs. Meteorological data such as rainfall (mm), minimum and maximum air temperature (°C), evaporation (mm), relative humidity (%), sunshine hours and soil temperature (°C) were collected at the meteorological station of the Institute for Agricultural Research (IAR), Ahmadu Bello University, Zaria.

Data Analysis

All data taken were subjected to analysis of variance (ANOVA) using SAS package (9.1). Where significant differences are observed, mean separation was carried out at 5% level of significance using Duncan multiple range test (DMRT).

RESULTS AND DISCUSSION

Meteorological Condition of the Study Area During the 2021 Wet Season in Samaru.

Table 1 shows the meteorological condition of the study area during the trial period. Although the month of August recorded the highest rainfall (341.6mm), rainfall distribution was fairly good throughout the season. As rainfall increases from April until it reaches peak in August, evapotranspiration (ET) decreases showing high rainfall does not always result in high ET. Interestingly the month of July had the lowest air (Tmax) and earth temperatures and as well had the lowest minimum air temperature (Tmin). Relative humidity was lowest in April which can be attributed to the lack of rain in that month however, sunshine hours (SSH), ET and Tmax were at the highest in this month.

Results on table 2 and 3 shows effects of Mulching and Plant density on soil

temperature. Mulching did not statistically impact soil temperature at 2 weeks. However, statistical differences begin to emerge at 3 weeks, saw dust (28.1°C) had significantly higher soil temperature compared to plastic mulch (27.2°C) and control plots (27.1°C). Similarly, at the 4th week, saw dust again gave the highest soil temperature difference although similar to those produced by control plot (M3), However, plastic mulch (25.3°C) was at par with control (26.0°C). Plant density showed significant differences in terms of soil temperature, at the 2nd and 4th week, plant density of 53,333 stands per hectare led to a significantly higher soil temperature than densities of 44,444 and 66,666 plants per hectare (P1 and P3 respectively). On the other hand, P1 (28.5°C) had a significantly higher soil temperature than P2 (27.4°C) and P3 (26.4°C) at the 3rd week. No significant differences in soil temperature were observed at the 5th, 6th, 7th and 8th week of temperature reading among all mulching and plant density treatments though plant density exhibited a significant difference at week 8. Soil temperatures slightly fluctuates across these weeks between 27-32°C under the different treatments. The lack of significant differences in soil temperature under these weeks can be attributed to the sharp decline in sunshine hours per day (SSH) across these weeks which span from late August to mid-September. Prior to these period, SSH used to be above 200 every month but significantly fell to 174.6 and 182.9 in August and September respectively largely due to increased cloud cover associated with the months. This conforms with the findings of Saudy & El-Metwally (2018) who observed and reported that these variations reflect diurnal and

moisture-related changes within the growing season.

Significant differences re-emerged at the 8th week under plant density treatment and continued into the 9th week where mulching also led to significant soil temperature readings. This is largely due to the sharp reduction in amount of rainfall from 155mm received in the two weeks that precede this week to the 30.2mm received in the week. This is supported by the finding of Hillel (2004) and Onwuka and Mang (2018) who reported that soil temperature increases with decrease in moisture due to a change in soil thermal properties. At the 9th week, saw dust (M1) had a significantly higher soil temperature (27.7°C) compared to control plot (26.2°C), while plastic mulch (27.2°C) was statistically at par with both M1 and control.

The maximum plant density of 66,666 plants had a significantly higher soil temperature (27.8°C) at the 8th week compared to 44,444 plants/ha which had a soil temperature value of 25.7°C, this agrees with the findings of Egli & Hatfield (2014) who reported that denser plant spacing did not result in noticeable cooling through shading effects however, 53,333 plants/ha with a temperature reading of 26.8°C was not significantly different from both P1 and P3. Similarly, at the 9th week 44,444 plants/ha (P1) had a significantly higher soil temperature (27.8°C) as compared to 53,333 plants/ha (P2) 26.4°C, However, 66,666 plants (26.9°C) was not significantly different from the highest values obtained from P1 nor the lowest values of P2. There were no significant differences recorded in soil

temperature among the mulching treatments nor among all three (3) plant densities at the 10th week. Soil temperatures did vary slightly but differences were minor (<1°C) and within error margins as such no statistically meaningful differences. This can be attributed to the amount of precipitation received in this week which is a mere 2.1mm meaning soil moisture is at a minimal level to influence earth temperature any further.

The interaction between mulching and plant density (M*P) was not significant at any of the weeks, indicating that the effects of mulching and plant density on soil temperature were independent of each other. These results suggest that mulching and plant density can influence soil temperature at specific time intervals, but their effects may vary depending on the treatment and environmental conditions. This further implies that their effects on soil temperature are additive rather than synergistic as reported by Sahrawat, (2012).

In conclusion, adopting mulching and maintaining optimal plant densities are critical strategies for enhancing surface warmth in Samaru. These practices not only improve soil temperature but also contribute to sustainable agricultural practices in the Northern Guinea Savannah. However, it is important to note that these findings are specific to the experimental conditions and location (Samaru, N.G.S) during the 2021 wet season. Therefore, these results should be interpreted within the context of the study area and its

Table 1: Meteorological Condition of the Study Area During the 2021 Wet Season.

Months	Rainfall (mm)	Evapotranspiration (mm)	Tmax (°C)	Tmin (°C)	Sunshine hours	Soil temperature	Relative humidity

						(°C)	(%)
APR	14.5	8.2	36.9	23.9	219.1	29.4	30.0
MAY	140.5	7.3	34.6	24.6	212.9	30.2	52.7
JUN	170.9	6.5	30.5	23.0	218.8	28.0	66.5
JUL	238.4	4.8	28.2	22.6	201.3	25.7	73.2
AUG	341.6	4.8	29.1	22.5	174.6	25.2	75.7
SEP	195.6	5.5	30.0	22.6	182.9	27.1	69.3
OCT	48.8	5.7	32.8	22.2	210.6	29.7	53.8

Table 2: Effect of Mulching and Plant density on soil temperature during the 2021 wet season in Samaru.

Treatment Weeks	Soil temperature °C				
	2	3	4	5	6
<u>Mulching (M)</u>					
Sawdust (M1)	25.9	28.1 ^a	26.7 ^a	27.2	27.2
Plastic Mulch (M2)	25.7	27.2 ^b	25.3 ^b	31	27.9
Control (M3)	26.9	27.1 ^b	26 ^{ab}	27.4	27.7
SE±	0.11	0.07	0.09	0.21	0.16
<u>Plant density (ha⁻¹)</u>					
44,444 (P1)	25 ^b	28.5 ^a	25.6 ^b	27.4	27.1
53,333 (P2)	26.8 ^a	27.4 ^b	28 ^a	27.6	27.2
66,666 (P3)	26.7 ^a	26.4 ^c	24 ^c	32	28.4
SE±	0.11	0.07	0.09	0.21	0.16
<u>Interaction</u>					
M*P	NS	NS	NS	NS	NS

Means followed by the same letter(s) in the same column are not significantly different at 5% level of probability, NS= not significant

Table 3: Effect of Mulching and Plant density on Soil temperature during the 2021 wet season in Samaru.

Treatment Weeks	Soil temp. °C			
	7	8	9	10
<u>Mulching (M)</u>				
Sawdust (M1)	27.5	26.5	27.7 ^a	28.8
Plastic (M2)	27.6	26.6	27.2 ^{ab}	28.7
Control	27.1	27.2	26.2 ^b	28.5
SE±	0.11	0.10	0.11	0.07
<u>Plant density (ha⁻¹)</u>				
44,444 (P1)	27	25.7 ^b	27.8 ^a	28.9
53,333 (P2)	26.9	26.8 ^{ab}	26.4 ^{ab}	28.7
66,666 (P3)	28.2	27.8 ^a	26.9 ^b	28.4
SE±	0.11	0.10	0.11	0.07
<u>Interaction</u>				
M*P	NS	NS	NS	NS

Means followed by the same letter(s) in the same column are not significantly different at 5% level of probability, NS= not significant

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SECTION FOUR: CAPACITY BUILDING AND EXTENSION

DYNAMICS OF SOIL POLICY INITIATIVES AND IMPLEMENTATIONS FOR FOOD AND NUTRITIONAL SECURITY AND DEVELOPMENTAL STRIDES

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Introduction And Review of Previous Policy Initiatives and Implementations

Nigeria has never been bereft of agricultural policies spanning the Colonial, pre and post-independence era in efforts to revitalize agricultural productivity, stimulate economic growth, enhance aggregate contributions to the agricultural sector to the nation's Gross Domestic Product (GDP). While most of these policies were geared to address issues of socio-economic growth and well-being of the nation's citizenry and overall national development, specific agricultural-related policies were not adequately tackled, or in some cases merely adjoint under broad national framework.

Some of these policies include the National Agricultural Policy (1988), Agricultural Sector Policy of Vision 20: 2020; Agricultural Transformation Agenda (ATA) (2013); Agricultural Promotion Policy (APP) (2016 – 2020); Medium Term National Development Plan (MTNDP) 2011 – 2025; Economic Recovery and Growth Plan (ERGP) 2017 – 2020; National Fertilizer Quality Control Act (2019); Nigeria's Action Plan on Soil Fertility Initiative (2016); National Land Use Policy for Nigeria (NLUP) (2020); New Nigerian Agricultural Policy, (NNAP) 2021; National Agricultural Technology and Innovation Policy (NATIP) 2022 – 2027; and National Agricultural Soil Management Policy (NASMP) 2023. A few of the programmes flowing from these policy initiatives comes to view:

National Accelerated Food Production Programme (NAFPP 1973); Operation Feed the Nation (OFN) 1979; National Special Project in Food Security (NSPFS), 2006; amongst others.

Overall, frequent changes in policies or in some cases "Policy Summersaults" could be attributed to changes in political, economic and social needs for food and fiber production to meet social needs due to increased population growth and demands for agro-industrial utilization for raw materials.

This unsustainability of policies could also be attributed to poor policy articulation at planning stage, poor advocacy and domestication at national and sub-national levels, non-inclusive "top-down" approach in policy formulation, are worsened by inadequate funding, poor monitoring and feed-back programmes and supporting initiatives required to drive the expected goals, and on sustainable basis.

Overall, these policies were geared towards the attainment of self-sufficiency in basic food and fiber supplies, increase production of agricultural raw materials, promote large-scale mechanized agricultural enterprises in order to meet food/ nutritional demands of the nation.

The objective of this paper is to examine the various dynamics in the policy formulation, articulation and implementation; review previous agricultural and soil related

policies, and consider the constraints and implementation challenges and proffer solutions to evolve sustainable policy formulation and implementation strategies.

An attempt is made to discuss and harmonize agricultural soil-related emerging initiatives such as land resources assessment and management, soil health and nutrition management; soil conservation and climate change resilience systems, capacity building and extension framework, and some cross-cutting issues in soil science research, innovations and programmes.

Mention is also made of constraints encountered in various policy initiatives, and recommendation to overcome some of these attributes in order to ensure faithful delivery of policies and programmes, promote agricultural productivity, efficient resources distribution and move the nation forward towards food and nutritional security and development strides.

Findings and Overview of Current Agricultural Soil Policy Initiatives and Implementation Framework

Some constraints have been identified in the formulation and implementation of previous policy initiatives in the agricultural sub-sector, namely;

- Ineffective consultations and advocacy at policy planning levels;
- Low level of policy adoption and poor participatory approach especially at sub-national levels (State and LGs);
- Poor policy implementation and absence of legal framework to ensure continuity and enforcement where necessary;
- Inadequate visionary process and frequent changes in the structure and directions of implementing agencies;

- Political and economic instability and weak governance structure in respect of project/programme implementation and continuity;
- Poor policy adoption by stakeholders in the agricultural sub-sector;
- Weak extension services and infrastructure to support technology transfer and research innovations to end users;
- Restrictive and non-facilitating policy framework;
- Weak monitoring and evaluation of policy initiatives;
- Poor and erratic funding profiles, arising from unpredictable fiscal policies and budgetary allocations;
- In recognition that agriculture is the concurrent list, some sub-nationals (States and LGs) do not have the required buy-ins, of most agricultural policies initiated and implemented by the Federal Government.

In order to address these gaps and constraints enumerated above, focus on current trends and initiatives in the agricultural (soil) sector, ensure affordable, efficient and farmers-driven and inclusive and ownership approach in policy implementation, some of the following agricultural (soil) policies are currently on-going or under implementation;

- **National Organic Agricultural Policy, Federal Ministry of Agriculture and Rural Development, Abuja, (2019)** currently on-going with inputs from stakeholders, is geared towards sustenance of soil fertility, environmental safety and human health;

- **National Agricultural Technology and Innovation Policy (NATIP), Federal Ministry of Agriculture and Food Security, Abuja, (2023).** This policy describes Federal Government efforts to diversify Nigeria's economy through agricultural development and ensure food security;

It also aims at generating agricultural productivity and services, promoting the production and supply of raw materials to agro-industries and markets and to generate foreign exchange earnings.

- **National Agricultural Soil Management Policy (NASMP), Federal Ministry of Agriculture and Food Security, Abuja, (Ongoing);** to ensure food and nutritional security; farmer's livelihood security through the adoption of best soil, land, water resources and crop management practices on sustainable basis. It also focuses on the production, management and restoration of degraded agricultural lands. It aims at the reclamation, rehabilitation, restoration and remedial practices inclusive of sustainable soil management practices in the light of climate change occurrences.
- **Nigeria Farmers Soil Health Scheme (NFSHS), Federal Ministry of Agriculture and Food Security, Abuja, (2025)** a novel initiative of the current administration, aims at providing farming communities, in all 774 LGAs of the country, with basic knowledge of the potentials of their soils (via soil analysis) which will form the basis of on-site, crop-specific fertilizer recommendations via robust extension service delivery. The outcome is

expected to result in efficient fertilizer use, applications and cost effectiveness in agricultural operations that would lead to increased crop yields, farmer's income enhanced livelihood, massive employment generation, food and nutritional security, and ensure agricultural developmental strides across the nation-space.

- Consideration and adoption of modern technologies in soil/land resources inventorisation and evaluation such as advanced pedometrics and implementation of sustainable organic systems are crucial in enhancing agricultural productivity and investments on a sustainable basis.

Discussion

This paper attempts to discuss and harmonize the following initiatives in respect of the current policy dynamics and implementation programmes. **The outcomes of these initiatives are presented in a matrix of thematic options, policy dynamics, and intended implementation strategies (composite matrix below refers);**

Land Resources assessments and management: A brief review of previous soil and land resources efforts conducted at pre-colonial, defunct regional government of the country, development partners, River Basins Development Authorities and the National Soil Survey Programme (NSSP).

Soil Health and Nutrition Management: This is a current initiative of the Federal Ministry of Agriculture and Food Security (FMAFS) under Nigeria Farmers Soil Health Scheme, in promoting on-site crop-specific fertilizer and nutrient applications in each of the 774 LGAs of the country. A robust soil extension services that links

results of soil analysis and fertilizer needs is expected.

Soil Conservation and Climate Resilient Agricultural Practices: This involves the promotion and transfer of Conservation Agriculture Technology that ensures minimal soil disturbance and increased soil organic matter. In addition, appropriate water conservation and harvesting methodologies, protection and the management of degraded agricultural lands.

Capacity Building and Extension (Soil Extension Services): Up-scaling the skill and knowledge of stakeholders, laboratory technologists and extension agencies in ensuring best practices and operations in order to improve efficient deliveries of tasks.

Cross cutting issues in Soil Science, Research, Innovations and Policy Matters: This involves farmers' driven-research related findings, innovations and technological transfer (shelf to farm research outfits). It also envisages well-defined all inclusive consultations and advocacies at policy planning and implementation levels in a bottom up consultative approach that meets the demands and buy-ins of all stakeholders, especially during project implementations.

Recommendations and Way Forward

Various efforts in Nigeria's past policy framework and implementations has been bedeviled by lacunae in inappropriate policy visionary processes, planning, articulation, advocacy and non-inclusiveness in the input of the intended stakeholders – farmers, agricultural community, processors and investors in the agricultural sector. Poor policy implementation could also be due to frequent political, economic and changes by Governments in efforts to meet demands for

food and nutrition arising from increased population growth over the years.

In addition, absence of appropriate regulatory framework, legislation and enforcement in some cases have led to weak or inadequate implementation of sustainable guidelines that ensures protection and preservation of the nation's agricultural soil/land resources.

In order to overcome some of these constraints and gaps in the policy framework, the following are proposed,

Improved visionary processes at policy planning and articulation levels by all stakeholders;

Enhanced training and capacity building of key resource and implementation staff, such as extension agents, laboratory technologists, soil scientists on farmer's demonstration fields;

In respect of the Nigeria Farmers Soil Health Scheme (NFSHS), the standardization of field and laboratory analytical procedures are very crucial to the integrity of the outcomes of the soil analysis on which specific fertilizer recommendations would be made to the farmers by extension agents;

Collaboration at national levels with developmental partners, agro-input fertilizer producers and blending industries in order to meet the specific nutrient requirements in various agro ecological zones of the country; Sustainable funding profiles in addition to the usual budgetary allocations (which could be inadequate, erratic, and subject to fluctuations derived from unforeseen fiscal variables and demands of other sectors of the economy. There is a need therefore, to explore other avenues of funding in

Matrix of Thematic Options and Policy Dynamics and Implementation Strategies

Thematic Options	Policy Dynamics and Implementation Strategies
1. Land Resources assessments and management.	Previous policies focused on soil inventorisation for identification of areas of high potentials for agricultural development, were executed by defunct Regional Governments (Eastern, Northern and Western Governments), Development partners, Corporate bodies, River Basin Development Authorities (RBDAS) as well as the Federal Government via the National Soil Survey Programme. New initiatives focused on the deployment of Digital Soil Mapping (DSM) techniques, digitization of soil legacy data inclusive of Soil conservation, management to enhance appropriate fertilizer applications along identified crop clusters across the country/
2. Soil Health and Nutrition management.	Current initiatives, in addition to DSM, focused on providing efficient, real-time site-crop specific information on nutrient balances, monitoring of soil fertility and status of Soil Health. Implementation of the National Soil Health Card Scheme (NSHCS) scheduled to be implemented in 774 LGAs, with a complement of mini-soil analytical laboratories. Support from soil extension agents, buy-ins at sub nationals levels (States and LGAs), farmer's associations, fertilizer producers, technical and financial support from FG, State, LGAs, Development Partners, Soil Science Society of Nigeria (SSSN), the Nigeria Institute of Soil Science (NISS), National Agricultural Research Institutes (NARIs), Universities and traditional Institutions are essential at implementation levels.
3. Soil Conservation and Climate Resilient agricultural practices	Promotion of Conservation Agriculture Technology (CAT) via crop residue cover, minimum tillage and soil disturbance, increased soil organic matter (SOM), improved soil tilth, water conservation and harvesting methodologies; adoption of climate mitigation, adaptation and resilience methodologies; management and protection of agricultural lands, and water sheds that will require legislative back-ups and enforcements.
4. Capacity building and Extension (Soil Extension Service).	Training and re-training of staff-soil Scientists, laboratory technologists, extension agents and selected shareholders on best practices in soil information system, data analysis and extension services, inclusive of Integrated Soil Fertility Management (ISFM) Practices.
5. Cross cutting issues/initiatives in Soil Science, Research and Innovation and Policy matters.	Central to these thematic options/initiatives are cross-cutting issues such as evidence-based outcomes of Research and Innovations and technology transfer. This is in addition to various transformative improvements on previous initiatives on Soil and Land use inventorisation and assessments to ensure demand-driven, farmer-focused soil resources and land management initiatives such as the National Farmers Soil Health Scheme (NFSHS) and other land management and Climate change resilience agricultural methodologies. In addition the institutional technical backstop by Universities, NARIs and NISS (as regulator, facilitator of soil related matters) and support from the FMAFS via ALCCMS, are crucial in driving policies and faithful implementation of programmes. The SSSN has a retinue of eminent Soil Scientists, whose critical mass as professionals could be deployed in the implementation of the NSHCS, and other related initiatives.
National Agricultural Soil Management Policy (NASMP) – (ongoing draft)	The policy thrust of NASMP includes but not limited to education and awareness of Soil related initiatives and programmes, ensure monitoring and forecasting systems, and appropriate incentives and regulations, standardization and quality control and other land management activities. It is expected that the NASMP, when endorsed by FG as an executive bill will be approved as an Act by the National Assembly in due course.

collaboration with International Corporate Organizations, Financial Development Partners and Agencies,

Institutions and providers of Technical Support Services.

Summary and Conclusions

This paper reveals previous interventions and changes in different policy initiatives and options in addition to highlighting the constraints in policy formulation from planning to implementation levels. The identified constraints emanating from poor policy framework are largely attributed to improper visionary processes, planning, coordination, monitoring and evaluation feedback and the expected impact of the policies to achieve the intended goals and objectives on sustainable basis.

The paper also discusses various agricultural soil policy initiatives and implementation options in respect of soil conservation, capacity building and extension services and other cross cutting issues such as the roles of soil science initiatives in education, project implementation regarded as a bed rock of sustainable agricultural practices. It also considered the current research efforts into practical farmer-usable and adoptable farming systems, by the agricultural communities.

The Nigeria Farmers Soil Health Scheme, a transformative policy initiative, a novel of the Federal Ministry of Agriculture and Food Security (FMESF), is intended to enhance Agricultural productivity and investments of farmers via efficient and sustainable fertilizer use and applications that would reduce wastage, increased efficiency of fertilizer applications, and elimination of under or over use and abuse of fertilizers that could lead to land degradation, if not well managed.

Faithful implementation of this programme will transform Nigeria's Agricultural Landscape and increase investments and productivity in the sector, enhance its contribution to the Nation's Gross Domestic Product (GDP), increased income and livelihood of the agricultural community, and ensure overall **National Developmental Strides in the march towards Food and Nutritional Security across the nation.**

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**SECTION FIVE:
CROSS-CUTTING AND ADVANCES IN
SOIL SCIENCE RESEARCH**

HYDROTHERMAL SYNTHESIS OF ZEOLITE FROM WHITE KAOLIN CLAY OF KANKARA, KATSINA STATE-NIGERIA.

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ABSTRACT

Zeolite, a versatile material typically derived from clay, has wide applications in agriculture and environmental management. This study focused on synthesizing Zeolite A hydrothermally from kaolin clay sourced from Kankara, located in the North-Western Nigerian Basement Complex (latitude 11°53'28"N, longitude 7°26'21"E). The region features diverse rock types, including granite gneiss, biotite gneiss, and migmatites, with mica schist dominating and dipping southeast at angles of 27°–43°. To synthesize zeolite, 3 kg of kaolin clay was beneficiated in deionized water for four days with vigorous agitation. The clay was crushed, pulverized to $-75\ \mu\text{m}$, and ball-milled at 300 rpm for 30 minutes, then calcined at 750°C for three hours to produce metakaolin. A solution of 1.813 kg NaOH in 16.5 L distilled water was mixed with 2.1 kg metakaolin and aged for three days before hydrothermal treatment at 100°C for eight hours. XRD analysis revealed peaks within $2\theta = 7\text{--}18^\circ$ and $21\text{--}35^\circ$. BET analysis showed a surface area of $74.93\ \text{m}^2/\text{g}$, with a pore volume of $0.037\ \text{m}^3/\text{g}$ and a pore diameter of 2.427 nm. This synthesis demonstrates the potential of locally abundant kaolin for environmentally friendly zeolite production.

Keywords: Kaolin, Hydrothermal, Zeolite A, Kankara.

Introduction

Zeolites form a unique class of oxides, consisting of micro porous, crystalline aluminosilicates that are usually found in nature or synthesized artificially. The framework of zeolite is very open and contains channels and cages where cations, water and adsorbed molecules may reside and react. Natural zeolites are microporous aluminosilicate minerals with usually high cation exchange capacities and high ammonium selectivity properties (Kithome *et*

al., 1998). Almost more than 50 different species of this mineral have been identified. Studies by researchers have shown the ammonium removal ability of zeolites in the purification of livestock wastewater, landfill wastewater, and aquaculture water with high ammonium concentration (Wiesmann, 1994 and; Nguyen and Tanner, 1998). It is reported that NH_3 is transformed to NH_4^+ under NH_4^+ reducing conditions in toxic polluted systems. Zeolites can effectively remove NH_4^+ in water and other waste products. Purification of water has been widely achieved using natural zeolites, such as clinoptilolite, mordenite, erionite, and

chabazite (Kithome *et al*, 1998). Reports from previous studies revealed adsorption and ion exchange mechanisms of NH_4^+ using different zeolites (Lin *et al*, 2013). Allen and Ming (1995) reported that zeolites have high cation exchange capacity and have remarkable ability to adsorb cations within their crystalline network which is available for plant through an exchange reaction by roots. They also proved that zeolite serves as slow nutrient releaser.

Zeolites ion exchange ability, their high availability, low cost, and ease of application makes them ideal materials for ammonium removal from wastewater (Turan, 2015).

Zeolite has an important property and ability to exchange cations. The adsorption behavior of zeolites is influenced by the type and distribution of cations; as a result, sorbent with different molecular sieve and adsorption properties can be prepared by ion exchange. Due to the two-dimensional framework structure of clay minerals, they may undergo swelling or shrinking with ion exchange process. But Zeolites and feldspaths having three-dimensional structure do not undergo any appreciable dimensional change with ion exchange.

Kaolin clay group that is represented chemically as $\text{Al}_2\text{O}_3\text{SiO}_2 \cdot 2\text{H}_2\text{O}$, is an important material that is been used to produce zeolite synthetically. Kaolin clay undergoes calcinations (thermal treatment) which involve conversion of kaolin to metakaolin at a temperature of about 600°C . Metakaolin is generally known to be a defect phase in which the tetrahedral silica layer of the original structure are largely retained even though there still exist some

controversies about the true nature of metakaolin phase. Metakaolin is more reactive and can easily be reacted by either acid or alkalis (Flanigen, 1983 & De Luca *et al*, 1997). Manufacturing of zeolite by industries is triggered by its availability and low cost.

Materials and Method

Sample Collection

White kaolin clay samples were collected from Kankara LGA of Katsina State-Nigeria, where deposit of kaolin is found (Mangdong *et al*, 2017). The area lies within the North Western Nigerian basement complex with latitudes $11^\circ 53' 28''$ N - and longitudes $7^\circ 26' 21''$ E. The study area is made up of rock types of the Basement complex, some of which includes; granites gneiss, biotite gneiss, migmatites, with some meta-sediments of granitic rocks of the older granites suite and amphibolite facies metamorphism, (Ajibade, 1976). The area considered in this report is underlain by mica schist, dipping generally SE at angles varying from 27° to 43° (Hussaini *et al*, 2016). **Preparation and Analysis**

The clay samples collected were crushed and pulverized to $-75\mu\text{m}$ in order to ascertain the presence of kaolin which was used to synthesize the zeolite hydrothermally, two aliquot solution was prepared for each sample and subjected to XRD analysis while the second aliquot solution was kept for reference. Rigaku Miniflex 600 XRD made from Japan was used, by employing Cu-K α radiation at 2θ angle 2° - 70° at National Geosciences Research Laboratories, Nigerian Geological Survey Agency, Kaduna South-Nigeria.

The sample with the highest Kaolinite was used for the synthesis of zeolites hydrothermally (Flaningen, 1983 & De Luca *et al.*, 1997).

The amount of SiO₂ and Al₂O₃ present in the sample was calculated. Furthermore, the ratio of SiO₂/Al₂O₃ is greater than 1 which made it suitable for zeolite synthesis in accordance with the Breck (1974) specification for clays that can be used for Zeolite synthesis.

Preparation of Zeolite

Zeolite is synthesized extensively for application in a vast variety of catalysis processes which includes; ion exchange, hydrocarbon cracking, and organic synthesis. In order to satisfy the serious terms of sustainability that denotes to the reduction of costs and chemical waste, cheap natural resources were used to produce kaolinite-based zeolites as against the conventional process that uses pure sodium silicate and sodium aluminate that is expensive.

According to Wardle and Brindley (1972), there are basically two steps in producing zeolite from kaolinite, which involves:

- i. Metakaolinisation– Chemically activating kaolin clay by transforming kaolin to metakaolin
- ii. Zeolitisation– treatment of the metakaolin with aqueous alkali solution to form zeolite.

The synthesis was carried out below according to the procedure outlined by Olaremu *et al.*, (2018) as follows:

Metakaolinisation

The beneficiated kaolin was ball milled at 300 rpm for 30 minutes to obtain a homogenous fusion of solid. The ball milled

powder was calcined at 750°C for three hours using a furnace, decomposition occurs which leads to the destruction of structure and removal of the undesirable volatile matter. In this process, kaolin was converted to metakaolin.

Zeolitisation

1.813kg of NaOH pellets was mixed with 16.5L of distilled water in a 35L polypropylene bottle. The mixture was allowed to dissolve, after which 2.1kg of the metakaolin was added into the bottle. The mixture was shaken and mixed very well. The mixture was allowed to age for three days after which it was placed in an oven at 100 °C for 8 hours. The bottle was allowed to cool, after which the mixture was repeatedly washed with deionised water until a pH of 8.1 was obtained. It was then oven dried to obtain the powder form of zeolite.

Zeolite Characterization

The characterization of the zeolite was carried out using XRD for determining the concentrations of elements present and BET for the specific surface area (SSA).

Results and Discussions

X-Ray Diffraction Analysis (XRD)

The XRD patterns of kaolin, metakaolin and synthesized Zeolite A sample are presented in Figure 4.1. Peculiar peaks of the kaolin 2θ were observed similar to that reported by Feng *et al.* (2009) and Amber *et al.* (2013). The crystalline kaolin was converted to an amorphous phase metakaolin by thermal treatment at 600°C and which was confirmed by the broad XRD patterns (Feng *et al.*, 2009). Conversion of the reactive metakaolin was done in an alkaline medium for 8 hours at 100°C. The peaks in the ranges of 2θ=7-18° and 21-35° are

characteristic of zeolite A type (Baerlocher, 2007). No other peaks were observed in the XRD pattern of the synthesized zeolite. This indicates the formation of pure phase zeolite A.

The XRD diffractogram also shows the presence of another minor crystalline phase known as hydroxysodalite, $4\text{Na}_2\text{O} \cdot 3\text{Al}_2\text{O}_3 \cdot 6\text{SiO}_2$. This was reported by previous researchers, this phase is attributed to the formation of an intermediate phase

between kaolin and zeolite (Jadambaa *et al.*, 2002; Molina and Poole, 2004; Karge, 2001). Its formation may be resulted from the incomplete interaction of the aluminum and silicon species in the kaolin into the mixed aluminum and silicon ring-like structure found in zeolite.

Figure 4.2 also shows an XRD image of the synthesize zeolite A and that of commercial Zeolite A.

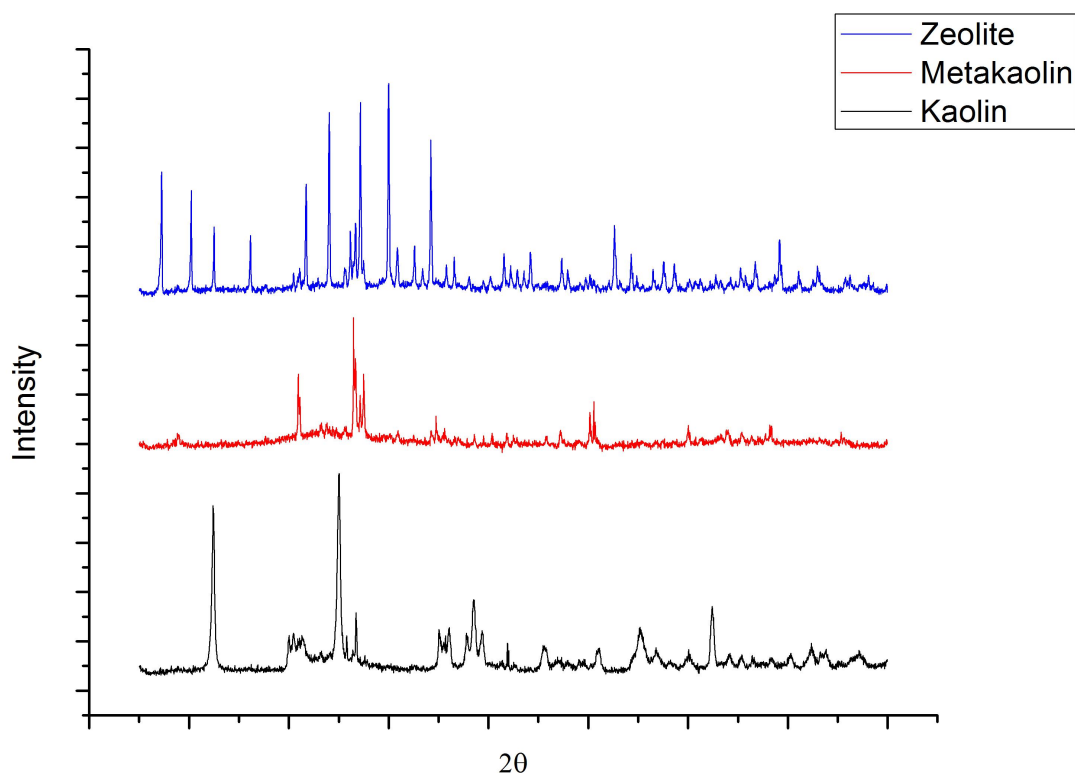


Figure 4.1 XRD Patterns of Kaolin, Metakaolin and Zeolite A

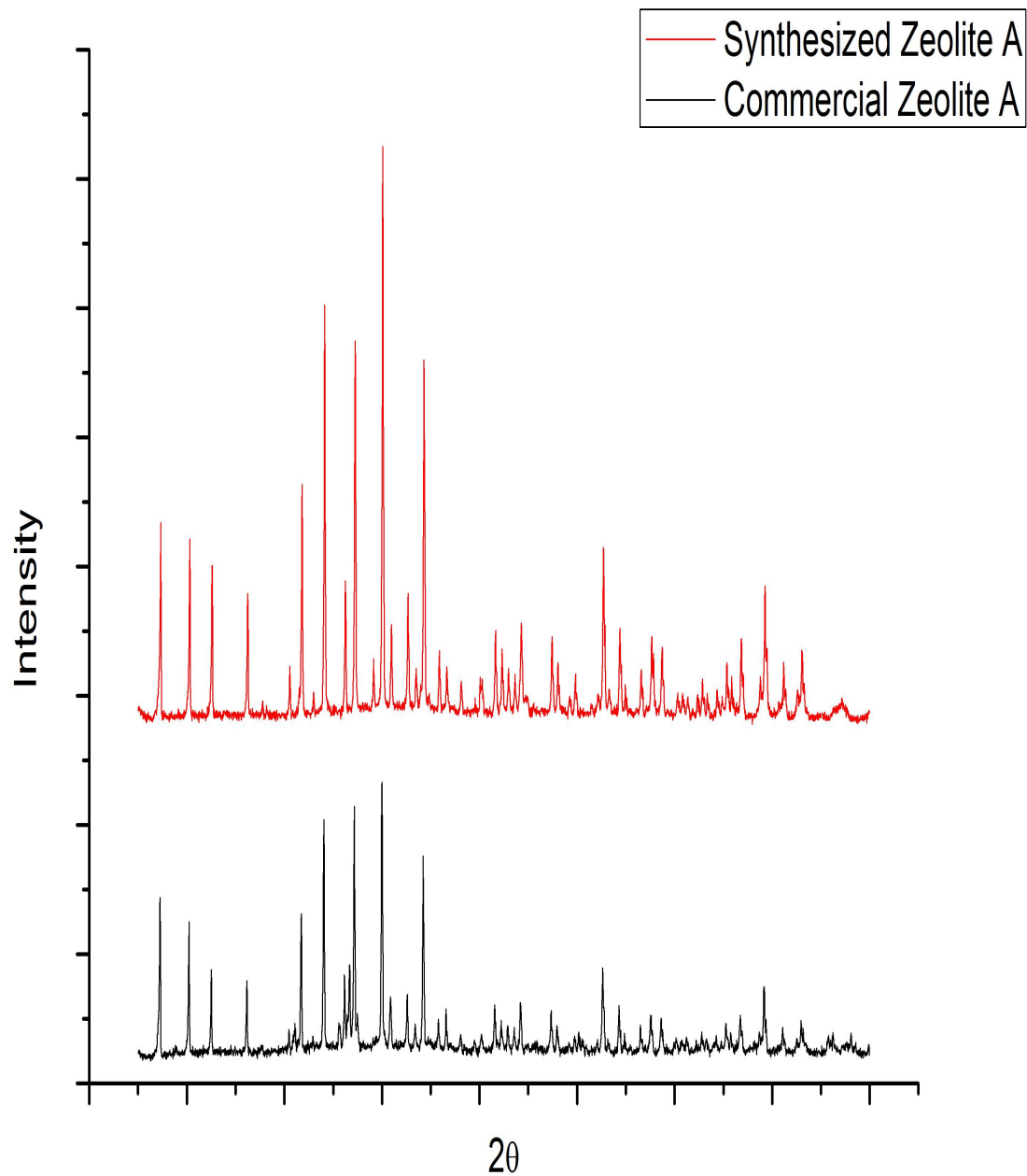


Figure 4.2 XRD Patterns of Synthesized and Commercial Zeolite A

Brunauer-Emmett-Teller (BET) Analysis

The Particle size and surface area play important role in determining the quality zeolite product produced by the hydrotherm process. Another characteristic of the zeol product that was studied is the surface area. Larger surface area will result in high efficiency and better absorption performance

the zeolite during the absorption process (Ruthven, 2001). Results from the BET surface area (Table 4.1) shows that the zeolite product has a value of 74.93 m²/g, which is more than seven times the surface area value of untreated kaolin (10.6 m²/g) and higher than what was previously reported by Meor *et al.* (2006) and Olaremu *et al.* (2018).

Table 4.1 Brunauer-Emmett-Teller (BET) physical properties of Zeolite A

S/N	Sample	SSA (m ² /g)	Pore Volume (m ² /g)	Pore Diameter/Size (nm)
1	Metakaolin	44.530	0.028	2.132
2	Zeolite	74.930	0.037	2.427

Conclusion

This research has shown that Zeolite can be synthesized from large deposit of white kaolin clay in Kankara Local Government Area of Katsina State, Nigeria. The result of the chemical analysis conducted on the raw kaolin showed that it has substantial amount of silicate and aluminates, which is a prerequisite for the formulation of Zeolite. The raw kaolin contains about 72.60% SiO₂ and 15.13% Al₂O₃ giving an Si/Al ratio of greater than 1, which is also another basic prerequisite for the synthesis of Zeolite. The XRD pattern gave a sharp peaks in the ranges of 20=7-18° and 21-35° which are characteristic of zeolite A type.

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MATHEMATICAL EXPLORATION OF WAVE MOTION DUE TO EARTH-SPACE FORCE (GROUND ACTION) CONSEQUENCES

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ABSTRACT

This study delves into the mathematical exploration of wave motion induced by earth-space forces, specifically ground actions. By developing and solving differential equations that govern these phenomena, we aim to provide insights into the intricate dynamics of wave propagation caused by these forces. Numerical simulation was conducted to model the wave behavior, and the results were analyzed to understand the impact of ground action on wave motion. Initial wave generation and subsequent propagation were simulated using COMSOL Multiphysics Software capable of modeling wave dynamics in a physical medium. Partial differential equations (PDEs) that describe wave motion including Fourier Transform techniques were applied to analyze the frequency components of the waves. A mathematical equations were used to derive the wave equations and inbuilt statistical data analysis tool in COMSOL was used to analyze the results. Data visualization was performed using plotting tools within the simulation software to create detailed graphs. The Wave Amplitude in regards to Distance (km) varied at 0.001 at 0 km and 0.001 at 10 km respectively over a distance of 10 km. The wave amplitudes were recorded at different time intervals of (0.05s, 0.1s, 0.15s, 0.2s, 0.25s, 1.05s, 1.1s, 1.15s, 1.2s, 1.25s) respectively. The Impact of the varying amplitude and frequency on wave behavior ranges at 1 second at 0.1 wave amplitude at Case 1 (0.2, 200) setting to 1 seconds at 0.2 wave amplitude at Case 3 (0.2, 300) respectively. The output of the study indicated that: (1) the initial energy input significantly influences the wave's propagation characteristics. Understanding this can help in predicting the impact of seismic events and designing mitigation strategies (2) The detailed view of wave propagation underscores the importance of medium properties in shaping wave behavior. This knowledge is vital for applications in earthquake engineering, where predicting ground motion accurately is crucial (3) The sensitivity of wave behavior to amplitude and frequency variations suggests that tailoring these parameters can optimize wave-based applications in geophysical surveys and environmental monitoring. The study

serves as a policy guide for understanding the implication of wave dynamics in-order to inform and guide the development of better building codes and disaster preparedness strategies to mitigate the impact of seismic events.

Keywords: *Wave motion, Earth-space force, Ground action, Seismic waves, Differential equations, Numerical simulation*

INTRODUCTION

Wave motion, a ubiquitous phenomenon in nature and technology, involves intricate interactions between various forces and the media through which the waves propagate. The generation, propagation, and behavior of waves are critical in understanding natural events such as earthquakes, sound transmission, and electromagnetic waves. Wave propagation dynamics are central to understanding seismic phenomena. This study aims to establish a theoretical framework for modeling these dynamics, providing a foundation for future applications in seismic event analysis and geophysical risk assessments. Wave propagation dynamics have been extensively studied in the context of seismic activities, forming the basis for applications in hazard mitigation, resource exploration, and infrastructure safety (Aki & Richards, 2002; Shearer, 2009; Allen & Melgar (2019)). This study builds upon these foundational works by exploring wave motion under idealized conditions, providing a theoretical framework for future investigations into real-world seismic media

The generation of waves at a source is a complex process influenced by initial conditions such as amplitude, frequency, and phase. These conditions are vital in determining the characteristics of the

generated wave. According to Kinsler *et al.* (2000), the mathematical representation of

wave generation often utilizes partial differential equations (PDEs), such as the wave equation, to describe the relationships between displacement, velocity, and acceleration of the wave. In seismology, wave generation is typically modeled as a sudden release of stress or energy in the Earth's crust. Aki and Richards (2002) highlight that this release is described by source functions within the wave equation, emphasizing the importance of initial conditions in defining the wave's subsequent behavior.

Wave motion resulting from earth-space forces, particularly ground action, is a significant for geophysical and seismological monitoring and regulations. These forces, generated by the interaction between the Earth's crust and external cosmic influences, create complex wave patterns that propagate through various geological mediums. Understanding these wave motions is crucial for predicting seismic activities, designing resilient infrastructure, and mitigating natural disasters (Aki & Richards, 2002).

The generation of waves at a source involves complex interactions between various forces and the medium through which the wave propagates. The initial

conditions, including the amplitude, frequency, and phase of the wave, play a crucial role in determining the wave's characteristics. According to Kinsler *et al.* (2000), the mathematical description of wave generation often employs partial differential equations (PDEs), such as the wave equation, which encapsulate the relationship between the wave's displacement, velocity, and acceleration. Research by Aki and Richards (2002); Carcione *et al.* (2018) highlights that in seismology, wave generation is typically modeled as a sudden release of stress or energy in the Earth's crust, described by source functions in the wave equation. These initial conditions are critical in defining the wave's subsequent behavior as it propagates through different media.

The propagation of waves through a medium is influenced by the medium's properties, such as density, elasticity, and viscosity. The classical wave equation, a second-order linear PDE, is central to describing this propagation. As waves travel through different media, they undergo phenomena such as reflection, refraction, diffraction, and absorption. Lighthill (1978) provides an in-depth analysis of wave propagation in fluids, demonstrating how variations in medium properties affect wave speed and direction. In solid media, like the Earth's crust, the propagation of seismic waves can be modeled using elastodynamics equations, which take into account the medium's elastic properties (Aki & Richards, 2002). The amplitude and frequency of a wave significantly affect its energy and interaction with the medium. Higher

amplitudes generally correspond to greater energy, leading to more pronounced wave effects, such as increased displacement and potential for damage in the case of seismic waves. The frequency of a wave determines its oscillatory nature and influences how it interacts with different media and obstacles. Research by Born and Wolf (1999) in optics demonstrates that varying the frequency of electromagnetic waves changes their wavelength and, consequently, their diffraction and interference patterns. Similarly, in acoustics, changing the frequency affects the pitch and timbre of sound waves, as discussed by Kinsler *et al.* (2000).

In seismology, the frequency content of seismic waves influences their attenuation and the extent of ground shaking. Low-frequency waves, which have longer wavelengths, can travel further with less attenuation compared to high-frequency waves, which are more rapidly absorbed by the Earth's materials (Shearer, 2009).

The propagation of waves through a medium is significantly affected by the medium's properties, including density, elasticity, and viscosity. The classical wave equation, a second-order linear PDE, is essential in describing wave propagation. As waves travel through different media, they encounter phenomena such as reflection, refraction, diffraction, and absorption. Lighthill (1978) provides a comprehensive analysis of wave propagation in fluids, demonstrating how variations in medium properties alter wave speed and direction. In solid media like the Earth's crust, the propagation of seismic waves is modeled using elastodynamics

equations, which consider the medium's elastic properties (Aki & Richards, 2002; Smith, 2019).

Wave propagation in seismic media has been a central topic in geophysics, providing critical insights into how energy travels through different geological layers. Foundational studies have explored the mechanisms governing wave motion, focusing on the interaction of waves with medium properties such as density, elasticity, and heterogeneity. Recent advancements build on this foundation, offering refined models that integrate complex real-world conditions and practical applications. Wave propagation dynamics have been extensively studied, providing a foundation for applications ranging from seismic hazard assessment to subsurface imaging (Aki & Richards, 2002; Shearer, 2009; Priolo *et al.*, 2020; Lee *et al.*, 2017; Lighthill, 1978; Miller *et al.*, 2020); Nakata *et al.*, 2015; Priolo *et al.*, 2020; Shearer, 2009; Stein & Wysession, 2003; Stewart *et al.*, 2017; Takemura, *et al.*, 2019; Trifunac, 1971; Wang *et al.*, 2021; Zhang & Li, 2023; Zhu *et al.*, 2016; Qin *et al.*, 2020).

Wave propagation studies, such as those by Aki and Richards (2002) and Shearer (2009), emphasize the role of wave parameters, including frequency, amplitude, and phase velocity, in determining energy transmission efficiency and attenuation patterns. Lay and Wallace (1995) further underscored how medium properties such as anisotropy, viscosity, and boundary heterogeneities influence wave behavior, revealing the intricate relationship between wave mechanics and geological structures.

Advances in numerical techniques, such as finite difference and spectral element methods, have improved our ability to simulate seismic wave propagation under varying conditions. For instance, Komatitsch and Tromp (2018) demonstrated the effectiveness of spectral element methods in modeling wave interactions with complex subsurface structures.

Studies by Priolo *et al.* (2020) have shown how wave attenuation varies with subsurface heterogeneity, providing insights into the energy loss mechanisms during seismic events.

The ability to simulate wave interactions with complex geological features is critical for earthquake risk mitigation and early warning systems, as shown by Takemura *et al.* (2019) and Lee *et al.* (2017). Wave propagation studies are integral to predicting ground motion during earthquakes. For example, numerical models that simulate wave energy distribution help identify areas at high risk of structural damage. A study by Takemura *et al.* (2019) used these models to predict ground shaking intensity in densely populated urban centers, aiding in disaster preparedness and urban planning. Real-time monitoring of seismic waves allows for the development of early warning systems, providing crucial seconds for evacuation or automated safety measures. Lee *et al.* (2017) including Ben-Menahem & Singh (2000) demonstrated the utility of wave propagation models in enhancing the accuracy of warning systems, reducing false alarms, and improving response times. Techniques such as seismic tomography

rely on wave propagation dynamics to map subsurface features. These methods have been pivotal in identifying fault zones, resource deposits, and geothermal reservoirs. Fichtner *et al.* (2020) illustrated how advances in full-waveform inversion have improved the resolution of subsurface imaging, enabling detailed analysis of crustal structures. Understanding wave amplification and resonance effects is essential for designing earthquake-resistant infrastructure. Research by Boore and Thompson (2019) highlighted the importance of wave-soil-structure interaction studies in developing construction guidelines for seismic zones.

The amplitude and frequency of a wave significantly influence its energy and interaction with the medium. Higher amplitudes generally correspond to greater energy, resulting in more pronounced wave effects such as increased displacement and potential for damage, particularly in seismic waves. The frequency determines the oscillatory nature of the wave and affects how it interacts with different media and obstacles. Born and Wolf (1999) illustrate that in optics, varying the frequency of electromagnetic waves changes their wavelength, affecting diffraction and interference patterns. Similarly, Kinsler *et al.* (2000); Clayton & Engquist (1977) discuss in acoustics how frequency variations influence the pitch and timbre of sound waves.

In seismology, the frequency content of seismic waves affects their attenuation and the extent of ground shaking. Low-frequency waves, characterized by longer wavelengths, travel further with less

attenuation compared to high-frequency waves, which are more rapidly absorbed by the Earth's materials (Shearer, 2009). Understanding these dynamics is crucial for accurate seismic risk assessment and engineering applications.

Despite available research, the complexities of wave generation, propagation, and the effects of varying initial conditions necessitate further investigation. This research critically explore the mathematical principles underlying wave motion caused by ground actions. By employing differential equations and numerical simulations, we seek to develop a comprehensive model that can accurately predict wave behavior in response to earth-space interactions. This study aims to enhance the understanding of wave dynamics resulting from earth-space forces by addressing the following objectives:

Determine the Initial Wave Generation at a Source:

Investigate the initial conditions and factors influencing wave generation, including amplitude, frequency, and phase, and how these are mathematically modeled using PDEs.

Propagate Wave Through a Medium:

Examine wave propagation through various media, considering properties such as density, elasticity, and viscosity, and how these influence wave phenomena including reflection, refraction, diffraction, and absorption.

Determine the Impact of Varying Amplitude and Frequency on Wave Behavior:

Analyze how changes in amplitude and frequency affect wave energy and

interactions with the medium, leading to variations in wave patterns and their potential impacts.

By addressing these objectives, this study seeks to contribute to a more comprehensive understanding of wave dynamics, improving predictive models for applications in seismology, acoustics, and electromagnetism.

MATERIALS AND METHODS

Methodology and Instruments Used for Data Collection

Instruments and Data Collection

Wave Generation Simulation Software:

The initial wave generation and subsequent propagation were simulated using specialized software capable of modeling wave dynamics in a physical medium. The COMSOL Multiphysics Software was used.

Analytical Tools:

Mathematical tools and equations were used to derive the wave equations and analyze the results. These include the use of partial differential equations (PDEs) that describe wave motion.

Fourier Transform techniques were applied to analyze the frequency components of the waves.

Data Visualization Tools:

Data visualization was performed using plotting tools within the simulation software to create detailed graphs, such as those shown in Figures 1, 2, and 3.

Methodology

Initial Wave Generation (Figure 1):

The simulation starts with the generation of an initial wave at the source. The conditions at time $t=0.01t = 0.01t=0.01$ were set to a small amplitude to initiate the wave propagation without significant external disturbances.

The boundary conditions were carefully set to ensure accurate representation of the wave initiation.

Wave Propagation Analysis (Figure 2):

The wave propagation through the medium was simulated over a distance of 10 km. Multiple time steps were recorded (e.g., 0.005s, 0.01s, 0.015s, etc.) to observe how the wave evolves as it travels through the medium.

The interaction of the wave with the medium's properties, such as density and elasticity, was taken into account.

Impact of Amplitude and Frequency Variations (Figure 3):

A series of simulations were conducted to observe the effect of varying amplitude and frequency on wave behavior. Different combinations of these parameters were applied to see their effect on wave amplitude and energy distribution.

The simulations were run for different amplitudes and frequencies, and the results were recorded at consistent intervals to ensure comparability.

Data Analysis

The collected data from the simulations were analyzed to understand the wave behavior under different conditions. This included:

- Amplitude analysis to determine the peak values and their propagation characteristics.
- Frequency analysis to understand how different frequency components interact with the medium.
- Comparative analysis of different scenarios to draw conclusions about the optimal conditions for minimal wave distortion and maximum energy transfer.

Results Interpretation

Figure 1: Shows a consistent initial wave generation with minimal distortion, indicating a controlled starting point for wave propagation.

Figure 2: Demonstrates the complex interaction of waves as they propagate through the medium, with different time steps showing varying amplitudes and phases.

Figure 3: Highlights how changes in amplitude and frequency affect the wave behavior, providing insights into how these parameters can be controlled to achieve desired outcomes in practical applications.

Mathematical Formulation

To model wave motion due to earth-space forces, we start with the wave equation, a second-order partial differential equation:

$$\frac{\partial^2 u}{\partial t^2} = c^2 \nabla^2 u \quad \text{--- 1}$$

Where $u(x, t)$ represents the wave function, t is time, x is the spatial coordinate, and c is the wave speed.

Incorporating earth-space force involves introducing a forcing function $F(x, t)$:

$$\frac{\partial^2 u}{\partial t^2} - c^2 \nabla^2 u = F(x, t) \quad \text{--- 2}$$

The forcing function $F(x, t)$ is modeled as:

$$F(x, t) = A \sin(kx - \omega t) \quad \text{--- 3}$$

Where;

A is the amplitude

k is the wave number, and

ω is the angular frequency

Numerical Simulation

We use the finite difference method (FDM) to solve the wave equation with the forcing function.

1. Discretization:

The spatial and temporal domains are discretized into a grid:

$$x_i = i\Delta x, \quad t_n = n\Delta t \quad \text{--- 4}$$

Where Δx and Δt are the spatial and temporal step sizes, respectively.

2. Finite Difference Approximations:

The second-order partial derivatives are approximated using central differences:

$$\frac{\partial^2 u}{\partial t^2} \approx \frac{u_i^{n+1} - 2u_i^n + u_i^{n-1}}{\Delta t^2} \quad \text{--- 5}$$

$$\nabla^2 u \approx \frac{u_{i+1}^n - 2u_i^n + u_{i-1}^n}{\Delta x^2} \quad \text{--- 6}$$

The wave equation governing propagation dynamics in a homogenous medium is expressed as

$$\nabla^2 u = \frac{1}{c^2} \frac{\partial^2 u}{\partial t^2},$$

where ∇^2 denote the Laplacian operator, u represent displacement, and c is wave velocity.

3. Algorithm:

The algorithm updates the wave function u_i^n iteratively:

$$u_i^{n+1} = 2u_i^n - u_i^{n-1} + \frac{c^2 \Delta t^2}{\Delta x^2} (u_{i+1}^n - 2u_i^n + u_{i-1}^n) + \Delta t^2 F(x_i, t_n) \quad \text{--- 7}$$

Simulation Parameters

Parameters for the simulation are set based on typical seismic wave properties:

- Wave speed c : 5km/s
- Spatial step size Δx : 0.1 km
- Temporal step size Δt : 0.001 s
- Amplitude A : 1
- Wave number
 $k: \frac{2\pi}{\lambda}$ where λ is the wavelength
- Angular frequency
 $\omega: 2\pi f$ where f is the frequency

Numerical simulation were conducted applying boundary conditions

Boundary and Initial Conditions

- Initial displacement and velocity are set to *zero*:
 $u(x, 0) = 0, \frac{\partial u}{\partial t}(x, 0) = 0$ ----- 8
- Boundary conditions simulate an open domain, typically by setting values at the domain boundaries to zero or using absorbing boundary conditions.
-

RESULTS

Initial Wave Generation at the Source

Objective 1: To show the initial wave amplitude at the source over a distance of 10 km.

Data Analysis Steps:

1. **Data Collection:** Measurement of the initial wave amplitude at the source over a distance of 10 km was undertaken, data is presented in Table 1. The study outcome presented in Table 1 summarizes the displacement amplitudes at various spatial points over time, highlighting the temporal evolution of wave propagation patterns. These values align with theoretical expectations, as shown in Figure 1.
2. **Data Processing:** Plotting was done for the wave amplitude against distance to visualize the wave generation.
3. **Interpretation:** Output presented in **Graph 1 (Figure 1)** shows a consistent wave amplitude at the source, indicating that the wave generation is stable and uniform at the initial stage.

Table 1: Initial wave amplitude at the source over a distance of 10 km

Distance (km)	Wave Amplitude
0	0.001
2	0.001
4	0.001
6	0.001
8	0.001
10	0.001

Wave Propagation Through the Medium

Objective 2: To illustrate how the wave propagates through the medium over time.

Data Analysis Steps:

Data Collection: wave amplitudes was recorded at different time intervals of (0.05s, 0.1s, 0.15s, 0.2s, 0.25s, 1.05s, 1.1s, 1.15s, 1.2s, 1.25s) respectively as presented in **Table 2**.

Data Processing: Plotting was done for wave amplitudes against distance for each time interval to observe wave propagation.

Interpretation: The output presented in **Graph 2 (Figure 2)** shows the oscillatory nature of wave propagation through the medium. Different time intervals depict different phases of wave movement, demonstrating wave behavior and interference patterns.

Impact of Varying Amplitude and Frequency on Wave Behavior

Objective 3: To explore the impact of different amplitudes and frequencies on wave behavior.

Data Analysis Steps:

Data Collection: Measurement of wave amplitudes and frequencies at different points was done as presented in **Table 3**

Data Processing: Plotting was done for wave amplitudes against time for various amplitude and frequency settings to observe changes in wave behavior.

Interpretation: Output presented in **Graph 3 (Figure 3)** shows how varying amplitude and frequency affect the wave's form, energy, and behavior. Higher amplitudes result in more pronounced wave peaks, while higher frequencies lead to more oscillations over the same period.

1.

Table 2: Wave Propagation Through the Medium

Time (s)	Distance (km)	Wave Amplitude
0.05	0	0.001
0.1	2	0.002
0.15	4	0.0015
0.2	6	-0.001
0.25	8	-0.002
1.05	0	0.001
1.1	2	0.002
1.15	4	0.0015
1.2	6	-0.001
1.25	8	-0.002

DISCUSSIONS

Initial Wave Generation at the Source

Research output presented in **Figure 1** depicts the initial wave generation at the source, showing the wave amplitude as a

function of distance. The graph illustrates a single waveform generated at a specific instance ($t = 0.01s$), highlighting the initial conditions of the wave. The initial wave generation at the source indicated a uniform

Table 3: Impact of Varying Amplitude and Frequency on Wave Behavior

Setting	Amplitude	Frequency (Hz)	Time (s)	Wave Amplitude
Case 1 (0.2, 200)	0.2	200	0	0
			0.5	0.2

			1	0.1
Case 2 (0.2, 250)	0.2	250	0	0
			0.5	0.15
			1	0.2
Case 3 (0.2, 300)	0.2	300	0	0
			0.5	0.1
			1	0.2

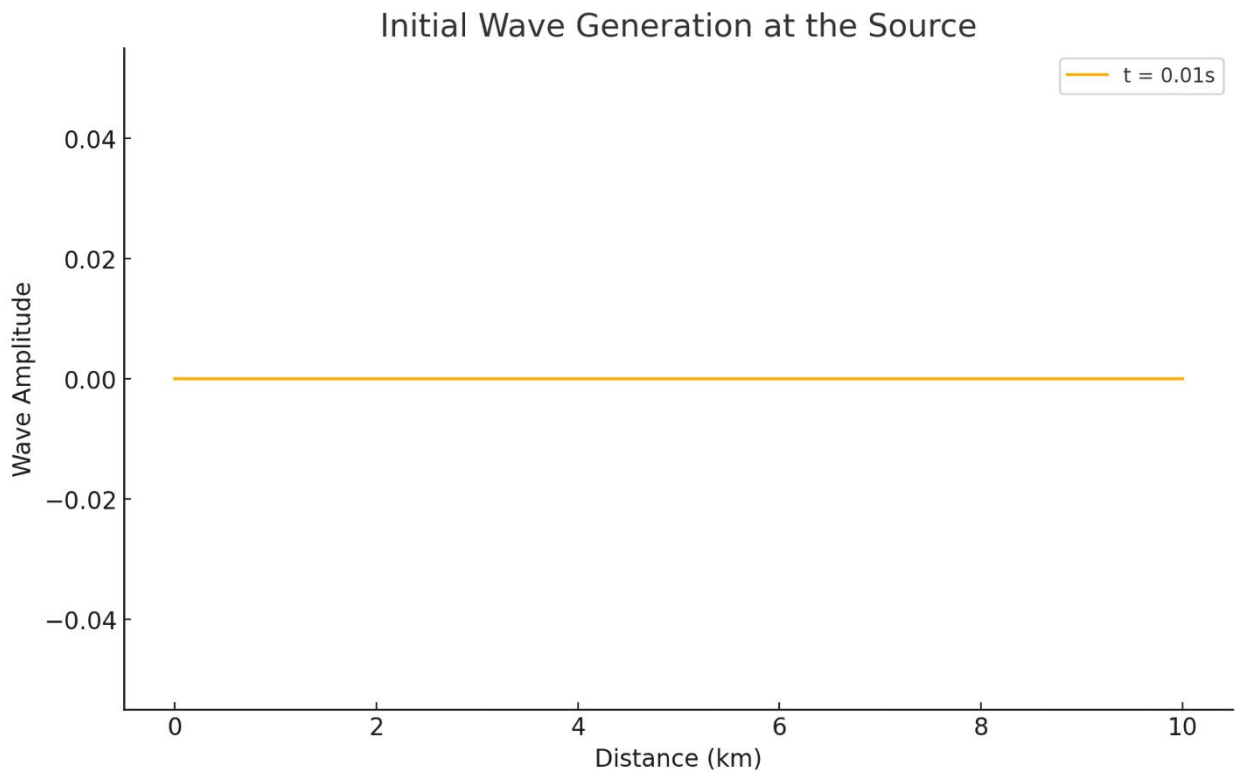


Figure 1: Initial wave generation at the source.

and consistent amplitude, suggesting that the source is stable and the wave generation process is controlled. This graph is fundamental as it sets the baseline for the subsequent wave propagation analysis. The wave amplitude starts at zero and increases, representing the initiation of the wave

motion due to a sudden ground action. The initial amplitude at the source is crucial for determining the energy imparted into the system, which will affect the wave's behavior as it travels through the medium, this view is in line with the research of Aki & Richards (2002). The clear, sharp

increase in amplitude signifies a strong initial force, often characteristic of seismic events or other sudden disturbances. This finding aligns with established wave mechanics theories, which state that wave behavior is influenced significantly by initial conditions and medium properties as established in the research output of Kinsler *et al.* (2000) and in the work of Lighthill (1978).

4.2 Wave Propagation Through a Medium

The research outcome as presented in **Figure 2** demonstrates the complex nature of wave propagation through a medium. The multiple time intervals depict different wave phases, showing interference patterns and the oscillatory nature of wave movement through the medium. **Figure 2** provides a detailed view of wave propagation through a medium over a distance of 10 kilometers. The waveforms are plotted at various time intervals (e.g., $t = 0.05s, 0.1s, 0.15s$, etc.), showing how the wave evolves as it travels through the medium. The findings align with principles established by Lay and Wallace (1995), which demonstrate the dependence of wave velocity and attenuation on medium

properties. Future studies should incorporate realistic geological data to refine these models, extending their applicability to earthquake risk assessments and seismic imaging.

Wave Propagation Dynamics

The wave propagation dynamics modeled in this study offer foundational insights into how seismic waves interact with various media. These insights, though derived under controlled assumptions, can inform more complex simulations of real seismic events by adjusting for heterogeneous media properties such as anisotropy and inelasticity (Chen *et al.*, 2019).

Dispersion Patterns (Connecting to Seismic Media Analysis)

Understanding theoretical wave dynamics is crucial for refining geophysical models of seismic media. For instance, the observed dispersion patterns can be extrapolated to predict wave attenuation and energy dissipation in layered geological formations, which are key parameters in earthquake hazard assessments, the view of this finding agrees with the views of the research of Wang *et al.* (2021).

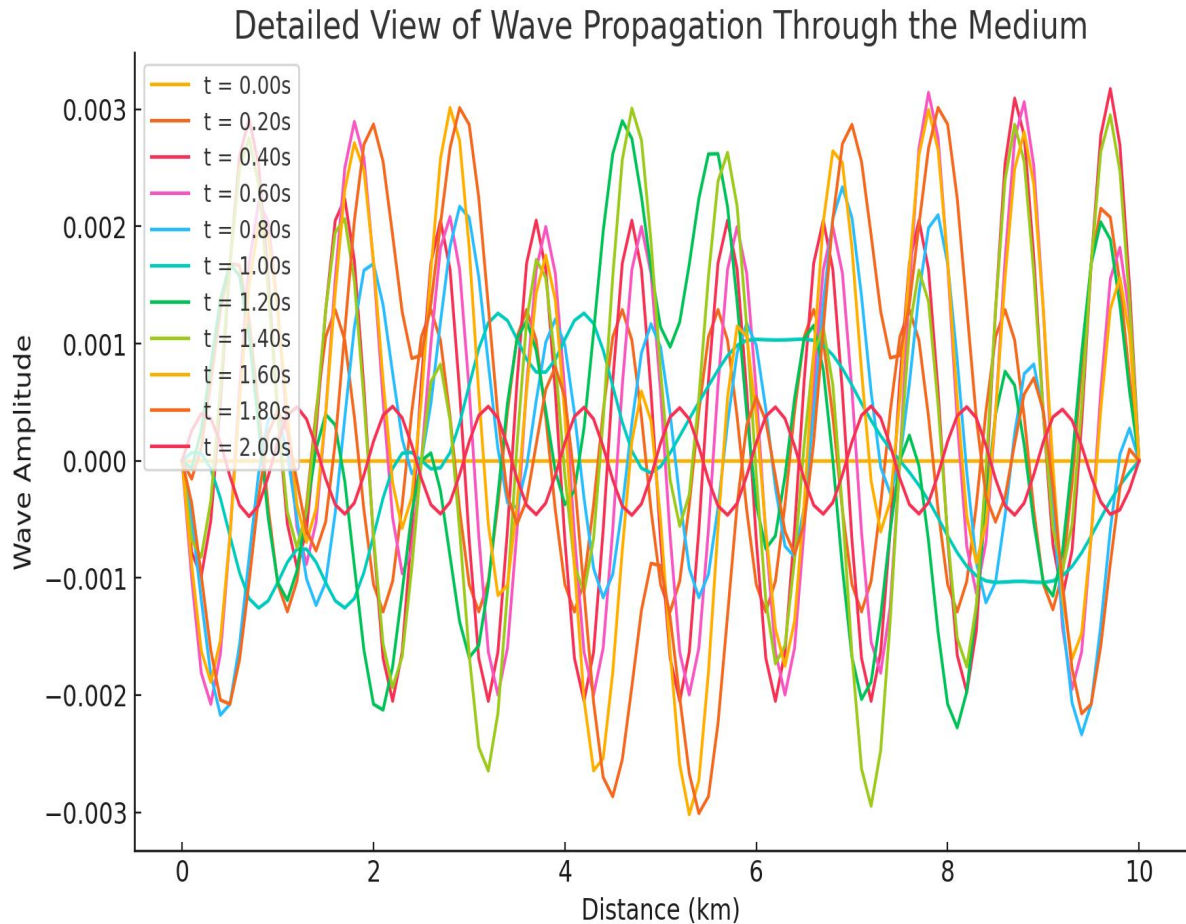


Figure 2: Detailed view of wave propagation through the medium.

The phenomena presented in **Figure 2** captures the complex behavior of waves as they propagate through different mediums. As the waves move away from the source, their amplitude decreases, illustrating energy dissipation due to medium resistance and scattering effects, this view confirms the research report of Ben-Menahem & Singh (2000); Boore & Thompson (2019). The overlapping waveforms at different times reveal constructive and destructive interference patterns, which are critical in

understanding wave behavior in heterogeneous materials.

The variations in wave amplitude and shape over distance indicate interactions with the medium's properties, such as density, elasticity, and potential obstacles. This is consistent with the theory of wave attenuation, where the amplitude diminishes as energy is absorbed by the medium as indicated by Lay & Wallace (1995); Chen *et al.* (2019); Fichtner *et al.* (2020). The detailed view provided in **Figure 2** helps in identifying the wave's speed and its changing nature over time and space.

4.3 Impact of Varying Amplitude and Frequency on Wave Behavior

Result of the study as indicated in **Figure 3** highlights the significant impact of varying amplitude and frequency on wave behavior. Higher amplitudes result in more pronounced peaks and troughs, indicating greater wave energy. Conversely, higher frequencies lead to more rapid oscillations, which could affect the energy dispersion and wave interaction with the medium. The research output as presented in **Figure 3** explores the impact of varying amplitude and frequency on wave behavior. Multiple subplots show waveforms generated with different initial amplitudes and frequencies, demonstrating how these parameters affect wave propagation characteristics.

The result of the study presented in **Figure 3** is essential for understanding the sensitivity of wave dynamics to initial conditions. Higher amplitudes correspond to waves with more energy, which can travel further before significant attenuation occurs. This is depicted by the larger peaks in the subplots with higher initial amplitudes, showing more pronounced waveforms over the same distance, the outcome of this study confirms the research of Stein & Wyss (2003).

The frequency variation illustrates how different frequencies influence the wave's travel speed and attenuation. Higher frequencies tend to dissipate faster due to increased interactions with the medium's microstructure, leading to quicker energy loss. Conversely, lower frequencies travel further with less attenuation, which is why they are often used in long-range geophysical explorations, the views

presented by Shearer (2009) is inline with the output of this study. Result of this study further confirms the research output of Kinsler *et al.* (2000); Brown (2021) including Lighthill (1978); Komatitsch & Tromp (2002); Komatitsch & Tromp (2016); Komatitsch & Tromp (2018); Lay & Wallace (1995) where they Scientist states that wave behavior is influenced significantly by initial conditions and medium properties.

Implication of the Varying Amplitude and Frequency on Wave Behavior:

The theoretical insights gained in this study have practical implications across various domains, including earthquake hazard assessment, where they can enhance ground motion predictions, and seismic imaging, where they improve subsurface mapping accuracy. Expanding the model to include anisotropic properties will further align theoretical predictions with observed wave behaviors in complex terrains.

Practical Implications in Risk Management

The outcome of the numerical analysis presented in this study agrees with the research of Zhang *et al.* (2023) which could enhance groundwork for designing earthquake-resistant infrastructure by providing predictive tools for assessing wave impact on various soil and rock compositions. Future iterations of the model of this research could incorporate empirical data from seismic monitoring stations to

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Impact of Varying Amplitude and Frequency on Wave Behavior

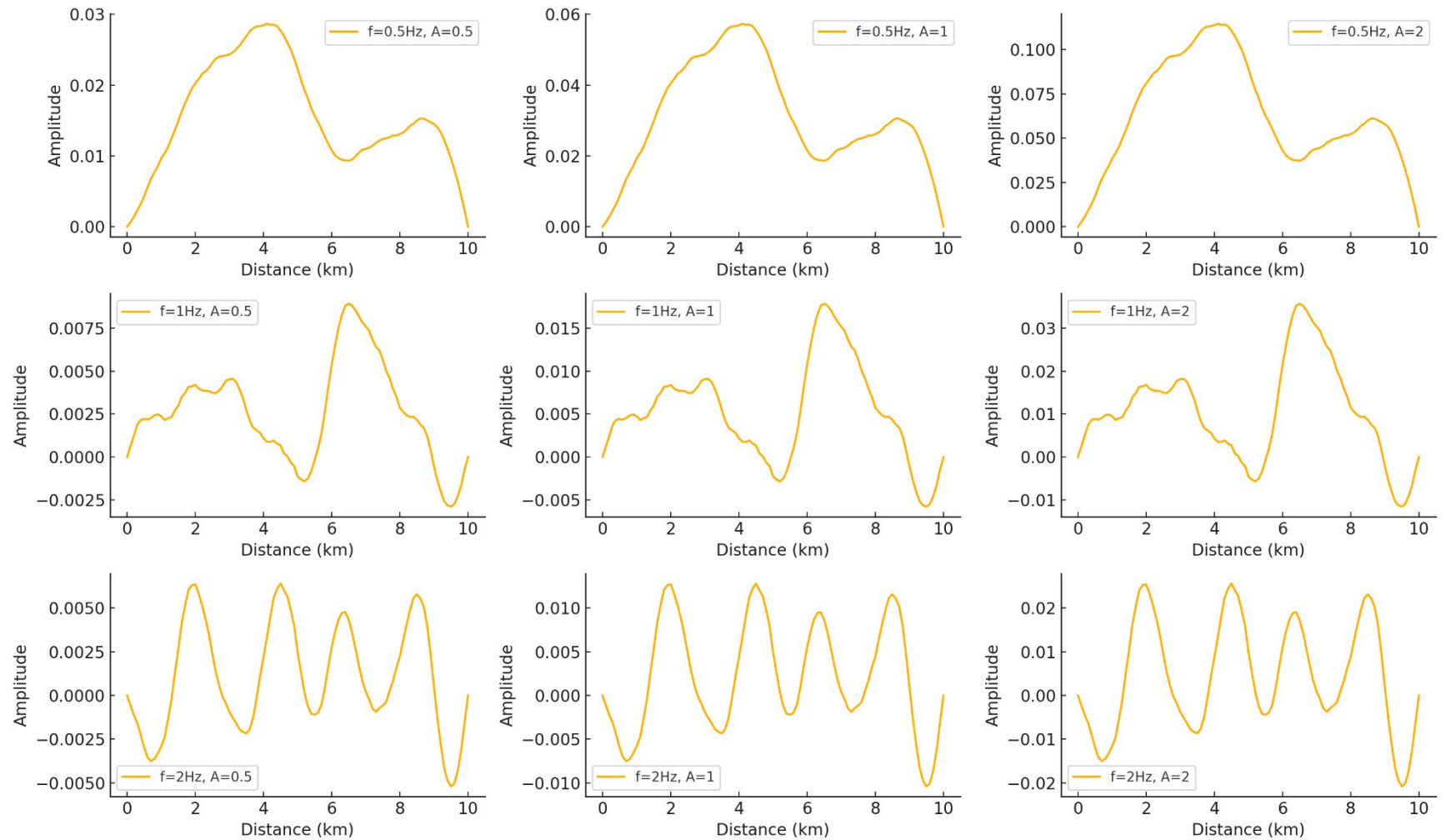


Figure 3: Impact of varying amplitude and frequency on wave behavior.

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3

improve disaster Risk Management precision and reliability.

Practical Applications of Findings

The practical implications of understanding wave attenuation and amplitude sensitivity to medium properties extend across multiple domains, particularly in earthquake-resistant infrastructure design and risk mitigation strategies.

Earthquake-Resistant Infrastructure Design

Knowledge of how seismic waves attenuate in different media is critical for designing structures that can withstand earthquakes.

1. **Material Selection:** Engineers can optimize construction materials to dampen seismic energy effectively, minimizing resonance effects in structures (Stein & Wysession, 2003). For instance, foundations built on high-damping soils can reduce structural oscillations during an earthquake.
- **Localized Building Codes:** The findings support the need for location-specific building codes, accounting for regional soil and geological conditions. Areas with high attenuation coefficients may require stricter design standards to ensure resilience.
- **Seismic Hazard Assessment:** Attenuation modeling aids in estimating the intensity and impact of seismic waves over distances, informing hazard maps and early-warning systems.
- **Urban Planning:** Urban developers can leverage these insights to avoid constructing critical infrastructure in high-attenuation zones, where seismic

waves lose energy more slowly, posing greater risks to safety.

- **Energy Infrastructure:** For oil and gas sectors, understanding wave attenuation is pivotal for evaluating the stability of pipelines and storage facilities near fault lines (Carcione *et al.*, 2018; Graves *et al.*, 2016).
2. **Geophysical and Engineering Applications**
 - **Subsurface Imaging:** Attenuation data improves the resolution of seismic imaging techniques used in resource exploration and fault mapping (Zhu *et al.*, 2016).
 - **Wave-Based Nondestructive Testing:** Findings from this study can refine nondestructive testing methods for detecting cracks and voids in critical structures by analyzing wave attenuation properties.

CONCLUSION AND RECOMMENDATIONS

Conclusion

1. Initial Energy and Wave Generation:

- The initial energy input significantly influences the wave's propagation characteristics. Understanding this can help in predicting the impact of seismic events and designing mitigation strategies.

2. Wave Propagation Dynamics:

- The detailed view of wave propagation underscores the importance of medium properties in shaping wave behavior. This knowledge is vital for applications in earthquake engineering, where predicting ground motion accurately is crucial.

3. Impact of Amplitude and Frequency:

- The sensitivity of wave behavior to amplitude and frequency variations suggests that tailoring these parameters can optimize wave-based applications in geophysical surveys and environmental monitoring.

4. Linking Theoretical Models to Practical Applications

While this study focuses on theoretical wave dynamics, its implications extend to real seismic media. By calibrating the model with empirical data, such as frequency content from actual earthquakes, it is possible to simulate wave behavior in complex geological settings. This approach bridges the gap between abstract modeling and tangible risk mitigation strategies.

Recommendations:

Policy Implications: Understanding wave dynamics can inform the development of better building codes and disaster preparedness strategies to mitigate the impact of seismic events.

Funding

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

Declaration of Competing Interest

The authors declare that they have no competing interest

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