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Residual Effects of Sawdust and Poultry Manure Biochars on Soil Chemical Properties and Vegetative Growth of Maize in Degraded Soils of Southwestern Nigeria

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Abstract

Soil fertility decline remains a major limitation to maize productivity in sub-Saharan Africa, where restricted access to fertilizers constrains efforts to close yield gaps. Sustainable soil management strategies that enhance residual nutrient availability are therefore critical for maintaining crop performance under low-input conditions. This study assessed the residual effects of sawdust biochar (SB) and poultry manure biochar (PB), applied singly and in combination at 0.5%, 1%, and 1.5% (w/w) in a preceding experiment, on soil chemical properties and maize growth under screenhouse conditions. The experiment comprised 40 pots arranged in a completely randomized design with 10 treatments replicated four times, and was conducted for eight weeks in the Department of Agronomy, University of Ibadan. The results showed that the residual effect of biochar treatments significantly enhanced maize growth, assessed via standardized vegetative growth indices and dry matter accumulation. Poultry manure biochar (PB) at 1.5% produced the highest growth index and dry matter yield, corresponding to increases of 32% and 156% relative to the control. Similarly, at harvest, soil nutrient contents ($p < 0.05$) remained significantly higher under PB and SB treatments, although total nitrogen remained the major limiting factor. These findings indicate that residual biochar can sustain soil fertility and improve maize growth, but require complementary N inputs for maximum benefits. For smallholder farmers managing highly degraded soils in Nigeria, integrating biochar with modest fertilizer use offers a pathway to restore soil fertility and support crop productivity under low-input conditions.

Keywords: biochar, residual effect, nitrogen limitation, maize productivity

1.0 Introduction

Maize (Zea *mays* L.) ranks among the most widely cultivated cereal crops due to its exceptional adaptability across diverse agro-climatic conditions (Manoj *et al*., 2023). It occupies approximately 197 million hectares in over 160 countries, reflecting its ecological versatility and role in global food security (Erenstein *et al*., 2022; FAO, 2022). Problems related to soil fertility and land degradation remain among the most pressing challenges limiting agricultural productivity in sub-Saharan Africa, including Nigeria (Adesemoye *et alet al*., 2023). Several factors have been identified as drivers of this decline, including poor implementation of soil fertility management practices, nutrient mining, soil acidification, population pressure and associated deforestation, as well as climatic variability and intensity (Jones *et al*., 2013; Vanlauwe *et al*., 2015; Tully *et al*., 2015; Bado *et al*., 2018). This decline in soil fertility is a major factor perpetuating poverty in the region, where a large percentage of the population relies on subsistence farming for their livelihoods (Sanchez, 2002; Vanlauwe *et al*., 2015). Thus, maize productivity, like that of other cereal crops, is significantly constrained by poor soil

fertility in the region. This is further worsened by smallholder farmers' limited access to fertilizers, a key factor known to reduce yield potential across sub-Saharan Africa (Sheahan and Barrett, 2017). Given these constraints, there is the need to explore cost-effective, locally available soil amendments such as biochar that can enhance soil fertility and crop productivity in low-input farming systems.

Biochar, a carbon-rich material produced from the pyrolysis of organic biomass, has received considerable attention as a soil amendment capable of enhancing soil fertility and supporting crop productivity (Lehmann & Joseph, 2009; Gao *et al*., 2019; Chen *et al*., 2022). Its porous structure, charged functional groups, and inherent nutrient content contribute to improvements in soil chemical and physical properties, such as cation exchange capacity, water retention, and nutrient availability (Amad *et al*., 2018). In addition to its agronomic benefits, biochar contains highly stable carbon forms, which contribute to long-term carbon storage and climate change mitigation (Preston & Schmidt, 2006; Schmidt *et al*., 2021). Although biochar improves water and nutrient retention in many contexts, its effects on nitrogen dynamics remain inconsistent. For instance, Ramlow *et al*. (2019) observed no significant impact of biochar on nitrogen retention despite enhanced soil moisture levels. In contrast, Gao *et al*. (2019) reported a significant increase in soil inorganic nitrogen following biochar application. A meta-analysis by Ippolito *et al*. (2020) demonstrates that differences in biochar effectiveness are largely driven by variations in feedstock type, pyrolysis temperature, and production method. This variability highlights the need to evaluate the effects of biochar from different feedstocks on soil fertility and crop performance when used as a standalone amendment, particularly in systems where fertilizers are not routinely applied.

Additionally, smallholder farmers in Nigeria, including those managing small back-yard plots, produce large amounts of agricultural residues (e.g., rice husks, maize stalks, sawdust, cassava peel) and animal waste like poultry, cow, or pig manure through combined crop cultivation, processing and livestock rearing activities (Nwakuba *et al*., 2016; Omilani *et al*., 2019). These materials often accumulate with limited disposal options, and farmers commonly burn them as an easy way to manage waste. In many cases, the resulting ash or partially burned material is reapplied to the soil, sometimes intentionally and other times out of habit or tradition. This practice introduces low-grade biochar-like substances into the soil, although most farmers may not recognize it as such. While several studies have investigated the use of biochar in combination with mineral fertilizers, fewer have examined its residual effects in the absence of further fertilizer application, despite this being a common reality in many smallholder farming systems (Azuka *et al*., 2025). However, the magnitude and persistence of these residual effects are expected to vary depending on biochar properties, which are largely influenced by feedstock source. Despite growing interest in biochar, limited information is available on the comparative residual effects of biochars produced from different feedstocks, particularly in inherently low-fertility soils. Understanding these differences is important because biochars derived from plant residues and animal wastes differ substantially in nutrient composition, ash content, and chemical characteristics, which may influence their long-term effects on soil fertility and crop performance. This study therefore evaluated the residual effects of sawdust biochar and poultry manure biochar on selected soil chemical properties and maize growth during a subsequent growing season when no additional biochar or fertilizer was applied. By comparing the residual effects of two contrasting biochar feedstocks, this study provides insight into their potential for sustaining soil productivity in low-input agricultural systems.

2.0 Materials and Methods

2.1 Experimental Soil and Description of Biochar Treatments

Soil used for the experiment was collected from the Department of Agronomy's Teaching and Research Farm along Parry Road, University of Ibadan, Oyo State, Nigeria (7°26′60.23″ N, 3°53′0″ E). The soil had a pH of 5.62, with 2.53

g/kg total organic carbon, 0.15 g/kg total nitrogen, 10.97 mg/kg available phosphorus, and 0.42 cmol/kg available potassium. The experiment was conducted in the screen house of the Department of Agronomy, University of Ibadan.

In 2017, ten soil treatments were established using biochar produced from poultry manure and sawdust. Poultry manure was sourced from the University's Teaching and Research Farm (poultry section) in Agbowo, air-dried under shade, crushed, and pyrolyzed at approximately 500 °C for two hours in an oxygen-limited chamber. Sawdust was collected from a nearby sawmill in the same district and processed similarly. Both biochar types were ground, sieved to <2 mm, and stored in airtight polyethylene bags before application. The treatments comprised: a control (no amendment); sawdust biochar (SB) and poultry manure biochar (PB) applied at rates of 0.5%, 1.0%, and 1.5% (w/w); and a 50:50 mix (SB +PB) applied at the same total rates, making a total of ten treatments. Each pot contained 5 kg of air-dried soil. These treatments were initially applied in 2017 to evaluate the immediate effects of biochar on soil properties and maize growth.

2.2 Residual Treatment Structure and Experimental Design

The residual effect trial was conducted in 2018, four months after the termination of the initial experiment. During this intervening period, the pots were kept under ambient screen house conditions. The soil in each pot was carefully removed, lightly crushed to break up caked material, and returned to its original pot to re-establish uniform soil conditions prior to replanting. No additional biochar or inorganic fertilizer was applied before the residual experiment, allowing assessment of the carry-over effects of the original biochar amendments. The experiment followed a Completely Randomized Design (CRD) consisting of the same ten treatments, each replicated four times, giving a total of 40 pots. Each pot was planted with three maize seeds of the hybrid EEWH-21 variety (*Zea mays* L.), obtained from the International Institute of Tropical Agriculture (IITA), Ibadan, Oyo State, and thinned to one plant per pot after two weeks. Data on growth parameters were obtained at 2, 4, 6 and 8 weeks after planting (WAP). The experiment was terminated at 8WAP while the dry matter yield was determined. Data on the effects on soil properties were obtained at planting and at harvest. Data on growth parameters were recorded at 2, 4, 6, and 8 WAP. The experiment was terminated at 8 WAP, at which point dry matter yield was determined. Soil samples were collected at planting and at harvest to evaluate changes in soil chemical properties.

2.3 Growth parameter measurements

Plant height was measured from the base of the stem to the tip of the longest leaf using a meter rule. Leaf number was recorded by counting all fully expanded leaves per plant while stem girth was measured at the base of the stem using a digital caliper. At harvest, plant samples were collected for fresh weight measurement, oven-dried at 75 °C for 72 hours, and subsequently weighed to determine dry biomass. A single composite vegetative growth index (VGI) was constructed following the metroglyph approach of Akoroda (1983). At 2, 4, 6, and 8 weeks after planting (WAP), plant height, stem girth, and number of leaves were scored 1 (low), 2 (medium), or 3 (high) based on performance intervals. A raw score (ranging from 3 to 9) was calculated for each stage as:

$$Raw\ score = Score_{Height} + Score_{Girth} + Score_{Leaves}$$

These raw scores were averaged across all four sampling dates to pool the time data. Finally, the pooled scores were scaled proportionally to a 100-point maximum relative to the highest-performing treatment:

$$VGI = \frac{Treatment\ Mean\ Pooled\ Raw\ Score}{Maximum\ Observed\ Mean\ Pooled\ Raw\ Score} \times 100$$

2.4 Soil Analysis

Soil chemical analyses were conducted following standard protocols. Soil pH was measured in a 1:1 soil-to-water suspension (Eckert and Sims, 1995). Organic carbon was determined via the dichromate wet oxidation method (Nelson & Sommers, 1982), while total nitrogen was analyzed using the Kjeldahl method (Bremner and Mulvaney, 1982).

Available phosphorus was extracted using Bray-1 and quantified with a spectrophotometer at 420 nm (Bauer *et al*., 1966). Exchangeable bases (Ca, Mg, K, Na) were extracted following Chapman (1982); Ca and Mg were analyzed by atomic absorption spectrophotometry (AAS), while K and Na were determined using a flame photometer. Micronutrients (Fe, Mn, Zn, Cu) were extracted with Mehlich-3 and measured using AAS. Exchangeable acidity was assessed by titration as described by Udo and Ogunwale (1986).

2.5 Data Analysis

Data recording and preparation were performed in Microsoft Excel. Statistical analyses were conducted using R software (v4.5.1). Analysis of variance (ANOVA) was used to evaluate treatment effects, and means were compared using Tukey's Honestly Significant Difference (HSD) test at the 5% probability level

3.0 Results

3.1 Residual effects of biochar on maize growth parameter

Plant height increased progressively with plant age across most treatments (Fig. 1a). At 2 weeks after planting (WAP), the tallest plants were observed in the SB0.5 treatment (62.5 cm), whereas the shortest were recorded in the Mix1.5 treatment (41.8 cm) ($p < 0.05$). A similar trend was observed at 4 WAP, with SB0.5 treatment producing the greatest plant height (114.12 cm), while the control recorded the lowest value (88.9 cm). By 6 WAP, the Mix1 treatment produced significantly taller plants than the control, representing a 36.4% increase in plant height ($p < 0.05$). At 8 WAP, several biochar treatments maintained significantly greater plant heights than the control. Plant height increased by 13.8%, 21.6%, and 38.7% under Mix1, with SB1, and PB1.5 treatments, respectively, relative to the control ($p < 0.05$). Overall, plant height increased in response to biochar application, with PB1.5 and Mix1 generally showing higher values at later stages.

Leaf number increased progressively with plant age across all treatments. At 2 weeks after planting (WAP), differences among treatments were not statistically significant ($p > 0.05$). At 4 WAP, PB1.5 produced the highest leaf number, although this was not significantly different from PB1 ($p > 0.05$). At 6 WAP, Mix1 recorded the highest leaf number, but this was not significantly different from PB1.5 ($p > 0.05$). At the final sampling stage (8 WAP), significant treatment effects were observed ($p < 0.05$). PB1.5, SB1.5, Mix1, and Mix1.5 recorded the highest leaf numbers and were not significantly different from each other, while SB0.5 and the control recorded the lowest values. Overall, leaf number at 8 WAP showed an increase of 33–39% under the highest-performing treatments relative to the control

Stem girth generally increased with plant age up to 6 weeks after planting (WAP), after which a slight decline was observed in most treatments. At 2 WAP, PB1.5 recorded the largest stem girth, while the control exhibited the smallest value ($p < 0.05$). At 4 WAP, PB1.5 again produced the highest stem girth, followed by Mix0.5, whereas the control remained the lowest ($p < 0.05$). A similar pattern was observed at 6 WAP, with Mix1.5 exhibiting the widest stem girth and the control showing the lowest value ($p < 0.05$). At the final sampling stage (8 WAP), PB1.5 and Mix1.5 maintained the highest stem girth values, while the control consistently recorded the lowest across all sampling periods. Compared with the control, PB1.5 and Mix1.5 increased stem girth by 112.7% and 58.9%, respectively ($p < 0.05$; Fig. 1c)

3.2 Residual effects of biochar on maize growth and biomass production

Biochar application significantly enhanced maize performance compared with the control, as reflected in the vegetative growth index and dry matter yield (Fig. 3). The control consistently recorded the lowest growth index (72.84) and dry matter yield (21.68 g). For the vegetative growth index, all biochar treatments improved growth by 16–37% relative to the control. PB1.5 (100.0) and SB1.5 (88.86) showed the greatest increases among sole applications, corresponding to 37% and 22% improvements, respectively, while Mix1 (93.31) recorded the highest value among the combined treatments. Similarly, dry matter yield increased significantly under biochar application ($p < 0.05$), with PB1.5 producing the highest biomass (55.5 g), which was significantly

greater than most other treatments and nearly three times higher than the control.

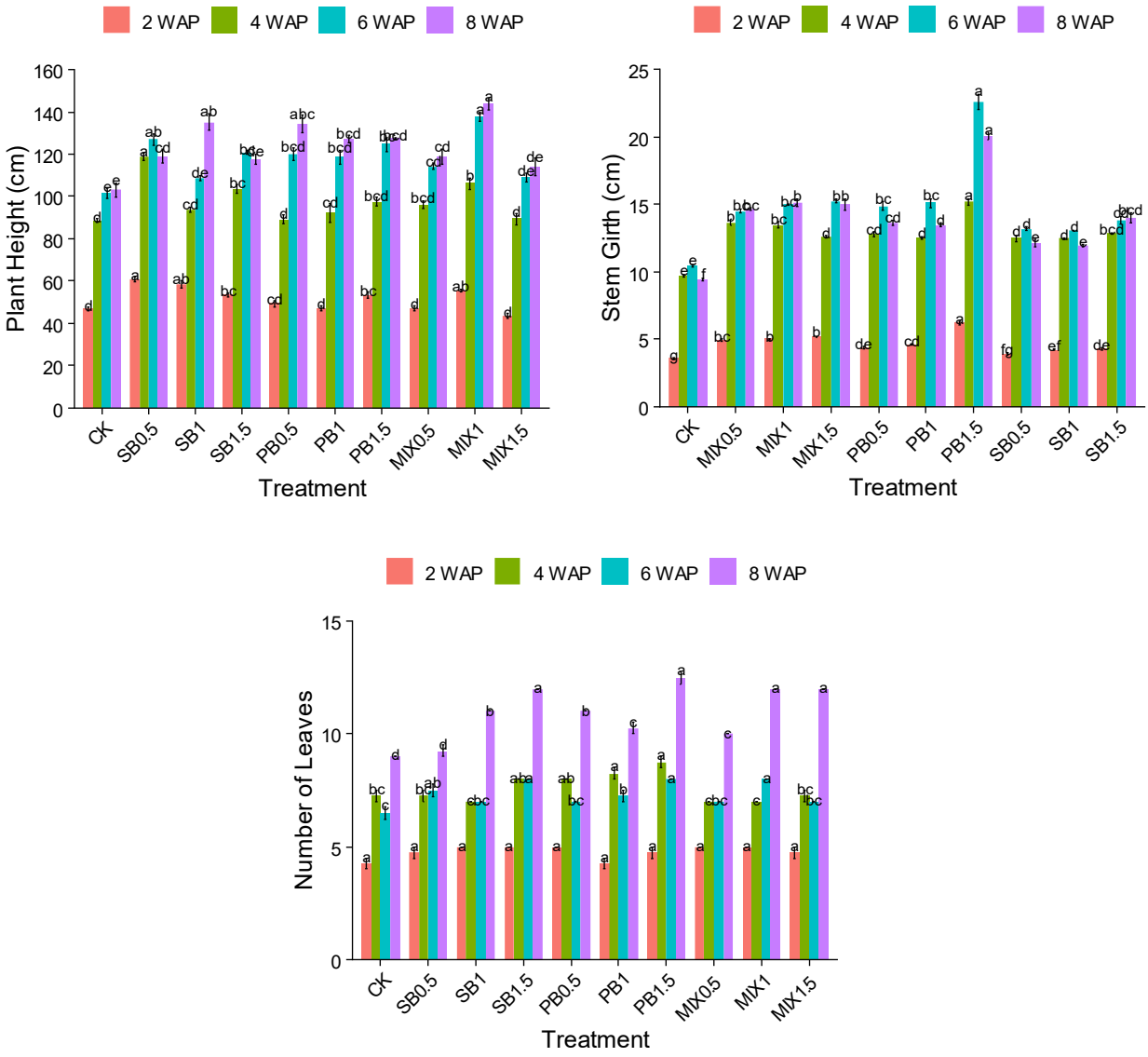


Fig. 1.: Residual effects of saw dust biochar and poultry manure biochar on (a) Plant height, (b) Number of leaves, (c) Stem girth. Significant differences between treatments are indicated by different letters ($P < 0.05$, n = 4). Error bars represent SE. CK: control (no amendment); SB0.5: 0.5% (w/w) sawdust biochar; SB1: 1.0% (w/w) sawdust biochar; SB1.5: 1.5% (w/w) sawdust biochar; PB0.5: 0.5% (w/w) poultry manure biochar; PB1: 1.0% (w/w) poultry manure biochar; PB1.5: 1.5% (w/w) poultry manure biochar; Mix0.5: 50:50 mixture of sawdust and poultry manure biochar applied at 0.5% (w/w); Mix1: 50:50 mixture applied at 1.0% (w/w); Mix1.5: 50:50 mixture applied at 1.5% (w/w). 0.5% (w/w) SB, saw dust biochar; 1% (w/w) SB, saw dust biochar; 1.5% (w/w) SB, saw dust biochar; 0.5% (w/w) PB, poultry litter biochar; 1% (w/w) PB, poultry litter biochar; 1.5% (w/w) PB, poultry litter biochar; 0.5% (w/w) SB+PB mix, 50:50 mixture saw dust biochar and poultry litter biochar applied at 0.5%; 1% (w/w) SB+PB mix, 50:50 mixture saw dust biochar and poultry litter biochar applied at 1%; 1.5% (w/w) SB+PB mix, 50:50 mixture saw dust biochar and poultry litter biochar applied at 1.5%

3.3 Residual effect of biochar on some soil properties

This study assessed temporal changes in soil total nitrogen (TN), available phosphorus (P), available potassium (K), and soil organic carbon (SOC), at two weeks after planting (2 WAP) and at harvest, while exchangeable Ca, Mg, and Na were measured only at harvest. Overall, TN, available P, and K generally decreased from 2 WAP to harvest, whereas SOC showed a less consistent temporal (Fig. 2). Soil TN was significantly higher in the Mix1.5 treatment at both sampling times, followed by Mix1, while the control consistently recorded the lowest TN ($p < 0.05$; Fig. 2a). At 2 WAP, available P was highest in PB1.5 and significantly higher than other treatments ($p < 0.05$). At harvest, PB1.5 again recorded the highest available P (6.41 mg kg^{-1}), remaining significantly greater than all other treatments, with increases of 17.9–89.8% compared with Mix1.5, PB0.5, PB1, and the control ($p < 0.05$; Fig. 2b). Similarly, available K was significantly affected by residual biochar effects ($p < 0.05$). At 2 WAP, PB0.5 recorded the highest value, while SB and Mix treatments showed intermediate values without significant differences among them. At harvest, PB1.5 produced the highest available K, significantly exceeding all other treatments. Compared with the control, Mix1, and Mix1.5, K in PB1.5 was higher by 87.3%, 2.2%, and 43.5%, respectively ($p < 0.05$; Fig. 2c).

SOC was also significantly influenced by residual biochar application. At 2 WAP, PB1.5 recorded the highest SOC (53.6 g kg^{-1}), while at harvest PB1.5 again remained highest (59.6 g kg^{-1}), followed by PB0.5, PB1, and Mix1.5, which did not differ significantly from each other ($p < 0.05$). Relative to PB1.5, SOC was lower by 3.9–4.8% in PB0.5, Mix1.5, and PB1, and by 95.2% in the control.

Exchangeable Ca, Mg, and Na were significantly influenced by residual biochar effects at harvest ($p < 0.05$; Table 1). Ca was lowest in the control (4.15 cmol kg^{-1}), while PB1 and Mix1 recorded the highest values (9.64 and 9.63 cmol kg^{-1}, respectively). Mg was highest in PB0.5 (1.25 cmol kg^{-1}), significantly exceeding the control (0.46 cmol kg^{-1}). For Na, the highest values were observed in Mix1 (2.02 cmol kg^{-1}) and PB0.5 (1.92 cmol kg^{-1}), approximately three times higher than the control, while other biochar treatments showed intermediate but significantly higher values than the control ($p < 0.05$).

Table 1: Residual effect of biochar on exchangeable calcium (Ca), magnesium (Mg), and sodium (Na) at harvest

Treatment	Ca	Mg	Na
CK	4.15 ^{d}	0.46 ^{b}	0.76 ^{b}
SB0.5	8.02 ^{b}	1.08 ^{ab}	1.61 ^{a}
SB1	9.09 ^{a}	1.05 ^{ab}	1.63 ^{a}
SB1.5	7.75 ^{b}	0.81 ^{ab}	1.71 ^{a}
PB0.5	8.24 ^{b}	1.25 ^{a}	1.92 ^{a}
PB1	9.64 ^{a}	1.14 ^{ab}	1.55 ^{a}
PB1.5	8.23 ^{b}	1.14 ^{ab}	1.49 ^{a}
MIX0.5	5.43 ^{c}	0.76 ^{ab}	1.44 ^{a}
MIX1	9.63 ^{a}	1.09 ^{ab}	2.02 ^{a}
MIX1.5	5.01 ^{c}	0.74 ^{ab}	1.46 ^{a}

The treatment abbreviations are listed in the legend of previous figures

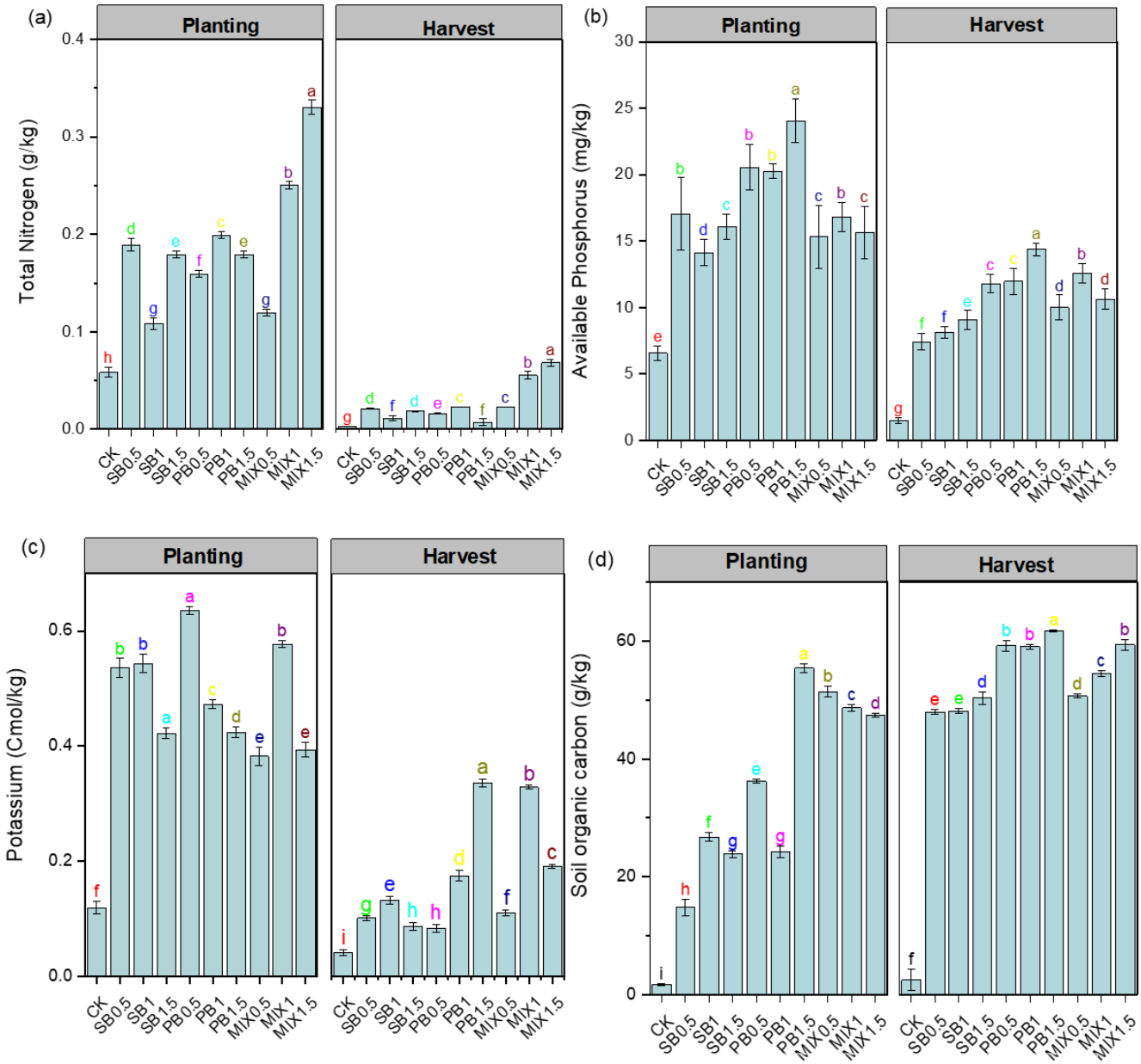


Fig. 2.: Residual effects of sawdust biochar and poultry manure biochar application on (a) Total nitrogen, (b) Available phosphorus, (c) Available potassium, and (d) Soil organic carbon content (SOC). Significant differences between treatments are indicated by different letters ($p < 0.05$, n = 4). Error bars represent standard error (SE). CK: control (no amendment); SB0.5: 0.5% (w/w) sawdust biochar; SB1: 1.0% (w/w) sawdust biochar; SB1.5: 1.5% (w/w) sawdust biochar; PB0.5: 0.5% (w/w) poultry manure biochar; PB1: 1.0% (w/w) poultry manure biochar; PB1.5: 1.5% (w/w) poultry manure biochar; Mix0.5: 50:50 mixture of sawdust and poultry manure biochar applied at 0.5% (w/w); Mix1: 50:50 mixture applied at 1.0% (w/w); Mix1.5: 50:50 mixture applied at 1.5% (w/w).

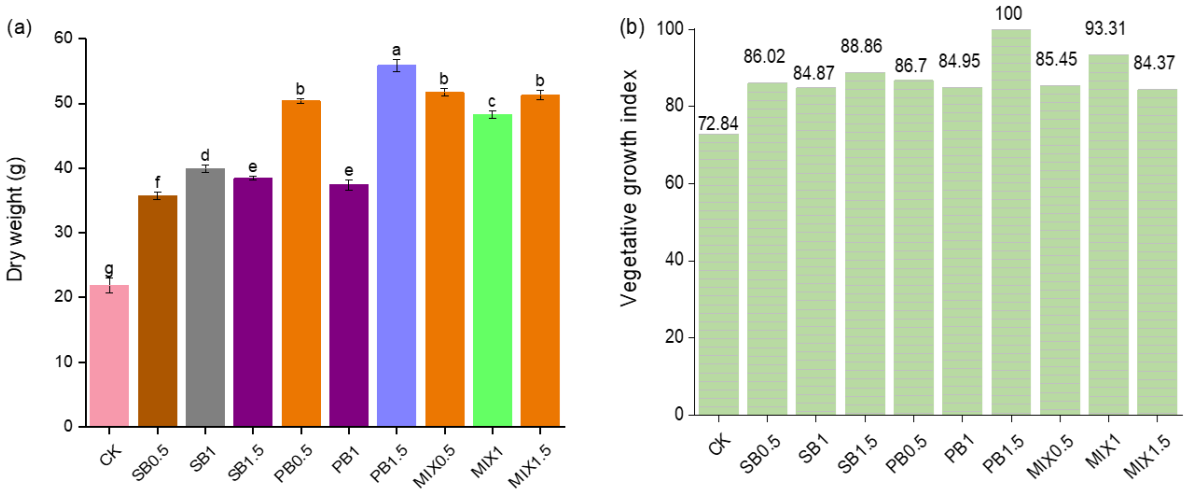


Fig. 3.: Residual effects of saw dust and poultry manure biochar applications on (a) Dry weight, and (b) Vegetative growth index of Zea *mays*. Significant differences between treatments are indicated by different letters ($p < 0.05$, n = 4). Error bars represent SE. CK: control (no amendment); SB0.5: 0.5% (w/w) sawdust biochar; SB1: 1.0% (w/w) sawdust biochar; SB1.5: 1.5% (w/w) sawdust biochar; PB0.5: 0.5% (w/w) poultry manure biochar; PB1: 1.0% (w/w) poultry manure biochar; PB1.5: 1.5% (w/w) poultry manure biochar; Mix0.5: 50:50 mixture of sawdust and poultry manure biochar applied at 0.5% (w/w); Mix1: 50:50 mixture applied at 1.0% (w/w); Mix1.5: 50:50 mixture applied at 1.5% (w/w).

4.0 Discussions

4.1 Changes in soil chemical properties under residual biochar application

Soil health, defined as the balance of biological, chemical, and physical properties that enable soil to function as a vital ecosystem, is strongly influenced by the management of organic inputs (Lehmann *et al*., 2020). Incorporation of organic amendments such as biochar or manure has been widely reported to improve soil organic matter and nutrient availability (He *et al*., 2021; Liang *et al*., 2024; Han *et al*., 2025). In this study, soil analysis revealed that residual biochar generally improved soil chemical properties compared with the control, both at planting and at harvest, demonstrating its capacity to sustain fertility under low-input conditions. Despite this overall improvement, total N, available P, and exchangeable K declined significantly and consistently across all treatments at harvest (Figure 2a–c), reflecting their intensive uptake by maize during the cropping season. In contrast, soil organic carbon (SOC) increased significantly over time (Figure 2d), a pattern attributable to carbon inputs from root exudation, rhizodeposition, and plant residue incorporation (Dijkstra *et al*., 2021; Lei *et al*., 2023). These dynamics align with earlier findings that cropping depletes macronutrients while simultaneously enhancing SOC pools when organic amendments are present (Qayyum *et al*., 2014). The capacity of residual biochar to maintain nutrient cycling and enhance carbon storage, even in the absence of fresh fertilizer or manure additions, highlights its long-term role in stabilizing soil chemical properties. Such findings extend beyond soil fertility management, as biochar-driven improvements in SOC underpin both enhanced crop productivity and broader ecosystem services, including food security and climate change mitigation through carbon sequestration (Lehmann *et al*., 2021).

Along with the control, soil TN levels were low in all treatments at planting and further diminished at harvest below the critical level of 1.5 g kg^{-1} (Agboola & Ayodele, 1985). This decline suggests that under low biochar inputs, organic N mineralization and retention were insufficient to replenish soil pools, leading to progressive depletion across planting cycles. Consequently, nitrogen emerged as the most limiting nutrient in all treatments, a trend consistent with Dempster *et al*. (2012), who observed that biochar-amended soils may still suffer from N limitation due to immobilization or enhanced microbial demand.

By contrast, available P was not a limiting factor at planting and remained adequate for plant uptake in all treatments except the control. However, phosphorus concentrations declined after harvest, with treatments SB0.5, SB1, and

SB1.5 falling below the critical level of 8.5 mg kg^{-1} (Ayodele & Agboola, 1985), indicating depletion through crop uptake during the growing period. In contrast, soils amended with poultry manure biochar maintained comparatively higher available P concentrations, likely reflecting the greater inherent phosphorus content of the feedstock. This pattern may also be associated with the ability of poultry manure biochar to increase soil pH and reduce phosphorus sorption onto Fe/Al oxides, thereby enhancing P availability over time, as reported in previous studies. Compared with the control at planting, residual biochar treatments increased available P by 135–268%, corresponding to a 2.2–3.7-fold increase. This finding is consistent with Glaser *et al*. (2019), whose meta-analysis demonstrated that biochar can act as both a short- and long-term source of phosphorus, with the magnitude of its effect depending on feedstock type, pyrolysis temperature, and application rate.

Exchangeable K also remained consistently above critical levels (K > 0.31 cmol kg^{-1}; Agboola & Ayodele, 1985), with soil analyses confirming adequate K across treatments (Jeffery & Novak *et al*., 2009). This persistence suggests that potassium supplied by the original biochar applications remained available throughout the residual cropping period and was not strongly fixed in the soil. Potassium enrichment further reflects the intrinsic K content of the biochars, which likely contributed to sustained soil fertility. Overall, these observations indicate that residual biochar, particularly at higher application rates, can maintain a pool of plant-available potassium and contribute to the long-term stability of soil fertility.

4.2 Maize Productivity Response to Residual Biochar

The enhanced vegetative growth of maize following previous biochar amendment demonstrates that biochar-induced improvements in soil function can persist beynd the initial application. The superior growth observed in soil previously amended with 1.5% (w/w) poultry manure biochar suggests that nutrient-rich biochar continue to provide favorable rhsizosphere environment even after the first cropping cycle. Poultry manure generally contains higher concentrations of plant-available nutrient, particularly nitrogen than lignocellulosic biochar like sawdust biochar. These characteristics can sustain nutrient availability over time through gradual mineralization and desorption processes while simultaneously improving soil cation exchange capacity and buffering nutrient losses (Yeboah *et al*., 2009). In contrast, soils previously amended with the 50:50 mixture of poultry manure biochar and sawdust biochar applied at 1.5% (w/w) exhibited comparatively lower vegetative growth despite receiving the same total biochar application rate. This finding suggests that the biological response to biochar is governed more by feedstock characteristics than by total application rate alone. Because only half of the applied biochar in the mixed treatment originated from poultry manure, the residual nutrient pool available for plant uptake was likely reduced relative to the sole poultry manure biochar treatment. In addition, sawdust biochar, owing to its greater carbon stability, higher aromaticity, and lower nutrient content, primarily contributes to long-term improvements in soil physical structure rather than serving as a readily available nutrient reservoir. Moderate combined biochar residues supported high vegetative growth, likely due to an optimal balance of residual nutrients, improved soil structure, and enhanced water retention (Lehmann & Joseph, 2015; Agegnehu *et al*., 2017).

The analysis of dry matter accumulation highlights an interesting pattern, where some combined biochar treatments that had slightly lower vegetative indices (eg 50:50 mix applied at 1 and 1.5%) still produced substantial dry matter. This can be attributed to the residual effect of biochar in enhancing soil nutrient retention, water-holding capacity, and cation exchange capacity, which promotes efficient assimilate allocation to structural biomass over time (Lehmann & Joseph, 2015; Agegnehu *et al*., 2017; Calys-Tagoe *et al*., 2019). These findings suggest that biomass allocation in these treatments may have favored structural dry matter accumulation rather than rapid vegetative expansion. Our results demonstrate that the residual effect of biochar application influences

maize growth in a nuanced manner. Single-source poultry biochar residues favor immediate vegetative vigor, while combined biochar residues, especially at moderate levels, optimize dry matter accumulation by sustaining nutrient availability over time. These findings highlight the importance of considering biochar legacy effects when planning biochar application strategies for crop productivity

5 Conclusion

This study demonstrates that the residual effects of biochar application significantly influenced both soil chemical properties and maize productivity. Residual poultry manure biochar, particularly at higher application rates, sustained greater nutrient availability and supported the highest vegetative growth, whereas combined applications of sawdust and poultry manure biochar enhanced dry matter accumulation, suggesting that different biochar formulations may favor distinct aspects of crop performance. Across all treatments, residual biochar improved soil organic carbon and maintained exchangeable base cations, highlighting its capacity to sustain soil fertility beyond the initial season of application. Although nitrogen remained the most limiting nutrient under the residual treatments, the overall findings indicate that biochar can provide lasting agronomic benefits and may be effectively integrated with modest supplemental nitrogen inputs to optimize crop productivity. Future research should evaluate these residual effects under field conditions across multiple cropping cycles and further investigate integrated nutrient management strategies for sustainable maize production.

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