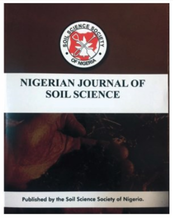
DOI: https://doi.org/10.67042/njss.2021.5prx0a5a

Odofin et al. *NJSS 31 (3) 2021 114-122*

Nigerian Journal of Soil Science

Journal homepage:www.soilsjournalnigeria.com



Effects of conservation tillage, phosphorus and variety on selected soil physical properties and cowpea productivity at Minna in Nigeria's Southern Guinea Savanna

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ARTICLE INFO

Article history:
Received June 25, 2021
Received in revised form July 28, 2021
Accepted August 29, 2021
Available online September 25, 2021

Keywords:

Cowpea,
Conservation tillage,
Phosphorus,
Soil physical properties

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njss.2021.310314
ISSN– Online **2736-1411**
Print **2736-142X**

ABSTRACT

This study was conducted to evaluate the influence of conservation tillage, inorganic phosphorus fertilizer and variety on soil physical properties and cowpea productivity at Minna in the Southern Guinea Savanna of Nigeria. Three tillage practices (zero, reduced and ridged), three phosphorus rates (0, 30 and 60 kg P_2O_5 ha^{-1}) and three cowpea varieties (IT93K-452-1, IT99K-573-1-1 and IT90K-277-2) were factorially combined and laid out in randomized complete block design with three replications. Two crops of cowpea were cultivated sequentially. Soil and crop indices used for the evaluation were soil bulk density, soil organic carbon content, mean weight diameter, soil moisture content, haulm yield and grain yield. Conservation tillage significantly affected the four soil indices while phosphorus rates significantly affected soil organic carbon content, mean weight diameter and soil moisture content. There was varietal effect on soil organic carbon content and soil moisture content. Conservation tillage methods influenced haulm yield significantly but had no significant effect on grain yield. Phosphorus application and variety, on the other hand, significantly affected both haulm and grain yields. Notably, in the early harvest, application of 60 kg P_2O_5 ha^{-1} raised haulm yield from 2,489 kg ha^{-1} (untreated control) to 5,482 kg ha^{-1}, and grain yield from 614 kg ha^{-1} (untreated control) to 1,440 kg ha^{-1}, representing 120% and 135% increments for haulm and grain yields respectively. Farmers are advised to combine either zero or reduced tillage with 60 kg P_2O_5 ha^{-1} and IT99K-573-1-1 for maximum haulm and grain yields.

1.0. Introduction

Cowpea (*Vigna unguiculata* L. Walp) plays a major role in contributing to food and nutrition security and poverty alleviation for millions of people in sub-Saharan Africa. It is a major staple food crop, especially in the dry savanna regions of West Africa (Dugje *et al.*, 2009). It is cultivated primarily for the grains, but also as a vegetable (leafy green and green pods), and a fodder and cover crop (Coker *et al.,* 2014). Nigeria is the largest producer and consumer of cowpea both in West Africa and in the world (IITA, 2011; FAO, 2012). In most parts of Nigeria, the grain, which contains 20-25% protein, is processed into bean cake, *moi-moi* and beans soup; while in the northern parts including Niger State, cowpea has been a key source of income for farmers and other players in the cowpea value chain (Coker *et al.*, 2014). Cowpea's ability to replenish soil nitrogen places it in a very important position in soil fertility management. By its inclusion in cropping systems, either by rotation or intercropping, associated crops benefit from cowpea's nitrogen fixing ability, thereby reducing their nitrogen fertilizer requirement (Osunde, 2015). According to Bala (2015), the crop's uses are majorly in three key areas, namely as food, as animal feed and soil fertility improver. However, the benefits of cowpea are not yet being exploited to the fullest. Grain yields of cowpea in Nigeria are low, the average being 687 kg ha^{-1} (Coker *et al.*, 2014); but with the use of improved technologies, grain yields of 1,500-2,00 kg ha^{-1} can be obtained from sole cropping (Musa *et al.*, 2010). Cowpea farmers who adopted improved cowpea varieties and better soil management practices reported higher fodder and grain yields that translated to an average of 55% rise in their income (IITA, 2011).

Soil erosion by water and wind is generally considered worldwide as the most serious among the various forms of soil degradation because it is the most widespread and least reversible. In the light of this, it was not surprising that in the United Nations Report of 1984, soil erosion was rated to be among the leading threats to mankind (Huypers *et al.*, 1994). The major farm practice that causes soil erosion is tillage, the process of preparing a field for seeding which renders the soil bare and unprotected. But if the soil can be kept covered by adopting conservation agriculture and eliminating or minimizing tillage, erosion can be prevented or reduced to the barest minimum. In a four-year experiment, average annual soil loss was 6 and 4748 lbs acre^{-1} from no-till and mouldboard-till plots respectively (CTIC, 2002). According to FAO (2014), conservation agriculture is an approach to managing agro-ecosystems for improved and sustained productivity, increased profits and food security while preserving and enhancing the resource base and the environment. It offers an opportunity to reverse land degradation that prevails in many parts of sub-Saharan Africa due to its positive effects on enhancement of physical, biological and chemical properties of soil when compared to conventional tillage practices. Smallholder farmers who have adopted conservation tillage methods cite the reduction in labour inputs and drudgery as major drivers for adoption (Andersson and D'Souza, 2014).

By 2015/16, conservation agriculture was practiced on approximately 180 M ha globally, representing 12.5% of total global cropland (Kassam *et al.*, 2018). The top five conservation agriculture countries are USA (43.2 M ha), Brazil (32 M ha), Argentina (31 M ha), Australia (22.3 M ha) and Canada (19.9 M ha). Since 2008/2009, the rate of expansion of conservation agriculture has been about 10.5 M ha annually. However, in Africa, practitioners are few and far apart, with eastern and southern Africa, and North Africa setting the pace. In Nigeria, area under conservation agriculture is negligible and this rapidly spreading agricultural production system is not being promoted in any part of the country by government or other organizations. Conservation agriculture is also grossly under-researched in Nigeria as only few studies have been carried out, e.g. by Lal (1991), Ojeniyi (1993) and Odofin *et al.* (2011).

Phosphorus is critical to cowpea yield because it stimulates root and shoot growth, initiates nodule formation, and influences the efficiency of cowpea-rhizobium symbiosis (Ndor *et al.*, 2012). Conversely, phosphorus deficiency stunts vegetative growth, nodule formation and nodule functionality. Symbiotic nitrogen fixation has a higher phosphorus requirement for maximum activity than growth supported by nitrate assimilation because of high energy requirement for the reduction of atmospheric nitrogen by nitrogenase system (Rotaru and Sinclair, 2009). In the tropics, the amount of available phosphorus in soils is largely insufficient to meet the demand of legumes and phosphorus deficiency is hence widespread in pulse crops (Tarawali *et al.* 2002; Singh *et al.*, 2011). But despite the need to apply phosphorus fertilizer for cowpea yield improvement, Nigerian farmers rarely do. This study was therefore carried out to quantify the effects of conservation agriculture, phosphorus fertilizer and cowpea varieties on soil physical properties and cowpea performance at Minna in the southern Guinea savanna of Nigeria.

2.0. Materials and Methods

2.1. Site location and characteristics

The study was conducted on the Teaching and Research Farm of Federal University of Technology, Minna (latitude 9^{o} 31′ 04.5″ N, longitude 6^{o} 26′ 48.4″ E, altitude 207.0 m above sea level). Minna is in the Southern Guinea Savanna vegetation zone of Nigeria and the climate is subhumid tropical with mean annual rainfall of 1,284 mm and a distinct dry season of about five months from November to March (Ojanuga, 2006). The mean maximum temperature is about 32^{0}C, with the hottest period being March to June. The site had been left uncultivated for two years prior to the year of this study.

2.2. Soil properties

The soil of the experimental site is an Alfisol classified by Lawal *et al.* (2012) as Typic Plinthustalf (USDA) or Plinthic Lixisol FAO/UNESCO). The surface soil (0-20 cm depth) has sandy loam texture, pH (H_2O) of 6.6 (neutral), very low levels of calcium (1.70 cmol kg^{-1}), potassium (0.19 cmol kg^{-1}) and effective cation exchange capacity (3.78 cmol kg^{-1}), low levels of organic carbon (4.08 g kg^{-1}), available phosphorus (6.0 mg kg^{-1}) and magnesium 0.64 cmol kg^{-1}, and high level of total nitrogen (2.80 g kg^{-1}) ((Esu, 1991; Chude *et al.*, 2012).

2.3. Treatments and experimental design

In this study, three tillage practices (zero, reduced and ridged), three levels of phosphorus (0, 30 and 60 kg P_2O_5 ha^{-1}) and three cowpea varieties (IT93K- 452-1, IT99K-573-1-1 and IT90K-277-2) were evaluated. The experimental design was 3x3x3 factorial in randomized complete block design (RCBD) with three replicates, giving rise to totals of 27 treatment combinations and 81 plots. Plot size was 4 m x 3 m and plots were separated by 0.5 and 1 m intervals within and between replicates respectively.

For zero and reduced tillage practices, growing weeds were killed with paraquat two days before planting, and the chemically killed weeds along with surviving weed residue from the previous season were preserved as soil cover. The zero tillage plots were not subjected to any mechanical soil disturbance apart from the digging of shallow holes for seed placement during sowing. On the reduced tillage plots, the planting lines were ripped with a hoe to a depth of 15-20 cm and a width of 15 cm, without destroying the soil cover on the interrow spaces. The ridged tillage plots were ridged with a bigger hoe, burying the soil cover in the process. The three levels of phosphorus were applied in form of single superphosphate in combination with a uniform dose of 20 kg N ha^{-1} in form of urea, two weeks after sowing at 5 cm depth and 5 cm away from the stands and covered with soil immediately after application. Two crops of cowpea were cultivated sequentially. The characteristics of the three white-seeded cowpea varieties evaluated in this study are briefly described below (Ajeigbe *et al.*, 2010; Ewansiha *et al.*, 2015):

IT93K-452-1

Extra-early maturity (60-69 days), erect growth habit, medium sized seeds, some level of resistance to insects and diseases, high fodder yield, high grain yield of 1500 kg ha^{-1}, good for double cropping.

IT99K-573-1-1

Early maturity (70-79 days), semi-erect growth habit, resistance to wilt disease and parasitic weeds, especially *Striga* and *Alectra*, high fodder and grain yields.

IT90K-277-2

Medium maturity (75-80 days), medium sized seeds, some level of resistance to insect pests and diseases, high fodder yield, high grain yield of 1500 – 2000 kg ha^{-1}.

2.4. Cultural practices

Three seeds were planted per hill at a spacing of 50 cm between rows and 20 cm within rows and thinned to two plants per hill two weeks later. Early planting was done on 2nd July, 2018 while late planting was done on 6th October, 2018. The plots were weeded using hand hoe. During the vegetative, flowering and pod-filling stages, an insecticide, lambda cyhalothrin + dimethoate, was applied as foliar spray as soon as insects were noticed.

2.5. Soil and crop parameters

2.5.1. Soil bulk density

Dry bulk density of the soil was determined using the core method (Blake and Hartage, 1986), involving the use of stainless steel core rings with dimensions of 5 cm diameter and 5 cm length. During harvest, triplicate soil cores were collected per plot from three intra-row mini-pits at 10 cm depth to represent 0-20 cm surface soil layer. The soil within each core was trimmed to the exact volume of the cylinder, extruded into a moisture can and oven-dried at 105^0C for 48 hours. Dry bulk density was determined as the ratio of mass of dry soil per unit volume of soil core, using the following formula:

$$\rho_b = Ms / Vb$$

where ρ_b is soil bulk density (g cm^{-3}), Ms is mass of oven-dried soil (g), and Vb is bulk volume of the soil (cm^3)

2.5.2. Soil organic carbon

Soil samples were taken from three points within inner crop rows and bulked to obtain a composite sample per plot. The composite samples were air-dried, gently crushed and passed through 0.5 mm sieve for organic carbon determination using Walkley-Black wet oxidation method which involved soil organic matter oxidation with potassium dichromate ($K_2Cr_2O_7{}^{)}$ and sulphuric acid (H_2SO_4) (Udo *et al.*, 2009).

2.5.3. Mean weight diameter

Mean weight diameter was determined by the wet-sieving method (Kemper and Rosenau, 1986). Three soil samples per plot were taken from inner crop rows, bulked, air-dried and passed through an 8 mm sieve. Thereafter, 50 g of each composite sample was put in the topmost of a nest of five sieves of 5.00, 2.00, 1.18, 0.50 and 0.25 mm sizes arranged on a sieve shaker in descending order i.e. sieve with the biggest opening size was kept on top and the sieve with the smallest opening size was kept at the bottom. The nest of sieves was slowly immersed in water and oscillated for 10 minutes at the rate of 1 oscillation per second. The soil was transferred from various sieves into moisture cans and oven-dried at 105^oC for 48 hours before weighing. Mean weight diameter was then calculated using the equation below:

$$MWD = \sum_{i=1}^{n} Xi.Wi$$

where MWD is mean weight diameter, Xi is the mean diameter of each aggregate size fraction, Wi is the proportion of the total sample weight occurring in the corresponding size fraction, where the summation is carried out over all n size fractions.

2.5.4. Soil moisture content

Soil moisture content was measured three times during the reproductive stage at 50% flowering, pod filling and full maturity. Triplicate soil samples were taken between crop stands from each plot for the surface soil layer (0 – 20 cm depth) with an auger. The samples were transferred into moisture cans with tight-fitting lids and transported to the laboratory for oven drying at a temperature of 105^0C for 48 hours. Soil moisture content was initially calculated on gravimetric basis using the equation below:

$$\omega = Mw/Ms$$

where ω is gravimetric water content (g g^{-1}), Mw is the mass of wet soil (g), Ms is the mass of oven-dried soil(g). Gravimetric water content was subsequently converted to volumetric basis using the following equation:

$$\theta = \omega.\rho b$$

where θ is volumetric water content (cm^3 cm^{-3}), and ρb is dry bulk density (g cm^{-3}).

2.5.5. Grain and haulm yields

The grains harvested from a net plot of 7.5 m^2 were weighed and the weight was converted to kg ha^{-1}. Haulm from the net plot was rolled up and sun-dried to a constant weight. The dry haulm was weighed and the weight was converted to kg ha^{-1}.

2.6. Statistical analysis

Data collected were subjected to analysis of variance (ANOVA) at 5% level of significance using SAS software version 9.1 (SAS, 2003) and mean values were separated using Duncan's Multiple Range Test (DMRT) also at 5% level of significance.

3.0. Results and discussion

3.1. Soil bulk density

Soil bulk density of the plots ranged from 1.38 to 1.47 g cm^{-3} and was significantly affected ($p \leq 0.05$) by tillage (Table 1). For both cropping periods, bulk density was significantly lower ($p \leq 0.05$) in ridged plots than in both zero and reduced tillage plots but there was no significant difference ($p > 0.05$) between the two conservation tillage methods. Phosphorus application and cowpea varieties had no significant effect ($p > 0.05$) on bulk density in both early and late crops. Zero tillage recorded the highest bulk density of 1.47 g cm^{-3} in this study and this is below the range of 1.55 to 1.75 g cm^{-3} which can significantly hinder root growth and affect cowpea haulm and grain yields in sandy loam soils (Ojo *et al.*, 2018). The lower bulk density observed in ridged plots was due to the physical loosening of the soil. The burial of surface residues and weeds during ridging might have further reduced the bulk density (Brady and Weil, 1999).

3.2. Soil organic carbon

Tillage significantly altered ($p \leq 0.05$) soil organic carbon content in both cropping periods (Table 1). There were significant differences ($p \leq 0.05$) between the three tillage methods in the early crop, with zero tillage and ridged tillage recording the highest (4.48 g kg^{-1}) and the lowest (3.57 g kg^{-1}) soil organic carbon content respectively. In the late crop, manual ridging again recorded the lowest soil organic carbon content while the two conservation tillage methods were at par ($p > 0.05$). Phosphorus application significantly affected soil organic carbon content, with the three levels of application having significantly different ($p \leq 0.05$) values in this order: 60 kg > 30 kg > 0 kg P_2O_5 ha^{-1}, for both cropping periods. Varietal effect on soil organic carbon content was not significant ($p > 0.05$) in the late crop, but in the early crop, plots grown to IT93K-452-1 stored significantly less ($p \leq 0.05$) soil organic carbon than plots grown to the other two varieties. Tillage x phosphorus interaction was significant ($p \leq 0.05$) in the early cropping period (Table 1). The combination of zero tillage and 60 kg P_2O_5 ha^{-1} recorded the highest soil organic carbon content while the combination of ridged tillage and zero phosphorus application recorded the lowest (Table 2). The results suggest superiority of (i) zero tillage and reduced tillage over ridged tillage (ii) phosphorus application at 60 and 30 kg ha^{-1} over zero application (iii) IT90K-277-2 and IT99K-573-1-1 over IT93K-452-1, in terms of boosting soil organic carbon content.

In line with our finding, Marcela and Nicholas (2013) had earlier reported higher soil organic carbon content in no-tillage plots compared with conventional tillage. Soil tillage is widely considered to be a major reason for the loss of soil organic matter. The lower soil organic carbon content observed in ridged plots compared with conservation tillage plots could be attributed to faster oxidation of organic matter in ridged plots due to increased soil aeration and higher soil temperature (Mansor *et al.*, 2014). The ridged plots might have also lost more organic matter by soil erosion. Furthermore, the burial of plant residues and weeds by ridging directly exposed the organic materials to putrefying soil bacteria, leading to faster decomposition compared with residues left on conservation tillage plots (Abiven and Recous, 2007). The higher content of soil organic carbon associated with phosphorus application might be because phosphorus enhanced root and shoot biomass production which in turn increased the addition of biomass to the soil. Varietal effect on soil organic carbon could likewise be attributed to differences in the amounts of biomass produced by the varieties.

3.3. Mean weight diameter

Mean weight diameter was significantly influenced ($p \leq 0.05$) by tillage (Table 1). The three tillage methods had significantly different ($p \leq 0.05$) mean weight diameter, with zero tillage having the highest value and ridged tillage the lowest, at the end of both cropping periods. Mean weight diameter responded to phosphorus as it responded to tillage. The three phosphorus levels recorded significantly different ($p \leq 0.05$) mean weight diameter, with 60 kg P_2O_5 ha^{-1} having the highest value and untreated plots having the lowest, at the end of both cropping periods. Variety did not have any significant effect ($p > 0.05$) on mean weight diameter.

The tillage x phosphorus interaction table (Table 3) shows that zero tillage plus 60 kg P_2O_5 ha^{-1} recorded the highest mean weight diameter, followed by zero tillage plus 30 kg P_2O_5 ha^{-1} while ridged tillage plus no phosphorus application recorded the lowest mean weight diameter at the end of both cropping periods. For the late cropping period, however, although ridged tillage plus no phosphorus recorded the lowest mean weight diameter, the value was statistically at par ($p > 0.05$) with the values for ridged tillage plus 60 and 30 kg P_2O_5 ha^{-1}. Zero tillage plus 60 kg and 30 kg P_2O_5 ha^{-1} as well as reduced tillage plus 60 kg and 30 kg P_2O_5 ha^{-1} recorded significantly higher ($p \leq 0.05$) mean weight diameter than ridged tillage plus 60 kg and 30 kg P_2O_5 ha^{-1} in both cropping periods. It was also observed that zero tillage at all levels of phosphorus recorded significantly higher ($p \leq 0.05$) mean weight diameter than ridged tillage at all levels of phosphorus in the late cropping period. These interactions suggest that, even though both tillage and phosphorus influenced mean weight diameter, tillage effect was stronger.

The lowering of mean weight diameter by manual ridging could be attributed to its direct physical effect on the topsoil which led to the breakdown of soil aggregates. Further reduction of aggregate stability might be attributed to lower soil organic carbon content in the ridged plots due to faster oxidation of organic matter (soil binding agent). Improvement of aggregate stability in plots treated with phosphorus could be attributed to the ability of phosphorus to enhance root and shoot biomass production thereby increasing soil organic matter content which in turn improved aggregate stability (Nweke and Nnabude, 2015). Mean weight diameter is a measure of macro-aggregate stability and larger mean weight diameter indicates higher proportion of macro-aggregates (Ezema *et al.*, 2018). Soil aggregation and stability of aggregates are regarded as major factors influencing soil quality and resistance to water erosion (Udom and Ogunwole, 2015). Soil water movement and retention, crusting and aeration are all influenced by aggregation (Ogunwole *et al.* 2010). Soil organic matter contributes to the stability of soil aggregates through binding or adhesion properties of organic materials, such as bacterial waste products, organic gels, fungal hyphae and worm secretions and casts (Bot and Benites, 2005).

3.4. Soil moisture content

Soil moisture content differed significantly ($p \leq 0.05$) among the three tillage methods in the following order: zero > reduced > ridged tillage in both cropping periods (Table 1). Soil moisture content increased significantly ($p \leq 0.05$) with each increment of phosphorus in both cropping periods. Plots of IT99K-573-1-1 recorded the highest soil moisture content while plots of IT93K-452-1 recorded the lowest in both cropping periods, with significant differences ($p \leq 0.05$).

Differences in soil moisture content under different tillage methods might be attributed to differences in soil organic carbon content. Secondly, the ridges might have lost more water by gravity because of their height above the level of the flat zero and reduced tillage plots. Thirdly, the ridges, by virtue of their configuration, exposed more surface area to soil evaporation.

In this study, soil moisture content followed the same trend as soil organic carbon content. The relationship between soil moisture content and soil organic carbon content is widely recognized. Certain types of soil organic matter can hold up to twenty times their weight in water and each 1% increase in soil organic matter could raise available water holding capacity of soil by up to 3.7% (Bot and Benites, 2005). Rawls *et al.* (2003) found out that at low organic carbon contents, additional organic materials led to increase of water retention in sandy soils, and to a decrease in fine-textured soils. At high organic carbon level, however, all soils respond to additional organic materials but the largest increase in water retention was in sandy and silty soils. The hydrophilic property of soil organic matter is due to the high specific surface area of colloidal organic particles and their charged surfaces which attract polar (partially charged) water molecules, so that a film or layer of water molecules adheres to each particle (Brady and Weil, 1999).

The higher soil moisture content of plots treated with phosphorus could be due to improved biomass production, which increased soil organic matter and consequently increased soil moisture content. The lowest soil moisture content observed in IT93K-452-1 plots could be due to increased soil evaporation as a result of the variety's erect growth habit which provided less protection from the evaporative heat of the sun.

3.5. Haulm yield

For the early crop, the three tillage methods produced significantly different ($p \leq 0.05$) haulm yields with the trend as follows: zero tillage > reduced tillage > ridged tillage (Table 4). Zero tillage increased haulm yield from 4,165 kg ha^{-1} (ridged tillage) to 4,446 kg ha^{-1}. Haulm yields of the late crop, on the other hand, were much lower in comparison with the early crop, with zero tillage (1,089 kg ha^{-1}) and reduced tillage (1,064 kg ha^{-1}) performing significantly better ($p \leq 0.05$) than ridged tillage (985 kg ha^{-1}). Haulm yields increased significantly ($p \leq 0.05$) with each incremental level of phosphorus in both harvests. In the early harvest, application of 60 kg P_2O_5 ha^{-1} raised haulm yield from 2,489 kg ha^{-1} for untreated control to 5,482 kg ha^{-1}, representing a quantum 120% increment. In the late harvest, 60 kg P_2O_5 ha^{-1} produced 1140 kg ha^{-1} of haulm while untreated plots produced 943 kg ha^{-1}, an increment of 21%. The three varieties differed significantly ($p \leq 0.05$) in haulm yield from the first harvest. IT90K-277-2 produced the highest yield (4,980 kg ha^{-1}) while IT93K-452-1 produced the lowest (3,508 kg ha^{-1}). For the second harvest, IT93K-452-1 again produced the lowest haulm yield (989 kg ha^{-1}) while IT90K-277-2 and IT99-573-1-1 with yields of 1076 and 1073 kg ha^{-1} respectively were statistically at par.

Effect of variety x phosphorus interaction on haulm yield was significant ($p \leq 0.05$) in the early cropping period (Table 4). IT90K-277-2 plus 60 kg P_2O_5 ha^{-1} produced the highest yield while IT93K-452-1 plus zero phosphorus produced the lowest yield (Table 5). IT90K-277-2 plus 60 kg and 30 kg P_2O_5 ha^{-1} produced significantly more haulm than IT99K-573-1-1 plus 60 kg and 30 kg P_2O_5 ha^{-1} which in turn produced significantly more haulm than IT93K-452 -1 plus 60 kg and 30 kg P_2O_5 ha$_{-1}$. The lowest haulm yields were produced by unfertilized plots irrespective of variety.

The results clearly indicate the necessity for phosphorus application in order to maximize haulm yield. The results also clearly rank the varieties in terms of haulm yield in this order: IT90K-277-1 > IT99K-573-1-1 > IT93K-452-1. The production of more haulm from zero and reduced tillage plots than ridged plots in this study agreed with the finding of Ewansiha *et al.* (2015) in the savanna agroecology of Northern Nigeria. Our finding also corroborated the finding of Vanlauwe *et al.* (2014) who reported significant response of haulm yield to phosphorus application.

3.6. Grain yield

Reduced tillage and zero tillage performed better than ridged tillage in terms of grain yield in both harvests but the yield advantage was not statistically significant ($p > 0.05$) (Table 4). Grain yields increased significantly ($p \leq 0.05$) as phosphorus level increased across both cropping periods. For the early crop, grain yield increased from 614 kg ha^{-1} for zero phosphorus application to 1,440 kg ha^{-1} for 60 kg P_2O_5 ha^{-1}, a whopping increment of 135%. For the late crop, 60 kg P_2O_5 ha^{-1} increased grain yield by as much as 104% from 379 kg ha^{-1} for unfertilized plots to 776 kg ha^{-1}. In terms of varietal effect, grain yields were in the following order: IT99K-573-1-1 > IT93K-452-1 > IT90K-277-2 for both harvests. For the second harvest, however, the yield advantage of IT93K-452-1 over IT90K-277-2 was not statistically significant ($p > 0.05$). Effect of variety x phosphorus interaction on grain yield was significant ($p \leq 0.05$) for both harvests (Table 6). IT99K-573-1-1 plus 60 kg P_2O_5 ha^{-1} out-yielded all other treatment combinations and the lowest yields were produced by unfertilized plots regardless of variety. In the first harvest, IT99K-573-1-1 out-yielded the other two varieties at each of the three levels of phosphorus application.

Our finding is consistent with that of Kihara *et al.* (2011) who observed similar grain yields from soybean cultivated under reduced and conventional tillage. They concluded that soybean production was better done under reduced tillage due to additional environmental benefits, such as greater biodiversity, better soil structure and reduced erosion. The grain yield advantage of conservation tillage methods over ridged tillage in this study, though insignificant, is quite noteworthy in view of the widely reported lower yield of cereal crops under conservation agriculture compared with tillage agriculture in the initial years of adoption (Baudron *et al.* 2015; Kassam *et al.*, 2015). The major reason for the initial yield advantage of tillage agriculture over conservation agriculture is that the latter causes nitrogen deficiency as a result of slower nitrogen release from the mineralization of soil organic matter (Giller *et al.* 1997). The nitrogen deficiency is exacerbated by the retention of dead plant materials with a wide carbon/nitrogen ratio (such as cereal residues) which leads to temporary nitrogen immobilization, even though retained as surface mulch and not incorporated in the soil (Abiven and Recous, 2007). This conservation tillage-induced nitrogen deficiency would, however, be expected to have less effect on nitrogen-fixing pulse crops than cereal crops. Perhaps all that is needed for conservation tillage to produce significantly more grain yield than manual or tractorized ridging in the early years is to apply higher dose of starter nitrogen to cowpea cultivated under conservation tillage, in line with the suggestion of Kassam *et al.* (2015) for cereal crops.

Significant responses of cowpea grain yield to phosphorus application were observed in soils with low available phosphorus in many studies. Our finding agreed with that of Singh *et al.* (2011) who observed the highest cowpea grain yield at 60 kg P_2O_5 ha^{-1}. Based on their research findings, Haruna and Usman (2013) recommended 30 kg P_2O_5 ha^{-1} for cowpea while Uzoma *et al.* (2006) recommended 20 to 40 kg P_2O_5 ha^{-1} and Nkaa *et al.* (2014) recommended 40 kg P_2O_5 ha^{-1}. The variation in responses might be partly due to variation in the level of native phosphorus in the soils (Asuming-Brempong *et al.* (2013). The high cost and scarcity of chemical inorganic fertilizers in Africa, however, constitute major hindrances to phosphorus application, especially among smallholder farmers.

The amount of atmospheric nitrogen that legume crops are able to fix determines their yields and is influenced by variety and soil environment. The degree of colonization by soil rhizobia are affected by the physical, chemical and biological properties of the soil which can be altered by cultural properties such as tillage and fertilizer (Gossa and de Varenness, 2002; Mabood *et al*., 2006). Zhang *et al.* (2012) stated that rhizobia population was higher in zero tillage plots compared to tilled plots. Ferreira *et al.* (2000) observed that zero tillage plots fixed more atmospheric nitrogen than tilled plots. According to Ferreira *et al.* (2000) and Zhang *et al.* (2012), the little or no soil disturbance under zero tillage protected soil organic matter from accelerated decomposition and promoted rhizobial activities.

Phosphorus is very important to cowpea, especially for nodulation. PPI (1999) and Asuming-Brempong *et al.* (2013) reported that phosphorus application increased the number and size of nodules while Amba *et al.* (2013) and similarly Ayodele and Oso (2014) reported that phosphorus fertilizer increased nodule dry weight. Varietal differences could be due to differences in genetic constitution regarding ability to fix atmospheric nitrogen. In addition, varietal differences could be attributed to the number of days required to attain maturity (Yusuf *et al.*, 2008). Higher amount of fixed nitrogen were found in longer duration genotypes by Sanginga *et al.* (2002). It could therefore be inferred that IT93K-452-1 produced significantly less haulm and grain yields than IT99K-573-1-1 because of its short duration which adversely affected the amount of nitrogen fixed, and ultimately its haulm and grain yields.

Table 1: Interaction effect of tillage and phosphorus on soil organic carbon (g kg-1) at the end of the early cropping period

	Phosphorus **(kg P_2O_5 ha^{-1})**		
Tillage methods	0	30	60
Zero	3.34^{d}	4.64^{b}	5.47^{a}
Reduced	3.47^{cd}	$4.11b^{cd}$	4.47^{b}
Ridged	2.39^{e}	4.14^{bc}	4.19^{bc}
SE±	0.21		

Means with the same alphabet are not significantly different (p>0.05).

Table 2: Interaction effect of tillage and phosphorus on mean weight diameter (mm)

	Phosphorus **(kg P_2O_5 ha^{-1})**		
Tillage methods	0	30	60
Early crop			
Zero	0.39de	0.46b	0.54a
Reduced	0.36f	0.40cd	0.42c
Ridged	0.33g	0.37ef	0.37ef
SE±	0.01		
Late crop			
Zero	0.41c	0.44b	0.48a
Reduced	0.38de	0.41c	0.40cd
Ridged	0.34f	0.36ef	0.36ef
SE±	0.01		

Means with the same alphabet are not significantly different (p>0.05).

4.0. Conclusions and recommendations

Conservation tillage practices significantly affected soil bulk density and improved soil organic carbon content, mean weight diameter, soil moisture content and haulm yield in comparison with manual ridging. Phosphorus application brought about quantum improvement in haulm and grain yields regardless of tillage method or variety, thereby highlighting the necessity for phosphorus application to cowpea. IT99K-573-1-1 which ranked first in terms of grain yield and ranked second in terms of haulm yield is the best selection. The early crop performed much better than the late crop because of more favourable amount and distribution of rainfall during the early cropping period. Conservation tillage methods are recommended to farmers for the production of cowpea as they produced better haulm yield than ridged tillage. In addition, they produced comparable grain yield with ridged tillage without showing the typical crop yield reduction in the initial years of conservation tillage adoption, as widely reported for cereal crops. Application of 60 kg P_2O_5 ha^{-1} and cultivation of IT99K-573-1-1 are also recommended to farmers for good haulm and grain yields.

Acknowledgement

The authors deeply appreciate N2Africa / International Insti-

Table 3: Main effects and interactions of tillage, phosphorus and variety on haulm and grain yields

Factor levels/ interactions	**Haulm yield (kg ha^{-1})**	**Grain yield (kg ha^{-1})**	**Haulm yield (kg ha^{-1})**	**Grain yield (kg ha^{-1})**
Tillage (T)	Early crop		Late crop	
Zero	4446.02a	1067.18	1089.34a	591.63
Reduced	4347.19b	1094.67	1063.53a	614.03
Manual ridging	4164.99c	1047.70	984.84b	568.83
SE±	289.00	79.16	20.74	38.20
Phosphorus (P) (kg P_2O_5 ha^{-1})				
0	2488.82c	613.82c	943.48c	379.30c
30	4987.65b	1155.67b	1054.81b	619.66b
60	5481.73a	1440.06a	1139.52a	775.54a
SE±	126.16	41.12	15.96	20.12
Variety (V)				
IT93K-452-1	3508.41c	970.80b	988.99b	564.50b
IT99K-573-1-1	4470.01b	1327.48a	1072.87a	689.44a
IT90K-277-2	4979.78a	911.27c	1075.94a	520.55b
SE±	261.83	69.52	20.96	35.50
Interactions				
T x P	NS	NS	NS	NS
V x P	*	*	NS	*
T x V	NS	NS	NS	NS
T x V x P	NS	NS	NS	NS

* = Significant at $P \leq 0.05$, NS = Not significant, Means of a factor in a column with the same alphabet are not significantly different ($P > 0.05$).

Table 4: Interaction effect of variety and phosphorus on haulm yield (kg ha-1) from the early crop

	Phosphorus (kg P_2O_5 ha^{-1})		
Varieties	0	30	60
IT93K-452-1	2,091.9i	3,719.4f	4,713.9e
IT99K573-1-1	2,472.6h	5,371.5d	5,565.9c
IT90K-277-2	2,901.9g	5,872.0b	6,165.4a
SE±	59.7		

Means with the same alphabet are not significantly different (p>0.05).

Table 5: Interaction effect of variety and phosphorus on grain yield (kg ha-1) from early and late crops

	Phosphorus (kg P_2O_5 ha^{-1})		
	0	30	60
Early crop			
IT93K-452-1	585.5f	1,086.7d	1,240.2c
IT99K-573-1-1	765.4e	1,412.0b	1,805.0a
IT90K-277-2	490.6f	968.3d	1,274.9c
SE±	29.3		
Late crop			
IT93K-452-1	356.2e	604.7cd	732.7b
IT99K-573-1-1	446.6e	689.6bc	932.1a
IT90K-277-2	335.13e	564.7d	661.8bcd
SE±	25.4		

Means with the same alphabet are not significantly different (p>0.05).

tute of Tropical Agriculture (IITA) for funding this study.

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