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Influence of Tillage-Seedbed and Manure-NPK-Micronutrient Management Options on Selected Soil Properties of Sandy-Loam Ultisols Evaluated using Sweet Potato

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ABSTRACT

This study assessed the effects of tillage and nutrient management practices on selected soil properties of degraded coarse-textured Ultisols and responses of sweet potato in Nsukka, southeastern Nigeria. It involved three tillage-seedbed types viz zero-tilled flatbed (ZT-FB), conventionally tilled-flatbed (CT-FB) and conventionally tilled tie-ridge (CT-TR), each with seven soil fertilizer amendments. They were sole application of poultry droppings at 20 t ha^{-1} (PD_{20}) and NPK 15:15:15 at 400 kg ha^{-1} ($NPK_{0.40}$) as well as their complementary use (PD_{10}+$NPK_{0.20}$), each with and without Agrolyzer fertilizer for micronutrients at 2 kg ha^{-1} (AGF), also including a no-amendment control. The study was thus laid out as a 3 × 7 split-plot in a randomized complete block. Soil sampling was done at the initial stage and at the harvest of sweet potato. Results showed that tillage significantly improved soil total porosity, soil pH and available phosphorus (AvP), with CT-TR having the highest porosity (50.81%). Soil pH (6.4) and AvP (80.88 mg kg^{-1}) were, however, highest in ZT-FB. As regards the soil amendments, the least improvements in soil properties occurred in the control. It not only showed the highest soil bulk density (1.47 g cm^{-3}) and hence the lowest total porosity (34.15%), but also the lowest soil pH (5.9), and AvP (13.1 mg kg^{-1}). The tillage type CT-TR improved the growth and tuber yield parameters of sweet potato, while PD_{10}+$NPK_{0.20}$ with and without AGF improved soil properties and tuber yield parameters, respectively. Overall, the treatment CT-TR with PD_{10}+$NPK_{0.20}$+AGF improved most soil properties better than the other treatments and also gave the best tuber yield of sweet potato.

1.0 Introduction

The agricultural soils of Nigeria are under enormous pressure to provide food and fiber for our ever-increasing population. Most of these soils are low in soil organic matter, macro and micronutrients (Adeyemo *et al*., 2019). These soils are fragile and suffer continuous degradation due to over-exploitation for crop production and imbalance in source and sink of carbon and plant nutrients. Soil fertility often changes in response to land use, cropping system, and land management practices (Jahiruddin and Satter, 2010; Khairul, 2014). Intensive cropping of these soils without adequate nutrient replenishment has resulted in further loss of soil organic matter with subsequent declines in nutrient and water holding capacity and soil macrostructure, leading to low crop yields (Gichuru *et al*., 2003). Aluminum toxicity and calcium, magnesium, and phosphorus deficiencies are common in these soils, limiting the growth and yield of crops grown on them especially tuber crops such as sweet potato (Ila'Ava *et al*., 2000). Since Agriculture is the primary economic activity in Nigeria and sub-Saharan Africa, declining soil productivity means reducing food and cash crops and associated income.

Any efforts toward enhancing the productivity of degraded Nigeria soils would involve soil and water conservation to improve soil-water relations and nutrient cycling for enhanced crop yields. Conservation agriculture is generally considered as the package of choice because it entails appropriate tillage and nutrient management combinations with residue application. This farming system could help to achieve farm household food security and facilitate agricultural development in Nigeria. Inappropriate tillage ruins the soil structure and hence porosity, water and aeration management of the soil, and soil fertility can also decline (Birkás *et al.*, 2009; Spoljar *et al*., 2011). Nyakatawa *et al.* (2001) suggest that, with appropriate tillage systems, it is possible to increase crop yields on physically degraded soils by using organic manure to improve soil fertility. Appropriate soil tillage can, therefore, be a suitable alternative to enhance nutrient availability to crop and reduce money spent on chemical fertilizers (Adekiya and Ojeniyi, 2002). The importance of no-till in soil and water conservation, growth, and crop yields in Nigeria has been reported (Agbede, 2008; Agbede and Ojeniyi, 2009; Obalum *et al*., 2011a). For large-scale production of crops especially root and tuber crops, the use of mechanized tillage is inevitable.

Soil tillage aims at creating an environment favourable to seedling emergence and propagule survival. When tillage involves loosening the soil, it aids the incorporation of crop residues, mineral fertilizers, and green manures into the soil. This tillage method corresponds to conventional tillage in Nigeria. Conventional tillage also increases soil aeration thereby contributing to the decomposition of organic matter, nitrification and weed control (Nicou and Charreau, 1980; Licht and Al-Kaisi, 2005; Anikwe and Ubochi, 2007). However, the effect of soil tillage can differ for the same location depending on the crop and magnitude of tillage (Obalum and Obi, 2010). Because agronomic management decisions influence resource use efficiency and hence crop productivity (Tittonell *et al*., 2011), a proper understanding of the contribution of soil tillage and nutrient management practices to variations in relevant soil properties is deemed a necessary step in the design of technical intervention measures to reduce yield gaps for root and tuber crops in south-eastern Nigeria. Research on tillage for this category of crops in the region is still scarce.

Sweet potato is the fifth most important food crop after rice, wheat, maize, and cassava in developing countries (Som, 2007). It is a highly tolerant tuberous root crop, and a moderate temperature of 21-28^{o}C and a well-distributed rainfall in the range of 75-150 cm is sufficient for its growth (Nedunchezhiyan and Byju, 2005). The tubers are used as a subsidiary food after boiling, baking, frying, and sweetener for kunu or pap, to produce starch, alcohol, and pectin for industrial use. It is a good source of minerals, vitamins, and energy provider. Sweet potato thus forms an important part of any agricultural strategy targeted at food and nutrition security of most poverty-stricken people in Nigeria.

Well-drained sandy loam soils are ideal for sweet potato cultivation and yielding (Nayar and Naskar, 1994). Such soils, however, often show high bulk densities. In the humid tropical environments with intense rainfall, they are subject to excessive leaching (Igwe, 2004). In such environments, sweet potato can be responsive to soil fertility management (Nnadi *et al*., 2020). Coarse-textured and low-fertility soils dominate the soil resources of southeastern Nigeria. Soil amendments for improving their overall quality extends beyond conventional ones to those that supply some non-primary and mainly micronutrients (Ogumba *et al*., 2020). The effects of soil tillage and nutrient management for sweet potato are thus expected to be pronounced in the region especially with the prevailing conditions of low status of soil organic matter and the associated fragility of the agroecosystems and declining soil fertility.

Therefore, the main objective of this study was to assess the influence of tillage and nutrient management practices on selected soil properties of degraded coarse-textured Ultisols and the responses of sweet potato in Nsukka, southeastern Nigeria. Specifically, the study sought to determine the influence of these soil 'physical' and chemical fertility management practices on soil bulk density, soil pH and available phosphorus, and to assess the growth and tuber yield responses of sweet potato.

2.0 Materials and Methods

2.1 Description of the Study Area

The study took place at the University of Nigeria Teaching & Research Farm, Nsukka (06° 51 N, 07° 25 E; 400 m asl), a derived savannah in southeastern Nigeria. Mean annual rainfall is about 1600 mm, with peaks in July and October. The dry season lasts from November to March. The range of mean temperature is 21-31°C, but sometimes the weather shows supra-optimal values of up to 35°C. The soil is a Ultisol belonging to the Nkpologu series and had been classified as Typic Paleustult and Haplic Acrisol by to the Soil Survey Staff (2003) and the FAO/UNESCO (1988) revised legend, respectively. Its clay mineralogy is composed mainly of kaolinite (Akamigbo and Igwe, 1990). The soil, formed from false-bedded sandstone, is of coarse texture. It is low in soil organic matter, and is typically of low fertility status (Obalum *et al*., 2011b), while showing an ustic moisture regime and an isohyperthermic thermal regime.

2.2 Treatments, Experimental Design and Land Preparation

The study had as treatments three tillage-seedbed types viz zero-tilled flatbed (ZT-FB), conventionally tilled flatbed (CT-FB) and conventionally tilled tie-ridges (CT-TR), each with seven soil fertilizer amendments, representing sole and complementary application of poultry droppings (PD) and NPK 15:15:15 (NPK) with and without Agrolyzer fertilizer at 2 kg ha^{-1} (AGF). The amendments were PD at 20 t ha^{-1} (PD_{20}), PD at 10 t ha^{-1} complemented with NPK at 200 kg ha^{-1} ($PD_{10}+NPK_{0.20}$), NPK at 400 kg ha^{-1} ($NPK_{0.40}$), PD_{20}+AGF, $PD_{10}+NPK_{0.20}$+AGF, $NPK_{0.40}$+AGF, and a no-amendment control. The study was executed as 3 × 7 factorial experiment, giving 21 tillage/amendment-based treatments (Table 1).

Treatments were replicated in three blocks in a split-plot fashion, with the tillage-seedbed types in the main plots and amendments in the sub-plots. In assigning treatments, the principle of randomisation was observed both for the main and the sub-plots, such that the experimental design was the randomised complete block design (RCBD).

An area of land 37 m × 16.5 m was cleared with cutlasses. The entire area was demarcated into three blocks and each block was divided into three plots for the main plot treatments. Each main plot was then demarcated into seven sub-plots for the sub-plot treatments. These gave 63 sub-plots. Blocks and main plots were 2 m apart while sub-plots were 1 m apart. The tillage-seedbed types were achieved manually using an African hoe. The ZT-FB was not tilled and was left flat without raising it, and so there was minimal disturbance of the soil. The CT-FB and CT-TR involved tilling the soil ca. 20 cm deep and raising it into a flatbed or overturning it to make ridges, respectively. The CT-FB and CT-TR could be said to represent minimum and maximum disturbance of the soil, respectively.

The PD was cured by air-drying, sieved and incorporated into the top-(0-20 cm) soil two weeks before planting, whereas NPK and Agrolyzer fertilizer were applied by band placement two weeks after planting (WAP). The Agrolyzer fertilizer contained secondary macronutrients as well as micronutrients as follows: Ca - 20.14%, Na - 1.04%, Zn - 0.11%, Mg - 0.19%, Cu - 0.19%, S - 2.72%, Fe - trace, Mn - trace, Bo - trace, and Mo - trace.

2.3 Field Establishment and Agronomic/Cultural Practices

The variety UMUSPO-3 (orange-fleshed sweet potato) was used for the study. Vine cuttings 20-25 cm long with about eight noodles per cutting were used to establish sweet potato on 10th September 2016. They were planted after opening the soil ca. 5 cm deep. Replacement of unsprouted stands was done 2 WAP. Plant spacing adopted was 75 cm × 30 cm. This gave 20 stands per plot (4.5 m^2), translating into a plant density of 44,000 stands per hectare. A density of 37,000 stands per hectare has been recommended for sweet potato in sandy-loam soils of humid tropical environments (Adubasim *et al*., 2017). The slightly higher density in the present study, by seemingly being of greater nutrient mining, was expected to enhance the discrimination among the tillage/amendment-based treatments under investigation, in terms of sweet potato tuber yields. During the first six weeks, weeding was done manually using a hoe at two- week intervals. Also, manual irrigation was used to support the already fully established crop as from 8 WAP when the rains in the study area had fully receded till maturity.

2.4 Soil Sampling and Laboratory Analyses

Before planting, soil cores and loose samples were randomly collected over the entire plot from 20 evenly distributed points. At crop harvest, five each of soil cores and loose samples were collected from the treatment sub-plots. In both occasions, sampling was limited to the topsoil (0-20 cm). A cylindrical metallic core sampler of height 5.0 cm and diameter 5.5 cm was used to take a field-moist soil core at a depth of 0-5 cm. The soil cores in their sampler were analysed individually and averaged. The loose samples were bulked into one, air-dried to constant weight and then crushed and sieved through a 2-mm mesh before laboratory analyses. To describe the soil at the initial stage of the field study, the pre-planting soil samples were subjected to routine analyses following standard laboratory methods.

2.4.1 Soil bulk density and total porosity assessment

Soil bulk density was determined using the core method (Blake and Hartage, 1986). The mass of the empty cylindrical core sampler (M_o), determined electronically, was first recorded. The dry mass of the soil core in its sampler (M_t) was obtained after trimming the field-moist soil to the size of the sampler and oven-drying same at 105°C for 24 h. Then the mass of the oven-dry soil core alone (M_s) was determined by subtracting M_o from M_t. Also, the volume of the core sampler (V_t) was also computed from its height and diameter. Dry bulk density (P_b) was calculated using the equation:

$$P_b \text{ (g cm}^{-3}) = M_s \text{ (g)}/V_t \text{ (cm}^3)$$

Soil total porosity was derived from using the equation:

$$\text{Total porosity} = [1 - (P_b/P_p)] \times 100;$$

where P_b is soil bulk density and P_p is soil particle density.

2.4.2 Determination of soil pH and available phosphorus

Soil pH was determined in a 1:2.5 soil-water ratio using a combined glass electrode pH following the procedure described by McLean (1982). Available phosphorus was determined using the Bray-2 method of Bray and Kurtz as described by Page *et al*. (1982).

2.4.3 Crop data collection

Data on vine length and number of leaves per stand of the sweet potato were collected at three-week intervals starting from 3 till 9 WAP. At crop harvest, data were collected on total weight of tubers and weight of marketable tubers. The weight of tubers was obtained by weighing the tubers from the 4.5-m^2 plot and, after that, tuber yield was calculated as:

$$\text{Tuber yield (t ha}^{-1}) = \frac{10{,}000 \text{ m}^2}{4.5 \text{ m}^2} \times \frac{\text{weight of tuber (g)}}{1{,}000{,}000}$$

2.5 Statistical Analyses

Analysis of variance for a split-plot fitted into an RCBD was conducted on the data using the software GenStat Discovery Edition 4. With this, means were separated by the least significant difference (LSD) at $p < 0.05$. Correlations were also done using the software Statistical Product and Service Solution (SPSS) for windows version 20.0.

Table 1: Combinations of tillage and nutrient management practices

	Nutrient management practices						
Tillage types	PD_{20}	PD_{20}+AGF	$PD_{10}+NPK_{0.20}$	$PD_{10}+NPK_{0.20}$ + AGF	$NPK_{0.40}$	$NPK_{0.40}$ + AGF	Control
ZT-FB	ZT-FB/PD_{20}	ZT-FB/PD_{20}+AGF	ZT-FB/$PD_{10}+NPK_{0.20}$	ZT-FB/$PD_{10}+NPK_{0.20}$+AGF	ZT-FB/$NPK_{0.40}$	ZT-FB/$NPK_{0.40}$+AGF	ZT-FB/Control
CT-FB	CT-FB/PD_{20}	CT-FB/PD_{20}+AGF	CT-FB/$PD_{10}+NPK_{0.20}$	CT-FB/$PD_{10}+NPK_{0.20}$+AGF	CT-FB/$NPK_{0.40}$	CT-FB/$NPK_{0.40}$+AGF	CT-FB/Control
CT-TR	CT-TR/PD_{20}	CT-TR/PD_{20}+AGF	CT-TR/$PD_{10}+NPK_{0.20}$	CT-TR/$PD_{10}+NPK_{0.20}$+AGF	CT-TR/$NPK_{0.40}$	CT-TR/$NPK_{0.40}$+AGF	CT-TR/Control

ZT-FB - zero-till; CT-FB - conventionally tilled flatbed; CT-TR - conventionally tilled tie-ridge;
PD_{20} - 20 t ha^{-1} poultry droppings; PD_{20}+AGF - 20 t ha^{-1} poultry droppings + Agrolyzer fertilizer at 2 kg ha^{-1};
$PD_{10}+NPK_{0.20}$ - 10 t ha^{-1} poultry droppings + 200 kg ha^{-1} NPK; $PD_{10}+NPK_{0.20}$+AGF - 10 t ha^{-1} poultry droppings + 200 kg ha^{-1} NPK + Agrolyzer fertilizer at 2 kg ha^{-1};
$NPK_{0.40}$ - 400 kg ha^{-1} NPK; $NPK_{0.40}$+AGF - 400 kg ha^{-1} NPK + Agrolyzer micronutrient fertilizer at 2 kg ha^{-1}; Control - plots that received no soil fertilizer amendments

3.0 Results and Discussion

3.1 Initial Soil and Poultry Droppings Characteristics

Table 2 shows the initial soil properties of the site and the properties of the poultry droppings. The textural class is sandy loam. The bulk density was moderate (1.58 g cm^{-3}). The soil was acidic, while soil organic matter (17.88 g kg^{-1}), total nitrogen (0.56 g kg^{-1}) and available P (8.39 mg kg^{-1}) all indicated low values. These values depict this coarse-textured Ultisols as being of low fertility status, which could have resulted from leaching of the nutrients due to the texture of this soil (Igwe, 2004). The truly drainable macropores in the soils in the study area often show very good correlations with soil permeability regardless of their structural stability status (Obalum *et al*., 2011c); hence, they are frequently described as 'porous' with respect to water transmission. Therefore, sustainable crop yield on this soil must require a consistent management plan that involves regular additions of soil organic matter and other nutrient sources. The value of soil CEC of 12.40 cmol kg^{-1} was moderate while the percentage base saturation of 80.27% was high (Landon, 1991).

The poultry droppings had 26.74 g OC kg^{-1}, 4.33 g N kg^{-1}, and 6.08 cmol Mg kg^{-1}. The contents of other nutrients were low. The pH in water was 8.5, depicting alkaline conditions.

Table 2: Physicochemical properties of the soil before the study and chemical composition of the poultry droppings used as organic soil amendment in the study

Parameters	**Soil**	**Poultry droppings**
Textural class	Sandy loam	-
Coarse sand (g kg^{-1})	510	-
Fine sand (g kg^{-1})	240	-
Silt (g kg^{-1})	70	-
Clay (g kg^{-1})	180	-
Bulk density (g cm^{-3})	1.58	-
% Total porosity	30.40	-
Soil pH - H_2O	5.5	8.5
Soil pH - KCl	4.8	8.3
Organic Matter (g kg^{-1})	17.88	-
Total Nitrogen (g kg^{-1})	0.56	4.20
Available Phosphorus (mg kg^{-1})	8.39	0.22
Exch. Potassium (cmol kg^{-1})	0.040	0.42
Exch. Calcium (cmol kg^{-1})	3.20	1.96
Exch. Magnesium (cmol kg^{-1})	0.80	6.80
Exch. Sodium (cmol kg^{-1})	0.028	0.38
Exch. Hydrogen (cmol kg^{-1})	1.00	-
Exch. Aluminium (cmol kg^{-1})	Trace	-
Cation exchange capacity (cmol kg^{-1})	12.40	-
% Base saturation	80.27	-

3.2 Influence of Soil Tillage and Nutrient Management Options on Some Properties of the Sandy-Loam Soil

The influence of tillage-seedbed type on the soil properties is presented (Table 3). The data show that the tillage-seedbed types of the study had no effect on soil bulk density. There was, however, a tendency for decreases in soil bulk density with an increase in intensity of soil disturbance due to the pre-planting tillage thus ZT-FB ≥ CT-FB ≥ CT-TR. Nutrient management, on the other hand, significantly affected the bulk density of the soil (Table 3).

Compared to the initial value before applying treatments, there was a decrease in soil bulk density after application of the amendments. The observed decrease in soil bulk density was higher in plots that received PD than in those that received NPK, applied alone or in combination with AGF. Obi and Ebo (1995) reported that organic amendment of PD at 10 t ha^{-1} decreased soil bulk density and increased soil organic matter content of the coarse-textured soil under investigation. The decrease in soil bulk density following application of PD is also consistent with Ewulo *et al.* (2008) who found that bulk density reduced and moisture content increased with increasing levels of PD application on a southwestern Nigerian soil. In sweet potato production, low soil bulk density is a positive soil productivity indicator as it makes for ease of root growth and tuberisation while encouraging downward movement of water through old root channels (Uwah *et al.*, 2012). Across all the tillage and nutrient management practices evaluated, application of PD_{20}/AMF gave the lowest mean bulk density reduction of 28.5% relative to the initial value before the imposition of treatments. Soil bulk density is sometimes used as an index of soil compaction and soil quality/health (Al-Kaisi and Kwaw-Mensah, 2016). Often times, reductions in soil bulk density arising from organic manure application increase the rate of water infiltration, available water capacity, rooting depth, soil porosity, plant nutrient availability and soil microbial activity, all of which positively influence other key soil processes that define crop growth and productivity (Haynes and Naidu, 1998; Agbede *et al.*, 2008).

Table 3: Influence of soil tillage and nutrient management practices on some properties of the sandy-loam soil

Treatments	Bulk density (g cm^{-3})	% Total porosity	Soil pH-H_2O	Available P (mg kg^{-1})
Tillage-seedbed types				
ZT-FB	1.35	38.03	6.4	80.88
CT-FB	1.31	46.29	6.1	53.82
CT-TR	1.24	50.81	6.3	59.48
$LSD_{(0.05)}$	*ns*	*4.32*	*0.2*	*7.87*
Nutrient management options				
Control	1.47	34.15	5.9	13.06
PD_{20}	1.15	52.72	6.3	67.05
PD_{20}+AGF	1.13	50.41	6.5	76.60
PD_{10}+$NPK_{0.20}$	1.21	54.88	6.4	84.87
PD_{10}+$NPK_{0.20}$+AGF	1.45	44.96	6.3	82.08
$NPK_{0.40}$	1.32	47.15	6.1	57.23
$NPK_{0.40}$+AGF	1.36	31.04	6.3	72.23
$LSD_{(0.05)}$	*0.11*	*2.87*	*0.3*	*12.02*

Abbreviations are as defined in Table 1

Soil porosity also increased with intensity of soil disturbance due to the tillage-seedbed types (Table 3), pointing to the importance of tillage on structure development of the soil. The ZT-FB had significantly lowest total porosity (38.03%), followed by CT-FB (46.29%) and then CT-TR (50.81%). These values, when related to the recommended total porosity for sweet potato and most crops Stathers *et al.* (2013), are within the desired range. For nutrient management options, all three tillage-seedbed types showed an improvement over the initial value, with the highest values in the PD_{10}+$NPK_{0.20}$.

Table 4: Interaction effects of tillage and nutrient management options on some properties of the sandy-loam soil

Treatments	Bulk density (g cm^{-3})	% Total porosity	Soil pH	Available P (mg kg^{-1})
ZT-FB/Control	1.58	26.17	5.7	13.68
CT-FB/Control	1.49	34.65	6.0	11.81
CT-TR/Control	1.36	41.63	5.9	13.68
ZT-FB/PD_{20}	1.26	33.33	6.2	64.98
CT-FB/PD_{20}	1.14	58.70	6.4	80.52
CT-TR/PD_{20}	1.05	66.13	6.3	55.65
ZT-FB/PD_{20} + AGF	1.20	49.15	6.7	86.74
CT-FB/PD_{20} + AGF	1.12	53.53	6.1	65.60
CT-TR/PD_{20} + AGF	1.06	48.54	6.6	77.44
ZT-FB/PD_{10} + $NPK_{0.20}$	1.29	47.13	6.6	116.58
CT-FB/PD_{10} + $NPK_{0.20}$	1.24	55.71	6.3	59.38
CT-TR/PD_{10} + $NPK_{0.20}$	1.10	61.81	6.2	78.65
ZT-FB/PD_{10} + $NPK_{0.20}$ + AGF	1.48	45.23	6.6	125.29
CT-FB/PD_{10} + $NPK_{0.20}$ + AGF	1.44	41.28	6.0	51.92
CT-TR/PD_{10} + $NPK_{0.20}$ + AGF	1.42	48.36	6.2	69.02
ZT-FB/$NPK_{0.40}$	1.32	40.80	6.4	68.08
CT-FB/$NPK_{0.40}$	1.38	47.82	5.5	44.46
CT-TR/$NPK_{0.40}$	1.26	52.82	6.2	59.14
ZT-FB/$NPK_{0.40}$ + AGF	1.33	24.43	6.4	90.78
CT-FB/$NPK_{0.40}$ + AGF	1.36	32.34	6.3	63.11
CT-TR/$NPK_{0.40}$ + AGF	1.40	36.36	6.3	62.80
$LSD_{(0.05)}$	*ns*	*1.55*	*ns*	*82*

Abbreviations are as defined in Table 1

This was closely followed by the sole application of PD at 20 t ha^{-1} (PD_{20}). In sweet potato and indeed most tuber field crop production, soil porosity is considered an important physical attribute of soil as it has a direct influence on the balance between water and air in the soil. The ratio of water to air in the soil is inversely related; as one increases, the other must decrease. 'Saturated' soils have all air displaced from the soil pores. Without air or oxygen, in particular, root respiration is usually impaired, and this may have a negative effect on root growth and development processes in sweet potato (Blanco-Canqui *et al.*, 2017).

Notably, soil total porosity in excess of 50% is often deemed unsuitable for sweet potato production as it may be too friable and may fail to provide the necessary anchorage for the crop (Stathers *et al.*, 2013). Also, such highly porous soils are bound to experience pronounced leaching of nutrients. This concern is in addition to the economic losses due to fertilizer leaching and reduced crop yields. Optimum soil total porosity could, therefore, be said to be achieved with PD_{20}+AMF with a value of 50.41%.

The main effects of treatments on soil pH and available P are also shown in Table 3. Compared to the initial value before initiating the study, the tillage-seedbed types and nutrient management practices reduced the acidity level of the soil as expressed by the increases in its content of potential hydrogen ions (soil pH-H_2O). With reference to the baseline value, the highest and lowest increases in mean soil pH by 0.9 and 0.6 units, respectively were recorded in ZT-FB and CT-FB plots, respectively. Table also shows that all nutrient management practices but $NPK_{0.40}$ improved the soil pH over the no-amendment control.

Tillage-seedbed types and nutrient management practices significantly affected the available P content of the soil (Table 3). The results show higher values in the ZT-FB than the CT-FB and CT-TR for which values were similar. Schoenau *et al.* (2007) reported a similar trend for available P among tillage methods varying in degree of soil turning in Saskatchewan, Canada. Zibilske and Bradford (2003) also reported higher P availability under zero tillage than conventional tillage. In ZT-FB systems, plant residues and residue-derived organic matter accumulate at the surface and the near-surface zone. Conventional tillage disrupts soil aggregates, exposing organic matter to microbial attack and reducing its moderating effects on soil water and available P. Therefore, the improvement in soil P availability under ZT-FB in this study could be ascribed mainly to residue-P accumulation in the near-surface soil layer and as plant residues decompose and release the P contained within (Ch'ng *et al.*, 2014). In the environment of the present study, it has been suggested that the one to increase available P over the other between zero and conventional tillage may depend on crop grown, litter-associated soil organic matter, and the tillage-crop field that enhances soil moisture status during the growing season (Obalum *et al.*, 2011b).

Among the nutrient management options, the lowest value of available P was recorded in the control, followed by $NPK_{0.40}$ and $NPK_{0.40}$+AGF (Tables 3). The PD_{10}+$NPK_{0.20}$ resulted in the highest available P (84.87 mg kg^{-1}), a value corresponding to over 900% improvement relative to the pre-planting value! Nutrient management practices similar to PD_{10}+$NPK_{0.20}$ were those fortified with AGF. These results point to the role of micronutrient fertilizers in inducing greater P availability, while also suggesting that complementary use of PD and NPK could subsist when micronutrient fertilizers are not accessible.

Interaction of tillage-seedbed type and nutrient management option had no effect on soil bulk density but affected soil total porosity (Table 4). The highest total porosity values were recorded in CT-TR+PD_{20} plots (66.13%), while the lowest values were recorded in ZT-FB+$NPK_{0.40}$+AGF plots (24.43%). The fact is that, in terms of porosity enhancement, each of the tillage options benefitted from sole application of PD or by complementary application of PD and NPK with or without AGF; the same could be said for the sole use of NPK only where AGF was not added. Again, it was observed that the AGF caused a reduction in total porosity of the soil, and that the use of ZT-FB and sole application of PD or at least complementary use of PD and NPK could counter this effect. Thus, treatments having $NPK_{0.40}$+AGF consistently showed lower values of soil total porosity than their counterparts involving tillage and the control amendment.

Soil pH indicated similar values while available P varied among treatments (Table 4). The lowest values of available P were due to treatments without soil amendments, while the highest values occurred in ZT-FB/PD_{10}+$NPK_{0.20}$+AMF plots. Regardless of the tillage-seedbed type adopted, growing sweet potato in this environment with sole or complementary application of PD and NPK with or without AGF could enhance P availability compared to doing so on unamended soil. Although tillage-×-nutrient interaction suggests no effects on soil pH, it is also logical to infer that the observed differences in soil P availability were partly a reflection of the significant main effects of tillage-seedbed types and nutrient management practices on soil pH.

3.3 Treatment Effects on Growth of Sweet Potato

Table 5 shows the effect of tillage-seedbed and nutrient management practices on vine length and number of leaves of sweet potato at 3, 6 and 9 WAP. The three tillage-seedbed types differed in vine length thus CT-TR > CT-FB = ZT-FB at 3 and 9 WAP, and their ability to increase number of leaves decreased in the order listed, being significant at 9 WAP.

Nutrient management also affected sweet potato growth at all three sampling stages. For vine length, PD_{10}+$NPK_{0.20}$+AGF was generally the best, being similar to others but not $NPK_{0.40}$ and the control. Notably, $NPK_{0.40}$ showed longer vines than the rest at but not beyond 3 WAP. Recall that NPK was applied to the soil 2 WAP. Therefore, this striking effect at 3 WAP reflects the fast release attribute of inorganic fertilizers. That it was not sustained suggests that nutrients in mineral fertilizers applied at once to 'porous' soils are highly leached in humid tropical locations (Umezinwa *et al.*, 2020).

Generally, number of leaves was significantly higher in the trio of PD_{20}- PD_{20}+AGF- and PD_{10}+$NPK_{0.20}$-amended than PD_{10}+$NPK_{0.20}$+AGF-amended plots which in turn showed higher values than the rest at 3 and 6 WAP. This trend was maintained at 9 WAP, but for PD_{20}- and PD_{10}+$NPK_{0.20}$+AGF-amended plots indicating similar values. From the data shown, longest vines and fewest leaves were generally from the control, $NPK_{0.40}$ or $NPK_{0.40}$+AGF.

Tillage-×-nutrient interaction affected sweet potato growth at 6 and 9 WAP (Table 6). The longest vines were measured in CT-FB/PD_{20} and ZT-FB/PD_{10}+$NPK_{0.20}$+AGF at 6 WAP, but in CT-FB/PD_{10}+$NPK_{0.20}$+AGF and CT-TR/PD_{20} later at 9 WAP. The shortest vines were measured in, among others, CT-FB/Control and CT-TR/$NPK_{0.40}$ at both sampling stages. Number of leaves counted was highest in the CT-TR/PD_{20} and CT-TR/PD_{10}+$NPK_{0.20}$ and lowest in the CT-FB/Control and CT-TR/Control at 6 and 9 WAP, respectively.

3.4 Treatment Effects on Tuber Yield of Sweet Potato

The effects of tillage-seedbed and nutrient management options on tuber yield of sweet potato in sandy-loam soil of the study are shown (Table 7). These factors affected both total tuber yield and marketable tuber yield. These two yield parameters were higher in CT-TR than CT-FB and ZT-FB for which values were similar. These results suggest that the

Table 5: Effects of treatments on vine length and number of leaves of sweet potato at 3, 6 and 9 weeks after planting (WAP)

Treatments	Sweet potato growth parameters					
	Vine length (cm)			Number of leaves		
	3 WAP	6 WAP	9 WAP	3 WAP	6 WAP	9 WAP
Tillage-seedbed types						
ZT-FB	56.9	121.9	161.7	65	87	122
CT-FB	55.3	121.8	166.4	64	86	137
CT-TR	65.2	111.6	184.3	67	90	159
$LSD_{(0.05)}$	*4.05*	*ns*	*14.27*	*ns*	*ns*	*9.08*
Nutrient management options						
Control	47.0	90.1	139.4	42	52	81
PD_{20}	58.4	131.1	187.9	80	115	144
PD_{20}+AGF	58.8	131.2	176.7	85	114	210
PD_{10}+$NPK_{0.20}$	59.4	133.9	187.8	82	112	205
PD_{10}+$NPK_{0.20}$+AGF	60.5	135.1	201.5	68	96	154
$NPK_{0.40}$	70.3	90.7	142.2	50	66	93
$NPK_{0.40}$+AGF	52.3	117.4	160.1	42	52	81
$LSD_{(0.05)}$	*6.19*	*18.10*	*37.74*	*11.99*	*17.50*	*13.87*

Abbreviations are as defined in Table 1

Table 6: Interaction effects of tillage and nutrient management on growth of sweet potato at 3, 6 and 9 weeks after planting (WAP)

Treatments	Sweet potato growth parameters			
	Vine length (cm)		Number of leaves	
	6 WAP	9 WAP	6 WAP	9 WAP
ZT-FB/Control	112.2	148.0	56	89
CT-FB/Control	74.8	126.4	45	79
CT-TR/Control	83.4	143.8	54	76
ZT-FB/PD_{20}	119.5	173.0	110	116
CT-FB/PD_{20}	159.3	170.6	96	140
CT-TR/PD_{20}	120.5	220.0	138	174
ZT-FB/PD_{20} + AGF	114.2	133.8	110	177
CT-FB/PD_{20} + AGF	148.7	185.7	117	205
CT-TR/PD_{20} + AGF	130.5	210.6	116	221
ZT-FB/PD_{10} + $NPK_{0.20}$	136.8	174.7	93	132
CT-FB/PD_{10} + $NPK_{0.20}$	140.7	170.9	131	230
CT-TR/PD_{10} + $NPK_{0.20}$	124.2	217.8	111	251
ZT-FB/ PD_{10} + $NPK_{0.20}$ + AGF	155.5	172.9	114	167
CT-FB/PD_{10} + $NPK_{0.20}$ + AGF	142.2	224.0	89	133
CT-TR/PD_{10} + $NPK_{0.20}$ + AGF	107.5	207.4	86	163
ZT-FB/$NPK_{0.40}$	96.4	163.9	70	82
CT-FB/$NPK_{0.40}$	79.8	144.7	66	82
CT-TR/$NPK_{0.40}$	95.8	117.8	62	114
ZT-FB/$NPK_{0.40}$ + AGF	119.0	165.6	56	90
CT-FB/$NPK_{0.40}$ + AGF	113.6	141.9	58	89
CT-TR/$NPK_{0.40}$ + AGF	119.4	172.6	65	114
$LSD_{(0.05)}$	*32.2*	*37.74*	*30.31*	*24.02*

Abbreviations are as defined in Table 1

CT-TR provided a more favourable soil environment for sweet potato root growth and tuberisation. FAO (2000) notes that ridging and mounding are the most suitable tillage methods for tuber crops production in the tropics because they loosen the soil, optimize infiltration, enhance rooting depth, and improve soil water management.

For nutrient management practices, PD_{10}+$NPK_{0.20}$+AGF-amended plots out-yielded the other options in terms of both total and marketable tuber yields. This was followed by PD_{20}+AGF, with the order for the rest which was consistent for the two yield parameters being PD_{20} = PD_{10}+$NPK_{0.20}$ $\geq$ $NPK_{0.40}$ = $NPK_{0.40}$+AGF = control. Notably, the yield trend suggests that complementary use of PD and NPK is more effective than sole use of PD only in the presence of AGF, otherwise the reverse holds true. The data in Table 7 show that the best soil amendment here (PD_{10}+$NPK_{0.20}$+AGF), relative to the control, represented tuber and marketable tuber yield increases of about 387% and 687%, respectively.

Table 7: Effect of tillage-seedbed type and nutrient management on tuber yield and marketable tuber yield of sweet potato

Treatments	Tuber yield ($t\ ha^{-1}$)	Marketable tuber yield ($t\ ha^{-1}$)
Tillage-seedbed types		
ZT-FB	2.75	1.22
CT-FB	3.03	1.50
CT-TR	6.63	4.20
$LSD_{(0.05)}$	*0.65*	*0.40*
Nutrient management options		
Control	1.49	0.60
PD_{20}	5.17	3.02
PD_{20}+AGF	6.39	3.58
PD_{10}+$NPK_{0.20}$	4.48	2.56
PD_{10}+$NPK_{0.20}$+AGF	7.25	4.72
$NPK_{0.40}$	2.46	1.03
$NPK_{0.40}$+AGF	1.70	0.63
$LSD_{(0.05)}$	*1.01*	*0.61*

Abbreviations are as defined in Table 1

Table 8: Interaction effects of tillage-seedbed type and nutrient management practices for sandy-loam Ultisols on marketable tuber yield of sweet potato at Nsukka

Treatments	Marketable tuber yield ($t\ ha^{-1}$)
ZT-FB/Control	0.22
CT-FB/Control	0.30
CT-TR/Control	1.26
ZT-FB/PD_{20}	1.90
CT-FB/PD_{20}	2.11
CT-TR/PD_{20}	5.04
ZT-FB/PD_{20} + AGF	1.48
CT-FB/PD_{20} + AGF	2.40
CT-TR/PD_{20} + AGF	6.85
ZT-FB/PD_{10} + $NPK_{0.20}$	1.14
CT-FB/PD_{10} + $NPK_{0.20}$	1.96
CT-TR/PD_{10} + $NPK_{0.20}$	4.54
ZT-FB/PD_{10} + $NPK_{0.20}$ + AGF	2.66
CT-FB/PD_{10} + $NPK_{0.20}$ + AGF	1.86
CT-TR/PD_{10} + $NPK_{0.20}$ + AGF	9.63
ZT-FB/$NPK_{0.40}$	0.87
CT-FB/$NPK_{0.40}$	1.16
CT-TR/$NPK_{0.40}$	1.06
ZT-FB/$NPK_{0.40}$ + AGF	9.24
CT-FB/$NPK_{0.40}$ + AGF	0.68
CT-TR/$NPK_{0.40}$ + AGF	0.96
$LSD_{(0.05)}$	*1.08*

Abbreviations are as defined in Table 1

The use of appropriate ratios of manures and fertilizers is a step towards developing viable soil and water management protocols in the humid tropics (Unagwu *et al*., 2013). Indeed, integrated nutrient management strategy has been advocated (Aulakh, 2010; Wei and Baoluo, 2015). A balanced application of appropriate fertilizers in a cropping system is a significant component of this strategy (Getachew and Tilahun, 2017). The best-performing soil fertilizer amendment of the present study (PD_{10}+$NPK_{0.20}$+AGF) typifies this very important component. For the low-fertility sandy-loam Ultisols of Nsukka in southeastern Nigeria, therefore, complementary use of promising manures and conventional mineral fertilizers and fortifying this combination with micronutrient fertilizers (that supply both secondary and micronutrients) in growing sweet potato could be a way to enhance its yield.

The interaction effects of tillage-seedbed type and nutrient management practice were not significant for tuber yield; only the marketable tuber yield was affected (Table 8). This suggests that the treatments influence tuber yield of sweet potato by causing greater differences in size than number of tubers. The CT-TR/PD_{10}+$NPK_{0.20}$+AGF and ZT-FB/$NPK_{0.40}$+AGF gave the highest marketable tuber yields, while ZT-FB and CT-FB each without amendment were among those giving the lowest values. The implication of these results is that the two tillage-seedbed types (ZT-FB and CT-TR) at the extremes in terms of degree of soil disturbance due to them differ in their preference of fertilizer type for enhancing sweet potato yield in humid tropical locations. With adequate surface coverage, CT-TR usually retains less water than ZT-FB during the growing season in the study area (Obalum *et al*., 2012, 2017). Thus, CT-TR/PD_{10}+$NPK_{0.20}$+AGF offers the tuberising sweet potato the more aeration it requires; ZT-FB/$NPK_{0.40}$/AGF offers less. This is compensated for by the slower nutrients release in the former than the later. With this, we infer that the results for marketable tuber yield was a reflection of the interplay between soil 'physical' and chemical fertility induced by the tillage/amendment-based management practices.

3.5 Relationship between Soil Properties and Sweet Potato Growth and Yield Parameters

The results of the correlations between the three soil properties assessed in this study and the growth and tuber yield parameters of sweet potato are shown (Table 9). Soil bulk density did not correlate with any of these agronomic parameters. By contrast, Agbede and Adekiya (2011) reported a negative correlation between soil bulk density and yield of sweet potato in southwestern Nigeria. Both soil pH and available P correlated with number of leaves at all three crop sampling stages and vine length at 6 WAP; however, these two soil properties had no correlations with tuber yield and marketable tuber yield. Sweet potato responds highly to soil-applied nutrients, especially P, due to the short cycle and high yield potential of the crop (Fernandes and Soratto, 2012). Following a field study carried out in the same location as the present study, Nnadi *et al*. (2020) reported that liming to elevate the soil pH before manuring with PD at 20 t/ha was the best soil nutrient management option for growing sweet potato. Xing *et al.* (2020) worked in Loess Plateau of China and, using partial least square regression, remarked that soil pH and available P were among the many soil fertility indices that influenced the quality of sweet potato.

In this paper, data for the treatment effects on number of tubers, number of marketable tubers, and vine dry biomass are not shown, but these tuber yield parameters were included in the correlation analyses between soil properties and crop growth/yield parameters. Soil pH correlated with number of tubers and number marketable tubers of sweet potato. Also, soil pH and available P correlated with vine dry biomass.

Table 9: Correlation coefficients for the linear relationships between soil properties and growth/yield parameters of sweet potato

Parameters	Soil bulk density	Soil pH	Available P
Vine length 3 WAP	0 075^{ns}	0 007^{ns}	0.114^{ns}
Number of leaves 3 WAP	0.056^{ns}	0.419**	0.437**
Vine length 6 WAP	0.077^{ns}	0.353**	0.405**
Number of leaves 6 WAP	0.106^{ns}	0.454**	0.407**
Vine length 9 WAP	0.005^{ns}	0.147^{ns}	0.249*
Number of leaves 9 WAP	0.031^{ns}	0.351**	0.370**
Tuber yield	0 012^{ns}	0.242^{ns}	0.169^{ns}
Number of tubers	0.002^{ns}	0.276*	0.165^{ns}
Marketable tuber yield	0.004^{ns}	0.151^{ns}	0.102^{ns}
Number of marketable tuber	0.038^{ns}	0.277*	0.185^{ns}
Vine dry biomass	0 078^{ns}	0.436**	0.437**

* - Significant at $p < 5\%$; ** - Significant at $p < 1\%$; ns - not significant

4.0 Conclusion

This study has shown that tillage and nutrient management practices on coarse-textured Ultisols of inherently low fertility status could enhance soil porosity and available phosphorus (P) and the productivity of sweet potato. Among all the tillage and nutrient management practices studied, conventionally tilled tie-ridge with application of 20 t ha^{-1} of poultry droppings plus 2 kg ha^{-1} Agrolyzer micronutrient fertilizer gave the highest reductions in soil bulk density of 28.5% relative to the value before treatment. Tillage and nutrient management practices also reduced soil acidity compared to the initial value. Averaged over the nutrient management practices, the highest increases in soil pH relative to the initial value were recorded in zero-till flatbeds, while the lowest increases were recorded in conventionally tilled flatbeds. Growing sweet potato on soil managed with the sole application of poultry droppings or NPK 15:15:15 and their combinations with or without Agrolyzer resulted in higher soil P availability compared to the control. Although conventional soil amendments with or without micronutrients could improve soil P-fertility, much better results could be achieved when poultry droppings are part of involved and complemented by fertilizers supplying micronutrients. The highest growth and tuber yield responses of sweet potato were due to the combinations 10 t ha^{-1} poultry droppings plus 200 kg ha^{-1} NPK 15:15:15 plus 2 kg ha^{-1} Agrolyzer and 20 t ha^{-1} poultry droppings plus 2 kg ha^{-1} Agrolyzer. In contrast, the lowest values were obtained with the use of NPK 15:15:15 (with and without Agrolyzer) and the control.

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