

Unveiling the effect of different tillage systems and fertilizer types on the physical and chemical properties in a coarse – textured soils of southeastern Nigeria

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Abstract

Understanding the complexity, dynamics and interconnecting soil properties, different tillage practices are critical to the management of arable soils for crop production. The trial was conducted during the early and late cropping season (July – October) 2020/2021 and 2022/2023 at the FEYRep (Family Empowerment and Youth Re-orientation Programme) farm in Etinan Local Government Area (LGA), Akwa Ibom State. The research field is located between latitudes 4°44'23" and 4°45'10" North and longitude 7°50'35" and 7°59'55" South of Southern Ima, Etinan. The experiment was (2 x 8) factorial in split plot arranged in a randomized complete block design with three replications in both cropping seasons. Treatments consisted of two tillage practices, as main plots (conventional and reduced tillage), and sub-plots (fertilizer types and combination), (T1: NPK 400kg/ha.; T2: poultry manure (PM) 5t/ha.; T3: microbial fertilizer (CHC) 240g/ha.; T4: NPK 400kg/ha + PM 5t/ha.; T5: NPK 400kg/ha + PM 2.5t/ha.; T6: NPK 400kg/ha + CHC 240g/ha.; T7: NPK 400kg/ha + CHC 120g/ha.; T8: control) given a total of 16 treatment combinations. Although there were no significant differences amongst the treatments on the soil physical and chemical properties, combined application of NPK 400kg/ ha + CHC 240g with conventional tillage increases the p^H slightly. Reduced tillage increases OC and OM.

Keywords: Tillage systems, fertilizer types, soil properties, southeastern nigeria, arable soil management

Introduction

Upholding sustainable agricultural production systems and tillage practices are critical to the management of arable soils for crop production. However, to understand the complexity, dynamics and interconnecting soil properties, different tillage practices should be adopted. Any management practices imposed on the soil to alter the heterogeneous state may result in harmful outcomes (Derpsch, *et al.*, 2010; Wolfarth, *et al.*, 2011). Management practices that are not suitable can damage the soil system and can also cause degradation in soil health and productivity particularly in the depletion of soil organic matter and nutrients which will lead to decline in crop yield (Ramos, *et al.*, 2011). Soil chemical, physical and biological properties and some interconnected properties of the natural body are affected by tillage operation (Lopez- Garrido, *et al.*, 2012; Page, *et al.*, 1989; Bronick and Lal, 2005 and Munoz, *et al.*, 2007).

Tillage contributes about 20% of the factors that affect crop production (Khurshid, *et al.*, 2006) and affects the sustainable use of soil resources through its influence on soil properties (Lal and Stewart, 2013). The soil remains unaffected through the judicious use of good tillage practices while poor tillage practices are responsible for a damaging effect on soil structure, soil organic matter level, disruption of soil hydraulic system, increased in soil erosion, loss of soil minerals (Lal, 1993). Minimal or zero-tillage positively influences several soil properties whereas repeated tillage operations exposed the soil to erosion, loss of soil nutrients and destruction of soil structure. Therefore, there is an advocacy for the need to shift from extreme or excessive tillage operation in arable soil to conventional

tillage or no- tillage to effectively conserve the soil for increased crop production (Iqbal, *et al.*, 2005). Conventional tillage practices cause change in soil structure by modifying soil bulk density and soil moisture content. In addition, repeated disturbance by conventional tillage gives birth to a finer and loose-setting structure while conservation and no tillage methods leave the soil intact. (Rashidi and Keshavarzpour, 2007).

Unfortunately, majority of the soils available for crop production in the tropics are ultisols have low organic matter and nutrient status (Okpara, *et al.*, 2011), hence, there is the need to search for organic amendments which could be utilized as fertilizers with appropriate tillage practice that will enhance the nutrient and soil structure. Such amendments should be readily available, cheap and environmentally friendly. To this end, this research seek to unveil the effect of tillage practices and fertilizer types on the physical and chemical properties of the studies soil.

Materials and Methods

Experimental site

The trial was conducted during the early and late cropping season (July – October) 2020/2021 and 2022/2023 at the FEYRep (Family Empowerment and Youth Re-orientation Programme) farm in Etinan Local Government Area (LGA), Akwa Ibom State. The research field is located between latitudes 4°44'23" and 4°45'10" North and longitude 7°50'35" and 7°59'55" South of Southern Ima, Etinan. Etinan is about 48m above sea level and is located in the Niger Delta region of Nigeria, having a total rainfall of 1500 mm to 2600 mm distributed between April and October with a mono-modal rainfall pattern. The mean annual

temperature ranged between 19.1^o C and 35.3^o C while the average relative humidity ranges from 69 % to 79 %. (Peters, *et al.*,1989). The soil belongs to soil order Ultisol (Eshiet, 1993; Reyment, 1965). The vegetation of the area is rain forest characterized by multiple plant species ranging from herbs, to shrubs and trees. Oil palm trees (*Elaeis guineensis*) is predominant over other tree species in the study area. Agriculture is practiced in a small holder farming in the area constituting the main socio-economic activities. Land preparation in the area is usually by slash-and-burn, followed by mound making and flat forms of tillage. Bush fallow is the main method of regenerating soil fertility in the area but fallow duration has been tremendously reduced such that some farmers practiced continuous cultivation. The major arable crops grown in the study area are Yam (*Dioscorea spp*), Maize (*Zea mays*), Cassava (*Manihot spp*).

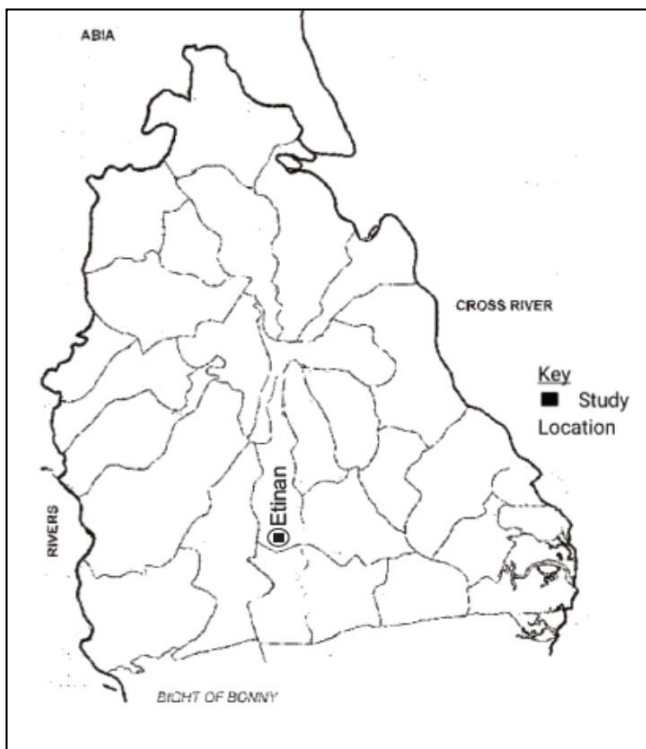


Fig 1: Map of Akwa Ibom State showing Etinan LGA and the Location of the FEYrep Farm.

Experimental Procedures

The trial was (2 x 8) factorial in split plot arranged in a randomized complete block design with three replications in both cropping seasons. Treatments consisted of two tillage practices, as main plots (conventional and reduced tillage), and sub-plots (fertilizer types and combination), (T1: NPK 400kg/ha.; T2: poultry manure (PM) 5t/ha.; T3: microbial fertilizer (CHC) 240g/ha.; T4: NPK 400kg/ha + PM 5t/ha.; T5: NPK 400kg/ha + PM 2.5t/ha.; T6: NPK 400kg/ha + CHC 240g/ha.; T7: NPK 400kg/ha + CHC 120g/ha.; T8: control) given a total of 16 treatment combinations. The main plots were 47 m x 14 m (658 m²) each and sub-plots 5 m x 4 m (20 m²), given a total of 48 sub-plots. Soil samples were collected immediately after slashing at the depth 0 - 30 cm using soil auger. The samples were bulked to form a

composite sample. The bulked sample was air-dried, sieved using 2 mm sieve. Particle size analysis was done using Bouyoucos hydrometer method (Gee and Or, 2002). Organic carbon was determined using the chromic wet oxidation method (Udo *et al.*, 2009). Percentage organic matter was determined by calculation and multiplying the values of organic carbon by a factor of 1.724 which is called Van Bemmelen factor. Soil pH was determined using 1:2.5 soil-water ratio with a pH electrode and values were read out from a pH meter (Hendershot *et al.*, 1993). Total Nitrogen was determined by kjeldahl digestion method (Bremner and Mulvaney, 2003). Exchangeable Ca and Mg were determined by the EDTA versanate titration method (Udo *et al.*, 2009). Exchangeable Na and K were determined by the flame photometer method. Exchangeable acidity was measured by leaching the soil with 1N KCl and titrated with 0.05N NaOH (McClean, 1982). Available Phosphorus was determined using Bray 2 method and exchangeable acidity (IITA, 1979).

The conventional tillage (CT) was mechanically ploughed, harrowed and ridged on the 20, 24, 26, July and 24, 28, 31 October respectively during 2020/2021 and 2022/2023 growing season. The inorganic fertilizer was applied by site placement, poultry manure by mixing with soil and CHC Agric Tech. was spray 3 times in one cropping cycle and at their recommended rates in approximate plots. NPK 15: 15: 15 at the rate of 400kg ha⁻¹, poultry manure (PM) at 2.5 t ha⁻¹ and 5 t ha⁻¹ and microbial fertilizer (CHC) at 120 g ha⁻¹ and 240 g ha⁻¹. And all combination were applied to all sub plot at first season of planting, second season was residual (no application of fertilizer). Nitrogen, phosphorus and potassium fertilizers (NPK; 15:15:15) was applied immediately after first weeding in first season.

Statistical analysis

Data collected was subjected to analysis of variance (ANOVA) using the mixed linear model MIXED Procedure of SAS, Institute Inc., (2009). Duncan's multiple range test was used to separate the means that will differ significantly at 5% level of probability. The level of interaction was compared computing the least square means and standard error of difference (SED) at 5% level of probability. Simple coefficient of correlation (r) analysis amongst the soil properties and yield parameters was also performed. Stepwise regression analysis was used to determine the significance of the independent variables on the dependent variable (cassava root yield). Moreover, principal component analysis (PCA) was performed on soil properties to evaluate their respective contribution to soil productivity.

Results

Pre-cropping soil analysis

The results for pre-cropping soil analysis showed that the texture of the studied soil was sand (Table 1). The soils were strongly acidic with a pH of 4.67. The organic carbon and organic matter contents were low. Total nitrogen was also low with value far < 0.20 %. The available phosphorus content was low. The exchangeable cations (Ca, Mg, K and Na) were all low. The exchangeable acidity was high. The ECEC and base saturation were also low.

Table 1: Physicochemical characteristics of the soil used for the experiment

Physical properties	Units	Soil values
Sand	%	96.44
Silt	%	3.20
Clay	%	0.36
Texture		Sand
Chemical Properties		
pH		4.67
EC	ds/m	0.15
OC	%	0.92
OM	%	1.59
TN	%	0.09
Av. P	mg/kg	7.00
Ca		1.44
Mg		1.20
K		0.02
Na	cmolkg ⁻¹	0.05
Al ⁺⁺⁺		0.48
H+		5.44
ECEC		8.15
BS	%	33.25

Effect of soil amendments on soil properties

The results showing the effects of amendments on soil properties are presented in Table 2. For soil pH, the result showed no significant (p>0.05) difference between soils treated with various amendments. However, it was observed that soil amended with NPK 400 kg/ha + CHC 120 g/ha had the highest soil pH value (4.55), while soil amended with PM 5 t/ha, had the lowest soil pH (4.41). Similarly, soil organic carbon (OC) and soil organic matter (OM) did not show any significant (p>0.05) difference between the soils treated with various amendments. However, soil amended with CHC 240 g/ha had the highest OC (1.5 %) and OM (2.47 %) values, while soil amended with NPK 400 kg/ha + PM 5t/ha, had the lowest OC (1.18 %) and OM (2.04 %). Further results revealed that total nitrogen did not show any

significant (p>0.05) difference between the soils treated with various amendments, though soil amended with PM 5 t/ha, recorded the highest TN (0.165 %), whereas the lowest TN (0.11 %) was associated with soil amended with NPK 400 kg/ha + PM 5 t/ha.

Moreover, the result further indicated significant (p≤ 0.05) difference in soil available phosphorus (AP) between the soils treated with various amendments, and soil amended with PM at 5 t/ha had the highest soil AP (10.28 mg/kg), which was significantly (p≤ 0.05) higher than other treatments and the control soil. Furthermore, the lowest soil AP (5.50 mg/kg) was associated with NPK 400 kg/ha + CHC 120 g/ha. From the result, it was also found that exchangeable Ca, Mg, K and Na did not show any significant (p>0.05) difference between soils treated with various amendments.

Table 2a: Effect of soil amendments and tillage methods on soil properties

Treatments	Ph	OC	OM	TN	AP	Ca	Mg	K	Na	H	Al
Fertilizer											
Control	4.49a	1.41a	2.46a	0.138a	7.57b	1.68a	0.78a	0.032a	0.15a	5.01a	0.32a
CHC240	4.45a	1.50a	2.47a	0.136a	6.68b	1.64a	0.64a	0.017a	0.13a	4.58a	0.24a
NPK400	4.54a	1.24a	2.16a	0.122a	6.04b	1.48a	1.09a	0.013a	0.14a	4.83a	0.37a
NPK400+CHC120	4.55a	1.33a	2.31a	0.128a	5.50b	1.60a	0.85a	0.027a	0.14a	4.19a	0.26a
NPK400+CHC 240	4.53a	1.26a	2.18a	0.123a	5.73b	1.56a	0.91a	0.015a	0.23a	4.75a	0.32a
NPK400+PM 2.5T	4.49a	1.34a	2.32a	0.130a	7.57b	1.68a	0.72a	0.016a	0.14a	4.67a	0.35a
NPK400+PM 5T	4.45a	1.18a	2.04a	0.115a	6.32b	1.44a	2.24a	0.013a	0.13a	5.13a	0.37a
PM 5T	4.41	1.25a	2.16a	0.165a	10.28a	1.80a	0.89a	0.010a	0.10a	4.41a	0.34a
TILLAGE											
CT	4.53a	1.29a	2.21a	0.135a	7.20a	1.57a	1.15a	0.016a	0.14a	4.64a	0.33a
RT	4.45b	1.34a	2.32a	0.130a	6.72a	1.65a	0.88a	0.017a	0.16a	4.75a	0.31a
Fertilizer x Tillage											
Control x CT	4.45a	1.57a	2.72a	0.153a	5.83a	1.52a	0.84a	0.047a	0.16a	5.07a	0.37a
Control x RT	4.54a	1.25a	2.20a	0.123a	9.31a	1.84a	0.72a	0.017a	0.15a	4.96a	0.27a
CHC240xCT	4.51a	1.53a	2.40a	0.133a	8.06a	1.36a	0.59a	0.010a	0.13a	4.52a	0.21a
NPK400 x CT	4.57a	1.23a	2.12a	0.120a	5.69a	1.44a	1.20a	0.017a	0.15a	4.59a	0.32a
NPK400+CHC120 x CT	4.55a	1.22a	2.11a	0.117a	5.14a	1.68a	0.85a	0.037a	0.14a	3.79a	0.21a
NPK400+CHC 240 x CT	4.60a	1.21a	2.08a	0.117a	6.53a	1.52a	0.99a	0.010a	0.16a	4.69a	0.32a
NPK400+PM 2.5T x CT	4.52a	1.15a	1.98a	0.110a	7.78a	1.68a	0.61a	0.013a	0.13a	4.75a	0.37a
NPK400+PM 5T x CT	4.56a	1.19a	2.06a	0.117a	6.39a	1.36a	3.61a	0.010a	0.12a	5.29a	0.42a
PM 5T x CT	4.46a	1.25a	2.16a	0.210a	12.22a	2.00a	0.54a	0.010a	0.11a	4.45a	0.41a
CHC240 x RT	4.39a	1.47a	2.55a	0.140a	5.31a	1.92a	0.69a	0.023a	0.13a	4.64a	0.27a
NPK400 x RT	4.51a	1.25a	2.20a	0.123a	6.39a	1.52a	0.98a	0.010a	0.13a	5.07a	0.42a

NPK400+CHC120 x RT	4.55a	1.45a	2.50a	0.140a	5.86a	1.52a	0.86a	0.017a	0.14a	4.58a	0.32a
NPK400+CHC 240 x RT	4.45a	1.32a	2.28a	0.130a	4.93a	1.52a	0.83a	0.020a	0.30a	4.80a	0.32a
NKP400+PM 2.5T x RT	4.47a	1.55a	2.67a	0.150	7.36a	1.60a	0.84a	0.020a	0.16a	4.59a	0.32a
NPK400+PM 5T x RT	4.33a	1.17a	2.02a	0.113a	6.25a	1.52a	0.87a	0.017a	0.13a	4.98a	0.32a
PM 5T x RT	4.36a	1.25a	2.16a	0.120a	8.33a	1.60a	1.23a	0.010a	0.09a	4.37a	0.27a

Note: means within a column not sharing a letter in common differ from other means significantly following Duncan's Multiple Range Test (DMRT) at 5 %.

Table 2b: Effect of soil amendments and tillage methods on soil properties

Treatments	Ph	OC	OM	TN	AP	Ca	Mg	K	Na	H	Al
Fertilizer											
Control	4.49a	1.41a	2.46a	0.138a	7.57b	1.68a	0.78a	0.032a	0.15a	5.01a	0.32a
CHC240	4.45a	1.50a	2.47a	0.136a	6.68b	1.64a	0.64a	0.017a	0.13a	4.58a	0.24a
NPK400	4.54a	1.24a	2.16a	0.122a	6.04b	1.48a	1.09a	0.013a	0.14a	4.83a	0.37a
NPK400+CHC120	4.55a	1.33a	2.31a	0.128a	5.50b	1.60a	0.85a	0.027a	0.14a	4.19a	0.26a
NPK400+CHC 240	4.53a	1.26a	2.18a	0.123a	5.73b	1.56a	0.91a	0.015a	0.23a	4.75a	0.32a
NKP400+PM 2.5T	4.49a	1.34a	2.32a	0.130a	7.57b	1.68a	0.72a	0.016a	0.14a	4.67a	0.35a
NPK400+PM 5T	4.45a	1.18a	2.04a	0.115a	6.32b	1.44a	2.24a	0.013a	0.13a	5.13a	0.37a
PM 5T	4.41	1.25a	2.16a	0.165a	10.28a	1.80a	0.89a	0.010a	0.10a	4.41a	0.34a
TILLAGE											
CT	4.53a	1.29a	2.21a	0.135a	7.20a	1.57a	1.15a	0.016a	0.14a	4.64a	0.33a
RT	4.45b	1.34a	2.32a	0.130a	6.72a	1.65a	0.88a	0.017a	0.16a	4.75a	0.31a
Fertilizer x Tillage											
Control x CT	4.45a	1.57a	2.72a	0.153a	5.83a	1.52a	0.84a	0.047a	0.16a	5.07a	0.37a
Control x RT	4.54a	1.25a	2.20a	0.123a	9.31a	1.84a	0.72a	0.017a	0.15a	4.96a	0.27a
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NPK400+CHC 240 x CT	4.60a	1.21a	2.08a	0.117a	6.53a	1.52a	0.99a	0.010a	0.16a	4.69a	0.32a
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PM 5T x CT	4.46a	1.25a	2.16a	0.210a	12.22a	2.00a	0.54a	0.010a	0.11a	4.45a	0.41a
CHC240 x RT	4.39a	1.47a	2.55a	0.140a	5.31a	1.92a	0.69a	0.023a	0.13a	4.64a	0.27a
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NPK400+CHC120 x RT	4.55a	1.45a	2.50a	0.140a	5.86a	1.52a	0.86a	0.017a	0.14a	4.58a	0.32a
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PM 5T x RT	4.36a	1.25a	2.16a	0.120a	8.33a	1.60a	1.23a	0.010a	0.09a	4.37a	0.27a

Note: means within a column not sharing a letter in common differ from other means significantly following Duncan's Multiple Range Test (DMRT) at 5 %.

Discussion

Effect of soil amendments and tillage methods on soil properties

The texture of the studied soil was sand which is known to be fragile in nature and susceptible to leaching and erosion by surface run-off water. In addition, coastal plain soils are usually characterized by sandy texture (Amalu and Isong, 2015). The findings of this study corroborate the observation of Akpan *et al.* (2020) [21], who worked on soil with similar textural characteristics. In this study, soil texture remained largely unaffected by amendments and tillage methods, as these practices primarily influence soil structure rather than the proportion of sand, silt, and clay. This observation is supported by Brady and Weil (2008), indicating that soil texture is a relatively stable property. The result also corroborates what was observed by (Amsili *et al.*, 2021) [18], that soil texture is largely determined by the proportion of sand, silt, and clay and is less influenced by soil amendments and tillage methods. Although Jayawardane and Blackwell (1986) [17], have reported that amendments like gypsum can improve the structure of clay soils, enhancing their workability and aeration. The amendments applied in this study was able to increase soil pH slightly. The highest pH (4.55) was associated with

soil amended with NPK400+CHC120 compared to 4.49 observed in control soil. Soil amendments such as lime utilized in other studies significantly increase soil pH, reducing acidity and enhancing nutrient availability (Getahun *et al.*, 2021) [19]. Organic amendments like compost can also gradually raise soil pH through microbial activity and organic matter decomposition (Narambuye *et al.*, 2006) [14]. Tillage methods impact pH distribution. For instance, conventional tillage tends to homogenize pH levels throughout the soil. Although the studied soil was strongly acidic, application of the amendments investigated under this study showed positive influence on soil pH. Notably NPK400+CHC 240g x CT was able to raise the soil pH and enhanced nutrient availability. This is consistent with findings by Li *et al.* (2023), who reported that soil amendments can effectively increase soil pH and reduce aluminum toxicity.

Soil organic carbon (OC) and soil organic matter (OM) did not show any significant ($p>0.05$) difference between the

soils treated with various amendments. However, soil amended with CHC 240g had the highest OC (1.5 %) and OM (2.47 %). The addition of organic amendments, can substantially increase soil OC content, improving soil

structure and fertility (Liu *et al.*, 2021) ^[4]. Reduced tillage practices further enhance OC levels by reducing the rate of organic matter decomposition and promoting the accumulation of plant residues on the soil surface (Loper *et al.*, 2010) ^[2]. This aligns with the results of Bhattacharyya *et al.* (2010), who demonstrated that organic amendments improve soil carbon sequestration and enhance soil fertility. The findings of this study showed that the control soil had the highest values of EC (0.158 ds/m). The impact of tillage methods on EC is also noteworthy. In this study soil under reduced tillage had the highest EC (0.122ds/m). Studies indicated that conventional tillage, which involves extensive soil disturbance, often leads to a temporary increase in soil EC due to the rapid mineralization of organic matter (Chagbe *et al.*, 2020) ^[5]. However, this can also lead to the loss of soil structure and increased erosion over time (Adekiya *et al.*, 2010) ^[3]. Conversely, reduced tillage practices help maintain soil structure and organic matter content, which can contribute to more stable soil EC levels and improved retention of nutrients like K (Wang *et al.*, 2023).

In terms of exchangeable cations, it was observed that soil amended with PM 5T, NPK400+PM 5T, control soil and NPK400+CHC 240g had the highest Ca (1.8 cmol/kg), Mg (2.24 cmol/kg), K (0.032cmol/kg) and Na (0.23 cmol/kg), respectively. In previous studies demonstrated by Jayawardane and Blackwell (1986) ^[17]. and Getahun *et al.* (2023), amendments such as lime and gypsum significantly increase the levels of exchangeable Ca and Mg, essential for soil structure and plant health. Organic amendments provide a steady release of nutrients, including K, which is crucial for plant growth (Mikha *et al.*, 2004) ^[24]. Among the tillage method implemented under this study, reduced tillage had high levels of exchangeable cations mostly. Reduced tillage practices generally help in maintaining higher levels of exchangeable Ca, Mg, and K due to reduced soil disturbance and better organic matter retention (Figueiredo *et al.*, 2017) ^[10, 16]. According to Esmaeil, (2018) ^[9], amendments that correct soil pH also enhance the availability of exchangeable cations, improving overall soil fertility. Moreso, soil amended with NPK400+PM 5T had level of ECEC (7.69 cmol/kg). Organic amendments enhance ECEC by increasing the soil's ability to retain and exchange cations, which is crucial for nutrient availability (Imakumbili *et al.*, 2021) ^[12]. Reduced tillage practices contribute to higher ECEC values by preserving soil organic matter and minimizing nutrient loss through erosion (Cadavid *et al.*, 1998) ^[11]. This was in line with the observation in this study. BS showed notable increases following the application of organic amendments and reduced tillage. This is attributed to the higher organic matter content and improved soil structure, which enhance the soil's ability to retain and exchange cations. These findings are corroborated by Asfaw (2016) ^[13], who emphasized the role of organic matter in improving soil cation exchange capacity and nutrient retention. The low pH, low exchangeable cations, P, TN and ECEC contents of the studied soil observed in the pre-cropping sampled soils are characteristics that typify the coastal plain sand, such values have also been observed by Akpan *et al.* (2020) and Afu *et al.* (2019) ^[20]. in their studies. In addition, such low values in an indication that the soil of the study site have low soil fertility status. Soils with these attributes need effective soil management through an adequate tillage

method and application of soil amendments capable of supplying appreciable quantities of nutrient elements and organic matter. Application of soil amendments and implementation of tillage methods did not have any significant ($p>0.05$) effect on soil properties, except for available P. Studies have shown that organic amendments, such as compost and manure, can significantly increase soil AP by providing a slow-release source of phosphorus, enhancing its availability to plants (Ahmad *et al.*, 2022) ^[6]. Moreover, the combination of organic amendments with reduced tillage methods can create synergistic effects, significantly enhancing soil nutrient e.g., AP while maintaining lower exchangeable acidity and stable EC levels. This integrated approach promotes a balanced soil environment that supports sustainable crop production (Figueiredo *et al.*, 2022). Enhancement of soil AP with organic amendments have been reported by Chagbe *et al.* (2020) ^[5], and it is attributed to the mineralization of organic phosphorus compounds (Liu *et al.*, 2021) ^[4]. In contrast, inorganic fertilizers provide a direct source of phosphorus, though their impact may vary based on the solubility and mobility of the phosphorus compounds used (Adekiya *et al.*, 2009) ^[3]. Tillage methods influence the distribution and availability of AP, with reduced tillage practices helping maintain higher AP levels due to less disruption of soil structure and microbial communities (Uko *et al.*, 2020) ^[22]. Several studies including Alam *et al.* (2014) ^[1], Loper *et al.* (2010) ^[2], Shirani *et al.* (2002) ^[7]. and Jin *et al.* (2023) ^[8, 23]. have recorded successes in the integration of appropriate soil amendments and tillage methods, showing it significant in optimizing soil health, promoting sustainable agriculture, and ensuring long-term productivity. The findings from this study underscore the importance of tailored soil management practices to meet specific agricultural and environmental needs.

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