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RESEARCH ARTICLE

Effects of integrated fertilization on soil sustainability and cassava (*Manihot esculenta* Crantz) yield in an ultisol

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ABSTRACT

The present study was aimed to assess the effects of integrated fertilization on soil and cassava yield. A randomized complete block design (RCBD) was used in the 24 x 5 factorial. Factor A comprised 24 cassava genotypes, while Factor B comprised five fertilizer treatment rates (2.5 t/ha poultry manure (PM) + 300 kg/ha NPKMg, 5 t/ha PM + 200 kg/ha NPKMg, and 7.5 t/ha PM + 100 kg/ha NPKMg), 400 kg/ha NPKMg fertilizer, and control. Integrated fertilizer application improved soil fertility compared to 400 kg/ha NPKMg and control treatments. Integrated fertilization of 7.5 t/ha PM and 100 kg/ha NPKMg had a 16–26% and 15–25% significant increase in soil pH compared to other treatments, respectively. Application of 7.5 t/ha PM + 100 kg/ha NPKMg had significant organic matter content at harvest (2.92 and 3.11%) compared to initial values of 1.37 and 1.55%. The treatments of 7.5 t/ha PM and 100 kg/ha NPKMg had (30-88% and 30-87%) and (8-94% and 11- 91%) higher organic matter and N than other treatments at harvest. Significant differences ($P<0.05$) were observed in storage root yields. The NR07/0240 produced significant storage root yields of 34.41 and 34.12 t/ha in both cropping seasons. *Obubit Okpo* had the least yield: 7.34 and 6.55 t/ha. Treatment with 7.5 t/ha PM and 100 kg/ha NPKMg out-yielded other fertilizer treatments, while control had the least storage root yield. The result revealed that treatments with integrated fertilizers had lower soil pH, significantly higher total N, organic matter, and exchangeable bases at harvest.

Keywords: Cassava, Integrated fertilization, Soil Sustainability, Yield

INTRODUCTION

Cassava (*Manihot esculenta* Crantz) is an essential source of carbohydrates for many families in Sub-Saharan Africa, especially in West and East Africa. Nigeria is a major producer of cassava. In 2021, Nigeria produced about 63 million metric tons of cassava. The Democratic Republic of the Congo followed this. Cassava is a staple food in many countries in the sub-Sahara region but is also industrially used in the production of ethanol, pharmaceuticals, animal feed, starch, and more. Despite Nigeria being the largest producer of cassava globally, the cassava industry has not achieved its full potential in meeting the global market for cassava.

In Nigeria and other parts of West Africa, cassava is usually cultivated without the application of organic or mineral fertilizers because it is presumed that cassava is well-adapted to marginal soil or soil with low fertility status; this assumption creates the false impression or superstition that cassava does not require any soil amendment, unlike yam or maize, which require a reasonable amount of fertilizer in low fertile soil. In the rainforest ecology of Nigeria, the soils are low in soil nutrient status. Farmers' yields are lower than the study area's potential cassava yield because of a need for an understanding of fertilizer. Fertilizer application significantly increased cassava root yields in Brazil, India, and Africa (FAO, 2013). Fertilizer increases cassava yield and maintains it for years in Nigeria (Akata, 2015; Ikeh, 2017). Without considering varietal differences or Nigeria's varied environment, Nigeria's cassava fertilizer recommendation is 400 kg NPK 15:15:15 per hectare (Udoh et al., 2005). Considering that mineral fertilizer is associated with many issues, such as soil acidification, leaching, and being expensive (Udounang et al., 2022) Therefore, such recommendations must also consider organic-based fertilizer as an option. Organic manure is slow-release and required in large quantities. Considering the pros and cons of both conventional and non-conventional fertilizers, there is a need to integrate both for efficient nutrient utilization without jeopardizing the environment. Integrated fertilizer application has been proven to be a sound method of low-nutrient management and acidic soil amelioration (Ndaeyo et al. 2013).

Organic manure helps reduce soil acidity and nitrogen fixation. Poultry droppings and cow dung provide nitrogen, phosphorous, potassium, and micronutrients that help plants grow and yield. Organic fertilizers like poultry manure, cow dung, etc., provide macro and trace components that mineral fertilizer lacks, according to Magkos et al. (2003). It stores humified nutrients. Poultry manure can reduce chemical fertilizer-produced toxins. Poultry manure boosts soil organic matter (OM) and releases nutrients (Magkos et al., 2003). Asaduzzaman et al. (2010) and Ikeh et al. (2017) noted that manure increased soil fertility and water holding capacity, stored plant nutrients, buffered nutrient fluctuations, increased soil cation exchange capacity, and stimulated microbial activity by increasing temperature, which improved soil physical properties. Poultry dung enhances root and vegetable growth due to its strong photosynthetic activity and vital nutrients (John et al., 2004). In intensive agricultural production, inorganic fertilizer and organic manure are better than either alone. Nweke and Nsoanya (2015) and Ikeh (2017) found that organic manure and mineral fertilizer increase nutrient usage efficiency. Sustainable agriculture requires inorganic fertilizer and organic inputs (Vanlauwe, 2010).

Smallholder farmers in tropical countries like Nigeria should use organic and mineral fertilizers to maintain soil fertility and crop yield. Ayoola and Makinde (2009) discovered that organic input plus inorganic fertilizer boosted cassava root yield by 73% to 95% in Western Nigeria. Akata (2006) found that 2.5 t/ha of poultry manure and 200 kg/ha of NPK increased cassava productivity in the rainforest zone of Nigeria. Poultry dung with NPK fertilizer enhanced nutrient availability in cassava, resulting in high tuber yield (Ojeniyi et al., 2012). Pypers et al. (2012) found cassava responded to inorganic fertilizer and green manure. Pypers et al. (2012) found that green manure (Tithonia or Chromolaena) plus mineral fertilizer made cassava farming more profitable than slash-and-burn in the DR Congo. Therefore, this research was carried out in the acid coastal soils of Akwa Ibom State to envisage a solution to poor cassava yield and determine the integrated fertilization level to improve cassava yield without jeopardizing the soil.

MATERIALS AND METHODS

Experimental Site and Cropping History

This study was conducted at the National Cereals Research Institute (NCRI) Uyo outstation, located at Owot Uta, Ibesikpo/Asutan Local Government Area of Akwa Ibom State, during the 2012 and 2013 planting seasons. Ibesikpo/Asutan is located 64.12 m above sea level at Latitude: 5° 02' 60.00" N Longitude: 7° 55' 59.99" E (UCCDA, 1988).

Southeastern Nigeria's humid tropical rainforest contains Ibesikpo/Asutan. It averages 2500 mm of rainfall and 9.29 hours of sunshine each month at 23.49oC. Ibesikpo/Asutan has a 70% mean annual relative humidity and 2.6 cm2 evaporation rate (Peters et al., 1989). Ibesikpo/Asutan has bimodal rainfall. Rainfall occurs from March to November, with an "August Break" of relative moisture stress in August (Peters et al., 1989). The area's temperature is generally high from February through April (Enwezor et al., 1990). In the 2012 planting, the experimental site was previously cropped with fluted pumpkin, rice, and okra before it was followed for two years, while in the 2014 planting, the site was previously cropped with maize, egusi melon, and okra, before planting, the site was fallowed for one year. Both the 2012 and 2013 trials were carried out in the same location but in different land rotations.

Soil Sampling

Before planting and after harvest, soil augers gathered composite soil samples at 0–15 cm and 15–30 cm depths. For physicochemical examination, soil samples were collected in polythene bags, labeled, air-dried, crushed, and sieved through a 2.0 mm screen.

Soil Analysis

Soil physicochemical properties: A pH meter with a glass electrode measured soil pH in water 1:2 (Bates, 1954). Micro-Kjeldahl digestion and distillation measured soil nitrogen (Ibia and Udo, 2009). Walkley and Black (1934) used dichromate wet oxidation to measure soil organic matter. Bray-1 (Bray & Kurtz, 1945) measured soil phosphorus. Neutral NH4OAC extracted exchangeable cations. EDTA titration determined calcium and magnesium in the extract (Jackson, 1962), whereas a flame photometer evaluated potassium and sodium. 1N KCl extracted exchangeable acidity. Juo (1975) titrated exchangeable acidity. Exchangeable acidity minus exchangeable aluminum yielded exchangeable hydrogen. ECEC was calculated by adding exchangeable cation and acidity (Ibia and Udo, 2009)). Percentage base saturation was calculated as described by Ibia and Udo (2009). Percentage Base Saturation= summation of exchangeable cations/ECEC × 100.

Experimental Design and Treatments

Twenty-four cassava genotypes and five integrated rates of poultry manure and mineral fertilizer (NPKMg 12:12:17:2) were set up in a RCBD and replicated three times in a factorial arrangement. Factor A treatments were of 24 cassava genotypes, namely: NR 07/0145, NR 07/0246, NR 07/0240, TMS 1070134, TMS 01/1412, TMS 01/1368, TMS 01/1371, TMS 1061635, TMS 1070337, and TMS 070593, NR05/0067, NR05/0363, NR05/0266, NR05/0028, NRCOB 3-5-4, NR05/0166, TMS 1071313, TMS 1950289, TMS 1010034, and TMS 1020452, and three National check varieties (TMS 30572; NR 8082 and TMS 98/0581) obtained from the International Institute of Tropical Agriculture (IITA), Ibadan, Nigeria and National Root Crops Research Institute (NRCRI) Umudike, Nigeria and one local variety (*Obubit okpo*) were used in the study. Factor B treatments were five fertilizer treatments: NPKMg (12:12:17:2) fertilizer with poultry manure (300 kg/ha NPKMg + 2.5 t/ha poultry manure, 200 kg/ha NPKMg + 5 t/ha poultry manure, 100 kg/ha NPKMg + 7.5 t/ha poultry manure, 400 kg/ha NPKMg, and control (no fertilization).

Experimental Plot Size

The experimental area was 148 m x 22 m (3256 m^2). Each plot was 5 m x 5 m (25 m^2), with 120 plots in each replicate and 360 plots in all. The spacing of 1.5 m paths separated plots and replications.

Agronomic Practices

The experimental site was plowed, harrowed, and ridged with a tractor and marked out with measuring tapes, rope, and pegs. Planting was 45° sloped at 1.0 m x 0.8 m spacing. September 2012 and 2013 saw all planting. After mechanical field preparation, poultry manure was mixed into the soil. The ring approach administered inorganic fertilizer (NPKMg-12:12:17:2) at 2 months after planting (MAP). Slashing was done at 5 MAP and manual weeding at 1 and 3 MAP with a native weeding hoe. Cassava storage roots were collected 12 months after planting (MAP).

Data Collection

Yield Parameters

Counting every storage root that each cassava stand produced allowed for the calculation of the harvested storage root quantity. Storage root length (in cm) was measured from the proximal to distal end using a flexible measuring tape. Storage root circumference (in cm) was measured by measuring the circumference of storage roots at the middle of each storage root with the aid of flexible measuring tape. Storage root yield (in kg) was determined with a top load weighing balance in kilograms. The weight of harvested cassava storage roots in each net plot was converted to storage root yield and expressed in tons per hectare.

Data Analysis

All the soil and yield data collected were subjected to analysis of variance using Genstat Discovering, 2012 version Model. Means were compared using Duncan Multiple Range Test (DMRT) at a 5% probability level.

RESULTS

Soil Physico-Chemical Properties of Experimental Site Before Planting

The soil analysis results before planting revealed that the soil was slightly acidic, with pH values of 5.13 and 5.25 in the 2012/2013 and 2013/2014 cropping seasons, respectively (**Table 1**). The percentage organic matter values were 1.37 and 1.55% in the 2012/2013 and 2013/2014 cropping seasons, respectively, while total nitrogen content (0.04 and 0.07%, respectively) was low. The available P (mg/kg) contents were 94.59 and 95.81 in the 2012/2013 and 2013/2014 cropping seasons, respectively (Table 1), further indicating that exchangeable bases showed that Ca, Mg, Na, and K concentrations in the 2012/2013 cropping season were 2.10, 1.73, 0.59, and 1.15 cmol/kg, respectively. In the 2013/2014 cropping season, the following values were recorded: 1.99, 1.45, 0.70, and 1.16 cmol/kg. The exchangeable acidity values were 1.05 and 1.37 in the 2012/2013 and 2013/2014 cropping seasons, respectively, while the ECEC of the soil was 6.06 in 2012/2013 and 5.88 in 2013/2014. The soil bulk density was 1.45 and 1.45 g/cm^3 in both cropping seasons. The particle size analysis revealed that the soils were predominantly sandy (88.40 and 83.95% in 2012/2013 and 2013/2014, respectively). Silt particles were 4.50 and 6.35%, respectively, while clay particles were 7.10 and 9.70% in the 2012/2013 and 2013/2014 cropping seasons, respectively.

Soil Chemical Properties at Harvest

Soil pH

The soil pH as influenced by cassava genotypes showed no significant difference in both cropping seasons (Table 2). However, soil pH influenced by the combined application of organic and inorganic fertilizer, varied significantly different ($p<0.05$) in both cropping seasons (**Table 2**). The highest soil pH (6.90 and 6.75 in the 2012/2013 and 2013/2014 cropping seasons, respectively) was recorded in the plot that received a reduced rate of inorganic fertilizer and a high level of poultry manure (100 kg/ha NPKMg + 7.5 t/ha poultry manure). It was followed by 5.78 and 5.75 in the treatment of 200 kg/ha of NPKMg + 5 t/ha of poultry manure in both cropping seasons. The lowest pH values, 5.10 and 5.05, in both cropping seasons were recorded in the treatment that received only 400 kg/ha NPKMg. The result shows that the plots that received 100 kg/ha NPKMg + 7.5 t/ha poultry manure had a 16–26% and 15–25% increase in soil pH compared to other fertilizer treatments in the 2012–2013 and 2013–2014 cropping seasons, respectively.

Electrical conductivity (EC) (dS/m)

The electrical conductivity of the soil as influenced by cassava genotypes and the combined application of organic and inorganic fertilizers showed no significant difference ($P<0.05$) in both cropping seasons. (**Table 2**). However, for the cassava genotypes, it ranged from 0.020–0.022 and 0.020–0.024 in the 2012–2013 and 2013–2014 cropping seasons. The effect of fertilizer application on EC also showed no statistically significant difference ($P<0.05$) in both cropping seasons. The EC values ranged from 0.020–0.021 and 0.020–0.023 in 2012–2013 and 2013–2014, respectively.

Organic matter (%)

The organic matter content of the soil at harvest varied significantly ($P<0.05$) among the cassava genotypes. In the 2012/2013 cropping season, significant organic matter content (2.09) was recorded in *Obubit okpo*, while the least organic matter (1.30) was recorded in the NR07/0240 genotype. In the 2013/2014 cropping season, *Obubit okpo* plot had 2.13% significant organic matter content, while the least was recorded at 1.45% in NR07/0240. The effect of integrated fertilizer application on soil organic matter content at harvest showed a significant difference ($P<0.05$) in both cropping seasons (**Table 2**). The combined application of poultry manure at 7.5 t/ha +100 kg/ha NPKMg plot had a significantly higher organic matter content in both cropping seasons (2.92 and 3.11%, respectively). This was followed by treatment with 5 t/ha + 200 kg/ha NPKMg (2.11 and 2.17%, respectively). The lowest organic matter content in both cropping seasons was recorded in the control (no soil amendment) plot. Application of 7.5 t/ha of poultry manure + 100 kg/ha of NPKMg had 30–88% and 30–87% higher organic matter content compared to the other treatments, respectively.

Total nitrogen

The total nitrogen content as influenced by cassava genotypes, varied significantly (P<0.05) in both cropping. The highest total nitrogen content in the 2012/2013 cropping season was 0.35% recorded in *the Obubit okpo* plot, while the least was 0.11% recorded in the NR07/0240 plot. In 2013/2014 cropping, TMS1010034 and *Obubit okpo* plot had the highest total N; 0.24 and 0.23%, respectively, while the least value (0.11%) was recorded in NR 07/0240 plots. The soil total nitrogen content, as influenced by integrated fertilization (**Table 2**), varied significantly (P<0.05) in both cropping seasons. Treatment of 7.5 t/ha of poultry + 100 kg/ha of NPKMg had significant higher total nitrogen contents of 0.52 and 0.55% in the 2012/2013 and 2013/2014 cropping seasons, respectively. This was followed by 0.48 and 0.49% of total nitrogen, respectively, recorded in the treatment that received 5 t/ha of poultry + 200 kg/ha of NPKMg. The lowest total N value (0.03 and 0.05%, respectively) were recorded in the control treatment. The treatment of 7.5 t/ha + 100 kg/ha of NPKMg plot had a total N of about 8–94% and 11–91% compared to the other fertilizer treatments in the 2012–2013 and 2013–2014 cropping seasons, respectively.

Available phosphorus

Both cropping seasons experienced significant differences in the amount of available phosphorus as a result of cassava genotypes and fertilization (**Table 2**). Among the cassava genotypes, the highest available phosphorus (133.45 and 138.55 mg/kg) was recorded in NR05/0166 plots in the 2012/2013 and 2013/2014 cropping seasons, respectively. The least available P (99.75 and 104.25), respectively, was recorded in the TMS 01/1412 genotype. The NR05/0166 genotype plots had 6-25% and 6-28% higher available P content than other cassava plots, respectively. The available P contents showed a significant difference (p<0.05) among the fertilizer treatments. The available P content ranged from 80.25–119.25 mg/kg in control and 88.70–122.94 mg/kg in 7.5t/ha of poultry manure + 100 kg/ha NPKMg.

Soil exchangeable bases

Calcium (Ca)

The soil calcium concentration at harvest differed significantly (p<0.05) among the plots of cassava genotypes in both cropping seasons (**Table 3**). The concentration of Ca ranged from 2.68 to 7.30 cmol/kg in 2012/2013, while a range of 2.89 to 4.69 cmol/kg was recorded in 2013/2014. NR05/0166 and TMS 070337 genotype plots had the highest and lowest Ca concentrations in both cropping seasons. The calcium concentration recorded in all cassava genotype plots was greater than the initial calcium concentration of 2.10 and 1.99 cmol/kg before planting in the 2012/2013 and 2013/2014 cropping seasons. The effect of fertilization on calcium content at harvest also varied significantly (p<0.05) (**Table 3**). The 7.5t/ha of poultry manure + 100kg/ha of NPKMg (12:12:17:2) plots had the highest Ca content (4.62 and 4.90 cmol/kg in the 2012/2013 and 2013/2014 cropping seasons, respectively). This was followed by 5 t/ha of poultry manure + 200 kg/ha of NPKMg (3.05 and 4.12 cmol/kg in 2012/2013 and 2013/2014 cropping seasons, respectively), while the least calcium concentration (0.35 and 0.40 cmol/kg in 2012/2013 and 2013/2014 cropping seasons, respectively) was recorded in the control treatment.

Magnesium (Mg)

The effect of cassava genotypes on the magnesium content of the soil at harvest showed a significant difference in both cropping seasons (**Table 3**). In the first cropping season, the magnesium content ranged between 2.11 and 2.95 cmol/kg in NR07/0145 and NR05/0028 plots, respectively. In the 2013/2014 cropping season, the range was from 2.18 to 3.60 cmol/kg in plots of TMS 01/1371 and NR05/0028, respectively. The Mg content of the soil as influenced by fertilization is presented in Table 3. The result showed a significant difference (p<0.05). The plots that received 7.5t/ha of poultry manure + 100 kg/ha had the highest Mg content (4.53 and 4.99 cmol/kg, respectively) in both cropping seasons. The control treatment had the least Mg content (0.13 and 0.15 cmol/kg) in both cropping seasons.

Sodium (Na)

Table 3 displays the sodium content of the soil at harvest in relation to cassava genotypes. The result varied significantly (P<0.05) among the cassava genotypes. The highest value of Na at harvest (0.88 cmol/kg) was recorded in TMS1070134 plots in the 2012/2013 cropping season. In the 2013/2014 cropping season, the highest Na content (0.88 and 0.89 mmol kg) was recorded in TMS30572 and TMS1020452 plots, respectively. The lowest Na content at harvest, 0.35 and 0.26 cmol/kg in the 2012/2013 and 2013/2014 cropping seasons, was recorded in TMS 01/1412 genotypes. The effect of fertilization on Na concentration at harvest showed a significant difference (p<0.05) in both cropping seasons (**Table 3**). Application of 7.5 t/ha of poultry manure + 100kg/ha of NPKMg had the highest Na concentrations of 0.83 and 0.81 cmol/kg in the

2012/2013 and 2013/2014 cropping seasons, respectively. The lowest values, 0.09 and 0.11 cmol/kg, respectively, were recorded in the control (no soil amendment) treatment.

Potassium (K)

The potassium concentration at harvest, as influenced by cassava genotypes, varied significantly different ($p<0.05$) (**Table 3**). The value of K at harvest ranged from 0.63 cmol/kg in the NRCOB3-5-4 genotype to 1.95 cmol/kg in the NR05/0166 genotype in the 2012/2013 cropping season. In the 2013/2014 cropping season, the value of K at harvest was between 0.66 cmol/kg in the NRCOB 3-5-4 genotype and 1.92 cmol/kg in the NR05/0166 genotype.The result of fertilization's effect on K concentration at harvest varied significantly different ($p<0.05$) in both cropping seasons (Table 3). The application of 400 kg/ha NPKMg had the highest K value at harvest (2.45 and 2.39 cmol/kg in the 2012/2013 and 2013/2014 cropping seasons, respectively). This was followed by the treatment of 2.5t/ha of poultry manure supplemented by 300 kg/ha of NPKMg (2.10 and 2.13 cmol/kg, respectively). The least K at harvest (0.40 and 0.36 cmol/kg, respectively) was recorded in the control treatment.

Exchangeable acidity (EA) and effective cation exchange capacity (ECEC)

Table 3 displays the results of EA and ECEC in relation to cassava genotypes at harvest. Results of both soil chemical properties at harvest showed significant differences in both cropping seasons. The ECEC values ranged from 5.37 cmol/kg in Obubit Okpo to 7.66 cmol/kg in TMS01/1371 in the first cropping season. In the second cropping season, the ECEC value ranged from 6.09 cmol/kg in the NR05/0166 genotype to 7.81 cmol/kg in the TMS 01/1371 genotype. The effect of integrated fertilizer application on exchange acidity showed significant differences in both cropping seasons. The treatment of the sole application of 400kg/ha NPKMg had significantly higher EA levels, 1.92 and 1.95, in both cropping seasons. Treatment of 300kg/ha NPKMg had EAs of 1.07 and 1.05 at harvest in the 2012/2013 and 2013/2014 cropping seasons, respectively. The control treatment had an EA content of 1.23 and 1.27 in both cropping seasons. The lowest EA concentrations, 0.99 and 0.95, were recorded in the treatment that received 7.5 poultry manures + 100kg/ha NPKMg. Table 3 illustrates how integrated fertilization affects effective cation exchange capacity (ECEC). The result of ECEC varied significantly ($p<0.05$) among the fertilizer treatments. Treatment with 7.5t/ha of poultry manure + 100 kg/ha of NPKMg had significantly higher ECECs of 7.20 and 7.60 in both cropping seasons. Treatment of 5 ha of poultry manure + 200 kg/ha of NPKMg had ECEC values of 6.84 and 6.91 in the 2012/2013 and 2013/2014 cropping seasons, respectively. The lowest ECEC values, 2.35 and 2.20, were recorded in the control treatment.

Base saturation (BS)

Soil saturation of the experimental soil at harvest, as influenced by cassava genotypes, differed significantly ($P<0.05$ (**Table 3**). In the first cropping season, the highest percentage of base saturation (76.81%) was recorded in TMS 070593 genotypes, while the least (68.11%) was recorded in NR07/0145 genotypes. In the second cropping season, base saturation ranged from 68.08 in TMS 1070134 to 75.70% in the NR05/0362 genotype.

Yield and Yield Components of Cassava

The number of storage roots per stand, as influenced by cassava genotypes, differed significantly ($p<0.05$) in both cropping seasons (**Table 4**). The NR07/0240 genotype produced a significantly higher number of storage roots per stand, 15.33 and 15.17, in the 2012/2013 and 2013/2014 cropping seasons, respectively. The least number of storage roots per stand, 5.03 and 5.13, respectively, was recorded in the NR05/0166 genotype. The NR07/0240 genotype had 6-66 % and 8-66 % higher storage roots than the other cassava genotypes.

The effect of integrated fertilization on the number of storage roots per plant showed a significant difference ($p<0.05$). The treatment that obtained 7.5 t/ha of chicken manure and 100 kg/ha of NPK Mg had a much higher number of storage roots per stand: 12.41 in the 2012/2013 cropping season and 12.04 in the 2013/2014 cropping season. The least number of storage roots (6.11 and 4.29), respectively, was recorded in the control (no soil amendment) treatment. The fertilizer treatment of 7.5t/ha poultry manure combined with 100kg/ha NPK Mg had 10-51% and 7-48% higher storage roots than other fertilizer treatments.

Cassava storage root length, as influenced by genotypes, varied significantly different ($P<0.05$) in both cropping seasons NR 07/0246 genotype had the longest storage root, 78.66 and 74.18 cm, in the 2013/2013 and 2013/2014 cropping seasons, respectively. The shortest storage roots, 25.30 and 28.24 cm, respectively, were recorded in the NR 05/0166 genotype (**Table 4**).

Table 1. Soil physico-chemical properties before planting

	2012/2013			2013/2014		
	Soil Depth (cm)			Soil Depth (cm)		
Parameters	0-15	15-30	Mean	0-15	15-30	Mean
pH	5.10	5.15	5. 13	5.20	5.30	5.25
EC (dS/m)	0.021	0.029	0.025	0.025	0.030	0.028
Organic matter (%)	1.75	0.98	1.37	1.84	1.25	1.55
Total nitrogen (TN) (%)	0.05	0.03	0.04	0.07	0.06	0.07
Available P (mg/kg)	83.43	105.75	94.59	92.11	99.51	95.81
Exchangeable Bases (cmol/kg)						
Calcium (Ca)	2.18	2.01	2.10	2.11	1.86	1.99
Magnesium (Mg)	1.75	1.70	1.73	1.55	1.35	1.45
Sodium (Na)	0.63	0.55	0.59	0.74	0.66	0.70
Potassium (K)	1.12	1.18	1.15	1.18	1.14	1.16
Exchangeable acidity (cmol/kg)	1.04	1.06	1.05	1.53	1.20	1.37
ECEC (cmol/kg)	5.98	6.14	6.06	5.86	5.90	5.88
Base saturation (BS) (%)	67.60	65.21	66.41	70.15	68.30	69.23
Bulk density (g/cm^3)	1.40	1.50	1.45	1.40	1.50	1.45
Sand (%)	91.30	85.50	88.40	86.70	81.20	83.95
Silt (%)	3.70	5.30	4.50	5.10	7.60	6.35
Clay (%)	5.00	10.20	7.10	8.20	11.20	9.70
Textural class	Sandy/loamy	Sandy/loamy	Sandy/loamy	Sandy/loamy	Sandy/loamy	Sandy/loamy

Table 2. Soil chemical properties at harvest

Treatments	2012/2013 Soil chemical properties					2013/2014 Soil chemical properties				
Cassava Genotypes	pH	EC (dS/m)	Org. Matter (%)	Total Nitrogen (%)	Av. P (mg/kg)	pH	EC (dS/m)	Org. Matter (%)	Total Nitrogen (%)	Av. P (mg/kg)
NR07/0145	6.84^{a}	0.021^{a}	1.95^{a}	0.15^{b}	114.55^{a}	6.70^{a}	0.021^{a}	2.01^{a}	0.18^{a}	122.45^{a}
NR07/0246	6.45^{a}	0.020^{a}	1.40^{b}	0.12^{b}	102.75^{c}	6.55^{a}	0.024^{a}	1.68^{b}	0.13^{dc}	124.30^{a}
TIMS1070134	6.70^{a}	0.03^{a}	1.67^{b}	0.17^{b}	119.88^{b}	6.75^{a}	0.022^{a}	1.75^{a}	0.19a	120.45^{a}
TIMS01/1412	6.60^{a}	0.02^{a}	1.50^{b}	0.13^{c}	99.75^{c}	6.70^{a}	0.022^{a}	1.68^{b}	0.12^{c}	104.25^{b}
NR07/0240	6.75^{a}	0.09^{a}	1.30^{b}	0.11^{b}	101.30^{c}	6.75^{a}	0.021^{a}	1.45^{b}	0.12^{c}	120.66^{a}
TIMS1061635	6.80^{a}	0.021^{a}	1.90^{a}	0.15^{c}	112.68^{b}	6.75^{a}	0.021^{a}	1.97^{a}	0.19^{a}	118.75^{b}
TIMS10170337	6.33^{a}	0.22^{a}	1.39^{b}	0.12^{c}	112.75^{b}	6.45^{a}	0.021^{a}	1.55^{b}	0.13^{bc}	120.45^{a}
TIMS01/1368	6.55^{a}	0.021^{a}	1.38^{b}	0.12^{c}	114.38^{b}	6.59^{a}	0.022^{a}	1.45^{c}	0.13^{bc}	120.45^{a}
TIMS01/1371	6.70^{a}	0.022^{a}	1.88^{a}	0.16^{b}	125.40^{a}	6.77^{a}	0.021^{a}	1.78^{a}	0.15^{b}	128.40^{a}
TIMS070593	6.80^{a}	0.020^{a}	1.58^{b}	0.14^{c}	120.71^{b}	6.84^{a}	0.023^{a}	1.75^{b}	0.15^{b}	119.96^{b}
TIMS1071313	6.70^{a}	0.021^{a}	1.75^{a}	0.17^{b}	114.45^{b}	6.80^{a}	0.023^{a}	1.85^{a}	0.17^{b}	120.45^{a}
NR05/0067	6.80^{a}	0.022^{a}	1.42^{b}	0.12^{c}	120.40^{b}	6.75^{a}	0.020^{a}	1.66^{b}	0.13^{b}	120.98^{a}
NR05/0362	6.70^{a}	0.021^{a}	1.48^{b}	0.13^{c}	102.50^{c}	6.77^{a}	0.023^{a}	1.65^{a}	0.14^{b}	118.33^{b}
NR05/0266	6.80^{a}	0.021^{a}	1.55^{b}	0.14^{bc}	122.75^{b}	6.85^{a}	10.023^{a}	1.68^{b}	0.14^{b}	124.84^{a}
TIM1020452	6.50^{a}	0.022_{a}	1.79^{a}	0.14^{bc}	120.66^{b}	6.58^{a}	0.024^{a}	1.82^{a}	0.15^{b}	123.45^{a}
NR05/0028	6.80^{a}	0.020_{a}	1.48^{b}	0.13^{c}	115.25^{b}	6.81^{a}	0.023^{a}	1.55^{b}	0.14^{b}	124.30^{a}
TMS195289	6.70^{a}	0.021^{a}	1.56^{b}	0.14^{bc}	119.33^{b}	6.75^{a}	0.022^{a}	1.70^{b}	0.14^{b}	120.47^{a}
NRCOB3-5-4	6.50^{a}	0.021^{a}	1.89^{a}	0.16^{b}	108.25^{c}	6.80^{a}	0.024^{a}	1.90^{a}	0.19^{a}	109.40^{b}
NR05/0166	6.33^{a}	0.020^{a}	2.02^{a}	0.32^{a}	133.45^{a}	6.35^{a}	0.023^{a}	2.08^{a}	0.19^{a}	138.55^{a}
TMS1010834	6.72^{a}	0.021^{a}	2.01^{a}	0.30^{a}	121.09^{b}	6.70^{a}	0.024^{a}	2.11^{a}	0.24^{a}	120.37^{a}
TMS30572	6.50^{a}	0.001^{a}	1.68^{b}	0.14^{b}	116.34^{b}	6.60^{a}	0.023^{a}	1.78^{b}	0.18^{ab}	119.68^{a}
NR8082	6.80^{a}	0.023^{a}	1.62^{b}	0.13^{c}	122.61^{b}	6.77^{a}	0.023^{a}	1.70^{b}	0.13^{b}	123.75^{a}
TMS98/0581	6.70^{a}	0.022^{a}	1.40^{b}	0.12^{c}	112.30^{b}	6.80^{a}	0.024^{a}	1.52^{c}	0.12^{b}	118.88^{a}
Obubit Okpo	6.51^{a}	0.022^{a}	2.09^{a}	0.35^{ab}	125.68^{a}	6.57^{a}	0.023^{a}	2.13^{a}	0.23^{b}	130.68^{a}
Fertilization										
400 kg/ha NPKMg	5.10^{b}	0.020^{a}	1.20^{b}	0.20^{b}	118.33^{a}	5.05^{b}	0.024^{a}	1.45^{b}	0.22^{b}	121.45^{a}
300 kg/ha NPKMg+2.5 t/ha PM	5.25^{ab}	0.022^{a}	1.50^{b}	0.18^{b}	115.30^{a}	5.18^{b}	0.021^{a}	1.56^{b}	0.19^{b}	122.08^{a}
200 kg/ha NPKMg+5.0 t/ha PM	5.78^{a}	0.021^{a}	2.11^{a}	0.48^{a}	108.30^{a}	5.75^{a}	0.028^{a}	2.17^{a}	0.49^{a}	121.33^{a}
100 kg/ha NPKMg +7.5 t/ha PM	6.90^{a}	0.025^{a}	2.92^{a}	0.52^{a}	119.25^{a}	6.75^{a}	0.023^{a}	3.11^{a}	0.55^{a}	122.94^{a}
Control	5.52^{b}	0.022^{a}	0.35^{c}	0.03^{c}	80.25^{b}	5.13^{ab}	0.021^{a}	0.40^{c}	0.05^{c}	88.70^{b}

Mean values having the same superscript within each column are not significantly different at 5% probability level.

Table 3. Exchangeable Bases, Exchangeable Acidity, ECEC and Base Saturation of the Experimental Site at Harvest

Cassava Genotypes	2012/2013							2013/2014						
	mg/kg				(cmol/kg)			mg/kg				(cmol/kg)		
	Ca	Mg	Na	K	EA	ECEC	BS%	Ca	Mg	Na	K	EA	ECEC	BS%
NR07/0145	3.89^{a}	2.95^{a}	0.87^{a}	1.08^{b}	1.03^{a}	6.45^{b}	68.11^{b}	4.11^{a}	2.88^{a}	0.75^{a}	1.11^{a}	1.01^{a}	6.74^{c}	68.75^{b}
NR07/0246	3.95^{a}	2.78^{a}	0.70^{a}	0.99^{b}	1.01^{a}	7.10^{a}	68.30^{b}	4.09^{a}	2.79^{a}	0.79^{a}	0.86^{c}	1.08^{a}	6.95^{c}	69.33^{a}
TMS1070134	3.89^{a}	2.65^{a}	0.88^{a}	1.33^{a}	1.03^{a}	7.20^{a}	67.60^{b}	4.20^{a}	2.75^{a}	0.85^{a}	1.24^{a}	1.03^{a}	7.10^{a}	68.08^{b}
TMS01/1412	3.55^{a}	2.68^{a}	0.35^{b}	0.87^{c}	1.08^{a}	7.01^{ab}	67.50^{b}	4.30^{a}	2.77^{a}	0.26^{c}	0.79^{c}	1.02^{a}	7.05^{a}	67.74^{ab}
NR07/0240	3.50^{a}	2.70^{a}	0.41^{b}	0.68^{c}	1.02^{a}	6.68^{ab}	70.15^{a}	4.60^{a}	2.90^{a}	0.40^{b}	0.68^{c}	1.03^{a}	6.15^{d}	71.90^{a}
TMS1061635	5.12^{a}	2.88^{a}	0.33^{b}	1.56^{a}	1.03^{a}	6.60^{ab}	68.30^{b}	3.05^{a}	2.89^{a}	0.31^{b}	1.57^{a}	1.02^{a}	6.70^{c}	69.30^{ab}
TMS10170337	2.68^{b}	2.45^{a}	0.54^{b}	1.51^{a}	1.01^{a}	6.80^{ab}	67.69^{b}	2.89^{b}	2.48^{a}	0.39^{b}	1.49^{a}	1.02^{a}	6.72^{c}	67.60^{b}
TMS01/1368	2.69^{b}	2.33^{ab}	0.42^{b}	0.75^{c}	1.03^{a}	7.01^{ab}	68.80^{b}	2.95^{ab}	2.41^{a}	0.41^{b}	0.71^{c}	1.03^{a}	6.77^{c}	69.30^{ab}
TMS01/1371	3.01^{ab}	2.93^{a}	0.62^{a}	0.85^{c}	1.05^{a}	7.66^{a}	69.30^{ab}	2.98^{b}	3.60^{a}	0.60^{a}	0.87^{c}	1.04^{a}	7.81^{a}	70.84^{a}
TMS070593	3.89^{a}	2.12^{b}	0.59^{a}	1.22^{b}	1.03^{a}	7.12^{ab}	76.81^{a}	4.20^{a}	2.55^{a}	0.56^{b}	1.28^{a}	1.03^{a}	7.18^{b}	71.55^{a}
TMS1071313	4.01^{a}	2.14^{b}	0.73^{a}	1.45^{b}	1.04^{a}	7.00^{ab}	68.74^{b}	4.12^{a}	2.20^{a}	0.75^{a}	1.50^{a}	1.02^{a}	7.10^{b}	70.84^{a}
NR05/0067	3.59^{a}	2.68^{a}	0.49^{a}	0.74^{c}	1.02^{a}	6.85^{ab}	69.55^{a}	3.88^{a}	2.77^{a}	0.52^{b}	0.77^{a}	1.03^{a}	6.86^{c}	72.68^{a}
NR05/0362	3.85^{a}	2.75^{a}	0.75^{a}	1.56^{a}	1.03^{a}	6.76^{ab}	76.14^{a}	3.99^{a}	2.80^{a}	0.74^{a}	1.57^{a}	1.04^{a}	6.80^{c}	75.60^{a}
NR05/0266	3.60^{a}	2.80^{a}	0.66^{a}	1.62^{a}	1.01^{a}	6.75^{ab}	74.33^{a}	3.78^{a}	2.90^{a}	0.69^{a}	1.69^{a}	1.03^{a}	6.81^{c}	75.70^{a}
TIM1020452	3.75^{a}	2.60^{a}	0.84^{a}	1.10^{b}	1.02^{a}	6.68^{ab}	68.74^{b}	3.86^{a}	2.75^{a}	0.89^{a}	1.17^{b}	1.04^{a}	6.67^{c}	69.80^{a}
NR05/0028	3.40^{a}	2.11^{b}	0.40^{a}	0.79	1.03^{a}	7.01^{ab}	66.75^{b}	3.90^{a}	2.18^{a}	0.44^{b}	0.81^{c}	1.03^{a}	7.08^{b}	67.50^{a}
TMS195289	3.99^{a}	2.50^{a}	0.55^{b}	0.87^{c}	1.04^{a}	7.11^{ab}	68.80^{b}	4.20^{a}	2.55^{a}	0.57^{ab}	0.84^{c}	1.05^{a}	7.20^{b}	69.75^{a}
NRCOB3-5-4	3.33^{a}	2.51^{a}	0.38^{b}	0.63^{c}	1.03^{a}	6.90^{ab}	70.60^{a}	4.11^{a}	2.52^{a}	0.39^{b}	0.66^{c}	1.03^{a}	7.10^{b}	71.60^{a}
NR05/0166	7.30^{a}	2.38^{ab}	0.78^{a}	1.95^{a}	1.02^{a}	6.84^{a}	68.51^{b}	4.69^{a}	2.39^{a}	0.75^{a}	1.92^{a}	1.03^{a}	6.09^{d}	67.50^{ab}
TMS1010834	3.70^{a}	2.75^{a}	0.75^{a}	1.14^{b}	1.03^{a}	7.10^{a}	67.90^{b}	4.24^{a}	2.90^{a}	0.71^{a}	1.12^{b}	1.04^{a}	7.20^{b}	68.75^{ab}
TMS30572	3.80^{a}	2.68^{a}	0.83^{a}	1.16^{b}	1.02^{a}	7.14^{a}	68.70^{b}	4.16^{a}	2.70^{a}	0.88^{a}	1.19^{b}	1.03^{a}	7.18^{a}	75.50^{a}
NR8082	3.85^{a}	2.75^{a}	0.85^{a}	1.25^{b}	1.03^{a}	6.88^{a}	67.50^{b}	4.01^{a}	2.90^{a}	0.78^{a}	1.31^{b}	1.03^{a}	6.84^{ab}	72.15^{a}
TMS98/0581	3.50^{a}	2.68^{a}	0.52^{a}	0.93^{c}	1.03^{a}	6.89^{a}	69.50^{a}	3.92^{a}	2.71^{a}	0.61^{a}	0.86^{c}	1.04^{a}	7.09^{a}	71.30^{a}
ObubitOkpo	3.90^{a}	2.75^{a}	0.87^{a}	1.68^{a}	1.02^{a}	5.37^{b}	68.33^{ab}	4.16^{a}	2.79^{a}	0.86^{a}	1.59^{a}	1.03^{a}	6.10^{d}	70.66^{a}
Fertilization														
400 kg/ha NPKMg	1.98^{b}	3.61^{a}	0.40^{b}	2.45^{a}	1.92^{a}	5.90^{c}	65.70^{b}	2.12^{b}	4.06^{a}	0.75^{a}	2.39^{a}	1.95^{a}	6.20^{c}	68.70^{ab}
300 kg/ha of NPKMg + 2.5 t/ha PM	2.01^{b}	3.71^{a}	0.69^{a}	2.10^{a}	1.07^{b}	6.80^{b}	68.40^{a}	2.19^{b}	4.10^{a}	0.60^{a}	2.13^{a}	1.05^{b}	6.75^{bc}	69.74^{ab}
200 kg/ha NPKMg +5.0 t/ha PM	3.05^{a}	3.76^{a}	0.75^{a}	1.95^{ab}	1.00^{b}	6.84^{b}	70.40^{a}	4.12^{a}	4.25^{a}	0.70^{a}	1.92^{b}	0.99^{b}	6.91^{b}	71.08^{a}
100 kg/ha NPKMg+7.5 t/ha PM	4.62^{a}	4.53^{a}	0.83^{a}	1.59^{b}	0.99^{b}	7.20^{a}	72.50^{a}	4.90^{a}	4.99a	0.81^{a}	1.63^{b}	0.95^{b}	7.60^{a}	71.45^{a}
Control	0.35^{c}	0.13^{b}	0.09^{c}	0.40^{c}	$1.23^{a b}$	2.35^{d}	66.70^{b}	0.40^{c}	0.15^{b}	0.11^{b}	0.36^{c}	1.27^{ab}	2.20^{d}	62.60^{b}

Mean values having the same superscript within each column are not significantly different at 5% probability level.

Table 4. Yield and Yield Components of Cassava Genotypes as Influenced by Integrated Fertilization

Cassava Genotypes	2012/2013 Months at harvest				2013/2014 Months at harvest			
	Number of Storage Root/plant	Length of Storage Roots (cm)	Circumference of storage Root (cm)	Storage Root Yield (t/ha)	Number of Storage Root/plant	Length of Storage Roots (cm)	Circumference of storage Root (cm)	Storage Root Yield (t/ha)
NR 07/0145	5.58^{c}	34.75^{de}	16.34^{bc}	12.34	6.33^{d}	38.30^{f}	12.01^{c}	13.92^{e}
NR 07/0246	8.75^{b}	78.66^{a}	20.33^{a}	20.20^{c}	9.12^{c}	74.18^{a}	20.77^{a}	29.40^{b}
TMS 1070134	13.01^{ab}	38.74^{d}	18.40^{b}	22.45^{c}	12.55^{ab}	37.18^{f}	14.67^{b}	24.14^{c}
TMS 01/1412	14.75^{a}	56.73^{b}	20.55^{b}	30.48^{ab}	14.99^{a}	58.22^{b}	22.75^{a}	29.85^{b}
NR 07/0240	15.33^{a}	76.45^{a}	20.33^{b}	34.41^{a}	15.17^{a}	74.31^{a}	20.88^{a}	34.12^{a}
TMS 1061635	5.35^{c}	75.13^{a}	16.30^{bc}	25.36^{bc}	7.25^{cd}	73.17^{a}	15.70^{bc}	26.08^{c}
TMS 1070337	8.99^{b}	45.88^{cd}	16.75^{bc}	29.25^{b}	7.59^{cd}	48.14^{cd}	16.88^{b}	30.40^{ab}
TMS 01/1368	12.81^{ab}	49.25^{c}	20.33^{b}	31.13^{a}	13.40^{a}	47.50^{cd}	21.12^{a}	32.66^{a}
TMS 01/1371	9.25^{b}	45.30^{cd}	20.11^{b}	28.55^{b}	10.20^{bc}	44.17^{d}	20.01^{ab}	27.91^{bc}
TMS 070593	8.28^{b}	52.51^{b}	19.40^{b}	30.10^{ab}	8.59^{c}	53.55^{c}	18.55^{b}	30.11^{ab}
TMS 1071313	9.20^{b}	27.51^{ef}	10.93^{c}	19.80^{cd}	8.75^{c}	29.30^{gh}	11.03^{c}	19.62^{d}
NR 05/0067	8.22^{b}	33.45^{de}	11.18^{c}	20.45^{c}	8.33^{c}	38.44^{f}	12.14^{c}	18.99^{d}
NR 05/0362	7.14^{c}	39.45^{d}	11.33^{c}	21.30^{c}	7.71^{d}	41.33^{e}	11.92^{c}	20.74^{cd}
NR 05/0266	5.66^{c}	65.30^{b}	12.30^{c}	20.11^{c}	6.12^{d}	61.25^{b}	13.66^{c}	19.88^{d}
TMS 1020452	6.20^{c}	45.60^{cd}	12.40^{c}	19.25^{cd}	6.77^{d}	43.11^{e}	13.90^{c}	18.20^{d}
NR 05/0028	10.15^{ab}	55.70^{bc}	18.91^{b}	18.30^{cd}	10.12^{bc}	58.49^{b}	17.66^{c}	17.34^{d}
TMS 1950289	7.33^{bc}	51.11^{c}	18.09^{b}	29.60^{b}	7.73^{cd}	49.91^{cd}	18.12^{b}	29.60^{b}
NR COB 3-5-4	13.88^{ab}	59.67^{b}	19.25^{b}	25.61^{bc}	13.43^{a}	60.17^{b}	19.45^{b}	23.14^{cd}
NR 05/0166	5.33^{c}	25.30^{f}	11.30^{c}	12.68^{e}	5.13^{d}	28.24^{g}	11.34^{c}	10.45^{f}
TMS 1010034	10.18^{b}	32.19^{e}	11.44^{c}	15.68^{d}	10.12^{bc}	39.92^{f}	11.74^{c}	15.75^{de}
TMS 30572	8.25^{b}	28.30^{ef}	10.25^{c}	20.40^{c}	7.58^{cd}	30.01^{g}	11.25^{c}	10.74^{ef}
NR 8082	7.55^{bc}	24.30^{f}	11.09^{c}	20.41^{c}	8.99^{c}	26.75^{h}	11.20^{c}	24.15^{c}
TMS 98/0581	10.58^{ab}	32.30^{e}	15.99^{bc}	20.41^{c}	10.22^{b}	33.45^{g}	14.70^{b}	23.11^{cd}
ObubitOkpo	8.62^{b}	31.07^{e}	11.00^{c}	7.34^{f}	7.34^{c}	30.01^{g}	11.20^{c}	6.55^{j}
Fertilization (F)								
400 kg/ha of NPK Mg	8.77^{ab}	45.95^{c}	12.30^{ab}	19.45^{a}	8.56^{ab}	43.75^{b}	11.70^{b}	18.75^{a}
300 kg/ha of NPK Mg + 2.5 t/ha PM	9.78^{ab}	56.81^{b}	14.30^{a}	20.11^{a}	9.18^{a}	49.90	13.14^{ab}	20.40^{a}
200 kg/ha NPK Mg +5 t/ha PM	11.05^{a}	62.13^{a}	15.30^{a}	20.40^{a}	10.99^{a}	55.30^{a}	14.98^{a}	20.70^{a}
100 kg/ha NPK Mg + 7.5 t/ha PM	11.95^{a}	64.33^{a}	16.75^{a}	20.75^{a}	11.08^{a}	58.11^{a}	16.74^{a}	21.08^{a}
Control	6.01^{b}	31.04^{d}	9.30^{b}	9.35^{b}	6.22^{b}	30.66^{c}	10.11^{b}	7.75^{b}

Mean values having the same superscript within each column are not significantly different at 5% probability level.

The effect of fertilization on the length of cassava storage roots differed significantly different (P<0.05) (**Table 4**). The longest storage root was recorded in fertilizer treatments of 7.5t/ha poultry manure and 100kg/ha NPK Mg. Control (no soil amendment) treatment produced the shortest storage roots in both cropping seasons. The combined application of 7.5t/ha poultry manure and 100kg/ha NPK Mg had 3–49% and 4–48% longer storage roots compared to other fertilizer treatments in both cropping seasons, respectively.

Cassava storage root circumference, as influenced by genotypes, differed significantly different (p<0.05). TMS 01/1412 had significantly bigger root circumferences (20.55 and 22.75 cm) in the 2012/2013 and 2013/2014 cropping seasons, respectively. The smallest storage root circumferences, 10.93 and 11.03 cm, respectively, were recorded in the TMS 1071313 genotype. The TMS 01/1412 genotype had a bigger storage root circumference of 1–47% and 8–52% in the 2012–2013 and 2013–2014 cropping seasons compared to the other cassava genotypes. The effect of fertilization on storage root circumference showed a significant difference (p<0.05) irrespective of cropping season (**Table 4**). In both cropping seasons, the largest storage root circumference (16.75 and 16.74 cm in both cropping seasons) was recorded in 7.5 t/ha poultry manure + 100 kg/ha NPK Mg treatment. The control treatment had the smallest storage root circumference (9.30 and 10.11 cm) in both cropping seasons.

The cassava storage root yield, as influenced by genotypes, varied significantly (P<0.05) in both cropping seasons. Cassava storage root yield ranged between 7.34t/ha in *Obubit okpo* and 34.41t/ha in the NR 07/0240 genotype in the 2012/2013 cropping season. In the second planting season, 6.55t/ha of *Obubit okpo* was recorded, while 34.12 t/ha of storage root yield was recorded in the NR 07/0240 genotype. The NR 07/0240 genotype had a 10–64% higher storage root yield than other cassava genotypes. The fertilizer application effect on cassava storage root yield also showed a significant difference (p<0.05) in both cropping seasons (**Table 4**). The highest storage root yield was recorded in the treatment that received 7.5t/ha poultry manure + 100kg/ha NPKMg (20.75, t/ha in 202/2013 and 21.08 t/ha in 2013/2014). This was followed by the application of 5.0t/ha poultry manure supplemented with 200kg/ha NPKMg (20.40 and 21.08 t/ha). Integrated treatments of 7.5 t/ha PM and 100kg/ha NPKMg had a 2-55 % and 2-56 % higher storage root yield compared to other fertilizer treatments in both cropping seasons, respectively.

DISCUSSION

The results of the study revealed significant variations in plant nutrient content at harvest. Even though there wasn't a clear pattern to how cassava genotypes affected the concentration of nutrients, the content of nutrients like organic matter, total nitrogen, and exchangeable bases was low in some cassava genotypes that had significantly higher yields of storage roots. TMS01/1412 and NR07/0240 that produced significant storage root yield were among the genotypes that had low soil nutrient reserves at harvest, while genotypes like Obubit Okpo that had the least storage root had a significant nutrient reserve at harvest. This observation shows genotype had an influence on soil nutrient reserve at harvest. The differences recorded in soil nutrient content at harvest could be that different cassava genotypes had different nutrient utilization patterns, and some genotypes had significantly higher organic matter and nitrogen content at harvest. This could be because the integrated fertilizers applied were well utilized by cassava genotypes, which invariably led to vigorous growth, branched profusely, therefore promoting higher storage root yields. This finding is consistent with Sneha et al. (2018) assertion that nutrient utilization efficiency demonstrates a crop's capacity to absorb and use nutrients for maximum yields. Nutrient use efficiency, according to Sneha et al. (2018), includes nutrient absorption, assimilation, and utilization. Shoot, grain, pod, tuber, or storage root yield per unit of nutrient accumulated in the shoot, grain, pod, tuber, or storage root varies with crop species, varieties, crop tissue, and crop age. This ratio can be used to measure a crop's efficiency in using nutrients. Some of the cassava genotypes in the study had much higher storage root yields than others; these genotypes included TMS01/1412, NR07/0224, and TMS01/1368, which had low levels of total nitrogen and organic matter at harvest. This might be the case because the majority of the cassava genotypes that produced notable storage root production were able to make use of the soil nutrients that were provided to them by the integrated application. This finding concurs with Ikeh's (2017) claim that genetic heterogeneity in crops for nitrogen utilization is widely known. Some processes and plant systems, such as variations in uptake, movement in the root, shoot demand, and biomass output, are influenced by genotypic variability, which has an impact on nutrient uptake. The efficiency of nutrient utilization is also impacted by intraspecific genetic variation (Sneha et al., 2018). The leaves that fell from cassava plants throughout the developing stage may have decomposed and been contributed to the soil as organic manure over the course of the 12-month plant growth period, increasing soil nutrients at harvest. This procedure might have helped sustainably improve the lack of nutrients in the soil.

The impact of fertilization on the yield and growth of several cassava genotypes varied greatly. All fertilized plots had significantly higher yields and yield component metrics than the control treatment. The low fertility of the acidic coastal plain soils in the southeastern Nigerian rainforest habitat might explain this. The low nitrogen content of the experimental soil may have contributed to the increased response to fertilizer observed in the study. This finding supports Akata et al. (2016), who found that crops respond to soil amendments more favorably in low-nutrient reserve soil than high-nutrient reserve soil. According to Ikeh et al. (2023), organic manure's liming effect, which helped raise soil pH, increased soil fertility, which may have contributed to the growth and production increases seen in groups that received both organic and inorganic fertilizers. While Ikeh et al. (2012) noted that organic fertilization is a different and less expensive source of liming material, Ndaeyo et al. (2013) noted the synergistic effect of organic and inorganic fertilization in improving crop output. Mullins et al. (2005) showed that excessive acidity caused a decrease in the uptake of nutritional elements, particularly phosphorus, nitrogen, and potassium, which resulted in a dramatic fall in crop output. Strong acid in soil restricts the availability of cations like Ca, Mg, and K, according to Udoh et al. (2005).

The increase in yield recorded in cassava genotypes grown in fertilized plots could be because the fertilizers applied were well utilized and thus could support the growth, development, and yield of cassava genotypes. Akata (2015) found that cassava used organic fertilizers for cell proliferation, amino acid synthesis, energy production, and photosynthesis. The sinks-growing buds and storing roots-received photosynthetic products. Akata et al. (2016) found that 400 kg/ha of inorganic fertilizer outperformed no soil amendment plots, showing that crops used nutrients well and increased sink capacity. Sink capacity (more storage roots per plant, longer and broader storage roots) enhanced cassava growth and production after fertilizer application. Fertilizer increases root dry matter partitioning per plant (Fermont, 2009).

The poultry manure (7.5 t/ha) supplemented with 100 kg/ha of NPKMg fertilizer treatment performed better than the sole application of 400 kg/ha of NPKMg. This could be due to the high content of some macro and micronutrients recorded in poultry manure, coupled with the NPK and Mg content of organic and inorganic fertilizers. Poultry manure supplemented with inorganic fertilizer (NPKMg) enhanced a higher number of storage roots per plant, storage root length, circumference, and yield compared to yield parameters recorded in the sole application of 400 kg/ha NPKMg. The significant yield recorded in integrated fertilizer treatments could result from the role of poultry manure in soil conditioning, such as moisture retention, improved soil structure and soil aeration, and liming potential, in addition to an increase in nitrogen availability. They have increased poultry manure levels with reduced inorganic fertilizer and performed better in cassava yields. According to Mouneke et al. (2013), organic manure improves soil fertility, water holding capacity, plant nutrient storage, cation exchange capacity, and microbial activity by increasing temperature, which improves soil agro-physical properties. Both fertilizers' nitrogen content increased stored root output in fertilizer plots. Nitrogen boosts plant physiological activity and photo-assimilates synthesis. An increase in N, P, K, and other micronutrients could have led to more merismatic and photosynthetic activity and more assimilate production in cassava, which moved to dry matter production.

CONCLUSION

The result of the study revealed that integrated fertilization could enhance cassava yield in an Ultisol and improve soil fertility even at harvest. The improvement in soil pH, increase in soil organic matter, and exchangeable bases at harvest have proved that integrated fertilization could sustain the marginal and impoverished soil of southeastern Nigeria and promote high cassava yield. The study shows that NR07/0240 and TMS01/1412 genotype plots had lower soil nutrient content at harvest while the highest was recorded in *Obubit okpo*. This revealed that different cassava genotypes respond differently to soil amendment. In general, application of integrated fertilizer would assist in enhancing food security and sufficiency for the nation. Cassava farmers should embrace this production technology for high storage root yield and to sustain the soil.

DISCLOSURE STATEMENT

The authors declare that there is no conflict of interest regarding the publication of this article.

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