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Integrated Use of Poultry Manure and NPK Fertilizer on Soil Properties and Cocoyam Production

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Authors' contributions

This work was carried out in collaboration between Professor NESL. Dr. BEU designed the study, performed the statistical analysis, and wrote the first draft of the manuscript. Professor NESL designed the experiment, wrote the protocol and managed the literature searches. Both authors read and approved the final manuscript.

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ABSTRACT

The increasing food security and industrial demand for cocoyam has compelled soil Scientist to evaluate the use of organic and inorganic fertilizers alone or in combination to enhance early establishment, canopy development and yield of cocoyam (*Colocasia esculenta* L. Schott.). In this study, integrated use of chemical fertilizer (N) with poultry manure (PM) as amendments at different rates on soil physical and chemical properties and cocoyam production in coastal plain soil was investigated. Treatments were: Control- (PM_0N_0), 5 t ha^{-1} PM (PM_5N_0), 10 t ha^{-1} PM ($PM_{10}N_0$), 200 kg NPK ha^{-1} (PM_0N_{200}), 100 kg NPK ha^{-1} (PM_0N_{100}), 2.5 t PM + 100 kg NPK ha^{-1} ($PM_{2.5}N_{100}$) and 5 t PM + 100 kg NPK ha^{-1} (PM_5N_{100}). Results revealed that physical and chemical properties of the soil and cocoyam yield were substantially ($p < 0.05$) improved by applications of 10 t ha^{-1} (PM_{10}) poultry manure and a combinations of lower rates (PM_5N_{100}). Water holding capacity, total porosity and soil organic matter were substantially increased by 64%, 30% and 72% respectively by the applications of 10 t ha^{-1} PM, and PM_5N_{100}. Saturated hydraulic conductivity was significantly ($p < 0.05$) higher in PM_5N_{100} (25.8 cm h^{-1}) followed by $PM_{10}N_0$ treatments (24.11 cm hr^{-1}). The PM_5N_{100} treatment also gave the highest yield of cocoyam (4.8 kg m^{-2}) with maximum leaf area index of 96%, sufficient to protect the soil surface from the impact of high tropical rains. In this study, integration of NPK (15:15:15) at 100 kg ha^{-1} with 5 t ha^{-1} poultry manure can be used to improve the soil structural indices and increase yield of cocoyam and allied crops on sustainable basis.

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1. INTRODUCTION

Cocoyam (*Colocasia esculenta* L. Schott) is stem tuber that is widely cultivated in the tropics and sub-tropical countries of the world. It is a member of *Araceae* family. Cocoyam is important crop in countries like Hawaii, Japan, Ghana and Nigeria [1]. In terms of digestibility, contents of crude protein and essential minerals, such as Ca, Mg and P, cocoyam is nutritionally superior to major competitor between cassava and yam [2-3]. They are tropical herbaceous tubers cultivated predominantly as annuals, mainly for their edible starchy-storage underground stems called corms and cormels [4]. Cocoyam has high economic potential, not only as food (main meal and snacks) but as an agro-industrial raw material for pharmaceutical, confectionery, and livestock industries [5].

Cocoyam is one of the fully edible crops, because, the corms and cormels portion are eaten in various food forms while the leaves and flowers are commonly used as spice to garnish and flavour food [3]. Products such as flour, infant foods and beverages have been produced from cocoyam [3]. *Colocasia esculenta* [2] is used in diet of allergic children and adults with gastro-intestinal disorder, and also known to reduce dental decay in children. Small starch granules of cocoyam (1 – 4 µ) are better sources of raw starch for the production of biodegradable plastics than cassava (15 – 17 µ), yam (10 – 70 µ) and potato (50 µ) [3].

A number of studies have discussed the role of organic and inorganic fertilizers in improving the physical and chemical properties of some tropical soils [6-7]. However, the roles of organic and inorganic fertilizers in improving the physical and chemical properties of some tropical soils have been discussed [8,6]. Similar evidence on macro characterization of West African farming systems [9], and perspectives in root and tuber crop research in Africa revealed that cocoyam is not well studied in tropical environment in terms of soil management and yield related constraints. A few studies such as [9], obtained high yield of *Colocasia esculenta* when 60 kg N, 10 kg P_2O_5, and 50 kg K_2O ha^{-1} were applied to a sandy loam soil.

The application of manure to improve soil physical properties such as hydraulic properties and aggregation is important in evaluating the capacity and suitability of the soil to sustain tuber crop production such as cocoyam [10]. In this study, we investigated the effects of poultry manure and NPK fertilizer as amendments in improving the physical and chemical properties of a coastal plain soil for cocoyam production. This will improve our knowledge and make positive contributions on the use of organic and inorganic fertilizers at optimum rates to increase crop production on sustainable basis.

2. MATERIALS AND METHODS

2.1 Site Description and Experiment Layout

The experiment was carried out on a 0.885 ha land area at the Teaching and Research Farm in University of Port-Harcourt, (Lat 4°45 ^{1}N and Long 6°15 ^{1}E) in the rain forest zone of southern Nigeria. Total annual rainfall in the area is in excess of 2400 mm, with two peaks in the months of June and September. Mean monthly temperature ranges from 22° to 32°C, with minimum and maximum relative humidity of 35% and 78% respectively [11]. The soil is classified as *Arenic acrisol* [12]. Sand, silt and clay contents are 710, 152, and 138 g kg^{-1} respectively. The physical and chemical properties of the before planting and poultry manure are shown in Table 1.

The experiment was laid out in a randomized complete block design (RCBD) with five replications. The field was demarcated into 35 plots with each measuring 25 x 10 m (250 m^2). Treatment were:

PM_0N_0: control (native nutrient)

PM_5N_0: plots amended with 5 t PM ha^{-1} yr^{-1}

$PM_{10}N_0$: plots amended with 10 t PM ha^{-1} yr^{-1}

PM_0N_{200}: plots amended with 200 kg NPK 15-15-15 ha^{-1} yr^{-1}

PM_0N_{100}: plots amended with 100 kg NPK 15-15-15 ha^{-1} yr^{-1}

$PM_{2.5}N_{100}$: plots amended with 2.5 t PM ha^{-1} + 100 kg NPK 15-15-15 ha^{-1} yr^{-1}

PM_5N_{100}: plots amended with 5 t PM ha^{-1} + 100 kg NPK 15-15-15 ha^{-1} yr^{-1}

The poultry manure was incorporated to the soil during tillage and allowed for two weeks before planting.

Table 1. Initial properties of soil and poultry manure used for the study

Properties	Soil	Poultry manure
Sand (g kg^{-1})	710	-
Silt (g kg^{-1})	152	-
Clay (g kg^{-1})	138	-
Textural class	Sandy clay loam	-
Bulk density (g cm^{-3})	1.43	-
WHC (g g^{-1})	0.26	-
Total porosity (%)	36.1	-
Ksat (cm hr^{-1})	15.12	-
Organic carbon (g kg^{-1})	16.94	21.58
Total N (g kg^{-1})	0.94	4.08
C/N ratio	18	5.3
Available P (mg kg^{-1})	17.16	-
pH (H_2O)	4.5	7.5
Base saturation (%)	61.6	-
Ca^{2+} (cmol kg^{-1}}	6.1	--
Mg^{2+} (cmol kg^{-1})	2.2	-
K^{+} (cmol kg^{-1})	0.24	-

WHC- water holding capacity, Ksat- saturated hydraulic conductivity, N- nitrogen

2.2 Planting and Crop Data Collection

Fifty grams (50 g) comels of *Colocasia esculenta* variety (NCe 001) were planted in March 2014 and repeated in April 2015 planting seasons. The planting was done on flat after minimum tillage of the soils at plant spacing of 50 x 90 cm. The NCe 001 commonly called cocoindia is characterized by central corm and satellite of smaller cormels. It is popularly used in making cocoyam chips, cocoyam fries and cocoyam frizzles. Total leaf area (LA) of the crop canopy as a measure of bio-productivity of the crop was measured by the method of [13] and calculated as:

Where L is maximum leaf length; B is breath at mid-point; k is reduction factor determined for the crop. Leaf area index (LAI) which expresses the performance of the crop per unit land area was calculated as:

$$\text{LAI}=\frac{LA}{P} \qquad (2)$$

Where LA is the leaf area of the crop is canopy and P is the ground area.

The corms and cormel yield were measured at harvest when the leaves physiologically turned brownish. Harvesting was done manually by gently pulling up the plant, then the cormels separated from the corms.

2.3 Soil Sampling and Analyses

Soil samples were collected at 0-15 cm depth after the 2- year application of the treatments. The disturbed soil samples were sieved through 2 mm sieve and analyzed for particle size distribution, total organic carbon, total nitrogen, pH, available phosphorus, exchangeable bases and base saturation, whereas, the undisturbed soil samples were used for determinations of bulk density, water holding capacity, total porosity and saturated hydraulic conductivity. Particle size-distribution was determined by the method of [14] after dispersion with sodium hexa-metaphosphate. Total organic carbon (TOC) was measured by the wet oxidation dichromate method [15] and was converted to organic matter by multiplying the TOC values by the Van Bemelen factor of 1.724 [16]. Soil pH in water was measured with glass electrode using a 1:2.5 soil/water aqueous solution [17]. Available phosphorus was measured by the Bray II soil extracting procedure [17]. Cation exchange capacity (CEC) was determined by the ammonium acetate displacement method. Exchangeable Ca and Mg were measured using the EDTA complexometric titration method and exchangeable Na and K by flame photometry [17].

Undisturbed samples were collected with a 6 x 5 cm (height x diameter) metal

Bulk density of the soil collected was determined by the method of [18] and calculated as:

$$Bulk\ density = \frac{mass\ of\ oven\ dried\ soil\ (g)}{volume\ of\ bulk\ soil\ (cm3)} \qquad (3)$$

Water holding capacity was calculated as:

$$WHC\ (gg-1) = \frac{Mw-Md}{Md} \qquad (4)$$

Where WHC is the gravimetric water content (g g^{-1}), Mw is mass of wet soil at saturation (g), and Md is mass of oven-dry soil (g).

Total porosity was calculated with core samples using the method of [19] as:

$$\%\ Total\ porosity = \frac{volume\ of\ water\ at\ 0\ kPa}{volume\ of\ bulk\ soil} \times \frac{100}{1} \qquad (5)$$

Saturated hydraulic conductivity was measured by the constant–head permeability test procedure of and calculated using the transposed Darcy's equation for vertical flow of liquids [20]. With this method, leachate volume was measured over time until flow was constant at which time the final flow rate was determined from the equation:

$$Ksat = \frac{Q}{AT} \times \frac{L}{\Delta H} \quad (6)$$

where Ksat is saturated hydraulic conductivity (cm h^{-1}), Q is volume of water that flows through a cross-sectional area (cm^3), A is cross sectional area of core (cm^2), T is time (s), L is length of core (cm), and ∆H is hydraulic head difference (cm).

2.4 Data Analysis

The analysis of variance (ANOVA) for various crop and soil parameters was performed following F-test. When F-test was significant at P < 0.05 probability, treatment means were separated using LSD test. Data were analyzed following standard procedure using the SAS software [21].

3. RESULTS AND DISCUSSION

3.1 Particle Size-Distribution, Water Holding Capacity, Bulk Density and Total Porosity

The applications of organic and inorganic fertilizers have affected the sand and clay content, but did not alter the soil texture. The percentage of total sand decreased while the clay-size fraction increased (Table 2). The increase in clay-size fractions found in organic fertilizer amendment soils may have been due to the additions of fine-particles from the application of poultry manure, and similar effect from the NPK 15-15-15 fertilizer. Conversely, [22] found decreased fine-particle (silt + clay) fractions in continuously ploughed plots without fertilizer application. They explained their finding to the removal of large amount of silt + clay fractions by runoff which was promoted by loss of soil structure through continuous cultivation. This tends to corroborate our assertion that application of organic and inorganic fertilizers increased the silt + clay fraction, improved the soil structure and prevented loss of find soil particle [23]. The significant non-effect of treatments on soil texture was not surprising because soil texture is a reflection of the coastal plain geological formations which is not usually changed by treatments or tillage practices [24]. Significant differences in water holding capacity (WHC), bulk density and total porosity were observed for the treatments. Unfertilized controlled plots showed the lowest values for WHC and total porosity (0.28 g g^{-1} and 45.28%) respectively. Highest bulk density was also found in the controlled plots (Table 2). Hence, combined applications of organic and inorganic fertilizers (PM_5N_{100}) increased WHC and total porosity by 64% and 24% respectively compared with the control (PM_0N_0) while 22% increase was found in plots with sole application of poultry manure or inorganic fertilizer (PM_5N_0, PM_0N_{200}).

The significant effect of treatments on soil bulk density, water holding capacity and total porosity (Table 2), was consistent with findings [7,8] who found that organic manure applications reduced soil bulk density, increased water holding capacity and total porosity. Hence, integrated use of poultry manure and N: P: K fertilizer improved WHC and total porosity compared to sole applications. However, organic fertilizer remained more effective in improving soil structural indices such as bulk density, WHC, porosity and silt + clay fractions. Significant ($p<0.05$) reduction in bulk density was found in plots treated with organic fertilizer (PM) alone followed by the plots integrated use of organic and inorganic fertilizers.

3.2 Soil pH, Organic Matter and Saturated Hydraulic Conductivity

Results showed that application of manure and inorganic fertilizer significantly modified the soil pH, soil organic matter (SOM) and saturated hydraulic conductivity (Ksat) (Table 3). Application of inorganic fertilizer alone increased the soil pH and reduced Ksat while sole application of manure lowered soil pH and increased SOM and saturated hydraulic conductivity.

Indeed, 2-season additions of poultry ($PM_{10}N_0$) increased SOM by 72% and a shift in Ksat toward higher values (moderately rapid). Among the treatments, soil organic matter was in the order of $PM_{10}N_0 > PM_5N_0 > PM_5N_{100} > PM_0N_{200} > PM_0N_0$. Saturated hydraulic conductivity ranged from13.6 cm hr^{-1} in controlled plot to 25.9 cm hr^{-1} in PM_5N_{100}, indicating significant ($p < 0.05$) effect on soil hydraulic properties.

In Table 3, the trend, PM_5N_{100} > $PM_{10}N_0$ > PM_5N_0 > $PM_{2.5}N_0$ > PM_0N_{200} > PM_0N_0 for saturated hydraulic conductivity (Ksat) further confirmed the positive influence organic manure and inorganic fertilizer on Ksat. This is consistent with [23,25] who reported increased in Ksat following applications of poultry manure, and spent mushroom wastes to a tropical sandy soil. The general agreement is that PM_5N_{100} significantly ($p < 0.05$) increased SOM, bulk density, total porosity, and saturated hydraulic conductivity. In addition, decreased in soil bulk density could be linked to increase in soil biopores, resulting in better soil aggregation which ultimately improved soil porosity and water holding capacity [26].

3.3 Effects on Soil Chemical Properties

Application of PM alone or in combination with the inorganic fertilizer increased the overall total N concentration, exchangeable Ca, Mg, K and base saturation status in the soil (Table 4). Maximum total N was found in P_5N_{100} while minimum total N was found in the unfertilized controlled plots. The $PM_{10}N_0$ increased available P of the soil from 14.3 mg kg^{-1} to 53.8 mg kg^{-1} compared with the control plots, indicating a 213.5% increase. Similarly, PM_5N_{100}, $PM_{2.5}N_{100}$, and PM_0N_{200} treatments increased available P by 230.8%, 112.6%, and 85.3% respectively, indicating that combined applications of organic and inorganic fertilizers increased available P, compared with sole application of inorganic fertilizer (Table 4). Exchangeable Ca, Mg and K and base saturation increased significantly ($p<0.05$) due to PM_5N_{100} followed by $PM_{10}N_0$. Similar studies [27] showed that application of organic amendments improved soil N, P and K concentrations when applied with inorganic fertilizers. Authors [28] agreed that organic fertilizers improved nutrient release and their availability similar to what was obtained in this study.

3.4 Effects on Crop Performance

The leaf area index of C*olocasia esculenta* as a measure bio-productivity per unit land area was significantly ($p<0.05$) higher in PM_5N_{100} followed by $PM_{10}N_0$ after the 2 seasons as shown in (Table 5). Maximum yield of corms + cormel was also found in PM_5N_{100} followed by $PM_{10}N_0$ while PM_0N_0 had the minimum yield of corms + comels. These explained that sole application of PM or combined with inorganic fertilizer increased leaf area index and consequently the yield of C*olocasia esculenta*. Hence, *Colocasia esculenta* cultivation without applications of higher rates of poultry manure or in combination at lower rates with N:P:K was not sustainable in low fertility soil [9]. However, PM_5N_0 and $PM_{10}N_0$ plots did not have any significant $P<0.05$ difference in the yield of *Colocasia esculenta*. This result is not widely report [4,9], which often lead to erroneous use of poultry manure in cocoyam production.

It is believed that organic fertilizers usually improved nitrogen use efficiency, micro and macro nutrient recovery and soluble P uptake by the plants. Enhanced K availability obtained in Table 4 may in turn have resulted in better growth and yield of the cocoyam. The is in concurrence with earlier studies [29, 30] applications of organic fertilizers improved soil physical and chemical properties and consequently, crop performance.

Table 2. Effects of organic and inorganic fertilizers on soil physical properties after two cropping seasons

Treatment	Sand ($g\ kg^{-1}$)	Silt ($k\ kg^{-1}$)	Clay ($g\ kg^{-1}$)	Texture	WHC ($g\ g^{-1}$)	Bulk density ($g\ cm^{-3}$)	Total porosity (%)
PM_0N_0	700a	157b	143c	SCL	0.28ab	1.45a	45.28b
PM_5N_0	680a	164b	156c	SCL	0.31b	1.37ab	48.30b
$PM_{10}N_0$	640ab	165b	195ab	SCL	0.36b	1.32ab	50.94b
PM_0N_{200}	600ab	158b	242a	SCL	0.38b	1.43a	53.53b
PM_0N_{100}	650b	158b	192ab	SCL	0.39b	1.42a	46.41b
$PM_{2.5}N_{100}$	600ab	155b	245a	SCL	0.33b	1.31ab	50.57
PM_5N_{100}	680a	158b	162b	SCL	0.46a	1.30ab	50.94a

WHC- water holding capacity; SCL- sandy clay loam Means followed by the same letters for each parameter were not significant at $p < 0.05$

Table 3. Effects of organic and inorganic fertilizer on pH, organic matter and saturated hydraulic conductivity of the soil after two cropping seasons

Treatment	pH (H_2O)	OM (g kg^{-1})	Ksat (cm h^{-1})	Permeability index	Permeability class
PM_0N_0	4.5b	21.6b	13.62b	4	Moderate
PM_5N_0	4.4b	30.9ab	18.34a	5	Moderately rapid
$PM_{10}N_0$	4.3b	37.2a	24.11a	5	Moderately rapid
PM_0N_{200}	5.0a	22.7b	14.72b	4	Moderate
PM_0N_{100}	4.6b	22.8b	13,44b	4	Moderate
$PM_{2.5}N_{100}$	4.4b	27.2c	15.12b	4	Moderate
PM_5N_{100}	4.4b	29.1c	25.85a	5	Moderately rapid

OM- organic matter; Ksat- saturated hydraulic conductivity;
Means followed by the same letters for each parameter were not significant at $p < 0.05$

Table 4. Effects of organic and inorganic fertilizers on some chemical properties of the soil after two cropping seasons

Treatment	Avail. P (mg kg^{-1})	TN (g kg^{-1})	Ca^{2+} (cmol kg^{-1})	Mg^{2+} (cmol kg^{-1})	K^+ (cmol kg^{-1})	BS (%)
PM_0N_0	14.30d	0.56c	6.40d	2.10ab	0.26b	69b
PM_5N_0	18.50d	0.89ab	14.11c	3.21b	0.34a	86a
$PM_{10}N_0$	53.80a	1.67a	15.29ab	4.32a	0.42a	87a
PM_0N_{200}	26.50c	1.49b	16.21a	5.11a	0.43a	85a
PM_0N_{100}	24.80c	0.70ab	12.18b	2.11ab	0.22b	82a
$PM_{2.5}N_{100}$	30.4b	1.52b	12.65b	3.21b	0.31a	77b
PM_5N_{100}	47.30ab	1.84a	16.14a	4.41a	0.36a	87a

TN- total nitrogen; BS- base saturation. Means followed by the same letters for each parameter were not significant at $p < 0.05$

Table 5. Effects of organic and inorganic fertilizers on yield and leaf area index of cocoyam

Treatment	Yield (kg m^{-2}) 1st planting	Yield (kg m^{-2}) 2nd planting	Leaf area index 1st planting	Leaf area index 2nd planting
PM_0N_0	2.2	2.1	5.8	4.3
PM_5N_0	2 8	3.4	6.2	7.4
$PM_{10}N_0$	3.9	4.6	6.9	8.1
PM_0N_{200}	2.7	3.8	6.4	6.7
PM_0N_{100}	2.3	2.9	5.2	6.2
$PM_{2.5}N_{100}$	3.4	4.2	6.1	8.4
PM_5N_{100}	3.5	4.8	6.6	9.6
LSD (0.05)	0.94	1.12	1.01	2.41

4. CONCLUSION

Significant conclusions drawn from this study are that individual and integrated use of poultry manure and N:P:K had significant positive effects the soil physical and chemical properties and cocoyam yield. Lower rates of poultry manure and inorganic fertilizer in particular improved the soil water holding capacity, total porosity, Ksat and bulk density more that applications of high rates of either organic or inorganic fertilizers. Improvements in the soil physical and chemical properties due to the treatments led to concomitant increases in yield and growth attributes of *Colocasia esculenta*. The $PM_{10}N_0$ and PM_5N_{100} can be adopted as promising rates for high yield of cocoyam and maintenance soil health to prevent degradation of soil properties.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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