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Yield Response Trends in a Sweetpotato- Cassava Rotation System under Integrated Composite Manure and Fertilizer Management Strategy

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Abstract Field experiments were conducted in 2014 through 2015 to investigate yield response trends of sweetpotato and cassava in a rotational cropping sequence under one-time application of five rates (0, 2, 4, 6 and 8 t ha^{-1}) of composite manure (M) and four rates (0, 200, 400 and 600 Kg ha^{-1}) of NPK fertilizer (F) on a southeastern Nigerian (SEN) degraded Ultisol. The treatments were replicated thrice and arranged in a randomised complete block design. The results showed that neither M nor F application alone, except their combinations, significantly affected sweetpotato yields. Maximum sweetpotato root yield (15.9 t ha^{-1}) was obtained with combined application of 4 t ha^{-1} M and 400 Kg ha^{-1} F (M_2F_2), which significantly out-yielded the control by 103.1%. In contrast, the treatments had significant (P <0.001) residual main and interaction effects on cassava root yields. Similarly, combining M and F at their highest rates (M_4F_3), also maximised cassava yields (57.69 t ha^{-1}) and significantly out-yielded the control by 89.9%. The results suggests that though M_4F_3, which also produced the 3rd best-performing sweetpotato yield (14.83 t ha^{-1}) that is comparable to those of M_2F_2, may be the technical optimum for sweetpotato and cassava production on the degraded SEN Ultisol under rotational cropping system, other lower rates such as M_3F_1 and M_3F_2which produced equally exceptionally high cassava yield (> 50 t ha^{-1}), could also be recommended on economic consideration and environmental benefits.

Keywords Sweetpotato- cassava, rotation system, integrated composite manure and fertilizer management strategy, degraded Ultisol, yield response trends.

1. Introduction

In a world engulfed in a vortex of population growth, economic instability and rapid climate change, attaining food security has become one daunting challenge for several nations. For Nigeria in particular, it has been reported that all the conventional indicators to food insecurity such as rapidly increasing energy prices, insufficient agricultural sector investment, population increase and rapid increase in the demand for food are prevalent and thus, millions of Nigerians, over 65%, simply cannot afford the food they need for a healthy and productive life [1].

Cassava (*Manihot esculenta* Crantz) and sweetpotato (*Ipomoea batatas* (L) Lam) are important root crops in Nigeria that have become a critical component of the food supply chain and food security needs of the country. They have great potential as an efficient and economic dietary energy source for man and livestock, ranking first and second in food calories production per unit time and area than any other root and tuber crops in Nigeria [2-3]. Their potential of having many value-added products with diverse agro-industrial end-uses [4-6] have expanded their value chain (production, processing, marketing and utilization) to become important food security crops in Nigeria with a huge export market, cash income-generating and foreign exchange–earning potentials [7]. Consequently, cassava and sweetpotato have moved from their respective relegated status of being a "famine crop" and "gap filler" to occupying enviable positions as the 1st and 4th most important root and tuber crops in Nigeria. Currently, Nigeria is the 1st and 2nd largest producer of cassava and sweetpotato in the world with annual production figures of 54 and 4.6 million metric tonnes, respectively [8].

Sweetpotato, like cassava, require low inputs and less management to give relatively reasonable higher yield per unit land area and labour even on marginal lands than other root crops [8-10] with cassava enjoying an added advantage of being drought tolerant and having the ability to survive the 4 – 6 months of dry season [11-12]. And in a world where food production will depend on bringing marginal lands into production, cassava and sweetpotato will play important roles. Despite the immense potentials of these crops, their yields of 14.1 t ha^{-1} for cassava and 4.2 t ha^{-1} for sweetpotato on farmers' fields in Nigeria are low [8] and not high enough to encourage adequate production to satisfy the growing domestic and export requirements of the crops. Yield, unarguably the most important traits farmers look for [13], is variable in relation to edaphic conditions, management and cropping systems (monoculture versus intercropping and crop rotation) [14].

Sweetpotato is a short-duration (3 – 4 months) crop well suited to the double cropping system, particularly during the wet seasons when it has the potential, as low-growing and faster soil-covering crop or planophile, to control erosion and conserve soil and nutrients for the subsequent broader ecologically adaptable crop like cassava. However, the crop is mostly grown as a monoculture but in the Southern part of Nigeria, it can be intercropped with maize, yam, okra, pepper and leguminous crops [15-16] and rarely with cassava due to fear of incompatibility as both are root crops. This most probably explains why references of works on sweetpotato/cassava intercrop cannot be easily cited. Although, intercropping compatible crops results in overall increase in yields of the system and has better land utilization efficiency [16-17], it has also been found to result in excessive competition for production inputs which consequently lower yields of the component crops in the mixture [18-19], results in a more difficult control of weeds [20] and more importantly, is more demanding and exhaustive of resources [21] than sole cropping of either of the two crops. In other words, soil fertility decline is more under intercropping of both tuber crops than sole cropping. In an era when the tendency is towards intensive cultivation or continuous cropping which often leads to soil erosion, nutrient depletion and land degradation [22-23], emphasis is on successful management of resources for agriculture to satisfy changing human needs while maintaining or enhancing the quality of the environment and conserving natural resources.

Decline of soil fertility as a result of continuous cropping and soil erosion has been identified as one of the major production constraints that are responsible for the low yields of crops on soils in southeastern agro-ecological zone of Nigeria [24]. Therefore, soil fertility management and appropriate cropping system(s) are critical to enhancing and sustaining crop productivity on soils of this region that have been found to be of friable consistence, low in organic matter content, water holding and nutrient retention capacities under the characteristically high intensity rainfall pattern of the region. Continuous use of mineral fertilizer alone on these soils without any compensatory organic input sources not only leads to nutrient imbalance and soil acidification but also has been reported to have limited residual effects of the applied fertilizer [25].

The use of animal and compost manure has been reported to contribute for the retention of inorganic nutrients in soils [26]. Results have also shown that poultry manure has a residual effect on the soil after a cropping season [27]. Similarly, Mian *et al.* [28] reported that one-time application of 10-15 t ha^{-1} of farm yard manure (FYM) with inorganic nitrogen (N) or phosphorus (P), increased wheat yields up to 3-4 successive crop cycles under the hot humid conditions of Bangladesh. Furthermore, complementary use of organic and inorganic nutrient sources has been found by several workers to be sustainable for the production of root and tuber crops with consistently higher crop yields [29-31] as well as required for sustainable soil productivity under intensive cultivation in Nigeria. But besides the presence of human pathogens in using animal manure as organic fertilizer [32], organic materials are low analysis fertilizer sources, implying that they are much less concentrated in terms of the nutrient contents and would therefore, require large application rates to meet the nutrient requirement of the crop relative to applying the same amount of the active ingredients in inorganic fertilizers [33]. Hence, the difficulty to source enough from a single organic source occasioned the paradigm shift to a combination of several organic sources (composite manure). Because alternative production systems are needed to satisfy economic and environmental needs, the potential of crop rotation under "integrated nutrient management", merits attention. Integrated nutrient management implies utilizing all available organic and inorganic nutrient resources and this has become a dominant paradigm shift for increased yields in smallholder agricultural system of SSA to ensure both efficient and economic use of scarce nutrient resources [34].

Intercropping systems and crop rotation research have centered mostly on the potential of N contribution by legume and its effect on subsequent, especially cereal crop, while other effects remain poorly understood. Therefore, rotation of sweetpotato with cassava, where sweetpotato is grown in the wet months during the growing season and cassava coming in late in the season appears a more promising alternative for reducing the potential of soil erosion and conserving soil and nutrients for the subsequent cassava crop. There is a dearth of information on this cropping system under the integrated nutrient management strategy. The objectives of this study were to determine: i) the immediate (direct) effect of composite manure and NPK fertilizer on the yield of sweetpotato and ii) the delayed (residual) effect of one-time application of these treatments on cassava yield in a double cropping system at Umudike, a southeastern agro-ecological zone of Nigeria.

2. Materials and Methods

2.1. Description of site and location of experiment

Fields studies were carried out on a sandy loam Typic Paleudult at the eastern research farm of the National Root Crops Research Institute (NRCRI), Umudike ($05^{o}29^{1}$N, 07 32^{1} E and attitude 122m a.s.l.) in Abia State, Nigeria during the 2014 through 2015 cropping seasons. The location is within the tropical rainforest agro-ecological zone of southeastern Nigeria (SEN), characterized by two distinct seasons, the wet season from April to October and the dry season from November to March. The mean annual rainfall of Umudike ranges between 2000 mm and above 2571 mm and temperature varying from 25 to 33^{o}C. The basic (rainfall) meteorological data during the growing seasons, (June – September, 2014 for sweetpotato and November 2014 – November, 2015 for cassava) are shown in Table 3.

The soil which has been derived from coastal plain sediments has been classified as Typic Paleudult [35]. Composite pre-cropping soil sample of twenty sub-samples, randomly collected at 0 – 20 cm soil depth from different spots within the experimental area, was analysed for some physical and chemical properties using standard laboratory methods as described in Udo and Ogunwale [36] and IITA [37]. The chemical composition of the composite manure agro-wastes used for the study was also determined as for the methods for soil. The soil and composite manure data are presented in Tables 1and 2, respectively

The experimental site had been under a 2-year, predominantly guinea grass (*Panicum maximum*) interspersed with giant grass (*Mimosa invisa*), fallow before land preparation.

2.2. Land preparation

The land was mechanically slashed, ploughed, harrowed and ridged with a tractor, manually de-trashed and demarcated into 3m x 3m experimental units or plots before incorporating the composite manure.

2.3. Treatments and design

The treatments consisted of five rates (0, 2, 4, 6 and 8 t ha^{-1}) of composite manure containing N, P_2O_5 and K_2O equivalents of [M_0 (0:0:0), M_1 (62:87:53), M_2 (124:174:106), M_3 (186:261:109) and M_4 (248:3481:212) N: P_2O_5: K_2O kg ha^{-1}] and four rates (0, 300, 400 and 600 kg $^{ha-1}$) of NPK 15:15:15 fertilizer (F) of N, P_2O_5 and K_2O equivalents of [F_0 (0:0:0), F_1 (30:30:30), F_2 (60:60:60) and F_3 (90:90:90) N: P_2O_5 : K_2O kg ha^{-1}). The treatments were laid out as a 5 x 4 factorial in a randomized complete block design (RCBD) with three replications to form 20 treatment combinations. The composite manure (M) was an equal mixture, by weight, of cow dung, poultry droppings (battery cage) and swine waste.

2.4. Fertilizer application/planting of test crops/harvesting

One week after banding in the composite manure and spraying the field with a mixture of pre-and post-emergent herbicide (primextra + sarosate), an orange-fleshed sweetpotato (variety Umuspo1) was planted on 29 June, 2014 on the crest of ridges at a spacing of 1m x 0.3m using four node length cuttings of the sweetpotato vine. The NPK fertilizer (F) was applied to the sweetpotato crop at four weeks after planting (4 WAP) and received one additional manual weeding at 8 WAP. It was grown for 16 weeks and harvested in September 2014, leaving the vegetative residues as surface mulch for the succeeding cassava crop.

Post-sweetpotato and pre-cassava composite soil samples of six sub- samples from each plot were collected at 0 to 30 cm depth. These were processed and analysed for some physico-chemical properties as for the pre-sweetpotato cropping soils (Table 1).

The second crop of cassava (variety NR 8082) was planted on 19 November, 2014 at an angle of 45^o and spacing of 1m x 1m using stem cuttings of 25 cm long into the same plots from where the previous sweetpotato crop was harvested. A mixture of pre-and post –emergent herbicide (Primextra plus Round-up) was applied to the plots, two days after planting the cassava. The cassava received two more additional manual weeding operations and there was no further fertilization of the cassava except incorporation of the decomposing and mineralising residues of the previous crop of sweetpotato during the manual weeding operations. The cassava was harvested on 7 November, 2015 and fresh root yields in tonnes per hectare (t ha^{-1}) estimated from the experimental plot yields (kg ha^{-1}).

2.5. Statistical data analysis

Data obtained from the trials were subjected to analysis of variance (ANOVA) according to the procedure for factorial experiments in RCBD using GENSTAT (2003). Comparison of the treatment means for significance was done using Fischer's least significant difference (LSD) test at 5% probability level.

3. Results and Discussion

3.1. Soil properties and composite manure composition

Some pre-sweetpotato soil properties at the experimental site (Table 1) showed that the surface soil (0 – 30 cm) was sandy loam in texture, extremely acidic in reaction (pH 4.2) and of low organic matter content but high base saturation. The total N, available P (Bray-2), exchangeable cations (K, Ca and Mg), exchange acidity (EA) and effective cation exchange capacity (ECEC) had levels considered low, indicating the low soil fertility status with high leaching potential but of no danger of aluminum (Al) toxicity. These suggest that the soil would require amendment with organic and/or inorganic fertilizer for sustainable crop production.

The high contents of the parameters assayed in the composite manure (M) used in the study (Table 2), implies an agro-waste of high potential to enrich the soil with nutrients and organic matter, as well as has liming potential when incorporated as soil amendment. It was therefore expected to support good crop performance in poorly productive soils.

The total rainfall and number of rainy days for the growing periods of sweetpotato (June – September, 2014) and the following cassava crop (November, 2014 – November, 2015) were 1246.2 mm and 65 days , and 2,223.8 mm and 143 days, respectively, bringing the main total rainfall and rainy days to 3,470 mm and 211 days respectively (Table 3). These indicate that the amount and distribution of rainfall for the establishment and growth of the respective crops during the growing season in the location are sufficient. Adiele *et al.* [38] reported that rainfall amount of 208 mm and distribution of 12 days (rainy days) in the first quarter of the year (Jan – March) was sufficient for the preparatory phase of the farming system, while [39-40] classified a total monthly rainfall greater than 101.6 mm as rainy season. This also suggests that enough moisture was available during the critical establishment period of the drought – tolerant cassava in November, 2014 which had a total rainfall of 147 mm and distribution of 11 days.

3.2. Sweetpotato root yield

The direct effect of composite manure and inorganic (NPK) fertilizer on total fresh root yield of sweetpotato is presented in Table 4. Composite manure or NPK fertilizer application alone recorded not significantly different ($P>0.05$) yields of sweetpotato compared to the control. However, plots that received a combination of composite manure and fertilizer had a significantly ($P<0.05$) higher yields of sweetpotato root. The significant interaction suggested that root yield responses of sweetpotato to either composite manure or NPK fertilizer depend on variation in the rate of each other. The highest root yield of sweetpotato (15.9 t ha^{-1}) was obtained with a combination of 4 t ha^{-1} composite manure and 400 kg ha^{-1} NPK fertilizer (M_2F_2), and this out-yielded the control yield of 7.83 t ha^{-1} by 103.1. This result is in agreement with those of several authors who reported increased sweetpotato yield with integrated application of manure and inorganic fertilizer [41-42] and is ascribable to improvement in the soil condition and nutrient status of the soil from application of the treatments as reported by Anedo [43].

The trial suggested that M_2F_2 was the optimal combined application rate for sustainable sweetpotato production on the degraded Typic Paleudult at Umudike in southeastern Nigeria, although 600 kg ha^{-1} of NPK fertilizer under zero composite manure application (M_0F_3) and 8 t/ha composite manure and 600 kg/ha (M_4F_3), produced statistically similar yield levels (14.93 t ha^{-1} and 14.83 t ha^{-1}, respectively), suggesting alternative fertilizer rates for sweetpotato.

3.2. Cassava root yield

The residual effect of M and F on fresh root yield of cassava is presented in Table 5. The results showed that there was a very highly significant ($P<0.001$) main and interaction effects of residual treatments on cassava root yield, suggesting that the composite manure and NPK fertilizer can be applied alone or in combination at various rates to elicit cassava root yield responses. NPK fertilization recorded a progressively significant higher yield than the control (39.77 t ha^{-1}) with increasing fertilizer rates by 12.2, 20.3 and 21.4%, respectively; indicating that the highest yield (48.28 t ha^{-1}) was obtained in plots that received the highest NPK fertilizer rate of 600 kg ha^{-1}. However, NPK fertilizer rates at F_1 (200 kg ha^{-1}), F_2 (400 kg ha^{-1}) and F_3 (600 kg ha^{-1}) exhibited non-significant differences in yield among themselves. Similarly, the highest rate of composite manure at M_4 (8 t ha^{-1}) also produced the highest root yield (50.29 t ha^{-1}), representing 17% higher yield than that of the control (Mo) (42.97 t ha^{-1}) but had similar yield effect as composite manure at M_3 (6 t ha^{-1}), which also significantly out-yielded the control by 14.6%. combining the highest application rate of each of the two fertilizer types (M_4F_3) (8 t ha^{-1} M and 600 t ha^{-1} F) recorded 89.9% significant higher yield than the control (M_0F_0) yield of 30.38 t ha^{-1}, indication the synergistic superiority of combined application over sole application of composite manure and NPK fertilizer. Other combinations such as 6 t ha^{-1}M and 200 kg ha^{-1} F (M_3F_1) and 6 t ha^{-1}M and 400 kg F (M_3 F_2) that induced statistically the same yield responses (51.45 and 54.18 t ha^{-1}), respectively as M_4F_3, significantly ($P<0.001$) improved root yield of cassava over the control by 69.4 and 78.3%, respectively. The overall picture indicates that though the highest rates of the composite manure and NPK fertilizer application either alone or in combination maximized cassava root yield responses, lower rates could be recommended depending on ease of sourcing, convenience of application and derivable economic and environmental benefits.

Generally, the overall mean cassava fresh root yield of 45.13 t ha^{-1} obtained in this study was high (>25 t ha^{-1}), with those from plots that received a combination of 6 t ha^{-1} composite manure and 200 kg ha^{-1} NPK 15:15:15 (M_3F_1), 6 t ha^{-1} composite manure and 400 kg ha^{-1} NPK fertilizer (M_3F_2) and 8 t ha^{-1} composite manure and 600 kg ha^{-1} NPK fertilizer (M_4F_3), producing yields described as exceptionally high (>50 t ha^{-1}) [44]. Good cultural management of application of composite manure and fertilizer, incorporation of previous sweetpotato residues as surface mulch, proper planting with healthy and improved (high-yielding) cassava variety (NR 8082) and timely weed control operations could have resulted in the recorded high cassava root yield in this study. This confirms those of earlier studies Ande *et al.* [44] who reported that under good combination of physical, chemical and cultural practices, exceptionally high yield of cassava (>50 t ha^{-1}) is obtainable. Residual nutrients, especially N, P and K from the applied composite manure, fertilizer and contributions from decomposing and mineralizing residues of the previous sweetpotato crop could have accounted for the observed improvements in soil nutrients and conditions as shown in Table 1 and similarly reported by several earlier workers [45-46]. It has also been confirmed that cassava requires fairly high level of K and responds to K addition in K-deficient soils [47] and that K adequacy in the soil is very important for carbohydrate synthesis and translocation and for increased plant resistance to anthracnose.

The improved soil condition (OM, pH), increased residual nutrient status and high cassava root yield obtained after harvesting sweetpotato, provide evidence that manure and/or inorganic fertilizer could carry a second and perhaps, a third year of cropping without further manure application. This finding also support similar earlier works by Jinadasa *et al.* [27] that the use of poultry manure has a residual effect on soil after a cropping season and that continuous use of fertilizer alone on degraded Ultisol has limited residual effects of the applied fertilizer [25].

Conclusion

The results of the study showed that combined application of composite manure and NPK fertilizer at the highest rate (M_4F_3) produced the 3rd best-performing sweetpotato yield (14.53 t ha^{-1}) that compares favourably with the maximum yield (15.9 t ha^{-1}) obtained from a lower combination of the treatments M_2F_2. The residual effect of this application rate (M_3F_3) with possible contributions from the decomposing and mineralizing sweetpotato residues also produced exceptionally high yield (57.69 t ha^{-1}) of the following cassava crop. The implication of these results is that, with proper selection of crops in the cropping sequence and recycling of residues of previous crops, large combined use of composite manure and NPK fertilizer has the potential to substantially improve soil conditions and leave enough nutrients to carry a 3rd and perhaps, a 4th crop cycle on a degraded SEN Ultisol without further fertilization.

Table 1: Some physico-chemical properties of the pre- and post-sweetpotato (pre-cassava) cropping soils of the experimental site

Soil properties	Pre-sweetpotato cropping soil values	Post-sweetpotato (pre-cassava cropping) soil values	Relative changes in soil characteristics (%)
Particle size distribution (%)			
Sand	79.6	78.6	-1.3
Silt	6.4	7.4	15.6
Clay	14.0	14.0	0.0
Texture	SL	SL	SL
pH (H_2O)	4.2	4.9	16.7
OM (%)	1.79	2.68	49.7
Total N (%)	0.028	0.124	342.9
Available P (Bray-2) (mg kg^{-1})	10.6	27.0	154.7
Exchangeable cations (cmol kg^{-1})			
K	0.043	0.056	30.2
Ca	3.2	3.45	7.8
Mg	0.8	1.63	103.8
Exchange acidity (EA) (cmol kg^{-1})	1.4	0.8	-42.9
ECEC (cmol kg^{-1})	5.54	6.04	9.0
BS (%)	74.7	86.5	15.8
C/N ratio	37.08	12.5	-66.3

ECEC = Effective cation exchange capacity; BS = Base saturation; OM = Organic matter; SL= sandy loam

Table 2: Some chemical composition of the composite manure used in the study

Parameters	Values
pH (H_2O)	10.5
OM	64.8%
N	3.1%
P	1.9 %
K	2.2%
Ca	4.4%
Mg	2.1%
Na	1.6%

Table 3: Monthly rainfall characteristics (amount and number of rainy days) for the experimental periods at Umudike location in 2014 and 2015.

Months	Year	Rainfall characteristics	
		Amount (mm)	**Number of rainy days**
June	2014	281.8	12
July	”	114.9	14
August	”	444.2	20
September	”	405.3	22
November	”	147.4	11
December	”	0.0	0
January	2015	8.4	1
February	”	81.7	6
March	”	130.5	7
April	”	61.7	4
May	”	246.8	15
June	”	346.2	21
July	”	129.2	18
August	”	366.2	19
September	”	276.0	23
October	”	380.0	12
November	”	49.7	6
Total for the period	**(2014/2015)**	**3,470**	**211**

Table 4: Sweetpotato root yield (t ha^{-1}) at 4 months after planting as influenced by composite manure and NPK fertilizer application

NPK fertilizer rate (kg ha^{-1})	Composite manure (M) rate (t ha^{-1})					
	0	**2**	**4**	**6**	**8**	**Mean**
0	7.83	11.37	13.17	11.67	10.70	10.93
200	8.30	12.07	13.13	12.37	12.27	11.63
400	11.53	13.73	15.90	9.93	12.60	12.62
600	14.93	10.47	9.13	13.13	14.83	12.50
Mean	10.65	11.91	12.85	11.78	12.45	

LSD (0.05) for comparing NPK fertilizer (F) means = NS;
LSD (0.05) for comparing composite manure (M) means = NS;
LSD (0.05) for comparing M x F interaction means = 4.387.
LSD = Least significant difference; NS = Not significant;

Table 5: Residual effect of composite manure (M) and NPK fertilizer (F) on fresh root yield of cassava (NR8082) (t ha^{-1}) at 12 months after planting (MAP)

Composite manure rate (t ha^{-1})	NPK fertilizer rate (kg ha^{-1})				
	0	**200**	**400**	**600**	**Mean**
0	30.38	46.85	47.31	47.56	43.03
2	31.11	34.44	45.56	42.85	38.49
4	41.04	41.00	46.37	50.26	44.67
6	48.30	51.45	54.18	43.02	49.24
8	48.00	49.48	46.01	57.69	50.30
Mean	39.77	44.64	47.85	48.28	

LSD (0.05) for comparing NPK fertilizer (F) means = 3.578;
LSD (0.05) for comparing composite manure (M) means = 3.2;
LSD (0.05) for comparing M x F interaction means = 7.156
LSD = Least significant difference; NS = Not significant;

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