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Effects of organic fertilizers on yam productivity and some soil properties of a nutrient-depleted tropical Alfisol

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Field experiments were conducted at Owo, southwest Nigeria to select organic fertilizer treatments most suitable for sustaining high soil fertility and yam productivity on a nutrient-depleted tropical Alfisol. Eight organic fertilizer treatments were applied at 20 t ha^{-1} with a reference treatment inorganic fertilizer (NPK 15–15–15) at 400 kg ha^{-1} and natural soil fertility (control), laid out in a randomized complete block design with three replications. Results showed that organic fertilizers significantly increased ($p = 0.05$) tuber weight and growth of yam, soil and leaf N, P, K, Ca and Mg, soil pH and organic C concentrations compared with the NSF (control). The oil palm bunch ash + poultry manure treatment increased tuber weight, vine length, number of leaves and leaf area of yam by 66, 25, 21 and 52%, respectively, compared with inorganic fertilizer (NPK) and 37, 22, 19 and 44%, respectively, compared with poultry manure alone. Sole or mixed forms of organic fertilizers showed significant improvement in soil physical conditions compared with IF (NPK) and NSF (control). Synergistic use of oil palm bunch ash + poultry manure at 10 t ha^{-1} each was most effective for sustainable management of soils and for improving agronomic productivity of yam.

Keywords: organic fertilizer; soil properties; yam; leaf nutrient content; Nigeria

Introduction

Yam (*Dioscorea rotundata* Poir) belongs to the family Dioscoreaceae and is a crop grown for its edible tubers, which is an important stable food in West Africa. Yam is of particular importance for the people of Africa, who derive ~15% of their total dietary calories from tuber crops (Howeler et al. 1993). Yam is second to cassava as the most important and cultivated tropical tuber crop in Nigeria. Because of its multipurpose uses, it occupies a principal place in farming the humid tropical region. Whereas Africa alone is responsible for 90% of the world production of yam; Nigeria accounts for over 70% of world production (Okoh 2004; Vernier and Dansi 2000; Agbede 2006). Yam tubers are eaten boiled, fried, mashed or pounded. Yam flour is the best form to preserve and store yams.

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Yams require a relatively rich soil, particularly in terms of organic matter and soil nutrients (Degras 1993; Howeler et al. 1993), in order to perform well. Because of their high demand for nutrients, yams are traditionally the first crops grown after fallow (Orkwor et al. 1998). The limitations imposed on soil productivity in the tropics, in terms of loss of fertility and pressure on land use due to non-agricultural development, is forcing farmers to cultivate degraded or depleted soils for yam production. It is therefore necessary to explore alternative means to improve the nutrient status of these soils. In sub-Saharan tropical Africa, the maintenance of soil productivity remains a knotty issue due to poor cultural practices, the fragile nature of most arable soils and poor organic matter and available nutrient status (Nottidge et al. 2005; Agbede and Ojeniyi 2009). Bationo et al. (2006) described soil fertility depletion as the single most important constraint on food security in West Africa. All efforts to maintain soil nutrients with chemical fertilizers alone in order to sustain high crop yield are hindered by the high cost of purchasing fertilizers, especially for resource-poor farmers, acute scarcity during planting and the destruction of soil properties arising from continuous use (Aduayi 1980).

According to Yadav and Prassad (1992), the tendency to supply all plant nutrients through synthetic fertilizers should be avoided as this has a deleterious effect on long-term soil productivity. It also enhances soil acidity, nutrient leaching, nutrient imbalance and degradation of soil physical properties and organic matter (Ojeniyi 2000; Agbede et al. 2008). Soil degradation, which is brought about by a loss of organic matter accompanying continuous cropping, is aggravated when chemical fertilizers are applied repeatedly. This is because the crop response to applied fertilizer depends on soil organic matter (Agboola and Omueti 1982).

The need to use renewable forms of energy and reduce the costs associated with fertilizing crops has revived the use of organic fertilizers worldwide. Improvements in environmental conditions and public health are important reasons for advocating the increased use of organic materials (Ojeniyi 2000; Maritus and Vleic 2001). Gruhn et al. (2000) suggested that future strategies for increasing agricultural productivity from available land resources will have to focus on using available nutrient resources more efficiently, effectively and sustainably than in the past. Integrated management of nutrients needed for proper plant growth, together with effective crop, water, soil and land management will be critical for sustaining agriculture over the long-term. In a sustainable low-input agricultural system, where nutrient depletion is a serious constraint to crop production, the use of organic fertilizers such as oil palm bunch ash, spent grain (sorghum-based brewery waste), poultry and goat manures is inevitable. Soils have to be amended and managed in a special manner to be cultivated profitably. The effect of different organic fertilizer materials on the actual yield of yam has not yet been properly documented. The current average gross tuber yield is low, being estimated at $\sim$10 metric tons (Mt) ha^{-1}. This implies that more research is needed to increase production to appreciable levels in order to meet global demand for yam. Use of organic fertilizers that are cheap, sustainable, edaphologically suitable, economically viable, culturally acceptable, environmentally friendly and compatible is considered a major method of increasing yam yield on a unit per area basis.

Organic manures are known to be effective in the maintenance of an adequate supply of organic matter into soil, with attendant improvement in soil physical and chemical conditions and enhanced crop performance (Ikpe and Powel 2003; Ano and Agwu 2005). Enormous quantities of organic wastes such as poultry manure, goat manure, spent grain and oil palm bunch ash are available in Nigeria where they pose disposal problems and environmental hazards, and are at the same time effective sources of nutrients for tuber crops like yam. Except for Adu-Dapaah et al. (1994), Moyin-Jesu and Atoyoseye (2002), Ojeniyi et al. (2007), Agbede and Ojeniyi (2009) and Ayeni et al. (2008) who reported the use of ash of cocoa husk, spent grain, goat manure, poultry manure, and saw dust and wood ash to grow maize, cocoa seedlings, tomato, sorghum and cocoa seedlings, respectively, research information on the use of goat and poultry manures, oil palm bunch ash and spent grain for the production of yam is yet to receive research attention. Yam is very exerting on soil moisture and nutrient levels, and the root volume per plant extends more deeply and more broadly than other crops, e.g. cereals (Onwueme 1978). Therefore, continuous cultivation of a crop like yam on the same land will lead to soil mining, degradation of soil quality and consequent low yield. According to Obigbesan and Agboola (1978), for a target yield of 37.9 t ha^{-1}, yam removes 148.0, 41.2 and 199.2 kg ha^{-1} of N, P and K, respectively, from soil. This calls for fertility-enhancing technologies including the application of organic manures/fertilizers. Thus, it is expected that application of organic fertilizers would enhance soil fertility and performance of yam. Organic fertilizers could also help by reducing soil acidity where necessary (Samuel et al. 2003; Moyin-Jesu and Adeofun 2008). Hence, the objective of this study was to evaluate the effects of no fertilizer, inorganic fertilizer and different organic fertilizers alone and in combination on soil and crop chemical composition, growth and yield of yam grown on an Alfisol of southwestern Nigeria.

Materials and methods

Site description, the trial design and duration, the treatments, field layout and crop husbandry

The experiments were carried out at the Teaching and Research Farm of Rufus Giwa Polytechnic, Owo, Ondo State, southwestern Nigeria at latitude 7°12′N, longitude 5°35′E. Available weather data indicate that the annual rainfall totals (mm) were 1335, 1346 and 1547 for 2007, 2008 and 2009, respectively. The rainy season starts in March, and lasts until October, while the dry season is between November and February, with temperatures ranging from 24 to 32°C. The soil of the experimental site belongs to an Alfisol classified as Oxic Tropuldalf (USDA 2010) or Luvisol (FAO 1998) derived from quartzite, gneiss and schist (Agbede 2006). Composite upper soil layer (0–15 cm) samples from the experimental site were taken to determine the physical and chemical properties of the soil before cropping. A vaierty of crops were grown at the site including cassava (*Manihot esculenta* Crantz), cowpea (*Vigna unguiculata* Walp), maize (*Zea mays* L.), melon (*Colosynthis citrullus* L.), etc. for at least 12 years without fertilizer application before the initiation of this study. The trials were conducted for three cropping seasons, 2007, 2008 and 2009, on the same site.

Each year, the experiment consisted of 10 treatments, concerned with three main comparisons — natural soil fertility (NSF, the control), soil with inorganic fertilizer (IF) added, and soil with organic fertilizers added, which, in turn, had three comparisons: animal manures (goat manure, GM, and poultry manure, PM), plant-derived residues (oil palm bunch ash, OBA, spent grain, SG and mixtures of the two, OBA with GM and PM; SG with GM and PM). The organic manures were applied at 20 t ha^{-1}, based on recommendation for high nutrient requiring tuber crop like yam (NRCRI 1982; Onweremadu et al. 2008) while inorganic fertilizer was applied at 400 kg ha^{-1}, based on field recommendation for yam production on a nutrient-depleted soil (FPDD 1989). Doses of organic materials were expressed on a fresh weight basis. The 10 treatments compared were: (1) control, NSF, a relatively degraded soil condition because of prior land use; (2) IF (NPK 15–15–15; 15 N, 15 P_2O_5, 15 K_2O) at 400 kg ha^{-1}; (3) GM at 20 t ha^{-1}; (4) PM at 20 t ha^{-1}; (e) OBA (waste product after the incineration of palm bunch refuse after fruit extraction containing N and K) at 20 t ha^{-1}; (6) SG at 20 t ha^{-1}; (7) OBA at 10 t ha^{-1} mixed with GM at 10 t ha^{-1}; (8) OBA at 10 t ha^{-1} mixed with PM at 10 t ha^{-1}; (9) SG at 10 t ha^{-1} mixed with GM at 10 t ha^{-1}; and (10) SG at 10 t ha^{-1} mixed with PM at 10 t ha^{-1}. The 10 treatments were laid out in a randomized complete block design and replicated three times.

After manual clearing and packing of debris away from the site, soil mounds were formed at a 1 × 1 m spacing in April each year. Each mound was ~1 m wide at the base and ~0.75 m high. The size of each of the 30 plots was 6 × 6 m, giving a plant population of 36 plants per plot. Blocks were 1 m apart and the plots were 0.5 m apart. Planting was done immediately after construction of the mounds in each year. One seedyam weighing ~0.4 kg of white yam (*Dioscorea rotundata* cv Gambari) was planted per hole on 3 April 2007, 6 April 2008 and 8 April 2009. The organic fertilizers were applied in a ring form at planting, and thoroughly worked into the soil with a hoe. NPK 15–15–15 fertilizer was applied in a ring form in two equal doses. The first dose was applied at 1 month after vine emergence, and the second 8 weeks later when tuber expansion, rapid stem and leaf development were in progress. Stakes were installed after sprouting. Weeding was manual with a hoe at 3, 8, 12 and 16 weeks after planting in each experiment.

Ten plants were randomly selected per plot for determination of vine length, number of leaves and leaf area at 5 months after planting when the yam plant formed a full canopy. Vine length was determined by meter rule. Number of leaves was determined by counting the number of leaves on each yam plant and the leaf area was measured using a graphical method (i.e. by placing the leaf on graph sheet for area determination). Tuber yield was determined at harvest (8 months after planting) by recording the weight of fresh tuber from 10 plants selected randomly from each plot using a top loading balance to determine their weights.

Soils, soil inputs and leaf analysis of yam plant

Two months after planting yam, determination of bulk density, total porosity and gravimetric water content in all plots was commenced and repeated at 2-month intervals on four occasions for each year. Five undisturbed samples (4 cm diameter, 15 cm high) were collected at 0—15 cm depth from the centre of each plot at random and ~15 cm away from each yam mound using steel coring tubes; the samples were used to evaluate bulk density, total porosity and gravimetric water content after oven-drying at 100°C for 24 h. Total porosity was calculated from the bulk density and particle density of 2.65 Mg m^{-3}.

Before the start of the experiment in 2007, surface soil (0–15 cm) samples were randomly collected from 10 different points on the experimental site. Disturbed soil samples were collected randomly at 0–15 cm depth from the centre of each plot on mounds at five sites per plot at harvest in 2009 (third crop). The soil samples were bulked, air-dried and sieved using a 2-mm sieve for routine chemical analysis, as described by Carter (1993). Particle-size analysis was carried out for textural class using the hydrometer method (Sheldrick and Hand Wang 1993). Soil pH was determined in a soil/water (1: 2) suspension using a digital electronic pH meter. Soil organic carbon was determined by the Walkley and Black procedure by wet oxidation using chromic acid digestion (Nelson and Sommers 1996). Total N was determined using micro-Kjeldahl digestion and distillation techniques (Bremner 1996), available P was determined by Bray-1 extraction followed by molybdenum blue colorimetry (Frank et al. 1998). Exchangeable K, Ca and Mg were extracted with a 1 M NH_4OAc, pH 7 solution. Thereafter, K was analysed with a flame photometer and Ca and Mg were determined with an atomic absorption spectrophotometer (Okelabo et al. 2002).

Oil palm bunch ash was obtained from the oil palm processing unit at the Ondo State Agricultural Development Project, Owo, and spent grain (sorghum-based brewery waste) was collected from a nearby local brewery. The poultry and goat manures were obtained from livestock pens at Rufus Giwa Polytechnic, Owo. The organic materials were processed to allow decomposition. Goat manure was ground to allow quick mineralization. The oil palm bunch ash was sieved to remove pebbles, stones and unburnt shafts, and the spent grain was partially composted for 6 weeks to reduce the C/N ratio. Poultry manure was stacked under a shed for 1 week to allow quick mineralization. In general, all the organic wastes are readily available, sustainable and inexpensive for growing commercial quantities of yam.

Small $\sim$2 g subsamples of each of the processed forms of the organic materials used in the experiments were analysed to determine their nutrient composition. The samples were air-dried and crushed to pass through a 2-mm sieve before analysis. The samples were analysed for organic C, total N, P, K, Ca and Mg. The percentage organic carbon was determined by the Walkely and Black procedure using the dichromate wet oxidation method (Nelson and Sommers 1996), total N was determined by micro-Kjeldahl digestion, followed by distillation and titration (Bremner 1996) while the determination of other nutrients such as total P, K, Ca and Mg was done using the wet digestion method based on 25–5–5 mL of $HNO_3-H_2SO_4-HClO_4$ acids (Horwitz 1997). Phosphorus was measured colorimetrically by the molybdate blue method in an auto-analyser, K by flame photometry, and Ca and Mg by atomic absorption spectrophotometer (Okalebo et al. 2002).

In the 2009 cropping season, representative leaf samples from the upper, middle and lower parts of the yam vines were randomly collected from five plants per plot at 5 months after planting for chemical analysis. The leaf samples were oven-dried at 70°C for 24 h before grinding in a Willey mill. Leaf N was determined by micro-Kjeldahl digestion. Ground leaf samples were dry ashed at 450°C for 6 h in a muffle furnace and extracted using a $HNO_3-H_2SO_4-HClO_4$ mixture to determine P, K Ca and Mg. Phosphorus was determined colorimetrically using the vanadomolybdate method. K was determined using a flame photometer and Ca and Mg were determined by the EDTA titration method (Horwitz 1997).

Statistical analysis

Data collected for yield and growth parameters, soil properties and leaf nutrient concentrations were subjected to analysis of variance (ANOVA) using SPSS 15.0 and Microsoft Office Excel 2007 packages, and the separation of treatment means were determined using Duncan's multiple range test (DMRT) and the least significant difference (LSD) at $p = 0.05$ probability level (Steel et al. 1997).

Results

Initial soil fertility status

The physical and chemical properties of the soil (0–15 cm) at the experimental site before cropping are presented in Table 1. Based on the established critical levels for soils in ecological zones of Nigeria, the soil was acidic with pH 5.4 (Moyin-Jesu and Adeofun 2008), compared with pH values of between 6.0 and 7.0 considered as optimum for yam cultivation (Shiwachi et al. 2004). The soil was low in organic carbon (OC), total N, available P and exchangeable Ca, according to the critical levels of 3.0 g 100 g^{-1} OM, 0.20 g 100 g^{-1} N, 10 mg kg^{-1} available P, 2.0 cmol kg^{-1} exchangeable Ca recommended for most crops (Akinrinde and Obigbesan 2000). The exchangeable K was less than the 0.15 cmol kg^{-1} critical level considered adequate for yam production (Okereke et al. 1987). The exchangeable Mg was lower than the 0.25–0.43 cmol kg^{-1} critical level considered as optimum for yam (Ohiri 1995), indicating poor soil fertility. The soil bulk density was high and the total porosity was low.

Chemical properties of the organic fertilizers used in the experiment

The chemical properties of the organic fertilizers used for yam production (means of three years, 2007–9) are shown in Table 2. PM had significantly higher ($p = 0.05$) N and P nutrient concentrations and the lowest C/N ratio of 7.4 compared with the other organic materials. GM was comparable with PM in organic C and K, but N, P, Ca and Mg in PM were significantly higher ($p = 0.05$) than in GM. OBA had significantly higher values of K, Ca and Mg compared with PM, GM and SG. SG had the lowest values of C, N, P, K, Ca and Mg, and the highest C/N ratio of 12.8.

Effect of different organic fertilizers on yield of yam

Organic fertilizers had a significant effect on tuber weight of yam in the 2007, 2008 and 2009 cropping seasons (Figure 1). In 2007, and among the sole forms of organic

Table 1. Mean ± standard deviation of soil physical and chemical properties of 0–15 cm depth of the experimental site before experimentation.

Soil property	Value
Sand (g kg^{-1})	675 ± 7.4
Silt (g kg^{-1})	153 ± 5.8
Clay (g kg^{-1})	172 ± 4.9
Textural class	Sandy loam
Bulk density (Mg m^{-3})	1.61 ± 0.08
Total porosity (%, v/v)	39.25 ± 0.5
pH (H_2O)	5.4 ± 0.2
Organic C (g 100g^{-1})	0.94 ± 0.04
Total N (g 100g^{-1})	0.08 ± 0.01
Available P (mg kg^{-1})	6.8 ± 0.2
Exchangeable K (cmol kg^{-1})	0.14 ± 0.02
Exchangeable Ca (cmol kg^{-1})	1.32 ± 0.03
Exchangeable Mg (cmol kg^{-1})	0.15 ± 0.01

Table 2. Chemical composition of organic fertilizers used for growing yam related to dry mass.

Organic fertilizer	C (%)	N (%)	C/N ratio	P (%)	K (%)	Ca (%)	Mg (%)
Goat manure	21.7a	2.54b	8.5c	0.85c	1.71b	0.80c	0.44c
Poultry manure	22.5a	3.03a	7.4d	1.4a	1.80b	0.86b	0.58b
Oil palm bunch ash	10.4b	1.76c	10.5b	1.1b	2.10a	0.93a	0.70a
Spent grain	10.0b	0.78d	12.8a	0.76d	0.56c	0.13d	0.18d

Note: Treatment means within each column followed by the same letters are not significantly different from each other at $p = 0.05$ according to Duncan's multiple range test (DMRT).

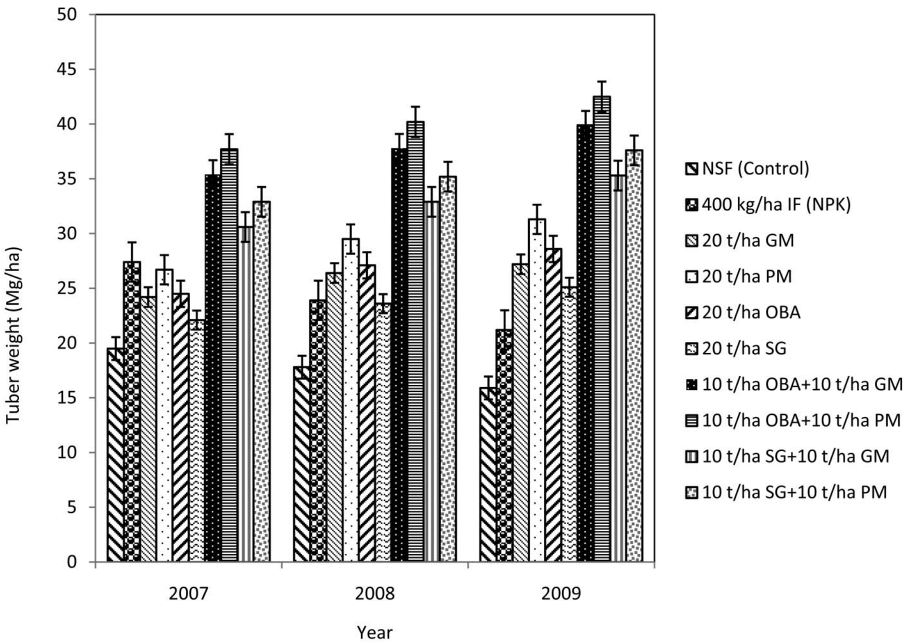

Figure 1. Tuber weight in 2007, 2008 and 2009 cropping seasons as affected by different organic fertilizers. Vertical bars show standard errors of paired comparisons.

fertilizers, the tuber weight of yam produced by PM was comparable with IF (NPK), which produced the highest tuber weight. The tuber weights produced by these treatments (IF and PM) were significantly higher ($p = 0.05$) than that of GM and SG. The NSF (control) treatment gave the lowest tuber weight and was significantly lower ($p = 0.05$) than other treatments.

However, the trend was reversed in the 2008 and 2009 cropping seasons (Figure 1). The PM treatment produced the highest tuber weight of yam, which was significantly higher ($p = 0.05$) than OBA, GM, IF and SG. The tuber weights of yam produced by OBA, GM and SG in these two years were significantly higher ($p = 0.05$) than IF, except for SG in 2008, which produced similar tuber weight of yam with IF. The lowest tuber weight of yam was also produced by NSF (control) treatment.

In the 2007, 2008 and 2009 cropping seasons, mixtures of organic fertilizers gave significantly higher ($p = 0.05$) tuber weights than their sole forms (Figure 1). Among the mixtures, OBA + PM produced the highest tuber weight of yam, and this was significantly higher than OBA + GM and SG + PM. Among the mixtures of organic fertilizers, SG + GM gave the lowest tuber weight.

The tuber yield in the organic fertilizer regime treatments increased over time, whereas that under NSF (control) or soil under IF (NPK) regime treatment declined (Figure 1).

Averaged over the 3 years, OBA + PM increased the tuber weight of yam by 50% relative to OBA alone (Figure 2). SG + PM increased tuber weight by 21% compared with PM alone. Relative to IF, OBA + PM increased tuber weight of yam by 66%. OBA + PM also increased tuber weight of yam by 70% compared with SG. The IF treatment increased tuber weight of yam by 37% compared with the NSF (control), whereas PM increased tuber weight by 21% compared with IF.

Economics of yam production under the different organic fertilizer treatments

The cost of purchasing fertilizer was higher than the cost of transportation for each of the organic fertilizer treatments (Table 3). OBA + PM gave the highest net return (₦1 451 766 ha^{-1}) followed by OBA + GM (₦1 295 208 ha^{-1}), and the lowest net return (₦1 137 917 ha^{-1}) was obtained from the NSF (control). All the organic fertilizer treatments, either sole or mixed forms, gave higher net profit over NSF (control). The economic returns and net benefits from sole or mixed forms of organic fertilizer treatments were significantly higher than the IF (NPK) treatment, except for the sole SG treatment, which produced economic returns and net benefit that were similar to IF. Economically, OBA + PM and OBA + GM proved to be more cost effective and profitable than all the other treatments, as shown by their

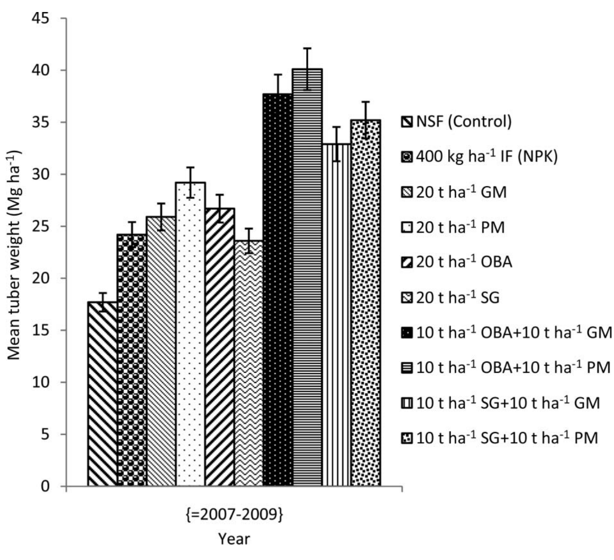

Figure 2. Mean tuber weight from 2007 to 2009 cropping seasons as affected by different organic fertilizers. Vertical bars show standard errors of paired comparisons.

Table 3. Economics of producing yam under each fertilization tested for years 2007–2009.

Treatment	Monetary gain (₦ ha^{-1})	Production increase value (₦ ha^{-1})	Production increase (%)	Cost of transportation of organic fertilizer/cost of NPK fertilizer (₦ ha^{-1})	Net return over each fertilization (₦ ha^{-1})	Return rate or value/cost ratio of each fertilization
NSF (Control)	1 137 917	–	–	–	–	–
400 kg ha^{-1} IF (NPK)	1 547 292	409 375	36	17 093	392 282	24
20 t ha^{-1} GM	1 682 083	544 166	48	9 000	535 166	60
20 t ha^{-1} PM	1 893 958	756 041	66	11 300	744 741	67
20 t ha^{-1} OBA	1 735 833	597 916	53	13 500	584 416	44
20 t ha^{-1} SG	1 530 417	392 500	34	15 000	377 500	26
10 t ha^{-1} OBA + 10 t ha^{-1} GM	2 444 375	1 306 458	115	11 250	1 295 208	116
10 t ha^{-1} OBA + 10 t ha^{-1} PM	2 602 083	1 464 166	129	12 400	1 451 766	118
10 t ha^{-1} SG + 10 t ha^{-1} GM	2 136 667	998 750	88	12 000	986 750	83
10 t ha^{-1} SG + 10 t ha^{-1} PM	2 285 208	1 147 291	101	13 150	1 134 141	87

Notes: NSF, natural soil fertility; IF, inorganic fertilizer (NPK 15–15–15); GM, goat manure; PM, poultry manure; OBA, oil palm bunch ash; SG, spent grain. In 2007, the price of yam tuber was ₦56.25 kg^{-1}; NPK 15–15–15 fertilizer was ₦35 kg^{-1}. In 2008 and 2009, the price of yam tuber was ₦68.75 kg^{-1}; NPK 15–15–15 fertilizer was ₦44 kg^{-1}. ₦120.00 = US$1.00 in 2007; ₦138.00 = US$1.00 in 2008; ₦150.00 = US$1.00 in 2009.

high return rates or value/cost ratios of 118:1 and 116:1 for the two organic fertilizers, respectively.

Effect of different organic fertilizers on growth components of yam

Data on the growth components of yam in 2007, 2008 and 2009 in response to different organic fertilizers are presented in Table 4. Growth parameters such as vine length, number of leaves and leaf area of yam plant increased significantly ($p = 0.05$) under different organic fertilizer treatments compared with NSF (control). In general, the growth components from plots with sole applications were lower than with the various mixtures of organic fertilizers. In the first year and among the sole forms of application, IF gave the highest values for growth parameters, which were not statistically different from PM and GM. In the second and third years, PM and GM gave the highest and similar values for growth parameters. In most cases, the growth parameters produced by these treatments were not significantly different from IF. The SG treatment consistently produced the lowest values of growth parameters, which in most cases were significantly lower than the other treatments, except NSF (control).

Mixed treatments or applications significantly increased ($p = 0.05$) vine length, number of leaves and leaf area. The trends in the values of these parameters in mixed treatments were remarkable in 2007, 2008 and 2009, and were significantly higher ($p = 0.05$) than their sole forms. Among the mixture of OBA and SG with GM and PM, the OBA + PM treatment consistently gave the highest values for vine length, number of leaves and leaf area in the 2007, 2008 and 2009 cropping seasons, followed by OBA + GM, SG + PM and SG + GM, respectively. The mean vine length for NSF (control), IF, GM, PM, OBA, SG, OBA + GM, OBA + PM, SG + GM and SG + PM were 2.75, 3.36, 3.36, 3.44, 3.23, 3.08, 4.11, 4.20, 3.73 and 3.82 m, respectively. The respective values for number of leaves per plant were 1907, 2463, 2500, 2509, 2355, 2264, 2907, 2977, 2650 and 2728, respectively, and the values for leaf area per plant were 1.41, 1.86, 1.89, 1.96, 1.84, 1.70, 2.57, 2.82, 2.18 and 2.35 m^2, respectively.

Pooled over the 3 years, OBA + PM increased vine length, number of leaves and leaf area by 30, 26 and 53%, respectively, compared with OBA (sole). SG + PM increased vine length, number of leaves and leaf area by 13, 9 and 20%, respectively, compared with PM alone. Relative to IF, OBA + PM increased vine length, number of leaves and leaf area by 25, 21 and 52%, respectively. This treatment (OBA + PM) also increased the aforementioned growth parameters by 36, 31 and 66%, respectively, compared with sole SG. IF increased the aforementioned growth parameters by 22, 29 and 32%, respectively, compared with NSF (control).

Effect of organic fertilizers on soil bulk density, total porosity and water content

In the 3 years of cropping, application of organic fertilizers gave relatively lower soil bulk density, higher total porosity and higher water content compared with NSF (control), whereas application of IF did not influence soil bulk density, total porosity and water content (Table 5). Mixtures of OBA and SG with GM and PM gave similar values for soil bulk density, total porosity and water content, which were not statistically different from one another. In general, the mixture of OBA and SG with GM and PM significantly reduced ($p = 0.05$) soil bulk density and increased total porosity and water content more than their sole applications (GM, PM, OBA and

Table 4. Effect of different organic fertilizers on vine length, number of leaves and leaf area per yam plant at 5 months after planting.

	Vine length (m)			Number of leaves per plant			Leaf area per plant (m^2)		
Treatment	2007	2008	2009	2007	2008	2009	2007	2008	2009
NSF (Control)	2.81h	2.76h	2.68h	1929h	1907h	1884g	1.46h	1.41h	1.37h
400 kg ha^{-1} IF (NPK)	3.44e	3.33ef	3.31ef	2500e	2445ef	2443f	1.92e	1.86ef	1.79fg
20 t ha^{-1} GM	3.29ef	3.39e	3.41ef	2470ef	2511e	2519e	1.81ef	1.92e	1.94ef
20 t ha^{-1} PM	3.38e	3.43e	3.52e	2491e	2516e	2524e	1.89e	1.98e	2.01e
20 t ha^{-1} OBA	3.19f	3.21f	3.30ef	2202g	2428f	2436f	1.79f	1.85ef	1.88f
20 t ha^{-1} SG	3.02g	3.07g	3.15g	2179g	2184g	2428f	1.65g	1.69g	1.76g
10 t ha^{-1} OBA + 10 t ha^{-1} GM	4.06ab	4.09ab	4.18ab	2886ab	2913ab	2921ab	2.53b	2.57b	2.62b
10 t ha^{-1} OBA + 10 t ha^{-1} PM	4.15a	4.18a	4.27a	2954a	2984a	2992a	2.78a	2.82a	2.87a
10 t ha^{-1} SG + 10 t ha^{-1} GM	3.67cd	3.72cd	3.81cd	2626cd	2658cd	2666cd	2.13d	2.17d	2.23d
10 t ha^{-1} SG + 10 t ha^{-1} PM	3.82c	3.85c	3.94c	2706c	2735c	2743c	2.30c	2.35c	2.40c

Note: Treatment means within each column followed by the same letters are not significantly different from each other at $p = 0.05$ according to Duncan's multiple range test (DMRT). NSF, natural soil fertility; IF, inorganic fertilizer (NPK 15–15–15); GM, goat manure; PM, poultry manure; OBA, oil palm bunch ash; SG, spent grain.

Table 5. Effect of different organic fertilizers on soil physical properties (0–15 cm depth) when averaged across four sampling periods (2, 4, 6 and 8 months after planting).

Treatment	Bulk density ($Mg\ m^{-3}$)			Total porosity (%, v/v)			Water content ($g\ kg^{-1}$)		
	2007	2008	2009	2007	2008	2009	2007	2008	2009
NSF (Control)	1.38a	1.43a	1.48a	47.9c	46.0c	44.2c	73c	81e	66d
400 kg ha^{-1} IF (NPK)	1.38a	1.42a	1.47a	47.9c	46.4c	44.5c	76c	80e	62d
20 t ha^{-1} GM	1.16b	1.09b	1.03b	56.2b	58.9b	61.1b	93b	104d	122c
20 t ha^{-1} PM	1.14b	1.07b	1.01b	57.0b	59.6b	61.9b	101b	118bc	137b
20 t ha^{-1} OBA	1.18b	1.11b	1.05b	55.5b	58.1b	60.4b	98b	106d	135b
20 t ha^{-1} SG	1.19b	1.12b	1.06b	55.1b	57.7b	60.0b	98b	111cd	135b
10 t ha^{-1} OBA + 10 t ha^{-1} GM	1.06c	0.99c	0.93c	60.0a	62.6a	64.9a	120a	131a	158a
10 t ha^{-1} OBA + 10 t ha^{-1} PM	1.04c	0.97c	0.91c	60.8a	63.4a	65.7a	124a	136a	165a
10 t ha^{-1} SG + 10 t ha^{-1} GM	1.06c	0.99c	0.93c	60.0a	62.6a	64.9a	112a	126ab	153a
10 t ha^{-1} SG + 10 t ha^{-1} PM	1.05c	0.98c	0.92c	60.4a	63.0a	65.3a	118a	129a	155a

Note: Treatment means within each column followed by the same letters are not significantly different from each other at $p = 0.05$ according to Duncan's multiple range test (DMRT). NSF, natural soil fertility; IF, inorganic fertilizer (NPK 15–15–15); GM, goat manure; PM, poultry manure; OBA, oil palm bunch ash; SG, spent grain.

SG). IF and NSF (control) produced similar values for bulk density, total porosity and water content.

Among the sole forms of the treatment, PM gave the lowest values of soil bulk density, highest total porosity and water content, which were not appreciably different from the values obtained with GM, OBA and SG treatments. Averaged over the 3 years, OBA + PM reduced soil bulk density, and increased total porosity and water content by 47, 37 and 95%, respectively, compared with IF and NSF (control), whereas application of the sole form of PM reduced soil bulk density, and increased total porosity and water content by 34, 29 and 51%, respectively, compared with IF and NSF (control).

Effect of different organic fertilizers on soil chemical properties

The results of soil analysis carried out on top soil (0–15 cm depth) at the end of the 2009 cropping season are shown in Table 6. Treatments with organic fertilizers gave significantly higher ($p = 0.05$) values for soil pH, organic C, total N, available P, exchangeable K, Ca and Mg compared with NSF (control). The mixture of OBA + PM significantly increased ($p = 0.05$) soil N, P and K concentrations after 3 years of cultivation compared with other treatments. Application of IF significantly increased ($p = 0.05$) soil total N, available P, exchangeable K, Ca and Mg compared with NSF (control), but did decrease soil pH and organic C. Application of organic fertilizers tended to improve soil pH, organic C, total N, and exchangeable K, Ca and Mg more than IF. In general, the mixture of OBA and SG with GM and PM increased soil total N, available P, and exchangeable Ca and Mg concentrations more than their sole forms (GM, PM, SG and OBA).

Table 6. Effect of organic fertilizers on soil chemical properties (0–15 cm depth) in 2009 after crop harvest.

Treatment	pH (water)	Organic C (g $100g^{-1}$)	N (g $100g^{-1}$)	P (mg kg^{-1})	K (cmol kg^{-1})	Ca (cmol kg^{-1})	Mg (cmol kg^{-1})
NSF (Control)	5.3ef	0.72e	0.05j	5.3g	0.10h	1.07h	0.12h
400 kg ha^{-1} IF (NPK)	5.1f	0.75e	0.14i	24.6d	0.46g	1.47g	0.20g
20 t ha^{-1} GM	6.5c	2.39b	0.23f	21.0e	0.53f	2.27e	0.69d
20 t ha^{-1} PM	6.6c	2.74a	0.25e	23.4d	0.59e	2.31e	0.66d
20 t ha^{-1} OBA	7.0ab	1.68d	0.20g	22.5d	0.90b	2.78d	0.73c
20 t ha^{-1} SG	6.3cd	1.72d	0.16h	20.5f	0.52f	1.75f	0.45e
10 t ha^{-1} OBA + 10 t ha^{-1} GM	7.0ab	2.09c	0.36b	30.3b	0.82c	3.86a	1.15a
10 t ha^{-1} OBA + 10 t ha^{-1} PM	7.3a	2.18bc	0.43a	36.1a	0.98a	3.91a	1.18a
10 t ha^{-1} SG + 10 t ha^{-1} GM	6.6c	2.03c	0.28d	26.7c	0.75d	3.41c	0.87b
10 t ha^{-1} SG + 10 t ha^{-1} PM	6.7bc	2.07c	0.32c	29.3b	0.78cd	3.64b	0.91b

Note: Treatment means within each column followed by the same letters are not significantly different from each other at $p = 0.05$ according to Duncan's multiple range test (DMRT). NSF, natural soil fertility; IF, inorganic fertilizer (NPK 15–15–15); GM, goat manure; PM, poultry manure; OBA, oil palm bunch ash; SG, spent grain

Among the sole forms of treatment, OBA gave significantly higher ($p = 0.05$) values for pH, K, Ca and Mg, whereas PM gave relatively high soil organic C and N. PM also gave the highest soil organic C concentration compared with sole or mixed applications. With the exception of the mixture of OBA + PM, application of OBA alone gave significantly higher values for K than sole or mixed applications.

At the end of 3 years of cultivation, OBA + PM increased soil pH, organic C, total N, available P, exchangeable K, Ca and Mg by 43, 191, 207, 47, 113, 166 and 490%, respectively, compared with IF. The treatment also increased soil pH, total N, available P, exchangeable K, Ca and Mg by 11, 72, 54, 66, 69 and 79%, respectively, compared with PM alone. However, PM alone increased soil organic C by 26% compared with a mixture of OBA + PM. In the same vein, OBA + PM also increased soil organic C, total N, available P, exchangeable K, Ca and Mg by 30, 115, 60, 9, 41 and 62%, respectively, compared with sole application of OBA. However, OBA alone increased soil-exchangeable K by 10, 15 and 20%, respectively, compared with OBA + GM, SG + PM and SG + GM. IF increased soil total N, available P, exchangeable K, Ca and Mg by 180, 364, 360, 37 and 67%, respectively, compared with NSF (control). PM alone increased soil pH, organic C, total N, exchangeable K, Ca and Mg by 29, 265, 79, 28, 57 and 230%, respectively, compared with IF.

Effect of different organic fertilizers on leaf nutrient concentrations of yam

Both mixtures of organic fertilizers and their sole forms showed significant increases ($p = 0.05$) in leaf N, P, K, Ca and Mg concentrations compared with NSF (control) treatment (Table 7). The mixed treatment OBA + PM gave the highest leaf N, P, K, Ca and Mg concentrations and was statistically superior to all other treatments. Among the mixed treatments, leaf N, P, K, Ca and Mg concentrations decreases in the following order: OBA + PM > OBA + GM > SG + PM > SG + GM. These

Table 7. Effect of different organic fertilizers on leaf nutrient concentrations of yam at 5 months after planting in 2009 cropping season.

Treatment	N	P	K (g 100g^{-1})	Ca	Mg
NSF (Control)	1.05i	0.14i	1.24h	0.11i	0.09i
400 kg ha^{-1} IF (NPK)	1.64h	0.32e	1.44g	0.21h	0.16h
20 t ha^{-1} GM	2.14f	0.28fg	1.62f	0.33f	0.26f
20 t ha^{-1} PM	2.37e	0.32e	1.78e	0.41e	0.28f
20 t ha^{-1} OBA	1.89g	0.30ef	1.81e	0.42e	0.33e
20 t ha^{-1} SG	2.12f	0.23h	1.59f	0.30g	0.21g
10 t ha^{-1} OBA + 10 t ha^{-1} GM	3.12b	0.48b	2.43b	0.58b	0.49b
10 t ha^{-1} OBA + 10 t ha^{-1} PM	3.45a	0.54a	2.68a	0.65a	0.55a
10 t ha^{-1} SG + 10 t ha^{-1} GM	2.64d	0.37d	2.03d	0.47d	0.38d
10 t ha^{-1} SG + 10 t ha^{-1} PM	2.86c	0.42c	2.25c	0.52c	0.43c

Note: Treatment means within each column followed by the same letters are not significantly different from each other at $p = 0.05$ according to Duncan's multiple range test (DMRT). NSF, natural soil fertility; IF, inorganic fertilizer (NPK 15–15–15); GM, goat manure; PM, poultry manure; OBA, oil palm bunch ash; SG, spent grain.

mixed treatments also gave significantly higher ($p = 0.05$) leaf N, P, K, Ca and Mg concentrations when compared with their sole forms. OBA + PM increased leaf N, P, K, Ca and Mg concentrations of yam by 110, 69, 86, 210 and 244%, respectively, compared with IF. The treatment also increased leaf N, P, K, Ca and Mg concentrations by 46, 69, 51, 59 and 96%, respectively, compared with sole application of PM.

All the sole forms of organic treatments significantly increased ($p = 0.05$) leaf N, Ca and Mg concentrations compared with IF. Among the sole treatments, PM significantly increased ($p = 0.05$) leaf N, P, K and Ca concentrations compared with GM and SG. PM was statistically similar to OBA in leaf K and Ca concentrations and was significantly higher ($p = 0.05$) in leaf N than OBA. Similarly, PM was significantly higher ($p = 0.05$) than IF in leaf N, K, Ca and Mg concentrations by 45, 24, 95 and 75%, respectively. The PM treatment also increased leaf N, P, K, Ca and Mg by 12, 39, 12, 37 and 33%, respectively, compared with SG treatment. The IF treatment significantly increased ($p = 0.05$) leaf N, P, K, Ca and Mg concentrations by 56, 129, 16, 91 and 78%, respectively, compared with NSF (control).

Discussion

The NSF (control) treatment gave the lowest yield and growth parameters for yam, such as tuber weight, vine length, number of leaves and leaf area, leaf and soil total N, available P, exchangeable K, Ca and Mg and soil pH and organic C. This could be attributed to initial lower nutrient status of the soil and continuous cultivation without fertilization, thus indicating poor soil fertility. The higher soil bulk density of 1.38–1.48 Mg m^{-3} recorded for the NSF (control) plots was also not suitable for yam production (Agbede and Ojeniyi 2003). At the end of 3 years of continuous cultivation, soil organic C decreased by 31% compared with other treatments, which increases soil organic C. This observation agreed with the study carried out by Adekiya and Agbede (2009), which reported a decrease of 23.8% in organic C over 2 years of continuous cultivation of tomato crop on an Alfisol at Owo, southwest Nigeria without fertilization.

However, application of organic fertilizers (solely or as mixtures) to soils with low fertility status enhanced favourable yield and growth parameters of yam, which could be due to their rich nutrient concentrations. This finding agreed with the work of Moyin-Jesu and Ojeniyi (2006), which reported a rapid response in the yield and growth of okra with the application of organic fertilizers. Hence, this finding highlighted the importance of organic fertilizer use for the enhancement of soil and crop productivity in the tropics.

After three cropping seasons, OBA + PM applied at suboptimal rates (10 t ha^{-1} each) significantly increased yield and growth parameters of yam, soil and leaf N, P, K, Ca and Mg, and increased soil pH and organic C compared with either sole or mixed applications of organic fertilizers. This could be attributed to its higher nutrient concentrations (N, P, K, Ca and Mg), which increased the availability of nutrients in the soil, leading to increased uptake by yam plants. In addition, another reason could be due to increased microbial activities and mineralization of nutrients induced by the addition of PM, which should have facilitated nutrient release and increased production of nutrients.

The effectiveness of OBA and SG in enhancing/improving yield and growth parameters of yam, leaf and soil N, P, K, Ca and Mg, and soil pH and organic C, when mixed with GM and PM could be attributed to the enhancement of their biodegradation rate by manures with a lower C/N ratio. In addition, the processing of organic fertilizers before application to the soil should have further facilitated their decomposition and rate of nutrient release to the soil. However, the deleterious effect of continuous application of chemical fertilizer in enhancing soil and crop productivity was clearly shown after 3 years of cropping because the IF (NPK) resulted in significantly lower ($p = 0.05$) leaf N, K, Ca and Mg compared with either mixed or sole application of organic fertilizers. This may be due to loss of nitrogen through the leaching of nutrients beyond the sampling depth (0–15 cm depth). The decrease in the soil-exchangeable K concentration over time was probably due to the exhaustive use of soil K by the yam plant for tuber formation. Also, part of the soil-exchangeable K could have been lost to leaching. This study agreed with the findings of Agboola and Omueti (1982) that continuous use of inorganic fertilizers resulted in the serious deterioration of soil properties and poor yield responses, whereas repeated application of organic fertilizers to soil has been shown to improve physicochemical properties (Mbagwu 1992; Kingery et al. 1993; Moyin-Jesu and Adeofun 2008). The increases in soil and leaf N, P, K, Ca and Mg concentrations attributed to IF (NPK fertilizer) compared with control might be due to high soluble and plant-available nutrients, as well as the decomposition of organic matter and mineralization of its nutrients.

The superlative performance of the OBA + PM treatment in increasing tuber weight, vine length, number of leaves and leaf area of yam compared with IF (NPK) could be a result of their improvement in soil physical properties (reduced soil bulk density, increased total porosity and water content), highest nutrient amounts provided (N, P, K, Ca and Mg), which increased the availability of soil nutrients and their subsequent uptake by yam plants. Low soil bulk density and high total porosity and water content are known to enhance root growth and uptake of N, P and especially K that is essential for yam. The lower yield and growth components recorded for IF (NPK) was consistent with higher soil bulk density and relatively low soil and leaf N, P and K concentrations recorded for IF (NPK). The mean soil bulk density recorded for the IF (NPK) (1.47 Mg m^{-3}) was almost above the value of 1.1 Mg m^{-3} found to be suitable for yam tuber formation (Agbede and Ojeniyi 2003).

The higher values of tuber weight, vine length, number of leaves and leaf area, soil N, P, K, pH and organic C in the OBA + PM treatment applied at 10 t ha^{-1} each compared with OBA + GM and SG + PM at (10 t ha^{-1} each) might be because PM had the highest N and P concentrations and the lowest C/N ratio, whereas OBA had the highest K, Ca and Mg concentrations. This affirmed the positive cumulative effect of that combination. Yam performance is known to be strongly influenced by N and K (Obigbesan 1981, 1999; Akanbi and Ojeniyi 2007). This finding was similar to the work of Moyin-Jesu and Adeofun (2008), who reported the best performance for OBA + PM in increasing growth, soil and leaf nutrient concentrations in bitter kola seedlings.

The better performance of the mixture of OBA and SG with GM and PM over their sole forms was attributable to their solubilizing effects and the fact that PM and GM have high nutrient concentrations and low C/N ratios and their mixture with OBA and SG increased/ fortified their nutrient supplying power. This also affirmed that mixed application of organic fertilizers may be more useful for nutrient addition to soil than sole applications of organic fertilizers.

The better performance of OBA in comparison with IF (NPK) after 3 years of cultivation could be attributed to increased soil organic C, its buffering action against pH fluctuation and leaching, improved soil structure and water retention capacity due to OBA addition and its relatively higher K. Potassium was reported to be an important nutrient in the production of yam (Obigbesan 1999).

The increase in tuber weight of yam over time in the organic fertilizer treatments could be attributed to their high residual effects on soil properties and were able to sustain three successive cropping of yam in this study. Whereas the decrease in tuber weight of yam over time in the IF (NPK) treatment was related to the fact that nutrients from IF are quickly released into soil, which may not benefit subsequent yam crops and its continuous application degrades soil properties.

The sole organic fertilizer applied at 20 t ha^{-1} and the mixture of OBA and SG with GM and PM applied at suboptimal rates (10 t ha^{-1} each) generally reduced soil bulk density and increased water content and porosity compared with IF (NPK) and NSF (control). The observed trend in these soil physical properties may be due to significant organic matter addition to the soil by organic amendments, which provided stable soil aggregate conditions and prevented leaching/eroding of colloidal fraction with high 'enrichment ratio' and valuable nutrients from soil. The effects of GM, PM, OBA and SG in reducing soil bulk density and increasing water content and porosity were attributable to the increase in organic matter status of the soil because organic amendments are known to stabilize soil structure, enhance soil porosity and water infiltration and retention (Ojeniyi et al. 2007; Agbede and Ojeniyi 2010). This study agreed with the findings of Mbagwu and Piccolo (1989) that repeated application of organic residues to soil improves physicochemical properties of such soils. Vinten et al. (2002) also reported an increase in microbial activity following application of organic amendments to soil, thus suggesting a more responsive microbial community. The importance of beneficial microbes in building a healthy soil microenvironment through enhancement of natural soil process cannot be overemphasized.

The increase in soil pH observed under OBA alone or when mixed with GM and PM compared with other treatments was attributable to its high K, Ca and Mg concentrations. This could be due to the liming effects of plant ash on the soil (Azeez et al. 2007; Moyin-Jesu and Adeofun 2008) unlike IF (NPK), which could lead to soil acidity (decrease soil pH) with repeated use. The increase in soil pH recorded for sole applications of PM and GM compared with IF (NPK) could be attributed to the increased availability of organic matter and calcium ions released into the soil solution during the microbial decarboxylation of manures (Agbede 2010), which is known to buffer change in soil pH.

Nutrient concentrations in the leaves of yam plants in the NSF (control) plots were below the critical levels of <2.9–4.0% N, 0.21–0.32% P, 2.2–2.8% K, 0.5–0.9% Ca and 0.10–0.14% Mg, as reported by O'Sullivan (2010), thus the leaves of yam plants exhibited symptoms of deficiencies in N (yellow colouration), P (purple colouration) and K (burnt leaf margin).

The application of GM and PM, OBA and SG (either solely or as mixtures) including the IF (NPK) increased the leaf N, P, K, Ca and Mg concentrations of yam plants compared with NSF (control), which could be attributed to their leaf nutrient concentrations (Table 7). This observation agreed with the study of Moyin-Jesu and Adeofun (2008), which reported that PM, turkey manure, OBA and SG were good sources of N, P, K, Ca and Mg when applied to soils.

Conclusion

The sole forms of organic fertilizer applied at 20 t ha^{-1} each and a mixture of OBA and SG with GM and PM applied at 10 t ha^{-1} each increased tuber weight, vine length, number of leaves and leaf area of yam and reduced bulk density and increased total porosity, water content, soil and leaf N, P, K, Ca and Mg, soil pH and organic C compared with the NSF (control). IF (NPK 15–15–15 fertilizer) did not improve soil physical properties, but did increase soil and leaf nutrient concentrations, growth and yield of yam compared with the NSF (control). OBA + PM applied at 10 t ha^{-1} each gave the highest yam tuber yield due to its higher N, P, K, Ca, Mg, total porosity, water content and lower bulk density and relatively low C/N ratio compared with other treatments and therefore recommended for yam production on an Alfisol of the humid tropics for improving soil fertility conditions and sustained productivity. This recommendation agreed with the fact that inorganic fertilizers are very scarce, expensive to purchase by small holding farmers of yam and also destroy soil properties when use repeatedly. These organic materials are cheap, available and sustainable, and also have beneficial secondary effects on soil properties and are more favourable to the environment.

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