Agro-Science Journal of Tropical Agriculture, Food, Environment and Extension
Volume 20 Number 1 (January 2021) pp. 65 - 71
ISSN 1119-7455

SOIL FERTILITY INDICES OF TROPICAL LOAMY SAND AS INFLUENCED BY BAMBARA GROUNDNUT VARIETY, PLANT SPACING AND FERTILIZER TYPE

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ABSTRACT
Agricultural sustainability ensues when cultivation of field crops and associated techniques improve not just crop yields but also management-responsive soil properties. Bambara groundnut as an underutilized crop lacks research-based information on its agronomic requirements. This paper reports the key fertility indices of a loamy-sand soil in southeastern Nigeria as influenced by soil and agronomic management practices involving factorial combinations of two bambara groundnut varieties (Caro and Olokoro), two plant spacings (30 cm × 75 cm and 45 cm × 75 cm) and four organic/inorganic fertilizer options. These fertilizer options were NPK 15-15-15 (NPK), single super phosphate (SSP), poultry manure (PM) and Control. The plots under Caro variety spaced 30 cm × 75 cm and grown with NPK or SSP fertilizer showed the highest CEC (8.40 cmol kg^{-1}) and exchangeable K (0.15 cmol kg^{-1}), respectively. Olokoro variety spaced 45 cm × 75 cm and grown with PM or SSP gave the highest total nitrogen (0.14%), soil pH-H_2O (6.35), available phosphorus (107.60 mg kg^{-1}) and exchangeable Ca (3.70 cmol kg^{-1}). The interactions plant spacing × fertilizer type and crop variety × fertilizer type affected all the soil fertility indices studied, while crop variety × plant spacing affected soil pH$_{water}$, available phosphorus, CEC and exchangeable Ca and Mg. Generally, as main factors, Olokoro variety, NPK and 45 cm × 75 cm improved soil properties better than their counterparts.

Key words: sandy tropical soils, plant population density, organic amendments, synthetic fertilizers, NPK status

INTRODUCTION
Bambara groundnut (*Vigna subterranea* (L) Verdc) is an important food legume and also remarkable for its environmental sustainability (Feldman *et al.,* 2019). As a leguminous crop, it fixes nitrogen (Nweke and Emeh, 2013), thereby reducing the inorganic nitrogen requirement of intercropped or the following crop in rotation. It can also be used as green manuring crop, where it rejuvenates soil and improves its fertility (Sprent *et al.,* 2010). It is known to be adaptable to adverse environmental conditions and can be grown on marginal lands (Cleasby *et al.,* 2016). In spite of all these potentials, bambara remains a neglected and underutilized crop (Dansi *et al*., 2012). Research on its agronomic requirements is still scarce (Hillocks *et al.,* 2012; Feldman *et al.,* 2019), leading to the speculation that it does not require fertilizer. Yields are generally poor (Mayes *et al.,* 2019), and this depends on location, genotype, season or time of planting, plant population and soil fertility.

The sustainability of crop production depends on soil fertility and its maintenance. Consequently, fertilizers help to improve soil fertility and sustain crop production. Studies on organic and synthetic fertilizers for growing cover crops focus on their growth and yields and rarely on soil properties (Idem *et al*., 2012; Nweke and Emeh, 2013; Ikenganyia *et al*., 2017; Ngwu and Edeh, 2018). This is despite the fact that but the growth/yields of such crops often reflect amendment-induced variations in soil fertility indices (Nwite *et al*., 2013).

The effects of NPK and other fertilizers have been evaluated on landraces of bambara groundnut (Wamba *et al*., 2012). Also, there have been studies on plant density and/or phosphate fertilizer effects on the crop's growth and yields (Nweke and Emeh, 2013; Ikenganyia *et al*., 2017). Research has shown the efficacy of phosphate fertilizer for bambara production in low-fertility tropical African soils, but these observations are often without supporting soil data (Wamba *et al*., 2012; Ikenganyia *et al*., 2017).

Please cite as: Umeugokwe C.P., Ugwu V.U., Umeugochukwu O.P., Uzoh I.M., Obalum S.E., Ddamulira G., Karwani G.M. and Alenoma G. (2021). Soil fertility indices of tropical loamy sand as influenced by bambara groundnut variety, plant spacing and fertilizer type. *Agro-Science*, **20 (1),** 65-71. DOI: https://dx.doi.org/10.4314/as.v20i1.11

Plant spacing is another factor that affects crop performance and soil fertility status. Plant spacing determines plant population density which affects resource use efficiency and overall crop performance (Adubasim *et al.,* 2017). It also determines the soil nutrient balance after harvest; the denser the plant population is, the more is nutrient removal from the soil. Close spacing makes the plants to be crowded, leading to competition for physical space, light, plant nutrients and water. As such, optimum yield of the crop is limited (Ikenganyia *et al*., 2017). Soil pH decreases due to more nutrient uptake by the overpopulated plants. Ahmed and Abdelrhim (2010) observed that increase in yields could occur with appropriate plant density that promotes efficient use of resources, while avoiding excessive competition among plants. Ikenganyia *et al*. (2017) reported better performance of bambara groundnut at lower than higher densities. These studies did not cover how different plant spacings influence soil chemical properties especially in tractor inter-row spacing which obtains in commercial farming. Obalum *et al.* (2017) noted that the plant spacing adopted for any crop should be able to conserve soil resources.

Cultivation of leguminous cover crops helps to promote soil quality; doing so with any destructive tillage operations requires that adequate surface coverage be ensured (Obalum *et al*., 2011). This could be achieved with appropriate plant spacing. Where tractors are used for primary tillage, the inter-row spacing is usually fixed; the only thing that could be manipulated is the intra-row spacing. This study was thus initiated to assess the integrated effects of cultivation of two bambara groundnut varieties at two plant spacings using different fertilizer types on some fertility indices of the soil.

MATERIALS AND METHODS

Experimental Site Description

The study was conducted in Igga, Uzo-Uwani Local Government Area, Enugu State, South-East Nigeria. Igga lies at latitude 6° 43' N and longitude 6° 56' E and is on a mean elevation of 98 m asl. The location has a mean annual temperature of 20°C and a mean annual rainfall of 2000 mm. The vegetation of the study area typifies a derived savanna which is the transitional zone between rainforest and savanna of the tropics (Obalum *et al*., 2013). The study was an on-farm experiment situated very close to Saint Theresa's Catholic Church, Igga.

Treatments and Experimental Design

Experimental design was a 4 × 2 × 2 factorial in a randomized complete block design (RCBD). The treatments consisted of factorial combinations of four fertilizer types [NPK 15-15-15 (NPK), 18% single super phosphate (SSP), poultry manure (PM) and a no-fertilizer control]; two bambara groundnut varieties (Caro and Olokoro); and two plant spacings (30 cm × 75 cm and 45 cm × 75 cm 45, henceforth referred to as 30 cm and 45 cm, respectively). There were, therefore, 16 treatments. They were replicated three times to give a total of 48 plots. The two varieties of bambara groundnut used were prominent within the study location and its environs. Caro variety is milky in colour while Olokoro variety is black and white in colour.

Planting and Fertilizer Application

Experimental field of 61 × 19.5 m^2 was ploughed, harrowed and ridged by a tractor. Plots were demarcated afterwards and the area for each plot was 4 m × 3.75 m. The bambara groundnut seeds were sown ca. 4-7 cm deep at the rate of three seeds per hole, for the two plant spacings of the study (30 cm and 45 cm). Seedlings emerged 5-7 days after sowing. Two weeks after sowing, supplying and thinning were done. Fertilizers were applied four weeks after sowing at the rates of 60 kg ha^{-1} for both NPK and SSP, and 10 t ha^{-1} for PM. Since NPK rate of 150 kg ha^{-1} had been successfully used to grow varieties of non-leguminous cover crop in the study area (Oraegbunam *et al*., 2016), the lower rate here considered bambara's N-fixing ability. The rates of SSP and PM used here were adopted after Uzoh *et al.* (2017) and Obi and Ebo (1995), respectively. Weeding was done by hand hoeing three weeks after sowing when earthening up was also done to cover roots exposed by rainfall.

Data Collection

Soil sampling

At the beginning of the experiment before planting, soil samples were randomly collected from several points within the experimental site, using auger, from the surface (0-15 cm) soil layer and bulked to form composite samples. Also, at crop harvest done three some months after sowing, soil samples were collected randomly within each plot from the 0-15 cm depth. These soil samples were air-dried and ground to pass a 2-mm sieve prior to analyses for treatment effects on soil chemical properties.

Laboratory analyses

Particle size distribution for describing the soil's texture was determined by the hydrometer method (Gee and Bauder, 1986). Soil pH was measured by reading off the values in stirred soil-water/KCl (1:2.5) suspensions with a glass electrode pH meter (McLean 1982). Soil organic carbon was determined using the wet dichromate acid oxidation method (Nelson and Sommers, 1982), and multiplied by 1.72 to derive the soil organic matter. Total nitrogen in the soil was determined by Macro-Kjeldahl digestion (Bremner and Mulvaney, 1982), and available phosphorus by Bray-2 extraction method (Olsen and Sommers, 1982). Cation exchange capacity (CEC) and exchangeable bases were determined using an ammonium acetate extraction method (Hendershot *et al.,* 1993). Exchangeable acidity was extracted with 1N KCl and measured titrimetrically by McLean's (1982) procedure.

Table 1: Initial soil physicochemical properties of the soil under investigation

Soil properties	Values
Total Sand (g kg^{-1})	792
Silt (g kg^{-1})	118
Clay (g kg^{-1})	90
Texture class	Loamy Sand
Soil pH-H_2O	5.80
Soil organic matter (g kg^{-1})	6.90
Soil organic carbon, C (g kg^{-1})	4.00
Total nitrogen, N (g kg^{-1})	0.80
Available phosphorus, P (mg kg^{-1})	68.48
C/N ratio	5.00
C/P ratio	0.58
Exch. K^+ (cmol kg^{-1})	0.15
Exch. Na^+ (cmol kg^{-1})	0.17
Exch. Ca^+ (cmol kg^{-1})	2.60
Exch. Mg^+ (cmol kg^{-1})	Nil
Exch. Acidity (cmol kg^{-1})	0.80
Effective CEC (cmol kg^{-1})	3.72
CEC (cmol kg^{-1})	4.80
% Base Saturation	60.83

CEC - cation exchange capacity

Statistical Analysis

Analyses of variance (ANOVA) was conducted on the data generated from the laboratory analyses using appropriate ANOVA procedure of GenStat Discovery Edition 9 (GenStat, 2012). The F-LSD test was used to determine significantly different means at 5% level of probability ($p \leq 0.05$).

RESULTS AND DISCUSSION

Initial Soil Properties

The physical and chemical properties of the soil on which the experiment was conducted are shown in Table 1. The soil pH was moderately acidic with loamy sand texture. The soil had low concentrations of organic matter, total nitrogen and exchangeable bases (K^+, Ca^{2+} and Mg^+), but adequate content of available phosphorus (Landon, 1991).

Interaction Effects of Bambara Groundnut Variety, Plant Spacing and Fertilizer Type on Cation Exchange Properties of the Soil

Table 2 shows the interaction effects of bambara groundnut variety, fertilizer type and plant spacing on CEC and exchangeable (exch.) bases in the soil. These cation exchange properties of the soil were affected by the interaction of these factors. Caro spaced 30 cm and grown with NPK gave the highest CEC (8.40 cmol kg^{-1}), and this was similar to Olokoro spaced 45 cm and grown with NPK (7.80 cmol kg^{-1}). The lowest CEC (4.0 cmol kg^{-1}) was obtained in plots where Caro was spaced 30 cm and grown without fertilizer (control). The treatments Caro spaced 30 cm with SSP, Olokoro spaced 30 cm with control, and Olokoro spaced 45 cm with SSP all gave the highest values (0.15 cmol kg^{-1}) of exch. K, which were similar to the values in Caro spaced 45 cm with control (0.14 cmol kg^{-1}). The lowest exch. K (0.10 cmol kg^{-1}) was obtained in Olokoro spaced 30 cm with PM. For exch. Na, Caro in both plant spacings with SSP gave the highest value (0.17 cmol kg^{-1}), while Caro spaced 45 cm with PM gave the lowest value (0.08 cmol kg^{-1}). The highest exch. Ca (3.70 cmol kg^{-1}) was obtained in Olokoro spaced 30 cm with PM, while the lowest value (2.00 cmol kg^{-1}) was obtained in Caro spaced 30 cm with PM. Thus the two bambara groundnut varieties exploited exch. Ca differently when spaced 30 cm and grown with PM. The data further show that, with NPK as the nutrient source, whether 30 cm or 45 cm spacing would deplete exch. Ca the more depended on the bambara groundnut variety grown.

Olokoro spaced 45 cm and grown with SSP gave the highest exch. Mg (4.80 cmol kg^{-1}), while Caro spaced 45 cm and grown with PM gave the lowest (0.40 cmol kg^{-1}) (Table 2). Notably, exch. Mg was generally higher under Olokoro than Caro variety, suggesting that the demand for Mg by the latter surpasses that of the former. By having differential effects on the soil fertility index of exch. Mg, the bambara groundnut varieties evaluated potentially could respond differently to fertilizer application to low-fertility tropical soils (Wamba *et al*., 2012).

The exch. H (H^+) showed highest values in plots where Olokoro was spaced 30 cm and grown with NPK (1.10 cmol kg^{-1}) and lowest values where Olokoro was spaced 30 cm and grown with control (0.30 cmol kg^{-1}). For 30 cm spacing, control and NPK gave the highest and lowest H^+ in Caro plots; the reverse was true in Olokoro plots. It is widely believed that inorganic fertilizers most times leave acid residue in the soil (Ojo *et al*., 2011). The observed contrast in treatment effects on H^+ suggests that the crop variety and/or plant spacing adopted explains those other times such unwanted effect of inorganic fertilizers are either reversed or not evident in highly weathered tropical soils.

Interaction Effects of Bambara Groundnut Variety, Plant Spacing and Fertilizer Type on Total Nitrogen, Soil pH and Available Phosphorus

Interaction of the three factors affected total nitrogen (TN), soil pH and available P (Table 3). Olokoro spaced 45 cm and grown with SSP gave the highest TN (0.14%), while Caro spaced 30 cm and grown with control gave the lowest TN (0.05 %). It would appear as if Caro is a heavy N feeder, since growing it at a closer spacing of 30 cm and without fertilizer depleted N the most. However, Caro fixing less N rather taking up more N compared to Olokoro is a more plausible reason for the observation. Hence, in NPK-amended plots, TN tended to be higher under Caro than Olokoro regardless of plant spacing. Also, treatments without fertilizer consistently had lowest TN except where Caro was spaced 45 cm.

Soil pH in H_2O was always above that in KCl, and this was due to the net negative charge in the soil (Obalum *et al*., 2012). The highest and lowest values of soil pH in H_2O were recorded in Olokoro spaced 45 cm, showing PM's role in ameliorating soil acidity. Available P followed this trend, with Caro spaced 30 cm and grown with control being among treatments showing the lowest values.

Table 2: Effects of interaction of variety, plant spacing and fertilizer on cation exchange properties of the soil at crop harvest

Variety	Plant spacing	Fertilizer type	CEC	K^+	Na^+	Ca^{2+}	Mg^{2+}	H^+
			cmol kg^{-1}					
Caro	30 cm × 75 cm	Control	4.00	0.12	0.13	3.30	1.60	0.90
		NPK 15-15-15	8.40	0.12	0.14	3.60	2.50	0.50
		Poultry manure	5.10	0.12	0.09	2.00	1.10	0.50
		Single superphosphate	6.20	0.15	0.17	2.40	0.70	0.80
	45 cm × 75 cm	Control	5.20	0.14	0.15	3.10	3.00	0.70
		NPK 15-15-15	4.60	0.13	0.14	2.70	1.80	0.70
		Poultry manure	5.40	0.12	0.08	3.00	0.40	0.80
		Single superphosphate	5.60	0.14	0.17	2.60	0.80	0.60
Olokoro	30 cm × 75 cm	Control	5.40	0.15	0.13	2.30	4.00	0.30
		NPK 15-15-15	5.60	0.13	0.13	2.30	0.40	1.10
		Poultry manure	6.00	0.10	0.10	3.70	1.20	1.00
		Single superphosphate	5.80	0.13	0.13	2.50	2.10	0.50
	45 cm × 75 cm	Control	4.80	0.12	0.14	2.30	0.90	0.40
		NPK 15-15-15	7.80	0.14	0.14	3.60	3.50	0.60
		Poultry manure	6.60	0.12	0.09	3.20	1.40	0.60
		Single superphosphate	6.40	0.15	0.14	3.30	4.80	0.80
	F-$LSD_{(0.05)}$		*0.97*	*0.02*	*0.05*	*0.69*	*1.89*	*0.35*

CEC - cation exchange capacity

Table 3: Effects of interaction of variety, plant spacing and fertilizer on total nitrogen, soil pH and available phosphorus

Variety	Plant spacing	Fertilizer type	% Total nitrogen	Soil pH		Available phosphorus (mg kg^{-1})
				H_2O	KCl	
Caro	30 cm × 75 cm	Control	0.05	5.60	5.10	19.1
		NPK 15-15-15	0.10	5.75	5.15	42.8
		Poultry manure	0.11	5.80	5.25	30.0
		Single superphosphate	0.11	5.70	5.15	22.4
	45 cm × 75 cm	Control	0.11	6.00	5.35	29.4
		NPK 15-15-15	0.10	5.60	5.15	32.7
		Poultry manure	0.12	5.85	5.50	59.1
		Single superphosphate	0.09	5.90	5.45	26.7
Olokoro	30 cm × 75 cm	Control	0.08	5.80	5.15	24.5
		NPK 15-15-15	0.08	5.85	5.25	34.9
		Poultry manure	0.13	6.15	5.65	54.2
		Single superphosphate	0.11	5.80	5.30	20.6
	45 cm × 75 cm	Control	0.08	5.50	5.15	20.3
		NPK 15-15-15	0.09	5.70	5.15	20.3
		Poultry manure	0.12	6.35	5.85	107.6
		Single superphosphate	0.14	6.20	5.90	50.9
	F-$LSD_{(0.05)}$		*0.04*	*0.34*	*0.12*	*23.3*

The soil fertility indices were increased mostly by Olokoro in 45 cm spacing and grown with either PM or SSP. These increases due to Olokoro may have resulted from less nutrient requirement and hence uptake by this variety compared to Caro. Ficiciyan *et al.* (2018) propose that crop varieties especially those encompassing landraces and hybrids have implications on the ecosystem. The wider 45 cm spacing had fewer plants per unit area than the narrower 30 cm spacing. This logically would translate into less nutrient depletion and more leftover nutrients in plots where bambara groundnut was spaced 45 cm than where it was spaced 30 cm.

Interaction Effects of Bambara Groundnut Variety and Plant Spacing on the Selected Fertility Indices of the Soil

Table 4 shows the interaction effects of bambara groundnut variety and plant spacing on soil chemical properties representing the fertility indices of the soil. Olokoro spaced 45 cm gave the highest values of CEC (6.40 cmol kg^{-1}), exch. Ca (3.10 cmol kg^{-1}), exch. Mg (2.65 cmol kg^{-1}), soil pH (5.94) and available P (49.8 mg kg^{-1}), while tending to also give the highest TN (0.107 %). Caro spaced 30 cm gave the lowest values of most of the soil chemical properties. The low nutrient requirement of Olokoro earlier alluded to and the lower population density given by 45 cm spacing would explain these results. The data for the two bambara varieties as compared for each of 30 cm and 45 cm spacings support the notion that Olokoro is a lighter feeder than Caro.

Interaction Effects of Plant Spacing and Fertilizer Type on the Selected Fertility Indices of the Soil

Interaction of plant spacing and fertilizer type affected all the soil chemical properties assessed (Table 5). The 45 cm spacing with PM had the highest TN (0.119%, similar to 30 cm with PM), soil pH (6.10) and available P (83.4 mg kg^{-1}). The 45 cm spacing with NPK had the highest values of exch. Ca (3.5 cmol kg^{-1}), but 30 cm spacing with NPK gave the highest CEC (7.0 cmol kg^{-1}) and exch. H (0.80 cmol kg^{-1}). The 45 cm spacing with SSP had the highest exch. K (0.15 cmol kg^{-1}) and Mg (2.80 cmol kg^{-1}). The 30 cm spacing with control had the lowest values of CEC (4.70 cmol kg^{-1}) and TN (0.067%), and also had about the lowest values of exch. H (0.60 cmol kg^{-1}), soil pH (5.70) and available P (21.80 mg kg^{-1}).

Table 4: Effects of the interaction of bambara groundnut variety and plant spacing on selected fertility indices of the soil

Variety	Plant spacing	CEC	K^+	Na^+	Ca^{2+}	Mg^{2+}	H^+	%	Soil pH		Av. P
		(cmol kg⁻¹)						TN	H_2O	KCl	(mg kg⁻¹)
Caro	30 cm × 75 cm	5.93	0.12	0.13	2.83	1.48	0.68	0.091	5.71	5.16	28.6
	45 cm × 75 cm	5.20	0.13	0.14	2.85	1.50	0.70	0.105	5.84	5.36	37.0
Olokoro	30 cm × 75 cm	5.70	0.13	0.12	2.70	1.93	0.73	0.102	5.90	5.34	33.6
	45 cm × 75 cm	6.40	0.13	0.13	3.10	2.65	0.60	0.107	5.94	5.51	49.8
$F\text{-}LSD_{(0.05)}$		*0.99*	*ns*	*ns*	*0.35*	*0.95*	*ns*	*ns*	*0.17*	*0.12*	*11.7*

CEC - cation exchange capacity; TN - total nitrogen; Av. P - available phosphorus; *ns* not significant at 5% probability level

Table 5: Effects of the interaction of fertilizer type and plant spacing on selected fertility indices of the soil

Variety	Plant spacing	CEC	K^+	Na^+	Ca^{2+}	Mg^{2+}	H^+	%	Soil pH		Av. P
		(cmol kg⁻¹)						TN	H_2O	KCl	(mg kg⁻¹)
Control	30 cm × 75 cm	4.70	0.13	0.13	2.80	2.80	0.60	0.067	5.70	5.13	21.8
	45 cm × 75 cm	5.00	0.13	0.15	2.70	1.95	0.55	0.095	5.75	5.25	24.9
NPK	30 cm × 75 cm	7.00	0.12	0.14	2.95	1.45	0.80	0.092	5.80	5.20	38.8
	45 cm × 75 cm	6.20	0.13	0.14	3.15	2.65	0.65	0.095	5.65	5.15	26.5
PM	30 cm × 75 cm	5.55	0.11	0.09	2.85	1.15	0.75	0.119	5.98	5.45	42.1
	45 cm × 75 cm	6.00	0.11	0.09	3.10	0.90	0.70	0.119	6.10	5.68	83.4
SSP	30 cm × 75 cm	6.00	0.14	0.15	2.45	1.40	0.65	0.109	5.75	5.23	21.5
	45 cm × 75 cm	6.00	0.15	0.16	2.95	2.80	0.70	0.116	6.05	5.68	38.8
$F\text{-}LSD_{(0.05)}$		*1.39*	*0.03*	*0.03*	*0.24*	*1.34*	*0.25*	*0.027*	*0.23*	*0.17*	*16.5*

NPK - NPK 15-15-15; PM - poultry manure; SSP - single super phosphate; CEC - cation exchange capacity;
TN - total nitrogen; Av. P - available phosphorus

The 45 cm spacing and use of PM, NPK or SSP as fertilizers improved the various fertility indices of the soil including soil pH and some primary nutrients; the only exception was CEC whose highest value was due to 30 cm spacing with NPK. More base-forming cations and plant nutrients were perhaps ‘spared’ in the soil at this wider 45 cm spacing than the narrower 30 cm spacing.

Interaction Effects of Bambara Groundnut Variety and Fertilizer Type on the Selected Fertility Indices of the Soil

All the soil chemical properties of this study were affected by the interaction of bambara groundnut variety and fertilizer type (Table 6). Caro grown with control had the lowest CEC (4.60 cmol kg⁻¹), TN (0.081%) and available P (22.4 mg kg⁻¹), while Olokoro grown with control had the lowest exch. Ca (2.30 cmol kg⁻¹) and soil pH (5.65).

Main Effects of Bambara Groundnut Variety, Plant Spacing and Fertilizer Type on Cations Exchange Properties of the Soil

Main effects of the factors investigated on cations exchange properties of the soil are shown (Table 7). Bambara groundnut variety affected only exch. Mg, with Olokoro having higher value than Caro. Main effects of plant spacing were consistently not evident.

Fertilizer type affected the soil’s CEC and the exch. bases. For CEC, the three fertilizer types of NPK, PM and SSP were similar with NPK and SSP higher than the control. The highest and lowest values of the exch. bases were, respectively due to SSP and PM for K and Na, NPK and SSP for Ca, and control and PM for Mg. The highest and lowest exch. H (H^+) were obtained in NPK/PM and control, respectively. Thus NPK had the highest values of most of the cation exchange properties of the soil (CEC, exch. Ca and exch. H), followed by SSP with the highest values of exch. K and Na. This may be understood from the relative ability of these two fertilizer types to supply cations to the soil.

Main Effects of Bambara Groundnut Variety, Plant Spacing and Fertilizer Type on Total Nitrogen, Soil pH and Available Phosphorus

The main effects of treatments on TN, soil pH and available P are shown (Table 8). Bambara variety affected soil pH and available P (Olokoro > Caro), plant spacing affected available P (45 cm > 30 cm), whereas fertilizer type affected all three soil fertility indices (highest and lowest values in PM and control, respectively). Crop variety did not affect TN, suggesting that the two varieties of this leguminous bambara are of equal ability to fix N. The higher soil pH and available P under Olokoro than Caro could be linked to the aforestated less uptake of nutrients by the former than the latter. And soil pH is indirectly related to nutrient status of the soil; the higher the uptake of nutrient is, the lower is the soil pH since H^+ will then occupy the exchange sites vacated by the nutrients.

Table 6: Effect of interaction of variety and fertilizer on selected fertility indices of the soil

Variety	Fertilizer type	%	pH		Av. P	CEC	K^+	Na^+	Ca^{2+}	Mg^{2+}	H^+
		TN	H_2O	KCl	(mg kg⁻¹)	(cmol kg⁻¹)					
Caro	Control	0.081	5.80	5.23	22.4	4.60	0.13	0.14	3.20	2.30	0.80
	NPK	0.099	5.68	5.15	37.7	6.50	0.12	0.14	3.15	2.15	0.60
	PM	0.112	5.82	5.38	44.5	5.25	0.12	0.09	2.50	0.75	0.65
	SSP	0.102	5.80	5.30	24.5	5.90	0.15	0.17	2.50	0.75	0.70
Olokoro	Control	0.081	5.65	5.15	22.4	5.10	0.13	0.13	2.30	2.45	0.35
	NPK	0.088	5.78	5.20	27.6	6.70	0.13	0.14	2.95	1.95	0.85
	PM	0.126	6.25	5.75	80.9	6.30	0.11	0.09	3.45	1.30	0.80
	SSP	0.123	6.00	5.60	35.8	6.10	0.14	0.13	2.90	3.45	0.65
$F\text{-}LSD_{(0.05)}$		*0.027*	*0.24*	*0.17*	*16.5*	*1.40*	*0.02*	*0.02*	*0.49*	*1.34*	*0.25*

NPK - NPK 15-15-15; PM - poultry manure; SSP - single super phosphate; CEC - cation exchange capacity

Table 7: Main effects of the three factors investigated on exchangeable cations and CEC of the soil

Main factors		CEC	K^+	Na^+	Ca^{2+}	Mg^{2+}	H^+
		(cmol kg^{-1})					
Crop Variety	Caro	5.56	0.13	0.14	2.84	1.49	0.69
	Olokoro	6.05	0.13	0.12	2.90	2.29	0.66
	F-LSD$_{(0.05)}$	*ns*	*ns*	*ns*	*ns*	*0.67*	*ns*
Plant Spacing	30 cm × 75 cm	5.81	0.13	0.13	2.76	1.70	0.70
	45 cm × 75 cm	5.80	0.13	0.13	2.98	2.08	0.65
	F-LSD $_{(0.05)}$	*ns*	*ns*	*ns*	*ns*	*ns*	*ns*
Fertilizer type	Control	4.85	0.13	0.14	2.75	2.38	0.58
	NPK	6.60	0.13	0.14	3.05	2.05	0.73
	PM	5.77	0.11	0.09	2.98	1.03	0.73
	SSP	6.00	0.14	0.15	2.70	2.10	0.68
	F-LSD$_{(0.05)}$	*0.99*	*0.02*	*0.02*	*ns*	*0.95*	*0.09*

Abbreviations are as explained in Table 6; *ns* - not significant at 5% probability level

Table 8: Main effects of the three factors investigated on total nitrogen, soil pH and available phosphorus

Main factors	% Total nitrogen	Soil pH H_2O	Soil pH KCl	Available P (mg kg^{-1})
Variety				
Caro	0.090	5.78	5.26	32.8
Olokoro	0.100	5.91	5.43	41.7
F-LSD $_{(0.05)}$	*ns*	*0.12*	*0.09*	*8.24*
Plant spacing				
30 cm × 75 cm	0.100	5.81	5.25	31.1
45 cm × 75 cm	0.110	5.89	5.44	43.4
F-LSD $_{(0.05)}$	*ns*	*ns*	0.09	8.24
Fertilizer type				
Control	0.081	5.73	5.19	23.3
NPK	0.093	5.73	5.18	32.7
PM	0.119	6.04	5.56	62.7
SSP	0.112	5.90	5.45	30.2
F-LSD$_{(0.05)}$	*0.020*	*0.17*	*0.12*	*11.7*

Abbreviations are as explained in Table 6

Wider spacing (45 cm) led to higher available P than narrower spacing (30 cm), an observation attributed to the ensuing differences in plant density and mining of plant nutrients in the soil. Ikenganyia *et al*. (2017) similarly reported that lower density of bambara groundnut plants led to higher available P at crop harvest. Gil (2009) and Duan *et al*. (2019) found that higher plant densities decreased soil contents of plant nutrients including P. Considering that Ikenganyia *et al*. (2017) and the present study share similar climate, and that the effect of plant density on soil fertility could be climate dependent (Duan *et al*., 2019), we deduce that wider spacing is a more sustainable option than narrower spacing for bambara groundnut in the study location.

The PM more than any other fertilizer type increased the soil pH, TN and available P. This was probably because organic amendments often have liming effect, and are known to decrease P fixation. The NPK reduced soil pH because most inorganic fertilizers leave acid residue during uptake by crops. That the PM had similar effect as NPK and SSP on TN agrees with a similar study in southwestern Nigeria (Adeniyan and Ojeniyi, 2003).

CONCLUSIONS

The results of this study on a low-fertility sandy soil have shown that, generally speaking, cultivation of Olokoro variety conserves the soil fertility better than cultivation of Caro variety. The latter can only improve exchangeable Na and H which normally do not contribute positively to soil fertility. Plant spacing of 45 cm improved most soil properties more than 30 cm. Of the four fertilizer options of this study, PM improved soil TN, available P and exch. H better than others, while NPK and SSP had varying effects on the other soil cation exchange properties. The rate at which these two inorganic fertilizers was applied in this study (60 kg ha^{-1}) was rather low, hence the observation.

In summary, the differential capacity of the bambara varieties to absorb plant nutrients resulted in the observed differences in their contents in the soil at crop harvest. The soil fertility-conserving benefit of wider spacing (45 cm) over closer spacing (30 cm) was less evident for plant nutrients in the exchangeable forms, which too were enhanced more by the inorganic fertilizers (NPK and SSP) than PM. Consequently, the most effective treatment bordering on agronomic and fertilizing practices somewhat depended on soil fertility index of interest; Olokoro at 45 cm spacing with SSP for soil TN and exch. Mg, or with PM for soil pH and available P; and Caro at 30 cm spacing with NPK for CEC and exch. Ca, or with SSP for exch. K.

ACKNOWLEDGEMENT

The authors wish to thank the International Foundation for Science (IFS) for sponsoring this study through the 2012 Collaborative Research Grant to one of them (Uzoh I.M.) in Bambara Team.

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