Description and Nutrient Management of Upland and Lowland Soils in Abeokuta, Southwestern Nigeria

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ABSTRACT

Field experiments were conducted to characterize lowland and upland soils and determine how their properties influence the effects of integrated nutrient management (INM) on soil productivity. One profile pit each was classified in the lower and upper slope positions where factorial experiments in randomized complete block design with three replicates were established. The factors were poultry manure (0, 5 and 10 t ha^{-1}), lime ($CaCO_3$) (0 and 250 kg ha^{-1}) and NPK 15-15-15 (0 and 100 kg ha^{-1}). The profile pits differ morphologically in terms of horizon depths, colour and iron concretions. Soil organic carbon content which decreased with increasing depth ranged from 1.0-4.9 g kg^{-1} in the lower slope and 1.8-25.5 g kg^{-1} in the upper slope soil. The mean clay dispersion ratio value of 20.2% was obtained at lower slope against a value of 25.9% obtained at the upper slope in response to INM. Application of poultry manure (PM) with NPK fertilizer significantly raised soil saturated hydraulic conductivity and resulted in 40% and 59% increases in soil infiltration rate (*IR*) at the lower and upper slopes, respectively. The *IR* at the upper slope was higher than that of the lower slope by about 190%. Integrated application of PM, lime and NPK significantly raised soil chemical properties than the control at both slope positions but were higher at upper slope than lower slope in most cases. Maize yield was significantly raised with the use of PM, especially 10 t ha^{-1}, than the control and inorganic amendments while maize yield was higher by 24% at the upper slope than the lower slope. Therefore, INM is a better option for improving maize yield, especially in soils dominated by non-expanding clay types.

KeyWords: Aggregate stability, clay dispersion ratio, integrated nutrient management, morphological properties

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INTRODUCTION

Sustainable land management requires a basic understanding of the nature and properties of soils. This could be achieved by detailed soil description and classification. Soil classification, particularly at series level has been reported to be useful as basis for yield prediction (Fasina, 2005) though the management of the land must be specified.

Topographic aspect has long been identified as a factor potentially significant in generating differences in ecosystem characteristics (Bale *et al*., 1998) most especially, soil. According to Birmingham (2003), topography, soil texture, gravel content and colour are key characteristics needed to express scientific information on soils to land users. Characterization of these parameters on agricultural landscapes is a fundamental requirement for the prediction of soil behavior and its response to management options (Salako *et al*., 2006). The effect of management in optimizing maize yield was observed by Fasina (2005) to be strong and even stronger than that of soil. Also, Hao *et al*. (2002) reported that soil organic matter content in cropland is strongly related to soil type, landscape morphology, crop and soil management practices. Among the proven low-input management practices is the use of animal manure with reduced level of inorganic fertilizer (Busari *et al*., 2008). Also, Adeniyan and Ojeniyi (2005) reported that soil that received poultry manure combined with low level of NPK 15-15-15 gave soil nutrient concentration significantly higher than fertilizer alone. Hornick and Parr (1987) also reported that regular addition of amendments such as animal manure and crop residues (with inorganic amendments) are of utmost importance in maintaining the tilth, fertility and productivity of agricultural soils, protecting them from wind and water erosion, and preventing nutrient losses through run off and leaching. This suggests that integrated nutrient management which involves application of both organic and inorganic sources of soil nutrient such as the use of poultry manure, NPK fertilizer and lime is a necessity in maintaining the fragile African soils.

There is a need to provide information on the relationship between slope positions in reference to improved management technique as they affect maize yield. The objectives of this study therefore, were to compare the properties of lowland and upland soils and determine how these properties influence the effects of integrated nutrient management on soil productivity.

MATERIALS AND METHODS

Site description: The field experiments were carried out between years 2004 and 2005 at Ajegunle farm Settlement Scheme's site, Ajebo road Abekouta, Ogun State. The study area lies between latitude 7° 26′ N and longitude 3° 48′ E. The area has two distinct seasons - the wet season, which extends from March to October and the dry season, which is usually from November to February. The rainfall is bimodal in distribution, having its peak in July and September with an August break. The long-term mean annual rainfall of the study site was1113 mm. The mean monthly temperature varies from 22.94° in August to 36.32° in March while relative humidity ranges from 75.52% in February to 88.15% in July.

Profile description: One profile pit (2 m long × 1.5 m wide × 2 m deep) was excavated and described at each of the slope positions. Detail profiles morphological properties were described in the field using the United State Department of Agriculture (USDA) procedure (Soil Survey Staff, 1999) while samples were collected from each diagnostic horizon for physical and chemical analyses. In the field, soil colour was described and colour development equivalents were estimated from Munsell soil colour (hues and croma) chart (Buntley and Westin, 1965). Qualitative description of soil structure and texture (by feel) were carried out. Undisturbed core samples were collected, using 5 cm deep × 5 cm diameter cylindrical core sampler, for bulk density and hydraulic conductivity determination.

Field Experiment: The experimental design was a 3 × 2 × 2 factorial experiment in randomized complete block (RBCD) with 3 replicates. Each plot size was 3 m × 4 m. The factors were 3 levels of poultry manure (0, 5, and 10 t ha^{-1}), 2 levels of lime (0 and 250 kg ha^{-1} lime) and 2 levels of NPK 15-15-15 fertilizer (0 and 100 kg ha^{-1}). Poultry manure and lime were applied three weeks before planting while the N:P:K was applied 2 weeks after planting using ring method of application. Chemical properties of the PM used for the experiment was determined. Two maize (TZSR-Y) seeds were planted per hole at a spacing of 50 cm × 75 cm.

Treatment combinations were as follows. (1) No amendment (control (C)), (2) NPK only, (3) Lime only (L), (4) Lime + NPK (LNPK), (5) 5 t ha^{-1} Poultry manure (PM5), (6) PM5 + NPK (PM5NPK), (7) Lime + PM5 (LPM5), (8) Lime + PM5 + NPK (LPM5NPK), (9) 10 t ha^{-1} Poultry manure (PM10), (10) PM10 + NPK (PM10NPK), (11) Lime + PM10 (LPM10), (12) Lime + PM10 + NPK (LPM10NPK).

Soil analysis: Soil physical and chemical properties were determined before planting and after harvest of the maize planted on the sites. Particle size analysis was done by hydrometer method (Bouyoucos, 1951). Clay dispersion ratio (CDR) was determined according to the procedure of Dong *et al*. (1983). This was done by determining the percentage ratio of the amount of clay in aggregate dispersed in distilled water to that in aggregate dispersed in sodium hexametaphosphate (Calgon). Hydrometer method was used to determine the percentage of clay particles. Saturated hydraulic Conductivity (K_s) was determined by collecting undisturbed core samples (0-5 cm deep) in duplicates from each plot on the field. The K_s was determined with the hydraulic conductivity rack in the laboratory. A constant water head was maintained on each core sample and Darcy's formula for constant head flow was used to calculate saturated hydraulic conductivity (Klute and Dirksen, 1986). Infiltration Rate (*IR*) was carried out by measuring unsaturated water flow from each plot on the field with a disc permeameter. The water head applied was -5 cm. The procedure described in the manual by CSIRO (1988) was used to set up the disc permeameter in the field. The *IR* was then obtained using Philip's equation, $IR = 1/2St^{-1/2}$ (Philip, 1957). Where, t = time; S = sorptivity. Sorptivity (S) was obtained as the slope of Cumulative infiltration (CI) plotted against the square root of time. Cumulative infiltration was calculated from the equation given by CSIRO (1988) as follows:
$CI = (Q/r^2) = (SR-SR_1)\ (RC)\ /r^2$. Where SR is the scale reading at the time of measurement; SR_1 is the initial scale reading, RC is the reservoir calibration.

Soil pH was determined in water and in 1N KCl, using equal volume (1:1) of water/KCl to soil sample. Organic Carbon (OC) was determined by complete oxidation method (Heanes, 1984). Total nitrogen was determined by adapted auto-analyzer method (Technicon, 1979). The effective cation exchange capacity (ECEC) was obtained as the sum of exchangeable cations and acidity. Exchangeable cations were extracted using 1M Ammonium Acetate pH 7.0 and the cations in the extract were determined by atomic absorption spectrophotometer (AAS). The exchangeable acidity (EA) was determined using KCl titration method where 25 ml of KCl extract was titrated against 0.05N NaOH to a pink colour using Phenolphthalein indicator. Available phosphorus was determined using Bray-1 P extractant and determined colorimetrically by the molybdenum blue procedure (Bray and Kurtz, 1945). Micronutrients (zinc and manganese) were extracted using 0.1 N Hydrochloric Acid (HCl) and determined by AAS.

Statistical analysis: Soil and maize yield data were analysed using analysis of variance (ANOVA) using Statistical Analysis System (SAS, 1988). Means were separated using least significant difference (LSD) at $P < 0.05$.

RESULTS AND DISCUSSION

Composition of poultry manure used and soil properties at the onset of the experiment

The poultry manure (PM) used for the experiment had a pH of 5.8, organic carbon of 177 g kg^{-1}, total nitrogen, phosphorus and potassium of 19.3 g kg^{-1}, 28.9 g kg^{-1}, and 14.7 g kg^{-1}, respectively. The C:N ratio of the PM was 9:1.

The soils of the experimental sites were sandy at the surface. The pH of the soils indicated that the sites were acidic at the onset of the study (Table 1). Initial soil properties at both slope positions were somewhat similar with the exception of CDR that was substantially lower in lower slope than upper slope.

Soil classification

Soil profile morphological description: The soils of the study sites are underlain by Pre-Cambrian basement complex rocks with possibly magmatized gneiss (lower slope position) and shale (upper slope). Lower slope soil is formed from alluvial parent material while that of the upper slope is suspected to be sedimentary materials of possibly terrace origin overlaying by colluvial materials. The lower slope soil was imperfectly drained while that of the upper slope was well drained with the depth to water table deeper than 200 cm. The two soils vary in horizon depth and colour and most other morphological properties observed in this study. Lower slope soil had varying degree of brown colour across the horizons whereas, at the upper slope brownish coloration appeared majorly at the upper layers ($Ap – Bt_1$) while other layers ($2Bt_2 – 2Bt_6$) had mixed coloration ranging from orange to reddish (Table 2). Mottle colour occurred only at the lowest layer at the lower slope while it extends from the $2Bt_2$ horizon down the depth in the upper slope. Iron concretion commonly occur in the lower slope soil while a distinct plinthic layer of quartz stones with iron concretions occurred at the upper slope (Table 2). Soil structures at both slope positions were generally sub-angular blocky.

Soil profile physical and chemical properties: Soil profile clay contents and bulk density increased with depth in both slope positions while total porosity and saturated hydraulic conductivity (K_S) decreased with depth (Table 3). Organic C, pH, total N and base saturation (BS) also decreased with increasing depth of the profile pits. Available P increased slightly down the depth at the lower slope while it decreased slightly downward in upper slope. However, OC was generally higher at the upper than the lower slope while available P was higher in lower slope than upper slope (Table 4). All micronutrients, except Cu, at the upper slope pit were generally higher than those of the lower slope.

Effect of slope position on soil properties and maize yields as affected by integrated use of poultry manure, lime and NPK 15-15-15 fertilizer

Soil physical properties: There was no significant differences in CDR values among the control plots and other treatments at both lower and upper slope positions with the exception of CDR value of 17.5% observed at the control, L and LNPK plots that was significantly lower than 25.9% and 23.5% given by PM10 and PM10NPK, respectively at the lower slope position (Table 5). The mean CDR value of 20.2% given by the lower slope (Table 5) was higher than the initial CDR value of the soil (Table 1) while the CDR value of 25.9% obtained at the upper slope was lower than the initial CDR value of the soil. Application of 10 t ha^{-1} PM alone and with NPK significantly raised soil saturated hydraulic conductivity (K_s) than the control plots at both slope positions. The infiltration rate (*IR*) was not significantly different among the treatments, except *IR* values of 37.48 cm min^{-1} (lower slope) and 11.38 cm min^{-1} (upper slope) given by PM10NPK which were significantly higher than the controls. Application of PM10 only also significantly increased soil *IR* than the control. The mean *IR* value at the lower slope was about 190% higher than the mean *IR* value at the upper slope position (Table 5).

Soil chemical properties: All treatments containing lime gave significantly higher pH values than the control at both slope positions (Table 5). There was no significant difference in soil organic carbon (OC) among all the treatments at the lower slope position. However, the soil OC of 16.5 g kg^{-1} (at the upper slope) and total N of 1.2 g kg^{-1} (at the lower lope) and 1.6 g kg^{-1} (at the upper slope) given by integrated use of L, PM10 and NPK was significantly higher than OC and total N values given by the control and all plots without poultry manure. The mean OC and total N was about 70% and 33% higher, respectively at the upper slope than that of the lower slope position. There was no significant differences in soil available P among all the treatments at the lower slope with the exception of available P of 17.65 mg kg^{-1} by PM10NPK which was significantly higher than the control. At the upper slope, all plots treated with PM alone or in combination with other soil amendments gave significantly higher soil available P than the control and plots that received inorganic amendments (Table 5).

Yield of maize: Integrated application of the three soil amendments, especially where 10 t ha^{-1} PM was used, resulted in significant maize yield increments than the control and combinations of inorganic amendments (Table 6). The performance of each of the nutrient amendments was better at the upper slope than the lower slope position. Consequently, the mean maize grain yield was about 24% greater at the upper slope than the lower slope.

Table 1: Initial surface soil (0-20 cm depth) chemical and physical properties at the onset of the experiment on the sites in 2004

Soil properties	Value	
	Lower slope	Upper slope
Soil pH (H_2O)	5.3	5.7
Organic carbon, OC (g kg^{-1})	6.1	10.5
Total N (g kg^{-1})	0.6	1.1
Available P	5.36	6.91
CDR (%)	17.1	30.2
Ks (cm min^{-1})	0.43	0.44
Sand (%)	81.7	84.5
Clay (%)	8.4	7.1
Silt (%)	10.0	8.5

Table 2: Soil profile morphological properties of the lower and upper slope positions of the experimental site

Horizon	Depth	Munsell colour	Texture	Structure	Consistency			Root	Pores	Iron concretions	Boundary
	Cm	(moist)			Dry	moist	wet				
Lower slope											
Ap	0-18	7.5YR4/4 (Brown)	ls	G	L	Fr	ns	mfco	mfco	none	gs
Bt$_1$	18-46	5YR 5/8 (brb)	scl	msbk	H	Fr	s	ff	mf	ff	gs
Bt$_2$	46-75	5YR 5/8 (brb)	scl	G	H	Fr	s	f	mf	mf	cw
2Bt$_3$	75-100	5YR 5/8 (brb)	sl	G	H	Fr	s	none	vf	f-m	gs
2Bt$_4$	100-126	5YR 5/8 (brb) 5YR 6/8 (mo)	scl	msbk	H	Fr	s	none	vff	mco	cw
2Bt$_5$	126-190	10YR 6/6 (byb) 2.5YR 5/6 (mbb)	scl	wmsbk	H	Fr	s	none	vff	mco	
Upper slope											
Ap	0-7	5YR 3/1 (bbl)	ls	Mcc	H	Fr	ns	mco	mf	none	cw
A$_1$	7-23	5YR 4/3 (drb)	ls	mcsbk	H	Fr	ns	mco	mfco	none	cs
Bt$_1$	23-40	5YR 4/3 (drb)	ls	mcsbk	H	Fr	ns	fco	mfco	none	cw
2Bt$_2$	40-58	5YR 4/4 (drb) 7.5YR 6/8 (o)	scl	mcsbk	h	Firm	s	f/m	mfco	few quartz	ds
2Bt$_3$	58-95	7.5YR 6/8 (o)	scl	mcsbk	H	Firm	s	ff/m	mfco	vf quartz	w
2Bt$_4$	95-105	A distinct layer of frequent gravel and rounded iron nodules occasional with rounded quartz stones with iron concretions line with clay materials; sandy clay texture.									cs
2Bt$_5$	105-142	10YR 5/2 (lgr) 7.5YR 6/8 (mo)	clay	mcsbk	H	Firm	vs	vff	mff	none	ds
2Bt$_6$	142-200	10YR 5/2 (lgr) 7.5YR 6/8 (mo)	clay	Ssbk	H	Smooth	vs	vff	mff	none	

Legend: brb = bright reddish brown, bl = black, d = dull, lgr = light gray, m = mottled, o = orange, y = yellow, ls = loam sand, scl = sandy clay loam, sl = sandy loam, g = granular, msbk = medium sub angular blocky, w = weak, cc = coarse crumb, l = loose, h = hard, fr = friable, ns = non-sticky, mfco = many fine coarse, ff = few fine, f = few, vf = very fine, s = strong f-m = fine-medium, f/m = few-medium, gs = gradual smooth, cw = clear wavy, cs = clears smooth, ds = diffuse smooth

Table 3: Soil profile physical properties of the lower and upper slopes positions of the experimental site

Horizon	Depth	Particle Size Analysis (%)			BD	Total porosity	K_s
	Cm	Sand	Silt	Clay	g cm^{-3}	%	cm min^{-1}
Lower slope							
Ap	0-18	87.4	6.0	6.6	1.43	46.0	0.48
Bt1	18-46	67.8	4.6	27.6	1.44	45.0	0.48
Bt2	46-75	65.8	4.6	29.6	1.47	44.5	0.46
2Bt3	75-100	73.8	6.6	19.6	1.57	40.8	0.43
2Bt4	100-126	69.4	5.0	25.6	1.48	44.2	0.46
2Bt5	126-190	68.8	7.6	23.6	2.01	24.2	0.39
Upper slope							
Ap	0-7	77.4	15.7	6.9	1.39	47.6	0.49
A1	7-23	78.4	14.7	6.9	1.40	47.2	0.50
Bt1	23-40	82.4	5.7	11.9	1.44	45.6	0.47
2Bt2	40-58	63.4	3.7	32.9	1.47	44.5	0.44
2Bt3	58-95	54.4	4.7	40.9	1.47	44.5	0.44
2Bt4	95-105	49.4	7.7	42.9	1.50	44.4	0.38
2Bt5	105-142	44.4	6.7	48.9	1.83	30.9	0.32
2Bt6	142-200	38.4	7.7	53.9	1.91	27.9	0.29

Table 4: Soil profile chemical properties of the lower and upper slopes positions of the experimental site

Horizon	Depth	pH (H_2O)	pH (KCl)	OC	TN	Avail P	Exchangeable Bases				EA	ECEC	BS	Micronutrients			
	cm			g kg^{-1}	g kg^{-1}	mg kg^{-1}	Ca	Mg	K	Na				Zn	Mn	Fe	Cu
							cmol kg^{-1}						%	mg kg^{-1}			
Lower slope																	
Ap	0-18	5.75	5.11	4.9	0.6	10.05	3.16	1.12	0.22	0.04	0.12	4.66	97.4	0.99	37.4	2.18	0.38
Bt1	18-46	4.54	4.05	2.2	0.4	15.05	2.74	1.23	0.15	0.03	1.05	5.20	79.8	0.33	35.9	1.64	0.42
Bt2	46-75	4.40	3.75	2.2	0.3	11.05	2.67	0.84	0.24	0.04	1.11	4.90	77.3	0.55	27.5	2.12	0.50
2Bt3	75-100	4.23	3.81	1.1	0.2	14.45	1.60	0.80	0.10	0.03	1.17	3.70	68.4	0.34	16.1	2.94	0.62
2Bt4	100-126	4.27	3.83	2.2	0.3	19.15	1.79	0.99	0.05	0.04	1.16	4.03	71.2	0.52	19.7	2.70	0.57
2Bt5	126-190	4.42	3.82	1.0	0.2	10.55	1.64	0.79	0.09	0.03	1.10	3.65	69.9	0.31	9.6	3.11	0.44
Upper slope																	
Ap	0-7	5.67	5.52	25.5	1.5	8.45	3.05	1.17	1.88	0.37	0.12	6.59	98.2	1.79	66.0	34.14	0.22
A1	7-23	5.25	5.20	5.8	0.6	4.90	1.01	0.75	0.57	0.35	0.11	2.79	96.1	1.05	52.0	35.04	0.24
Bt1	23-40	5.18	4.73	2.8	0.7	5.40	0.31	0.63	0.65	0.30	0.11	2.00	94.5	0.19	11.1	38.20	0.25
2Bt2	40-58	4.20	4.14	2.0	0.5	4.15	1.31	0.73	0.54	0.34	1.13	4.05	72.1	0.12	57.1	16.81	0.34
2Bt3	58-95	4.22	4.11	2.8	0.8	5.00	1.07	0.67	0.41	0.36	1.13	3.64	68.9	0.10	22.7	19.22	0.30
2Bt4	95-105	4.21	3.95	2.6	0.4	5.60	1.18	0.62	0.28	0.37	1.15	3.60	68.1	0.11	12.0	19.22	0.25
2Bt5	105-142	4.19	4.03	1.8	1.0	4.85	0.86	0.64	0.32	0.34	1.13	3.29	65.7	0.10	15.2	20.00	0.23
2Bt6	142-200	4.28	4.08	1.8	1.0	4.85	1.06	0.73	0.38	0.35	1.08	3.60	70.0	0.09	12.4	19.53	0.11

Legend: EA = Exchangeable acidity
BS = Base saturation

Table 5: Effect of integrated application of poultry manure, lime and NPK 15-15-15 fertilizer on some soil physical and chemical properties as influenced by lower and upper slope position

	Lower slope position							Upper slope position						
Treatment	CDR (%)	K_s (cm min^{-1})	*IR* (cm hr^{-1})	pH (H_2O)	OC (g kg^{-1})	TN (g kg^{-1})	Avail P (mg kg^{-1})	CDR (%)	K_s (cm min^{-1})	*IR* (cm hr^{-1})	pH (H_2O)	OC (g kg^{-1})	TN (g kg^{-1})	Avail P (mg kg^{-1})
C	17.5	0.49	22.57	5.5	6.9	0.6	9.05	24.4	0.47	4.62	5.6	11.7	0.9	10.85
NPK	18.0	0.61	19.72	5.9	7.0	0.8	9.25	23.3	0.46	9.42	5.5	10.5	1.0	13.22
L	17.5	0.41	24.75	6.3	6.4	0.6	8.50	28.0	0.42	8.38	6.1	9.8	0.7	9.77
LNPK	17.5	0.46	28.34	6.2	6.6	0.9	11.68	27.8	0.48	8.86	6.0	8.9	1.0	12.42
LPM5	20.6	0.60	14.68	6.3	8.9	0.9	12.17	22.8	0.68	7.81	6.2	13.0	1.1	18.68
LPM5NPK	20.6	0.74	19.58	6.9	9.0	1.1	11.05	26.1	1.11	5.77	6.1	13.5	1.3	18.83
LPM10	20.6	0.50	18.34	6.4	9.6	1.0	15.05	24.4	0.54	5.86	6.1	15.0	1.2	19.95
LPM10NPK	20.6	0.79	15.14	6.5	6.5	1.2	15.15	22.8	0.86	4.08	6.3	16.5	1.6	39.15
PM5	20.6	0.95	20.77	6.1	7.3	0.8	12.47	29.6	0.63	7.33	5.9	13.0	1.1	18.18
PM5NPK	19.5	0.72	24.74	6.1	7.0	0.9	11.78	27.8	0.65	6.33	5.7	13.5	1.2	18.77
PM10	25.9	1.08	23.02	6.1	7.7	0.9	13.18	29.7	1.70	12.91	6.1	14.0	1.2	21.83
PM10NPK	23.5	1.03	37.48	6.3	7.2	1.1	17.65	24.4	0.94	11.38	5.9	13.5	1.5	21.88
Mean	20.2	0.70	22.43	6.2	7.5	0.9	12.25	25.9	0.75	7.73	5.9	12.74	1.2	18.63
LSD ($P<0.05$)	3.3	0.44	13.08	0.66	2.9	0.2	6.20	7.03	0.57	3.83	0.31	4.4	0.3	4.81

Key: No amendment (control (C)); NPK only (NPK); Lime only (L); Lime+NPK (LNPK), 5 Mg ha^{-1} Poultry manure (PM5); PM5+NPK (PM5NPK); Lime+PM5 (LPM5); Lime+PM5+NPK (LPM5NPK); 10 Mg ha^{-1} Poultry manure (PM10); PM10+NPK (PM10NPK); Lime+PM10 (LPM10); Lime+PM10+NPK (LPM10NPK); Clay dispersion ratio (CDR); Saturated hydraulic conductivity (K_s); Infiltration rate (*IR*); Organic carbon (OC); total nitrogen (TN)

Table 6: Effect of integrated application of poultry manure, lime and NPK 15-15-15 fertilizer on maize yields at the lower and upper slopes

	Grain yield (t ha^{-1})	
Treatment	Lower slope position	Upper slope position
C	1.90	2.50
NPK	3.16	3.50
L	2.30	3.47
LNPK	1.61	3.08
LPM5	3.15	3.77
LPM5NPK	2.96	4.53
LPM10	4.62	4.08
LPM10NPK	4.00	4.96
PM5	3.72	3.96
PM5NPK	2.84	3.61
PM10	2.95	4.30
PM10NPK	4.02	4.31
Mean	3.10	3.84
LSD ($P<0.05$)	1.38	1.14

Key: No amendment (control (C)); NPK only (NPK); Lime only (L); Lime+NPK (LNPK),

5 Mg ha^{-1} Poultry manure (PM5); PM5+NPK (PM5NPK); Lime+PM5 (LPM5); Lime+PM5+NPK (LPM5NPK); 10 Mg ha^{-1} Poultry manure (PM10); PM10+NPK (PM10NPK); Lime+PM10 (LPM10); Lime+PM10+NPK (LPM10NPK)

The low total N content of the poultry manure used in this study may be attributed to its volatilization during the long period the manure has piled up in the poultry house where it was collected (Busari *et al*., 2008). The surface soils at the two slope positions used for the experiment were similar in their physical properties at the onset of the study except that lower slope soil was more aggregated (lower CDR value) than upper slope. The pH of the soils indicated that both slope positions were acidic before the commencement of the experiment. The soil organic carbon (SOC) was low at both slope positions. As a result of this, the low total N observed was not unexpected. Soil nutrients measured before cropping at both slope positions were low (Landon, 1984).

Profile pits, described at the two slope positions, have depths exceeding 1.8 m which is an indication of well developed soils (Jim, 2003; Salako *et al*., 2006). However, soil profiles at both slope positions differ in their morphological, physical, and chemical characteristics. The two profiles were different in terms of horizon depth, colour and iron concretions. The observation in this study that the upper slope soil has more mature profiles was similar to that of Jim (2003). The presence of plinthic layer (10 cm thick) at the upper slope profile is an indication that the horizon was saturated with water for sometimes during the year (Soil Survey Staff, 2006). Plinthite layer was however, not observed in the lower slope soil indicating that the two soils were different. The high prominence of iron concretions in the subsoil of lower slope than upper slope found in this study has similarly been reported by Salako *et al*. (1999).

Increase in clay contents down the profile depth may be attributed to elluviation process and an indication of old weathered soils. Similarly, Yimer *et al*. (2006) reported that an increasing trend of clay fraction with depth indicate clay translocation from top layer to lower layers. The high bulk density values obtained as the profiles depth increases, according to Mbagwu *et al*. (1984) could be caused by translocation of clay from eluvial horizon, with simultaneous loss of structure and closer packing of sand grains in the eluvial horizon. Other authors such as Rasool *et al*. (2007), Singh *et al*. (2007) have reported increase in bulk density with increasing soil depth because of influence of soil organic matter which was higher in the upper horizon than the lower horizons (Salako *et al*., 2006). The decreases in K_s as the clay content increases down the depth indicate that clay has a strong influence on water movement through the soil.

Soil organic carbon across the depths in both soils were generally low (Landon, 1984) with the exception of Ap layer in the upper slope profile pit (Table 4). The high SOC in this Ap layer was due to the fact that the soil, prior to the commencement of the study, was under secondary re-growths with high litter falls compared with the lower slope which was under continuous cultivation of maize and cassava. The observation in this study, due to the reason stated earlier, contradicts the report of Hao *et al*. (2002) that lower slope position for all soil have highest SOC pool due to downslope transportation of manure (organic nutrient) during runoff. This reflects the strong link of soil surface management to SOC content. The total N at lower slope were generally low while that of the upper slope soil ranged from low to very low. Total N levels between 1 and 2 g kg^{-1} are considered to be low while below 1 g kg^{-1} are regarded as very low (Landon, 1984). One of the basic features of tropical environment is its high temperature which leads to rapid loss of soil nitrogen due to volatilization (Olowolafe and Dung, 2000). Heavy rainfall events leading to leaching also contributed to nitrogen losses in this environment. The generally low available P in both soils is evident from the acidic nature of the soils. Phosphorous fixation has been reported as one of the unique properties of acid tropical soils (Kamprath, 1984). An increase in available P in lower slope down the soil profile as against a decrease down the profile observed in upper slope could be explained based on report of Anderson and Xia (2001) that P movement down the soil profile depends upon two separate mechanisms. First, a 'break' point above which the accumulated P in the surface horizons is less strongly held and therefore amenable to dissolution and movement down the profile. Second, a mechanism by which some solute P from the surface horizons can travel rapidly through horizons of low P status to greater depth in the soil by preferential flow. Actually, preferential flow might have effect on soil available P in the lower slope because of inconsistent clay behaviours down the profile depth (Table 3) and the presence of granular structure between 46 to 100 cm depth (Table 2) but this could not be the case in upper slope where clay contents consistently increased down the depth and the structure were generally sub-angular blocky.

The upper slope soil had generally high chemical fertility than the lower slope apparently due to higher SOC. Though, reports have it that high water table at the lower slope usually influence soil chemical reaction greater than that of the upper slope (Salako, *et al*., 2007) the occurrence of plinthite layer might have offered the upper slope the ability to behave as observed in this study. The low CEC values from both pedons reflect the meager soil organic carbon and clay of kaolinitic type (Jim, 2003). From the values obtained, the base saturation from both slope positions may be regarded as high. This does not mean that the soils have high basic cations but because the kaolinitic clay content has low capacity to adsorb cations and the little available bases will easily saturate the exchange site (Kparmwang *et al*., 1998).

Based on the observed morphological, physical and chemical properties of the described pits, soil in lower slope was classified as Arenic Paleudalf while that of upper slope was classified as Arenic plinthic Kandiudalf in United State Department of Agriculture (USDA) classification system (Soil Survey Staff, 2006). Using the Food and Agricultural Organization/United Nation Educational and Scientific Organization (FAO/UNESCO) classification system the lower and upper slope soils were classified as Chromic Lixisol and Calcic Lixisol respectively (WRB, 2006).

In response to integrated nutrient management, the significantly higher CDR resulting from PM10 at the lower slope compared with the control is an indication that higher rate of poultry manure applied led to disaggregation of soil micro-aggregate. This is because CDR is an index of soil micro-aggregate stability with lower value implying higher stability (Opara, 2009). The disaggregation effect observed was due to the fact that the soil was originally well aggregated because it has a low CDR at the commencement of the experiment (Table 1). Application of 10 t ha^{-1} to the soil probably resulted in preponderance of negative charges at the surface of the organic manure resulting in disaggregation (Busari *et al*., 2009; Hillel, 1998). However, application of the soil amendments reduced the CDR values compared with the initial value thereby improved soil micro-aggregate stability at the upper slope soil. This implies that the effect that poultry manure will have on soil micro-aggregate stability depends on the rate of application and the initial stability status of the soil prior to application. Relatively lower CDR has also been reported to occur due to organic matter content of the soil (Salako *et al*., 2006) which was raised in this study due to poultry manure application. Also, poultry manure applied at 10 t ha^{-1} raised soil K_s and *IR* than the control due to stimulating effect of the manure on soil aggregation (Celik *et al*., 2004). The increased micro-aggregate stability of the lower slope soil may be responsible for its higher *IR* than the upper slope soil.

Integrated nutrient management significantly raised all the soil chemical indicators than the control at both slope positions. The presence of adequate amount of nutrients in the manure used for the experiment may be responsible for this observation. Better improvement in soil chemical properties in response to the applied treatments at upper than lower slope soil may be as a result of its higher inherent fertility status than lower slope as discovered by their preplanting and profile pits soil chemical analyses.

The higher performance associated with 10 Mg ha^{-1} PM when combined with other soil amendments implies that nutrients are better released when larger quantities of manure are used (Busari et al., 2008). Integrated nutrient management raised maize yield at the upper slope than the lower slope. Though, Oyedele and Aina, (1998) advanced reasons for higher maize yield from lower slope position to be due to deposition of soil nutrients from upper slope by surface wash and subsurface interflow as well as more favourable moisture conditions compared with the upper slope positions, the reported higher grain yield from upper slope in this study might not be unconnected with the inherent soil nutrient in the upper slope as pointed out earlier in this report. Also, since a plinthitic horizon was observed in upper slope soil, moisture condition would not place an advantage on lower slope over the upper slope soil. It therefore, implies that the use to which a soil was previously subjected is an important factor in its capability to support fresh production exercise. Above all, integrated nutrient management raised the expected maize yields in this location. Reported average maize yields in this zone of Nigeria in an eight year study involving different land management options by Lal (1997) was 3.1 t ha^{-1} for grain yield.

CONCLUSION

The two profile pits described were well developed but differ in some morphological, physical and chemical characteristics. Of major importance is the higher SOC in the upper slope position which resulted in its better performance than the lower slope. The influence of previous land use before a land is opened for renewed cultivation has a marked effect on soil response to management and its productivity. Above all, integrated nutrient management is a better option for improving maize yield in soils, especially those dominated by non-expanding clay types.

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