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Original Research Paper

Effect of application of organic and mineral soil amendments in a continuous cropping system for 10 years on chemical and physical properties of an Alfisol in Northern Guinea Savanna zone

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Demography and heavy dependence on maize as major staple have contributed to intensive maize production in the northern Guinea Savanna of Nigeria.This study assessed 10 years of management practices and inputs on soil quality under maize. Sampled soils were assessed by measuring appropriate physical and chemical quality indicators in the 2006 and 2007 rain-fed cropping season. The treatments were made of urea fertilizer, cow dung, *Centrosema pascuorum, Vigna unguiculata* and applied to make 45 and 90 kg N ha^{-1}. Results showed that cow dung alone or in combination with sole urea fertilizer at the rate of 90 kg N ha^{-1} increased soil pH, organic carbon and total nitrogen by 2%, 55%, 17% respectively compared to sole urea. Cation exchange capacity significantly increased by 26% with application of cow dung while bulk density was reduced by 18% and total porosity increased by 15%. Further, moisture contents at field capacity and permanent wilting point increased by 50 and 25% respectively over sole urea treatment. To restore or maintain soil fertility for optimal crop yields under comparative long-term soil productivity, adoption of a balanced fertilization that combines urea fertilizer with animal manure is recommended.

Key words: Continuous cropping, organic amendments; urea fertilizer; soil fertility; maize, intercrop; Alfisol.

INTRODUCTION

Increasing population and high consumption of maize has led to its continuous intensive production in Africa, and Nigeria in particular. Intensive cultivation of land requires continuous application of synthetic fertilizers and organic amendments to maintain soil productivity. Soils of the Nigerian northern Guinea savanna (NGS) ecological zone have mainly low- activity clays and low soil organic matter (SOM) hence have low buffering capacities (Odunze, 2003). However, continuous intensive cultivation with application of sole urea fertilizer could alter the soil physical and chemical properties by decreasing the pH and reducing the exchangeable base contents which leads to soil degradation (Odunze et al., 2012).

As a result of these problems and the increasing soil degradation, the use of sole urea fertilizer is greatly minimized in crop production practices at present (Vanlauwe *et al.,* 2001; Odunze *et al.,*2012). This has led to the increasing research efforts on combining organic and synthetic amendments to enhance crop production to a sustainable level. The combination of organic and synthetic amendments would reduce the amount of synthetic fertilizer needed and the amounts of nutrients contained in the synthetic fertilizers may be more efficiently utilized (Vanlauwe *et al.,* 2002). A combination of organic and synthetic amendments has been reported to improve crop yield, soil fertility levels or both (Palm *et al.,* 1997; Vanlauwe *et al.,* 2002; Odunze *et al.,* 2012).

Grain and herbaceous legumes intercropped or relayed with cereals are good sources of SOM as they produce adequate quantities of biomass and contain considerable amounts of N fixed from the atmosphere (Odunze *et al.,* 2004 a, b). Results obtained from the urea-only, animal-only, legume-only and the combination of urea with animal manure or legume would give an insight into which fertility treatment remains the best against intensive nutrient removal inherent in a continuous mono-crop system. The study therefore aimed to evaluate the comparatively long-term effect of organic-synthetic fertilizers on the physico-chemical properties of the soil which is directly related to soil productivity.

MATERIALS AND METHODS

Experimental field characteristics

The field trial is a comparatively long- term "Balanced Nutrient Management Systems (BNMS)"experiment established in 1997 at the Institute for Agricultural Research (IAR) Samaru, Zaria in the northern Guinea savanna of Nigeria. The field is located at longitude 11·1591°N and latitude 7·6349°E at 683 m above sea level. The soil was silty loam in texture having 47% sand, 43% silt, and 10% clay at the commencement of trial in 1997 (Ogunwole *et al.,* 2010) and sandy loam in texture having 54% sand, 32% silt, and 14% clay at the surface and clay loam having 42% sand, 29% silt, 29% clay at the sub-surface levels at the beginning of this study in 2006 (Eche, 2011). It is a leached tropical ferruginous soil classified as Typic Haplustalf (USDA, 1998). Mean annual rainfall (1997-2007) was 1084.65mm and fall within the months of May-October while the average annual temperature was 26.36°C (IAR Meterological station, 2007). The treatments consisted of urea fertilizer, animal manure (cow dung) and two legumes (*Centrosema pascuorum* and *Vigna unguiculata*) applied at two rates as 45 and 90 kg N ha^{-1} (sole or mixed - 45kg urea + 45kg animal manure or legume. The legumes were intercropped with maize but after crop maturity the residues were incorporated into the soil as green manure. The treatments were arranged in a randomized complete block design with three replicates. Plot size was 36 m^2 (6m by 6m). The animal manure was incorporated into the furrows about 10cm deep below the original soil surface a week before planting. Each experimental plot consisted of 8 ridges with the four inner ridges used as net plots while the two outer ridges on both sides of the net plot as sampling plots. The maize variety used throughout the study period (1997-2007) was Oba Super II, which is a long duration (110-120 days), drought tolerant, and N efficient hybrid (Heuberger, 1998). In 2 weeks after planting (WAP), urea was split – applied (⅓) for plots requiring urea fertilizer treatment. The remaining two third (⅔) of the urea fertilizer was applied in 5 WAP. In 2003, missing nutrient trial was conducted and results obtained confirmed possible limitations of Zn, K, S, and Mg. From 2004 to 2006, a yearly blanket application of 180 kg $MgSO_4$ $ha^{-1}$and 3 kg $ZnSO_4$ ha^{-1} (corresponding to 3 kg Zn, 18 kg Mg, and 25 kg S ha^{-1}) in all plots were carried out and K application rate was also increased from 30 – 50 kg K ha^{-1}.

Soil Sampling and Chemical Analysis

Eight disturbed soil samples were taken on a diagonal transect of each plot from depths of 0 – 10 and 10 – 30 cm respectively. The samples were bulked to form a composite sample per plot and per depth and sub-samples taken for chemical analyses. Samples were taken at tarselling (vegetative) stage of maize crop which is the critical stage of maize growth and taken once to determine the soil conditions at optimum crop nutrient uptake. Soil pH was determined with a pH meter, both in water and 0.01M $CaCl_2$ solution at a soil to solution ratio of 1:2.5. Organic C was determined by dichromate oxidation (Nelson and Sommers, 1982). Total and inorganic N (NO_3-N, NH_4-N) were determined by Kjeldahl method (Bremner and Mulvaney, 1982; Okalebo *et al*., 2002). Available P was extracted by the Bray 1 method (Bray and Kurtz, 1945). Exchangeable bases and cation exchange capacity were determined by the methods described by Kundsen *et al*. (1982).

Measurements of Soil Physical Properties

Eight undisturbed soil samples were taken on a diagonal transect of each plot from depths of 0 – 10 and 10 – 30 cm respectively for soil physical property determination. Particle size analysis was determined using the standard hydrometer method (Gee and Bauder, 1986) and calculations made for the particle fraction using the formulae and the textural classes as described by Okalebo *et al*. (2002).

Bulk density (BD) was determined by the gravimetric method using undisturbed soil cores (Blake and Hartge, 1986) while total porosity (f) was determined from the bulk density of the soil as shown below:

$$f = (1 - BD/2.65\ g\ cm^3) \times 100.$$

Saturated hydraulic conductivity (Ks) measurement was carried out by the constant head permeameter using undisturbed soil cores as shown below:

$$Ks = VI/At\Delta H$$

Where,

V = Volume of water collected (cm^3)

A = Cross sectional area of the soil column (cm^2) equivalent to area of core

l = Length of soil column (cm)

t = Time (units of time, T)

∇H = Hydraulic head difference (cm).

Statistical Analysis

Preliminary and group contrast data obtained were analysed by standard ANOVA procedures at rain-fed cropping season (June-September / October) of each year, and also pooled over two years of maize cropping. The analysis of variance was performed using the GLM Proc. of SAS (SAS, 1999) and treatment means were compared using Duncan's Multiple Range Test (Duncan, 1955) at 5% level of significance. Principal component analysis (PCA) was carried out to identify the soil properties that most importantly explained variability in maize grain yield (Litchter *et al.*, 2008; Hinojosa *et al.*, 2004: Wander and Bollero, 1999).

RESULTS

Soil Chemical Properties

Result on soil pH (Table 1) showed a slight pH decrease at the 10-30cm depth compared to 0-10cm depth. Application of animal manure alone or in combination with sole urea fertilizer (pH 5.5- surface, 5.2-subsurface) at the rate of 90 kg N ha^{-1} increased pH value by 2 % at the surface and 1% at the subsurface levels compared to sole urea (pH 5.3-surface, 5.0-surbsurface).

Result obtained showed a general decline in soil organic carbon (SOC) for all treatments (Table 1). The SOC contents in the sole urea fertilizer ranged from 0.7 to 2.0 g kg^{-1} with C: N ratio of 2 to 3. Treatments involving legume and animal manure incorporation (sole or mixed) resulted in higher levels of SOC, although the legumes (OC 2 – 5 g kg^{-1}, C: N ratio 8-9) gave higher OC than animal manure (OC 3 g kg^{-1}, C: N ratio 6). Application of sole animal manure or mixed at the rate of 90 kg N ha^{-1} increased SOC by 55 % at the surface and 49 % at the subsurface compared to sole urea fertilizer application.

The total nitrogen (TN) content of the soils was generally low for all treatments (Table 1). Among the legumes incorporated, *C. pascuorum* gave higher TN compared to cowpea. Treatments involving animal manure incorporation mixed with urea fertilizer gave the highest level of TN (0.60 g kg^{-1}) though not statistically different from the other treatments at 90 kg N ha^{-1}. Application of animal manure mixed increased TN by 17 % at the surface and 45% at the subsurface levels compared to sole urea at the rate of 90 kg N ha^{-1}.

Among the sole urea fertilizers, the rate of N applied at 90 kg N ha^{-1} had slightly higher TN, compared to the other treatment.

Available phosphorus (AP) was observed to decrease generally with depth (Table 1). The AP contents at the 0-10cm depth were higher in treatments involving the incorporation of legumes (especially *C. pascuorum*) and animal manure, although the values were in the moderate range (10 - 19 mg kg^{-1}). Application of animal manure sole or mixed at the rate of 90 kg N ha^{-1} increased AP by 63 % at the surface and 73 % at the subsurface levels. Little or no significant difference was observed between the sole urea treatments.

Results for cation exchange capacity (CEC) showed higher CEC values at 10-30 cm depth compared to the 0-10 cm depth (Table 1). The high CEC values obtained in the AM treated plot (mixed) compared to sole urea at 90 kg N ha^{-1} showed improvement by 26 % and 38 % at the 0-10 and 10-30 cm depths respectively.

Soil physical properties

The results obtained from the measured bulk densities showed higher bulk densities at 10-30 cm depth compared to 0-10 cm depth (Table 2). The soil bulk density values obtained from the incorporation of legumes and animal manures were lower (<1.45 g cm^{-3}) compared to the values of the treatments with sole urea fertilizer (>1.52 g cm^{-3}).

Total porosity values obtained were lower at 10-30 cm than at 0-10 cm. The incorporation of these soil amendments increased total porosity at both depths compared to treatments with sole urea fertilizer.

Soil moisture contents at -33 kPa were lower at 0-10 cm depth compared to 10-30 cm depth. Higher moisture retention content was observed with the treatments involving *C. pascuorum* and animal manure at 0-10 cm depth compared to the 10-30 cm depth.

Saturated hydraulic conductivity (Ks) of the various treatments was also affected though high variability in the results was obtained.

Urea fertilizer in combination with AM at 90 kg N ha^{-1} at the 0-10cm depth, significantly reduced soil bulk density by 18 % (1.24 g cm^{-3}), improved total porosity by 15 % (53 %), available moisture contents at field capacity by 50 % (0.2 kPa) and permanent wilting point by 25 % (0.12 kPa) compared to sole urea fertilizer treatments (1.52g cm^{-3}, 45%, 0.1 hkPa and 0.09 kPa).

Principal Component Analysis of Soil Chemical Properties

Six principal components were greater than one and; cumulatively explained 89 % of the variation within the soil fertility treatments (Table 3). Principal component one (PC1) explained 49 % and was dominated by AP and CEC. The second PC explained an additional 17 % of the total variance and was dominated by Na with a negative loading. The PC3 explained additional 9 % of the total variance with a negative loading on OC, while PC4 further explained additional 6.0 of the total variance respectively. Principal component four was dominated by pH.

Principal Component Analysis of Soil Physical Properties

Principal component analysis was used to investigate which soil physical variables or clusters of variables might explain the majority of the variability. Three principal components were greater than one (>1) and; cumulatively explained 92

Table 1: Soil chemical properties at 0-10 cm and 10-30 cm depths at tarselling stage comparing S (sole organic or sole urea) and M (mixed organic and urea) at 45 and 90 kg N ha^{-1}

Treatment	**pH10**	**OC10**	**TN10**	**AP10**	**CEC10**	**pH30**	**OC30**	**TN30**	**AP30**	**CEC30**
Sole 45 kg N ha^{-1}										
urea1	5.20^{b}	0.70^{f}	0.40^{b}	0.70^{f}	3.25^{d}	5.13^{c}	0.60^{c}	0.20^{c}	0.60^{c}	4.34^{c}
CP (only)	5.45^{a}	2.40^{d}	025^{c}	2.40^{d}	3.22^{d}	5.34^{a}	1.55^{b}	0.10^{c}	1.55^{b}	5.41^{bc}
Pas (only)	5.45^{a}	4.20^{b}	0.50^{ab}	4.20^{b}	4.24^{bc}	5.27^{ab}	1.35^{b}	0.40^{ab}	1.35^{b}	6.85^{b}
Sole 90 kg N ha^{-1}										
urea2	5.27^{b}	1.50^{c}	0.50^{ab}	1.50^{c}	3.93^{cd}	5.04^{d}	0.77^{c}	0.22^{bc}	0.77^{c}	6.12^{bc}
AM (only)	5.45^{a}	3.40^{c}	0.55^{ab}	3.40^{c}	6.66^{a}	5.20^{bc}	1.49^{b}	0.45^{a}	1.49^{b}	11.45^{a}
Mixed 90 kg N ha^{-1}										
AM+ urea	5.50^{a}	3.30^{c}	0.60^{a}	3.30^{c}	5.31^{b}	5.15^{bc}	1.50^{b}	0.40^{ab}	1.50^{b}	9.89^{a}
Pas + urea	5.42^{a}	4.87^{a}	0.57^{ab}	4.87^{a}	4.50^{bc}	5.16^{bc}	2.47^{a}	0.50^{a}	2.47^{a}	7.65^{b}
CP + urea	5.40^{a}	4.10^{b}	0.50^{ab}	4.10^{b}	3.59^{cd}	5.12^{c}	2.20^{a}	0.30^{b}	2.20^{a}	5.93^{bc}
SED	0.034	0.058	0.058	0.058	0.351	0.037	0.099	0.061	0.099	0.729
Significance	*	*	*	*	*	*	*	*	*	*
Contrast										
S45 vs M 90	*	*	*	*	*	*	*	*	*	*
S 90 vs M 90	*	*	*	*	NS	*	*	*	*	NS
S45 vs S 90	NS	NS	*	NS	*	NS	NS	*	NS	*

Means with the same letter in the same column are not significantly different, SED: standard error difference; NS: Not significant; urea 1 & 2: 45 and 90 kg N ha-1 respectively; AM: animal manure; Pas: C. *pascuorum*; CP: cowpea; OC: organic carbon; pH: pH (H20); TN: total nitrogen; AP: available phosphorus; CEC: cation exchange capacity; 10 & 30: 0-10 cm and 10-30 cm depths; M: mixed; S: sole; *: significant at 5% level of probability.

Table: 2: Soil physical properties at 0-10 cm and 10-30 cm depths at tarselling stage comparing S (sole organic or sole urea) andM (mixed organic and urea) at 45 and 90 kg N ha^{-1}

Treatment	**BD$_{10}$(gcm^{-3})**	**TP$_{10}$(%)**	**SHC$_{10}$(cm sec^{-1})**	**Soil Moisture content (kPa)**		**BD$_{30}$(gcm^{-3})**	**TP$_{30}$(%)**	**SHC$_{30}$(cm sec^{-1})**	**Soil Moisture content (kPa)**	
				-33	**-1500**				**-33**	**-1500**
Sole 45 kg N ha^{-1}										
Urea1	1.55^{a}	44.91^{f}	1.36^{h}	0.10^{d}	0.07^{c}	1.68^{a}	37.77^{g}	4.91^{h}	0.13^{bc}	0.06^{b}
CP (only)	1.46^{b}	45.42^{e}	6.41^{e}	0.11^{cd}	0.09^{b}	1.54^{e}	39.44^{f}	10.65^{f}	0.13^{bc}	0.06^{b}
Pas (only)	1.40^{c}	47.17^{d}	11.11^{c}	0.15^{b}	0.09^{b}	1.53^{e}	41.13^{d}	15.35^{e}	0.1^{c}	0.07^{b}
Sole 90 kg N ha^{-1}										
Urea 2	1.52^{a}	44.91^{f}	3.46^{g}	0.10^{d}	0.09^{b}	1.65^{b}	41.13^{d}	7.13^{g}	0.16^{a}	0.07^{b}
AM (only)	1.27^{d}	54.15^{a}	6.32^{f}	0.20^{a}	0.12^{a}	1.49^{g}	44.69^{a}	21.55^{d}	0.11^{d}	0.09^{a}
Mixed 90 kg N ha^{-1}										
AM +urea	1.24^{d}	52.65^{b}	10.49^{d}	0.20^{a}	0.12^{a}	1.51^{f}	43.21^{b}	33.84^{a}	0.12^{cd}	0.09^{a}
Pas + urea	1.43^{bc}	48.81^{c}	12.62^{b}	0.15^{b}	0.09^{b}	1.61^{d}	41.88^{c}	25.02^{b}	0.13^{bc}	0.07^{b}
CP + urea	1.48^{b}	44.78^{g}	15.22^{g}	0.12^{c}	0.07^{c}	1.63^{c}	40.88^{e}	24.87^{c}	0.14^{b}	0.06^{b}
SED	0.013	0.006	0.017	0.006	0.006	0.006	0.006	0.006	0.006	0.006
Significance	*	*	*	*	*	*	*	*	*	*
Contrast										
S45 vs M 90	*	*	*	*	NS	NS	*	*	NS	NS
S 90 vs M 90	*	*	*	NS	*	NS	NS	*	NS	NS
S45 vs S 90	*	*	*	*	*	NS	NS	*	NS	NS

Means in the same column followed by the same letter (s) are not significantly different at $p<0.05$; SED: standard error difference; NS: Not significant; Urea 1 & 2: 45 and 90 kg N ha^{-1} respectively; AM: animal manure; Pas: *C. pascuorum*; CP: cowpea; BD: bulk density; TP: total porosity; SHC: saturated hydraulic conductivity; M: mixed; S: sole; *: Significant at 5% level of probability; 10 & 30: 0-10 cm and 10-30 cm depths.

Table 3: Principal components analysis of soil chemical properties

	Principal Component			
Measurements	**PC1**	**PC2**	**PC3**	**PC4**
Eigen values	12.80	4.32	2.24	1.56
% Contribution	49.23	16.57	8.61	6.00
Cumulative Percent	49.23	65.80	74.41	80.41
Chemical Parameters	**Rotated Score of six retained eigen vectors**			
PH 1	0.443	0.319	-0.167	0.701
OC1	0.690	0.172	-0.546	0.197
TN1	0.825	0.424	0.086	-0172
Av.P1	0.923	-0.024	-0.056	0.038
Ca1	0.889	-0.107	-0.021	0.158
Mg1	0.589	-0.251	0.348	-0.182
K1	0.752	0.238	-0.299	0.138
Na1	0.485	-0.665	0.338	0.325
CEC1	0.913	-0.149	0.048	0.111
PH2	0.004	0.502	-0.041	0.613
OC2	0.598	0.181	-0.531	-0.333
TN2	0.811	0.351	-0.208	-0.156
Av. P2	0.874	0.052	-0.437	0.022
Ca2	0.924	-0.275	-0.056	0.090
Mg2	0.828	-0.466	-0.125	0.056
K2	0.923	-0.003	-0.060	0.029
Na2	0.723	-0.528	0.287	0.157
CEC2	0.918	-0.316	-0.069	0.084

Values in bold (>0.500) represents chosen parameters that explains variation with the treatments;1&2: 0-10 & 10-30 cm soil depths respectively

Table 4: Principal components analysis of soil physical properties

	Principal component		
Measurements	**PC1**	**PC2**	**PC3**
Eigen values	6.12	1.89	1.15
% contribution	61.18	18.89	11.47
Cumulative percent	61.18	80.07	91.54
Physical Parameters	**Rotated Scores of three retained eigen vectors**		
BD 1	-0.812	-0.134	0.498
TP 1	0.967	0.095	-0.109
-33a	0.964	0.207	0.013
-1500a	0.939	-0.106	-0.081
SHC 1	-0.099	0.825	0.511
BD 2	-0.876	0.000	0.055
TP 2	0.797	-0.397	0.300
-33b	0.106	-0.787	0.577
-1500b	0.913	-0.212	0.091
SHC2	0.677	0.553	0.428

Note: 1 and a: 0-10cm depth; 2 and b: 10-30cm depth; Values in bold (>0.500) represents chosen parameters that explains variation with the treatments

% of the variation within the soil fertility treatments (Table 4). Principal component one (PC1) explained 61 % of the total variance and was dominated by soil moisture retention at field moisture capacity (FMC), permanent wilting point (PWP) and total porosity (TP); with a negative loading for soil bulk density (BD). The second PC explained an additional 19 % of the total variance and was dominated by saturated hydraulic conductivity (SHC), while PC3 explained a further 12 % of the total variance. The factor loadings of soil physical parameters on PCA therefore showed the following ordination: TP> soil moisture (FMC) > soil moisture (PWP) > SHC.

DISCUSSION

Soil chemical properties

The low pH values obtained at the 10-30cm depth could be due to reduced organic matter content and increasing Fe content at this depth (Eche, 2011). The earlier application of 180 kg $MgSO_4$ and 3 kg $ZnSO_4$ from 2004 to 2006 could have left strong residual acidity to the soil. This is because the presence of sulphate ions could contribute to soil acidity. The application of animal manure alone or in combination with sole urea fertilizer increased pH value by 2 % at the surface and 1% at the subsurface levels compared to sole urea. Perhaps, the organic manure at decomposition mitigated soil acidity even at the immediate subsoil level (10-30 cm).

The relatively low soil organic carbon (SOC) in the sole urea fertilizer is largely due to non- addition of organic matter to the soil as well as the high rate of organic mineralization in the Nigerian NGS. Because of the high diurnal temperature, the rate of decomposition is rapid which depletes residual carbon in the soil. The higher levels of SOC obtained in the treatments involving legumes and animal manure incorporation (sole or mixed) could be due to the fact that the legumes may have provided more C as an energy source for microbes, while the introduced animal manure was undergoing rapid mineralization due to its narrow C: N ratio. The general decline in SOC could be due to rapid mineralization of OM incident in the NGS of Nigeria and the effects of runoffs and erosion.

The generally low TN for all treatments may be due to plant uptake, runoff and leaching effects. The higher TN content by *C. pascuorum* was due to the production of a good biomass produced and incorporated at maize planting. The mineralized N from below ground biomass of the in-situ grown *C. pascuorum* would also have contributed to higher TN under *C. pascuorum* treatment. The significantly ($p<0.05$) generally lower TN in the sole urea fertilizer treated plots could be due to the rapid growth of maize which made the maize plant capture more N to the detriment of the microorganisms, since the N in urea fertilizer is already in the plant available form. This result agrees with the findings of Adeboye (2006). The higher TN obtained from *C. pascuorum* and animal manure showed narrow C: N ratios indicating higher rate of decomposition of organic materials which is common with most savanna soils (Tarawali *et al*., 2001) and soil quality improvement (Ogunwole, 2005).

Available phosphorus (AP) was observed to decrease generally with depth. This could be due to the fact that P is not mobile in soil. Legumes and animal manure have been observed to release considerable amounts of organic acids into the soil thereby resulting in the hydrolysis of organic P; hence, improving P-nutrition for plant and microorganisms (Rao *et al*., 2002; Li *et al*., 2003,2004). This could be the reason for the higher P levels obtained in the legume and animal manure treatments compared to sole urea fertilizer treatment. Little or no significant difference was observed between the sole urea treatments. This could be because the P is already in the plant available form, thus higher rate of uptake.

Higher CEC values at 10-30 cm depth showed that nutrients like Ca and Mg may have illuviated into the subsoils (10-30 cm depth) and influenced CEC at that depth. This agrees with the findings of Odunze and Kureh (2006) who observed that the organic colloidal fractions were low in soils of the Samaru area indicating that nutrients in these soils are susceptible to leaching. Results obtained from this study showing CEC values in the range of 3 - 12 cmol kg^{-1} for both soil depths, suggests a dominance of low activity clays (sesquioxides and kaolinite clays) and organic colloidal fractions (Odunze and Kureh, 2006). The high CEC values obtained in the AM treated plots (mixed) compared to sole urea at 90 kg N ha^{-1} showed that the potential of the soil to exchange cations had been improved by 26% and 38.12% at the 0-10 and 10-30 cm depths respectively, showing that the soil quality has been upgraded.

Soil physical properties

Lower soil bulk density at the 0-10 cm depth appeared to be due to incorporation of these soil amendments which contributed to improved soil physical conditions compared sole urea treatments. This agrees with the findings of Ogunwole (2005), who found that soil quality increases with low bulk density, aggregate strength and residue cover. Evanylo and McGuinn (2000) observed similar trend and suggested that bulk density values of 1.55 to <1.65 g cm^{-3} can affect root growth and development in silt loams while soil bulk density of $\leq$ 1.40 g cm^{-3} are ideal for optimum root growth.

The higher total porosity values obtained from treatments involving incorporation of animal manures and residues of *C. pascuorum* could be due to their increased organic carbon inputs and the abundant root biomass and exudates of the maize/ *C. pascuorum* intercrop which supported the stability of their microaggregates. This agrees with the findings of Ogunwole et al. (2010) who reported improved microaggregate stability under long term incorporation of *C. pascuorum* residue. A contributing factor to the lower percentage of total porosity at 10-30 cm could be the higher clay contents obtained at this depth.

The higher soil moisture retention observed in the AM treated plots indicates better conditions for plant water and nutrient uptake leading to good crop growth and development and thus enable the plant to withstand period of drought. This would result in higher crop yield in the animal manure-amended soils compared to the other treatments. Vanlauwe *et al*. (2001) observed large numbers of maize plants being barren in sole urea treatments due to stress resulting from low soil water and N availability.

Saturated hydraulic conductivity (Ks) of the various treatments were affected, leading to lateral movement of roots and water when water cannot percolate down as a result of hard pan or laterite pan (Ogunwole, 2005). There was high variability in the results obtained, which could have been the result of difficulties in obtaining representative undisturbed core samples. The presence of roots and other macro pore channels coupled with the fact that laboratory measurements are on undisturbed smaller diameter soil cores could be additional reasons for such variability. This finding agrees with the work of Abdulkadir, (2006) who observed high variability in Ks due to difficulty in obtaining representative undisturbed core samples. As a result of the wide differences in the results obtained, the Ks values determined using laboratory analysis of soil core samples cannot be expected to give reliable results.

This improved physical quality attributes enhanced soil pH, organic carbon, nitrogen, phosphorus and CEC. The higher SOC in the animal manure treated plots could be attributed to greater soil water holding capacity, nutrients availability in plants, improvement of soil physical properties and the efficiency of fertilizer nutrients by organic amendments (Benbi *et al*., 1998).

The findings of the PCA of soil chemical properties supported the ANOVA results (Table 1) and showed that the soil chemical parameters that dictate variability include AP and CEC and these captured about 49% of the variability. However, AP will be strongly related given that the study soil is mostly strongly acid (pH 5.1 – 5.6) and P will be more readily available under acid condition.

Principal components analysis of soil physical properties indicated that the plant available water (soil moisture retention at FMC and PWP) is the physical property that best influenced variability on field and this captured about 61% of the variability. These results are consistent with Harris *et al*. (1996) and Ogunwole, (2005) who found that soil quality decreases with increasing bulk density and increases with aggregate strength and residue cover.

Conclusions

Results of this study indicate that combined application of urea fertilizer with animal manure had a profound effect on cation exchange capacity, bulk density, total porosity and soil moisture content at the soil surface. Under this treatment the soils were acid both at surface and subsurface layers and had low OC and TN contents. Also, bulk density (1.24 g cm^{-3}), total porosity (53 %), available moisture contents (0.20 kPa and 0.12 kPa respectively) of the soils were improved upon better than urea fertilizer treatments (1.52g cm^{-3}, 45 %, 0.10 kPa and 0.09 kPa respectively). In conclusion therefore, combined application of urea fertilizer with either animal manure or herbaceous legume inter crop restored and maintained soil fertility in the long-term trial for sustainable soil productivity in Samaru, NGS zone of Nigeria.

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