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Soil properties of a fallow field under long-term cultivation and fertilization regimes in Northern Guinea Savanna, Nigeria

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The long-term dung (D), Nitrogen (N), Phosphorus (P) and Potassium (K) commonly referred to DNPK experiments in northern guinea savannah of Nigeria was subjected to different fertilization regimes from 1950 to 1996 under continuous cultivation. Experimental plots have been under fallow from 1997 till now. Surface soils (0 to 5 and 5 to15 cm) were sampled and analyzed for physical and chemical properties under different combinations and application rates with organic and or inorganic fertilizers; that is, DNP, DNK, DNPK, NPK, DPK, and control (CT) received no fertilization treatments. From 0 to 5 cm soil depth, bulk density was high except for NPK and DNPK which recorded the lowest values of 1.46 and 1.48 Mg m^{-3}, and decreased by 14 and 16%, respectively compared to the control. Mean weight diameter (MWD) indicate water stable aggregates of 0.55 and 0.66 mm in DNPK and NPK, and dry macroaggregates between 1.08 to 1.71 mm across all treatments. Saturated hydraulic conductivity (Ks) was higher with 150.4 and 104.1 cm hr^{-1} in DNK and DNP, which increased by 6 and 9 folds, respectively, compared to CT while total porosities of 32 to 44% was observed for all treatments except DNP and CT, and increased by 47 to 88% in the other dung treatments compared to CT at 0 to 5 cm. Soils organic matter content was moderate to high (28.7 to 44.1 g kg^{-1}) across all the treatments while soil (pH) with calcium chloride was lowest in NPK. Most of the moisture is retained in the soils at field capacity and permanent wilting point in dung treatments and CT, while it was lowest for NPK. Taking all the properties into consideration, soil quality decreases in the order DNPK > DNK > DNP > DPK = NPK > CT and implies better quality under dung fertilization with mineral fertilizer in the long term. The positive effect of long-term integrated application of organic and inorganic fertilizers is further emphasized as a recommended sustainable soil management practice for tropical soils.

Key words: Soil quality, long-term experiments, mean weight diameter, soil organic matter (SOM), inorganic fertilizers

INTRODUCTION

Studies on soil physical properties are significant to determine to some extent the strength of soil, which is beneficial in providing support for plants and in protecting the air and water supply system of the soil against damage (Lal, 1979; Lipiec and Hatano, 2003). This may have a direct relationship to soil fertility because for a soil to be productive and fertile, it's physical and chemical status must reciprocate each other (Babalola, 1978).

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Savanna soils are often characterized as having weak structure, poor water infiltration capacity, high rate of erosion run-off and depleted in soil nutrients due to continuous cultivation (Bationo et al., 1997; Wuddivira, 1998; Odunze, 2003; Ogunwole and Ogunleye, 2005). Rainfall is erratic in savanna region (Owonubi et al., 1991) and thus, sustainable production on these soils is threatened under continuous cultivation with little consideration for soils' ability to recover.

Sustainability in crop production may be achieved through proper management of the soil to maintain both its physical status at the same time as it replenishs its soil nutrient reserve. Proper farm management through different fertilization regimes significantly influences the physical state of soils, which has a direct effect on the hydraulic properties (Rasmussen and Parton, 1994; Pagliai et al., 2004). Incorporation of manure or organic residues may lower dry soil bulk density, thus, reducing soil compaction and encouraging the formation of soil aggregates (Haynes and Naidu, 1998).

Soil aggregate is an important soil physical property that defines the nature of pores and pore channels and directly or indirectly influences its hydraulic properties (Horn et al., 1995; Brady and Weil, 1999). Several studies have indicated the importance of an integrated use of organic and inorganic soil amendments to improve soil fertility and yield of crops (Manna et al., 2005), improved physical condition (Celik et al., 2004; Hati et al., 2007; Yang et al., 2013), improved chemical and biochemical conditions during stages of crop growth (Mandal et al., 2007) or all three conditions above (Bullock et al., 2002). Similar finding were also observed on improved physical and chemical conditions with integrated organic and inorganic fertilizers additions in the long-term fertilizer experiments in northern Nigeria savanna (Ogunwole and Ogunleye, 2004, 2005).

The long-term DNPK experiments in northern savanna of Nigeria and West Africa has been subject to 45 years of continuous cultivation under different fertilizer management from 1950 to 1996. Fertilizer application involves a combination of organic (Dung) and/or mineral fertilizers (NPK, single super phosphate, murate of potash) in various proportions applied to cultivated crops. Studies conducted on these plots from 1950 until of recent range from subjects on soil fertility (Heathcote, 1969; Heathcote and Stockinger, 1970; Jones, 1971; Lombin and Abdullahi, 1977; Mokwunye and Stockinger, 1978), nutrient dynamics (Agbenin and Goladi, 1997), micronutrients (Yaro et al., 2002), physico-chemical properties of the soil (Ogunwole and Ogunleye, 2005), and most recently on carbon sequestration potentials (Raji and Ogunwole, 2006). The later four studies were conducted when plots were under natural fallows starting from 1997 to 2001. However, few studies on physical and chemical status of these plots exist since beyond 2001. The objectives of this study was to investigate the soil properties of these plots after 10 years under natural fallow, and to determine temporal changes that may have occurred under the current land use (fallow).

MATERIALS AND METHODS

Study area

The study was conducted on the long-term experimental plots popularly known as the DNPK plots that received DNPK. It is located in Samaru, Zaria, Nigeria (Latitude 11° 11" N, Longitude 7° 38" E) at an altitude of 686 m above sea level. The area falls within the northern Guinea savannah ecological zone of Nigeria, with an average annual unimodal rainfall of 1065 mm that falls mostly between May and September. Soils are ferruginous tropical (Kowal and Knabe, 1972) and classified as Typic haplustalfs according to the United State Soil Taxonomy classification (Ogunwole et al., 2001). The soils originated from parent material made up of basement complex precambrian rocks (Raji and Ogunwole, 2006). Vegetation consists of trees, shrubs and woodland typical of the Guinea savannah zone.

Plot descriptions and history of use

The long-term DNPK experiments was laid in 1949 and full experiments started in 1950 and is the oldest fertilizer experiment in West Africa that was modeled after the Rothamsted long-term trials in the United Kingdom (Amapu, 2007). It has 81 plots in 3^4 replicated factorial design randomly arranged with a plot size of 220 m^2. There are 27.4 m long ridges, which are 75 cm apart in each plot. Discarded areas of 0.91 m separate the plots from each other. The 81 treatments exist under combinations of DNPK fertilizers (Table 1). The plots received different management practices that ranges from crop rotation, tillage practices, lime and micro nutrient application, and changes in mineral fertilizers as sources of the major nutrient and cultivated crops. Ogunwole and Ogunleye (2005) gave a detailed description of these management practices.

Soil sampling and analysis

A stratified random sampling technique was used to collect surface soil (0 to 5 cm and 5 to15 cm) from 6 selected plots from the trial field in 2008. The sampling procedure divides the plot into 3 homogenous subplots of 72 m^2 each similar to the procedure adopted by Ogunwole and Ogunelye (2005). From the 6 selected main plots, 3 replicates of disturbed and 2 replicated undisturbed core samples (5 × 5 cm in diameter) were selected from each soil depth in each subplot; the disturbed samples were later bulked to form one composite sample per plot per soil depth, while the undisturbed samples were immediately taken to the laboratory for subsequent analysis.

A brief description of fertilizer combinations and application rates of the selected plots is presented on Table 2.

After removing debris and prominent residues, the disturbed and composited soil samples were passed through a 4 mm sieve before being air-dried. Half of the air-dried sample was grounded and sieved with a 2 mm meshed-sized sieve and the less than 2 mm sample was stored in a polythene bag before analysis, while the undisturbed soil cores where used to determine bulk density and hydraulic properties. Soil pH was determined in 1:2 soil to solution ratio in water (H_2O) and 0.01M calcium chloride ($CaCl_2$). Soil organic carbon was determined by the Walkley-Black wet oxidation method (Allison, 1965), and later converted to soil organic matter (SOM) by multiplying by 1.724, while Total Nitrogen (TN) was determined using the micro Kjedahl distillation method. Particle size distribution was determined by the Bouyoucous hydrometer method

Table 1. Fertilizer combinations for the various treatments in the experimental plots.

Treatment	Abbreviation	Rates [a] (kg ha^{-1})		
Dung	D	0	2500	5000
Urea	N	0	67.5	135.0
Single Super Phosphate (SSP)	P	0	13.5	27.0
Murate of potash	K	0	29.0	58.0

[a] Each fertilizer applied at 3 levels of 0, 1, 2, (3 × 3 × 3 × 3 = 81). Each row of the application rates represents the level number 0, 1, 2 respectively.

Table 2. Fertilizer combinations histories in selected study plots.

S/N	Treatment Combination	Acronym[a]	Rates (kg ha^{-1} yr^{-1})
1.	Dung + Nitrogen + Phosphorus	DNP	N = 84 – 135; P = 18 – 54; D = 5000
2	Dung + Nitrogen + Potassium	DNK	D = 5000; N = 48 – 135; K = 29 – 58
3	Dung + Nitrogen + Phosphorus + Potassium	DNPK	D = 5000; N = 48 – 135; P = 18 – 54; K = 29 – 58
4	Nitrogen + Phosphorus + Potassium	NPK	N = 48 – 135; P = 18 – 54; K = 29 – 58
5	Dung + Phosphorus + Potassium	DPK	D = 5000; P = 54; K = 29 – 58
6	Zero amendment/Control	CT	NIL

[a] Treatments were under the various combinations and proportions of fertilizers when under continuous cultivation.

(Bouyoucous, 1927), and Dry bulk (ρ_b) and Particle densities (ρ_p) were determined according to the method by Blake and Hartge (1986a, 1986b). Total porosity (F) was calculated using the values of bulk density and measured particle density from the given expression:

$$F = \left(1 - \frac{\rho_b}{\rho_p}\right)100$$

The other half of the 4 mm sized aggregate fractions were used to determine aggregate stability using both the dry and wet sieving methods (Kemper and Rosenau, 1986). 200 g of air-dried sample was placed on the top-most sieve composed of a column of 6 sieves (10, 5, 2, 1, 0.5 and 0.25 mm) to separate the aggregates into different fractions. Aggregates were shook on a mechanical shaker for 5 min and each sieve was weighed with the fraction of aggregates retained. Weight of aggregates retained in each sieve is subtracted from the weight of the empty sieve. Wet sieving was conducted from pre-wetting 200 g of soil aggregate samples and oscillating the set of sieves (5, 2, 1, 0.5, 0.25 mm) in water in an up and down motion/stoke for 3 min at approximately 30 stocks per min, to ensure that the water flow through the assemblage of sieves. Soil aggregates retained in each sieve was transferred to aluminum cans and oven dried at 105°C for 24 h and weighed. Weight of each aggregated in each sieve was recorded and mean weight diameter (MWD) was calculated as:

$$MWD = \sum_{i=1}^{n} \overline{X}_i W_i$$

Where $\overline{X}_i$ denotes the mean diameter of each aggregate class (*i*) and W_i is the proportion of each aggregates fraction or class to the total weight of the aggregates, *n* denotes the number of classes. Similar calculation is made for the two methods described above.

Soil moisture retention was determined with the pressure plate apparatus to estimate soil water from field capacity (33 kPa) to wilting point (1500 kPa) through a range of matric potentials from 10, 33, 100, 500, 1000, 1500 kPa. Constant head permeameter was used to determine the saturated hydraulic conductivity (Ks) using the method of (Klute, (1965).

Data analysis

The data obtained were analyzed statistically using analysis of variance (ANOVA) with Tukey's HSD test for comparing the means of the different treatment using the SPSS 17.0 version (SPSS, 2008). Correlation analysis was conducted with the measured soil properties to determine the relationships across all treatments under the fallow.

RESULTS AND DISCUSSION

Physical properties

Soils are generally sandy loam, sandy clay loam to loam in texture (Table 3) characteristic for most savannah soils (Jones and Wild, 1975; Ogunwole and Ogunleye, 2005). The highest sand fraction was found in the DNPK and DNK treatments at 0 to 5 and 5 to 15 cm soil depths respectively, while the control plot recorded the highest clay content at both depth ranges. The increased sand fractions of the DNPK and DNK treatments may be the result of a higher resistance of the soil to continuous cultivation, while the NPK treatments have lower resistance (Ogunwole and Ogunleye, 2005). High clay in the surface soils of CT treatment indicates low level of clay eluviation due to minimal or no disturbance through cultivation (Table 4).

Dry soil ρ_b values were not significantly different ($p > 0.05$) among the treatments, and much lower values at 0

Table 3. Particle size distribution of the study plots.

Soil depth (cm)	Treatment	Sand (%)	Silt (%)	Clay (%)	Textural class
0 - 5	DNP	54	30	16	SL
	DNK	54	28	18	SL
	DNPK	54	31	17	SL
	NPK	49	17	34	SCL
	DPK	52	30	18	SL
	CT	37	30	33	L
5 - 15					
	DNP	53	29	18	SL
	DNK	60	25	15	SL
	DNPK	52	29	19	SL
	NPK	57	13	30	SCL
	DPK	54	27	19	SL
	CT	41	38	21	L

SL = Sandy loam; L = Loam; SCL = Sandy Clay loam.

to 5 cm were obtained in DNPK (1.48 Mg m^{-3}) and NPK (1.46 Mg m^{-3}) treatments, respectively. Bulk density values increased with depth and there was no statistical relationship with SOM and clay content but only a significant negative relationship with total porosity ($p < 0.05$) and wet aggregate stability index (MWD_{wet}). Mean ρ_b values for DNP, DNK, DPK and control (CT) treatments are high and indicate a chance of restricting root penetration in the lower soil depths especially in the DNP treatment where porosity values were very low (9 to 10%) at both depth ranges, which was further confirmed in the inverse relationship between ρ_b and soil porosity (Table 7).

Earlier work on similar treatments indicates ρ_b values for the DNPK plots similar to those found in this work, but contrary to values in NPK and CT treatments (Ogunwole and Ogunleye, 2005). Also, when compared with the same study, the ρ_b value is reduced in the NPK treatments while it was increased in CT plot. Reduced ρ_b in NPK treatment may be as a result of resilience of soils due to natural fallow, while for CT, the absence of cultivation and tillage operations continues to tighten the soil over time as observed for non-tilled loam soils of China (Zhou et al., 2007). High ρ_b in CT treatment with average value of 1.725 Mg m^{-3} across both soil depths implies that root growth will be impeded, except when surface soil is ploughed for cultivation on such plots. Although organic additions have been shown to lower bulk densities and penetration resistances (Celik et al., 2010), high ρ_b values for DNP, DNK and DPK obtained in this study are consistent with earlier findings, and reflect observation that bulk density could be increased even with dung application (Sommerfeldt and Chang, 1987; Ogunwole and Ogunleye, 2005). High bulk densities in the dung plots could be as a result from spatial variability of soil properties within the field (Cambardella et al., 1994) or as a result of fallow which causes the tightening of the soil and decrease in the volume of soil pores over time (Zhou et al., 2007).

F was statistically different ($p < 0.05$) in all the treatments in 0 to 5 cm (Table 4) and was not affected by organic additions. Lowest porosity values of 10 and 8% in 0 to 5 and 5 to15 cm depth respectively was observed for DNP treatments and was statistically different from the other treatments ($p < 0.05$). Although statistically, the relationship was not significant ($p > 0.05$), F relates negatively with soil moisture content at all potentials. This indicates that, the soils are dominated by macropores because of the rapid decline in soil moisture as the water held tends away from field capacity (Mbagwu, 1995).

Macroaggregate under dry sieving were stable for all treatments and statistically different between all the fertilization regimes (Table 4) and increases with soil depth except in DNP treatment. However, water stable macroaggregates are less distinct among the treatments at upper soil layer with no statistical difference between the treatments at 5 to 15 cm and a greater stability exhibited by DNPK and NPK treatments at the uppermost soil layer (0.55 and 0.66 mm, respectively). The order of decreasing water stability of the soil aggregates for the treatments is NPK > DNPK > DNK > DNP > DPK > CT. Water stable aggregates decrease with soil depth and the reverse was the case for dry macroaggregates. This is a contrast to the work of Anderson and McBratney (1995) as well as Guber et al. (2005) who showed an increase of macroaggregate stability with depth.

Although organic matter is important in aggregation of macroaggregates (Mbagwu, 1991), the presence of available N from fertilizer may increase the growth and stimulate activities of soil fungi and other microbes, which partly play a role in the stabilization of soil aggregates from produced organic binding agents (Tisdall and Oades, 1982). The results here are in accordance with findings of N'Dayegamiye et al. (2010) who reported that,

Table 4. Selected physical and hydraulic properties of the study plots at two soil depth.

Soil depth (cm)	Treatments	Bulk density ($Mg\ m^{-3}$)	Particle density ($Mg\ m^{-3}$)	Total porosity (%)	Dry sieving MWD (mm)	Wet sieving MWD (mm)	Saturated hydraulic conductivity ($cm\ hr^{-1}$)
0 - 5	DNP	1.59^{ab}	1.76a	9.69^{a}	1.71^{f}	0.47^{bc}	104.1^{bc}
	DNK	1.60^{ab}	2.71^{c}	40.96^{d}	1.24^{b}	0.49^{bc}	150.4^{c}
	DNPK	1.48^{a}	2.18^{b}	32.10^{c}	1.31^{c}	0.55^{c}	82.2^{b}
	NPK	1.46^{a}	2.56^{c}	42.97^{d}	1.46^{d}	0.66^{d}	34.0^{a}
	DPK	1.63^{b}	2.68^{c}	39.28^{d}	1.52^{e}	0.45^{b}	21.2^{a}
	CT	1.73^{b}	2.21^{b}	21.71^{b}	1.08^{a}	0.32^{a}	16.6^{a}
5 -15							
	DNP	1.71	$.86^{a}$	8.32^{a}	1.43^{a}	0.32	51.1^{b}
	DNK	1.69	2.12^{b}	20.52^{b}	1.53^{e}	0.49	80.3^{c}
	DNPK	1.66	2.85^{d}	41.85^{c}	1.65^{b}	0.39	50.1^{b}
	NPK	1.63	2.28^{bc}	28.73^{b}	1.71^{f}	0.52	26.3^{a}
	PK	1.72	2.13^{b}	19.69^{b}	1.84^{d}	0.43	18.0^{a}
	CT	1.72	2.49^{c}	30.73^{bc}	1.12^{c}	0.41	12.1^{a}

Means with the same letter within columns and soil depth are not significantly different (Tukey HSD test, $P \leq 0.05$)

increased application of mineral fertilizer N increased water stable aggregates in a clay loam soil. However, it contrasts with studies that show that, long-term application of NPK fertilizers reduces soil macroaggregates (Nyiraneza et al., 2009).

NPK fertilization may play an indirect role in macro aggregate stability because of the role it plays in biomass accumulation and root exudation (Beare et al., 1994). This was indicated in the high SOM levels present in NPK treatments of 36.6 and 48.4 g kg^{-1} in 0 to 5 and 5 to 15 cm soil depths, respectively (Table 6). In addition, water stable aggregates has a negative but significant relation with silt and moisture content from 1000 to 1500 kPa, but relationship was positive with sand content. Water stable macroaggregates may be composed mainly of sand fractions which are composed mainly of macropores having little contribution to water retention at high matric potential (Saxton et al., 1986; Schjønning et al., 2002).

Soil aggregates are influenced by pore sizes and pore geometry and are the major determinants of water retention in aggregated soils at different suction range (Ahuja et al., 1998). In their study, Boix-Fayos et al. (2001) obtained variable correlation between large macroaggregates and water stable microaggregates with soil properties. They concluded that, the presence of these two aggregates fractions must be used with caution when interpreting soil structural conditions. Celik et al. (2004) also observed a higher MWD in manured plots in their study compared with other fertilizer treatment (mineral and control).

Soil hydraulic properties

Measured Ks indicates statistical similarity in DNP, DNK, and DNPK treatments which recorded the highest values and different from DPK, NPK and CT treatments with lower conductivities in both soil layers. Ks decreases with soil depths (Table 4) and has a significant but negative relationship with SOM across all treatments. This is in contrast with values reported by Ogunwole and Ogunleye (2005) from similar plots which indicate Ks were similar in DNPK and NPK treatments as against CT. The fallow period must have masked these differences over years. Similar to this work, manure application was found to increase Ks (Shirani et al., 2002) amongst treatment. However, a study by Wu et al. (2003) reported no significant change in Ks with organic additions. Many researchers (Obi and Ebo, 1995; Schjønning et al., 2002; Arriaga and Lowery, 2003) have also reported a substantial increase in Ks due to the addition of manure while it did not show any significant difference between fertilizations in loess soils in China due to large variation in data (Zhang et al., 2006). Miller et al. (2002) also found that, the effects of manure applications on saturated conductivity were highly variable on both dry and irrigated land. Water conductivity in DNP treatment which recorded a low porosity value may be more influenced by high SOM content observed in the plot than by flows through macropores (Mbagwu, 1991).

Average soil moisture retention at 0 to 5 cm depth at 10 kPa was highest in the NPK treatment and statistically similar ($p < 0.05$) for DNK, DPK and control treatments (Table 5) and there was no significant difference between all treatments at 33 to 500 kPa. Moisture retention was highest in the control with dung addition from field capacity (33 kPa) to permanent wilting point (1500 kPa) at both soil depths (Figure 1) which bears similarity to finding by Zhang et al. (2006).

There is a general decrease in moisture held as the

Table 5. Moisture retention of the treatments at two soil depths.

Soil depth (cm)	Treatment	Moisture content (%, w/w) at different potential					
		10 kPa	33 kPa	100 kPa	500 kPa	1000 kPa	1500 kPa
0 - 5							
	DNP	15.71^{b}	10.65	9.45	7.45	6.90^{ab}	6.80^{bc}
	DNK	13.30^{a}	11.22	10.31	9.11	8.75^{b}	5.10^{a}
	DNPK	19.10^{c}	9.80	7.30	6.40	5.90^{a}	5.60^{ab}
	NPK	26.21^{d}	8.91	7.56	6.92	5.47^{a}	4.70^{a}
	DPK	13.62^{a}	8.65	7.30	6.80	6.30^{a}	5.80^{ab}
	CT	13.20^{a}	10.05	9.05	8.32	7.61^{ab}	7.50^{c}
5 -15							
	DNP	17.32^{c}	13.32^{b}	11.71^{d}	8.95^{b}	8.71^{c}	8.31^{b}
	DNK	13.30^{a}	9.82^{a}	7.45^{a}	6.52^{a}	6.13^{a}	5.15^{a}
	DNPK	19.65^{d}	13.40^{b}	10.43^{c}	9.94^{c}	9.94^{d}	8.32^{b}
	NPK	21.70^{e}	16.60^{d}	9.70^{b}	8.40^{b}	8.05^{b}	8.30^{b}
	DPK	15.85^{b}	14.50^{c}	12.85^{e}	12.21^{d}	11.91^{e}	11.32^{c}
	CT	12.65^{a}	10.33^{a}	9.59^{b}	8.60^{b}	8.61^{c}	8.45^{a}

Means with the same letter within columns and soil depth are not significantly different (Tukey HSD test, $P \leq 0.05$).

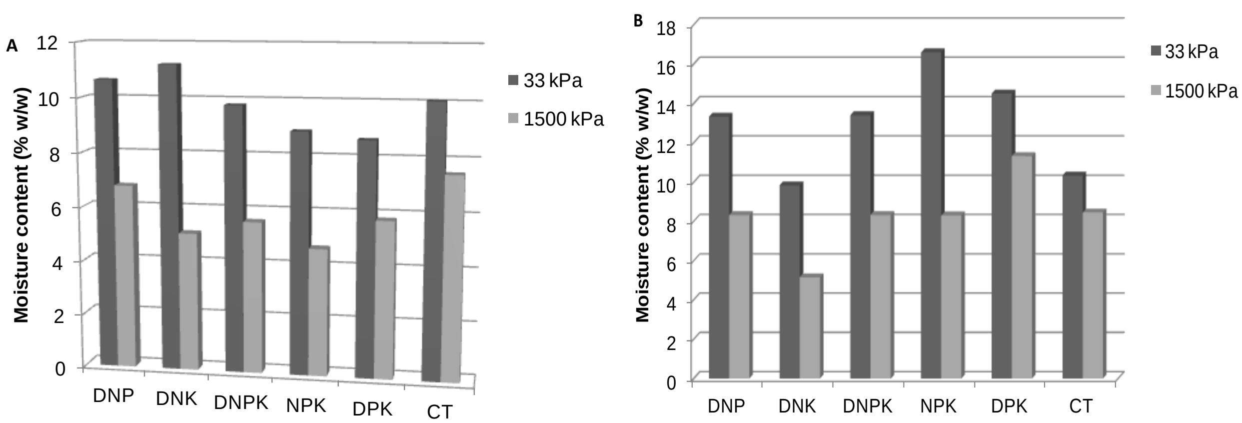

Figure 1. Moisture content of treatments at (A) 0 to 5 cm and (B) 5 to15 cm soil depths.

Water potential increase from 10 to 1500 kPa in all the plots (Table 5). Such a decrease in moisture retention in relation to water was recorded earlier for other soils (Bruand and Prost, 1987; Dexter, 2004). Soil moisture was the highest in the NPK plot at both depths at the initial water potential of 10 kPa, however, it retained the least amount of moisture as the matric potential increases beyond field capacity. The high clay content of the soil in CT treatments may have played important roles in retaining moisture at both soil depths and across all pressure potentials.

Chemical properties

Soil reaction (pH) in water ranges from 5.3 to 5.8 in the 0 to 5 cm depth and 5.0 to 5.7 in 5 to 15 cm depth and differ statistically in the DNPK and NPK treatments ($p < 0.05$) (Table 6). Soil pH with $CaCl_2$ indicate moderate to low acidity with the DNPK and CT treatment having a moderate near neutral reaction on the surface soil while NPK treatment exhibits the lowest pH at both soil depths compared to other treatments but statistically similar ($p > 0.05$) to DPK treatments at 5 to 15 cm. Such reduced pH may be the effect of prolong use of chemical fertilizer and continuous cultivation (Buri et al., 2005), which is reflected even after a 10 fallow years. Decrease of soil pH with depths may also be attributed crop uptake of basic cations, which induces an acidic environment with soil depth (Sanchez and Miller, 1986).

SOM is high in all treatments except for the moderate values in the DNK and CT treatments (28.7 and 29.2 g kg^{-1} respectively) at 0-5 cm depths which are statistically similar ($p > 0.05$) even in the lower soil depth (Table 6).

Table 6. Selected soil chemical properties of the study plots at two soil depths.

Soil depth (cm)	Treatment	SOM[a] (g kg^{-1})	PH(H_20)	pH($CaCl_2$)	Total N (g kg^{-1})
0- 5					
	DNP	44.1[c]	5.55[abc]	4.85[b]	0.8[ab]
	DNK	28.7[a]	5.35[ab]	4.90[b]	1.1[b]
	DNPK	40.9[bc]	5.85[c]	5.25[c]	1.2[bc]
	NPK	36.6[b]	5.30[a]	4.15[a]	0.8[ab]
	DPK	44.3[c]	5.35[ab]	4.25[a]	1.7[c]
	CT	29.2[a]	5.65[bc]	5.70[d]	0.4[a]
5-15					
	DNP	41.7[bc]	5.55[bc]	4.90[b]	0.9[b]
	DNK	30.9[a]	5.35[b]	5.00[bc]	0.6[a]
	DNPK	46.6[c]	5.05[a]	4.95[bc]	1.7[c]
	NPK	48.4[c]	5.50[bc]	4.45[a]	0.9[b]
	DPK	24.4[a]	5.05[a]	4.65[ab]	0.8[ab]
	CT	35.1[ab]	5.75[c]	5.05[c]	0.5[a]

[a] SOM = soil organic matter; Means with the same letter within columns and soil depth are not significantly different (Tukey HSD test, $P \leq 0.05$).

Table 7a. Correlation matrix between the soil properties across all treatments and soil depths.

Parameter	SOM	OC	pHH($_2$0)	pH($CaCl_2$)	Total N	Ks	ρ_b	ρ_p	F	MWD_{dry}
SOM	1.000									
OC	1,000**	1.000								
pH_{H20}	0.122	0.122	1.000							
pH_{CaCl2}	-0.311	-0.311	0.469*	1.000						
Total N	0.562**	0.562**	-0.321	-0.335	1.000					
Ks	-0.468*	-0.468*	-0.523**	-0.293	0.210	1.000				
ρ_b	-0.282	-0.282	-0.066	0.369	-0.227	0.179	1.000			
ρ_p	0.033	0.033	-0.371	-0.257	0.503*	0.255	-0.141	1.000		
F	0.081	0.081	-0.264	-0.329	0.472*	0.177	-0.459*	0.935**	1.000	
MWD_{dry}	0.294	0.294	-0.622**	-0.562**	0.306	0.238	-0.049	-0.190	-0.186	1.000
MWD_{wet}	0.090	0.090	-0.059	-0.540**	0.053	0.060	-0.721**	0.174	0.432*	0.186
$\theta_{10\ kPa}$	0.425*	0.425*	-0.169	-0.491*	0.160	-0.451*	-0.593**	0.108	0.294	0.349
$\theta_{33\ kPa}$	0.192	0.192	-0.313	-0.098	0.066	-0.102	0.299	-0.138	-0.227	0.521**
$\theta_{100\ kPa}$	-0.203	-0.203	-0.376	0.079	-0.065	0.036	0.478*	-0.183	-0.361	0.293
$\theta_{500\ kPa}$	-0.296	-0.296	-0.530**	0.051	0.000	0.176	0.454*	0.061	-0.115	0.288
$\theta_{1000\ kPa}$	-0.306	-0.306	-0.448*	0.102	-0.011	0.204	0.550**	0.023	-0.179	0.269
$\theta_{1500\ kPa}$	-0.092	-0.092	-0.235	0.102	-0.113	-0.064	0.579**	-0.216	-0.383	0.353
sand	0.039	0.039	-0.424*	-0.389	0.255	0.368	-0.464*	-0.160	-0.017	0.540**
silt	-0.192	-0.192	0.333	0.759**	0.011	0.008	0.443*	-0.159	-0.303	-0.434*
clay	0.133	0.133	0.214	-0.244	-0.288	-0.398	0.042	0.255	0.260	-0.189

SOM content at both 0 to 5 and 5 to15 cm depths in DNPK fertilized plot was higher than those recorded for the other plots but not statistically different ($p > 0.05$) from DNP and NPK plots. However, SOM in DNPK treatment statistically differs with DNK ($p = 0.002$) and CT ($p = 000$) at 5 to 15 cm depths (data not shown). No regular pattern was observed for SOM with soil depth. The higher occurrence of SOM in the dung fertilized plots may be as a result of dung application even though, fallow effect may have induced a greater amount of organic material on the soil surface (Sanchez and Miller, 1986) as observed in CT and NPK treatments.

TN was observed to be generally low in all treatments and do not differ ($p > 0.05$) between DNK, DPK and CT at 5 to 15 cm (Table 6) with the lowest values occurring in the control plots, and high values consistent for DNPK

Table 7b. Correlation matrix between the soil properties across all treatments and soil depths.

Parameter	MWD_{wet}	$\theta_{10\ kPa}$	$\theta_{33\ kPa}$	$\theta_{100\ kPa}$	$\theta_{500\ kPa}$	$\theta_{1000\ kPa}$	$\theta_{1500\ kPa}$	sand	silt	clay
SOM										
OC										
pH_{H20}										
pH_{CaCl2}										
Total N										
Ks										
Bd										
Pd										
F										
MWD_{dry}										
MWD_{wet}	1.000									
$\theta_{10\ kPa}$	0.575**	1.000								
$\theta_{33\ kPa}$	-0.221	0.236	1.000							
$\theta_{100\ kPa}$	-0.481*	-0.106	0.744**	1.000						
$\theta_{500\ kPa}$	-0.381	-0.094	0.686**	0.928**	1.000					
$\theta_{1000\ kPa}$	-0.82*	-0.215	0.704**	0.935**	0.968**	1.000				
$\theta_{1500\ kPa}$	-0.518**	-0.095	0.715**	0.808**	0.813**	0.857**	1.000			
sand	0.465*	0.328	-0.045	-0.160	-0.200	-0.253	-0.397	1.000		
silt	-0.728**	-0.755**	-0.234	0.124	0.103	0.186	0.190	-0.426*	1.000	
clay	0.196	0.299	0.166	-0.009	0.046	0.043	0.212	-0.623**	-0.413*	1.000

Spearman's rank 2-tailed correlation; *, ** indicates significance at 5% and 1% probabilities, respectively.

plots at both soil depths. Earlier studies have reported similar values and conform to the characteristic nature of most savanna soils (Jones and Wild, 1975; Oyinlola and Chude, 2010). TN of the surface soil across all the treatments ranges from 0.4 to 1.7 g kg^{-1} and 0.5 to 1.7 g kg^{-1} for the lower soil depth. Only the DPK plots at 0 to 5 cm and DNPK at 5 to 15 cm have moderate TN values (1.7 g kg^{-1}). Despite this low value, significant relationship was observed between SOM and TN (0.56) at 1% probability (Table 7a and b). High C:N ratio observed (data not shown) for all the treatments indicates that, low level of TN was due to rapid assimilation of mineralized N by microorganism. Rapid mineralization and decomposition of organic matter is a significant characteristic of most savanna soils (Jones and Wild, 1975), whence, the low TN values.

Conclusion

Soils from the long-term DNPK fertilizer experiment were sampled and investigated for physical and chemical properties under 10 year fallow after 45 years of continuous cultivation. A clear relationship was observed between soil properties and improvement in soil quality of these plots as influenced by management. F and aggregate stability were generally moderate, as well as the hydraulic conditions of the soils. Soil pH was generally on the low side, tending towards acidity especially on NPK treatment plots and thus, requires proper management practices that increases soil pH. Soil bulk density is moderate for NPK and DNPK treatment plots but is high for the other treatments and increases in CT. Macroaggrgates are stable across all treatments with more water stability in NPK and DNPK treatment plots. Using a quality ranking of 1 for best and 5 for poor, soil quality of the plots decreases in the order DNPK > DNK > DNP > DPK = NPK > CT. Results also show the resilience of soils under the different fertilization as indicated in temporal changes of some soil properties as a result of natural fallow when compared with those of earlier studies. The positive effect of long-term integrated application of organic and inorganic fertilizers is further emphasized as a sustainable soil management practice; although, it showed some negative implications on certain soil physical and chemical properties.

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