Changes in properties of tropical ferruginous soils under long-term fertility management and continuous cultivation

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Abstract—Soil fertility is an important resource to enhance crop productivity and meet global food demand. The present work investigated the impact of long-term fertility management and continuous cultivation on selected soil properties of ferruginous soils. 8 plots of the experimental research plot situated behind the Agricultural Extension Research and Liaison Services (AERLS) building in Samaru, Zaria, Nigeria, were subjected to different fertility treatment for over 50 years. These treatment were: control (C); nitrogen (N); nitrogen & potassium (NK); nitrogen & phosphorus (NP); nitrogen & phosphorus & potassium (NPK); dung & potassium (DP); dung & nitrogen (DN); and dung & nitrogen & phosphorus (DNP). Using a completely randomized design (CRD) sampling technique, triplicate soil samples were collected from each fertility plot from the first 300 mm of the soil surface and analysed for selected properties. Results showed that the soils were majorly sandy loam. Sand component of the fertility plots was significantly (P<0.05) higher compared to the Control, while silt was observed to have reduced in the experimental plots. Soil organic carbon (SOC) was significantly (P<0.05) higher in the Control. Soils with dung as part of its fertilizer treatment showed slightly higher organic carbon content, with the DNP treatment having the highest value (0.76%), while lowest OC (0.36%) was recorded in the soils treated with inorganic fertilizer of NPK combinations. The OC content (0.35%-0.78%) recorded in soils of the various fertility plots was well below the 2% critical level required to guarantee soil structural stability. The pH values of treated soils were from 5.1–6.1 and significantly (P<0.05) higher in the Control. Bulk density was highest (1620 kg/m^3) in the Control, while the plot under DP showed the least value of 1520 kg/m^3. The different fertility treatments were observed to have reduced the plasticity of the soils from highly plastic recorded in Control to medium plastic observed in most of the other treatments. It is suggested that measures to enhance the soil OC be implemented as that will not only enhance the soil aggregate stability, but reduce the risk of soil erosion.

Keywords—Long-term, fertility management, soil quality, ferruginous, aggregate stability

I.   INTRODUCTION

The need to sustain agricultural systems has become a concern of global dimension due to the rising decline in soil productivity. Soil quality and fertility are important resource to enhance crop productivity in order to meet the food required for the current and future population, particularly in the developing countries whose economy mainly depends on agriculture [1]–[4]. Soil quality means the capacity of the soil to deliver the intended functions for both biomass and yield production [5], [6].

When an agricultural land is under intense cultivation and use, there is the need to maintain soil fertility, soil sustainability and soil erosion control. Various methods have been adopted to achieve this. These include better land use management, continuous cultivation, crop rotation and fertility management programmes. Fertility management programmes refer to the various techniques adopted to enhance and ensure that essential plant nutrients are not depleted to undesirable levels. Fertility management is important to maintain crop yield and

protect the land from the depletion of important soil nutrients.

In much of sub-Saharan Africa, the lack of organic soil amendments constitute one of the principal causes for declining soil fertility in intensifying farming systems. The challenge, therefore, remains to increase the availability of organic inputs and to develop recommendations for their combination with inorganic fertilizers [7].

Continuous and judicious application of manure has been shown to improve the physical and chemical properties of the soil, especially those that are coarse textured, or have low organic matter, thus reducing the potential for degradation of the quality of soil [7]. Interest in organic farming has increased following the determination that use of green manure and other organic matter can improve soil structure, improve nutrient exchange, and maintain soil health [8], [9].

The application of chemical fertilizers and organic manure to the soil has both positive and negative effects on plant growth and the soil properties. Though chemical fertilizers are relatively inexpensive, and have high nutrient contents which are rapidly absorbed by plants, applying them in excess can lead to a number of problems. Such problems may include loss of nutrient, contamination of surface water and groundwater, soil acidification, reductions in population of useful microbial communities, as well as increased sensitivity to harmful insects. On the other hand, use of organic manure is reported to have a number of deficiencies including slow decomposition and low nutrient in comparison to chemical fertilizers [10]. Despite the deficiencies in the use of organic fertilizer, it is reported to have multiple benefits due to the balanced supply of nutrients, increase in soil nutrient availability as a result of increased soil microbial activity, the decomposition of harmful elements, improvements in soil structure and root development, and increased soil water availability [10]. According to the authors, organic manure that generated from animal byproducts has been used to overcome environmental contamination and plant productivity reductions which are the results of prolonged application chemical fertilizers to the soil. The combined application of both chemical fertilizer and organic manure has shown diverse results in soil characteristic and plant yield.

Continuous cultivation and long-term fertility management programmes have direct bearing on soil structure and some other properties such as pH, infiltration rates and erodibility; and if not properly managed, it may cause adverse effect on the soil. Understanding variability of soil fertility, its distribution and the causes of the observed variability are important to improve sustainable land use strategies [11]. This work was therefore designed to investigate changes in properties of Samaru soils in Zaria, Nigeria under long-term fertility management and continuous cultivation.

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II.   MATERIALS AND METHODS

Location

The experimental research plot for this study was situated behind the Agricultural Extension Research and Liaison Services (**AERLS)** building in Samaru, Zaria, Nigeria. Samaru (11º 11' N, 07 º 38' E, on altitude of 686 m above mean sea level) is situated in the Northern guinea savanna zone. Annual rainfall is about 1100 mm (May–September). The soils of the study area are classified as are ferruginous (a soil that is of or contains iron or iron rust) tropical soils formed from drift material, and are largely representative of the loess plain soil unit.

Plot layout

The plots behind the Agricultural Extension Research and Liaison Services building in Samaru were originally established to study and compare the effectiveness of inorganic fertilizers and dung (farmyard manure) in maintaining crop yield under continuous cultivation. It is a research project monitored by the Institute of Agricultural Research (IAR), Samaru. The soils were from the same parent body prior to commencement of the fertilizer treatment. A section of the research plots was thus selected for the purpose of this experiment. Eight (8) different blocks of the research plot were subjected to different fertilizer treatment. These treatment were: control (C); nitrogen (N); nitrogen & potassium (NK); nitrogen & phosphorus (NP), nitrogen & phosphorus & potassium (NPK). Other treatments were dung & potassium (DP); dung & nitrogen (DN); and dung & nitrogen & phosphorus (DNP). Source of nitrogen fertilizer used was ammonium sulphate; while single superphosphate and muriate of potash were used as source for P and K respectively. Fertilizer treatments were applied in two levels (Level 1 & Level 2), and all plots were subjected to uniform continuous cultivation for a period of thirty-three (33) years. Treatment level 1 comprised supplying a specific amount of fertilizer for the first 22 years of the experiment, while treatment level 2 involved supplying another level of fertilizer for the remaining 13 years of the experiment. The application rate and total amount of fertilizer treatment received by respective plots during the period of the experiment is shown in Table 1.

Table 1. Amount of fertilizer for Level 1 and Level 2

Fertilizer type	Treatment Level (kg/ha)				Total amount of Fertilizer received in 33 yrs. (tonnes/ha) = Total for 22 yrs. + Total for 13 yrs.
	Level 1		Level 2		
	Application Per yr.	Total for in yrs.	Application Per yr.	Total in 13 yrs.	
Control	-		-		-
N	36	792	74.5	968.5	1.761
P	14	308	48	624	0.932
K	22.5	495	69	897	1.392
Dung (D)	5000	110000	5000	65000	175

Table 2. Total fertilizer treatment received by individual plots in 33 yrs.

Plot no	Treatment combination	Total amount of Fertilizer received in 33 yrs. (tonnes/ha)			
		Dung (D)	N	P	K
1	Control	-	-	-	-
2	N	-	1.761	-	-
3	NK	-	1.761	-	1.392
4	NP	-	1.761	0.932	-
5	NPK	-	1.761	0.932	1.392
6	DP	175	-	0.932	-
7	DN	175	1.761	-	-
8	DNP	175	1.761	0.932	

Soil sample collection

This research adopted a completely randomized design (CRD) sampling technique. Triplicate soil samples were collected from each soil fertility treatment plot. Samples were collected from the first 300 mm of the soil surface using a soil auger. Samples were placed in black properly labeled polythene bags, and transported to the laboratory for analysis. Samples for bulk density were collected using a core sampler. Each soil sample was analyzed for pH, organic carbon, bulk density, consistency limits, and particle size distribution (PSD).

III. LABORATORY ANALYSIS

Determination of selected soil chemical and physical properties

The bulk density of each soil sample was measured by determined by core sampler method [12], soil pH value was determined using a 1:2.5 soil to water paste and the glass electrode pH meter, organic carbon by Walkely and Black's oxidation method as described by Jackson et al. [13].

Particle size analysis using sedimentation method

The hydrometer test was carried out to determine the percentage of sand, silt and clay in the soil samples from the various fertility plots. Percentage of sand, silt and clay were determine by hydrometer method [14] and the textural class was determined using the USDA textural triangle.

$$\% \text{ sand} = \frac{Sample\ weight - 40\ seconds\ reding}{Sample\ weight} \quad (1)$$

$$\% \text{ clay} = \frac{\frac{8\ hour\ reading}{Sample\ weight} \times 100}{} \quad (2)$$

$$\% \ silt = 100\ \% - (100\% + clay) \quad (3)$$

Determination of consistency limits

The liquid limit was determined using the standard cup and grove method. This was carried out following the standard laboratory methods (ASTM standard test method D 4318). The plastic limit was determined by the method of rolling a 3mm thread of the soil until the thread crumbles. The plasticity index was calculated as the difference between the value of the liquid and plastic limit of the soil.

IV.   RESULTS AND DISCUSSION

Particle size distribution

Table 3 shows the textural compositions, organic carbon, and pH of the soils under different fertility treatments. The results show that Samaru soils are basically Sandy loam with the exception of the Plot no 4 and 5 under NP and NPK treatments, respectively, which fall in the Loamy sand category.

Table 3. Effect of fertility treatment on selected soil properties

Plot no.	Soil Treatment	Sand (%)	Silt (%)	Clay (%)	Textural class	OC (%)	pH
1	Control	59	37	4	Sandy loam	0.78	6.2
2	N	54	40	6	Sandy loam	0.49	6.1
3	NK	64	31	5	Sandy loam	0.35	5.4
4	NP	77	20	3	Loamy sand	0.45	5.5
5	NPK	75	21	4	Loamy sand	0.36	5.7
6	DP	66	30	4	Sandy loam	0.70	5.8
7	DN	72	24	4	Sandy loam	0.64	5.4
8	DNP	66	30	4	Sandy loam	0.76	5.1
LSD 5%		1.413	1.322	NS		0.030	0.166

The sand content of the soils was significantly influenced by the fertility treatment. The sand content (54−77%) dominated the textures, followed by silt (20−40%) and clay contents (3−6%) respectively. The sand fractions are mainly the fine sand fraction (0.06mm – 0.2mm). These are very erodible fractions indicating that these soils are actually susceptible to erosion.

However, sand component of the various fertility treatment plots was observed to be significantly ($P<0.05$) higher compared to the Control, while silt was observed to have reduced in the experimental plots. No noticeable change in level was observed for clay fraction of the soil before and after the fertility treatment. Highest variation in sand and silt fractions relative to the Control plot was observed in the NP treatment plot with sand and silt percentages of 77% and 20% respectively, against 59% and 37% sand and silt percentages in the Control plot. The relative increase in the proportion of fines in the treatment plots could be the result of frequent mixing of the fertilizers and soil by machines used in the farm. According to Toy *et al.* [15], soils having more sand and silt components at the surface cap facilitates runoff, and are susceptible to water erosion. Compared to the Control plot, the results show that long-term fertility treatment did not cause any major change in the textural properties of the soils, though there were variations in the individual soil components.

Soil organic carbon

Soil OC was significantly ($P<0.05$) higher in the Control plot compared with the various treatments. Soils with dung as part of its main treatment treatment showed slightly higher organic carbon content, with the DNP treatment having the highest value (0.76%), while lowest OC was recorded in the soils treated with inorganic fertilizer of NPK combinations. The result agrees with the findings of Islam *et al.* [16] who reported that the OC content of soils slightly decreased due to application of inorganic fertilizers while the results tended to increase in soils treated with organic fertilizer. Similarly, [17] reported that application of organic manure increased the OC content of the soil whereas a decreasing trend was detected with the application of chemical fertilizers. The soil OC recorded in the various plots (0.35%-0.78%) was, however, below the 2% critical level suggested by [18] below which soil structural stability will not be guaranteed.

Soil OC is beneficial for long-term sustainability of the agro-ecosystem. It is reported that soil OC affects the soil physical, chemical and biological behaviour [19] and plays

a significant role in maintaining soil quality andagricultural production [20]. It is also reported that SOC promotes aggregation, improve soil physical properties, and increase productivity and activity of soil organisms [21].

Soil pH

pH value was significantly (P<0.05) higher in the Control compared to the fertility treated soils. The pH values of treated soils were from 5.1 – 6.1 indicating acidic nature, and with the DNP treated soil having the lowest value. A report by [22] showed that the soil pH decreased by the application of organic fertilizer. This is in agreement with the findings of Janzen [23] that application of nitrogen fertilizer significantly depressed soil pH. The findings of this result is also in agreement with the report of Ge *at al.* [24] that long-term fertilization can decrease soil pH due to the continuous excessive application of N fertilizers. Likewise, [25] opined that addition of inorganic fertilizers increases soil acidity.
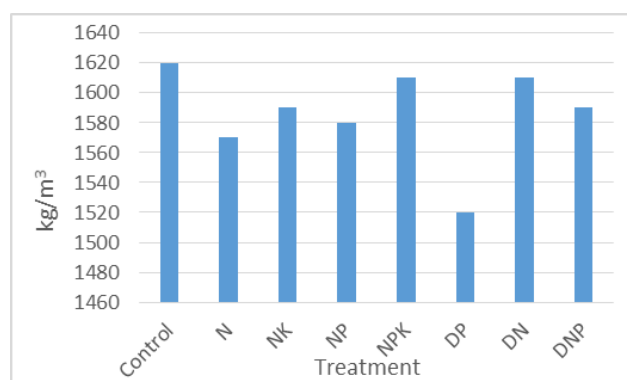
Bulk density

Fig. 1. Variation in bulk density for various soil treatments

Figure 1 showed that highest bulk density was highest in the Control, while the plots under fertility treatments showed slightly lower bulk densities. Among the fertility plots, highest bulk density was recorded in the NPK and DN plots respectively, while the lowest occurred in the N plot. Amoah*et al.* [7] reported that bulk densities of soils treated with cow dung and those with inorganic (NPK) fertilizer combined with cow dung were less than Control (with no fertilizer application). Reduction in bulk density

of soil due to application of cattle manure in a long-term integrated nutrient management was also reported by [26]. Similarly, [27] reported decrease in bulk density of soils treated with inorganic fertilizer and those with inorganic fertilizer and farm yard manure as against Control with no fertilizer application under long-term fertility management. The authors however reported no significant difference in the bulk densities of the soils treated with inorganic fertilizer and those in combination with farm yard manure. According to Amoah*et al.* (2012), the decrease in bulk density could be attributed to manure effect, which improves the soil by reducing its density. The decrease in bulk density could also be the result of greater organic matter content of the soil and better aggregation [28].

Soil consistency

Table 4 shows the result of soil consistency with fertility treatment. Analysis of the soils showed that the Control was highly plastic, and the application of fertility treatment has reduced the plasticity. Thus, there was decrease in plasticity index of the soils under the various fertility treatments to medium plastic from highly plastic of the Control, with the exception of the plot under N treatment. Soils containing N and P are observed to have relatively lower plastic limits, while dung (D) appeared to be an improver of the plastic limit (i.e. increases plastic limit). The plasticity index is the difference between the plastic limit and the liquid limit and it indicates the range of moisture content over which soil have various shear strength values in increasing order from plastic limit, being highest at the plastic limit. Soils with low plastic limits had lower clay content, while soils with higher limits had higher clay contents. According to Ezeokonkwo [30], plastic soil become less plastic by the introduction of NPK fertilizer. The author reported that the plastic quality of the soil decreases as the percentage of fertilizer increases. The reason for was the bounding of fertilizer elements by the soil particles, a situation that could cause the soil containing NPK fertilizer to crumble easily. The findings of this study is also in agreement with the report of Paul and Abraham [31] that addition of fertilizer to soils affects the Atterberg's limits properties of the soil by reducing the liquid limit and the plastic limit of soils.

Table 4. Effect of fertility treatment on soil consistency

Plot no.	Soil treatment	Plastic limit %	Liquid limit %	Plasticity index %	Degree of plasticity*
1	Control	9.64	28.80	20.77	High plastic
2	N	9.23	30.00	20.27	High plastic
3	NK	7.15	23.00	15.85	Medium plastic

4	NP	6.35	24.00	17.05	High plastic
5	NPK	7.64	23.00	15.36	Medium plastic
6	DP	10.43	24.00	13.57	Medium plastic
7	DN	8.48	22.60	14.12	Medium plastic
8	DNP	6.42	22.00	16.58	Medium plastic

*Burmister [29]

V. CONCLUSION

Results of this study showed that properties of ferruginous soils are influenced by fertility treatment under long-term continuous cultivation. Inorganic fertilizer, when singly applied, or in combination with dung, affects the soil particle size, resulting in reduction of sand component and increase in silt. Clay component of the soils was not affected. Soil OC and pH were significantly ($P<0.05$) lower in the fertility plots compared to the Control. Long-term fertility treatment also resulted in lower soil bulk density and plasticity from high to medium plasticity. Bulk density was highest (1620 kg/m3) in the Control, while the plot under DP showed the least value of 1520 kg/m^3. Measures to enhance the soil OC are thus recommended as that will not only enhance the soil aggregate stability, but reduce the risk of soil erosion.

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