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Open Access Journal of Agricultural Research
ISSN: 2474-8846

Changes in the Physical and Chemical Properties of an Ultisol in Response to Short Term Fertilizer Management

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Research Article
Volume 5 Issue 2
Received Date: June 22, 2020
Published Date: July 15, 2020
DOI: 10.23880/oajar-16000240

Abstract

The study investigated the short term effects of organomineral and inorganic fertilizers on the physicochemical properties of an Ultisol. The experimental site is a maize plantation of the Teaching and Research Farm, Obafemi Awolowo University, Ile – Ife, Nigeria that received mineral fertilizers applied as 400 kg NPK ha^{-1}, 1300 kg Urea ha^{-1} and 680 kg SSP ha^{-1} and organomineral fertilizer applied as 1700 kg OF ha^{-1} arranged in a Randomized Complete Block Design with five replicates. Surface soil was sampled from 0-15 cm and 15-30 cm soil depth for laboratory analyses and selected soil properties were determined while the hydraulic conductivity and the soil strength were determined in-situ. Data obtained were subjected to analysis of variance; Duncan's New Multiple Range Test was used to separate significant means at $p < 0.05$. The results indicated high significant difference for organomineral fertilizer treatment on the bulk density at the topsoil. Organomineral fertilizer also had significant effect on soil hydraulic conductivity at the topsoil (2.2×10^{-7}) compared with control plot. Combined application of organomineral fertilizer and urea significantly increased the nitrogen content of the topsoil. It was concluded that the Organomineral fertilizer improved the fertility status and hydraulic property of the soil.

Keywords: Fertilizer; Organomineral fertilizer; Ultisol; Soil bulk density; Soil organic matter

Introduction

Globally during early agriculture, it was easier for man to employ the traditional methods of farming such as bush fallowing, crop rotation, mixed farming, shifting cultivation and use of manure. Continuous cultivation of fields increased and lands were exploited due to increased urbanization. In developing countries like Nigeria, the population growth rate is high which implies that improved technologies such as rational use of fertilizers must be employed to meet the food requirement of the people [1]. Soils of the tropics are highly weathered and are therefore poor in minerals, their organic matter decomposition is very rapid because of high humidity and high temperature, these make continuous cultivation difficult on a long term basis [2]. Improving soil fertility through the application of fertilizers is an essential factor enabling the world to feed the millions of people that are added to its population. The impacts of these fertilizers on soil structure and function as well as on nutrient availability can vary widely with different impacts on crop productivity [3,4]. The use of inorganic fertilizers improves soil fertility and increases crop production. However, these fertilizers are expensive, out of the reach of most farmers and also have negative effects on the soil if used continuously. Organic fertilizers are alternative means of increasing soil fertility but need to be applied in large quantities for optimum plant growth. However, they release nutrients slowly over a long period of time such that crop demands might not be satisfied leading to low yield [5]. The use of organomineral fertilizers have been advocated as a means of harnessing the beneficial effects of both chemical and organic fertilizers in sustaining crop production [6-8]. The combination of both organic and inorganic fertilizers increases the beneficial effects of fertilizers in sustaining crop production and land conservation [9]. There is therefore the need to evaluate how the use of fertilizers impact on soil physical and chemical properties. The objectives of the study was to examine the impact of continuous use of different mineral and organ mineral fertilizer on soil physical and chemical properties on a relatively short term basis.

Materials and Methods

Soil Sampling, Preparation and Analysis

The field experiment was carried out at Obafemi Awolowo University Teaching and Research Farm, Ile-Ife (latitude 7° 25' N, and longitude 4° 39' E), Nigeria. Topsoil (0-15 cm) and subsoil (15-30 cm) sample of Iwo soil series (an ultisol) was obtained from a cultivated maize plantation that has received inorganic and organomineral fertilizers over a period of five (5) years, bulked, air- dried and sieved using 2 mm sieve to remove extraneous materials. The fractions that passed thorugh the sieve were used for analyses.

Soil Physical and Chemical Analyses

Soil particle size distribution and bulk density as well as soil porosity were determined using the hydrometer method [10] and core sampling method [11] respectively, while the aggregate stability was determined by wet sieving method [12]. The soil strength (cone index) and saturated hydraulic conductivity were determined on the field with a dynamic cone penetrometer and a Guelph permeameter [13] respectively.

Soil pH was determined in a soil solution ratio of 1:2 in 0.01 M $CaCl_2$ using a glass electrode pH meter [14]. Exchangeable cations were extracted with 1.0 M ammonium acetate at pH 7.0 [15]. Potassium and Na content of the extract were determined with flame photometer, while the Ca and Mg content were determined with atomic absorption spectrophotometer. The organic carbon content of the soils was determined by modified Walkley – Black procedure. The total Nitrogen (N) was determined using the chromic acid digestion method [16] and micro-Kjeldahl digestion and distillation process [17]. Available Phosphorus was determined using Bray-1 method [18] and read at 660 nm wavelength after the development of the molybdenum blue colour.

Inorganic and Organomineral Fertilizer Application

The organomineral fertilizer applied was sourced from Sunshine Fertilizers Company, Akure, Ondo State, Nigeria with NPK content of 3.5%, 1.0% and 1.2% respectively. The inorganic fertilizer was applied as Urea and Single Super Phosphate (SSP) to supply Nitrogen and Phosphorus respectively. The treatment used were as follows:

1. Soil only (control)
2. Soil + 1700 kg OF/ha
3. Soil + 400 kg NPK/ha
4. Soil + 1300 kg urea/ha
5. Soil + 680 kg SSP/ha
6. Soil + 850 kg OF/ha + 650 kg urea/ha
7. Soil + 850 kg OF/ha + 340 kg SSP/ha
8. Soil + 850 kg OF/ha + 200 kg NPK/ha

Data Analyses

The data collected were analyzed using the ANOVA technique and means were separated using the Duncan's New Multiple Range Test (DNMRT) at 5% level of probability with the SAS software package.

Results and Discussion

Effects of the Treatments on the Soil Textural Composition

(Tables 1 and 2) shows the treatment effects on the soil texture used for the experiment. The textural composition within 0-15 cm and 15-30 cm soil depths ranged from sandy loam to loamy sand. The high sand content was expected since the soil was formed from granite gneiss which has average quartz content of about 25% [2]. This suggests that the soil texture are homogenous and did not constitute variation on the experimental site. At depth 0-15 cm, the single superphosphates (SSP), had high significant ($p< 0.05$) effects on sand fraction (75.69%) although, there were no significant difference among other treatments. The particle size indicates that the sand fractions of topsoil will enhance good root growth and aeration [19]. The topsoil sand fraction of control was significantly lower than the sand fraction for other treatments but all the treatments had no effect on the silt fractions. Organomineral fertilizer was significantly high on the clay fraction at both depths (17.76%) and (25.24%) respectively.

The topsoil and subsoil can be described as light textured soils because of their predominant sand related texture. Soil texture is very important and one can do little or nothing to modify it as the texture of the soil determines nutrients and water holding capacity [20].

Treatments	Sand -----(%)--	Silt	Clay	Si-Cl Ratio	Textural Class
Control	64.34b	17.89a	17.76a	0.93ab	Sandy loam
OF	72.72ab	9.52a	17.76a	0.45c	Sandy loam
NPK	73.72ab	10.92a	15.36ab	0.67bc	Sandy loam
N (urea)	75.34ab	13.76a	10.89d	1.27ab	Sandy loam
P (SSP)	75.69a	12.44a	11.87bcd	1.07ab	Sandy loam
OF + N (urea)	73.20ab	16.68a	11.92bcd	1.41a	Sandy loam
OF + P (SSP)	71.14ab	15.16a	12.32bcd	1.20ab	Sandy loam
OF + NPK	66.37ab	19.20a	15.42ab	1.28ab	Sandy loam

Table 1: Effects of inorganic and organomineral fertilizer on soil particle size analysis in the topsoil
Means followed by different letters in a column are significantly different ($p < 0.05$) according to Duncan's New Multiple Range Test.
Where OF and SI-CL= Organomineral fertilizer and silt- clay ratio respectively.

Treatments	Sand -------- (%)---	Silt	Clay	Si-Cl Ratio	Textural Class
Control	72.00ab	10.88a	20.24abc	0.41ab	Sandy loam
OF	68.00b	6.76b	25.24a	0.27b	Sand clay loam
NPK	75.52ab	8.4ab	16.0c	0.53ab	Sandy loam
N (urea)	77.92a	7.2b	14.88c	0.52ab	Sandy loam
P (SSP)	79.12a	7.92ab	12.96c	0.65a	Sandy loam
OF + N (urea)	73.52ab	7.52ab	18.96abc	0.40ab	Sandy loam
OF + P (SSP)	67.92b	8.32ab	23.7ab	0.40ab	Sandy loam
OF + NPK	77.12a	8.88ab	14.00c	0.65a	Sandy loam

Table 2: Effects of inorganic and organomineral fertilizers on soil particle size analysis in the subsoil.
Means followed by different letters in a column are significantly different ($p < 0.05$) according to Duncan's New Multiple Range Test.
Where OF and SI-CL= Organomineral fertilizer and silt- clay ratio respectively.

Effects of the Treatments on Soil Bulk Density, Soil Porosity and Soil Aggregate Stability

Table 3 shows that for all the treatments including the control, bulk density and porosity of the topsoil did not vary significantly ($p<0.05$). However the bulk density values of the subsoil were higher than that of the topsoil. This might be due to the repeated pulverization of topsoil and the compaction of the subsoil as a result of the heavy machineries been used on the field [21]. Soil bulk density increases significantly with an increase in compaction depending on the number of passes of tractor wheels. Lower bulk density values of topsoil could also be as a result of higher organic matter content of topsoil when compared with that of subsoil. The porosity of the subsoil was lower than that of the topsoil, organomineral fertilizer significantly affected the porosity of the subsoil but there was no significant difference within other treatments. The organomineral fertilizer also reduced the bulk density and improved the porosity of the soil compared to the control at both depths, this was expected since organic materials are known to have low densities and therefore can improve the porosity of the soil and make it less dense [22]. Combined application of organomineral fertilizer with NPK 15-15-15 or SSP significantly affected the aggregate stability values of the topsoil. Organomineral fertilizers act as binding agent in the soil, particularly at the topsoil with little effects. The presence of more root and root hairs which physically enmeshed the fine soil particles into aggregates was the reason for higher aggregate stability at 0 – 15 cm depth [23].

Treatments	B.D Porosity Agg. Stab (G/Cm^3) (%) (%)			B.D Porosity Agg.Stab		
Control	1.45a	45a	78.78b	1.52b	42a	83.75a
OF	1.14a	57a	82.28ab	1.50b	43a	76.74ab
NPK	1.23a	53a	82.92ab	1.62ab	39ab	73.92ab
N (urea)	1.26a	54a	82.61ab	1.58ab	40ab	75.00ab
P (SSP)	1.55a	41a	89.28ab	1.60ab	39ab	74.40ab
OF+N(urea)	1.32a	50a	84.69ab	1.70ab	35ab	81.44a
OF+P(SSP)	1.69a	40a	93.63a	1.62ab	38ab	66.86b
OF +NPK	1.60a	39a	94.28a	1.74ab	34ab	77.46ab

Table 3: Effects of inorganic and organomineral fertilizer on soil bulk density, soil porosity and soil aggregate stability.
Means followed by different letters in a column are significantly different ($p < 0.05$) according to Duncan's New Multiple Range Test.
Where OF = Organomineral fertilizer, B.D = Bulk density, Agg. Stab = Aggregate stability

Effects of Treatments on Soil Strength and Saturated Hydraulic Conductivity

The soil resistance to cone penetrometer (cone index) was used as a measure of soil strength in this study. (Table 4) shows soil cone index and hydraulic conductivity values at depths as influenced by fertilizer application. There was no significant difference ($p < 0.05$) at 0 -15 cm and 15 – 30 cm soil depths for most of the treatments. Although control plots had higher penetrometer resistance values at both depths, this could be due to non-application of amendments, which might be responsible for the increase in soil resistance [24]. Independent application of organomineral and combination with NPK were significantly high on the hydraulic conductivity and cone index at 0 – 15 cm soil depth respectively. At 15 – 30 cm soil depth, only OF + SSP had high effect on the cone index. Similar to bulk density, the cone index which expresses the resistance of soil to root penetration and seedling emergence also increases with the soil depth. Organic matter content is an important factor for soil stability, especially the low activity clay soils of the tropics. Loss of structure in the subsoil with low SOC resulted into soil compaction and may be responsible for higher bulk density and the consequently higher penetration resistance.

Treatments	S.H.C Cone Index		S.H.C Cone Index	
	(cm/s) (kg/m^2)		(cm/s) (kg/m^2)	
Control	4.1x 10^{-6}ab	7.28ab	4.2x10^{-6}a	24.56ab
OF	2.2x10^{-7}a	6.51ab	6.6x10^{-6}a	16.53b
NPK	3.2x10^{-7}b	7.07ab	6.6x10^{-6}a	23.43ab
N (urea)	6.9x10^{-7}ab	4.20b	5.2x10^{-6}a	21.23ab
P (SSP)	9.5x10^{-7}ab	7.48ab	1.6x10^{-6}a	24.77ab
OF + N (urea)	9.7x10^{-7}ab	6.71ab	4.7x10^{-6}a	26.69ab
OF + P (SSP)	3.4x10^{-7}ab	8.04ab	4.2x10^{-6}a	28.66a
OF + NPK	2.0x10^{-7}ab	10.20a	1.5x10^{-6}a	20.26ab

Table 4: Effects of inorganic and organomineral fertilizer on saturated hydraulic conductivity and cone index.
Means followed by different letters in a column are significantly different ($p < 0.05$) according to Duncan's New Multiple Range Test.
Where OF = Organomineral fertilizer and S.H.C = Saturated Hydraulic Conductivity

Effects of the Treatments on Soil Ph, SOC, Total N and Available P Contents

The pH measured in 0.01 M $CaCl_2$ solution had values at both depths for all the treatments in acidic range (Table 5). The acidity recorded on these soils might be as a result of the acidic nature of the parent rock coupled with the continuous use of organomineral and inorganic fertilizers in the absence of liming programme [2]. Although the soil sample was acidic, it has less consequence towards the healthy growth of arable crops because maize is well adapted to soil pH that ranges between 5.5 and 6.5 [25,26]. The soil organic carbon content (SOC) across the two depths for all the treatments showed high statistical significant effect but the subsoil had lower values than the topsoil. These results implied that organo-mineral associations with clay minerals and/or iron oxides on topsoil might sequester soil organic carbon and protect it from decomposition [27-29]. It might also be as a result of enhanced mineralization of SOC at the topsoil [30]. The changes in SOC were associated with the organic and inorganic fertilizer management practices at each plot which supply nitrogen and carbon to soils when compared with control. The nitrogen content of the subsoil for all the treatments fell in the medium class and that of the topsoil was high. This was in agreement with the report of Uponi and Adeoye [31]. Combine application of organomineral fertilizer and urea had a significant ($p < 0.05$) effect on the N content of the topsoil when compared with control and there was no significant difference ($p < 0.05$) amongst other treatments within the subsoil. This was consistent with the work of Pagel [32]. This could also be due to rapid mineralization of the applied inorganic fertilizer. The result was also in line with the report of Awodun *et al.* and Agbede *et al.* who observed that application of inorganic fertilizer did not increase the nitrogen content of soil as much as organic materials applied on the soil [33,34].

The values for available P for the topsoil and subsoil ranged from low to moderate. Application of NPK had significant effect ($p < 0.05$) on the available P content of the topsoil and there was no effect among other treatments including the subsoil. Application of nitrogen as urea resulted in a decreased content of available P when compared with control on the topsoil. This might be due to reduced solubility of P-compounds due to increased soil acidity [35]. As a result of soil acidity, P is complexed with hydrous oxides of iron (Fe) and Aluminium. Studies have shown that P is most available at neutral pH levels. Ayeni and Adeleye also found that organomineral fertilizers increased the availability and uptake of P [36].

Treatments	Ph O.C T.N Avail. P				Ph O.C T.N Avail. P			
	(%) (%) (mg/kg)				(%) (%) (mg/kg)			
Control	5.06d	0.43a	0.34ab	13.27ab	5.26d	0.15a	0.09a	10.93a
OF	5.06d	0.61a	0.30ab	9.51b	5.3d	0.25a	0.15a	9.24a
NPK	5.00d	0.60a	0.26ab	22.19a	5.04d	0.21a	0.13a	9.73a
N (urea)	5.36bc	0.58a	0.29ab	6.09b	5.70bc	0.15a	0.09a	12.80a
P (SSP)	5.5ab	0.50a	0.28ab	9.70b	5.9a	0.20a	0.12a	11.46a
OF + N	5.54ab	0.60a	0.51a	12.53ab	5.74ab	0.23a	0.14a	13.91a
OF+P(SSP)	5.58a	0.55a	0.33ab	14.92ab	5.34cd	0.26a	0.16a	13.46a
OF + NPK	5.30c	0.53a	0.27ab	10.68b	5.20d	0.18a	0.19a	16.00a

Table 5: Effects of inorganic and organomineral fertilizers on soil chemical properties.
Means followed by different letters in a column are significantly different ($p < 0.05$) according to Duncan's New Multiple Range Test.
Where OF, N, P = Organomineral fertilizer, Nitrogen (urea), and P (SSP) respectively

Effects of Treatments on Exchangeable Cation (K, Ca, Mg And Na) Contents

The effects of the amendments on soil exchangeable cations are shown in Table 6. The exchangeable cations were lowest in the control than in the topsoil, which might be due to uptake of these nutrients by plants. This result agrees with the earlier reports of increase in soil exchangeable cations with the application of organic wastes applied individually or combined with inorganic fertilizers [37-41]. The content of exchangeable Ca for the topsoil was lower than that of subsoil and all the treatments had no significant effects on the exchangeable Ca of the topsoil when compared with control. The NPK treatment significantly affected the exchangeable Ca of the subsoil while other treatments had no effect ($p < 0.05$). The reason for decrease in exchangeable Ca content of the topsoil when compared with control might be due to plant uptake and leaching due to soil acidification and processes of nitrification that particularly apply to soils with a pH < 7. For Mg content of the topsoil, application of organomineral fertilizer alone had a significant effect on the exchangeable Mg compared with application of NPK, urea and SSP. This result confirmed the previous observation of Mengel and Kirkby [42], with decreasing trend in the content of Mg for all the treatment on the surface soil when compared to the control. Combination of organomineral fertilizer and SSP and application of SSP alone to the soil was significantly high on the exchangeable Mg of the subsoil compared within dependent application of organomineral fertilizer and urea, and combination of organomineral fertilizer and NPK.

There was no significant effect ($p < 0.05$) for all the treatments on the Na content of the topsoil. Organomineral fertilizer application to the soil was significantly high on the Potassium content of subsoil. Combined application of OF with urea had high significant effects on the Na content of the subsoil. These results might be attributed to quicker release and plant uptake of cations, N, P and K from these fertilizers. This is in conformity with the report of Awodun, et al. [33]. Katalin and Katalin also reported that the application of chemical fertilizers proved to be more beneficial to the plants than soil since it contained balanced nutrient [43].

Treatments Ca Mg Na K					**Ca Mg Na K**			
(cmol kg^{-1})					(cmol kg^{-1})			
Control	3.09a	0.64a	0.01ab	0.23a	5.35bc	0.56b	0.07bc	0.14ab
OF	1.21b	0.64a	0.01ab	0.22a	4.60c	0.69ab	0.08b	0.16a
NPK	0.71b	0.31b	0.04ab	0.21a	8.71a	0.55b	0.06bcd	0.15ab
N (urea)	0.43b	0.31b	0.01ab	0.22a	6.91b	0.63ab	0.05bcd	0.09c
P (SSP)	0.09b	0.31b	0.04ab	0.09c	5.25bc	0.68a	0.04d	0.10bc
OF + N	0.41b	0.30bc	0.01ab	0.17ab	5.77bc	0.56b	0.12a	0.12ab
OF + P	0.41b	0.31b	0.02ab	0.21a	5.86bc	0.69a	0.07b	0.10bc
OF +NPK	0.78b	0.30bc	0.01ab	0.21a	5.06bc	0.60ab	0.06bcd	0.06bc

Table 6: Effects of inorganic and organomineral fertilizers on contents of exchangeable cations.
Means followed by different letters in a column are significantly different ($p < 0.05$) according to Duncan's New Multiple Range Test.
Where OF, N, P = Organomineral fertilizer, Nitrogen (urea), and P (SSP) respectively

Conclusion

The soil properties considered showed that application of both fertilizers (organomineral and inorganic fertilizers) had no or little effect on their activities in a short term context. However, the results of the study showed encouraging improvements in the properties of the ultisol. It demonstrated the relative abilities of the organic amendment to improve the bulk density, total porosity and hydraulic conductivity within the soil. The soil suffered nutrient deficiencies, despite the fact that it has records of receiving nutrients annually as an essential component of the farming system.

Acknowledgements

The authors thank the technical staff at the Soil Science Unit of the Teaching and Research Farm and the Soil Testing Unit of the Department of Soil Science and Land Resources Management, Faculty of the Agriculture, Obafemi Awolowo University, Ile-Ife, Nigeria for their supports.

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