Influence of Granular and Fine-Grained Urea Fertilizers with Animal Manure on Physical Properties of a Sandy Loam Soil

***Udom, B. E., Hamadina E. I., Kamalu, O. J. & Solomon, T.B.**
Department of Crop and Soil Science, University of Port Harcourt, Port Harcourt, Nigeria.
*Corresponding Author: Bassey E. Udom, Department of Crop and Soil Science, University of Port Harcourt, Port Harcourt, Nigeria.
Email: ebassidy@yahoo.com

Abstract

Improvement of soil physical properties through proper fertilization is very important in enhancing soil quality and crop productivity. A 2-season experiment were carried out to evaluate changes in some physical properties of a sandy loam soil as influenced by the application of granular and fine-grained urea fertilizers alone or integrated with P and K and 25% poultry manure. Results showed that granular and fine-grained urea in combination with P. K and 25% poultry manure gave a marginal 12% improvement in soil bulk density over the control after the second season. Total porosity, water retention and saturated hydraulic conductivity varied significantly ($p < 0.05$) amongst the treatments and much higher when granular and fine-grained urea was supplemented with P, K and 12% poultry manure. The fine-grained urea exhibited deflocculating tendencies on soil aggregation which reduced the water release pattern and amount of water retained between field capacity (-10 kPa) and permanent wilting point (-1500 kpa). Granular urea tended to improve flocculation of soil aggregates more than the fine-grained. The application of granular fertilizer with P and K and 25% poultry manure improved the soil structure through increased in soil porosity, water holding capacity at field capacity and saturated hydraulic conductivity.

Keywords: *Soil water retention; bulk density; granular urea; fine-textured urea; field capacity*

Introduction

Inappropriate and improper fertilizations can increase the risk of soil degradation, aggravating the susceptibility of cropland soils to decline of soil structure, loss in soil biodiversity and even disruption in ecosystem functions (Lal, 2015). On the other hand, a judicious fertilization practice can restore degraded soils, through enhancing soil bulk density, improving soil structure, and increasing agronomy performance (Lal, 2015; Mikha *et al*., 2015; Luna *et al*., 2015). Traditionally, application of animal manure is commonly recommended to apply together with inorganic fertilizers.

Integrated use of animal manure with NPK was found to increase saturated hydraulic conductivity (Ksat), reduce bulk density and increase yield of cocoyam in a sandy loam soil (Udom and Lale, 2017). Studies (Yao *et al*., 2007) have showed that application of animal manure or N-fertilizers alone may stress crop growth and degrade soil structure. However, these detrimental effects are often generally ignored in a number of soil studies.

Although the effects of N-fertilization on physical properties of soils have been documented in previous studies (Haynes and Naidu, 1998; Bronick and Lal, 2005), there is still no consensus on the effects grain size of the N-fertilizers on soil bulk density, permeability and soil moisture characteristics. Some studies have reported that long-term application of inorganic fertilizer improved aggregate stability of soils in comparison to non-fertilization (Das *et al*., 2014; Tripathi *et al*., 2014). Other studies (Xie *et al*., 2015; Xin *et al*., 2016; Zhang *et al*., 2016; Zhou *et al*., 2017) showed that inorganic fertilization did not change or even decreased the aggregate stability, although it increased the SOC level. It was further observed that reduction soil aggregation was associated with the contents of binding and dispersing agents usually associated with animal manure and N-fertilizers.

Hydraulic conductivity is universally recognized as an indicator of soil structure (Amézketa, 1999), and often regarded as a fundamental property of soil fertility and quality (Peng *et al.*, 2015), which provides pathways for the transport of water, nutrients and gases, and habitats for microorganisms. Therefore, it is important that, the texture of N-fertilizer (urea) can influence clay flocculation and/or dispersion and play a key role in water affinity to crop plants.

Coarse- and fine-grained urea is often used preferably in farmers' fields without adequate understanding of their effects on soil hydraulic properties. Hence the objective of this study was to evaluate the effects of granular (coarse-grain) and fine-textured urea supplemented with animal manure on bulk density, hydraulic conductivity and water retention characteristics, so as to provide additional information to our current knowledge on sustainable use of N-fertilizers to improve soil water relations.

Materials and Methods

The Study Area and Treatments

The study was carried out at the Teaching and Research Farm in University of Port-Harcourt, (Lat. 4°45′N and Long. 6°15′E) in the rain forest zone of southern Nigeria. Total annual rainfall in the area is about 2400 mm, with two peaks in the months of June and September. Mean minimum and maximum monthly temperatures are 22 °C and 32 °C, and minimum and maximum relative humidity of 35% and 78% respectively (NIMET, 2014). The area was cropped to maize and tomato in 2018 and 2019 planting seasons. The field was divided two land units, consisting of seven (7) treatments, arranged in a randomized complete block design (RCBD) in 3 replications, giving a total of 21 plots each measuring 5 m x 5 m that had the following treatments:
KTR: a control, untreated plot,
100GU: plots amended with 100% granular urea,
100PU: plots amended with 100% fine-textured urea,
PK+GU_{75}: plots amended with 100% P_2O_5 and K_2O+75% granular urea,
PK+PU_{75}: plots amended with 100% P_2O_5 and K_2O+75% fine-textured urea,

$PK+GU_{75}+FM_{25}$: plots with 100% P_2O_5 and K_2O+75% granular urea+25% poultry manure and $PK+PU_{75}+FM_{25}$: plots with 100% P_2O_5 and K_2O+75% fine-textured urea+25% poultry manure. The FM for this experiment was sourced from the Poultry Unit of the Faculty of Agriculture while P and K were of Single superphosphate with 30% P_2O_5 and Muriate of potash with 60% K_2O. The characteristics of the soil and the poultry manure are shown in Table 1.

Soil Sampling and Analyses

Soil samples were collected at 0-15 cm topsoil in duplicates in 2018 and 2019. A total of 84 core and composite soil samples were collected. Laboratory analysis was carried out for soil bulk density, total porosity, saturated hydraulic conductivity and water retention characteristics at specific pressure potentials.

Bulk Density and Total Porosity

Bulk density was determined with core samples by the method of Blake and Hartge (1986) using the formulae:

$$\text{Bulk density} = \frac{mass\ of\ oven{-}dried\ soil\ (g)}{volume\ of\ bulk\ soil\ (cm3)} \qquad (1)$$

Total porosity was calculated with core samples using the core method as described by Flint and Flint (2002) as:

$$\%\,Total\ porosity = \frac{volume\ of\ water\ at\ saturation}{volume\ of\ bulk\ soil} \times 100 \qquad (2)$$

Soil Water Retention Characteristics (pF Curves)

Soil water-retention characteristics (SWRC) were measured on undisturbed core samples 5 cm in diameter and 6 cm in height, using the pressure chamber apparatus and Tension Tables with ceramic plates. The following suctions were obtained: 0, -0.3, -10 and -1500 kPa. The water content at -10 and -1500 kPa represent the field capacity (FC) and permanent wilting point (PWP) respectively, as suggested by Cassel and Nielsen (1986) for most tropical soils. After saturation, samples were subjected to pressures 0 to -10 kPa using the hanging water column method as described by Wang and Benson (2004), and -1500 kPa using the pressure plate apparatus. Excess water drained through the ceramic plates until balance was established between pressure force and water retention force in the samples after 2 days. The gravimetric water content in the soil samples were measured on oven-dried at 105 ^oC and the values converted to volumetric moisture content ($cm^3\ cm^{-3}$) by multiplying it by the dry bulk density of each core sample.

Saturated Hydraulic Conductivity (Ksat)

Saturated hydraulic conductivity (Ksat) was determined by the constant head core technique (Reynolds *et al*., 2002). Volume of water draining out was measured over time period until flow was constant, at which time; the flow rate was determined by the equation:

$$\text{Ksat} = \frac{Q}{AT} \text{x} \frac{L}{\Delta H} \qquad (3)$$

where Q is the volume of water collected (cm^3), A is area of core (cm^2), T is time elapse (s), L is length of core (cm) and ΔH is the hydraulic head difference (cm). Permeability class was according to the Soil Survey Staff (1993).

Results and Discussion

Soil Texture, Bulk Density and Total Porosity

The soil is sandy loam with sand, silt and clay contents of 730, 194 and 76 g kg^{-1} respectively (Table 1). The soil texture was not altered by the treatment due dominance of the parent material earlier reported by Akamigbo and Asadu (1983). Bulk density decreased slightly from 1.41 to 1.35 g cm^{-3} during the first year, although not significantly different ($p > 0.05$) and generally slightly porous (Table 2). Mean total porosity values were low for granular and fine-textured urea fertilizers alone (32.1 and 33.4%) respectively, while supplementing them with 25% poultry manure increased total porosity by about 35% during the first planting season and increased marginally during the second year. Mean values of total porosity ranged between 28.6% for controlled plot and 51.2% for fine-textured urea supplemented with 25% poultry manure. \this showed that additions of P, K and 25% poultry manure enhanced the effectiveness of granular and fine-textured urea fertilizers to store about 29.6% of soil water in the topsoil for crop use (Table 3).

Topsoil bulk densities were within acceptable threshold values, indicating that the soil can support crop production on sustainable bases if well managed, but could slightly inhibit germination of fragile seeds if the soil is worked on during very high moisture condition.. The significantly higher bulk density in granular (100GU) and fine-textured (100PU) urea may have been due to their disaggregating effect on soil structure. This is consistent with Zhang *et al.* (2016) and Zhou *et* al. (2016), who reported reduction of soil aggregation associated with the contents of binding and dispersing agents usually found with animal manure and N-fertilizers. Although the bulk density values were within acceptable threshold values that can support crop production on sustainable bases in well managed soils, there was tendency that the emergence germination of fragile seeds could be inhibited if tillage is done during very high moisture condition (Gangwar *et al*., 2006; Udom *et al*., 2016).

Table 1
Physical properties of the soil and poultry manure used at the beginning of the experiment during the first planting season

Properties	**Unit**	**Soil**	**Poultry manure**
Sand	g kg^{-1}	730	-
Silt	g kg^{-1}	194	-
Clay	g kg^{-1}	76	-
Textural class	-	SL	-
Bulk density	g cm^{-3}	1.41	-
Total porosity	%	33.2	-
Saturation moisture content at 0 kPa	g g^{-1}	0.23	0.86
Saturated hydraulic conductivity	cm hr^{-1}	18.2	-
Permeability class	-	Moderately slow	-
Total nitrogen	%	0.084	0.408
Organic matter	%	2.3	3.22

C:N ratio	-		4.58
pH(H_2O)	-	5.3	7.5

Table 2
Soil physical properties at the end of first planting season 2018/2019

Treatments	Bulk density ($g\ cm^{-3}$)	Total porosity (%)	WHC (%)	Ksat ($cm\ h^{-1}$)	Permeability class
100GU	1.43a	32.1b	28.5a	19.4b	Moderately slow
100PU	1.47a	33.4b	27.9a	20.6ab	Moderately rapid
PK+GU_{75}	1.41a	40.7a	25.8b	22.1ab	Moderately rapid
PK+PU_{75}	1.40a	41.5a	24.8b	23.8a	Moderately rapid
PK+GU_{75}+FM_{25}	1.38a	43.1a	28.8a	24.6a	Rapid
PK+PU_{75}+FM_{25}	1.35a	44.0a	29.6a	24.1a	Rapid
KTR	1.41a	33.4b	23.1c	18.9b	Moderately slow

Means followed by the same alphabet were not significantly different at $p < 0.05$. WHC- water holding capacity, Ksat- Saturated hydraulic conductivity, GU- granular urea, PU- fine-textured urea, PK- 100% P_2O_5 and K_2O, FM- poultry manure, GU_{75}- 75% granular urea, PU_{75}- 75% fine-textured urea, FM_{25}- 25% poultry manure, KTR- control plot

Saturated Hydraulic Conductivity (Permeability)

During the first year Permeability was moderately slow to moderately rapid in plot that received granular and fine-textured urea fertilizers alone, and rapid in plots where the urea fertilizers were supplemented with full P, K and 25% poultry manure (Table 2). These values showed increases during the second year (Table 3). Saturated hydraulic conductivity (Ksat) ranged from slow (16.7 $cm\ h^{-1}$) to very rapid (33.8 $cm\ h^{-1}$), with the highest values found in granular and fine-textured urea supplemented with full P, K and 25% poultry manure. The significant improvement in Ksat values after the second planting season found in granular and fine-textured urea plots urea supplemented with full P, K and 25% poultry manure was not surprising, of the positive effects of P and Poultry manure in structural improvement of soils (Udom and Nuga, 2016; Udom and Ogunwole, 2015). The significant improvement in water holding capacity maintained for the treated plots could possibly been due to the flocculation of the soil aggregates earlier reported by Zhang *et al*. (2016).

Table 3
Soil physical properties at the end of second planting season 2019

Treatments	Bulk density ($g\ cm^{-3}$)	Total porosity (%)	WHC (%)	Ksat ($cm\ h^{-1}$)	Permeability class
100GU	1.51a	30.7c	28.5a	20.2c	Moderately rapid
100PU	1.48a	30.4c	27.9a	20.9c	Moderately rapid
PK+GU_{75}	1.41a	38.6b	25.8b	25.4b	Rapid
PK+PU_{75}	1.41a	40.9b	24.8b	25.2b	Rapid

$PK+GU_{75}+FM_{25}$	1.35b	49.3a	28.8a	32.8a	Very rapid
$PK+PU_{75}+FM_{25}$	1.36b	51.2a	29.6a	33.8a	Very rapid
KTR	1.50a	28.6d	23.1c	16.7d	Slow

Means followed by the same alphabet were not significantly different at $p < 0.05$. WHC- water holding capacity, Ksat- Saturated hydraulic conductivity, GU- granular urea,
PU- fine-textured urea, PK- 100% P_2O_5 and K_2O, FM- poultry manure, GU_{75}- 75% granular urea, PU_{75}- 75% fine-textured urea, FM_{25}- 25% poultry manure, KTR- control plot

Soil Water Retention Curves (pF-Curves)

The soil water retention curves (SWRCs) of the soils during the first year are shown in Fig 1. The shape of the water retention curves also showed that water release pattern was gradual within the 0-15 cm topsoil. A mean of about 12.5% of the soil water was released between saturation and field capacity water potentials for granular urea and 10.3% for the fine-textured urea. During the second year, the soil water retention curves (SWRCs) of the soils in Fig. 2 showed greater water release pattern between saturation and field capacity. Mean values increased from 12.5% during the first year to 19.6% at the end of the second year. The pattern of change of water content per unit change in matric potential (specific water capacity) showed a relationship with the Ksat. However, supplementing granular urea with P, K and 25% poultry manure increased water affinity to plant by 17.5% in the first year and increased to about 25.2% in the second year compared with the controlled plots without treatments. From the graph, the Plateau of water retention curve can be projected from Figures 1and 2 of which between saturation and field capacity water potentials, about 25% of the water retention curves lie within at least 15 cm topsoil. It is also believed that the degree of flocculation of soil aggregates was still the dominant factor that regulated the pattern of change of soil water retention per unit change in matric potential (specific water capacity) specifically by the coarse nature of the granulated urea. However, supplementing granular urea with P, K and 25% poultry manure increased water affinity to plant much higher. The fine-textured urea tended to exhibit deflocculating tendencies which reduced the water release pattern as well as the soil water retained between field capacity (-10 kPa) and permanent wilting point (-1500 kpa). This further support the earlier report that N-fertilizers can reduce water affinity to plant due to high osmotic potential associated with the fertilizers (Haynes and Naidu, 1998; Bronick and Lal, 2005).

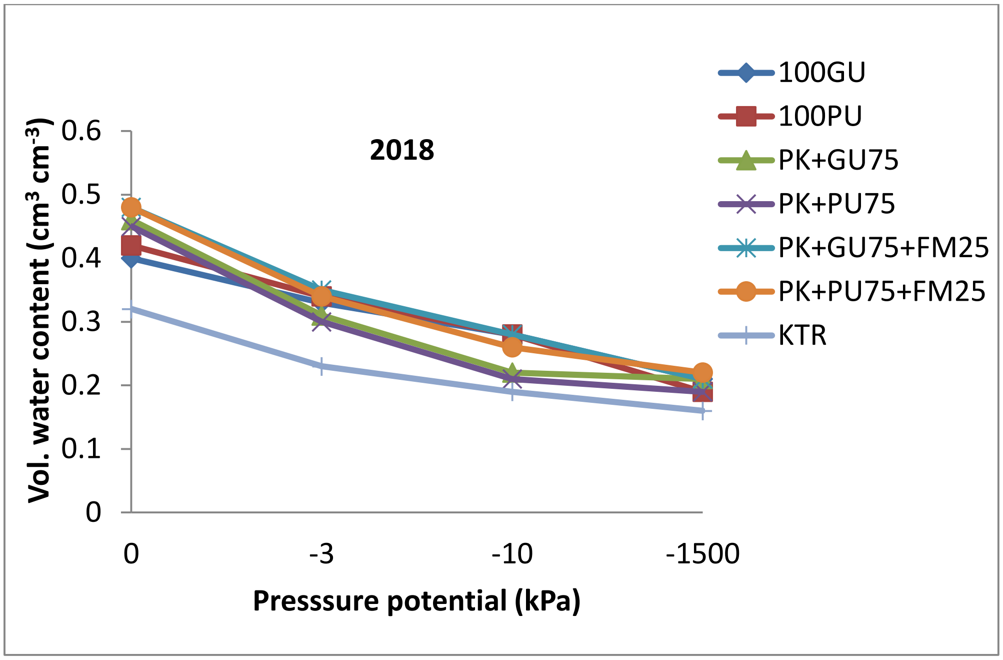
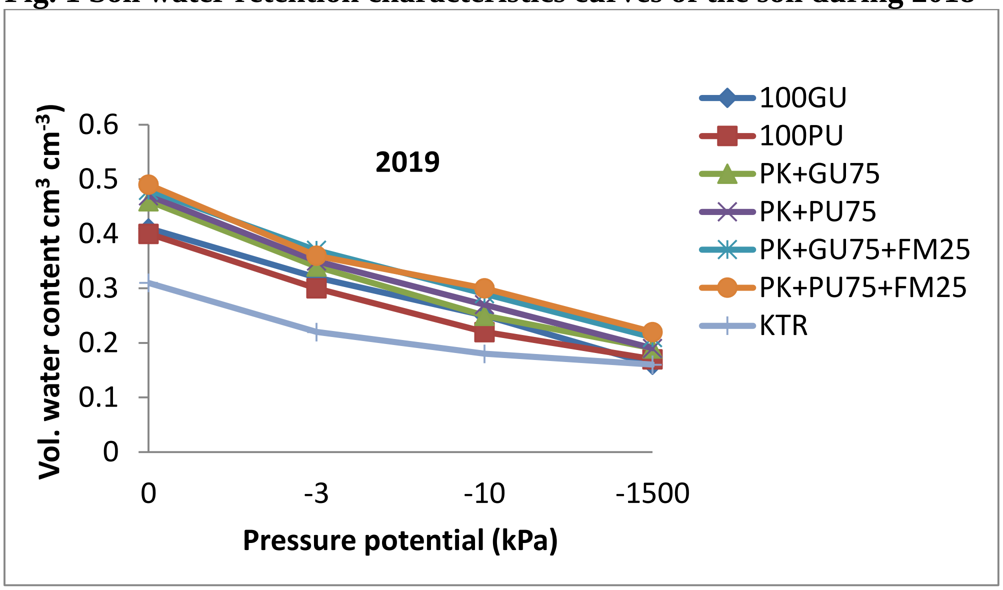


Fig. 1 Soil water retention characteristics curves of the soil during 2018



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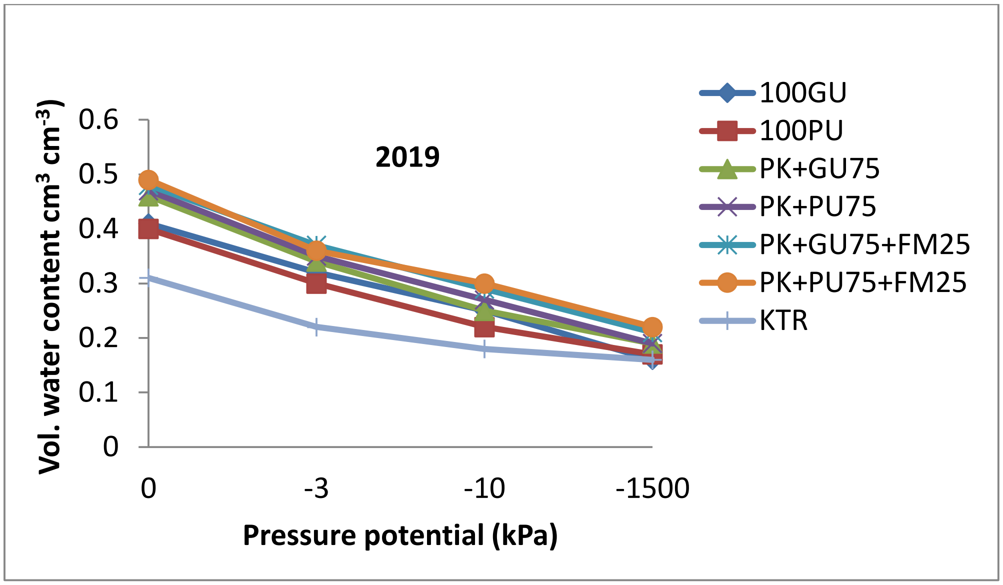

Fig. 2 Soil water retention characteristics curves of the soils during 2019

Conclusion

Conclusions drawn from this study are that: (1) Granular and fine-textured urea alone did not improve the soil bulk density during the period. (2) Granular and fine-textured urea supplemented with full P and K and 25% poultry manure showed a 10% improvement in soil bulk density during the same period. (3) Granular urea tends to increase the water holding capacity of the soil compared to the fine-textured type. (4) Granular urea with P and K and 25% poultry manure improved the soil structure through certain improvements in total porosity, water holding capacity and saturated hydraulic conductivity. (5) There was indication that the soil can quickly dry up after rainfall and/or irrigation due to the narrow range between water retention at field capacity (-10 kPa) and permanent wilting point (-1500 kPa), especially where fine-textured urea is applied alone.

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