Influence of soil depth and texture on moisture characteristics and plant available water content of Alfisols in northern Guinea Savannah of Nigeria

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Mahmud Sani^{1*} and Ibraheem Alhassan¹

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ABSTRACT

This study was designed to find out the influence of soil texture and depth on soil volumetric moisture retention (θ) in percentage at three matric potentials (0, 0.3, and 15 bars suction) and Plant Available Water Content (PAWC) on Nigerian Northern Guinea Savannah (NGS) Alfisols. After laboratory moisture determination using pressure plate apparatus, descriptive statistics was employed to summarize the data of disturbed soils sampled from four depth (0-20cm; 20-40cm; 40-60cm; and 60-80cm), and grouped by surface layer textures into Sandy-Loam (SL), Loam (L), Loamy-Sand (LS), Sandy Clay-Loam (SCL), and Clay-Loam (CL). Generally, all the moisture characteristics increased with depth in the overall study area. Sandy Clay-Loam (SCL) however, retained the highest moisture at saturation ($76.6 \pm 11\%$) in term of textural groups. For moisture retention at Drained Upper Limit (DUL), Drained Lower Limit (DLL) and Plant Available Water Content PAWC, Clay-Loam texture group retained the highest with 33.3 ± 6 , $18.6 \pm 4\%$, and $14.7 \pm 1\%$ respectively. It could therefore be concluded that CL texture exhibited the ability to retain the most agriculturally important moisture characteristics, while the moisture availability itself increase down soil depth in NGS irrespective of its texture.

INTRODUCTION

Several agronomic as well as hydrologic practices require information on the amount of water contained in a particular soil volume. Information on soil moisture availability like the moisture retained at soil Saturation (SAT) level, moisture at Field Capacity (FC)/Drained Upper Limit (DUL) and Permanent Wilting Point (PWP)/Drained Lower Limit (DLL) that could be influenced by soil texture and soil depth are important in irrigation studies, for assessing plant water requirement, for land suitability studies (Zotarelli et al. 2011) and in Cropping Systems Modeling CSM (Gijssman et al. 2007 and 2002).

As a property vital to soil quality, moisture influences the biological, chemical, and physical characteristics of a soil. Biologically, it determines the plant species that inhabit an area, as the plants and associating beneficial microorganisms require

water for their metabolic activities such as synthesis, mineralization, fixation, solubilization, and dissolution of colloidal minerals (Busari et al. 2015). Different plants have varying water requirements for optimum performance as yields of crops are often determined by the amount of water available. Deficiency in nutrient and soil water are detrimental to photosynthesis (Cook and Orchard 2008). Chemically, soil water dissolves salt and make up the soil solution containing different nutrients that are important and needed by growing plants (Busari et al. 2015). Furthermore, it serve as carrier of nutrients for plant growth and also as a nutrient itself (Mbah 2012). Physically, moisture regulates soil temperature, aids soil forming processes and weathering, it also plays the crucial role of water and heat energy exchange between land surface and the atmosphere of its surroundings through evaporation and transpiration (Wesseling 2009). On environmental conservation note however, soil moisture greatly influences the development of weather patterns, soil moisture regime, and the amount of precipitation in water cycle (Zamir et al. 2013).

Various literature (Diallo and Mariko 2013; Lal and Shukla 2004) refer to moisture availability

¹ Department of Agronomy, Federal University Gashua, Yobe State, Nigeria

* E-mail: mahmudsani17@gmail.com

with different nomenclature (such as Characteristics or Constants), the names are generally aimed at expressing the availability of soil moisture at given matric potentials on the soil moisture characteristic curve. Soil moisture retention is affected by different phenomena such as gravity, adhesion, cohesion, surface tension, plant up-take, evapor-transpiration, texture, organic matter content, etc. that cumulate and determine the moisture status of a soil. The most widely used moisture constants in the literature are; SAT, a condition of zero suction pressure when all the available (macro and micro) pores in the soil are filled with water, and volumetric moisture equals soil porosity and drainage occurs freely due to gravity (Rossi and Nimmo 1994). Next to SAT is DUL, also referred to as the Field Capacity (FC) or near saturation of moisture, a condition at which soil water has been fully drained under the effect of gravity such that the moisture that remained in the soil is in the form of capillary and hygroscopic water only. This condition is generally believed to be at 0.3 bars suction pressure (-33 kPa) in laboratory and at fields (Dalglish et al. 2009). Another widely used moisture constant is the Drained Lower Limit, otherwise known as PWP or near oven dryness, is the moisture content below which plant can no longer access water in the soil (Mohamed and Ali 2006), when the forces of adhesion and cohesion holding water to soil particles exceed that the roots can exert to obtain water sufficient for crop growth (Zamir et al. 2013), and a situation when the plant wilts due to moisture deficit and cannot recover even if soil moisture rises (Dalglish et al. 2009). The matric pressure signifying DLL has been unanimously agreed to be 15 bar suction (-1500 kPa). Plant AWC however, is the amount of moisture held between the DUL (0.3 bars) and DLL (15 bars) of moisture (Mbah 2012). It is an important characteristic that determines soil's physical qualities and for Cropping System Models (CSMs), it is the basis for soil-water balance upon which all crop simulations rely (Costa et al. 2013; Hunink and Baille 2011). Soils with high PAWC have higher biomass production potential than those with low PAWC (Burk and Dalglish 2008).

An understanding of the NGS soils moisture characteristics and its trend on different soil textures and depth, will inform decisions on land suitability, capability, moisture regime and soil classification, irrigation studies, and general crop production in the Agro Ecological Zone (AEZ). This study was therefore aimed at determining the influence of texture and depth on soil moisture retention in NGS of Nigeria.

MATERIALS AND METHODS

Study area

The study was conducted in the NGS AEZ of Nigeria spanning over Kano, Kaduna and Katsina States. Thirty-seven (37) locations were selected and sampling was done from depths of four layers (Figure 1). The soils across the locations were generally Alfisols, predominantly Plinthosols, Cambisol and Gleysols in Kano sites, Cambisols, Acrisols and Lixisols in Kaduna, with Cambisols, Lixisols and Luvisols in Katsina (Shehu et al. 2018). NGS soils are well drained and of Chad formation and Basement Complex parent materials like shale, schist and granite (FDALR 1990). The climate of Northern Guinea Savannah is Aw (Koppen system) signifying Tropical wet and dry (Dugje et al. 2009). The cumulative annual rainfall in the past three seasons in the study area ranged from about 1000mm at Tudunwada in Kano to about 1400mm at Giwa in Kaduna (Shehu et al. 2018) as a unimodal occurrence between May and October, with average annual temperature range of 20°C – 34°C across the study area from 2015 to date (NASA 2018). The gross study area falls within latitudes 8.839637°N to 12.01780°N and

Figure 1. The Nigerian map highlighting sampled soil locations

longitudes 7.14796°E to 8.62854°E (Figure 1).

Experimental setup

The soil samples were classified based on soil surface (0-20 cm) texture into table 1 using hydrometer particle size distribution method and USDA textural triangle as described in Diallo and Mariko (2013).

Soil sampling

Disturbed soil samples were collected from the depths of 0-20cm, 20-40cm, 40-60cm and 60-80cm by way of digging mini-profile pits of 0.5 x 0.5m at the surface and 1m deep at each of the locations making a total of 148 soil samples. Samples were then air dried, gently crushed with pestil and mortar, and sieved with 2mm mesh.

Determination of SAT, DUL, DLL and PAWC Moisture contents

A 15 Bar Gas Pressure plate extractor was used for the determination of soil moisture at Zero suction (Saturation), 0.3 Bar suction (DUL), and 15 Bar suction (DLL) in gg^{-1} as described in CORP. (2009). Values obtained were then converted to percentage volume thus:

$$\theta (cm^3 cm^{-3}) = w (gg^{-1}) \times \frac{\rho_s}{\rho_w}$$

$$\text{Moisture in (\% volume)} = \theta \times 100$$

θ = Volumetric moisture content

ρ_s = Density of soil

ρ_w = Density of water

PAWC was estimated by taking the difference between soil moisture at DUL and DLL.

Statistical Analysis

Descriptive statistics was used to summarize the moisture characteristics of both the general samples of studied sites and samples of the identified textural groups respectively using STAR (2013).

RESULTS AND DISCUSSION

Soil Moisture Characteristics of the Gross Experimental Soil Samples

Figures 2-4 are descriptions of observed moisture contents at different matric potentials and PAWC across the study area. All the measured moisture contents at various tensions increased with depth and attained the highest levels at the deepest layers. This implied that observed moisture characteristics at different tensions are affected by such intrinsic soil factor as depth. The same trend of soil moisture retention increase with depth was also found temporally in the study of Penna and Dalla Fontana (2013) during wet and dry periods. The finding is also at par with significantly simulated layer moisture contents in the study of Abdulhalem et al. (2014). Salako (2003) reported this characteristic increase in moisture retention with increase in the depth of Nigerian NGS soil. As shown in figure 2, SAT moisture content increased down the layers thus: range = 49.1% – 74.6% with median = 61.5%, range = 50.4% – 81.6% with median = 67.9%, range = 51% – 85.6% with median = 69.1% and range = 43.5% – 93% with median = 70% for the surface, second, third, and bottom layers respectively. The same saturated moisture behavior was exhibited by the NGS soil in the report of Salako (2003). A probable attribute to this, is that SAT moisture content is basically affected by particle distribution and percentage porosity as reported by Mbah (2012). Moisture content at DUL in figure 3 also increased with

depth, where the highest moisture content was recorded at the bottom layer with range 19% – 43.7% and median 30.1%, while the least was in the surface layer with 15%, 37.3% and 22.5% as the minimum, maximum and median DUL moisture contents. DUL also exhibited a downward increase resultant of increase in clay content from the particle size distribution of the samples, and probably clay mineral type in the locations since both were found to influence DUL in Mbah (2012). In figure 4, moisture content at DLL followed the same trend of increment down the depths as SAT and DUL moisture consistent with the result in Salako (2003). The deepest layer held the highest DLL moisture followed by the upper layers in a decreasing manner with medians 18.8% followed by 18.5%, 16.5% and 11.5% accordingly. This could also be due to texture, mineral type and its expansiveness (Mbah 2012). Porosity and organic matter (OM) content however, were established to have no effect on the amount of moisture at retention at DLL (Gijssman et al. 2002).

PAWC showed a different trend in figure 5, in which the bottom layer has the highest PAWC with median 11.5% and ranged 3.8% to 24.6% then the first layer > second layer, while 8.8% as the least PAWC median value was observed in the third layer. This trend might have occurred due to the increased OM content in the bottom layers of the CL textural group, for the finer the soil particle, the higher the moisture it retained (David 2007). Also, OM generally increase DUL of moisture but not DLL of moisture, therefore could increase PAWC as reported by Diallo and Mariko (2013).

Soil Moisture Characteristics of Samples in Different Textural Groups

The moisture characteristics of the soils in identified textural groups in the study area are presented in Table 2. For Laboratory determined moisture contents in table 2, the SAT moisture contents were reported in TerraGIS (2017) to generally depend on the Porosity of soils. In SL texture, SAT and DUL moistures increased with depth, moisture at DLL increased from a mean of 12.4% in the first to 16.1% and 19% in the second and third layers then decreased to 15.9% at the bottom layer. Equal PAWC were recorded for layers one and two (11.4%) while an increase was observed in layer three (11.8%) and four (14.4%).

All the SAT, DUL and DLL moisture contents increased with depth in L texture while PAWC decreased alternately; layer one followed by layer three followed by layer two with layer four having the least PAWC values. SAT, DUL and DLL moisture contents showed a trend similar to that of L in the LS texture. PAWC that was highest in the surface layer however, was seconded by the bottom layer, while second layer has the least PAWC value

Table 1. Experimental Setup

Texture (USDA)	Location		No. of samples in State	No. of samples in textural class
	State	L.G.As		
Sandy Loam (SL)	Kano	Doguwa & Tudun Wada	20	88
	Kaduna	Giwa, Kauru, Ikara, Soba & Makarfi	40	
Loam (L)	Katsina	Funtua, Dandume & Faskari	28	28
	Kaduna	Giwa, Soba & Samaru	16	
	Katsina	Faskari	12	
Loamy Sand (LS)	Kano	Tudun Wada	8	16
	Kaduna	Kauru & Lere	8	
Sandy Clay Loam (SCL)	Kaduna	Lere	4	8
Clay Loam (CL)	Katsina	Dandume	4	8
	Kano	Doguwa	4	
	Kaduna	Soba	4	
Total			148	148

USDA = United States Departments of Agriculture and L.G.As = Local Government Areas.

Table 2. Soil Moisture Characteristics of Samples in Different Textural Groups

Depth (cm)	Volumetric moisture contents			
	SAT (%)	DUL (%)	DLL (%)	PAWC (%)
Sandy Loam (n = 88)				
0-20	61.5±6	23.8±5	12.4±4	11.4±5
20-40	67.9±6	27.5±7	16.1±5	11.4±5
40-60	68.8±9	30.8±9	19.0±4	11.8±9
60-80	68.7±10	30.3±7	15.9±6	14.4±6
Loam (n = 28)				
0-20	60.9±5	22.9±5	12.0±3	10.9±7
20-40	66.0±13	28.4±3	19.5±2	8.90±5
40-60	67.2±17	29.9±8	20.8±6	9.10±8
60-80	68.7±13	32.2±3	23.5±3	8.70±2
Loamy Sand (n = 16)				
0-20	55.7±5	19.2±7	7.00±2	12.1±7
20-40	59.1±6	20.1±3	12.1±5	8.00±3
40-60	61.6±7	23.8±3	13.2±6	10.6±2
60-80	66.3±13	28.9±7	17.3±5	11.6±3
Sandy Clay Loam (n = 8)				
0-20	76.6±11	26.9±10	15.1±5	11.8±2
20-40	64.6±5	29.1±2	20.2±3	8.90±5
40-60	67.0±1	31.8±2	25.5±6	6.30±4
60-80	62.6±10	37.0±10	19.9±10	17.1±1
Clay Loam (n = 8)				
0-20	67.8±7	33.3±6	18.6±4	14.7±1
20-40	65.4±4	28.8±1	16.9±2	12.0±3
40-60	72.0±2	28.8±4	19.3±3	9.60±1
60-80	64.9±8	26.7±1	16.5±1	10.2±2

Values are mean ± standard deviation.

(Table 2). The results from Table 2 further showed that SCL have the highest PAWC at the bottom layer followed by the surface, second and third layers, and SAT moisture content decreased down the layers, while DUL and DLL moisture increase down the layers. In CL, soil moisture at DUL and PAWC decreased with depth, while SAT and DLL moisture with highest values of 72.0% and 19.3% respectively, were recorded in layer three. Surface layer mean values for SL, L, LS, SCL and CL were 38.5%, 22.9%, 19.2%, 26.9%, 33.3% for DUL, and

12.4%, 12.0%, 7.0%, 15.1% and 18.6% for DLL respectively (Table 2). At DUL and DLL moisture levels, all the moisture contents were found to relate to their texture-specific ranges (TerraGIS, 2017). The DUL and DLL moisture contents in the surface layers of the textural groups were within the normal ranges: 18% – 28% for SL, 20% – 30% for L, 22% – 36% for SCL, 32% – 40% for CL (TerraGIS, 2017), and 6% – 16% for SL, 7% - 17% for L, 3% - 10% for LS, 9% - 21% for SCL and 17% – 29% for CL (TerraGIS, 2017) respectively.

Figure 2. SAT (%) Moisture content of studied samples by depth

Figure 3. DUL (%) Moisture of the studied samples by depth

Figure 4. DLL (%) Moisture of studied samples by depth

Figure 5. PAWC (%) Moisture of studied samples by depth

CONCLUSIONS

In conclusion, the study found that for the gross samples of the general study area, all the moisture characteristics increased with depth. More so, for the texture grouped soils, Sandy Clay Loam (SCL) retained the highest moisture at SAT. For moisture retention at DUL, DLL and PAWC, Clay Loam texture group retained the highest. It could therefore be concluded that CL texture retained exhibited the ability to retain the most agriculturally important moisture characteristics, while the moisture availability itself increase down soil depth in NGS irrespective of its texture.

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CONFLICT OF INTEREST

The authors declare that there are no conflicts of interest regarding the publication of this manuscript.

ORCID

Mahmud Sani: <https://orcid.org/0000-0002-1001-0523>

Ibraheem Alhassan: <https://orcid.org/0000-0002-7453-0210>

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