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Comparative Analysis of Moisture Characteristics of Soils Derived from Sandstone Parent Material in Darazo and Alkaleri Areas of Bauchi State, Nigeria

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Abstract
This study was carried out to Evaluate and compare the Moisture Characteristics of Soils Derived from sandstone Parent Material in Alkaleri and Darazo Local Government Areas of Bauchi State. Four (4) locations (AlkaleriTown, Gargawu, Darazo Town and Kili) were selected for the study. Eighteen core samples were collected randomly per location within the depths of 0 - 20cm, 20-40cm and 40 – 60cm using 5.0cm diameter and 3cm high rings of known weight (W1) and volume (V). Soil moisture contents at pressure of 0.33bar, 1.00bar, 3.33bar, 7.00bar, 10.00bar and 15.00bar were determined using pressure plate extractor. Graphs of the moisture contents on mass basis were plotted against their corresponding tension values to give soil-specific curves known as the Soil Moisture Characteristics (SMC) curves of the different locations. Also three (3) disturbed samples were taken from each depth and composited to one in all locations and soil texture was determined following standard procedure. Plant available moisture in each location was determined. The results indicated that all the study locations recorded high plant available soil moisture contents. However,hydraulic conductivity was higher in soils of Alkaleri sandstone compared to soil of Darazo sandstone due to larger sand particles in the area. In conclusion, the high leaching effect experienced in Alkaleri Local Government Area is as a result of macro pores in the soil due larger sandy particles. Therefore, the use of organic manure is encouraged among farmers in the area to improve moisture retention for optimum crop production.

Keywords: Soil moisture characteristics, Sandstone parent materials, available moisture, Soil Texture, Agricultural Productivity, Bauchi State.

Introduction

Soil moisture is that constituent of the soil that makes it characteristically wet. It represents the liquid phase component of the three-phase (solid, liquid, and gas) soil system. Sources of moisture to the soil include precipitation (especially rainfall, snowfall, and throughfalls), irrigation, and groundwater recharge. With rainfall, overland flow sometimes occurs, depending on some characteristics of the rainfall, as well as on the topographic, structural, and cover management features of the soil. This overland flow, termed runoff, does not enter the soil from where it emanates. If, however, the rainwater is impounded in depressions or a reasonable proportion is trapped by some techniques geared primarily towards conserving soil water, the 'harvested' runoff automatically becomes part of the soil moisture, provided the soil physical conditions favour infiltration. Strictly speaking, water lost to runoff never contributes to soil moisture, since soil moisture refers to the water which had already infiltrated into, and is part of the soil. Runoff is, therefore, considered an important process of loss of rainwater from the soil surface. On the other hand, deep percolation is another important process of loss of soil moisture, and is influenced mainly by soil texture and climate, being more pronounced in sandy soils and in the wetter regions than in clayey soils and in the drier regions. Based on the foregoing, effective rainfall rather than total rainfall aptly describes the rainfall contributing to soil moisture – total rainfall less runoff and deep percolation.

Since the amount of moisture in the soil is subject to fluctuations between the two stated extremes, it is more realistic to think of available moisture relative to the bulk soil. A 'saturated' soil has a tension near zero, but at any given moisture content below saturation, water is held in the soil by some forces. As the moisture reserve of the soil depletes further, the force increases correspondingly. The implication is that plant roots have to work too hard or at least have slightly above equivalent energy of the soil water, known as the soil matrix potential or soil moisture tension, to be able to extract water from the soil (Scherer *et al.*, 1996**).** In the course of depletion of the soil moisture reserve, three different remarkable stages are reached, assuming no water input. The first is Field Capacity (FC), normally reached 2-3 days after rainfall or irrigation, when all the gravitational or superfluous moisture held in the macro-pores must have been freely drained. In other words, downward movement of water practically ceases, with the soil retaining all the moisture it can hold against gravity. At this stage, the extractive force of the plants' roots exceeds that with which moisture is held to the soil matrix. Below the FC, soil water is partly liquid and vapour and, so, its subsequent movement is limited.

The second is Incipient Wilting Point (IWP) presumably reached at the onset of exertion of additional force by the plant's roots, to be able to extract capillary or available water from the micro-pores of the progressively drying soil; the plant leaves show signs of loss of turgidity, which could still be arrested with timely interventional irrigation.

The third is Permanent Wilting Point (PWP) reached when the extractive force of the plant roots and that which moisture is held to the soil matrix at equilibrium; the hygroscopic or unavailable moisture left in the soil is held tightly to the matrix with a force equal to the much the plant roots could exert. Water extraction temporarily ceases. The roots had to do extra work to remove water from micro-pores in the soil. Beyond this point, the roots suffer loss of water to the surrounding soil due to osmotic pressure gradient, which instantly results in an irreversible drop of osmotic pressure of the plant leaves due to water stress. Morphologically, the plant loses turgidity, which culminates in wilting – a situation that could not be revived. Scherer *et al.* (1996) indicated that the value of soil moisture tension at FC varies with soils of different textures with a range generally between 0.05 and 0.33 bars. They held that for most agronomic crops and soils, PWP occurs at about 15-bar tension, and that this tension with which the soil holds the water equals the maximum energy exerted by the plant at that stage. The soil moisture contents at FC and PWP are regarded as the upper and the lower limits of available water respectively, and the difference between the two gives the available water capacity (AWC) of the soil (Salter *et al*., 1966; O'Geen 2013). All the water held between FC and PWP are available to plants, and all tension values from FC to PWP correspond to given moisture contents for any soil. These moisture contents on volumetric basis when graphed against their corresponding tension values give a soil-specific curve known as the soil moisture characteristics (SMC) curve. Such a curve represents the moisture release pattern of the soil.

The movement of water in the soil is heavily influenced by tension levels. Tension or matrix potential, determines how tightly water is held in the pore spaces. Higher tension levels result in slower movement of water as it requires more energy to overcome the forces holding it in the soil. Conversely, lower tension levels facilitate faster water movement as there's less resistance. So, tension levels essentially dictate the rate and direction of water movement in soil. Water is stored and redistributed within soil in response to differences in potential energy. A potential energy gradient dictates soil moisture redistribution and losses, where water moves from areas of high- to low-potential energy (Hillel, 1982).

An assessment of water retention and release characteristics is an important agricultural practice that is not available in agriculturally potential Bauchi State, Nigeria. Keeping this in view, this study was undertaken to assess the soil water retention and release characteristics in parts of Bauchi State soil derived from sandstone parent material with the view to explore seasonal variations and long term trends in soil moisture dynamics for enhanced agricultural planning and management in the region. Crops grown Alkaleri Study Area includes; Bambara nut and millet while in Darazo Study Area crops like millet, cowpea, maize, groundnut are grown.

Materials and Methods

Bauchi State occupies a total land area of 49,119km^2 representing about 5.3% of Nigeria's total land mass and is located between latitudes 9^0 30^1 and 12^0 30^1 North and longitudes 8^0 45^1 and $11^0$0' East (UNDP Report 2018). The state is bordered by seven states; Kano and Jigawa to the north, Taraba and Plateau to the south, Gombe and Yobe to the east and Kaduna to the West.

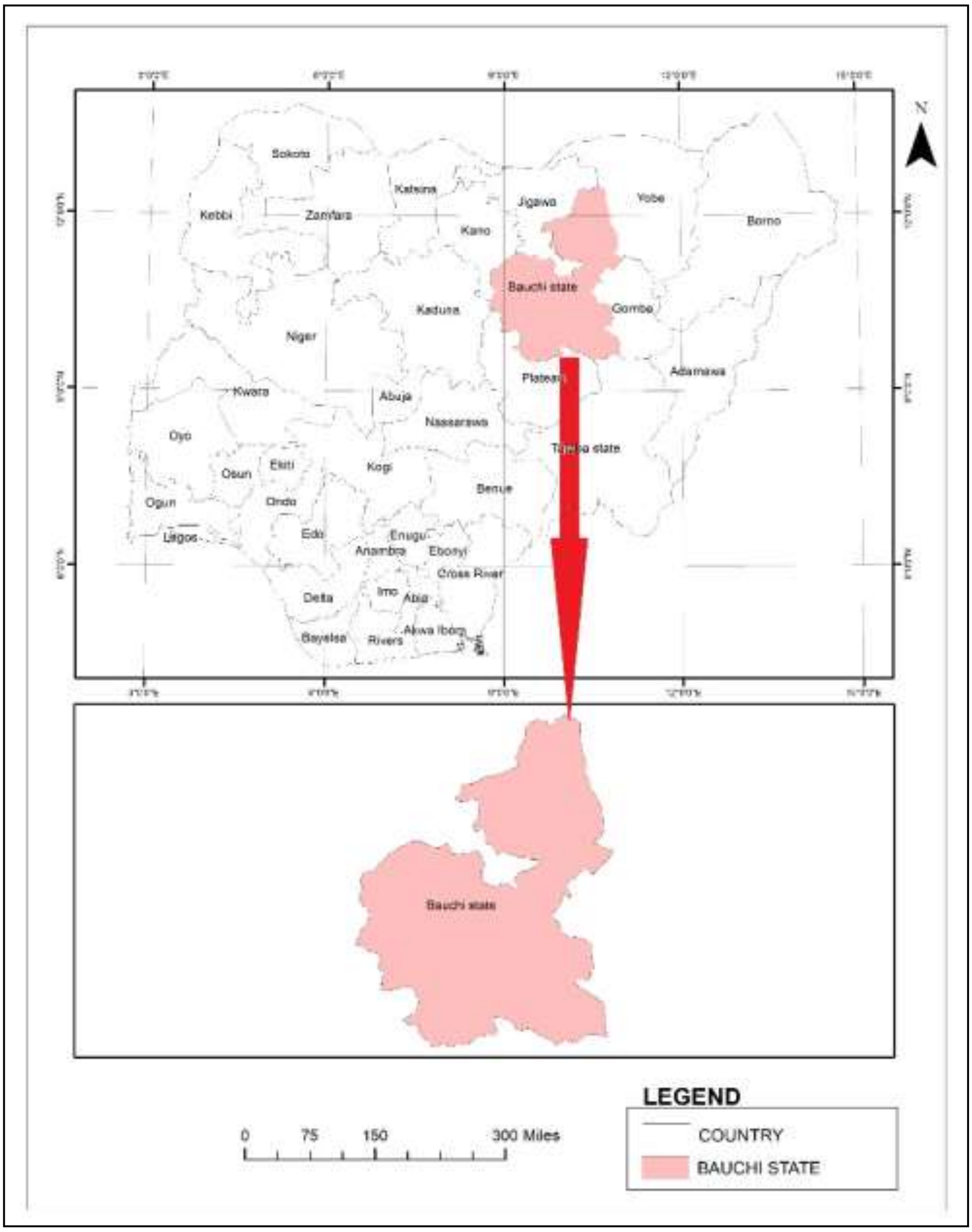

Figure 1: The Study Area

Climate of the Study Area

The state experiences two main seasons; rainy and dry Seasons. The rainy season usually commenced from May and ends in September with minimum rainfall of about 700mm per annum in the north to a maximum of about 1300mm per annum in the South. The vegetation is typically Sudan Savanna type comprising widely dispersed trees (Ibrahim, 2010)

Geology of Bauchi State

Lithologically, soils in Bauchi State are formed from Basement Complex Rock (BCR) and the Sedimentary Rocks comprising the Kerri-Kerri Formation (KKF) and the Chad Formations (CF)

(Macleod *et al*., 1971). The BCR covers most part of the State. Bauchi is basically composed of crystalline rocks, basement complex mostly Precambrian to the early Paleolithic in age. The rocks include the mixture of granites, gneisses, pegmatite and some amount of charnokite at the margin around the area of Alkaleri. Granites are coarse grained and are composed of quartz, alkali, feldspar, biotite and muscouite with ancestry horn bled and haematite. Pegmatite veins within the gneisses are composed of potash feldspar and very large crystal may form. A charnokitic rock occurs around the margin where it forms small out crops. Bauchi metropolis lies within the undifferentiated basement complex with older granites outcrops and young granites out crops. The basement complex is best described as crystalline rocks of the area (Macleod *et al*., 1971).

Soil Physico-chemical Property of the Study Area

The physical and chemical properties of the soil of the soil of the study area is shown below:

Table 1: Mean soil particle distribution, total organic carbon, total nitrogen, available phosphorus, exchangeable soil Ca, Mg and K(cmolkg-1) in maize field in Local Government Areas of Bauchi State

LGA	sand	silt	clay	pH	Organic C (gkg^{-1})	Total Nitrogen gkg^{-1}	Available P $mgkg^{-1}$	Ca ($cmolkg^{-1}$)	Mg ($cmolkg^{-1}$)	K ($cmolkg^{-1}$)
Alkaleri	810	100	90	6.7	4.40	0.30	16.1	3.10	0.36	0.21
Bauchi	710	140	150	6.5	5.84	0.50	9.3	3.70	0.44	0.35
Ganguwa	680	150	180	6.9	9.23	0.78	26.6	5.39	0.69	0.43
Toro	590	180	230	6.1	7.14	0.64	10.8	3.82	0.51	0.27

Source: Ekelemee*et al*., (2014)

Sampling Technique

The samples were taken from two different locations within a local government area. Two local government areas were used. A total of 54 samples were used in each location given rise to 216 samples in all. The coordinates of the specific locations where samples were taken were marked using Geographic Positioning System (GPS) as presented in Table 1 below

Table 2: Sample locations and their coordinates

Site	Latitude	Longitude	Evaporate (m.a.s.j)
Toro town	N10^o 08' 17.5''	E009^o 24' 10.4''	978m
Nabordo	N10^{o}12'57.6''	E009^o 24' 10.4''	712m
Birshe Fulani	N10^{o}14' 46.3''	E009^o 40' 39"	638m
Gubi	N10^o 27' 42.2''	E009^o 49' 57.8''	603m

Field Procedure

The collection of soil sample was done starting from the upper layer (0 – 20cm). The excavation of the soil to allow for taking of soil samples was carried out by the use of digger while shovel was used to move out the soil particles. After the excavation of the pit to 1m, a measuring tape was used to measure the depth at which the samples were taken (0 – 20cm, 20 – 40cm and 40 – 60cm) depth. The undisturbed samples were collected using the core samplers while the disturbed samples were taken using a hand trowel into sampling polythene bags. All the samples collected were labeled and the same procedure was used in collecting the samples from all locations and depths. Materials used in the field were Cutlass, Digger, Shovel, Meter rule, Sampling rings, Auger, Polythene bags, Hammer, Global Positioning System (GPS), Rubber ban, Piece of cloth.

Laboratory Procedure

Particle Size Determination

Soil samples were air-dried and served through a 2mm mesh. Particle size analysis was carried out by hydrometer method (Juo, 1979) using sodium hexametaphosphate as the dispersant.

Bulk density

Soil bulk density was determined by undisturbed core method (Klute, 1986). Three core samples were collected randomly within 0 – 60cm at an interval of 0 – 20cm using 5.0cm diameter and 3cm high rings of known weight (W_1) and volume (V). The samples were put in an oven at 105^{0}C for 24hours and its weight (W_2) was recorded. Bulk density was calculated at each tension levels as presented in appendix i. Bulk Density = Weight of even dry soil/volume of the cylinder

Determination of Soil Hydraulic Properties

Soil moisture content on mass basis

Soil moisture content on mass basis (mass wetness) was determined by weight of water at a given tension level divided by weight of oven dried soil. The water content was then expressed on percent basis, thus: Mass of water/mass of soil solids x 100 as described by Anderson and Ingram, (1993) and presented in appendix i. Mass wetness = weight of soil water /weight of dry soil x 100

Moisture content at field capacity

Moisture content at field capacity is mass wetness 0.33bar as shown in appendix i (Anderson and Ingram, 1993)

Moisture content at permanent wilting point

Moisture content at permanent wilting point is the mass wetness at 15bar as shown in appendix i (Anderson and Ingram, 1993)

Available soil moisture in the soil

Available moisture in the soil is the difference between the soil moisture obtained on mass or volume basis at field capacity and permanent wilting point {Fc-PWP} (Israelson and Hanson, 1962).

Soil moisture retention and release characteristics

Soil moisture retention and released characteristics of the samples was determined using the pressure plate apparatus. A triplicate samples was used at each depth for each pressure head (0.33bar, 1.0bar, 3.3bar, 7bar, 10bar and 15bar) from 0 – 60cm depth at an interval 0 – 20cm for undisturbed samples as described by Smith & Mullins (1991). Each sample was carefully taken and covered at the bottom with a piece of cloth tied by rubber ring to the sampling ring. The rings were 50mm in diameter and 30mm in height. The soil samples while in the rings were soaked in water inside a tray overnight and pressure was applied to the system the next morning. For each depth, a moisture retention determination was made in triplicate at all the tension levels chosen. However, the triplicate samples were all place on the equipment at the same time. The amount of moisture was determined after equilibrium was reached in about 3 – 5days depending on the texture of the sample. The samples were oven-dried at 105^{0}C for 24hours and the results were expressed in percent moisture on a dry weight basis. All the water held between FC and PWP are available to plants, and all tension values from FC to PWP correspond to given moisture contents for any soil. These moisture contents on mass basis was graphed against their corresponding tension values to give a soil-specific curve known as the soil moisture characteristics (SMC) curve.

Results

Table 3: Particle Size Distribution of Soils of the Study Area.

Location	Depth (cm)	%passing through 2mm sieve	Total sand 0.02-2mm	Silt(0.002-0.02mm)	Clay (<0.002mm)	Texture class
Alkaleri	0-20	92.00	75.04	14.56	10.40	Loamy sand
	20-40	94.50	77.60	10.44	11.96	Loamy sand
	40-60	93.10	79.60	10.44	9.96	Loamy sand
Gargawu	0-20	98.30	77,60	7.44	10.96	Loamy sand
	20-40	95.50	75.04	12.56	10.96	Loamy sand
	40-60	94.20	79.60	14.44	11.40	Loamy sand
Darazo	0-20	97.00	67.60	19.44	12.96	Sandy loam
	20-40	97.90	65.60	21.44	12.96	Sandy loam
	40-60	98.20	65.60	23.44	10.96	Sandy loam
Kili	0-20	96.30	65.60	21.44	12.96	Sandy loam
	20-40	90.20	69.60	19.44	10.96	Sandy loam
	40-60	96.60	65.60	21.44	12.96	Sandy loam

Table 4: Soil Hydraulic Parameters of Soil of Sandstone origin (Alkaleri and Darazo LGA) in Bauchi State

Sample No	Soil Depth	Bulk Density	FC water (%)	PWP water (%)	Available Water(%)	Volume water(%)
AK (I)	0-20cm	1.57	15.10	32.50	17.40	24.20
AK (II)	20-40cm	1.48	17.10	34.30	17.20	22.50
AK (III)	40-60cm	1.53	18.20	37.00	18.80	28.80
GG(I)	0-20cm	1.55	18.30	31.40	13.10	20.30
GG(II)	20-40cm	1.52	19.20	35.90	19.70	29.90
GG(III)	40-60cm	1.45	23.50	38.50	15.00	21.80
DZ (I)	0-20cm	1.43	12.9	28.4	15.50	22.20
DZ (II)	20-40cm	1.46	13.00	28.20	15.20	22.20
DZ (III)	40-60cm	1.40	17.20	32.80	15.60	21.80
KL (I)	0-20cm	1.43	14.30	28.40	14.10	20.20
KL (II)	20-40cm	1.46	12.90	27.10	14.20	20.70
KL (III)	40-60cm	1.40	14.50	32.80	18.30	25.60

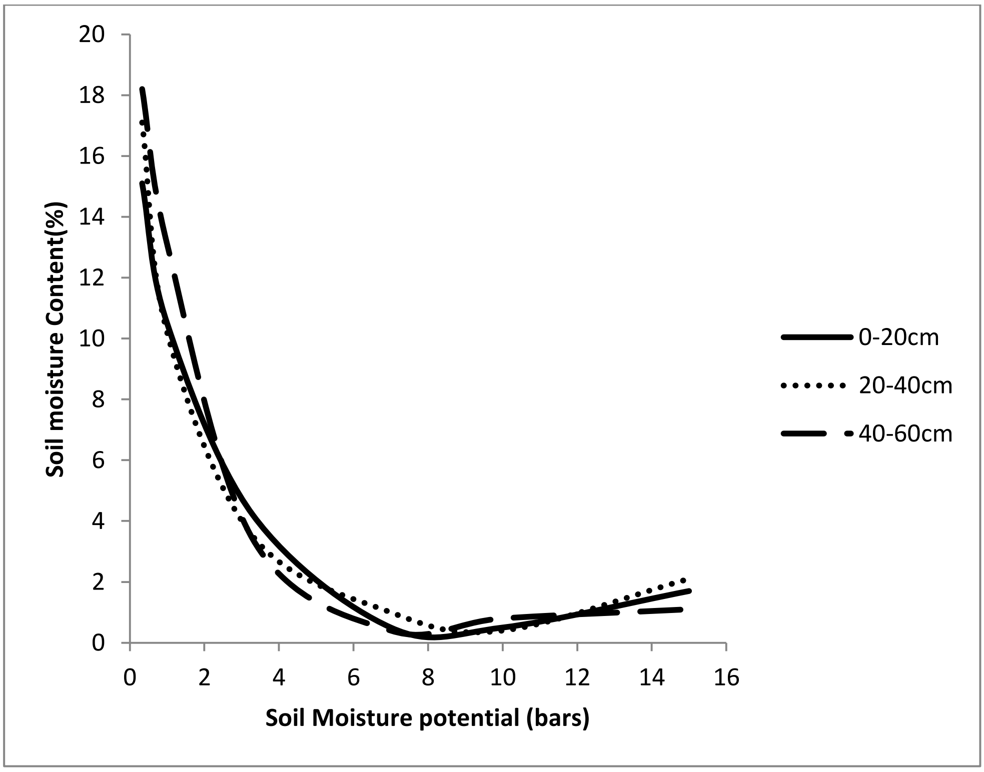

Figure 2: Soil Moisture Characteristics Curve ofAlkaleri Town in Alkaleri Local Government Area of Bauchi State.

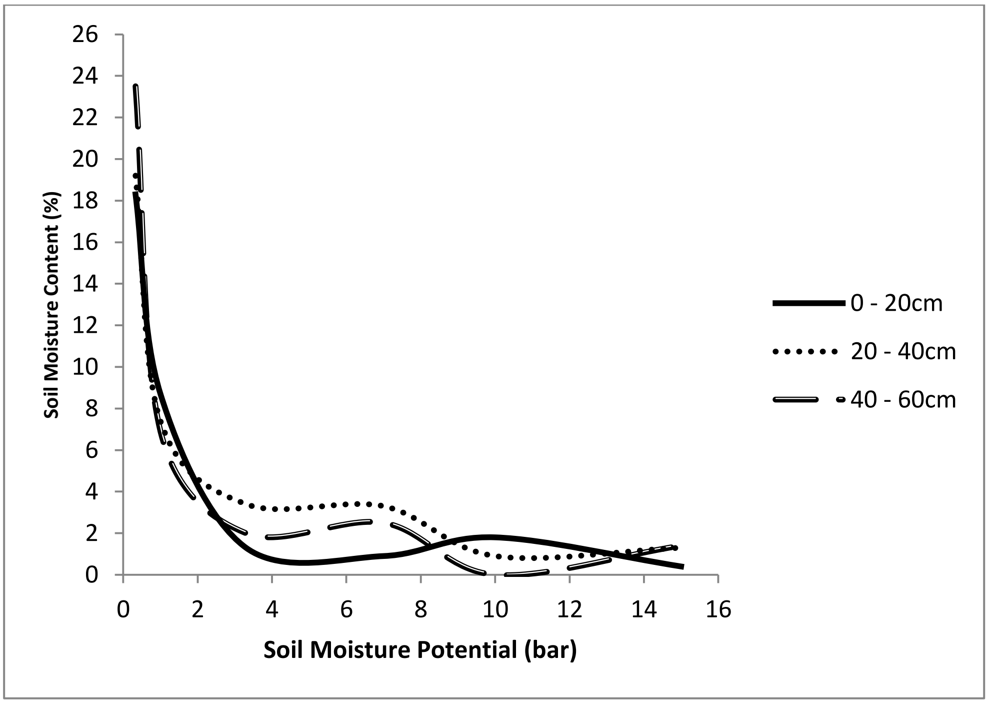

Figure 3: Soil Moisture Characteristics Curve OfGargawu Village in Alkaleri Local Government Area of BauchiState.

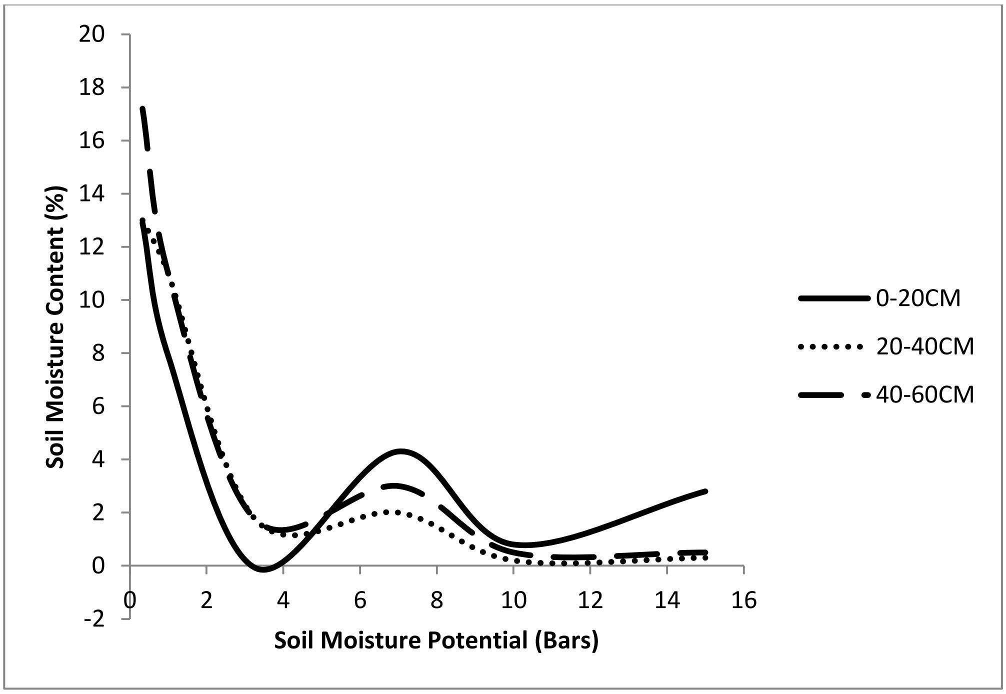

Figure 4: Soil Moisture Characteristics Curve ofDarazo Town in Darazo Local Government Area of Bauchi State.

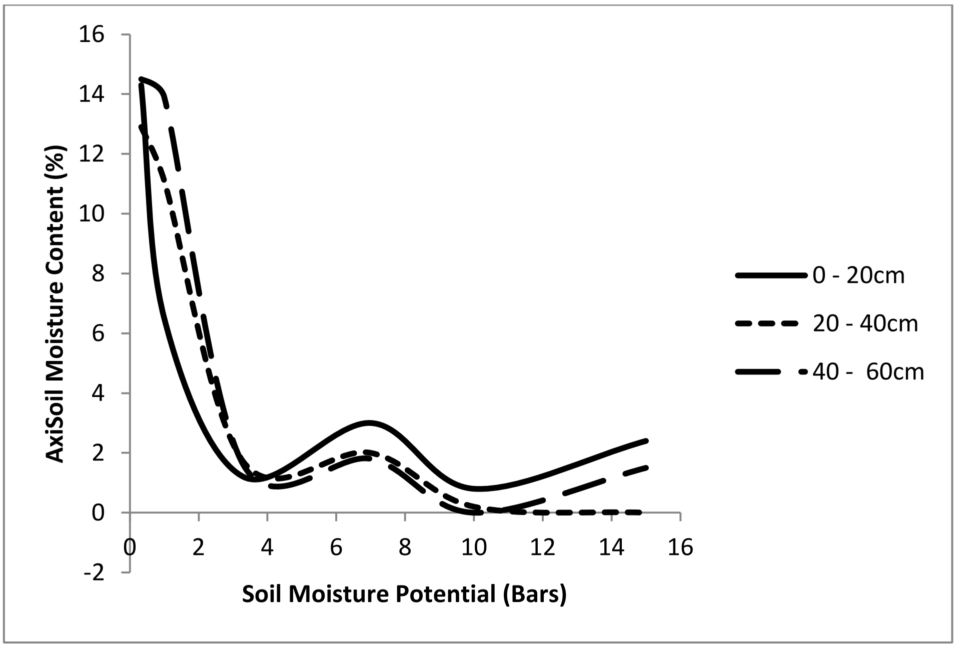

Figure 5: Soil Moisture Characteristics Curve of Killi in Darazo Local Government Areaof Bauchi State

Discussion

Tables 3 and 4 showed soil texture and soil physical parameters of the study area. From Table 3, it was observed that Darazo and Kili had more silt particles compared to Alkaleri and Gargawu study location. The textural class of Alkaleri and Gargawu was loamy sand while that of Darazo and Kili was sandy loam. Table 4 showed the soil physical parameter of the study area. The Table 4 showed that the hydraulic parameter measured (plant available moisture, moisture at field capacity and permanent wilting point) were higher in soil derived from sandstone parent materials compared soils derived from basement complex parent materials.

Figs.2 and 3 represented the soil moisture retention curve of Alkaleri and Gargawu study location respectively. From the beginning, the curves of Alkaleri (Fig. 2) and Gargawu (Fig. 3) experienced a steep slope at low tension between 0 – 1bar, which is an indication of high plant available moisture lost at lower tension. Afterwards, the curves became gentle up till 12bar which indicated steady supply of plant available moisture. Generally, the curves in Figs2 and 3 had available moisture up-till the tension of 15bar. The soil moisture retention curve of Alkaleri (Fig. 2) and Gargawu (Fig. 3) all in Alkaleri Local Government Areas were similar in nature due to similar mechanical content. This free available moisture content throughout the curve could be linked with combination of silt and very fine sand. This result was supported by the work of Vucic, (1987) who opined that pF values are affected by the mechanical content and according to the same author, the bigger the participation of the fine fractions the greater the pF values, especially under pressure of 0.33bars. Similar result was reported in a study by Filizola *et al*., (2017), in his study of sandy soils with different management practices in an agricultural area. The high moisture released at lower tension between 0 – 1bar was as a result of high fine sand content in this location. As they usually have larger pores, sandy soils are more rapidly emptied at low tensions, leaving only small amounts of water retained at lower potentials. This fact according to Hillel (1982), explains the reason for fast released of moisture at the lower tension levels. Generally, the curves were not far from each other till 15bar due to similar mechanical properties (equal mineralogical content of the soil, homogeneity of the profile).

The soil moisture retention curve of Darazo and Killi is represented in Fig. 4 and 5.This profile showed that moisture retention was low up to 3bar tension (silt content) as also reported by Mbagwu,

(1987) but jump up between tensions of 4 – 9bars. The jump in the moisture retention between 4 - 9bars on the curve may have been as a result of high proportion of fine and very fine sand as also reported Franzmeier *et al*., (1960), Rivers and Ship, (1978). They studied soils with light texture and reported that the amount of available water varied significantly with the percentages of very fine sand content. This means that among sandy soils, there are differences in water retention, guided by granulometric composition of the sand fraction. Similar result was found in a study by Filizola *et al*., (2017), in their study of sandy soils with different management practices in an agricultural area. Manfredini *et al.,* (1984) reported that in medium-textured soils and in Quartz sands (Arenosols) the distribution of pores was predominantly determined by the granulometry of the sand fraction, highlighting that there is a significant correlation between the percentage of fine sand and the water storage capacity of sandy soils, which indicated greater microporosity. Because of the similar mechanical content of the soil of this study area, the retention curve did not differ essentially from each other. This assertion is supported by the work of Filipovski, *et al*., (1980).

Conclusion

The analyzed mineralogical content and retention of the study area showed that moisture retention characteristics depend on soil texture. Findings revealed that soils derived from sandstone in Darazo study location had sandy loam and well distributed plant available moisture across the tension levels due to high silt content compared to soils derived from sandstone parent materials in Alkaleri study location that is loamy sand. The implication was the high leaching of nutrient in the soil of Alkaleri that farmers complained of and needed to be prevented for optimum crop production in the area. It is therefore recommended that farmers should use high organic matter in in soil of Alkaleri study area to build good soil structure that will reduce the menace of leaching of nutrient in the area.

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