Adamawa State University Journal of Scientific Research
(ADSUJSR)
Volume 12 Issue 2, 2024
ISSN: 2705-1900 (Online); ISSN: 2251-0702 (Print)
adsujsr.adsu.edu.ng

Comparative Analysis of Soil Moisture Characteristics between Soils Derived from Basement Complex and Sandstone Parent Materials in Parts of Bauchi State. Nigeria

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(Received in November 2024; Accepted in December 2024)

Abstract
This study was undertaken to evaluate soil moisture characteristics in parts of Bauchi State under soil derived from basement complex and sandstone parent materials with the view to reveal the major cause of moisture stress experienced in soil derived from basement complex in early stage of every dry season. Triplicate 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).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. These moisture contents on mass basis were graphed against their corresponding tension values to give a soil-specific curve known as the soil moisture characteristics (SMC) curve. The analyzed mineralogical content and retention of the studied area showed that moisture retention and released characteristics depended on soil texture. Findings revealed that soils derived from sandstone exhibited higher plant available moisture at all tension levels evaluated compared to soils derived from basement complex. The result also showed that plant available moisture was fast lost at lower tension level of 1bar in soils of basement complex while it was slowly and steadily released till tension of 15bar in soil of sandstone origin. Therefore, early planting, drought resistance or early maturing varieties of crops are recommended for planting in soil derived from basement complex.

Keywords: Soil moisture retention, parent materials, irrigation, agricultural productivity, Bauchi State.

Introduction

The Northern Guinea/Sudan Savanna of Nigeria commonly witness poor rainfall distribution, dry spells, surface wash and runoff on farms (Kowal and Knabe, 1972), and result in soil moisture deficiency that depress crop yield or complete crop failure at the uplands (Odunze*et al*., 2010). Also, the upland soils have very low moisture retention capacity, poor inherent fertility status and are dominated with low activity clays; in particular kaolinitic clays (Jones and Wild, 1975; Lombin, 1987; Odunze, 2006). Crops grown at the uplands in the zone include maize, sorghum, upland rice, cowpea, groundnut and soybeans, and these crops suffer moisture stress following insufficient soil moisture during their growth phase. This implies that field crops would experience insufficient soil moisture to undergo proper growth and production processes, resulting in low yields or complete crop failure in some cases in the area. This problem of limited available water for plant growth is worst in selective parts of BauchiState, Nigeria that had their soil derived from basement complex parent materials. Widespread occurrences of crop failure towards the dry season which has caused farmers nightmare in part of Bauchi State have prompted this investigation into the causes of such early dry spell in the area. Adversely affected areas include parts of Bauchi, Toro, TafawaBalewa and Dass Local Government Areas of Bauchi State. The crop failure starts with the leaves showing signs of moisture stress a week or two (depending on the severity of the problem) after cessation of rainfall and no irrigation carried out and thereafter the crops are wilted completely off the surface without a single output. This problem had left so many farmers in these areas with famine throughout the season since most of them lack the capacity to provide water inform of irrigation to the crops in the field. Some who have the capacity to irrigate do so and gets harvest at the end of the productive period; however, it has adverse effect on the production cost of the farmers. The possible cause of this problem could be hard pan on the subsurface preventing root penetration, high altitude that may have cause run-off that reduced soil moisture, high clay content that resist moisture absorption/promotes moisture retention or unfavourable climatic condition.

In my own view as a researcher, the problem needs to be properly diagnosed and the root cause of it known before solutions provided can be effective. In other word, a problem with its cause known is 50% solved. Therefore, this research work was focused on revealing the primary cause of moisture stress to crops in the selective parts of Bauchi State soils derived from basement complex parent material.

Moisture Retention

The soil water retention is a result of two forces: adhesion (soil particles attract the water molecules) and cohesion (mutual attraction of the water molecules). The adhesion is much stronger than the cohesion. The force which retains the water in the soil is called capillary potential and is closely related to the water content. The free flowing water in the soil has a capillary potential equal to zero, a condition where all the soil pores, both capillary and non-capillary, are filled with water. Soil water potential can be determined indirectly by recourse to measurements of soil water content and soil water release or soil moisture characteristic curves that relate volumetric or gravimetric content to soil water potential. The measurement of water potential is widely accepted as fundamental to quantifying both the water status in various media and the energies of water movement in the soil- plant-atmospheric continuum (Livingston, 1993). Mukaetov (2004) underlines that by decreasing the water content in the soil, the value of the capillary potential were increased.

Widespread occurrences of crop failure towards the dry season which has caused farmers nightmare in Bauchi State have prompted this investigation into the causes of such early dry spell in the area. Affected areas include parts of Bauchi, Toro, Tafawa Balewa and Dass Local Government Areas of Bauchi State. The crop failure starts with the leaves showing signs of moisture stress a week or two (depending on the severity of the problem) after cessation of rainfall. This problem had left so many farmers in these areas with famine throughout the season since most of them lack the capacity to provide water inform of irrigation to the crops in the field. Crops grown soil derived from sandstone parent materials include millet, maize, groundnut and cowpea while in soil derived from basement complex, crops like sorghum, soya beans, cowpea and rice were the most noticeable crops.

One possible way of investigating the cause of this moisture stress in these areas is through an assessment of soil moisture retention and release characteristics. Such an assessment of water retention and release characteristics was not available in agriculturally potential Bauchi State, Nigeria. Keeping this in view, this study was undertaken to evaluate the soil water retention and release characteristics in parts of Bauchi State under soil of basement complex and sandstone origin with the view to reveal the major cause of moisture inadequacy in soil derived from basement complex.

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.

Climate of the Study Area

The state experiences two main seasons; rainy and dry season. 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: Ekelemeet *al*., (2014)

Sampling Technique

The samples were taken from two different locations within a local government area. One local government area was usedeach in thetwo soil formations.Triplicate 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). A total of 54 samples were used in each location given rise to 216 samples in all. The names of the specific locations where samples were taken and the coordinates marked using Geographic Positioning System (GPS) were presented in Table 1 below

Table 2: Sample Locations and their Coordinates

Site	Latitude	Longitude	Evaporate (m.a.s.j)
Gumau	N10° 15’ 8’’	E09° 0’ 55’’	830m
Buzaye	N10° 14’ 53’’	E09° 39’ 38’’	667m
Gar	N10° 04’ 46’’	E10° 15’ 26’’	379m
Yankari Road	N10° 03’ 05’’	E10° 17’ 20’’	361m

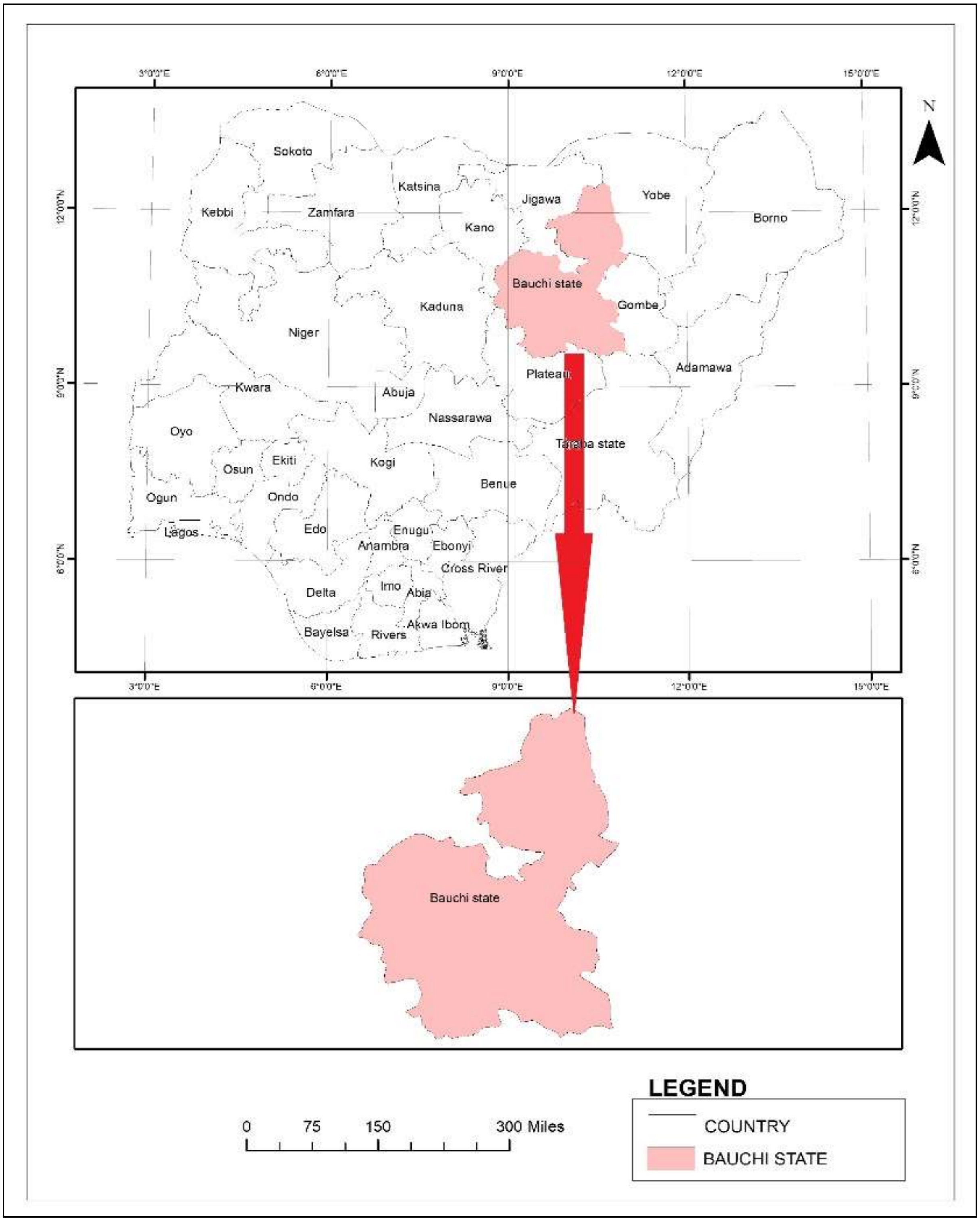

Figure 1: The Study Area

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). 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 sieved 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 even at 105^{0}C for 24hours and its weight (W_2) was recorded. Bulk density was calculated at each tension levels that is Bulk density = weight of dry soil/volume of the cylinder (Ws/Vt) as presented in appendix i. Where Ws = weight of solid and Vt = volume total

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 (Mw/Ms x 100) as described by Anderson and Ingram, (1993) and presented in appendix i

Moisture content at field capacity

Moisture content at field capacity was the mass wetness at 0.33baras shown in appendix I (Anderson and Ingram, 1993).

Moisture content at permanent wilting point

Moisture content at permanent wilting point was 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 that is Mass wetness at 0.33bar – mass wetness at 15bar as shown in Table 3 (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 taken each/depth/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 carried out in triplicate at all the level of tension 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 even-dried at 105^{0}C for 24hoursand 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
Gar	0 – 20	93.50	73.60	12.16	14.24	Loamy sand
	20 -40	95.40	69.60	16.16	14.24	Loamy sand
	40-60	94.80	75.04	12.00	12.96	Loamy sand
Yankari Road	0-20	94.20	73.60	12.16	14.24	Loamy sand
	20-40	95.60	75.04	12.56	10.96	Loamy sand
	40-60	97.53	74.80	11.32	13.88	Loamy sand
Gumau	0-20	50.46	50.32	29.68	21.44	Sandy clay loam
	20-40	55.09	52.32	21.44	26.24	Sandy clay loam
	40-60	49.90	51.68	25.44	26.24	Sandy clay loam
Buzaye	0-20	78.54	54.32	19.44	26.24	Sandy clay loam
	20-40	83.06	52.32	21.44	26.24	Sandy clay loam
	40-60	84.32	52.32	21.41	26.24	Sandy clay loam

Table 4: Hydraulic Parameters of Soil of Sandstone and Basement Complex Origin (Alkaleri and Toro LGA) on Uncultivated Land in Bauchi State.

Sample No	Soil Depth	Bulk Density	FC (water%)	PWP (water%)	Available water(%)
GR (I)	0-20cm	1.36	16.60	29.60	13.00
GR(II)	20-40cm	1.14	20.00	34.60	14.60
GR (III)	40-60cm	1.17	22.00	34.90	12.90
YR(I)	0-20cm	1.20	15.00	33.20	18.20
YR(II)	20-40cm	1.20	18.00	33.20	15.20
YR(III)	40-60cm	1.20	17.00	31.60	14.60
GM(I)	0-20cm	1.42	16.10	29.50	13.40
GM(II)	20-40cm	1.28	18.10	21.90	3.80
GM(III)	40-60cm	1.13	22.90	28.60	5.70
BZ(I)	0-20cm	1.44	11.90	16.90	5.00
BZ(II)	20-40cm	1.10	18.10	23.40	5.30
BZ(III)	40-60cm	1.22	18.40	22.40	4.00

FC = Field capacity
PWP = Permanent wilting point

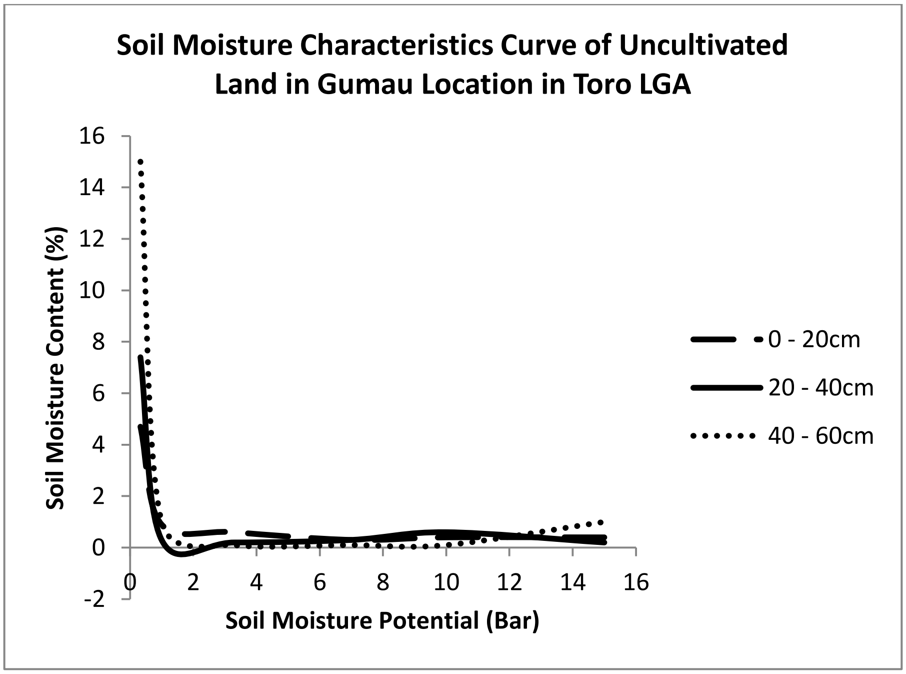

Figure2: Soil Moisture Characteristics Curve of Uncultivated Land of Gumau in Toro Local Government Area of Bauchi State.

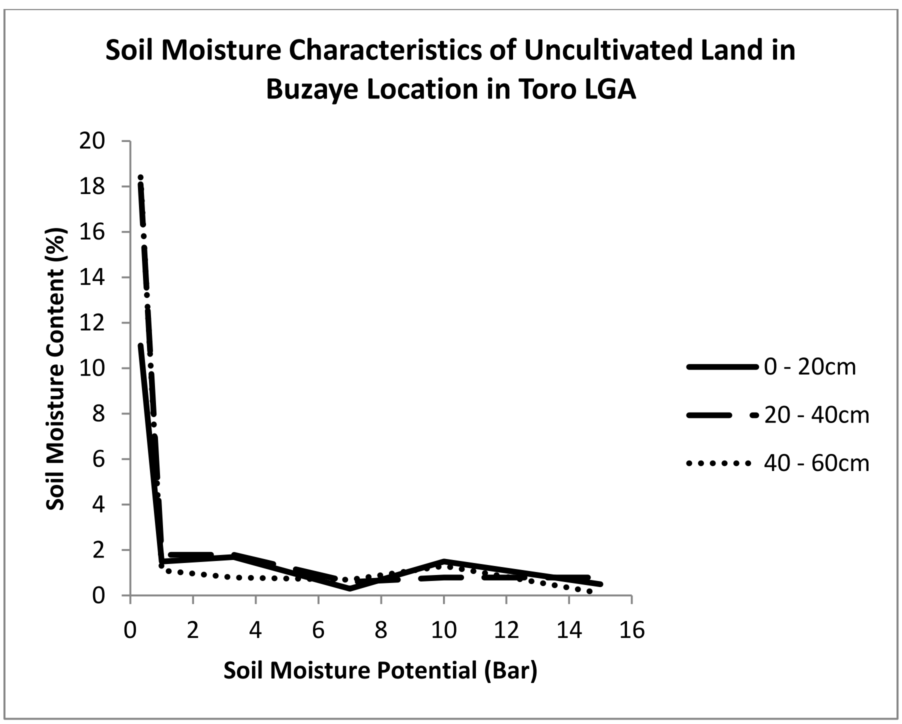

Figure3:Soil Moisture Characteristics Curve of Buzaye in Toro Local Government Area of Bauchi State.

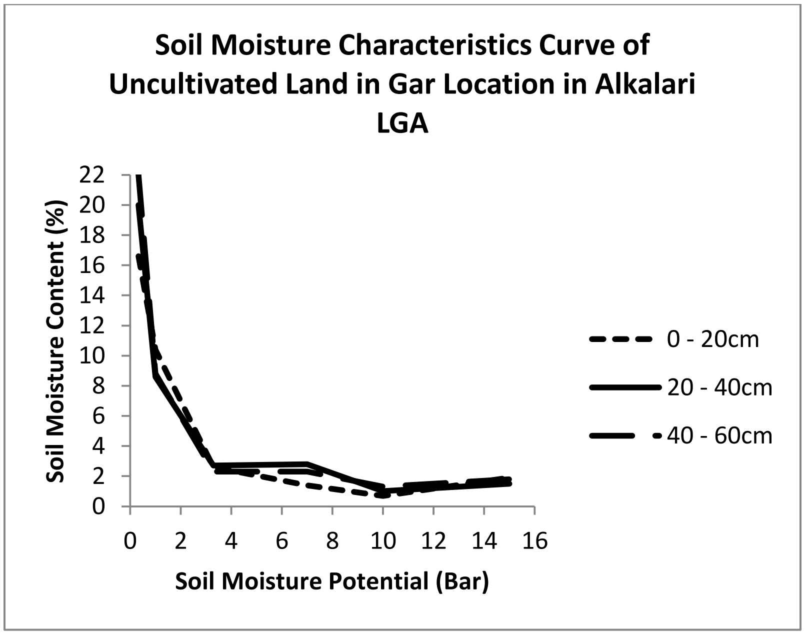

Figure4: Soil Moisture Characteristics Curve Of Gar Village in Alkaleri Local Government Area of Bauchi State.

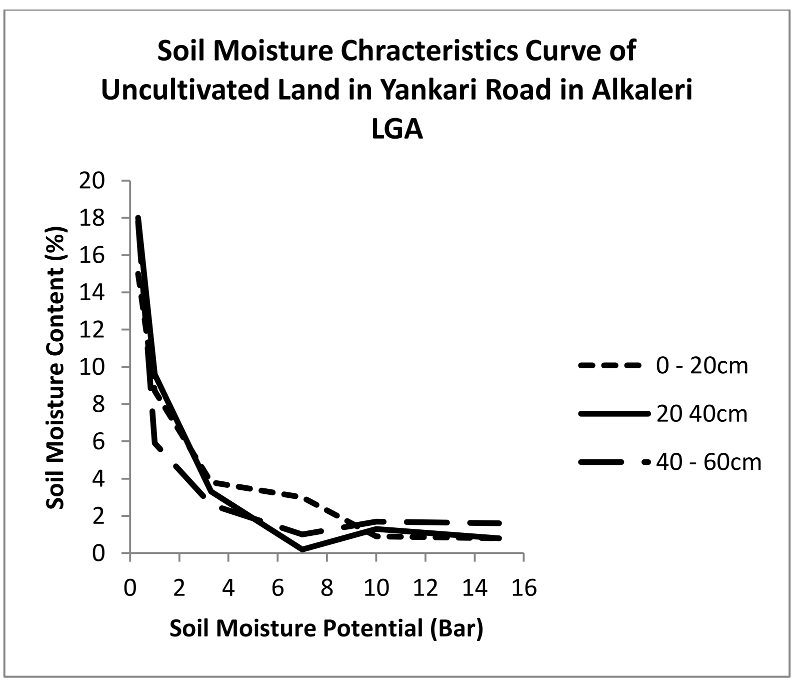

Figure 5: Soil Moisture Characteristics Curve of Yankari Road in Alkaleri Local Government Area of Bauchi State.

Discussion

Table 3 showed the textural class of the study area. From the Table 3,Alkaleri representing soil derived from sandstone parent material was of loamy sand class while Toro Local Government representing basement complex parent materials was of sandy clay loam. Table 4 showed the soil hydraulic parameters such as field capacity (FC), permanent wilting point (PWP) and available moisture. From the Table 4, moisture was higher at field capacity, permanent wilting point and available form in soil derived from sandstone compared to that of basement complex parent material.

Figure 2 and 3 represented the soil moisture retention curve of Gumau and Buzaye respectively.From the beginning, the curves of Gumau (Fig. 2) and Buzaye (Fig. 3)experienced a very steep slope at low tension between 0 – 1bar, which is an indication of high available moisture lost at lower tension. Afterwards, the curves ran more or less parallel to the soil moisture tension axis, indicating that little or no moisture was released between field capacity and permanent wilting point. This result was also reported by Obi and Akamigbo, (1981) " when the curve runs more or less parallel to the soil moisture tension axis, it implies that little or no water is released between FC and PWP, as observed for some fine-textured soils in Nsukka; but when the curve slopes down quickly and then subsequently becomes gentle, it implies that much of the AWC of the soil sample is lost at very low tension" The curves were all horizontal from 1bar down to tension of 15bars indicating no available moisture at higher tension. Also, the curves did not differ essentially from each other as a result of similar mechanical contents of the sample.

The soil moisture retention curve of Gar (Fig. 4)and Yankari Road (Fig.5) all in Alkaleri Local Government Areas are similar in nature due to similar mechanical content. Both curves showed gradual slope from the beginning to 7bar and turn gentle till 15bar. This was an indication of free flow of plant available moisture for plant use at all tension levels. 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 ofVucic, (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 results were found 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 – 7bar was as a result of high 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).

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 parent material exhibited higher plant available moisture at most tension levels evaluated compared to soils derived from basement complex parent materials. The result also showed that plant available moisture was fast lost at lower tension level of 1bar in soils derived from basement complex whereas in soils derived from sandstone parent materials, it was slowly and steadily released till tension of 15bar. Therefore, early planting or early maturing or drought resistance varieties of crop is recommended for planting in soil derived from basement complex parent material to avoid dry spell that could cause complete loss of crops.

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