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

Impact of Aggregate Stability on Plant Available Moisture Content in Bauchi State

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(Received in November 2024; Accepted in December 2024)

Abstract
Soil quality, aggregate stability, plant available moisture content and pore structure of any land can be influenced by management practices but the manipulability of this structure largely depends on soil properties such as texture and water quality. This study investigated the comparative impact of aggregate stability on plant available moisture content between soil derived from basement complex and sandstone geology in Bauchi State. Composite samples were collected randomly within 0 – 60cm at an interval of 0 – 20cm from four locations each in four Local Government Areas of the state. The Local Governments were Toro, Bauchi, Darazo and Alkaleri. Nested design was used in this study. Aggregate stability and soil texture were assessed using standard procedures. Plant available moisture content was determined through laboratory procedure. The result revealed that soil derived from basement complex parent material had significantly ($p < 0.05$) larger aggregate stability compared to soil derived from sandstone parent material. Findings also revealed that plant available moisture content was significantly ($p < 0.05$) higher in soil derived from sandstone compared to soil derived from basement complex parent materials. Further research is recommended to explore management practices aimed at promoting aggregate stability that will improve plant available moisture in soil derived from basement complex geology in the Bauchi State to increase crop production in the area.

Keywords: Aggregate stability, Plant available moisture, parent material, texture, management practices.

Introduction

Large scale soil and water conservation and management against disaster and risk requires very often a thorough understanding of the transport processes in the unsaturated zone and the integration of this knowledge into holistic management and engineering approaches. While a fairly adequate description of these processes has been aided at the experimental local level by the present availability of accurate measuring techniques and devices, it is still difficult to make reliable predictions on their evolution, particularly at the space and time scales of interest for environmental planning .In that connection, soil pores display a number of important characteristics related to the storage, conductivity and movement of soil water and gases. The volume of pore-space, size, shape, type and continuity of pores and distribution in soil are the main factors that influencing water storage, infiltration, hydraulic conductivity and surface (water runoff) and subsurface water movement in soil (Klute, 1972). The unsaturated condition of soil water content is a major state in nature after irrigation process or rainfall. The quantitative application of the theory of unsaturated flow to field or laboratory flow system requires knowledge of the hydraulic conductivity and water characteristic of the soil involved (Klute, 1972).

An effective use of waste, run-off and drainage water in arid and semi-arid zones with limited water resources could be a viable practice to reduce fresh water requirement. Therefore, in time of various climate changes scenario, to assess alternative water sources is particularly critical to control amount and pollution of fresh water bodies. Use of alternative water sources in semi arid soils may; offer opportunity for ground water recharge and alleviate the shortage of water, assist to increase financial gain since plants act as a treatment during evapo-transpiration, alter quantity and distribution of soil micro-organisms, modify soil physical and chemical properties, affect soil structure and physical condition, run off generation and erosion (Jiao *et al*., 2010). Soil aggregate and structure stability is one of the vital physical parameters employed in agricultural and environmental studies, which involved irrigation and drainage management, erosion, run-off and water pollution. One of the core characteristics that affected soil structure are the soil texture and water quality, which is expected to be modified with application of different water resources, because of their contribution on solution electrolyte concentration and composition (Levi, *et al*., 2003).

The difficulty to quantify the impact of soil properties and water type on soil structure stability has been commonly recognized. The effects of water quality on structure and macropore continuity of soil with different texture and property are not clearly understood (Levi *et al*., 2003; Bronick and Lal 2005). This difficulties could be associated with a number of physical and physic-chemical mechanisms of soil aggregate breakdown by water such; slaking, breakdown caused by compression of entrapped air during fast wetting, breakdown by differential swelling, breakdown by impact of raindrops, physic-chemical dispersion because of osmotic stress upon wetting with low electrolyte water(Le Bisonnais, 1996). These mechanisms differ in the type of energy involved in aggregate disruption and in aggregate size distribution of the disrupted products, and hence in the type of soil and soil properties affecting the mechanisms. Changes in the macro pore system of the soil appear to be the prevailing factor for soil physical properties, infiltration and hydraulic conductivity decline and sealing and run-off generation during irrigation and precipitation. Soil structure deterioration and decreases in infiltration may result in surface run-off, which leads to surface contamination by the effluents and soil erosion. Most of the studies mentioned a significant decrease in soil permeability after the application of rain, run-off or waste water (Shainberg*et al*., 2002; Green *et al*., 2003). The aim of this study is to reveal the impact of aggregate stability on plant available moisture in the study area.

Materials and Methods

Geographical Location of Bauchi State

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 (Fig. 1) (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 (UNDP Report 2018).

Climate of the Study Area

The state experiences two main seasons; rainy and dry seasons. The rainy season usually commence 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)..

Sample Locations

The samples were taken from four different locations within each of the Local Government Area. Two locations each from cultivated and uncultivated lands in two Local Government Areas from soil derived from sandstone and that of basement complex parent materials. The names of the specific locations where samples were taken and the coordinates marked using Geographic Positioning System (GPS) were as follows;

Table 1: Location and Elevation of study sites

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
Gumau	N10^{o} 15’ 8’’	E09^{o} 0’ 55’’	830m
Buzaye	N10^{o} 14’ 53’’	E09^{o} 39’ 38’’	667m
Birshe Fulani	N10^{o}14’ 46.3’’	E009^{o} 40’ 39”	638m
MarabaLinman	N10^{o} 05’.88”	E009^{o} 40’ 39”	626m
Dindima	N10^{0} 14’.27”	E10^{o} 08’ 37”	444m
Gubi	N10^{o} 27’ 42.2’’	E009^{o} 49’ 57.8’’	603m
Alkaleri	N10^{0}16’14.0”	E10^{0}20’36.0”	385m
Gargawu	N10^{0}16’12.3”	E10^{0}20’36.0”	385m
Gar	N10^{o} 04’ 46’’	E10^{o} 15’ 26’’	379m
Yankari Road	N10^{o} 03’ 05’’	E10^{o} 17’ 20’’	361m
Darazo	N10^{o}53’57.9	E10^{o} 24’ 06.2’’	513m
Killi	N11 06 55.2	E10 25’ 46.9’’	491m
MarabaHashidu	N10^{o}53’20”	E10^{o} 37’ 76.3’’	335m
Konke	N11^{0} 13’ 11’	E010^{0} 45’ 53”	495m

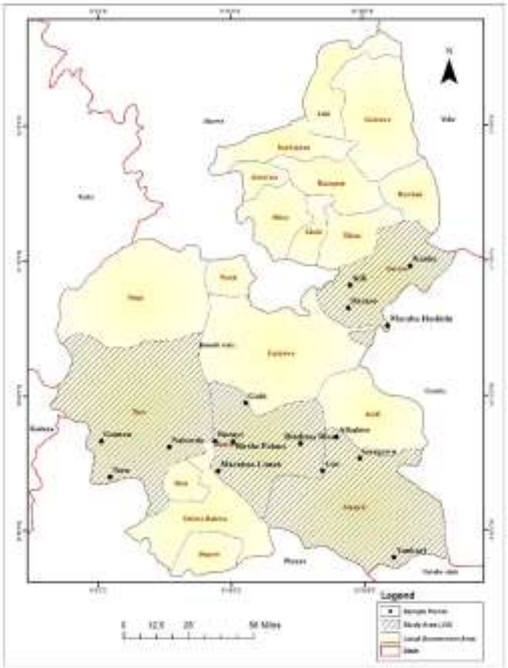

Figure 1: Map of Bauchi State Showing Local Government Areas and Sampling Points

Experimental Design

The nested design procedure was used for this research work. Composite samples taken per depth were nested on the locationsin four local government areas of the state. Two of the local government areas each were further nested in two parent material type (Basement complex rock and sandstone) within the study area in Bauchi State.

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 105^0C for 24hours and its weight (W_2) was recorded. Bulk density was calculated at each tension levels.

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).

Soil moisture content on volume basis

Moisture content on volume basis (volume wetness) was determined by multiplying percent moisture content on mass basis by bulk density (Anderson and Ingram, (1993).

Moisture content at field capacity

Moisture content at field capacity was determined by multiplying the mass wetness obtained at 0.33bar tension by the bulk density of same sample (Israelson and Hanson, 1962).

Moisture content at permanent wilting point

Moisture content at Permanent wilting point was determined by multiplying the mass wetness obtained at 15bar by the bulk density of same sample (Israelson and Hanson, 1962).

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 (Israelson and Hanson, 1962).

Aggregate stability

Three samples collected from each depth were combined to form a composite sample. The samples were sieve through 2mm diameter sieve. 10g of the sieved soil was placed on 0.25mm sieves on a container filled with distilled water such that the water surface is just above the soil sample. The sieve was then move up and down in the water through vertical distance of 30 oscillations. After this, the soil was dried and weighed. Calgon solution was added to the sample and running water allowed to pass through the mixture to get sand separates. The sand was dried and weighed as described by Emerson, (1964).

Data Analysis

The dataobtained on aggregate stability and plant available moisture content was subjected to fully nested analysis of variance (ANOVA) using Minitab software version 15.

Results

Table 2: 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
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
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
MararabaHashidu	0-20	97.34	75.04	13.56	11.40	Loamy sand
	20-40	98.10	77.60	11.44	10.96	Loamy sand
	40-60	97.80	79.60	9.44	10.96	Loamy sand
Konke	0-20	96.71	65.60	17.44	16.96	Sandy loam
	20-40	98.00	63.60	17.44	18.96	Sandy loam
	40-60	97.80	63.60	18.44	17.96	Sandy loam
Toro	0-20	40.10	66.32	21.44	12.24	Sandy clay loam
	20-40	51.50	53.32	31.44	16.24	Sandy clay loam
	40-60	77.20	36.24	33.44	30.34	Sandy clay loam
Nabordo	0-20	88.00	64.32	16.24	19.44	Sandy clay loam
	20-40	89.60	64.32	25.44	10.24	Sandy clay loam
	40-60	91.80	62.32	25.44	12.24	Sandy clay loam
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
BF	0-20	81.50	55.60	13.44	30.96	Sandy clay loam
	20-40	77.40	57.60	9.44	32.96	Sandy clay loam
	40-60	79.60	53.60	17.44	28.96	Sandy clay loam
Gubi	0-20	88.80	56.60	25.44	18.96	Sandy clay loam
	20-40	77.10	54.24	22.80	22.96	Sandy clay loam
	40-60	43.20	58.24	16.80	24.95	Sandy clay loam
M Lanman	0-20	79.33	56.24	19.52	24.24	Sandy clay loam
	20-40	76.21	52.60	21.44	26.24	Sandy clay loam
	40-60	77.01	53.60	17.44	28.96	Sandy clay loam
Dindima R	0-20	81.32	56.24	21.52	22.24	Sandy clay loam
	20-40	73.38	55.60	23.44	20.96	Sandy clay loam
	40-60	67.42	60.60	17.44	21.96	Sandy clay loam

Table 3: 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(g/cm^3
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
GR (I)	1 – 20cm	1.36	16.60	29.60	13.00	17.68
GR (II)	20 - 40cm	1.14	20.00	34.60	14.60	16.64
GR (III)	40 – 60cm	1.17	22.00	34.90	12.90	15.09
YK (I)	1 – 20cm	1.20	15.00	33.20	18.20	21.84
YK (II)	20 – 40cm	1.20	18.00	33.20	15.20	18.24
YK (III)	40 – 60cm	1.20	17.00	31.60	14.60	17.52
MH (I)	1 – 20cm	1.10	20.30	37.70	17.40	19.14
MH (II)	20 - 40cm	1.10	19.70	36.10	16.40	18.04
MH (III)	40 – 60cm	1.10	17.50	29.80	12.30	13.53
KK (I)	1 – 20cm	1.43	18.20	24.70	6.50	9.30
KK (II)	20 – 40cm	1.36	14.52	27.20	12.68	17.24
KK (III)	40 – 60cm	1.33	15.90	30.30	14.40	19.15
DZ (I)	0-20cm	1.43	12.9	28.4	15.50	22.2
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

FC = Field Capacity, PWP = Permanent Wilting Point.

Table 4: Soil Hydraulic Parameters of Soil of Basement Complex Origin (Toro and Bauchi LGA) in Bauchi State.

Sample No	Soil Depth	Bulk Density	FC (water%)	PWP (water%)	Available water(%)	Volume water(g/cm3)
TR (I)	0-20cm	1.37	17.90	31.70	13.80	18.90
TR (II)	20-40cm	1.36	19.50	23.60	4.10	5.60
TR (III)	40-60cm	1.38	21.30	27.40	6.10	8.40
NB(I)	0-20cm	1.36	18.40	26.20	7.80	10.6
NB(II)	20-40cm	1.33	20.60	27.80	7.20	9.60
NB(III)	40-60cm	1.36	18.20	24.20	6.00	8.20
GM(I)	0-20cm	1.42	16.10	29.50	13.40	19.03
GM(II)	20-40cm	1.28	18.10	21.90	3.80	4.86
GM(III)	40-60cm	1.13	22.90	28.60	5.70	6.44
BZ(I)	0 -20cm	1.44	11.90	16.90	5.00	7.20
BZ(II)	20 – 40cm	1.10	18.10	23.40	5.30	5.83
BZ(III)	40-60cm	1.22	18.40	22.40	4.00	4.88
BF(I)	0-20cm	1.37	15.50	22.70	7.20	9.90
BF(II)	20-40cm	1.23	24.40	37.80	13.40	16.50
BF(III)	40-60cm	1.24	25.60	32.50	6.90	8.60
GB(I)	0-20cm	1.42	15.20	19.50	4.30	6.10
GB(II)	20-40cm	1.52	26.80	31.40	4.60	7.00
GB(III)	40-60cm	1.51	23.00	29.50	6.50	9.80
ML(I)	0-20cm	1.20	14.50	20.20	5.70	6.84
ML(II)	20-40cm	1.21	19.80	27.50	7.70	9.32
ML (III)	40 – 60cm	1.30	18.70	23.80	5.10	6.63
DR(I)	0-20cm	1.20	14.70	19.00	4.30	5.16
DR(II)	20-40cm	1.43	14.50	18.00	3.50	5.01
DR(III)	40 – 60cm	1.31	18.50	23.40	4.90	6.42

Table 5: The Effect of Aggregate Stability on Available Water Content of the Study Area.

	% aggregate /Depth (cm)					
Location	0-20	20-40	40-60	Total	Mean(%)	Available water(%)
AK	25.6	9.2	1.8	36.6	12.2	53.4
GG	23.9	10.1	2.1	36.1	12.0	47.8
GR	27.2	11.6	2. 7	41.5	13.8	49.4
YR	22.5	9.6	2.3	34.4	11.5	57.6
DZ	28.9	11.9	3.5	44.3	14.8	46.3
KL	29.2	14.5	2.9	46.6	15.5	46.6
MH	21.8	10.7	2.2	34.7	11.6	50.7
KK	28.2	12.4	4.3	44.9	15.0	45.7
TR	46.7	42.5	44.3	133.5	44.5	24.0
NB	29.5	21.2	23.6	74.3	24.8	28.4
GM	33.1	18.5	12.9	64.5	21.5	30.3
BZ	30.8	19.9	22.1	72.8	24.3	18.0
BF	46.0	24.9	39.2	110.1	36.7	35.0
GB	26.7	31.6	43.3	101.5	33.8	15.4
ML	25.9	29.4	31.3	86.6	28.9	22.8
DR	27.8	24.6	35.8	88.2	29.4	16.6

Discussion

Table 2 showed the textural distribution of the study area. From Table 2, the textural class of soil derived from sandstone in Alkaleri Local Government Areas was loamy sand while soil of sandstone origin in Darazo Local Government Area was sandy loam whereas soils derived from basement complex parent material in both Toro and Bauchi Local Government was sandy clay loam. Table 3 and 4 represented the hydraulic parameters (FC, PWP and plant available moisture) of the study area. Table 3 representing the hydraulic parameters of soil derived from sandstone parent material did not differ much from each other as regard to moisture at field capacity, PWP and available moisture to plants but differ considerably ($p<0.05$) with Table 4 representing the hydraulic parameters of soil derived from basement complex parent materials. The aggregate stability of the soil sample as it was related to available water content was presented in Table 5. The percentage of aggregate stability among soil samples in the study area indicated a significant ($p < 0.05$) differences in the proportion of aggregates between soils derived from basement complex and that of sandstone parent materials with those of basement complex parent materials having larger percentage compared to areas covered by soil of sandstone origin. This could be attributed to high clay content in soil derived from basement complex. This result is in agreement with the work of Levi, *et al*., (2003) who reported that susceptibility of aggregate to disintegration increases with the decrease in soil clay content. Also from Table 5, it was observed that the proportion of percentage aggregate had an inverse relationship with the available moisture. The higher the aggregate percentages the lower the available water to plants and vice-versa. This could be attributed to greater internal porosity exhibited by soil with larger aggregates. The same result was also reported by Wittmus and Mazuak (1958).He reported that the larger aggregates had greater internal porosity than smaller aggregate and therefore exhibited higher moisture retention. This could be also because higher aggregates have higher microporosity that promoted moisture retention than release due to high clay content. This is in agreement with the work of O'Geen, (2013) who stated that although fine textured soils have the highest total water storage capacity due to large porosity values, a significant fraction of water is held too strongly (strong matrix forces/low, negative water potentials) for plant uptake. Plant available moisture was significantly ($p < 0.05$) higher in soil derived from sandstone parent materials compared to soil derived from basement complex. The higher plant available moisture in soil derived from sandstone could be due to high content of fine fractions in the soil of the area as also reported by Vucic, (1987). He opined that potential free water (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. Also Mbagwu (1987) opined that, considering only particle size fractions, available water storage increased with silt content and decreased with clay or sand content.

Conclusion

Soil quality, aggregate stability, plant available moisture content and pore structure of any land can be influenced by management practice but the manipulability of this structure largely depends on soil properties such as texture. The higher aggregate stability observed in soil derived from basement complex compared to soil of sandstone parent material was as a result of high clay content in the soil derived from basement complex parent material. The higher plant available moisture (PAW) in soil derived from sandstone parent material was because their textural classes gave rise to a wide range of pore size distribution that results in an ideal combination of meso- and micro-porosity. Further research is recommended to explore management practices aimed at promoting aggregate stability and maximizing plant available moisture in soil derived from basement complex geology.

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