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ASSESSMENT OF PRODUCTIVITY STATUS OF VERTISOLS IN SUDAN SAVANNA ZONE OF NIGERIA

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ABSTRACT
Higher water and nutrient retention of vertisols make it an important soil order with greater potentials for intensified agricultural production, especially in Sahel and Sudan Savannah; where rainfall is inadequate and erratic, as well as poor soil nutrient base. Hence, its utilization begs for research intervention for sustainable management. One hundred and twenty (120) each of composite and core samples were collected from the eastern part of Jigawa state (Longitude 12. 14 – 12. 69˚N; Latitude 9. 54 – 10. 21˚ E) at three varying depths: 0 – 30, 30 – 60 and 60 – 90 cm. The samples were prepared and analysed employing standard procedures. Result after statistically analysis showed that, the Vertisols pH status ranged from moderately acidic at the surface (0 – 30 cm) through slightly acidic (30 – 60 cm) and moderately alkaline (60 – 90 cm). Organic carbon, total nitrogen and available phosphorus were low in all the depths. Most of the exchangeable bases were medium to high and a medium cation exchange capacity throughout. The Vertisols was texturally sandy clay loam throughout, highly aggregated and low in permeability. It can be inferred that, Vertisols in the Sudan Savannah Zone of Nigeria has good production potential to rice and Wheat crops. But maize and tomato could not thrive well due to little permeability observed, which indicates waterlogging tendency. However, complimentary application of organic and mineral fertilizers is required to argument its nutrient reserve for optimum and sustained production. Incorporation of crop residue and off season ploughing will go a long way in enhancing its water hydraulic conductivity (permeability) and reduction of surface caking which facilitates runoff and nutrient loss.

Keywords: Vertisols, productivity, water and nutrient retention; Sudan Savannah, sustainability.

INTRODUCTION

Vertisols is one of the twelve soil orders (Soil survey staff, 2000, Michael and Dunn, 2000, Brady and Weil 1999) and is characteristically dark in colour, hence the common names; Black Earths, Black Cotton soils, Dark Cracking soils (Dudal 1965). However, that does not signify organic matter content. The name 'Vertisols' was derived from a Latin word *Vetere/Verto*, meaning to turn (Brady and Weil, 1999; Jutzi, *et al*., 1988). Inconsistencies exist in the description of Vertisols between the classification systems used. United State Soil Taxonomy describes Vertisols as mineral soils that have a mesic, isomesic or warmer soil temperature regime; that do not have a lithic or paralithic contact or petrocalcic horizon or duripan within 50 cm of the soil surface; that, after the upper soil to a depth of 18 cm has been mixed, have 30% or more clay in all horizons down to a depth of 50 cm or more; that at some period in most years have cracks that are open to the surface or to the base of a lower layer and are at least 1cm wide at a depth of 50 cm unless the soil is irrigated; and that have one or more of the following characteristics: Gilgai; at some depth between 25 cm and 1m, slickensides close enough to intersect; or at some depth between 25 cm and 1 m, wedge – shaped (sphenoid), structural aggregates whose long axes are tilted 10° to 60° from the horizontal."

The World Reference Base (WRB) system, on the other hand describes Vertisols as soils with high shrink – swellproperties having diagnostic ochric epepedon, usually without argillic epepedon (Michael and Dunn, 2000). However, Pal *et al.* (2009) had reported that Vertisols can also have argillic horizon. Vertisols are soils with high content of clay minerals that shrink and swell as they change water content. The shrinking – expansion property is as a result of the presence of interparticle and intraparticle porosity with changes with moisture content (Pal *et al*., 2012). This is in contrast to the commonly invoked process of clay interlayer hydration – dehydration to explain shrink – swell phenomenon (Pal *et al.*, 2012). As Vertisols dry, the contraction property brings about wide cracks, which permit deep water percolation at initial entry and subsequently becomes very slow upon swelling. Vertisols have a more uniform soil profile; a self – mixed.

Distribution of Vertisols

In the taxonomic nomenclature, Vertisols bear formative element 'ert' and are most commonly formed in warm, sub – humid or semi – arid climates (Jutzi,*et al.,* 1988) where the natural vegetation is predominantly grass, open forest, or desert shrub (Pal,*et al.*, 2012). Globally, Vertisols comprise of about 2.5% (about 250 mha) of the total land area (Brady and Weil, 1999).Large areas of Vertisols coverage are found in Northeastern Africa, India, and Australia with smaller areas scattered worldwide (Smith, 2016; Ahmad, 1996). Five countries; namely; Australia, India, Sudan, Chad and Ethiopia contain over 80 % of the total area of Vertisols coverage in the world (Virmani,*etal*., 2000;Wilding and Coulombe, 1996). In Africa, Sudan, Chad and Ethiopia are the countries with larger area of Vertisols: 40 mha, 16.5 mha and 10 mha respectively (Asnakew, 1999). Vertisols in Nigeria occur over an area of about 4 mha between latitudes 8°30' and 12°30'N and longitudes 10° and 14° E within Savannah ecological zone of the country (Klinkenberg and Higgins, 1968). Ojanuga, (2006); Kowal and Knabe, (1972) reported that in Nigeria, Vertisols predominantly occur in the Sudan and Northern Guinea Savannah Zones in the northwest and northeast of the country. Generally, Vertisols are most commonly found in lower landscape such as depression, bottomlands, lower foot slope (Pal,*et al.*,2012). In Jigawa state, even though there is no inventory of area of coverage of Vertisols, but its large fraction is found in the eastern part of the state within Hadejia river basin. The area is topographically low and flooded for part of every year.

Although Vertisols cover only a small area of the world's land surface and only a sub-dominant portion of any geographical zone, but is an important soil order particularly in drylands (Adeoye, 1992). The major factor contributing to the productivity of Vertisols in semi – arid environments is its high water-holding capacity (Virmani,*etal*., 2000). In this area, rainfall is uncertain, inadequate and highly variable (Ojanuga, 2006). For this, the ability of Vertisols to store sufficient water to carry crops through droughty periods is of great importance. More so, high surface area that ranged from 628 to 770 m^2/g (Abdu and Uyovbisere, 2007, Adeoye, 1992) could support higher production by increasing nutrient retention, which is alimiting factor in Sudan savannah soils (Ojanuga, 2006). Because of its high clay content, vertisols is as well resilient to degradation compared to other soils. As such, Vertisols is considered significant global resources that serve as lifeline in subsistence agriculture. However, some characteristics, viz: lesser water intake, more hazards of waterlogging, difficult tillage (due to hardness and stickiness when dry and when wet respectively), poor seedbed conditions, and surface crusting, (Pal,*et al.*, 2012; Dudal, 1973) do pose constraints for cultivation of diverse crops as well as sustained utilization. And some of these problems assume greater importance where a number of crop choices are needed for sustainable intensification to meet huge demand for food and product by man and industries (Myers and Pathak, 2001; Syers,*et al.,* 2001; Virmani *et al*., 2000). Efforts toward comprehensive and successful utilization of Vertisols are imperative for continued productivity and long – term sustainability.

Though Vertisols make up a relatively homogeneous soil order in taxonomic sense, but it is worth notice that they show diverse characteristics that are very important in agronomic context for their suitability to various crop productions. Therefore, adopting a general management and utilization recommendations may be misleading and detrimental. Based on the foregoing, this research was conceived and geared toward investigating some physical and chemical characteristics of Vertisols in Sudan Savannah Zone (SSZ) of Nigeria in order to furnish site specific data and management practice as well as suitable crop choices relevant to the farmers in the research locality for optimum exploitation of its potentials.

MATERIAL AND METHOD

Description of Area of the study

Jigawa State (Longitude 12. 446˚N, Latitude 9.7233˚ E), (Fig. I) has great potentials for agricultural production required for household consumption, commerce and industrial uses. About70 % of the state's landmass is considered arable which makes it one of the mostagriculturally endowed state in Nigeria (Kaugama and Ahmad, 2014). The eastern part of the state (Longitude 12. 14 – 12. 69˚ N, Latitude9. 54 – 10. 21˚ E) is regarded food basket of the state (Wakili, 2016) (Fig. II). The largest area of Vertisols coverage is cropped to rice rotated to wheat and or green vegetables.

Geology, vegetation, hydrology and climatology of the area

The geologic formation of the upstream area consists of largely impermeable Basement Complex Rocks while the lowland area is of alluvial sediments of Chad formation. Rainfall period is from June to October, averaged 600 – 700 mm. Evapotranspiration ranges 1200 – 1500 mm (Sobawole, *et al.*, 2001; Sanyu, 1994) and annual mean temperatures record 12 – 40 ˚C(Roger, 2013). The relief is characteristic of gentle slope. Basic soils of the wetlands are halomorphic and formed of deltaic alluvium. Whereas, the uplands surrounding the wetlands are non – leached ferruginous dune soils (Adams,*et al.*, 1993). Composition of the vegetation entails diverse trees and grass species: *Guiera* spp and *Mitragyna* are foundon low hills, while*Vetiveria* and *Andropogon gayanus* dominate swamp grassland. There are now large expanses of *Azadirachta indica*, *Adonsonia digitata* in many areas and large clusters of coppiced *Hyphaene thebaica* (doum palm) dominate great tracts of land. Many of the swamp grasslands have been succeeded and channels are blocked by an invasive weed species, *Typha dominguensis*.

Sampling frame

The sampling covered the entire eastern part where the Vertisols is dominant ((Long. 12. 14 – 12. 69˚ N, Lat. 9.54 – 10. 21˚E). First, the area was divided into four sampling locations; the east, west, north and south. Ten (10) replicates each of composite and core samples were randomly collected (adopting diamond shaped pattern) from each location to allow for complete coverage. A grand total of 120; (10 x 3 x 4) each of composite and core sample were thus collected for three depths considered; 0 – 30 cm, 30 – 60 cm and 60 – 90 cm. Samples were prepared and stored under standard procedure and subjected to appropriate laboratory analyses.

Laboratory Analysis

Auger (disturbed) samples, were air dried and passed through 2 mm sieve, for determination of particle size distributions by Bouyoucos hydrometer (Gee and Bauder, 1986); soil acidity (pH) in water and $CaCl_2$ as described by (Thomas, 1996); organic carbon by the dichromate wet oxidation method, (Nelson and Sommers, 1982); total nitrogen by the Kjeldahl digestion method (Bremner, 1982); available P by Bray No. 1 method (Bray and Kurtz, 1945), exchangeable bases (Black, (ed) 1965), exchangeable acidity by titration method (McLean, 1965), cation exchange capacity neutral K – acetate saturation and neutral NH_4- acetate Displacement method (Black, 1975) as described by the International Institute of Tropical Agriculture IITA 1979.). Sample that passed through 5mm sieve was used to determine wet and dry mean weight diameters (Van Bavel, 1950) as modified by Kemper and Rosenau, (1986),

Collected Undisturbed core (height = 5 cm, diameter = 4 cm and volume = 62.86 cm^3) samples were used to determine dry bulk density (BD) (Anderson and Ingram, 1993), saturated hydraulic conductivity (Ksat) by constant head permeameter. Macro, micro and total porosities were determined as described by(Jarvis,*et al.*,2002; Dexter and Czyz, 2007; Reynolds,*et al.*, 2008; Dexter,*et al.* 2008) as follows:

Pt = the volume of water at saturation (0.0 bar), Thus

$$Pt = \frac{Ws}{Wd} \times \frac{BD}{\rho W} \quad \text{equation (1)}$$

Where:

Ws = weight of saturated soil

Wd = weight of oven dry soil

BD = Bulk density

ρw = density of water at 20˚C

Macro – porositywas computed using the formula:

$$Pmac = \theta s\ (\psi=0.0\ bar) - \theta m\ (\psi=0.33bar), \quad \text{equation (2)}$$

Where;

θs = Moisture content at saturation,

θm = Moisture content at field capacity,

ψ = Suction/ Pressure

Whereas, microporosity was determined as;

$$Pmic = . Pt - Pmac \quad \text{equation (3)}$$

Where;

Pt = Total porosity

Pmac = Macro porosity

After obtaining aggregate size proportion of various mesh size the following formular was used to compute for mean weight diameters (MWD)

$$MWD = \sum_{i=1}^{n} x_i \omega_i \quad \text{equation (4)}$$

Where:

MWD = Mean Weight Diameter (mm),

n = number of aggregate fractions,

x_i = arithmetic mean diameter of the size fraction and

ω_i= proportion of the total water stable aggregates in the corresponding size fraction after deducting the weight of sand/gravels particles.

∑= Summation.

(Van Bavel, 1950 as modified by Kemper and Rosenau, (1986). Sand correction was done.

Proportional macro aggregate and micro aggregate fractions were computed as described by (Ontel *et al.*, 2015):

$$\frac{Weight\ of\ stable\ macro\ aggregate\ (> 0.25\ mm)}{Total\ weight\ of\ all\ the\ aggregate\ (200g)} \text{ and } \frac{Weight\ of\ micro\ aggregate\ fraction\ (<0.25)}{Total\ weight\ of\ all\ the\ aggregates\ (200g)}$$

respectively

equation (5) and (6)

Statistical analysis

GenStat (ed 4^{th}) was used to run analysis of variance (ANOVA) in order to compare means for the three depths. While, means with significant difference were separate with the least mean square difference (LSD).

RESULT AND DISCUSSION

Chemical Properties

Based on table 1, the soil pH (H_2O) was generally slightly acidic to moderately alkaline (6.11 – 7.90). It was higher at 95 % confidence level in 60 – 90 cm. Similar trend was also recorded with respect to pH in $CaCl_2$ which ranged between 5.44 – 6.33. This could have occurred due to presence of more exchangeable sodium in the lower layer. This agreed with Virmani (2000); Leka *et al.* (2012) who reported pH of Vertisols ranges between 6.3 and 7.4 for the surface soils and 6.9 to 8.0 for the subsoils. Furthermore, the pH (H_2O) was more variable than pH ($CaCl_2$), this may be due the ability of $CaCl_2$ solution to mimic natural field condition.

The result showed that exchangeable calcium (Ca) depicted somewhat uniform distribution but increased slightly with increase in depth. However, no significant difference was observed among the three depths. It ranged 2.81 – 2.95 Cmol/kg and was more variable at 0 – 30 (CV = 3.91 %) Both exchangeable magnesium (Mg) and potassium (K) showed significant variation and were statistically higher at 0 – 30 cm, followed by 30 – 60cm and lastly 60 – 90 cm. The higher Mg and K observed in the surface may be ascribed to their dissolution from soil mineral due to waterlogging. Pal *et al.* (2012) obtained similar trend in India. The exchangeable sodium (Na) on the other hand assumed a reverse trend; meaning it was significantly higher at 60 – 90 cm compared to the two upper depths. This may be attributed to its successive deposition overtime by fluctuating watertable through capillarity rise. The Na was also more variable throughout the depths compared to the others exchangeable bases tested. This may probably be due to fluctuation of soil moisture status and water table, which tend to simultaneously dissolve and deposit sodium ions respectively.

Based on Table 2, cation exchange capacity (CEC) increased uniformly with depth thus observed to be higher at the 60 – 90 cm and was rated low to medium. The linearity depicted by CEC with depth is probably related to increase in clay content. Pal *et al.* (2012) reported in consistent CEC pattern with depth. The electrical conductivity (EC), showered inconsistent result but significantly varied at 0.01% probability level and was higher at 0 – 30 cm, it went down at 30 – 60 cm but sharply increased at 60 - 90 cm. The observed sharp increase in EC in 60 – 90 cm may be in response to the Na content increase. However, there is no threat to salinity development across the depths. Elsewhere, Virmani, (2000) indicated that the soils are not saline, which conform well with this finding.

Three parameters viz; organic carbon (OC) (4.78 – 7.33 g/kg), organic matter (OM) (8.33 – 12.50 g/kg) and total nitrogen (TN) (0.56 – 1.11 g/ kg) presented in Table 1 behaved in similarity. This is because they are from common source. They were all higher in the surface soil, 0 – 30 cm and steadily decrease down the depth, hence, the 60 – 90 cm got least mean value accordingly. Customary/ traditional application of organic materials: animal dung, home wastes and plant leftover, may have resulted in the higher OC, TN and OM in the 0 – 30 cm soil. This is in harmony with finding by (Yule and Ritchie, 1980) who stated that A_l horizon has higher OC, TN and generally decreased in the lower horizons.

Physical properties

Table 3 presented result for particle size distribution. Sand content showed statistical variation, 0 – 30 cm obtained highest value while 60 – 90 cm recorded least mean value. A sharp contrast of that was obtained with respect to clay content. However, the two lower depths (30 – 60, 60 – 90 cm) were statistically similar. Silt percentage was similarly higher in the deeper depths (24.06 and 32.44 g/kg for 30 – 60 and 60 – 90 cm respectively) and more variable at 60 – 90 cm. The higher sand content and lower clay recorded in the 0 – 30 cm may be attributed to gradual deposition of sand particles from neighboring sites. Dudal, (1965) had similarly reported a gradual increase in clay content with depth. It was thought that the increase in clay content with depth is due not to argillation of clay (migration of clay) but not due to inheritance from parent material.

Result for macroporosity (Pmac) consistently decreased with increase in depth. On the other hand, microporosity (Pmic) showed nearly opposite outcome. Total porosity (Pt) reflected zigzag/ broken trend; it decrease at 30 – 60 cm but plateaued at 60 – 90 cm. The two deeper depths showed increased bulk density (BD), whereas, the upper 0 – 30 cm recorded the least mean value statistically ($P \leq 0.05$). The reduced BD may be due to pulverization through tillage operation and organic matter decomposition. This is in concord with Eswaran *et al.* (1988); Mermut *et al.* (1996) and Butler and Hubble, (1977). The bulk density of Vertisols usually tends to increase with depth, due to compression caused by overburden weight.

The 60 – 90 cm showed limited saturated hydraulic conductivity (Ksat) comparative to the two overlying layers. This is attributed to dominance of micropores and surface sealing effect observed in the area. The dry mean weight diameter (MWDd) and macro aggregate proportion indices showed no significant difference across the three depths. Oppositely, the wet mean weight diameter (MWDw) significantly varied, in which 60 – 90 cm and 30 – 60 cm depicted similarity and were higher than the surface layer. The greater mean value in these lower depths may be due to less disturbance and more binding assist by clay. An irregular pattern was observed with respect to microaggregate proportion. The 0 – 30 cm and 60 – 90 cm were statistically not different while the 30 – 60 cm recorded lowest mean values.

CONCLUSION

An investigation was carried-out objectively to determine the productivity potential of Vertisols in Sudan Savannah Zone of Nigeria. Standard procedures for soil sample collection, processing and analyses were adopted. ANOVA was used for the analysis using GenStat ed 13th. From the result, it can be concluded that, the Vertisols is potentially productive and resilient to water and wind degradation. However, addition of both organic and inorganic fertilizer is necessary for attaining optimum agricultural productivity and profitability. Rice and wheat crop could perform well when grown on these soils.

Table 1: Mean values for some chemical properties of the Vertisols at varying depth

Depth	pH (H_2O)	pH ($CaCl_2$)	OC	OM	TN	Avail.P
				g/ kg →		mg/kg ←
0 – 30 cm	6.11b	5.44c	7.33a	12.50 a	1.11a	2.39 a
SD	0.42	0.14	0.17	0.39	0.09	0.08
CV (SD/X)	6.87	2.74	2.32	3.12	8.11	3.35
30 – 60 cm	6.50b	5.78b	5.83b	10.17b	0.89b	2.11b

SD	0.25	0.17	0.21	0.18	0.07	0.09
CV(SD/X)	3.85	2.94	3.60	1.77	7.87	4.27
60 – 90 cm	7.90a	6.33a	4.78c	8.33c	0.56c	1.68 c
SD	0.131	0.79	0.132	0.288	0.085	0.091
CV(SD/X)	1.66	12.48	2.76	3.46	15.17	5.42

CV = coefficient of variance, SD = Standard deviation, X = mean, OM = organic matter, OC = organic carbon and TN = total nitrogen, Avail.P = available phosphorus. Means with the same letter across the column are not statistically different.

Table 2: Mean values for some chemical properties of the Vertisols at varying depth

Depth	Ca	Mg	K	Na	CEC	EC	EA
	cmol / kg					dS/ m	
0 – 30 cm	2.81	1.76 a	0.34a	0.39b	5.28c	0.061b	0.38
SD	0.11	0.04	0.01	0.03	0.13	0.004	0.05
CV (SD/X)	3.91	2.27	2.56	7.69	2.46	6.56	13.16
30 – 60 cm	2.96	1.53 b	0.27b	0.40b	6.05b	0.04c	0.48
SD	0.07	0.04	0.007	0.02	0.13	0.003	0.04
CV (SD/X)	2.36	2.61	2.59	5.00	2.15	7.5	8.33
60 – 90 cm	2.95ns	1.34 c	0.209c	0.613a	6.44a	0.138a	0.41ns
SD	0.064	0.045	0.008	0.043	0.120	0.015	0.065
CV (SD/X)	**2.17**	**3.36**	**3.83**	**7.01**	**1.86**	**10.86**	**15.85**

Ca = Calcium, Mg = Magnesium, K = Potassium, Na = Sodium, CEC = cation exchange capacity, Ec = electrical conductivity, EA = exchangeable acidity, SE = standard error, CV = coefficient of variability, SD = Standard deviation, X = mean. Means with the same letter across the column are not statistically different.

Table 3: Mean values for some physical properties of the Vertisols at varying depth

Depth	Sand	Silt	Clay	Textural class	Pmac	Pmic	Pt
			(%)				
0 – 30 cm	59.17a	19.72b	21.11b	SCL	29.44a	34.58b	64.02a
SD	2.39	2.45	1.03		1.86	1.66	2.15
CV (SD/X)	4.04	12.4	4.88		6.32	4.80	3.36
30 – 60 cm	51.00b	21.22ab	27.79a	SCL	23.61b	33.72b	57.33b
SD	1.62	2.04	0.95		1.97	1.91	1.52
CV(SD/X)	3.18	9.61	3.42		8.34	5.66	2.65
60 – 90 cm	43.5 c	24.06a	32.44a	SCL	19.11c	42.19 a	61.30ab
SD	2.132	2.151	1.5215		0.632	1.998	2.761
CV (SD/ X)	4.9	8.94	4.69		3.33	4.74	4.5

Pmac = macro porosity, Pmic = micro porosity, Pt = total porosity, SE = standard error, CV = coefficient of variability, SD = Standard deviation, X = mean. Means with the same letter across the column are not statistically different.

Table 4: Mean values of some physical properties of the Vertisols at varying depth

Depth	BD	Ksat	MWDd	MWDw	Mac.Agg	Mic. Agg.
	mg/ m^3	mm/s			(%)	
0 – 30 cm	1.00b	2.89a	1.01	0.38b	19.67	78.91a
SD	0.01	0.14	0.04	0.03	1.60	3.63
CV(SD/X)	1	4.84	3.96	7.89	8.13	4.60

30 – 60 cm	1.20a	2.56a	1.10	0.42 a	22.67	75.67b
SD	0.05	0.09	0.03	0.04	2.12	5.533
CV (SD/X)	4.17	3.52	2.73	9.56	9.31	7.31
60 – 90 cm	1.25a	1.83b	1.13ns	0.40a	19.50 ns	79.00a
SD	0.045	0.072	0.033	0.0071	1.181	1.222
CV (SD/X)	3.60	3.93	2.92	1.77	6.06	1.55

BD = bulk density, Ksat = saturated hydraulic conductivity, MWDd = dry mean weight diameter, MWDw = wet mean weight diameter, Mac.Agg = macro aggregate, Mic. Agg. micro aggregate, CV = Coefficient of variance, SD = Standard deviation, X = mean. Means with the same letter across the column are not statistically different.

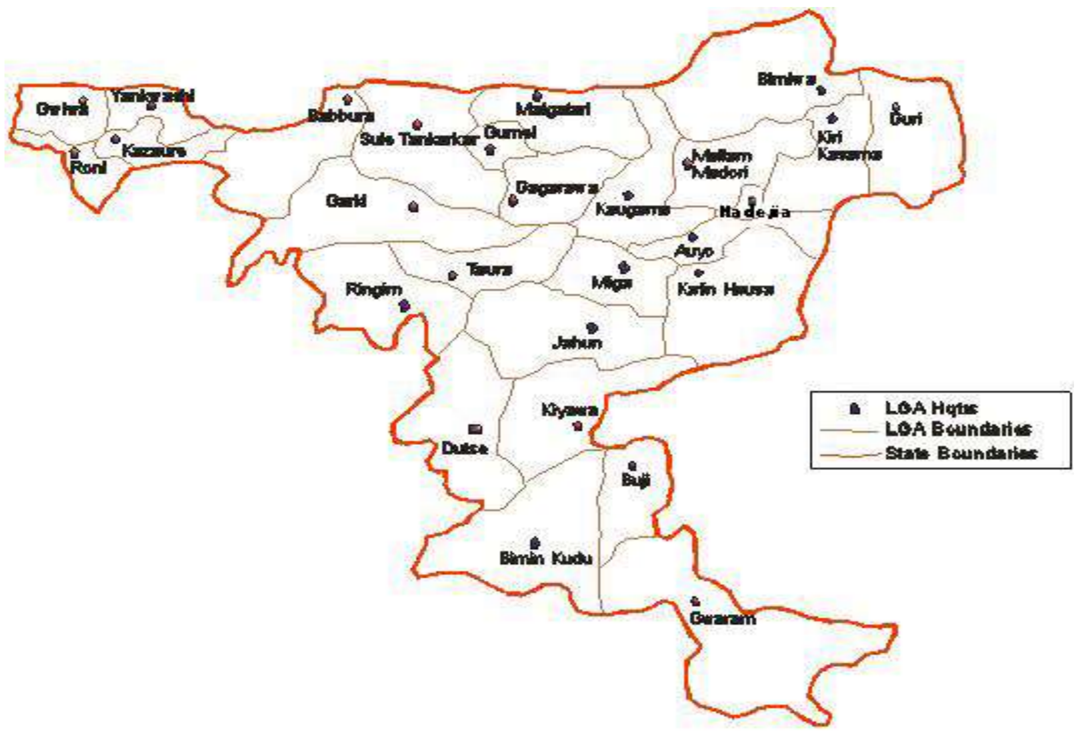

Figure I: Map of Jigawa State, Nigeria

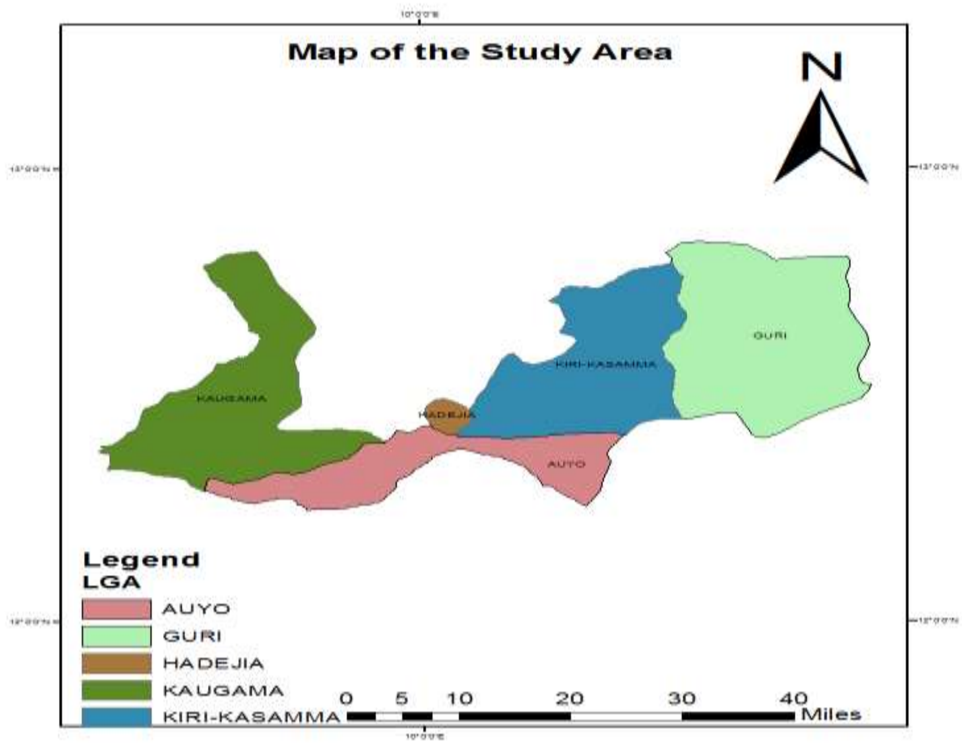

Fig. II: Location of the Study Area

REFERENCES

Abubakar, M.M., Kutama, A.S., Sulaiman, I.M. and Ringim, A.S (2016).Impact of Climate Change on the Hadejia-Nguru Wetlands: A Review.*Dutse Journal of Pure and Applied Sciences 2(1)*.Pp 150 – 158

Ahmad, N. 1986. Soil and Agronomic Factors Influencing Fodder Production in the Ethiopian Highlands of East Africa. PSD Working Paper No. B4. International Livestock Centre for Africa (ILCA) , Addis Ababa, Ethiopia. Pp.58.

Ahmad, N., (1983). Vertisols. Pedogenesis and Soil Taxonomy. : In: Wilding, L.P., Smeck, N.E., Hall, G.F. (Eds.), The Soil Orders, vol. II. Elsevier, Amsterdam.Pp. 91–123.

Ahmad, N., (1996) Occurrence and distribution of vertisols. In: Ahmad, N., Mermut, A. (Eds.), Vertisols and Technologies for Their Management. Elsevier, Amsterdam.Pp. 1–41.

Anderson, J.M and Ingram J.S.I (1993). Tropical Soil Biology and Fertility: A Hand Book of Method. International Walling , U.K. Pp. 38-39.

Asnakew, W., (1987). Physical properties of Ethiopian Vertisols. Proceedings of A conference held at ILCA Adis ababa, Ethiopia, 31 August – 4 September, 1987. Management of Vertisols in Sub-Saharan Africa Pp 111 – 115

Bates, R.G., (1954). *Electrometric pH Determinations*. John Wiley and sons inc. New York.

Black, C.A., (Ed)(1965) *Methods of Soil analysis.* NO.9, (2) American Society of Agronomy Madison, Wisconsin. Pp 34, 41.

Blake, G.R., Hartge, K.H. (1986). Bulk Density, Methods of Soil Analysis, Part 1. Soil Science Society of America. Pp 363 -376.

Brady, N.C and Weil R.R (1999). Role of NPK in Plant Nutrition in the nature and Properties of Soil. Prentice Hill Publishers, New Jersey USA.

Bray, R.H. and Kurtz L.T., (1945*) Determination of Total Organic and Available Forms of Phosphorus in Soil Soil Science*.Pp 59, 39-54.

Coulombe, C.E., Wilding, L.P., Dixon, J.B., (1996). Overview of Vertisols: Characteristicsand Impacts on Society. In: Sparks, D.L. (Ed.), Advances in Agronomy, vol. 57. Academic Press, New York.Pp. 289–375.

Dasog, G.S., Acton, D.F., Mermut, A.R., (1987). Genesis and Classification of Clay Soils with Vertic Properties in Saskatchewan. *Soil Science Society of America Journal* 51.Pp 1243–1250

Dudal, R. (1965). Dark Clay Soils of Tropical and Sub-tropical Regions. Agricultural Development Report 83. FAO (Food and Agriculture Organization), Rome. Pp 161

Dudal, R., Eswaran, E., (1988). Distribution, Properties and Classification of Vertisols. In:Wilding, L.P., Puentes, R. (Eds.), Vertisols: Their Distribution, Properties, Classification and Management. Texas A andM University Printing Centre, College Station, Texas.Pp. 1–22.

Eswaran, H., Kimble, J., Cook, T., (1988). Properties, Genesis and Classification of Vertisols. Classification, Management and Use Potential of Swell–Shrink Soils: In: HirekerurL.R., Pal, D.K., Sehgal, J.L., Deshpande, S.B. (Eds.), INWOSS, October 24–28, 1988.National Bureau of Soil Survey and Land Use Planning, Nagpur.Pp. 1–22.

Eswaran, H., van den Berg, E., (1992). Impact of building of atmospheric CO_2 on length of growing season in the Indian sub-continent. Pedology 42, 289–296.

Haladu, H.K., and Bello, A.A., (2014). Prospect and Challenges of Farming in Hadejia-Nguru Wetland in Jigawa state, Nigeria. *International Journal of Academic Research in Economics and Management.* Vol. 3, 6. Pp 43 -48.

International Institute of Tropical Agriculture, (1979). *Selected Methods for Soil and Plant Analysis.* Manual Series No. 1.Pp 4-14, 37.

Jarvis, N.J., Zavattaro, L., Rajkai, K., Reynolds, W.D., Olsen, P.-A., McGechan, M., Mecke, M., Mohanty, B., Leeds-Harrison, P.B., Jacques, D., 2002. Indirect Estimation of Near Saturated Hydraulic Conductivity from Readily Available Soil Information, Geoderma. Pp1–17, 108,.

Jigawa State Agricultural and Rural Development Authority and Institute for AgriculturalResearch, (1997). *Detailed Survey Report* Vol. III.Pp. 178-179.

Kemper, W.D. and Rosenau, R.C., (Ed) (1986). *Aggregate Stability and Size Distribution Methods of Soil Analysis part 1* Agronomy Society of America and Soil Science Society of America Medison. Pp 425 – 442.

Leka, M., Dragutin D. and Marijana P. (2012).Microbial Characteristics of Vertisol Under Different Fertilization Systems. *Journal of Central European Agriculture*, 13(1).Pp.1 – 9.DOI: 10.5513/JCEA01/13.1.1005.

Mermut, A.R., Padmanabham, E., Eswaran, H., Dasog, G.S., (1996). Pedogenesis. In: Ahmad, N., Mermut, A.R. (Eds.), Vertisols and Technologies for Their Management. Elsevier, Amsterdam.Pp 43–61.

Michael, S.and Dunn, S.M.(2000). Soil: An Introduction(6th ed). Reprinted by Courier Kendall Ville, Pearson Education, Australia

Murthy, R.S., Bhattacharjee, J.C., Landey, R.J., Pofali, R.M., (1982). Distribution, Characteristicsand Classification of Vertisolsand Rice Soils of the Tropics. Symposia Paper II, 12th International Congress of Soil Science, New Delhi. Indian Society of Soil Science. Pp 3–22.

Myers, R.J.K., Pathak, P., (2001). Indian vertisols: ICRISAT's Research Impact — Past, Presentand Future. In: Syers, J.K., Penning de Vries, F.T., Nyamudeza, P. (Eds.), The Sustainable Management of Vertisols. CAB International Publishing, Wallingford.Pp. 203–219.

Ojanuga, A., (2003).Management of Fadama Soil for Environmental Quality.. Proceeding of the 30th Annual conference of Soil Science Society of Nigeria held in the University o Agriculture Makurdi Soc. Management of Fadama Soils for Food Security and Poverty Alleviation. Pp 11, 13-15.

Pal, D.K., Bhattacharyya, T., Chandran, P., Ray, S.K., Satyavathi, P.L.A., Durge, S.L., Raja, P., Maurya, U.K., (2012). Vertisols (cracking clay soils) in a Climosequence of Peninsular, India: Evidence for Holocene Climate changes. Quaternary International.Pp209,6–21.

Roger, B., (2013). An Overview of the Context of the Jewel Project: Access Rights and Conflict Over Common Pool Resources In The Hadejia-Nguru Wetlands. Kay Williamson Educational Foundation 8, Guest Road Cambridge CB1 2AL United Kingdom.

Sobowale, A., Adewumi, J. K. , Otun, J. A. and Adie, D.B., (2010).Water Resources Potentials of Hadejia River Sub-Catchment of Komadugu Yobe River Basin, Nigeria" Agricultural Engineering International: the CIGR Ejournal. Manuscript 1065. Vol. XII. Pp 26 – 33.

Soil Survey Staff (1993). Soil Survey Manual. Soil Conservation Service, (9th Ed), Wahington, D.C. Pp 187, 192.

Syers, J.K., Penning de Vries, F.T., Nyamudeza, P. (Eds.), (2001). The Sustainable Managementof Vertisols. CAB International Publishing, Wallingford.

Van Bavel C.H.M. (1950). Mean Weight Diameter of Soil Aggregate, Soil Science Society of America, 15. Pp 21- 25.

Virmani, S.M, Sahrawat, K.L., and Burford, J.R (2011). Physical and Chemical Properties of Vertisols and their Management. International Crop Research Institute for Semi-Arid Tropic. Pp 81-87.

Wilding, L.P., Coulombe, C.E., (1996). Expansive soils: distribution, morphology and genesis.In: Baveye, P., McBride, M.B. (Eds.), Proceedings NATO-ARW on Clay Swellingand Expansive Soils. Kluwer Academic, Dordrecht, The Netherlands.

Wilding, L.P., Tessier, D., 1988. Genesis of vertisols: shrink–swell phenomenon. In:Wilding, L.P., Puentes, R. (Eds.), Vertisols: Their Distribution, Properties, Classificationand Management. Texas A&M University Printing Centre, College Station, Texas.Pp. 55–79.