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Morphological and physical characterization of Ngurore Vertisols for improved crop productivity in Adamawa State, Nigeria

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ABSTRACT

A soil survey was carried out on the vertisols of Ngurore, Yola South Local Government Area (LGA) of Adamawa State, Nigeria to evaluate the significance of its morphological and physical properties to improve agricultural productivity. Three soil mapping units were identified in the study area designated as NVM (Ngurore Vertisols Mapping unit) 1, 2 and 3 respectively. The mapping units based on their characteristics were defined as *Eutric Chromusterts, Eutric Plinthusterts and Typic Chromusterts* (USDA). The Ngurore vertisols generally exhibits some characteristics unique from other vertisols elsewhere; the particle size distribution appeared to be more of sand than the usual clay and its irregular trends of distribution (average mean sand range: 44.20 – 48.20%). The soils have a moderate bulk density (1.33 – 1.35gcm^{-3}) and good total porosity (53.60 – 55.50%) and poor soil structure. It is therefore recommended that tillage operations should be properly timed, when the soil moisture is moderate for easy land preparation using farm implements and machineries. Incorporation of organic manures will improve soil structure and other vital soil processes e.g. nutrient availability and its uptake, soil aeration, optimum moisture retention etc. Sprinkler method of irrigation discharging water at slower rates is recommended over flood irrigation during the dry season for a sustainable utilization all year round.

INTRODUCTION

Vertisols cover roughly 335 million ha globally (FAO 2001), these soils constitute a group of soils that occur mainly in hot environments (FAO 2006). They are mineral soils that are strongly affected by argillo-pedoturbation under alternate wetting and drying (Zata et al. 2013). Vertisols appears to occur extensively in several countries in Africa under arid, semi-arid, and humid climates, and have an agroecological potential for food production well above their present level of use. Recent research shows that these vertisols are of great productive potentials if well managed, and can produce high crop yields with improved soil management practices (Lombin and Esu 1988; Tekwa et al. 2008).

Vertisols are clayey soils (> 30 % clay) that have deep, wide cracks for some time during the year and have slickensides within 100 cm of the mineral soil surface (Dinka and Lascano 2012). They are generally dark coloured, heavy textured soils of low permeability poor internal drainage; and derived either from calcareous rocks rich in Ferro-magnesium minerals (Lithomorphic Vertisols), or in depressions enriched by constituents coming from surrounding higher land (Topographic Vertisols) (Egbuchua and Enujeke, 2013). Vertisols are generally found on sedimentary plains as the result of thousands of years eroding the clay content out of the surrounding hills (Dengiz et al. 2013). They however can also be found on level land and in depressions that can favour the development of vertisols on alluvial material in flat inland areas.

Vertisols are perceived to be the most productive for rain fed and irrigated agriculture in the semi-arid tropics. Their high water-holding capacity allows them to compensate better than most other soils for the low and erratic rainfall, which is a major constraint to crop production in the semi-arid tropics (Swindale 1988).

However, vertisols have been relegated to the background just because their manageable

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constraints for maximum utilization. Although their high natural fertility and positive response to management make vertisols attractive for agriculture, some of their other properties impose critical limitations on low-input agriculture. The inherent limitations of vertisols are largely a function of the moisture status of the soils and the narrow range of moisture conditions within which mechanical operations can be conducted. The Nigerian vertisols could offer a considerable potential for agricultural development, particularly under irrigation. Large areas remain uncultivated because of the serious problems associated with the soil management. Information on the genesis, properties and management of vertisols are available elsewhere in the world but very little or no information on these aspects is available in Nigeria especially the vertisols of Adamawa State (Zata et al. 2013). Hence, a good inventory on soil properties and associated site characteristics is necessary for advice on both current and potential land users on how best to use the resource. The objective of the study was to evaluate the inherent morphological and physical properties that could influence the productivity of vertisols in Ngurore.

MATERIALS AND METHODS

Location

The study area covered Ngurore in Yola south local Government area in Adamawa state, Nigeria (Figures 1). Ngurore lies between latitudes 9^0 14' N and longitudes 12^0 32' E at an elevation of 200 m above sea level (Bello et al. 2014), along the Yola – Gombe road. The geological succession of the study area is underlain by the upper cretaceous rocks of marine sediments. The sediments are predominantly argillaceous and consist of alternating shale and limestone with sandy mudstones, siltstones and sandstones respectively. The remnants of these included materials form the major components of the resultant soils (Bawden 1972).

Climate of the Study Area

The climate of the area is that of the semi-arid type characterized by wide seasonal and diurnal temperature ranges with two main seasons: rainy season (May-October) and dry season (November to April) (Adebayo and Tukur 1999). The average annual rainfall is put at 1000mm with the greater part falling between July and September (Adebayo 1999). April is usually the hottest month (maximum temperature being 40^{o}C) while December and January has the lowest temperature averaging 10^{o}C (Mirchalum and Eguda 1995).

A rigid grid technique was employed for the survey at a scale of 1:25,000. Traverses were made at 2 km interval and auger observations were taken along each transect with the aid of hand held GPS device. Observations were made on nature and gradient of slope, slope position, vegetation, soil morphology, parent materials, erosion and land use. Auger points with similar morphological features soils were delineated as soil mapping unit and a representative profile pit dug. (Dent and Young, 1981). Three (3) soil mapping units were then identified and delineated in the study area and designated as NVM 1, 2 and 3 respectively. (NVM refers to Ngurore Vertisols Mapping Unit). 1 profile pits was dug in NVM 1 while NVM 2 and 3 having two profiles pits each. A total of five (5) profile pits were dug and designated as WYV (Wuro Yolde Vertisols), WLV (Wuro Lamido Vertisols), SVV (Savannah Vertisols), GGV (Gasanga Vertisols) and HSV (Hosere Vertisols) respectively in the areas so delineated from the three identified mapping units. Generally, the pedogenic horizons were three per pit in all pedons. Then, soil samples were collected according to the pedogenic horizons identified for laboratory analysis.

The soil morphological characterization was described in-situ with reference to the vegetation, drainage condition, soil colors, textures, consistence, horizon boundary, structure and inclusions (roots, ants, worms, charcoal, etc). Soil profile observations were fully described according to the FAO guidelines (1990). Soil color was determined per horizon using the Munsell soil color chart notations (Munsell 1954). Mottles were estimated in the field. Bulk density samples were taken from the field using core samplers.

Preparation of Soil Samples

The collected soil samples were air-dried in the laboratory. The dried samples were ground using wooden pestle and mortar and sieved to pass through 2 mm meshed sieve.

Laboratory Analysis

The particles size distribution was determined by the hydrometer method (Jaiswal 2003). The soil bulk density was determined from undisturbed soil samples in the field using core samplers (Black 1965). Total porosity was evaluated by core method (Ibitoye 2008). The pH of the soil was measured in a 1:2.5 soil-water suspensions and also in 0.5 M KCl solution using glass electrode pH meter (Jaiswal 2003). The electrical conductivity of the soil samples was measured alongside pH with an EC meter using the same soilwater suspension (Jaiswal, 2003). The organic carbon content of the soil samples was determined using Walkley and Black (1934) potassium dichromate wet-oxidation method. Total nitrogen content of the soil was determined by the Kjeldahl's wet digestion method (Bremnar 1965). Available phosphorus content of the soil samples was determined by bicarbonate extraction method (Olsen and Dean 1965) for near

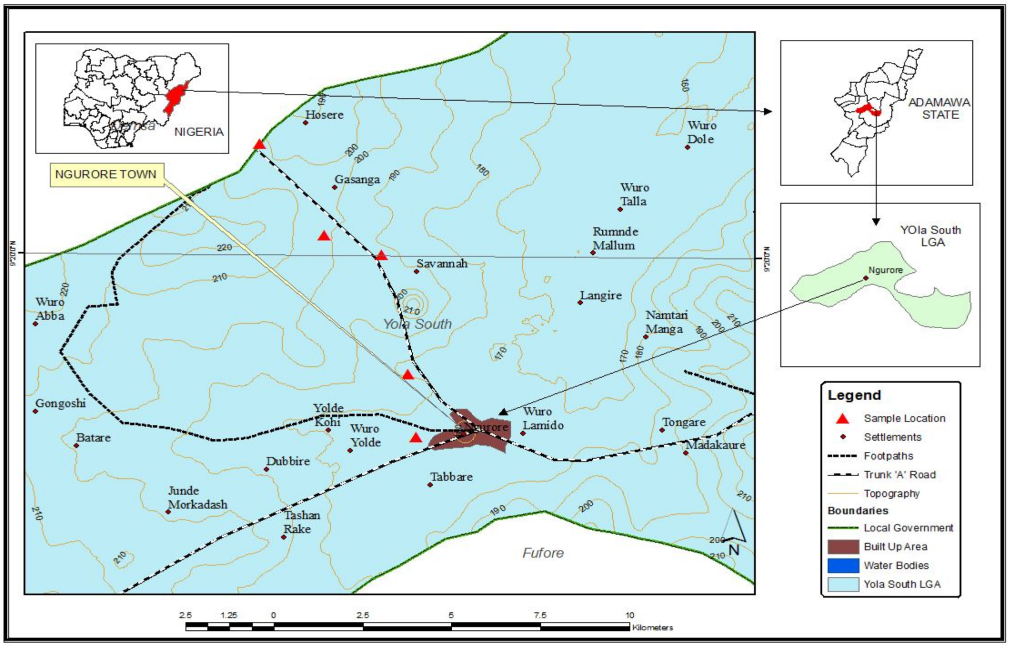

Figure 1. Map of Ngurore Showing Wuro Yolde, Wuro Lamido, Savannah, Gasanga and Hosere.

Field Survey

neutral and slightly alkaline soils while for acidic soils, the determination of the available phosphorus was done by Bray No. 1 method (Black 1965).

The exchangeable cations in the soil samples were determined in the extract of I N neutral ammonium acetate (NH_4OA_c) (Black 1965). The exchangeable Calcium and Magnesium content of the Soil were determined titrimetrically while the exchangeable Potassium and Sodium were determined by flame photometer. Total Exchangeable acidity determination was carried out by displacement with I N KCL and titrating the extract with 0.025 N NaOH solution using phenolphthalein indicator (Jaiswal 2003). The effective cation exchange capacity was determined by summing up the exchangeable cations and the exchangeable acidity (Black 1965). Base saturation was calculated by dividing the sum of the exchangeable bases by the CEC (soil) expressed as a percentage (Black 1965).

RESULTS AND DISCUSSIONS

Morphological Characteristics of Ngurore Vertisols

The morphological characteristics of the pedons of the various mapping units in Ngurore are presented in Table 1:

Soil Profile Depth and Boundary

The pedons of Ngurore vertisols are relatively deep, in mapping unit 1 (NVM 1) covering Wuro Yolde Pedon, the A horizon ranged from 0-39 cm, AC horizon 39-110cm while the C horizon is 110-164 cm; this pedon is the deepest with a depth of 164 cm. The horizon boundaries are clear wavy, gradual wavy and gradually diffused (cw, gw and gd) for horizons 1, 2 and 3 respectively (Table 1). For mapping unit 2 (NVM 2) consisting of Wuro Lamido and Savannah pedons, the Ap horizon ranges from 0 – 25 cm to 0 – 31 cm with the deepest depth of 152 cm (Savannah pedon). These soils show pedogenic horizons ranging from clear wavy to diffused wavy (cw, dw) boundaries on an average. While the mapping unit 3 (NVM 3) covering Gasanga and Hosere pedons have an A/Ap horizons ranging from 0 -15 cm to 0 -23 cm with the deepest depth 137 cm at Gasanga pedon. The soils have clear wavy, gradual wavy and gradually diffused boundaries (cw, gw and gd) for most horizons. This results shows that soils of the aping unit 1 are deepest (164 cm) while those of unit 3 are shallowest (137 cm) in Ngurore vertisols. All the pedons of Ngurore vertisols are deep, occurring on a level to nearly level topography (0-2 %) which might have accounted for the deeper depth of the soils. Faniran and Areola (1978); Shafiu (2000) and Vonicir (2002) reported that slope is an important aspect of soil depth especially in determining the depth of the topsoil of A-horizons. However, the result is in conformity with the findings of Folorunso et al. (1988) who reported that vertisols are usually deep soils with high clay content. The horizon boundaries are mostly diffused and wavy; this result is similar to the

Table 1. Some Morphological Properties of Ngurore Vertisols

Mapping Unit	Pedon	Coordinates	Depth	Horizon	Colour		Texture	Structure	Consistency			Boundary	Mottles	Inclusions	Special Features
					Dry	Moist			Wet	Moist	Dry				
1	WYV	1028370 N, 0206086 E	0 – 39	A	10YR 6/3	10YR 5/3	L	3msbk	st	fi	h	Cw	f c d	rg co m	Cracks
			39 – 110	AC	10YR 5/2	10YR 4/2	SCL	3msbk	st	fi	h	Gw	f fn d	r f fn	Cracks
			110 -164	C	10YR 4/3	10YR 4/4	SCL	3msbk	st	fi	h	Gd	co fn pr	cr f m	Cracks
2	WLV	1030370 N, 0195400 E	0 – 25	Ap	10YR 4/2	10YR 3/2	CL	3msbk	st	fi	h	Cs	f fn d	r co fn	Cracks
			25 – 79	AC1	10YR 4/3	10YR 3/3	SC	3msbk	st	fi	h	Dw	f fn d	cr f fn	Cracks
			79 – 133	AC2	10YR 4/2	10YR 3/3	SC	3msbk	st	fi	h	As	co m pr	cr co m	Cracks
	SVV	1032943 N, 0194741 E	0 – 31	Ap	10YR 5/3	10YR 3/2	CL	3msbk	st	fi	h	Cs	n	r f fn	Cracks
			31 – 85	AC	10YR 5/2	10YR 4/2	CL	3mplt	st	fi	vh	Cw	n	cr f fn	Cracks
			85 – 152	C	10YR 4/2	10YR 3/3	SCL	3msbk	st	fi	h	Dw	n	cr f fn	Cracks
3	GGV	1033557 N, 0193112 E	0 – 23	A	10YR 4/2	10YR 3/2	CL	3msbk	st	fi	h	Cs	n	r f m	Cracks
			23 – 76	AC	10YR 5/2	10YR 3/2	SC	3msbk	st	fi	h	Gw	f fn d	r f m	Cracks
			76 – 137	C	10YR 5/3	10YR 4/3	SC	3mplt	st	fi	h	Gd	n	cr f fn	Cracks
	HSV	1036426 N, 0191294 E	0 - 15	Ap	10YR 5/3	10YR 4/2	SCL	3msbk	st	fi	h	Gd	n	rg f fn	Cracks, slickenside
			15 – 125	AC1	10YR 4/3	10YR 3/3	SC	3msbk	st	fi	h	Cw	n	r f fn	Cracks, slicken side
			125 –136	AC2	10YR 6/3	10YR 4/4	SC	3msbk	st	fi	vh	Dw	f fn d	cr co m	Cracks, slicken side

Abbreviations: Pedon: WYV = Wuro Yolde vertisols; WLV = Wuro Lamido Vertisols; SVV = Savannah Vertisols; GGV = Gasanga Vertisols; HSV = Hosere Vertisols. Texture: L = loam; S = sand; C = clay. Structure: 3= strong; m = massive; sbk = subangular blocky; plt = platy. Consistence: (Wet) st = sticky; (Moist) fi = firm; (Dry) h = hard; vh = very hard Boundary: c = clear; w = wavy; g = gradual; s = smooth; d = diffused. Mottles: (Abundance) f = few; co = common; n = none; (Size) fn = fine; m = medium; c = coarse; (Contrast) d = distinct; pr = prominent. Inclusions: rg = roots and grasses; r = roots; cr = concretions; co = common; f = few; fn = fine; m = medium.

finding of Temga et al. (2015) who also observed wavy boundaries in Cameroonian vertisols.

Soil colour

Soil colour across all mapping units was within 10YR when dry and moist. Wuro yolde Pedon of mapping unit 1 (NVM 1), the soil colour ranged from very dark gray to grayish brown 10YR. Similarly, The colour of mapping unit 2 (NVM 2) covering Wuro lamido and Savannah pedons soils are within the very dark gray to grayish brown 10YR range and same trend was observed in Gasanga and Hosere (NVM 3) the colour characteristics of soils in the unit appeared very darker gray to grayish brown 10YR range when moist and dry. The dark matrix colour of Ngurore vertisols could be attributed to the nature of parent materials and the presence of high organic matter content in the surface horizons. Tripathi et al. (2006) reported similar results and attributed it to the accumulation of organic matter at the surface horizon.

Soil Texture and Structure

The particle size distribution of Ngurore vertisols revealed that, the soils are sandy clay loam, clay loam and sandy clay in texture for Wuro yolde pedon (NVM1), Wuro lamido and Savannah pedons (NVM 2) and Gasanga and Hosere pedons (NVM 3) respectively (Table 1). The soil structures for Wuro yolde (NVM1), Wuro lamido and Savannah pedons (NVM 2) and Gasanga and Hosere pedons (NVM 3) are strong sub-angular blocky (3msbk), strong sub-angular blocky (3msbk) except for the AC horizon in Savannah pedon which showed a strong platy structure and strong sub-angular blocky (3msbk) in most horizons except for C horizon of Gasanga pedon which shows a strongly platy structure respectively. Therefore, it is clear that Ngurore vertisols generally have strongly developed structures within pedons and across all mapping units. Structure in all pedons black soils were predominantly strong medium sub-angular blocky in the surface horizons. Ravikumar et al. (2009) and Coulombe *et al.* (1996) linked such results to the characteristic features of black soils with smectite as dominant mineral. Similarly, Kaistha and Gupta (1994) reported similar findings regarding structure of red and black soils made by previous workers.

Soil Consistency

The results of wet, moist and dry soil consistency of Ngurore vertisols are sticky when wet, firm when moist and very hard when dry (st, fi and h), sticky when wet, firm when moist and very hard when dry (st, fi and h) except for AC horizon in Savannah pedon which showed a very hard (vh) consistency when dry and sticky when wet, firm when moist and very hard when dry (st, fi and h) in most horizons except for AC2 horizon of Hosere pedon that exhibits a very hard (vh) consistency for Wuro Yolde pedon (NVM1), Wuro Lamido and Savannah pedons (NVM 2) and Gasanga and Hosere pedons (NVM 3) respectively (Table 2). The sticky when wet, firm when moist and hard when dry soil consistency of Ngurore vertisols may be reflecting the characteristic features of black soils with smectite as dominant mineral. Coulombe et al. (1996) reported that stickiness and plasticity may be due to high clay content. Similar observations were made by Sarkar et al. (2001) in soils of lower outer of Chhotanagapur plateau.

Mottles

There appear few fine and distinct mottles, nodules of $CaCO_3$ and other concretionary deposits such as quartz, Fe, Mn are quite common with Calcic horizons; few fine and distinct mottles, nodules of $CaCO_3$ and other concretionary deposits such as quartz, Fe, Mn are quite common with Calcic horizons in Wuro Lamido pedon and no mottles were observed in Savannah pedon but few fine and distinct mottles, nodules of $CaCO_3$ and other concretionary deposits such as quartz, Fe, Mn were also common in AC and AC2 horizons in Wuro Yolde (NVM1), Wuro Lamido and Savannah pedons (NVM 2) and Gasanga and Hosere pedons (NVM 3) respectively (Table 1). The presence of calcic diagnostic horizon in Ngurore has pedologically conformed to the report of Kilmer (1990) that most vertisols have calcic diagnostic horizons with yellowish brown mottles. Since the soils are developed in semi-arid region, occurrence and abundant distribution of calcium carbonate nodules is expected. Nodules of CaC03 and yellowish brown mottles may be an indicative evidence for a reduction process (gleying) at lower depths (Ahmad 1996; Brady 2003). Mottling of the subsoil is an evidence of seasonal rise in water table or waterlogging and hence drainage problem (Fanning and Fanning 1989; Akamigbo et al. 2002).

Inclusion and Special Features

From the result presented in Table 1 for Wuro Yolde pedon (NVM1), Wuro Lamido and Savannah pedons (NVM 2) and Gasanga and Hosere pedons (NVM 3) shows few medium root and concrete inclusions. Other features common are deep cracks in this pedon; few medium root and concrete inclusions appears. Other features common are deep cracks that appear in all the pedons and few medium root and concrete inclusions appears in all pedons. Cracks appeared prominent in all the pedons with some slickensides noticed in Hosere pedon respectively. According to Orhan et al. (2012), extensive swelling and shrinking upon wetting and drying is the major characteristics of these soils, cyclic cracking and swelling contribute to the formation of slickensides. This resulted into pedoturbation or mixing of the soils with minimal horizonation (Ahmad, 1996). Temga et al. (2015) also found dark color, desiccation cracks and microrelief at the surface soils and presence of slikensides within the profiles of vertisols in Cameroon.

Physical Properties of Ngurore Vertisols

Physical characteristics of the soils Ngurore vertisols were presented in Tables 2.

Particle Size Distribution

In Wuro Yolde pedon (NVM 1), the sand particle distribution showed an increasing with depth trend within the pedon and ranges from 40.2 to 47.2 %. Silt particle ranged from 19.2 to 34.2 % decreasing with depth while clays increased with depth and ranges from 25.6 to 33.6 %, mean sand, silt and clay are 44.2 %, 25.5 % and 30.3 % respectively; for Wuro Lamido and Savannah pedons (NVM 2), a perusal of results of particle size analysis indicates that sand, silt and clay particles ranges from 43.2 to 51.2 %, 14.2 to 28.2 % and 28.6 to 36.6 % respectively. The corresponding mean values for sand, silt and clay are 46.3 %, 20.6 % and 33.1 % respectively. However, highest mean sand and silt percentages 46.4 % and 21.0 % were recorded in Savannah pedon while Wuro Lamido has the highest mean clay of 33.6 %. There appears a trend of an increase in sand particles, decrease in silt and increase in clay particles with depth in all pedons, while Gasanga and Hosere pedons (NVM 3) results of particle size analysis indicates the ranges of sand, silt and clay distribution as 44.0 to 50.2 %, 11.2 to 24.2 % and 31.6 to 38.6 % corresponding to mean values of 46.7 %, 18.1 % and 35.2 % respectively. Highest mean sand and clay 48.2 % and 35.9 % were recorded in Hosere pedon while Gasanga pedon has the highest mean silt distribution of 20.3 %. A similar trend of increasing sand and clay, decreasing silt content with depth was observed in the Hosere pedon. Generally, Highest mean of sand and clay contents 46.7 % and 35.2 % were recorded in mapping unit 3 (NVM 3) while the lowest mean sand and clay content 44.2 % and 30.3 % were recorded in mapping unit 1 (NVM 1) which also has the highest silt content of 25.5 % while mapping unit 3 (NVM 3) having the lowest silt of 18.1 %. A trend of increasing sand and clay, decreasing silt with depth was observed across mapping units (Table 2).

Bulk Density and Particle Density

Bulk density and particle density ranges are 1.34 to 1.37 gcm^{-3} and 2.40 to 2.70 gcm^{-3} with corresponding means of 1.35 gcm^{-3} and 2.53 gcm^{-3} respectively in Yolde pedon (NVM 1). However, bulk density increased with depth while particle density appears irregular with depth. For Wuro Lamido and Savannah pedons (NVM 2), the bulk density and particle density of this unit ranged from 1.33 to 1.35 gcm^{-3} and 2.40 to 2.50 gcm^{-3} respectively corresponding to 1.34 gcm^{-3} and 2.45 gcm^{-3} means. The results tends to be increasing with depth, bulk density remain constant in all horizons of Savannah pedon. However, highest mean bulk density 1.35 gcm^{-3} was recorded in Savannah pedon while Wuro Lamido has the highest mean particle density of 2.47 gcm^{-3}. While at Gasanga and Hosere pedons (NVM 3), Bulk density and particle density varied from 1.33 to 1.35 gcm^{-3} and 2.40 gcm^{-3} with corresponding means of 1.34 gcm^{-3} and 2.52 gcm^{-3} respectively. Highest mean bulk density and particle density 1.35 gcm^{-3} 2.70 gcm^{-3} were recorded in Gasanga and Hosere respectively. A bulk density change appears irregular with depth while particle density tends to increase with depth. Therefore, mapping unit 1 (NVM 1) has the highest mean bulk density 1.35 gcm^{-3} while mapping units 1&2 (NVM 1&2) having the lowest 1.34 gcm^{-3} and highest particle

Table 2. Physical Properties of Ngurore Vertisols

Mapping Unit	Pedon	Coordinates	Depth (cm)	Sand (%)	Silt (%)	Clay (%)	BD (gcm^{-3})	PD (gcm^{-3})	TP (%)	WHC (%)
1	WYV	1028370 N, 0206086 E	0 – 39	40.20	34.20	25.60	1.34	2.40	57.10	6.70
			39 –110	45.20	23.20	31.60	1.35	2.70	50.00	5.20
			110 -164	47.20	19.20	33.60	1.37	2.50	53.60	13.10
			Mean	**44.20**	**25.50**	**30.30**	**1.35**	**2.53**	**53.60**	**8.30**
2	WLV	1030370 N, 0195400 E	0 – 25	43.20	28.20	28.60	1.33	2.40	55.40	14.60
			25 – 79	48.20	16.20	35.60	1.34	2.50	53.60	12.20
			79 – 133	47.20	16.20	36.60	1.33	2.50	53.20	4.00
			Mean	**46.20**	**20.20**	**33.60**	**1.33**	**2.47**	**54.10**	**10.30**
	SVV	1032943 N, 0194741 E	0 – 31	44.00	24.40	31.60	1.35	2.40	56.30	7.90
			31 – 85	44.00	24.40	31.60	1.35	2.40	56.30	9.10
			85 – 152	51.20	14.20	34.60	1.35	2.50	54.00	8.10
			Mean	**46.40**	**21.00**	**32.60**	**1.35**	**2.43**	**55.50**	**8.40**
3	GGV	1033557 N, 0193112 E	0 – 23	44.20	24.20	31.60	1.33	2.40	56.30	13.30
			23 – 76	47.20	17.20	35.60	1.34	2.50	53.60	5.50
			76 – 137	44.00	19.40	36.60	1.35	2.50	53.20	12.70
			Mean	**45.10**	**20.30**	**34.60**	**1.34**	**2.47**	**54.40**	**10.50**
	HSV	1036426 N, 0191294 E	0 - 15	47.20	19.20	33.60	1.34	2.50	63.60	12.10
			15 – 125	47.20	17.20	35.60	1.34	2.70	49.60	14.20
			125- 136	50.20	11.20	38.60	1.33	2.50	53.20	7.70
			Mean	**48.20**	**15.90**	**35.90**	**1.33**	**2.57**	**55.50**	**11.30**

Abbreviations: BD=bulk density; PD = particle density; TP = total porosity; WHC = water holding capacity

density 2.70 gcm^{-3} was recorded in mapping unit 3 (NVM 3) while lowest 2.45 gcm^{-3} was recorded in mapping unit 2 (NVM 2). The result shows no definite trend of change in distribution (Table 2). The trend of irregular distribution of bulk density with depth while particle density increasing with depth in most pedons could be an indication that the Ngurore vertisols may still be undergoing pedogenic processes like argilli pedoturbation . The particle densities of the soils in this study were closer to the average range of particle density for mineral soils. This present study reveals a seeming increase in particle density with depth of soil horizons. Brady (2003) reported that particle density values increase with soil depth. Similar results were also reported by Idoga et al. (2006) in soils of Samaru area, Nigeria.

The higher sand percentage observed in Ngurore vertisols may be due to large quantities of sand buried by clays during pedogenesis in contrast to Soil Survey Staff (1999) with the opinion that vertisols have higher clays and relatively low sands. However, this result is in line with the findings of Folorunso and Ohu (1989) who reported that some vertisols have high sand content (> 90 %) with a correspondingly low silt and clay fractions. Similarly, Lombin and Esu (1988) had earlier reported that, sand content in Ngala vertisols increased with depth to the underlying sand layer while silt content decreased from the surface to the substrata. The increase in clay content through the soil depth observed in the study may be as a result of clay eluviation – illuvation in soils. Atofarati et al. (2012) obtained similar results, they reported that in vertisols, processes like argilli pedoturbation, and movement of the finer fraction to the lower depth through cracks with runoff water during high intensity rainfall could have accounted for the increasing trend.

Total Porosity and Water Holding Capacity

The data presented in Table 2 shows that total porosity and water holding capacity of Yolde pedon (NVM 1) varies from 50.0 to 57.1% and 5.2 to 13.1 % respectively. The mean total porosity and water holding capacity are 53.6 % and 8.3 % respectively with no regular changes with depth. For Wuro Lamido and Savannah pedons (NVM 2), total porosity and water holding capacity, the results shows the ranges of 53.2 to 56.3 % and 4.0 to 14.6 % respectively with corresponding means of 54.8 % and 9.4 %. Total porosity appears to decrease with depth and water holding capacity tends to have an irregular trend with depth. However, Savannah pedon shows the highest mean total porosity 55.5 % and highest water holding capacity was recorded in Wuro Lamido pedon and for Gasanga and Hosere pedons (NVM 3), total porosity and water holding capacity results ranges from 49.6 to 63.6 % and 5.5 to 14.2 % corresponding to means 55.0 % and 10.9 % respectively. The results indicate decrease in total porosity with depth and water holding capacity shows no regular trend of change with depth. However, both total porosity and water holding capacity means 55.5 % and 11.3 % respectively were recorded highest in the Hosere pedon. This result indicates that mapping unit 3 (NVM 3) has the highest mean values of total porosity and water holding capacity as 55.5 % and 11.3 % respectively. There appear no regular distribution changes in these parameters across the mapping units.

In Ngurore vertisols, total porosity decreased with depth and water holding capacity having irregular trend with depth may be due to relatively high value of bulk density in surface A horizons. This result is in conformity with the findings of Singh and Rathore (2015) they noticed that, generally the porosity was high in surface horizons and decreases with depth and attributed this to may be due to higher value of bulk density in subsurface soils. Similar observations were also reported by Wick and Whiteside (1959), Rathore (1993) and Sharma (1994). The results indicates that, all pedons have greater than 50 % total porosity, Fetter (1998) and Riue and Sposito (1991) recommended that soils having porosity of over 50 percent and 45-50 percent of volume are good agricultural soils. Generally the water holding capacity of vertisols are high, however the water holding capacity of Ngurore vertisols are relatively low. This low water holding capacity may be due to increase in calcium carbonate in the lower layers and increase in sand particle. This is in line with the findings of Mishra, et al. (2012) they reported that the field capacity decreased significantly from 32.6 to 16.4 % when sand and soil ratio increased from 0:1 to 1:1.

Management of Vertisols for Improved Crop Production

The major soil problems to be overcome are related to tillage, land preparation, water management, and the identification of suitable cropping systems. Kanwar and Virmani (1985) have recommended some improved Vertisols management technologies which we feel can work well for Ngurore Vertisols if adopted and practiced by the farmers in the area for improved crop production. The strategies are:

i. Improved land and water management practices are applied for alleviating the constraints, such as waterlogging, which arise due to the physical properties of Vertisols. Surface drainage could be improved through the provision of surface drains and land smoothing. (Ridge-furrow)

ii. Primary tillage to prepare a rough seedbed is best carried out soon after the harvest of the post rainy-season or rainy-season crops. Land should be harrowed whenever 20-25 mm of rain is received over a period of one-two days. Blade-harrowing should be done so that the clods can easily be shattered and a satisfactory seedbed attained.

iii. Since the preparation of the seedbed and the sowing of crops present serious problems in Vertisols, planting of crops in dry soils ahead of the commencement of rains ensures their establishment early, and avoids the difficulty of planting in a wet, sticky soil.

iv. Improved cropping systems such as intercropping of long duration crops (e.g. pigeon pea) with short-duration crops (eg. maize or sorghum or soybean) and sequential cropping of crops (eg. sorghum or maize followed by chickpea or saf- flower) provide a continuum of crop growth from the commencement of the rainy season until most of the available moisture is utilized by the crop.

v. Appropriate crop management like weed control, integrated pest management, the placement of fertilizers at an appropriate depth and their application at critical stages of crop growth are some of the crop management factors which could lead to the realization of high and sustained yields on Vertisols.

CONCLUSIONS

The soils of the area are relatively deep, mostly greater than 100 cm, high chroma and colour hues of 10YR. The texture ranged from clay loam to sandy clays in the lower horizons. The vertisols meet the taxonomic for placement as Eutric Chromusterts, Eutric Plinthusterts and Typic Chromusterts in mapping units 1, 2 and 3 respectively. The Ngurore vertisols generally exhibits some characteristics that make them unique from other vertisols elsewhere because of the particle size distribution which appeared to be more of sandy than even the clay and its irregular trends of distribution. These soils present advantages like relative fair drainage and less plasticity over other vertisols posed by a combined effects of climate, topography, geology and pedogenesis prevalent in the area. The soil properties in terms of morphology and physical characteristics as well as chemical properties and other features should be taken into consideration for appropriate recommendations. Therefore it is recommended that tillage operations should be properly timed, when the soil moisture is moderate for easy land preparation using farm implements and machineries. The incorporation of organic manures can help in improving soil structure and other vital soil processes like nutrient availability, aeration, moisture retention etc. Sprinkler method of irrigation discharging water at slower rates is recommended over other irrigation methods for the Ngurore vertisols during the dry season for a sustainable utilization all year round.

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