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Effect of Land Use on Soil Physical and Hydrological Properties on Sandstones Parent material in Akwa Ibom State, Nigeria

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ABSTRACT

Knowledge of soil physical and hydrological properties is used by soil scientists, agronomists, hydrologists, irrigation engineers and environmental scientists for developing best management practices for efficient and economical management of soil and water for optimum crop production and designing liquid waste disposal systems. A study was conducted on the sandstone parent material in northern Akwa Ibom State to evaluate the effects of forest (FO), fallow (FA), and cultivated (CU) land use types on soil physical and hydrological properties. The effects of the three land use practices on soil properties were generally, statistically non-significant; however, there were remarkable differences among the land uses. It was observed that bulk density (BD), water stable aggregates (WSA), soil organic carbon (SOC), saturated water content (SWC), field capacity water content (FC), and sorptivity (S) were higher in CU than in FO and FA, indicating that forest soils may not always have improved soil physical and hydrological properties than cultivated soil. However, since the soils are coarse-textured (with low clay content), conservation tillage involving the application of plant materials on the surface or ploughed into the soil and occasional fallowing to replenish the organic matter content, are needed to bind the primary particles, stabilize soil structure, and improve water intake and storage, important indices for the optimum edaphological functions of the soils in the study area.

1. Introduction

Soil is an important and dynamic component of the biophysical environment; its quality and management determines the productivity of all (natural and managed) ecosystems (Lal and Shukla, 2005). Soil quality defines soil's inherent and dynamic properties and functionality in relation to human needs (Gregorich *et al.,* 1997; Doran *et al.,* 1999; Lal and Shukla, 2005). Conversely, the sustainability of soil functions is dependent on soil properties and processes and management. Soil quality attributes affecting the sustainability of soil functions are its physical, chemical, and hydrological properties and characteristics which have developed as a result of the factors and processes of soil formation. Jenny (1980), observed that soils and soil properties are known to be configurations of environmental or state factors at a given location. In general, Shukla (2014), stated that the quality of land is dependent on its physical properties. Knowledge of the physical and hydrological properties of soils is essential to an understanding of the practical agricultural problems related to soil productivity.

Soils comprise essentially, the solid matrix (inorganic and organic matter) of vastly different sizes of particles, spanning the lower limits of the colloidal state to the coarsest fractions of sand and gravel, and pores, which may be fully or partially filled with fluids and solutes of considerably differing composition. Together, the solid matrix and the associated pore spaces determine and influence soil's physical and hydrological properties and processes and thus, soil quality and productive capacity. Lal (1999) and Doran *et al.* (1999), stated that high soil physical quality plays an important role in enhancing soil productivity and in sustainable management of natural resources. For instance, soil fertility, in its broad sense, depends on a favourable interaction between soil components and phases that optimize soil quality (Lal and Shukla, 2005). Soil physical properties important to soil productivity and management are soil texture, soil structure, and soil water properties. Soil texture is an important consideration in the growth of certain crops, in the application of some mechanized treatments, and in decisions on soil conservation (Babalola and Obi, 1981). Soil texture and structure profoundly affect soil's static and transmission properties. For instance, soil bulk density, an index of soil texture and soil structure, is an important factor in root penetration (Pierce *et al.,* 1983), prediction of water transmission (Rawls *et al.,* 1998), evaluation of soil organic C sequestration and as an indicator of soil quality (Arshad *et al.,* 1996).

Thus, soil properties govern the transport processes (water retention, hydraulic conductivity etc.) and water balance in the vadose zone of soils, exerting a crucial role in the hydrological cycle, because it partitions the incident water in runoff and infiltration, for which saturated hydraulic conductivity exerts a dominating influence (Zimmermann *et al.*, 2013). Conversely, water plays an important role in the genesis of most soil properties and soil properties influence and govern soil hydrological characteristics as well. The interactive relationship between soil and hydrological properties is essential for the determination of local energy and water balance, transport of applied chemicals to plants and groundwater, and in irrigation management (Seyfried and Murdock, 2004; Souza *et al.,* 2004). Turner *et al.* (2000), had observed that determining soil hydraulic properties is necessary for interpreting and simulating many hydrological processes having environmental and economic importance such as rainfall partition into infiltration and runoff (Rockström *et al.*, 1998; Cassinari *et al.*, 2015; Iovino *et al.*, 2016).

During rainfall or irrigation, water infiltrates into the soil and continues to move to greater depths, increasing the water content of the soil profile. The amount of water stored in the soil is highly dependent on soil characteristics, especially soil texture and soil structure (micro-porosity, bulk density), soil depth, clay mineralogy, and organic matter content. Soil water retention is defined by capillarity and adsorptive forces, the result of adhesion and cohesion, and both capillarity and soil water retention are affected to a greater extent by particle -size distribution, soil texture and soil structure (Sharma and Uehara, 1968; Reeve *et al.,* 1973; Ritchie, 1981; Dane and Hopmans, 2002). Soil texture and structure are uniquely important in the prediction of infiltration rate and water retention (Philip, 1973; Arya *et al.,* 1999a, b). Harte (2000) and Imohoff *et al.* (2004), reported that soil moisture content related with soil texture, and over time (Chertkov *et al.,* 2004), to influence soil behavior. Similarly, the rate of water movement is important because it affects the entry of water into the soil, movement of water in the soil profile, flow of water to drains, and evaporation from soil surface (Rawls *et al.* 1993). Rawls *et al.* (1982), had reported that in fine-textured silty soils, the saturated hydraulic conductivity was lower than in coarse-textured sandy soils. Chaney and Swift (1984), had observed that soil hydraulic properties were highly correlated with structural stability and macroporosity.

Factors affecting hydrological properties can be grouped into soil, soil surface, and land use and soil management, with the latter (Rawls *et al.,* 1993) having the most influence. That is, land-use practices are of key importance to soil hydrology, because they generally affect surface soil hydraulic properties and pore-size distribution. The effects are attributed to tillage, erosion, compaction, and pore structure evolution (Obi and Nnabude, 1988; Rasiah and Kay, 1995; Harden, 2006). Reports (Schwartz *et al.*, 2003; Zhou *et al.*, 2008), showed that such disturbances, in some cases, outweigh genoform traits (those inherited from parent material, topographic setting, etc.) in determining soil water movement. For instance, in comparison with soils impacted by human land use, soils underlying forest vegetation generally have low bulk density and high saturated hydraulic conductivity, total porosity, and macroporosity, as a result of ample litter cover, organic inputs, root growth and decay, and abundant burrowing fauna (Lee and Foster, 1991), than pasture in different climates and parent materials throughout the world (Reiners *et al.,* 1994; Godsey and Elsenbeer, 2002; Jiménez *et al.,* 2006; Li and Shao, 2006; Abbasi *et al.,* 2007). In contrast, soils exposed to human impact are often stripped of the organic-rich topsoil horizons and compacted by heavy equipment, livestock or raindrop impact, increasing bulk density and reducing infiltration rates (Celik, 2005; Li and Shao, 2006). In many cases, soils impacted by change in land-use demonstrate marked disparities from the original soil (Jiménez *et al.,* 2006; Zhou *et al.,* 2008). Price *et al.* (2010), reported that particle size distributions did not significantly differ among land-use classes or parent materials, and the differences between the hydraulic properties of forest vs. non-forest soils were attributed to compaction associated with land management practices. The magnitude of differences between forest and non-forest infiltration rates suggest that widespread conversion of forest to other land uses would be accompanied by decreased infiltration and increased overland flow, potentially significantly altering water budgets and leading to reduced base-flows and impaired water quality.

Similarly, lands under undisturbed grass cover tend to increase infiltration and decrease runoff due to improved organic matter content, soil aggregation and faunal activities (Lepilin, 1989; Naeth *et al.*, 1990; Schwartz *et al.,* 2000). Relative to well-managed grasslands, conventional crop-fallow rotation decreases macroporosity and saturated and unsaturated hydraulic conductivity (Spewak, 1997) resulting in a decrease in water infiltration and increased surface runoff. Reports (Schwartz *et al.*, 2000; Bormann and Klaassen, 2008; Zhou *et al.*, 2008), have shown that conversion of forested land to cultivated fields resulted in significant decreased water retention capacity. Zhou *et al.* (2008), stated that the effect of land use on soil water retention was through its effect on soil organic matter (SOM) content and porosity.

Soils of South-eastern Nigeria are formed from diverse parent materials (Onweremadu *et al*., 2007), mostly unconsolidated coastal plain sands, and therefore vary spatially on the landscape profoundly influencing the development and characteristics of the soils and their use potentials (Gray and Murphy, 2002). Sandstones and Shale are one of the four major parent materials occurring in Akwa Ibom State (Petters *et al.,* 1989). The soils are characterized by the dominance of sandy textured fragments comprising larger quantities of coarse-textured over fine-textured materials, have low fertility due to the dominance of low activity clays and inherently low organic matter contents (Ojanuga *et al.*, 1981; Ofomata, 1981; Ogban and Ekerette, 2001), as well as being deeply permeable, poorly structured and unstable, and droughty. A variety of soil-use practices, including forest, fallow, and cultivation are common, and soil use is under the low input rainfed traditional farming. Yet, soil use is changing and land cover is being depleted rapidly with degradative consequences on soil productive capacity. Soil physical properties and hydrological characteristics combine to influence soil productive capacity. Understanding these properties and characteristics could be used to guide and optimize their management under the intensifying traditional soil uses for increases in crop production.

This study examined the effect of different land use practices on the physical and hydrological properties of soils formed on sandstones parent materials to guide the formulation of soil conservation and management technologies to improve the productive capacity of the soils in northern Akwa Ibom State.

2. Materials and Methods

Site characteristics: The study was carried out on the sandstones parent material occurring in the northern Akwa Ibom State, South-eastern Nigeria. The area lies between latitudes 4^0 30′ N and 5^0 30′ N and longitudes 7^0 30′ E and 8^0 20′ E.
The climate is hot humid tropical, characterized by two seasons, the rainy season which lasts from April to October, and the dry season which lasts from November to March, with variations occurring in some years. Annual rainfall is usually heavy, varying from 3,000 mm along the coast to about 2,250 mm in the northern fringes. Mean annual temperatures vary between 26 and 28^{0}C, while the relative humidity ranges from 75% to 80%.

The sandstones and shale parent material occur in a belt east of Nkari, including Obotme and stretches to the Itu and Enyong–Cross River Confluence. The study area consists of very rough and intensely dissected hills, valleys and sharp crested sandstone ridges. Generally, parent material and other soil forming processes play an important role in the development of the inherent soil characteristics and productive capacity. The soils developed from these parent materials have been subjected to eons of weathering and erosional cycles, resulting in the soils being deeply permeable, structurally unstable with low buffering capacity, low in organic matter content, and fragile to intensive land use practices without suitable soil management technologies to alleviate these and other soil-related constraints (Udo and Sobulo,1981).

The hot humid climate favours the luxuriant tropical rain forest which has however been almost completely replaced by secondary forest of predominantly wild oil palm trees, woody shrubs and various grasses as undergrowth. The predominant land use is the bush fallow-cropping system operated with low productive farming tools and systems. This cropping system leaves more than 80% of the soil surface bare and exposed to the high intensity rainfall erosivity on the highly erodible soils common in the area (Petters *et al*., 1989; Udosen, 2017).

2.1. Field Study

Eleven bulk and core soil samples were collected from the top 30 cm depth of forest (FO), fallow (FA), and cultivated (CU) soils in the study area. This gives a total of 33 bulk and core sample, respectively. The bulk samples were collected with a spade, while the core samples were collected with 7.2 cm long and 6.8 cm wide internal diameter metal cylinders. The bulk soil samples were used for the determination of particle-size fractions, water stable aggregates, and organic carbon content, while the core soil samples were used for the determination of saturated hydraulic conductivity, saturated water content, field capacity water content, permanent wilting percentage water content, and bulk density.

Ponded infiltration was determined up to a cumulative time of 2 hours, adjacent the soil sampling locations using the double ring infiltrometer (Reynolds *et al.*, 2002). The data generated were used to calculate the initial infiltration rate (i_o), final infiltration rate (i_f), and cumulative infiltration (Cum I) as well as sorptivity, S, and transmissivity, A, parameters.

2.2 Laboratory Analysis

The soil samples were air dried, crushed and sieved through a 4-mm mesh. A sample was finely ground and preserved for determination of organic carbon. The particle-size analysis was determined using the Bouyoucos hydrometer method and sodium hexametaphosphate as the dispersant. Saturated hydraulic conductivity (K_s), field capacity water content ($FC_{0.01bar}$), wilting point water content (PWP_{15bar}) and available water capacity (AWC) were determined as described by Romano and Santini (2002). Bulk density (Bd) was determined as described by Grossman and Reinsch (2002), and total porosity (Tp) was computed from bulk density values and an assumed particle density of 2.65 Mg m^{-3}. Aeration porosity was calculated from the following relationship:

where Ap is aeration or non-capillary pore space. Total available water capacity (AWC) was obtained from values of FC and PWP as follows:

$$Ap = Tp - \theta_v(FC\ water\ content) \qquad (1)$$

where $\theta_g(0.1)$ is gravimetric water content at 0.1 bar suction; $\theta_g(15)$ is gravimetric water content at 15 bar suction; ρ_b is soil bulk density; ρ_l is the density of water assumed to be 1.00 Mg m^{-3}; d is the sampling depth (0.40 m).

$$AWC = \{\theta_g(0.1) - \theta_g(15)\}(\rho_b/\rho_l)d \qquad (2)$$

Void ratio (Vr) was calculated from inferred from the relation, Clay-free sand (CFS) fraction, to evaluate the uniformity of parent material, was adjusted for bulk density using the relation:

$$Vr = Tp/(1 - Tp) \qquad (3)$$

Aggregate stability or specifically, wet aggregate stability (WSA) was determined with the soil samples that passed the 4-mm sieve using a 0.25 mm sieve (Nimmo and Perkins, 2002), and subsequently, the percentage water stable aggregates (WSA) >0.25mm for the *i*th fraction was computed according to Hillel (1980) as:

$$CFS = \left(\frac{sand\ g\ kg^{-1}}{1000 - clay\ g\ kg^{-1}}\right) * Bd\ Mgm^{-3} \qquad (4)$$

where, $M_{soil,i}$ is the total mass of oven-dry soil material after wet-sieving for the *i*th fraction, $M_{s\,and\,i}$ is the oven-dry weight of the sand for the *i*th fraction, $M_{soil,t}$ is the total mass of the whole soil sample, and $M_{sand,t}$ is the mass of sand in the whole soil sample.

$$WSA_i = \frac{M_{soil,i} - M_{sand,i}}{M_{soil,t} - M_{sand,t}}\ x\ 100 \qquad (5)$$

Soil organic carbon content was determined using the Walkley and Black wet oxidation method (Nelson and Sommers, 1996).

The infiltration data were fitted into Philip (1957) model to estimate sorptivity and transmissivity parameters thus:

where I [cm] is cumulative infiltration at the time, t $[sec]$, S $[cm\ sec^{-1/2}]$ is the soil water sorptivity, A $[cm\ sec^{-1}]$ is the soil water transmissivity. To estimate A and S parameters both sides of Equation (5) were divided by $\sqrt{t}$ giving

$$I = St^{1/2} + At \qquad (6\ )$$

$$I/\sqrt{t} = A\sqrt{t} + S \tag{7}$$

A plot of $I/\sqrt{t}$ against $\sqrt{t}$ gives S as the intercept and A as the slope. By differentiating Equation (5) we obtain

$$\frac{dI}{dt} = i = \frac{1}{2}S\sqrt{t} + A \tag{8}$$

where i is the instantaneous infiltration rate $[cm\ sec^{-1}]$ at time t. The lowest value of i is the equilibrium infiltration rate, which has practical implications for water management studies.

Statistical Analysis: Analysis of variance was used to establish the effects of the land use practices on soil physical and hydrological properties. Pearson's product moment correlation was used to relate soil water properties to soil physical properties.

3. Results and Discussion

Data of the physical properties and organic matter content of the soil under forest (FO), cultivated (CU), and fallow (FA) land uses are shown in Table 1. The distribution of particle sizes in the land use types showed that the sand fraction (FO = 863 g kg^{-1}; FA = 856 g kg^{-1}; CU = 859 g kg^{-1}) was proportionately greater ($p<0.05$), constituting more than 80%, than the silt and clay separates and therefore the soil was predominantly sandy and coarse-textured in all three land use types. Babalola and Obi (1981), stated that soil texture is related to parent material and topography and is influenced by land use. The similarity in soil texture, therefore, reflected the uniformity in the underlying lithology as well as the influence of other predominating soil formation factors, mainly climate, and processes, and could explain the lack of statistical differences in particle-size fractions (psf) among the land use types. Thus, the observed data on psfs were related to parent material (Akamigbo, and Asadu, 1983; Igwe *et al.,* 1999) than the land use practices. Already, the parent material of the soil, the Ameki (sandstone) Formations, derived from Tertiary Sediments have been affected by intense weathering, strongly leached and millennia of erosional cycles (Ojanuga *et al.,* 1981) under the high and erosive rainfall common in the area, and could explain the low silt and clay fractions in the soil.

Particle sizes are the major components of mineral soils, affecting solute transport and other physical properties of soils (Mbagwu *et al.,* 1983; Ogban and Ekerette, 2001). Similar to other soils dominated by the skeletal fraction (sand) in the soil matrix, the soil under FO, CU, and FA would be easily workable because of the low clay content, but would be characterized by weak cohesive and adhesive forces, and therefore low aggregation potential, as well as being easily slaked, highly detachable and dispersible (Babalola and Obi, 1981). Water can easily infiltrate the soil because of large suction gradient, provided the application rate is less than or equal to the infiltration rate. However, coarse-textured soils may experience soil moisture stress because of a low content of colloidal material and therefore low moisture retentive capacity, as well as low productive capacity (Babalola and Obi, 1981). Thus, short-duration cessation of rain during the wet season easily causes plant water stress unless mulch-farming or best management practices are adopted to conserve soil moisture during the cropping season and soil's productive capacity sustainably.

Table 1: Soil Physical Properties

Land use	CS	FS	TS	Si	Cl	SCR	Bd	Tp	Ap	VR	CFS	WSA	MWD	SOC
			gkg^{-1}				Mgm^{-3}	m^{3}m^{-3}	m^{3}m^{-3}		gkg^{-1}	%	mm	gkg^{-1}
FO	619a	244a	863a	22a	115a	0.38a	1.33a	0.495a	0.163b	0.98a	0.97a	11.86a	9.52a	16.99a
FA	637a	219a	856a	32a	112a	0.31a	1.36a	0.488a	0.204a	1.01a	0.96a	9.80a	9.19a	17.57a
CU	650a	208a	859a	31a	110a	0.31a	1.46a	0.457a	0.177b	0.88a	0.97a	14.40a	8.15a	18.22a
LSD $_{0.05}$	71.6	59	37.5	16.1	30.5	0.16	0.19	0.08	0.04	0.28	0.02	6.4	2.08	3.67

FO= forest; FA= fallow; CU= cultivated; Cs= coarse sand; FS= fine sand; TS= total sand; Si= silt; Cl= clay; SCR= silt clay ratio; BD= bulk density; Tp= total porosity; Ap= aeration porosity; VR= void ratio; CFS= clay-free sand; WSA= water stable Aggregates; MWD= mean weight diameter; SOC= soil organic carbon

Table 2: Effect of Land use on Soil Physical Properties on Sandstone Parent material

	SWC	FC	PWP	AWC	Ksat	i_o	i_f	cum I	S	A
		m^3m^{-3}				cm h^{-1}		cm	cm min$^{-0.5}$	cm h^{-1}
FO	0.371b	0.245a	0.110a	8.24a	10.64a	0.38a	0.12a	27.5a	0.33a	0.12a
FA	0.414b	0.253a	0.129a	11.45a	15.26a	0.58a	0.34a	43.8a	0.40a	0.33a
CU	0.488a	0.255a	0.106a	10.77a	9.55a	0.62a	0.31a	42.0a	0.46a	0.18a
LSD0.05	0.07	0.05	0.03	3.43	8.51	0.47	0.33	37.6	0.26	0.22

Data of bulk density, total porosity, aeration porosity and void ratio as influenced by FO (1.33 Mg m^{-3}), CU (1.46 Mg m^{-3}), and FA (1.36 Mg m^{-3}) are also shown in Table 1. Bulk density was moderately high ($p<0.05$) and unaffected by the traditional land use practices in the study area. Bulk density is an index of soil strength, the resistance that soil offers to the penetration and growth of roots. Thus, soil strength may be low in FO, CU, and FA. The values obtained were generally m^{-3} that may be favourable to the growth of roots and tubers commonly grown in the area. Also, bulk density is a soil parameter that significantly influences soil processes (Manrique and Jones, 1991) including water retention and fluid flow and has widely been used in the prediction of water transmission (Rawls *et al.,* 1998) and as an indicator of soil quality (Lal *et al.,* 1998).

Similarly, total and aeration porosity were also moderately high and statistically ($p<0.05$) similar among FO (0.495 m^3m^{-3}), CU (0.457 m^3m^{-3}), and FA (0.488 m^3m^{-3}). Porosity (total, aeration, pore-size distribution, etc.) is that feature of the porous medium that encompasses the pathways and volume available for fluid and gas flow and transport as well as for storage and retention of water (Flint and Flint, 2002). The results indicate that bulk density, total and aeration porosity may be more related to the texture of the soil than to the land use practices. Also, the low values of bulk density and moderate total and aeration porosities indicate that fluid flow through the soil would not be impeded. Thus, the combination of low bulk density, moderately high total and aeration porosity may dispose the coarse-textured soils to high absorptive properties and high infiltration since it is a dominant control on infiltration particularly at the onset of rainfall or irrigation, as long as the water supply rate equals the infiltration or less than the infiltration capacity of the soil.

When the clay-free sand fraction of each land use was adjusted for its bulk density with Eq. (4), it was shown that these values were reasonably constant for FO, CU, and FA. The statistical similarity among the land use types also indicated uniform lithology for the soils.

Data of water stable aggregates (WSA) and mean weight diameter (MWD) in FO (11.86%), CU (14.40 %), and FA (9.80 %) are shown in Table 1. There were no differences ($p<0.05$) in the effect of the land uses on %WSA, but the effect was in the order CU>FO>FA. Land use either protects the soil by enhancing aggregate stabilization and its shear resistance or exposes it to the detaching force of raindrop or flowing water. The higher %WSA in CU was attributed to cultivation-induced aggregate-stabilizing agents in the land use type (Molope *et al.,* 1987). This is however contrary to reports (Oguike and Mbagwu, 2009), that land use causes a deterioration of soil physical properties. Mbagwu and Auerswald (1999), also reported that land use negatively affected soil structural stability; soil aggregate stability declined with cultivation. Kemper *et al.* (1987), had observed that soils that are low in the clay fraction have a less cohesive affinity to make larger and stable aggregates. The potential for aggregate formation is none with skeletal, non-reactive psf, and is the reason that soils dominated by sand have high detachability and dispersion potential. However, the low %WSA and high detachability potential of sandy soils indicate that the metabolic products of organic matter act as transient non-humic binding agents which are rapidly decomposed by microorganisms (Tisdall and Oades, 1982).

Associated with water stability of aggregates is the mean weight diameter (MWD), an index of macroaggregate stability to the disruptive energy of water (infiltration) or against dispersion and detachment. The study also showed that land use did not affect MWD ($p<0.05$). However, the response to land use was in the order FO>FA>CU, that is 9.52 % > 9.19 % > 8.15%. The high values of MWD obtained may be deceptive because of the low percent WSA from which it is obtained. Thus, aggregate stability whether computed as % WSA or MWD (the sum of the size distribution of the aggregates) is generally low in soils of the study area. Soil aggregate stability is essential for maintaining soil surface integrity, allowing water to infiltrate rather than run off and cause erosion, and the ability of soils to remain productive (Franzluebber *et al*., 2000). Generally, soils dominated by skeletal materials and poorly aggregated are droughty because they have a low affinity for water and low plant available water capacity. Moreover, the stability of soil aggregates is essential to water retention and movement because it is an index of the intrinsic resisting force of the soil aggregates against disruption as water enters and is transmitted through the soil. Soils of high potential detachability are easily deformed, and the dislodged fine particles can clog the soil pores limiting water intake and transmission.

The soil organic carbon (SOC) content in Table 1 showed that FO, FA, and CU were similar ($p<0.05$) in SOC content. However, the magnitude of SOC was in the order CU>FA>FO, that is, 18.22>17.57>16.99 g kg^{-1}. The high SOC in CU indicated that cultivation may not always adversely affect C sequestration in soil. The low SOC content in FO indicated that SOC might not be a linear function of the status of the plant community regarding the quantity of plant materials deposited on the soil surface, most of which may not have been transformed into organic matter and therefore not contribute to the genesis of soil structure. This is contrary to reports by Lee and Foster (1991), that compared with soils impacted by human land use, soils underlying forest vegetation generally have low bulk density and high saturated hydraulic conductivity, total porosity, and macroporosity, as a result of ample litter cover, organic inputs, root growth and decay, and abundant burrowing fauna. Theng (1976), showed that organic carbon contributes to aggregate stabilization by forming stable complexes with polyvalent cations and clay particles. Moreover, since both the clay particles and organic matter are binding agents, one compensates for the other in their roles as aggregating agents. However, in sandy soils with low organic matter content, Mbagwu and Bazzoffi (1988) and Mbagwu (1988), reported that the level of organic matter directly influenced aggregate stability. Similarly, Igwe and Obalum (2013), observed that in coarse-textured soils with low clay content, SOC is the principal aggregating agent. Many reports (Tisdall and Oades, 1982), have stated that macroaggregates are bonded and stabilized by binding agents derived from organic matter, which in the tropics is considered to be the dominant aggregating agent (Igwe and Obalum, 2013). Consequently, the low SOC may thus explain the equally low %WSA in the soil.

The data of soil water constants such as saturation water content (SWC), field capacity (FC), permanent wilting percentage (PWP), and available water capacity (AWC) (Table 2), showed that all four parameters, except SWC, were not significantly ($p<0.05$) different among the land use types. The SWC, the maximum amount of water a soil can hold when all pores are filled with water, was significantly ($p<0.05$) higher in CU (0.488a m^3m-^{3}) than in FA (0.414 m^3m^{-3}) and FO (0.371 m^3m-^{3}); the differences between FA and FO were similar. Also, FC was greater in CU (0.255 m^3m-^{3}) than in FA (0.253 m^3m^{-3}) and FO (0.245 m^3m^{-3}). AWC was equally greater in FA (11.45 m^3m^{-3}) and CU (10.77 m^3m^{-3}) than in FO (8.24 m^3m^{-3}). The higher SWC, FC and AWC in CU were attributed to the more compact soil in that land use practice (soil density of 1.46 Mg m^{-3}). AWC, in particular, is a measure of the soil's ability to supply the water that plants need, and is a soil parameter that can be used to predict the fertility of a soil. Generally, AWC was quite high for the coarse-textured soil and land uses. Babalola and Obi (1981), stated that sandy soils are characteristically droughty, i.e., they have a low water retentive capacity, because they generally have a low content of the colloidal material and high percentage of large pores. They hold little water below a matric potential of -1 bar, and have a narrow (4-7 %) available water range (i.e. the difference between the field capacity, FC, and permanent wilting percentage, PWP). Since the clay fraction is generally low, the values of the soil water constants in this study were associated with the SOC (Mbagwu *et al.,* 1994; Oguike and Mbagwu, 2004) because the effect of land use on soil water retention was found to be through its effect on soil organic matter (SOM) content (and porosity) (Zhou *et al.,* 2008). The results of this study thus, indicate that forest soils may not always have higher soil water retention capacity than cultivated soils.

Romano and Santini (2002), stated that soil water retention characteristic is a soil property, while field water capacity is a process-dependent process value of the water content of the profile. Consequently, Gardner (1968), reported that field water capacity should be more related to the hydraulic conductivity of soil than to the soil water matric potential; soils of high Ksat have low water capacity. Saturated hydraulic conductivity, Ksat, is shown in Table 1. All three land use types were similar ($p<0.05$) in Ksat, but soil under FA (15.26 cm h^{-1}) was far less resistant to the saturated flow of water and in agreement with Gardner (1968) than FO (10.64 cm h^{-1}) and CU (9.55 cm h^{-1}) where the relationship between Ksat and AWC was contradicted. Mbagwu (1987), observed that Ksat varied widely both spatially and temporarily in response to land use due to its influence on bulk density (Khan and Afzal, 1990). The low Ksat in CU with comparable high AWC could be ascribed to the high soil density or compaction (Table 1) as well as plugging of pores by dispersed clay and fine sand particles. Ksat characterizes the ability of a soil to transmit water when it is saturated or near saturated (Reynolds *et al.,* 2002). It is a function of the macroscopic capillary length, the ratio of gravity to capillary forces during infiltration or drainage (Raats, 1976). Coarse-textured soils are characterized by high Ksat or rapid water transmission when saturated which is mostly gravity flow, or low in fine-textured soils dominated by capillary flow. Reynolds and Elrick (2002), observed that Ksat is highly sensitive to soil texture and structure and tends to increase significantly with coarser texture and enhanced structure because of an increase in the number and size of large, highly water-conducting pores, and is responsible for the high hydraulic conductivity of these soils at high matric potential (Babalola and Obi, 1981).

The water infiltration characteristics of the land use systems during the cumulative time of two hours are shown in Table 2. The land use practices were similar in the infiltration parameters, but the magnitude of the numerical values differed ($p<0.05$) among the systems. The trend in the infiltration rate, however, agreed with the theory of initially high (that is, theoretically infinite at zero time) rain or irrigation water acceptance and decreased asymptotically with time to approach a quasi-steady state value or the final infiltration rate, if. The magnitude of the io and if was higher in CU, followed by FA and FO. The higher values in CU indicated the influence of capillary forces over gravity forces associated with the higher bulk density and the probability that the soil particles laid in closer proximity than in FO and FA. However, infiltration is induced by the downward hydraulic gradient from a combination of the effect of gravity and capillary surface tension forces (Miller *et al.,* 1998) and may have applied in these coarse-textured soils. These results differed from the high infiltration rates in soils under bush fallow compared to arable cropland by Wilkinson and Aina (1976) in South-western Nigeria and Osuji *et al.* (2010), in South-eastern Nigeria. The if, representing the infiltration capacity of the soil, was comparatively moderately high for the soil and land use practices but could easily be exceeded under the stormy rainfall common in the area. The characteristics of the rain (high amount and intensity) contribute to lower soil infiltrability by entrapping air and inhibiting entry of water into the soil. Cumulative infiltration, Cum I, soil water sorptivity, S, and soil water transmissivity, A, over the time of measurement followed a trend similar to io and if, that is, FA>CU>FO; for instance, for S, CU(0.46 cm min-0.5)>FA(0.40 cm min-0.5)>FO(0.33 cm min-0.5). All three parameters were high; with Cum I indicating that the water storage depth was considerable in extent and agreed with Petters *et al.* (1989), that the soils are deeply permeable. However, under the timescale of this study, Philip (1957; 1969) assertion that theoretically A should approximate Ksat did not hold; Ksat was several orders of magnitude greater than A. Collis-George (1977) and Skaggs and Khaleel (1982), cited entrapped air during the infiltration process as being responsible for the inequality between Ksat and A. Stewart *et al.* (2013), stated that water infiltration characteristics of soil are of practical significance in soil and water conservation, irrigation and watershed management.

4. Conclusion

A study was conducted on the sandstone parent material in northern Akwa Ibom State to evaluate the effect of forest (FO), fallow (FA), and Cultivated (CU) land use types on soil physical and hydraulic properties. The effects of the three land use practices on soil properties were generally not statistically significant; however, there were remarkable differences among the land uses. For instance, it was observed that bulk density (Bd), water stable aggregates (WSA), soil organic carbon (SOC), saturated water content (SWC), field capacity water content (FC), and sorptivity (S) were higher in CU than in FO and FA, indicating that forest soils may not always have improved soil physical and hydrological properties than cultivated soil. However, since the soils are coarse-textured (with low clay content), conservation tillage involving the application of plant materials on the surface or ploughed into the soil and occasional fallowing to replenish the organic matter content, are needed to bind the primary particles, stabilize soil structure, and improve water intake and storage, essential indices for the optimum edaphological functions of the soils in the study area.

References

Abbasi, M. K., Zafar, M. and Khan, S. R. (2007). Influence of different land-cover types on changes in selected soil properties in the mountain region of Rawalakot Azad Jammu and Kashmir. *Nutr. Cycling in Agroecosystems* 78: 97-110.

Akamigbo, F. O. R. and Asadu, C. L. A. (1983). Influence of parent materials on soils of South-eastern Nigeria. *East African For. J.* 48:81-91.

Anderson, J. L. and Bouma, J. (1973). Relationships between saturated hydraulic conductivity and morphometric data of an argillic horizon. *Soil Sci. Soc. Am. Proc*. 37: 408-413.

Arshad, M. A., Lowery, B. and Grossman, B. (1996). Physical tests for monitoring soil quality. pp.123 - 142. In: Doran, J. W. and Jones, A. J. (ed) *Methods for Assessing Soil Quality.* SSSA Spec. Publ. 49. SSSA, Madison, WI.

Arya, L. M., Leij, F. G., van Genuchten, M. Th. and Shouse, P. J. (1999a). Scaling parameter to predict the soil water characteristic from particle-size distribution data. *Soil Sci. Soc. Am. J.* 63: 510-519.

Arya, L. M., Leij, F. G., Shouse, P. J. and van Genuchten, M. Th. (1999b). Relationships between the hydraulic conductivity function and the particle-size distribution. *Soil Sci. Soc. Am. J.* 63:1063-1070.

Babalola, O. and Obi, M. E. (1981). Physical properties of the Acid Sands in relation to land use. Pp. 27-54. In: *Acid Sands of Southern Nigeria. Soil Science Society of Nigeria. Special Publication Monograph* No.1.

Bormann, H. and Klaassen, K. (2008). Seasonal and land use dependent variability of soil hydraulic and soil hydrological properties of two Northern German soils. *Geoderma* 145: 295-302.

Bouma, J. (1981). Comment on Micro-, Meso- and Macro-porosity of soil. *Soil Sci. Soc. Am. J.* 45: 1244-1245.

Cassinari, C., Manfredi, P., Giupponi, L., Trevisan, M. and Piccini, C. (2015). Relationship between hydraulic properties and plant coverage of the closed-landfill soils in Piacenza (Po Valley, Italy). *Solid Earth* **6** (3): 929–943 DOI: 10.5194/se-6-929-2015.

Celik, I. (2005). Land-use effects on organic matter and physical properties of soils in a southern Mediterranean highland of Turkey. *Soil Till. Res*. 83: 270–277.

Chaney, K. and R. S. Swift (1984). The influence of organic matter on aggregate stability in some British soils. *J. Soil Sci*. 35:223-230.

Chikezie, I. A., Eswaran, H., Asawalam, D. O. and Ano, A. O. (2010). Characterization of two benchmark soils of contrasting parent materials in Abia State, South-eastern Nigeria. *Global J. Pure and Applied Sci.* 16: 23-29.

Chertkov, V.Y., Ravina, I. and Zandoenko, V. (2004). An approach for estimating the shrinkage geometry factor at a moisture content. *Soil Sci. Soc. Am. J.* 68: 1807-1817.

Collis-George, N. (1977). Infiltration equations for simple soil systems. *Water Resources Res.* 18: 1311-1325.

Dane, J. H. and Hopmans, J. W. (2002). Water retention and storage. Pp. 671-673. In: Dane, J. H. and Topp G. C. (eds.). *Methods of Soil Analysis. Part 4-Physical Methods. Soil Sci. Soc. Am.* Book Series No. 5. Madison, WI.

Doran, J. W., Jones, A. J., Arshad, M. A. and Gilley, J. E. (1999). Determinants of Soil Quality and Health. Pp.17-36. In Lal. R. (ed) Soil Quality and Soil Erosion. CRC/SWCS, Boca Raton, FL.

Ezekiel, O., Henry, U. I., Stanley, A. A. and Njese, I. M. (2015). Evaluation of water infiltration on a sandy loam soil in Jos, Plateau State, Nigeria. *Nig. J. Soil Envirn. Res*. 13: 1- 8.

Fallavier, P., Babre, D. and Breysse, M. (1985). *Determination de la capacite d'exchange cationique des sols tropicaux acides. Agron. Trop.* 40(4): 298-308.

Flint, L. E. and Flint, A. L. (2002). Porosity. Pp. 241-254. In: Dane, J. H. and Topp, G. C. (eds) *Methods of Soil Analysis. Part 4: Physical Methods. Soil Sci. Soc. Am. Book* Series No. 5. Madison, WI.

Franzluebber, A. J., Wright, S. F. and Stuedemann, J. A. (2000). Soil aggregation and glomalin under pastures in the Southern Piedmont, USA. *Soil Sci. Soc. Am. J.* 64: 1018-1026.

Gardner, W. R. (1968). Availability and measurement of soil water. Pp. 107-135. In: Kozlowski, T. T. (ed.) *Water Deficit and Plant Growth*. Vol. 1. Academy Press, Inc., New York.

Godsey, S. and Elsenbeer, H. (2002). The Soil hydrologic response to forest regrowth: a case study from South-western Amazonia. *Hydrol. Processes* 16: 1519-1522.

Gregorich, E. G. and Carter, M. R. (eds.) (1997). Soil Quality for Crop Production and Ecosystem Health. *Developments in Soil Sci.,* Elsevier, Holland. 448p.

Grossman, R. B. and Reinsch, T. G. (2002). Bulk density and linear extensibility. Pp. 201-228. In: Dane, J. H. and Topp, G. C. (eds.). *Methods of Soil Analysis.* Part 4- *Physical Methods. Soil Sci. Soc. Am.* Book Series No. 5. Madison, WI..

Harden, C. P. (2006). Human impacts on headwater fluvial systems in the northern and central Andes. *Geomorp*. 79: 249–263.

Harte, K. K. (2000). The effect of soil deformation on physical soil properties: A discourse of a common background. *Adv. Geo Ecol.* 32: 22-31.

Hillel, D. (1982). *Introduction to Soil Physics*. Academic Press, Orlando., FL.

Hillel, D. (1980). *Fundaments of Soil Physics*. Acad. Press, New York.

Igwe, C. A. and Obalum, S. E. (2013). Macroaggregates of tropical soils and the role of some aggregating agents in their stability. *Adv. Agrophy. Res*. 8: 175-192.

Igwe, C. A., Akamigbo, F. O. R. and Mbagwu, J. S. C. (1999). Chemical and mineralogical properties of soils in Southeastern Nigeria in relation to aggregate stability. *Geoderma* 92: 111-123.

Imhoff, S., Da Silva, A. P. and Fallow, D. (2004). Susceptibility to compaction, load support capacity, and soil compressibility of Hapludox. *Soil Sci. Soc. Am. J.* 68: 17-24.

Iovino, M., Castellini, M., Bagarello, V. and Giordano, G. (2016). Using static and dynamic indicators to evaluate soil physical quality in a Sicilian area. *Land Degrad. Dev*. **27** (2): 200–210 DOI: 10.1002/ldr.2263.

Jenny, H. (1980). *The Soil Resource: Origin and Behaviour. Ecological Studies* No. 37. Springer, NY.

Jiménez, C. C., Tejedor, M., Morillas, G. and Neris, J. (2006). Infiltration rate in andisols: effect of changes in vegetation cover (Tenerife, Spain). *J. Soil Water Conser*. 61(3): 153–158.

Karvonen, T., Koivusalo, H., Jauhiainen, M., Palko, J. and Weppling, K. (1999). A hydrological model for predicting runoff from different land use areas. *J. Hydrol.* 217: 253-265.

Khan, G. S. and Afzal, T. (1990). Hydraulic characteristics of some important soil series of Pakistan. Pp. 224-237. In: *Soil Physics: Application in a stressed environment. Pakistan Agric. Res. Council,* Islamabad.

Klute, A. (1986). Water retention: Laboratory methods. Pp. 635-662. In Klute, A. (ed.). *Methods of Soil Analysis.* Part 1. 2nd ed. Agron. Monogr. 9. ASA and SSSA, Madison, WI.

Koorevaar, P., Menelik, G. and Dirksen, C. (1983). *Elements of Soil Physics*. Elsevier, Amsterdam. 228p.

Kutilek, M. and Nielsen, D. R. (1994). *Soil Hydrology*. Catena *Verlag, Cremlingen-Destedt,* Germany. 370p.

Lal, R (1990). Tropical soils: Distribution, Properties, and Management. *Resource Management and Optimization*. Vol. 7: 39-52.

Lal, R. (1999). Soil quality and food security: The global Perspective. Pp. 3-16. In: Lal, R. (ed.) *Soil Quality and Soil Erosion*. CRC/SWCS, Boca Raton, FL.

Lal, R., Kimble, J. M., Follet, R. F. and Caole, C. U. (1998). *The potential of U.S. cropland to sequester carbon and mitigate the greenhouse effect.* Sleeping Bear Press, Ann Arbor, MI.

Lal, R. and Shukla, M. K. (2005). *Principles of Soil Physics*. Marcel Dekker, Inc. New York. 682p.

Lee, K. E. and Foster, R.C. 1(991). Soil fauna and Soil Structure. *Aust. J. of Soil Research* 29 (6), 745–775.

Leeper, G. W. and Uren, N. C. (1993). *Soil Science: An Introduction*. 5th edition. Melbourne University Press, Melbourne.

Lepilin, A. (1989). Effect of the age of perennial grasses on the physical properties of Meadow Chernozem soil. *Soviet Soil Sci.* 21:121-126.

Li, Y. Y. and Shao, M. A. (2006). Change of Soil Physical properties under long-term natural vegetation restoration in the Loess Plateau of China. *J. Arid Envir.* 64: 77-96.

Marique, L. A. and Jones, C. A. (1991). Bulk density of soils in relation to Soil physical and Chemical properties. *Soil Sci. Soc. Am. J*. 55: 476-481.

Mbagwu, J. S. C. (1987). Effect of land use on the hydrological properties of a South-eastern Nigerian soil. *Beitrage trop land wirtsch vetrinamed* 25: 375-382.

Mbagwu, J. S. C., Lal, R. and Scott, T. W. (1983). Physical Properties of three soils from Southern Nigeria. *Soil Sci.* 136: 48-55.

Mbagwu, J. S. C., Unamba-Opara, I. and Nevo, G.O. (1994). Physico-chemical properties and productivity of two tropical soils amended with dehydrated swine waste. *Biores. Technol.* 49: 163-171.

Mbagwu, J. S. C. and Auerswald, K. (1999). Relationship of percolation stability of soil aggregates to land use, selected properties, structural indices and simulated rainfall erosion. *Soil & Till. Res*. 50:197-206.

Mbagwu, J. S. C. (1989). Influence of cattle feedlot manure on aggregate stability, plastic limit and water relation of soil in North Central Italy. *Biol. Wastes* 287-269

Mbagwu, J. S. C. (1988). Influence of cattle feedlot manure on aggregate stability, plasticity limit and water relations of three soils in north-central Italy. *Biol. Wastes* 28: 257-269.

Mbagwu, J. S. C. and Bazzoffi, P. (1988). Stability of microaggregates as influenced by antecedent moisture content, organic waste amendment and wetting and drying cycles. *Catena* 15: 565-576.

Mariamma, J. (2010). A study on the water retention characteristics of soils and their improvements. A Thesis in the Division of Civil Engineering School of Engineering, Cochin University of Science and Technology, Kochi, India. 200p.

Marshall, T. J. and Holmes, J. W. (1988). *Soil Physics.* 2nd ed. Cambridge University Press. 374p.

Miller, J.J., Sweetland, N. J., Larney, F. J. and Volkmar, K.M. (1998). Unsaturated hydraulic conductivity of conventional and conservation tillage soils in Southern Alberta. *Can. J. Soil Sci.* 78:643-648.

Molope, M. B., Grieve, I. C. and Page, E. R. (1987). Contributions of fungi and bacteria to aggregate stability of cultivated soils. *J. Soil Sci.,* 38: 71-77.

Naeth, M. A., R. L. Rothwell, D. S. Chanasyk, and A.W. Bailey (1990). Grazing impacts on infiltration in mixed prairie and fescue grassland ecosystems of Alberta. *Can. J. Soil Sci.* 70:593-605.

Nelson, D. W. and Sommers, L. E. (1996). Total carbon, organic carbon, and organic matter. Pp. 961-1010. In: *Methods of Soil Analysis*. Part 3: *Chemical Methods. Soil Sci. Soc. Am.* Book Series, No. 5. Madison, WI., USA.

Nimmo, J. R. and Perkins, K. S. (2002). Aggregate stability and size distribution. Pp. 317-328. In: *Methods of Soil Analysis.* Part 4: *Physical Methods*. *Soil Sci. Soc. Am.* Book Series No. 5. Madison, Wisconson, USA.

Obi, M. E. and Asiegbu, B. O. (1980). The Physical Properties of some eroded soils of south-eastern Nigeria. *Soil Science* 130: 39 – 48.

Obi, M. E. and Nnabude, P. C. (1988). The effect of different management practices on the physical properties of a sandy loam soil in Southern Nigeria. *Soil Till. Res.* 12: 81-90.

Ofomata, G. E. K. (1981). Actual and potential erosion in Nigeria and measures for control. Pp. 151-165. In: Acid Sands of Southern Nigeria. *Soil Science Society of Nigeria. Special Publication Monograph* No.1.

Ogban, P. I. and Ekerette, I. O. (2001). Physical and Chemical Properties of the coastal plain sands soils in South-eastern Nigeria. *Nig. J. Soil Res.* 2: 6 – 14.

Ogbukagu, I. K. N. (1988). Influence of geology on soil erosion. Pp. 123-130. In: *Ecological Disaster in Nigeria*. Federal Ministry of Science and Technology, Lagos.

Oguike, P. C. and Mbagwu, J. S. C. (2004). Changes in some physical properties of two degraded soils treated with water hyacinth residues. *Int. J. Agric Biol. Sci.* 3: 47-52.

Oguike, P. C. and Mbagwu, J. S. C. (2009). Variations in some physical properties and organic matter content of soils of coastal plain sands under different land use types. *World J. Agirc. Sci.* 5(1): 63-69.

Ojanuga, A. G., Lekwa, G. and Akamigbo, F. O. R. (1981). Survey, classification, and genesis of acid sands. Pp. 1-7. In: Udo, E. J. and Sobulo, R. A. (eds.) *Acid Sands of Southern Nigeria. Soil Science Society of Nigeria Special Publication Monograph* No. 1.

Olatunji, O. O., Ogunkunle, A. O. and Tabi, F. O. (2007). Influence of parent material and topography on some soil properties in Southwestern Nigeria. *Nig J. Soil Environ. Res.* 7:1-6.

Onweremadu, E. U., Akamigbo, F. O. R. and Igwe, C. A. (2007). Lithosequential variability and relationship between erodibility and sodium concentration in soils of a rainforest. *Res. J. For.* 1(2): 73-79.

Osuji, G. E., Okon, M. A., Chukwuma, M. C. and Nwarie, I. I. (2010). Infiltration Characteristics of Soils under Selected Land Use Practices in Owerri, Southeastern Nigeria. *World J. Agric Sci.* 6 (3):322-326.

Park, S. J., McSweeney, K. and Lowery, B. (2001). Identification of the spatial distribution of soils using a process-based terrain characterization. *Geoderma* 103: 249-272.

Petters, S. W., Usoro, E. J., Udo, E. J., Obot, U. W., and Okpon, S. N. (1989). *Akwa Ibom State: Physical Background, Soils and Land use and Ecological Problems*. Govt. Print Office, Uyo. 603p.

Philip, J. R. (1973). Flow in porous media. Pp. 279-294. In: Becker, E. and Mikhailov, G. K. (ed.) *Applied Mechanics.* Proc. 13th Int. Congr. Theor. App. Mechs., Moscow. Springer, Berlin.

Philip J. R. (1969). The Theory of infiltration. *Adv. Hydrosci.* 5: 215-296.

Philip, J. R. (1957). Theory of infiltration: Sorptivity and algebraic infiltration equations. *Soil Sci.* 84:257 – 260.

Pierce, F. J., Larson, W. E., Dowdy, R. H., and Graham, R. A. P. 1983. Productivity of soils: Assessing long-term changes due to erosion. J. Soil and Water Conserv. 38:39-44.

Price, K., Jackson, C. R. and Parker, A. J. (2010). Variation of surficial soil hydraulic properties across land uses in the southern Blue Ridge Mountains, North Carolina, USA. *J. Hydr.* 383: 256–268.

Raats, P. A. C. (1976). Analytical solutions of a simplified flow equation. *Trans. ASAE* 19: 683-689.

Rasiah, V. and Kay, B.D. (1995). Runoff and soil loss as influenced by selected stability parameters and cropping and tillage practices. *Geoderma* 68: 321–329.

Rawls, W.L., Bradensiek, D.L. and Saxton, K.E. (1982). Estimation of soil water properties. *Trans. ASAE* 25: 1316–1320.

Rawls, W. J., Ahuja, L. R., Brakensiek, D. L. and Shirmohammadi, A. (1993). Infiltration and soil water movement. Pp. 5.1-5.51. In: Maidment, D. R. (ed.) *Handbook of Hydrology*. McGraw Hill, Inc. NY.

Rawls, W.J., Gimenez,D. and Grossman, R. (1998). Use of soil texture, bulk density, and slope of the water retention curve to predict saturated hydraulic conductivity. *Trans. ASAE* 41:983-988.

Rawls, W. J., Pachepsky, Y. A., Ritchie, J. C., Sobecky, T. M. and Bloodworth, H. (2003). Effect of organic carbon on soil water content. *Geoderma* 116: 61 – 76.

Reeve, M. J., Smith, P. D. and Thomasson, A. J. (1973).The effect of density on water retention properties of field soils. *J. Soil Sci*., 24: 355 – 367.

Reiners, W. A., Bouwman, A.F., Parsons, W. F.J. and Keller, M. (1994). Tropical rainforest conversion to pasture: changes in vegetation and soil properties. *Ecol. Appl*. 4(2): 363–377.

Reynolds, W. D. and Elrick, D. E. (2002). Principles and parameter definitions. Pp. 797-801. In :*Methods of Soil Analysis*. Part 4: *Physical Methods. Soil Sci. Soc. Am*. Book Series No. 5. Madison, Wisconsin, USA.

Reynolds, W. D. and Elrick, D. E. (2002). Constant head soil core method. Pp. 804-808. In: *Methods of Soil Analysis*. Part 4: *Physical Methods. Soil Sci. Soc*. Am. Book Series No. 5. Madison, Wisconsin, USA.

Reynolds, W. D., Elrick, D. E. and Youngs, E. G. (2002). Ring or cylinder infiltrometer (vadose zone). Pp. 818 -843. In: *Methods of Soil Analysis*. Part 4: *Physical Methods. Soil Sci. Soc. Am.* Book Series No. 5. Madison, Wisconsin, USA.

Reynolds, W. D., Elrick, D. E., Amoozegar, A., Booltink, H. W. G. and Bouma, J. (2002). Saturated and field-saturated water flow parameters. Pp. 797. In: *Methods of Soil Analysis*. Part 4: Physical Methods. Soil Sci. Soc. Am. Book Series No. 5.Madison, Wisconsin, USA.

Ritchie, J.T. (1981). Soil water availability. *Plant Soil*. 58: 327-338.

Romano, N. and Santini, A. (2002). Field. Pp. 721-738. In: *Methods of Soil Analysis*. Part 4: *Physical Methods. Soil Sci. Soc. Am. Book* Series No. 5.Madison, Wisconsin, USA.

Rockström. J., Jansson P. E. and Barron J. (1998). Seasonal rainfall partitioning under run on and runoff conditions on sandy soil in Niger. On-farm measurements and water balance modelling. *J. Hydr.*210(1): 68–92.

Schulze, R. E. (1995). Hydrology and agrohydrology: A text to accompany the ACRU 3.00 agrohydrological model ling system. *Water Res. Comm. Report* No. 63/2/84. WRC, Pretoria.

Schwartz, R.C., Unger, P.W. and S. R. Evett. (2000). Land use effects on soil hydraulic properties. ISTRO. http://www.cprl.ars.usda.gov/programs/land_use.pdf

Schwartz, R. C., Evett, S. R. and Unger, P. W. (2003). Soil hydraulic properties of cropland compared with reestablished and native grassland. *Geoderma* 116: 47-60.

Seyfried, M. S. and Murdock, M. D. (2004). Measurement of soil water content with a 50-MHz soil dielectric sensor. *Soil Sci. Soc. Am. J*. 68: 394-403.

Sharma, M. L. and Uehara, G. (1968). Influence of soil structure on water relations in low humid latosols: Water retention. *Soil Sci. Soc. Am. Proc*. 32: 765-770.

Sharma, R. B. and Verma, G. P. (1972). Moisture retention characteristics of some important soils of Madhya Pradesh in relation to their physical and chemical properties. *J. Indian Forester* 98: 22 - 29.

Shukla, M. K. (2014). *Soil Physics: An Introduction*. Taylor & Francis Group, Boca Raton, FL. 466p.

Sivapalan, M. (2003). Prediction in ungauged basins: A grand challenge for theoretical hydrology. *Hydrol. Processes* 17: 3163-3170.

Skaags, R. W. and Khaleel, R. (1982). Infiltration. Pp. 121-166. In Haan, C. T., Johnson, H. P. and Brakensiek, D. L. (eds.) *Hydraulic Modelling of Small Watersheds*. ASAE Mongr. 5. Am. Soc. Agric. Engr. St. Joseph, MI.

Spewak, R.P. (1997). The effect of land use on the soil macropores characteristics of prairie soils. MSc Thesis. University of Saskatchewan.

Souza, C. F., Or, D. and Matsura, E. E. (2004). Available volume TDR probe for measuring water content in large soil volumes. *Soil Sci. Soc. Am. J.* 68: 25-34.

Stewart, R, D., Rupp, D. E., Abou-Najm, M. R. and Selker, J. S. (2013). Modeling effect of initial soil moisture on sorptivity and infiltration. *Water Resources Research,* Vol. 49, 7037-7047, Doi:10.1002/Wrcr.20508, 2013

Theng, B. K. G. (1976). Interaction between montmorillonite and fulvic acid. *Geoderma* 15: 243-251.

Tisdall, J. M. and Oades, J. M. (1982). Organic matter and water stable aggregates in soils. *J. Soil Sci.,* 33: 141 -164.

Turner, R. K., van den Bergh, J. C. J. M., Söderqvist, T., Barendregt, A., van der Straaten, J., Maltby, E. and van Ierland, E. C. (2000). Ecological-economic analysis of wetlands: scientific integration for management and policy. *Ecol. Econ.* **35**(1): 7–23 DOI: 10.1016/S0921-8009(00)00164-6.

Udo, E. J. and Sobulo, R. A. (eds). (1981). Acid Sands of Southern Nigeria. *Special Publication, Monograph* No.1. Soil Sci. Soc. of Nigeria (SSSN). 165p.

Udosen, C. (2017). *Rainfall Trends in a Humid Tropical Environment*. AniHap Resources, Uyo. 244p.

Terleev, V., Petrovskaia, E., Sokolova, N., Dashkina, A., Guseva, I., Badenko, V., Volkova, Y., Skvortsova, O., Nikonova, O., Pavlov, S., Nikonorov, A., Garmanov, V. and Mirschel, W. (2016). Mathematical modeling of hydro-physical properties of soils in engineering and reclamation surveys. MATEC Web of Conferences. 53: 1-13

Terleev, V., Petrovskaia, E., Nikonorov, A., Badenko, V., Volkova, Y., Pavlov, S., Semenova, N., Moiseev, K., Topaj, A. and Mirschel, W. (2016). Mathematical modeling the hydrological properties of soil for practical use in the land ecological management. MATEC Web of Conferences. 73 03001.

Ticehurst, J. L., Cresswell, H. P., McKenzie, N. J. and Clover, M. R. (1995). Interpreting soil and topographic properties to conceptualize hillslope hydrology. *Geoderma* 137: 279-292.

Warrick, A. W. and Nielsen, D. R. (1980). Spatial variability of soil physical properties in the field. Pp. 319-344. In: Hillel, D. (ed.). *Applications of Soil Physics*. Acad. Press, New York.

Wilkinson, G. E. and Aina, P. O. (1976). Infiltration of water into two Nigerian soils under secondary forest and subsequent arable cropping. *Geoderma* 15(1): 51-59.

Wischmeier, W. H. and Mannering, J. V. (1969). Relation of soil properties to its erodibility. *Soil Sci. Soc. Am. Proc.,* 33:131-137.

Zimmermann, A., Schinn, D. S., Francke, T., Elsenbeer, H. and Zimmermann, B. (2013). Uncovering patterns of near-surface saturated hydraulic conductivity in an overland flow-controlled landscape. *Geoderma* 195&196:1–11.
DOI: 10.1016/j.*Geoderma*.2012.11.002.

Zhou, X., Lin, H. S. and White, E. A. (2008). Surface soil hydraulic properties in four soil series under different land uses and their temporal changes. *Catena* 73(2): 180-188.

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