EFFECTS OF DIFFERENT LAND USE TYPES ON INFILTRATION CAPACITY IN HYDRIC SOILS OF DADIN KOWA GOMBE STATE, NIGERIA.

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ABSTRACT
Infiltration capacity is an important variable for understanding and predicting a range of soil processes. This study was conducted with the main aim of evaluating the infiltration capacity of soils under five different land use types in Hydric soils of Dadin kowa, Gombe state, Nigeria. The land use types considered were: amaranth (AMR), millet (MLT), mango (MNG), rice (RCE) and tomato (TMT) cultivated lands. To achieve this objective, two soil profiles pits were dug in each of the identified land uses and soil samples were then collected from identified genetic horizons. The physical properties of the collected soil samples were determined in the laboratory using standard Laboratory procedures, while the infiltration characteristics of the soils studied were measured using the double-ring infiltrometer for a cumulative time of 180 minutes. Results indicated that mean values of sand, clay and silt ranged from 73.38 to 84.8, 7.8 to 16.7 and 6.58 to 9.91%, respectively, while soil texture was predominantly loamy sand in nature. Bulk density, particle density and total porosity across land uses varied from 1.60 to1.67 g/cm^3, 2.57 to 2.71 g/cm^3 and 35.82 to 40.41% respectively. The results for Infiltration characteristics indicated that land use under tomato (TMT), amaranth (AMR), rice (RCE), millet (MLT) and Mango, recorded infiltration rates (IR) of 2.43, 1.74, 2.36, 3.48, and 6.98 cm/hr, respectively, while the accumulated infiltration (AI) characteristics, indicated that land use under tomato (TMT), amaranth (AMR), rice (RCE), millet (MLT), and Mango (MNG), recorded cumulative infiltration (AI) of 33.3, 30.08, 48.43, 49 and 94.05 cm, respectively. The result of the study also showed that the infiltration characteristics of the studied soils in higher recorded values, followed the trend; mango >millet >tomoato >rice >amaranth. Conservation measures involving planting of tree crops with deep rooting systems, and management practices such as avoidance of excessive soil disturbance, maintenance of surface cover and addition of organic matter, are essential and recommended for optimizing conditions for soil infiltrability, water storage in the soil, and availability to plants.
Key words: Accumulated infiltration, Hydric Soils, Infiltration capacity, Land use, Soil water storage

INTRODUCTION

Infiltration is the movement of water into the soil from the surface by downward or gravitational flow (Hillel, 1998; Lal and Shukla, 2005; Haghaib *et al.*, 2011). It is the key to soil and water conservation because it determines the amount of runoff over the soil surface during a rainstorm, water storage in the root zone and groundwater, and the amount of soil erosion (Pla, 2007).

Soil water is one of the principal factors limiting the growth of plants not only in the arid and semi-arid environment where total crop water requirements usually exceed water supply, but also in the humid environment where poor rainfall distribution and water management result in occasional water stresses (Musa and Adeoye, 2010). An important soil ecosystem function is the enhancement of soil water storage and minimization of runoff and erosion (Lal and Shukla, 2005). This process is controlled by soil biophysical interacting forces which create a stable soil structure with enough macropores to rapidly transmit water (Ogban, 2017). However, soil that is continually disturbed by tillage and other anthropogenic activities often loses its resilience and develops poor structural characteristics, including surface sealing and crusting, and consequently reduced infiltration and high runoff and erosion. This is because intensified land use primarily affects soil's intrinsic and dynamic properties including soil structure and structure-moderated soil properties (Ogban, 2017).

Water infiltration into soils is highly sensitive to land use and soil management, which affects the nature and properties of the soil surface resulting in the alteration of the hydrological balance and the infiltration characteristics of the soil. Also, soil hydraulic properties such as water retention capacity, saturated hydraulic conductivity, infiltration rate, sorptivity and transmissivity are affected differently by land use practices, due to the accompanying changes in soil's intrinsic properties. Selby (1972) reported that the conversion of land from forest to pasture resulted in significant changes in the infiltration characteristics of the soil surface layer in central North Island, New Zealand, because the open structure of the forest soil had been destroyed by grazing. Similarly, in Angra, India, Agnihotri and Yadav (2002) reported infiltration rates that were greater in the forested land than in farmland. Similarly, in Ndola, Tanzania, Saiko and Zonn (2003) obtained higher infiltration rates in fallowed land than in cultivated land. In south-western

Nigeria, Wilkinson and Aina (1976) reported higher infiltration rates into two tropical-forest soils under bush fallow (natural re-growth) compared to arable crop land where soil structural integrity had been compromised. Also, Amusan and Anderson (2005) found that soil texture and infiltration rate declined due to changes in vegetation and soil structural characteristics in south-western Nigeria. Similar research results have been reported in south-eastern Nigeria. For instance, Antigha and Essien (2007) and Osuji *et al*. (2010) reported highly significant (p=0.01) infiltration rates in bush fallow land than in arable crop land. Eze *et al*. (2011) observed that the infiltration rate of a sandy soil under forest was higher than under sparse vegetation and bare cultivation. Also, Osuji *et al.* (2010) reported significant relationships between steady infiltration rates and soil organic matter, bulk density, and total porosity. Shukla *et al*. (2003), Bormann and Klassen (2008) and Haghighi *et al*. (2010) attributed changes in infiltration rates to soil hydraulic properties, porosity, soil organic matter and bulk density and different land use practices.

Infiltration is affected by the inherent properties of the soil such as soil texture and soil structure, which in turn affect the pore space and matric and gravitational forces, and initial moisture condition, the rainfall pattern, and land use and soil management practices (Hillel, 1998). Quantification of infiltration is necessary to determine the availability of water to crops and to estimate the amount of additional water needed for irrigation. It is also needed in watershed management to predict flooding, erosion, and pollutant transport (Ogban, 2017). Thus, understanding infiltration and the factors that affect it is important in determining surface runoff, subsurface water movement and storage within a watershed (Skaggs and Khaleel, 1982). It is in the light of the above that this study was aimed at evaluating the influence of different land use types on infiltration characteristics so as to designing an improved soil and water management technologies to reduce soil erosion improve soil water storage thereby increasing crop production in the study area.

MATERIALS AND METHODS

The Study Area

The study area is at Dadin kowa in Yamaltu Deba Local Government Area of Gombe State (Fig. 1). It is located between latitudes, 8º 30' and 12 º 30' N, and longitudes 10º and 14º E within the Savannah ecological zone of the country (Klinkenberg and Higgins, 1968). It lies at an elevation ranging from 184 to 351 m above sea level (Ikusemoran *et al.,* 2016), situated about 40km along Gombe – Biu road in the Northern Guinea Savanna Zone of Nigeria. According to Ikusemoran *et al.,* (2018), the geological succession of the Dadin Kowa 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 (Ikusemoran *et al.,* 2018). The climate of the area is that of the semi-arid type characterised by wide seasonal and diurnal temperature ranges with two main seasons: rainy season (April-October) and dry season (November to March) (Abubakar, 2013). The average annual rainfall is put at 1000 mm with the greater part falling between July and October (UBRDA, 2018). April is usually the hottest month (maximum temperature being 39ºC) while December and January has the lowest temperature averaging 16º C (UBRDA, 2018).

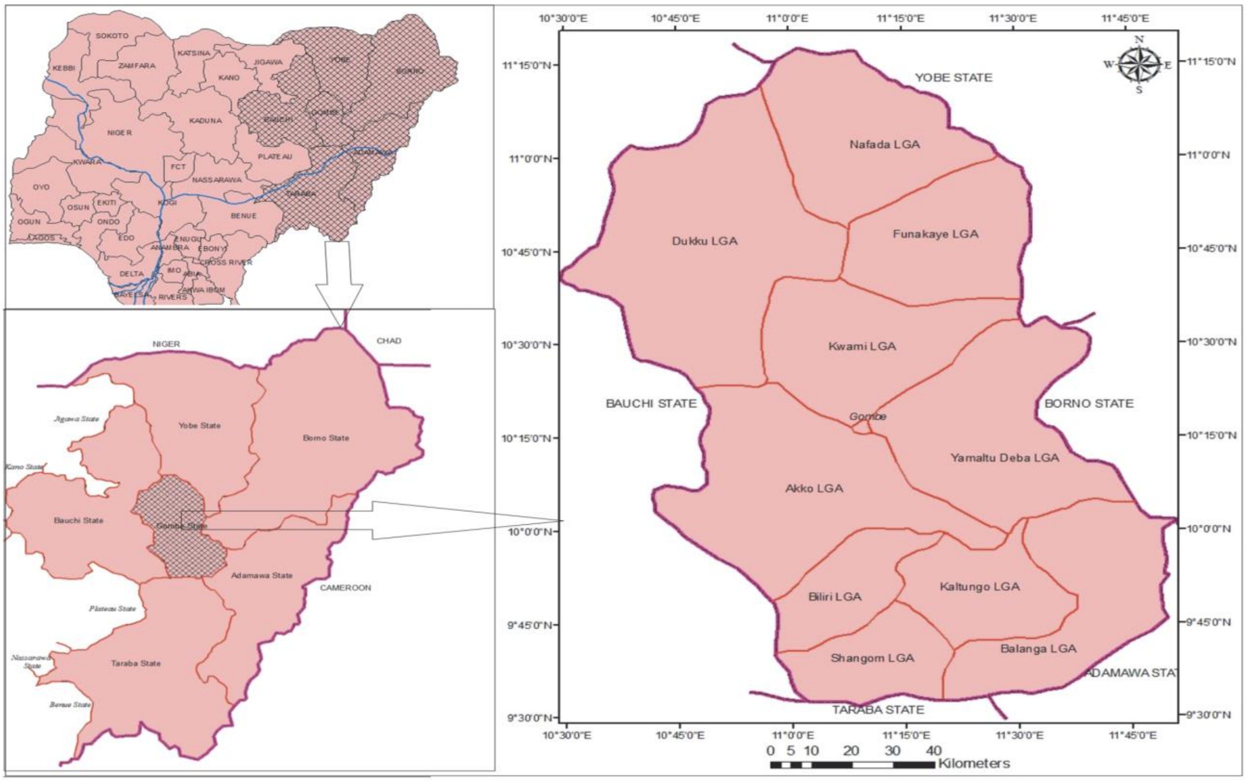

Fig.1. Map of Gombe State and Yamaltu-Deba Local Government Area

Field Methods

Five (5) extensively cultivated farms/orchards were identified and mapped as soil mapping units; they are tomato (TMT), amaranth (AMR), mango (MNG), millet (MLT) and rice (RCE). To achieve objectives of the study, two soil profile pits were dug on each of the 5 mapping units identified, and soil samples from each recognizable pedogenic horizon from each of the dug profile pits were collected, stored, and tagged in polythene bags for laboratory analysis. Two infiltrations run to a cumulative time of 3 hrs was also carried out in each of the mapped units using double ring infiltrometer as described by Reynolds *et al*. (2002).

Laboratory Analysis

Particle-size fractions were determined using the Bouyoucos hydrometer method (Gee and Bauder, 1986), bulk density and particle density were determined in the laboratory using the methods described by Blake and Hartge (1986), while total porosity was calculated mathematically from the results of bulk density and particle density (Agbenin, 1995).

Data Analysis

Descriptive statistics were used to assess the normal distribution of data for parameters analyzed in the laboratory (Agbenin, 1995). Data collected from the laboratory analysis were also subjected to Analysis of variance (ANOVA), using GenStat Statistical Software 17th edition. Means that are significant were separated using LSD at 5% level of probability.

RESULTS AND DISCUSSION

The particle-size distribution mean data for the various land use systems (LUS) is presented in Table 1. The particle size distribution is dominated by the sand fraction (Table 1). The predominance of Sand particles in arid and semi-arid climates is not uncommon because many of them were formed from aeolian deposits blown from across several thousands of kilometers (Mortimore, 1989 and Imadojemu *et al*., 2017). Onweremadu *et al. (*2011), attributed the high Sand content to the nature of parent material. This observation of sand fraction predominance in this study is consistent with the findings of Salem, *et al*. (2017); Collis *et al*. (2018); Askira *et al.* (2019a); Askira *et al.* (2019b). Such deposits are commonly found covering the surfaces of underlying soils that may be formed from other parent materials such as the alluvial deposits common in fadama areas, such as the study area. The highly significant ($p<0.01$) variation in mean Sand distribution across land uses (Table 1) could be attributed to variation in the processes of illuviation and clay lessivage.

Silt particle values (Table 1) ranged from 7.8 to 16.7% across the different land uses. A notable feature in all the soils studied is their high silt content (Table 1). Ogbodo (2011); Nsor and Uhie (2016); Askira *et al.* (2019); Askira *et al.* (2019b), all reported higher Silt content in their various studies.

This high Silt content obtained in this study could be attributed to the nature of parent material and stage of soil development (Maniyunda, 1999). There was a highly significant (p<0.001) difference in Silt content between the different land uses (Table 1). The high mean content of Silt recorded in soils under rice, tomato and amaranth, could be attributed to the received fine colluvial and alluvial sediments from the upper slope positions through erosion and deposition (Maniyunda and Gwari, 2014).

Clay content (Table 1) ranged from 6.58 to 9.91% across the different land uses. The result for particle size distribution (Tables 1) showed that percentage Clay content was lowest when compared to Sand and Silt, in all the studied soils. Such low values of Clay content obtained in this study, agreed with the findings of Akintoye *et al.* (2012); Akpan *et al.* (2017); Askira *et al.* (2019a); Askira *et al.* (2019b), who worked on similar soils. The value of mean Clay content differed significantly (p<0.05) across the different land uses (Table 1). The significant variation in Clay distribution obtained in this study could be related to the pedogenic processes such as lessivage, eluviations and illuviation (Ojetade *et al.*, 2014; Usman *et al.*, 2017).

Table 1: Ranking of the means of the physical properties of the different land uses

	Sand	Silt	Clay	Soil texture	BD	PD	TP
	——— % →		← ———		g/cm^3 →		% ← ———
Land Uses							
Amaranth	77.36bc	14.00a	8.64ab	Sandy loam	1.61b	2.71a	40.41a
Millet	83.12ab	7.80b	9.07a	Loamy sand	1.61b	2.57ab	37.14ab
Mango	84.80a	8.62b	6.58c	Loamy sand	1.67a	2.64a	36.76ab
Rice	73.38c	16.70a	9.91a	Sandy loam	1.60b	2.48b	35.82b
Tomato	78.36bc	14.04a	7.60ab	Loamy sand	1.63b	2.66a	38.70ab
LSD (p<0.05)	*5.23*	*4.07*	*1.95*		*0.04*	*0.12*	*2.72*
LOS	**	***	*		*	*	*

LOS (Level of significant) (p): NS (Not Significant) > 0.05, * < 0.05, ** < 0.01, *** < 0.001

Note: Means followed by the same letters in the column are not significantly different at 5% LOS

Soils textures across mapping units were found to be loamy sand and sandy loam particles, (Table 1). Salem *et al.* (2017); Askira *et al.* (2019b), also reported the occurrence of Loamy sand and Sandy loam in their various studies. Soil texture is an important soil physical property which affects water holding capacity, nutrient retention capacity, organic matter content and soil aeration (Kefas *et al.,* 2016). The texture of these soils reflected the parent rocks from which they are formed (Ahukaemere *et al.,* 2016). Several authors linked soil texture to the nature of parent materials from which the soils were derived and also to the rate and nature of some weathering processes (Ahukaemere *et al.,* 2012).

The mean data for bulk density (BD) values for the studied soils is presented in Table 1. The mean values across the different land uses ranged from 1.60 to 1.67 g/cm^3. The values of bulk density obtained in this study are within the range reported in earlier findings by Ande *et al.*, (2016), who recorded values of 1.11 to 1.98 g/cm^3, while working on floodplain soils in Southern Guinea Savanna of North Central Nigeria. There was an observed significant variation (p<0.05) in mean bulk density values, between the land uses (Table 1). The highest value of Db recorded in soils under mango cultivation could be attributed to high intensity grazing of livestocks (Raji 1995; Raji *et al.,* 1996). Root growth could be inhibited due to high bulk density because of soil resistance to root penetration, poor aeration, slow movement of nutrients and water and build up of toxic gases and root exudates (Sharu *et al.,* 2013). However the values obtained in these studies are generally considered to be safe for root penetration because penetration might be hindered in soil having bulk density value >1.75 g/cm^3 (Esu, 2005; Ashenafi *et al*., 2010). Donahue *et al*. (1990) pointed out that good plant growth is best at bulk densities below 1.40 g/cm^3 for Clay, and 1.60 g/cm^3 for Sandy soils.

The mean Particle density values (Table 1) across the different land uses ranged from 2.57 to 2.71 g/cm^3, indicating that quartz, feldspar, micas and the colloidal silicates with densities between 2.60 to 2.75 g/cm^3 forms the major portion of minerals in the study area (Brady and Weil, 2008). The mean value of PD differed significantly (p<0.05) across the different land uses (Table 1). Generally, the values of particle density recorded in this study were considered satisfactory (Kachinskii, 1965).

Porosity and pore size distribution within the soil are a reflection of bulk density values and have direct influence on the water retention capacity of the soil (Obi, 2000). The general low porosity values recorded in this study falls within the range of 35.82 to 40.41%. Therefore, porosity is a limiting factor in this present study (Kachinskii, 1965). Similar low porosity values were also reported for some studied soils by Ogban and Utin (2015) and Akpan *et al.* (2017), while working on wetland and coastal plain soils in Calabar, Cross River state, Nigeria. There was a statistically significant ($p<0.05$) variation in mean porosity values with respect to land use (Table 1). Land use under *Amaranth* cultivation recorded a higher mean value of 40.41% when compared to the other land uses. The higher mean porosity value recorded in the *Amaranth* land use may be attributed to loosening of soil materials by plant roots and during cultivation of soil (Ahukaemere and Akpan, 2012). Brady and Weil (2008) stated that optimum total pore space value for crop production is >50%. According to Kachinskii (1965), best soils should have porosities of over 50%; good soils between 45-50%; satisfactory soils 40-45 %; unsatisfactory soils fewer than 40% and poor soils, below 30%. In terms of porosity rating, soils under amaranth cultivation could be classed as satisfactory soils, while millet, mango, rice and tomato are classed as unsatisfactory soils (Kachinskii, 1965). Incorporation of organic manure to the soils will decrease the soil bulk density and ultimately increase the percentage pore distribution, thereby enhancing the soil physical condition for optimum crop production and food security (Hassan and Shuaibu, 2006).

Infiltration Characteristics

The study area has its rains with the highest intensity during the first few minutes especially at the onset. The initial high infiltration rates of the soils are therefore useful in relating rainfall characteristics, to soils water characteristics and to soils water storage capacity, while the final equilibrium rates determine the degree and amount of runoff that would occur on the soils. Table 2 and Fig. 2 show the equilibrium infiltration rate or steady state rate of soils after a period of three hours (180 mins) of field measurements. However, at the commencement of infiltration (Table 2 and Fig. 2), the rate is usually high (i.e., theoretically infinite at the initial stages of the process) when the soil is unsaturated and the suction gradient across the soil surface is very high and predominating, which then gradually decreases to approach a constant quasi-steady-state value, due to the limiting rate of water entry into the soil, also referred to as the infiltration capacity or the maximum rate that the soil can absorb water. Therefore, the results of this study with high initial infiltration decreasing to low constant or asymptotic final infiltration towards the end of the cumulative time of three hours are in agreement with the theoretical concept of infiltration (Ogban, 2017). It is also noticeable that the steady state rate occurred between 2 to 3 hours after initial infiltration (Table 2 and Fig. 2).

The results further indicated that land use under tomato (TMT), amaranth (AMR), rice (RCE), millet (MLT) and mango (MNG), recorded infiltration rates (IR) of 2.43, 1.74, 2.36, 3.48, and 6.98 cm/hr, respectively (Table 2 and Fig. 2). The values so obtained for infiltration rates across the different land uses are generally considered to be low. Zata *et al.* (2009); Ogban and Utin (2015) and Ogban (2017), also reported low infilteration rates, while investigating soils in their respective studies. The low infiltration rates recorded across the different land use systems could be attributed to tillage practices involving the use of hoes, diggers and animal traction, which contributed in altering the soil structure (Akintoye, 2012). The aforementioned cultural practices very often affect soil pores, as the migration of fine colloidal materials or inwash down the profile become inevitable in the process. The colloidal particles in turn usually swell and cause pore surface sealing, thereby reducing the sizes of voids and lowers infiltration with time (Dibal *et al.*, 2013).

Table 2: Average Infiltration Data across Land uses

Time Interval (mins)	Land Uses (cm/hr)									
	TMT		AMR		RCE		MLT		MNG	
	IR	AI	IR	AI	IR	AI	IR	AI	IR	AI
5	25.8	2.15	28.8	2.4	42	3.5	63	5.25	82.8	6.9
10	8.4	3.55	8.1	3.75	15	6	15.9	7.9	21.6	10.5
20	6.45	5.7	6.15	5.8	10.5	9.5	10.05	11.25	15.15	15.55
30	3.6	7.5	3.4	7.5	9.8	14.4	8.4	15.45	10.4	20.75
50	3.84	10.7	3.42	10.35	5.1	18.65	5.16	19.75	11.4	30.25
70	2.4	13.5	1.84	12.5	7.29	27.15	2.31	22.45	7.11	38.55
90	2.83	17.75	2.4	16.1	4.4	33.75	4.5	29.2	8.67	51.55
120	2.43	22.6	1.74	19.58	2.36	38.48	3.48	36.15	6.98	65.5
150	2.16	28	2.08	24.78	1.96	43.38	2.58	42.6	5.64	79.6
180	1.77		1.77	30.08	1.68	48.43	2.13	49	4.82	94.05

33.3

TMT= tomato, AMR= amaranth, RCE= rice, MLT= millet, MNG= mango, IR= infiltration rate, AI= accumulated infiltration

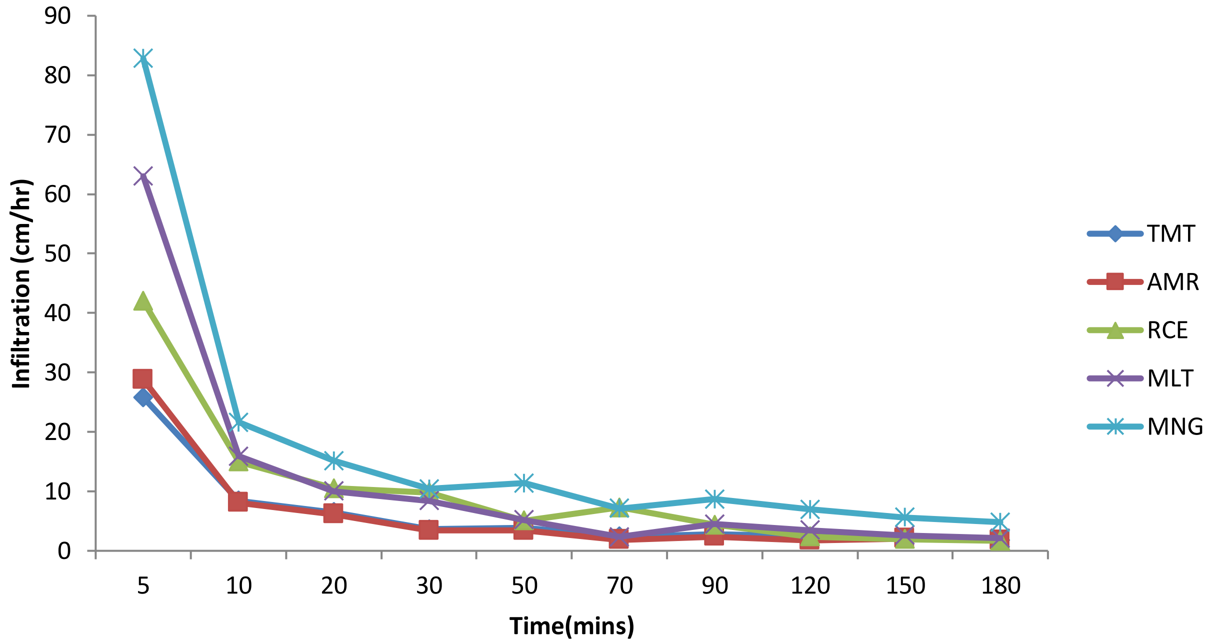

Fig. 2: Infiltration rates against time

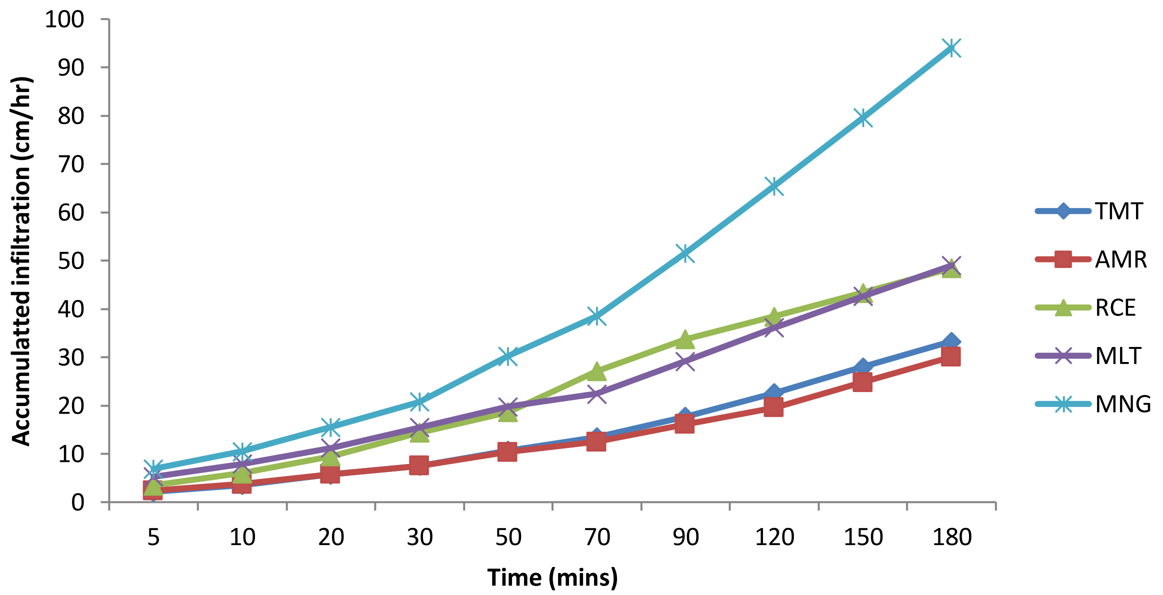

Fig. 3: Accumulated infiltration against time

From the above results, it is also evident that, of the five land uses; mango (MNG) recorded the highest average infiltration rate value of 6.98 cm/hr (Table 2 and Fig. 2). The higher infiltration rate recorded in soils under mango land use could be attributed to soil texture (Hillel, 1998), total porosity (Osuji *et al.*, 2010), dense litter cover (Sharma, 2000), adventitious root system (Akintoye, 2012) and less soil disturbance. Sharma (2000) observed that the presence of a dense vegetal cover on the surface increases infiltration as soils under such land uses, have higher water absorption capacity in the event of heavy storm than other land practices, while Akintoye, (2012) attributed the higher infiltration rate in soils cultivated with mango to the loosening of surface soil arising from lateral spread of plant roots, which creates miniature channels that ease conduct of water and moderate its flow down the soil profile. Therefore, infiltration excess or Hortonian overland flow may readily occur in land use under amaranth, rice, tomato and millet with lower infiltration rate than in land use under mango cultivation. Soils that are continuously cultivated usually experience degradation of soil physical attributes in the soil surface zone especially soil structure and structure-moderated soil properties, e.g., bulk density, total porosity and pore-size distribution, and hydraulic conductivity (Antigha and Essien, 2007; Haghighi *et al.*, 2010; Osuji *et al.*, 2010). Such degradation is common in low resilient soils and under the traditional soil use systems in the humid tropics. Burch *et al.* (1987) reported that agricultural soils, particularly seasonally bare soils, exhibit lower infiltration capacities and less macroporosity than do forest soils. The results from this study also demonstrate that the effect of bulk density on infiltration rate was probably masked by soil texture, land use practices and soil management, which agrees with the fact that water infiltration into the soil is highly sensitive to soil texture, land use and soil management practices as earlier reported by Lal and van Doren (1990), Osuji *et al.* (2010) and Eze *et al.* (2011). Amusan and Anderson (2005) further reported, that soil infiltration rate changes with changes in vegetation and soil structural characteristics in Southwestern Nigeria. Ogban (2017), also reported that avoidance of excessive soil disturbance and maintenance of surface cover of vegetation as in the case of the mango orchard are essential to optimizing conditions for soil infiltrability, water storage in the soil and it's availability to plants. These quality soil management practices will sequester organic carbon, stabilize soil aggregates and improve soil water infiltration for crop production and eventually control erosion in the study area.

The Data for accumulated infiltration (AI), after a period of three hours (180 mins) of field measurements is presented in Table 2 and Fig. 3. Similarly, the results indicated that land use under tomato (TMT), amaranth (AMR), rice (RCE), millet (MLT), and mango (MNG), recorded Cumulative infiltration of 33.3, 30.08, 48.43, 49 and 94.05 cm, respectively (Table 2 and Fig. 3). The results showed that soils under mango cultivation maintained a more open structure that allowed higher total amount of water intake when compared to other land uses. The result also indicated that if the different land use systems received water continuously for three hours, the maximum amount of water that would infiltrate per unit surface area would be 33.3, 30.08, 48.43, 49 and 94.05 cm, in land use under tomato (TMT), amaranth (AMR), rice (RCE), millet (MLT), and mango (MNG), respectively (Table 2 and Fig. 3). Similarly, the soil in the study area was predominantly coarse-textured which indicated that pore-size distribution was skewed towards macropores or drainage pores. However, absorption infiltration predominating initially determined the infiltration rate into the soil and decreases over the time scale of this study. The implication is that a great proportion of the average annual rainfall in the study area which usually comes in storms of high intensity is lost as Hortonian overland flow with the potential for massive accelerated soil erosion on the unconsolidated sandstone material. Consequently, if rainfall intensity was less than the initial infiltration rate, the soil would continue to accept the rain water and ponding and runoff would never occur. On the contrary, when rainfall is in excess of the infiltration capacity of a given soil, initially the soil would continue to absorb the incoming water until the matric potential gradients near the surface diminish to the point where the water cannot be taken up by the soil as fast as it is entering through the surface, as a result, the surface saturates, rapid ponding develops and eventually surface runoff.

The results from this study indicated that rainfall characteristics (amount and intensity), soil texture, land use and soil management practices have been implicated in the low infiltration characteristics in the study area. However, in this study the infiltration characteristics were higher in mango than in the other land use practices, therefore land use under mango will experience a delayed occurrence in infiltration-excess or surface runoff or the so called Hortonian overland flow when compared to the other land use systems.

CONCLUSION

The study revealed that different land use systems had differential effects on soil infiltration characteristics, with soil texture, land use and management practices playing a prominent role. The result of the study also showed that the infiltration characteristics of the studied soils are generally found to be low, and in higher recorded values followed the trend mango> millet> tomato> rice> amaranth. Similarly, the low soil infiltrability recorded in this study generally indicates low soil water storage and potentially high accelerated erosion and soil degradation. The study further indicated that planting of tree crops with deep rooting systems, avoidance of excessive soil disturbance and maintenance of surface cover, as in the case of land use under mango cultivation, are essential to optimizing conditions for soil infiltrability, water storage in the soil, and availability to plants. These quality soil management practices will sequester organic carbon, stabilize soil aggregates and improve soil water infiltration for crop production and control erosion in the study area.

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