Evaluation of the Textural, Physical, and Infiltration Properties of Topsoils in Parts of Michael Okpara University of Agriculture, Umudike Southeastern Nigeria

C. Amos-Uhegbu, Ph.D.*, C.D. Akoma, M.Sc., and S.T. Jokotagba, B.Sc.

Department of Geology, Michael Okpara University of Agriculture, Umudike,
PMB 7267 Umuahia, Abia-State, Nigeria.

E-mail: amos-uhegbu.chukwunenyoke@mouau.edu.ng *

ABSTRACT

Using the falling head method of a 60/30 cm double ring infiltrometer, the infiltration characteristics of the Michael Okpara University of Agriculture (Umudike, Nigeria) soils were assessed at sixteen sites under a comparative analysis of the textural classification and the land use practices. Soil cover, initial moisture content, textural class, and degree of compactness were found to be the possible contributors to the variability of the infiltration rate of the topsoils in the study area, with no discernible relationship to the soil pH or porosity. Loam, sandy loam, sandy clay loam and clay loam were identified as the four soil textural classes present.

The infiltration rates reflect a similar pattern in all the soils with mean values ranging from 1.23 cm/hr to 7.42 cm/hr at 150 minutes and an outlier value of 11.83 cm/hr reported from the forest soil. Similarly, the mean cumulative water intake value of the forest soil was measured to be 7.89 cm while those of the other fifteen locations ranged from 1.20 cm to 7.89 cm. The soil textural class and land use practices were significant as their effect were observed in the infiltration capacity trends of the soils with those of the coarse soils and forest soil almost doubling the values of the clay loam soils and exposed soils. Unlike exposed soils and farmland soils, forest soils require very high rainfall intensities to generate surface runoff. Percentage moisture content varied from 29.83 to 45.35. In order to stabilize soil aggregates, enhance soil water infiltration for crop production, and to checkmate erosion in the study area; good farm/soil management strategies are recommended.

(Keywords: outlier, moisture content, topsoil texture, Infiltration properties)

INTRODUCTION

Infiltration describes the capacity of water to travel vertically down the soil profile. This process may be quantified as it is a key factor in hydrologic, pedologic, hydrogeologic, and irrigation investigations (Kale and Sahoo, 2011; Mahapatra, *et al.,* 2020). The total amount of water that soil strata can absorb from irrigation or rainfall is known as cumulative infiltration. The rate at which it occurs is known as the infiltration rate, and it is dynamic due to the effects of various factors like land use type, initial moisture content, biological matter and activities, degree of compactness, soil texture, porosity, etc. (Angelaki, *et al.,* 2013; Ma, *et al.,* 2015). The soil profile's water transmission properties set a restriction on the rate of infiltration.

According to Hillel (1998), swelling in clay soils and an impervious soil layer slow down infiltration, but macropores, high organic matter, good porosity, and dense vegetative cover accelerate it. Infiltration helps move substances through the soil, contributes to ground water recharge, reduces runoff and erosion, and affects the water budget of vegetation, among other things (Angelaki, *et al.,* 2004; Mahapatra, *et al.,* 2020). Enhancing rainwater infiltration into the soil, while reducing runoff and erosion is a crucial function of soil and ecosystems (Lal and Shukla, 2005).

According to Bisong (2001), deforestation and urbanization have a negative impact on soil quality, soil structure, and the capacity of soil to carry out ecological, agronomic, and environmental tasks. Due to the resulting changes in the intrinsic properties and hydrological balance of soils, different aspects of soil infiltration, such as water retention capacity, saturated hydraulic conductivity, infiltration rate, sorptivity, and transmissivity, are impacted by land use practices. Therefore, characterizing infiltration is crucial because it controls how much runoff occurs over the soil surface during rainstorms, how much water is stored in the root zone and groundwater, and how much soil erosion occurs (Pla, 2007). This investigation was carried out at field scale with the aim of quantifying the spatial variability of infiltration of the topsoils of Michael Okpara University of Agriculture, Umudike.

STUDY AREA

The study area (Michael Okpara University of Agriculture, Umudike) has typical annual average temperature ranges of about 29º -31º C and is located between latitudes 5º 28' and 5º 29' N and longitudes 7º 32' and 7º 33' E (Fig. 1). With relative humidity levels of 70%, the region is in the sub-equatorial belt.

The wet season lasts from mid-April to October, with rainfall peaks in July and September and a brief break in August. In Abia state, Nigeria, there are about 11 different geologic Formations, although the Benin Formation of the Cenozoic Niger Delta covers nearly half of the state. Geologically, the Michael Okpara University of Agriculture, Umudike (MOUAU) is located in the Benin Formation of the Cenozoic Niger-Delta Basin of Nigeria (Figure 1). The region is a portion of the earliest surface outcrop of the Cenozoic Eastern Niger-Delta Basin due to its proximity to the surface outcrop of the underlying the Bende-Ameki Formation of the Anambra Basin (Figure 1). The study locations in MOUAU are presented in Table 1.

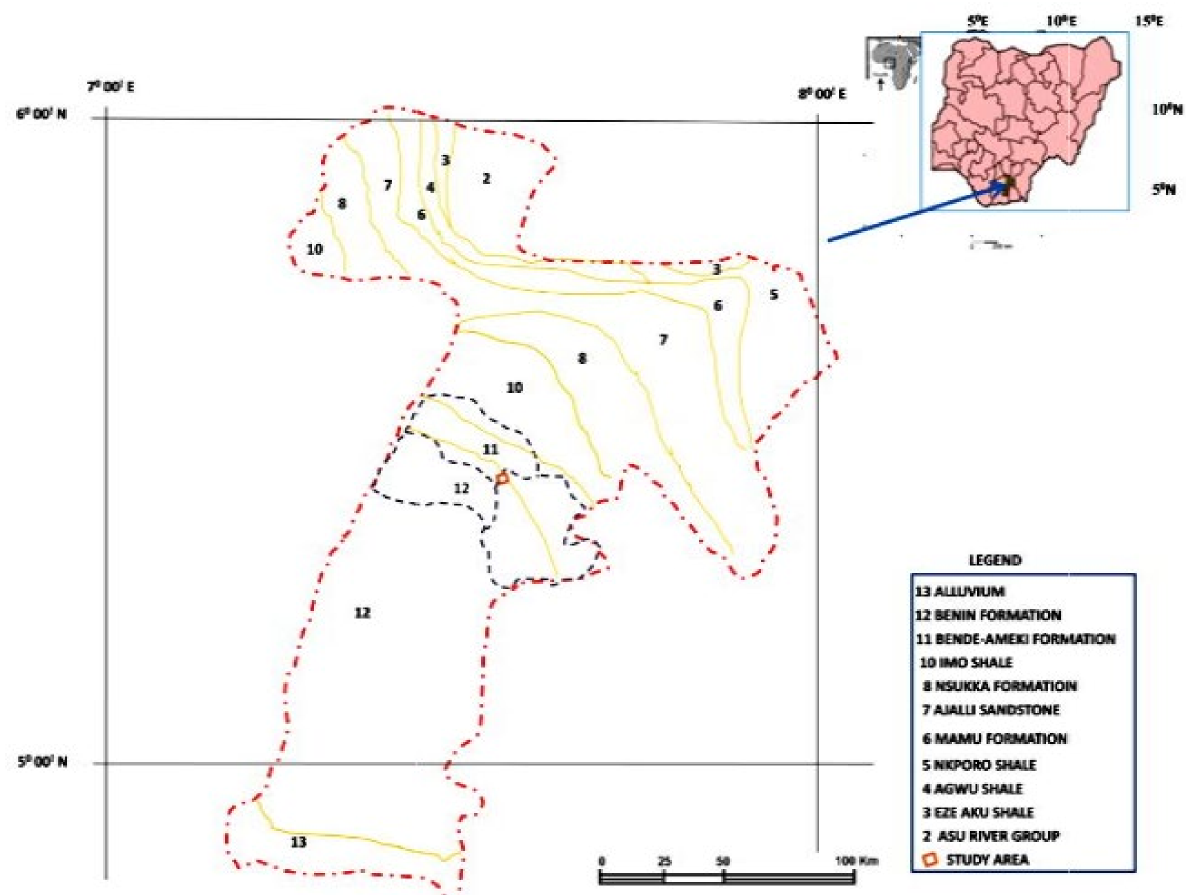


Figure 1: Geologic Map of Abia State, Nigeria showing the Study Area.

Table 1: The Study Locations in MOUAU.

S/N	NAME	LATITUDE (N)	LONGITUDE (E)	ELEVATION (m)
1	T&R FARM	5° 28.504	7° 31.809'	379.2
2	FOREST	5° 28.295	7° 32.502'	373.9
3	STADIUM	5° 28.549	7° 32.488'	395.4
4	CEC	5° 28.937	7° 32.665'	390.1
5	COLNAS	5° 28.863	7° 32.377'	386.9
6	CEET	5° 28.584'	7° 32.416'	387.1
7	CAERSE	5° 28.924'	7° 32.676'	323.6
8	COLMAS	5° 28.599'	7° 32.339'	386.5
9	CAFST	5° 28.577'	7° 32.629'	425.6
10	COED	5° 28.913'	7° 32.485'	372.0
11	PG SCHOOL	5° 28.670'	7° 31.917'	367.7
12	FARMLAND	5° 28.588'	7° 32.532'	397.7
13	CVM	5° 28.664'	7° 32.206'	354.7
14	CCSS	5° 28.896'	7° 32.398'	412.4
15	COLPAS	5° 28.782'	7° 32.413'	409.0
16	PG HOSTEL	5° 28.652'	7° 31.917'	366.9

MATERIALS AND METHODS

The double ring infiltrometer method (Bouwer, 1986; ASTM, 2002) was used to in the study. The double ring infiltrometer method is more reliable than the single ring method because it minimizes the error arising from lateral flow of water (Gregory, *et al*., 2005). Care was taken to carefully place the 60/30cm infiltrometer cylinders 15 cm into the soil, with the heights of the two rings (concentrically positioned to reduce unnecessary soil disturbance) roughly at the same level of 12cm. Water was poured into both the inner and outer rings at the same time. The soils' water intakes were calculated using the rule that was attached to the bridge. The inner ring's water level was periodically measured at intervals of 5, 10, 15, 20, and up to 150 minutes while the water levels in the outer rings were kept at a constant level of 5 cm. A pH meter was used to determine the soils' pH levels. To find the bulk density of the soil as well as other physical characteristics, fresh core samples were collected using core samplers and were subsequently taken to the laboratory for analysis.

The Philip model is the most frequently used of the various models that have been developed and used to calculate soil infiltration rates. Philip claims that the infiltration process can be separated into two parts: that which is affected by gravity and that which is triggered by sorptivity variables. The rate at which water will be drawn into a soil in the absence of gravity is known as sorptivity, which combines the effects of capillarity in soil pores with absorption at soil particle surfaces. The influence of pores on how water flows through soil when gravity is present causes the gravity factor. The Philip's model is given by the two-parameter equations:

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

The differentiation of Equation (1) yields:

$$\frac{dt}{dI} = \frac{1}{2}St^{-\frac{1}{2}} + A, \qquad \textbf{(2)}$$

Equation (2) allows for the estimation of the infiltration rate. The constants A and S are obtained from a graph of $\frac{dI}{dt}$ vs $t^{-\frac{1}{2}}$. Where A (gravity factor) = intercept, and S (sorptivity factor) = slope.

RESULTS AND DISCUSSION

The results obtained in the course study are as presented in Tables 2, 3, and 4 alongside Figures 2 – 7. The largest water intake was obtained from the Forest topsoil, with an average value of 10.97 cm, whereas the average values for the other sites ranged from 1.20 cm to 7.89 cm (Table 2, Figure 2); with CEET topsoil having the lowest infiltration rate. (Table 3, Figure 3). With a mean value of 11.83 cm/hr, the Forest topsoil is an outlier and fell beyond the typical infiltration rate range of 1.23 cm/hr – 7.42 cm/hr for other sites (Table 3 and Figure 4).

Table 2: The Cumulative Water Intake (cm) of the Topsoils in the Study Area.

Cumm. Time Intake (mins)	T&R FARM	FOREST	STADIUM	CEC	COLNAS	CEET	CAERSE	COLMAS	CAFST	COED	PG SCHOOL	FARMLAND	CVM	CCSS	COLPAS	PG HOSTEL
5	2.37	2.14	0.87	0.72	0.35	0.15	0.27	0.55	0.43	0.56	1.01	1.35	0.63	0.24	1.19	1.03
10	3.39	4.01	1.31	1.09	0.65	0.28	0.46	1.05	0.71	0.88	1.53	2.45	1.11	0.44	2.23	1.77
15	4.18	5.09	1.64	1.26	0.91	0.41	0.67	1.43	0.99	1.18	2.05	3.12	1.55	0.63	2.95	2.36
20	4.83	5.99	1.96	1.53	1.06	0.53	0.87	1.64	1.22	1.47	2.52	3.73	1.96	0.80	3.66	2.86
30	5.96	7.78	2.56	2.02	1.35	0.77	1.15	2.32	1.61	1.92	3.33	4.80	2.38	1.13	5.06	3.83
45	7.44	10.33	3.43	2.71	1.75	1.11	1.51	3.54	2.13	2.52	4.22	6.43	2.96	1.56	6.23	5.13
60	8.91	12.25	4.25	3.04	2.10	1.44	1.87	4.11	2.59	3.06	5.02	7.65	3.58	1.93	7.30	6.16
75	9.99	14.14	4.89	3.22	2.37	1.75	2.15	4.90	3.04	3.58	5.76	8.76	4.20	2.26	8.33	7.16
90	11.12	16.01	5.45	4.04	2.62	2.01	2.43	6.02	3.33	4.06	6.45	9.62	4.60	2.50	9.26	8.03
120	13.28	19.66	6.53	5.11	3.12	2.35	2.95	7.74	3.52	5.02	7.63	11.33	6.00	2.77	10.00	9.36
150	15.35	23.31	7.61	6.18	3.58	2.41	3.44	9.46	3.67	5.97	8.80	13.65	7.50	3.02	10.73	10.63
Mean value	7.89	10.97	3.68	2.81	1.81	1.20	1.62	3.89	2.11	2.75	4.39	6.62	3.31	1.57	6.08	5.30

Table 3: The Infiltration Rates (cm/hr) of the Topsoils in the Study Area.

Cumm. Time Intake (mins)	T&R FARM	FOREST	STADIUM	CEC	COLNAS	CEET	CAERSE	COLMAS	CAFST	COED	PG SCHOOL	FARMLAND	CVM	CCSS	COLPAS	PG HOSTEL
5	16.20	25.68	10.44	8.64	4.20	1.80	3.24	6.60	5.16	6.72	12.12	16.20	7.56	2.88	14.28	12.36
10	12.24	22.44	5.34	4.44	3.60	1.56	2.28	6.00	3.36	3.84	6.24	13.17	5.82	2.40	12.42	8.84
15	9.48	12.96	3.96	2.04	3.12	1.56	2.52	4.56	3.36	3.60	6.24	8.04	5.28	2.28	8.70	7.08
20	7.80	10.80	3.84	3.24	1.80	1.44	2.40	2.52	2.76	3.48	5.64	7.38	4.92	2.04	8.52	6.00
30	6.78	10.74	3.60	2.94	1.74	1.44	1.68	4.08	2.34	2.70	4.86	6.41	2.52	1.98	8.40	5.82
45	5.92	10.20	3.48	2.76	1.60	1.36	1.44	4.88	2.08	2.40	3.56	6.51	2.32	1.72	4.68	5.20
60	5.88	7.68	3.28	1.32	1.40	1.32	1.44	2.28	1.84	2.14	3.20	4.91	2.48	1.48	4.28	4.12
75	4.32	7.56	2.56	0.72	1.08	1.24	1.12	3.16	1.80	2.10	2.96	4.43	2.46	1.32	4.12	4.00
90	4.52	7.48	2.24	3.28	1.00	1.04	1.12	4.48	1.16	1.92	2.76	3.44	1.62	0.96	3.70	3.48
120	4.32	7.30	2.16	2.14	1.00	0.68	1.04	3.44	0.38	1.92	2.36	3.42	2.80	0.54	1.49	2.66
150	4.14	7.30	2.16	2.14	0.92	0.12	0.98	3.44	0.30	1.90	2.34	4.64	3.00	0.50	1.46	2.54
Mean value	7.42	11.83	3.91	3.06	1.95	1.23	1.75	4.13	2.23	2.97	4.75	7.14	3.71	1.65	6.55	5.65

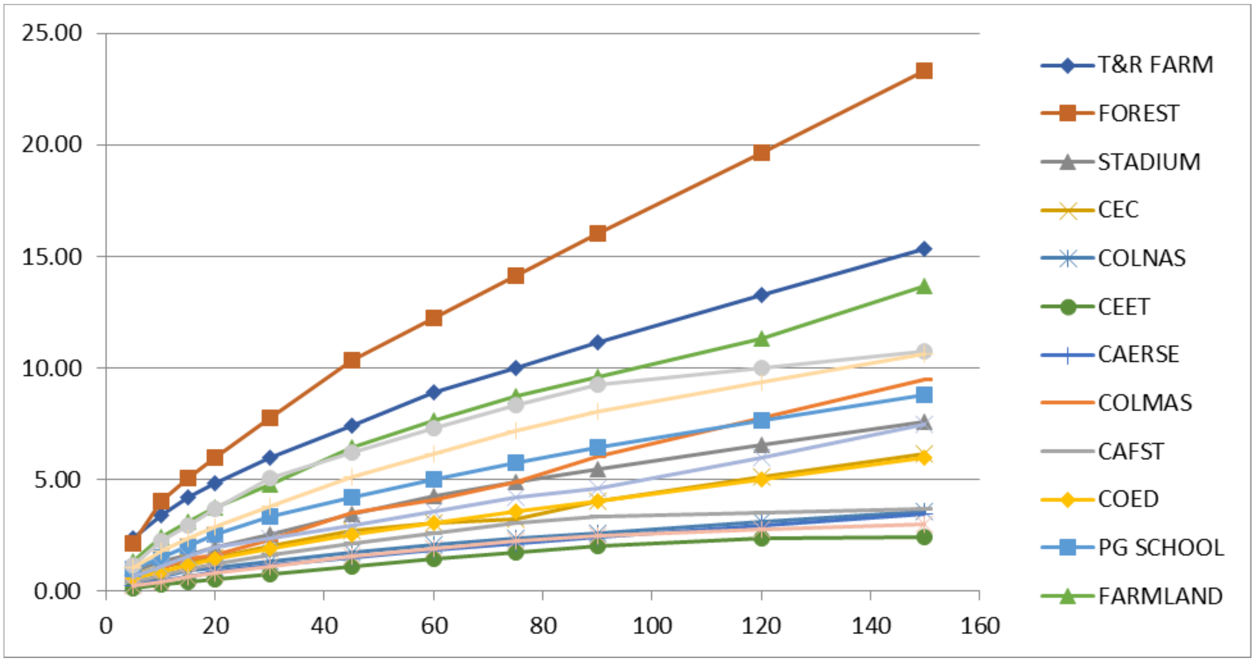
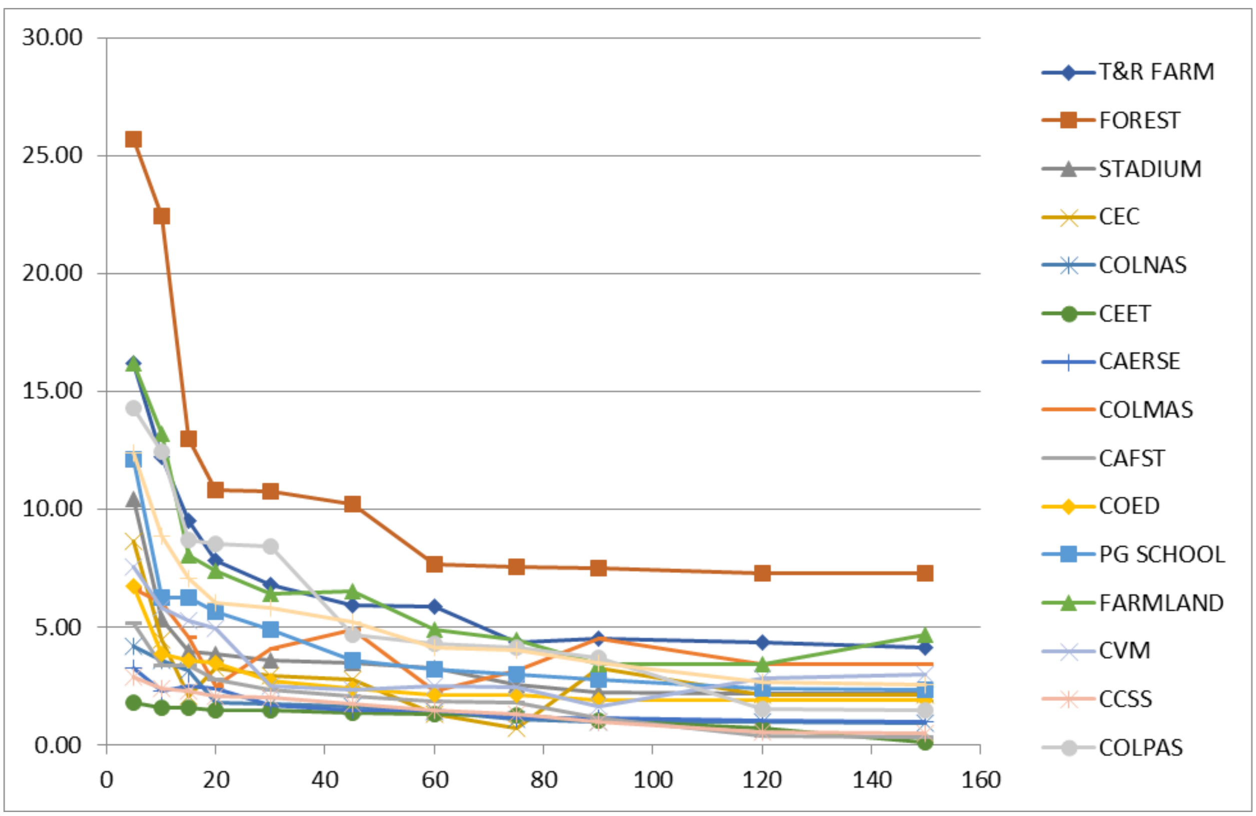


Figure 2: The Cumulative Water Intake of the Topsoils in the Study Area.



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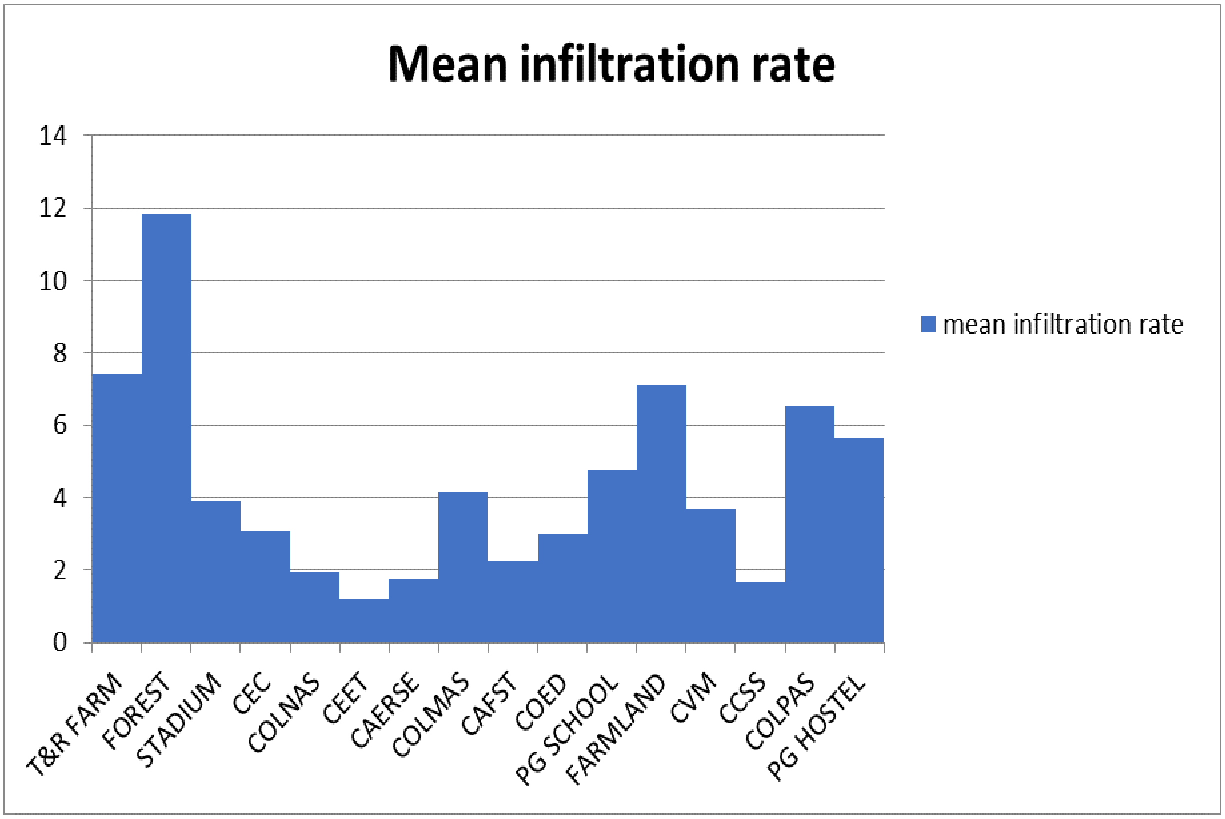

Figure 4: The Mean Infiltration Rates of the Topsoils in the Study Area.

According to the topsoils' compositional ratio of the study area, there are four textural classifications: loam 6.25%, sandy loam 31.25%, sandy clay loam 25%, and clay loam 37.5% (Figure 5, Figure 6, and Table 4). The loam and sandy loam soils accumulated more water input than their counterparts.

The average cumulative intake at 150 minutes ranged from 1.20 cm – 4.39 cm for clay loams, 1.57 cm – 3.89 cm for sandy clay loams, as well as 3.68 cm – 7. 89 cm for sandy loams and 10.97 cm for loam topsoil.

Texture is a crucial aspect of soil because it affects how quickly water is absorbed into the soil, how much water is stored there, how easily tillage can be performed, how well the soil is aerated, and other factors. The rate of infiltration seems to follow a consistent pattern (Figure 3).

This grouping of the sites into coarser (loam and sandy loams peaking at 11.83 cm/hr) and finer (clay loams and sandy clay loams peaking at 5.23 cm/hr) textural groups showed that the percolating rates of the coarser group were roughly twice as high as those of the finer group.

With vegetation succession and the accumulation of organic matter, it is anticipated that the physical and chemical properties of soil will improve, resulting in a tighter soil texture and, ultimately, a higher water infiltration rate; thus illustrating how soil texture affects infiltration rate.

The higher clay content of the clay loams in addition to having a finer texture may have been the cause of their lower infiltration rate as clay particle swellings and dispersion are known to obstruct soil pores and cause slow percolation rates. Clay loam soils have a medium to fine texture compared to sandy loam soils, which may be another contributing factor. Gregory, *et al.,* (2005) noted the infiltration rate of the group of coarse soil to be significantly higher than that of the group of medium to fine soil.

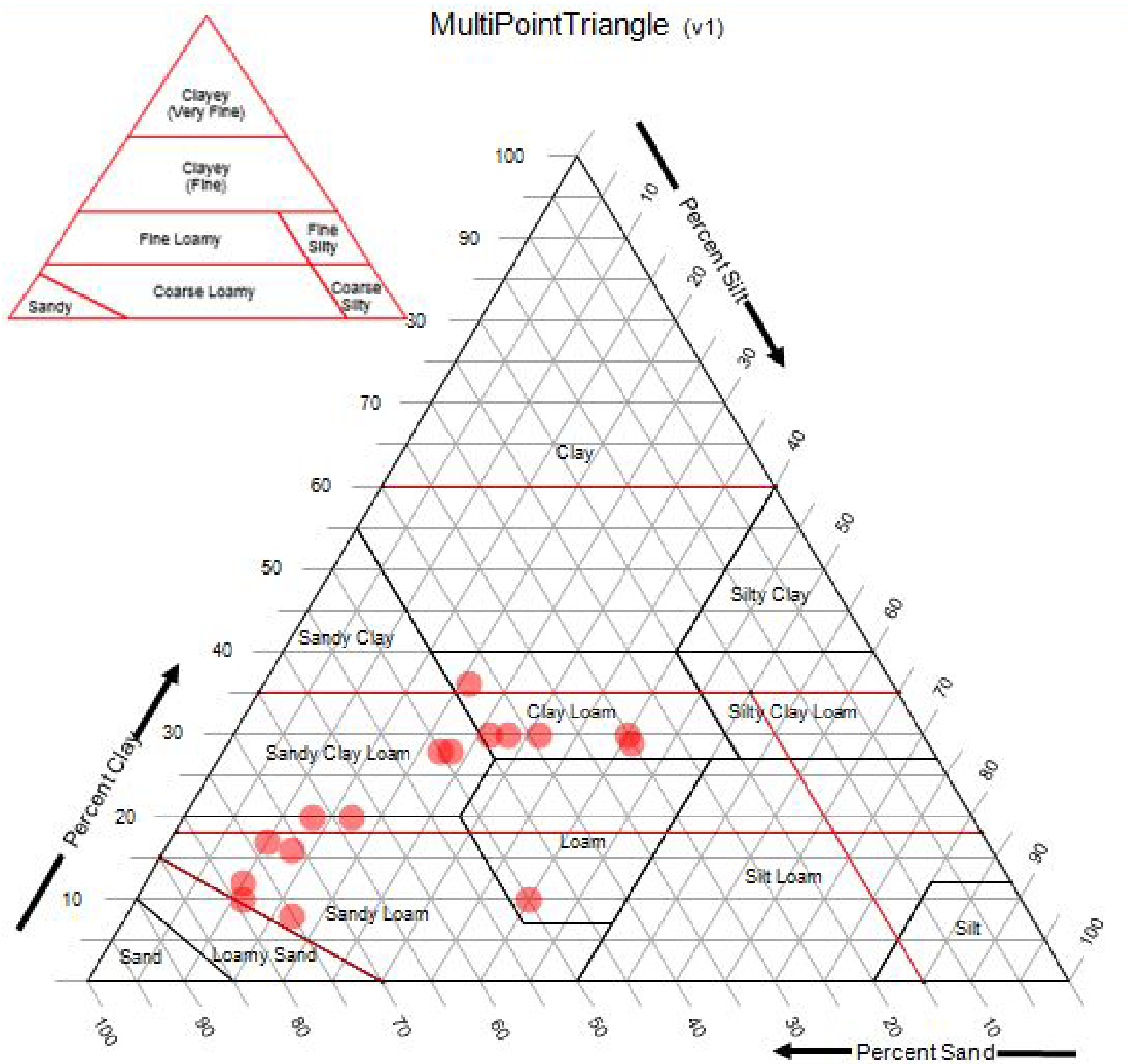

Figure 5: Textural Classification of the Topsoil Composition.

Rock fragments from the past and accumulated decaying vegetation are the sources of topsoil. The ratio of these two elements greatly influences how acidic a soil is, along with how much water is present in the pore spaces. According to Johnson *et al.,*, (1988), the main determinants of soil acidity are edaphic, climatic, and biological factors. Sandy soils get more acidic more quickly because they contain fewer clay particles and have a higher leaching potential. The acidity of the soil is also increased by the decomposition of organic matter. In this study, the arbitrary increasing acidity pattern (trend) with some overlap was loam soil, sandy clay loams, sandy loams and clay loams.

In seeing that his arable soils were more acidic than forest soils, Donald (2012) made a similar observation. They linked low organic matter levels, the use of ammonium fertilizers, soil erosion, and tillage activities that impair soil structural stability and cation exchange capacity to the low pH values of arable soils as corroborated by Amir *et al.,* (2010). Overall, the geology of the region suggests that the parent material of the soils is likely sandstone (Figure 1), and because sandstone contains a lot of silica, the pH value range of 6.55–6.80 indicates that the soils are slightly acidic (Table 4).

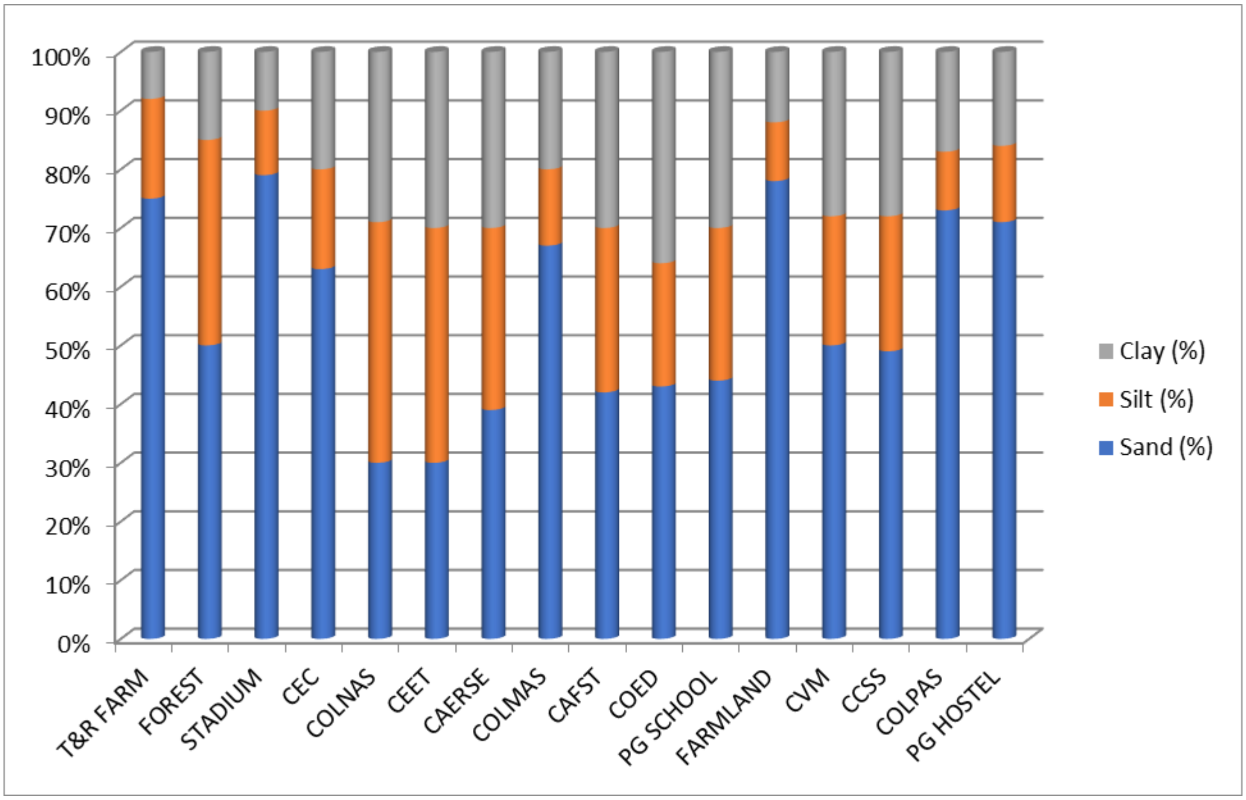

Figure 6: Composition of the Topsoils in the Study Area.

Table 4: The Physical Properties of the Topsoils in the Study Area.

S/N	LOCATION	SAND (%)	SILT (%)	CLAY (%)	TEXTURE	BULK DENSITY (g/cm^3)	ORGANIC MATTER (%)	pH	MOISTURE CONTENT (%)	POROSITY (%)
1	T&R FARM	75	17	8	Sandy loam	1.65	1.91	6.75	30.02	35
2	FOREST	50	35	15	Loam	1.56	2	6.80	45.35	40
3	STADIUM	79	11	10	Sandy loam	1.73	1.09	6.70	30.22	28
4	CEC	63	17	20	Sandy clay loam	1.67	1.15	6.60	31.35	29
5	COLNAS	30	41	29	Clay loam	1.63	1.19	6.55	34.05	29
6	CEET	30	40	30	Clay loam	1.66	1.55	6.50	36.05	28
7	CAERSE	39	31	30	Clay loam	1.65	1.32	6.55	34.05	29
8	COLMAS	67	13	20	Sandy clay loam	1.73	1.15	6.70	31.15	30
9	CAFST	42	28	30	Clay loam	1.60	1.4	6.70	33.85	28
10	COED	43	21	36	Clay loam	1.63	1.42	6.75	33.22	28
11	PG SCHOOL	44	26	30	Clay loam	1.65	1.21	6.60	30.15	32
12	FARMLAND	78	10	12	Sandy loam	1.68	1.85	6.65	30	36
13	CVM	50	22	28	Sandy clay loam	1.67	1.15	6.70	30.05	30
14	CCSS	49	23	28	Sandy clay loam	1.67	1.21	6.60	34.35	28
15	COLPAS	73	10	17	Sandy loam	1.65	1.6	6.55	29.83	33
16	PG HOSTEL	71	13	16	Sandy loam	1.67	1.09	6.55	29.96	33

The organic matter level of the topsoils ranges from 1.09 % to 1.91%. The porosity (28 - 40%) and moisture content (29.83 - 45.35%) values of the soils are high with a trend of Forest soil > farmland soils > bare soils, in both cases. These show the effects of land use activities on such soil properties with an implication that the properties of the virgin forest soil are still being preserved. According to a report by Yimer, *et al.,* (2012), human tillage and trampling of the soil caused soil to become more compact, this in turn reduced the macro-pore volume.

Since the soils may be able to store additional water both in and on the soil, the steady infiltration rate sets a minimum absorption capacity. The amount stored depends on the preceding weather conditions and on micro-relief (Diamond and Shanley, 1998). The study indicates that infiltration rates showed a pattern whereby that of forest topsoil is greater than that of exposed topsoils, with farmland topsoils also having slightly greater infiltration rates than exposed topsoils.

Osuji, *et al.,* (2010) showed higher average infiltration rates under bush fallow than under arable cropland in South-eastern Nigeria, thus supporting this finding. In Calabar, Southern Nigeria, Antigha and Amalu (1999), Antigha and Essien (2007), and Eze, *et al.* (2011), similarly noted that a sandy soil's infiltration rate was higher under a forest than under sparse vegetation and bare surface. In a rural district of Ndola, Tanzania, Saiko, and Zonn (2003) also noted that infiltration was roughly twice as high in fallow ground as it was in farmland that had been cultivated.

According to Wei *et al.,* (2022), the initial soil moisture content has a significant impact on the relationship between infiltration rate and soil moisture content, suggesting a clear negative correlation. The experimental results of this study show that a decrease in soil pore volume has a direct negative impact on infiltration capacity and moisture content, which promotes soil erosion. High initial moisture content appears to indicate lower mean infiltration rates, with few exceptions (Figure 7).

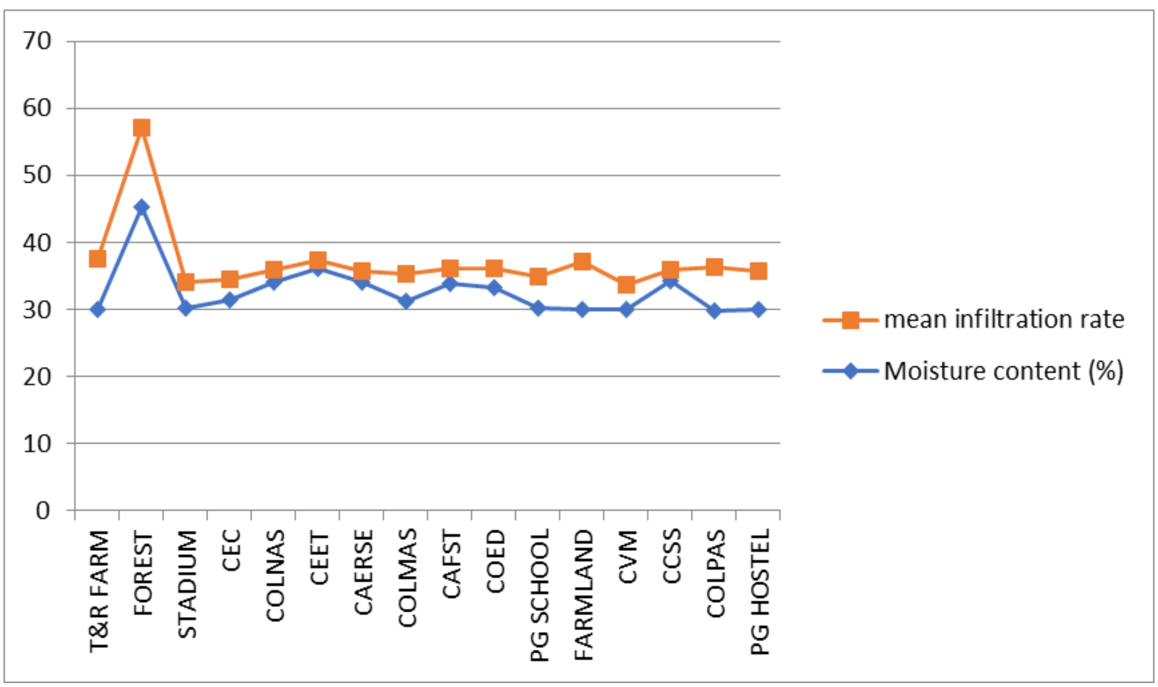

Figure 7: The Relationship between the Mean Infiltration Rate and the Moisture Content of the Topsoils.

Significant correlations between steady infiltration rates and soil organic content, bulk density, and total porosity have been documented by Osuji, *et al.,* (2010).

Thrash (1997) and Marshall *et al.,* (1999) discovered an inverse correlation between bulk density and infiltration rate in their studies. In this study, the bulk density varied from 1.56 to 1.73 g/cm3, and a decreasing pattern of forest topsoil, farming topsoils, and exposed topsoils was seen. The counterparts, in contrast to the naturally preserved forest area, are more susceptible to human-caused (tillage practices and resulting organic matter reduction) and weather-related (such as evaporation-induced crusting and raindrop effects) factors. This is supported by Amir *et al.,* (2010) and Oyedele *et al.,* (2019).

If the intensity of the rainfall exceeds the pace of potential infiltration, water will collect on the soil's surface and start to flow overland. Due to its micro-topography of humps and hollows, the soil surface beneath forests has better water retention. Where runoff occurs, less water may be stored in the soil for plant growth or transported as base flow for streams.

CONCLUSION

Evaluation of the textural, physical and infiltration properties of the topsoils in Michael Okpara University of Agriculture, Umudike has shown some effects of environmental and anthropogenic variables on the infiltration rates and other physical properties. The study has shown from the local geology that the parent rock materials of the topsoils is mainly sandstone.

Although the dispersion of clay particles may have further lowered its infiltration rates, but the coarseness of the sandy loams may have contributed to the higher infiltration rates seen in contrast to clay loams. The denseness of the exposed lands, which results in the reduced rate, is likely caused by treading and the raindrop effect. The comparative analysis of forest topsoil, farmland topsoils and exposed topsoils reveals the natural conservativeness of the forest environment. It further indicates that maintaining a surface layer of vegetation and avoiding excessive topsoil disturbance are essential for enhanced hydrogeological and physical conditions (improving soil infiltration, water storage and its availability to plants).

Since soils with faster infiltration rates, higher levels of organic matter and improved soil structure have a greater resistance to erosion; therefore, optimal soil management techniques will reduce erosion in the study area, stabilize soil aggregates, sequester organic carbon and promote soil water infiltration for crop productivity.

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