

EFFECTS OF SOME SOIL PHYSICAL PROPERTIES ON INFILTRATION RATE AT PHASE 2B OF LAKE GERIYO IRRIGATION PROJECT, YOLA, NIGERIA

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ABSTRACT

The problem of water logging and drainage conditions can partly be solved by understanding the infiltration characteristics. Infiltration rate of the selected areas were determined using a double ring infiltrometer and soil samples collected at different depths of 0 to 15 and 15 to 30 cm respectively for a good representation of the surrounding soil. Collected samples were analyzed to determine Moisture content by gravimetric method, Particles size distribution by hydrometer analysis and Bulk density using core sampler method respectively. Moisture content for points A to E ranged between 19.15% to 53.85%. The textural classification of the soil indicated that the soil type in point A to E is mainly loamy sand. The bulk density of the soil is found to range between 1.58 g/cm³ and 1.73 g/cm³. The infiltration analysis shows that; Point A has a steady infiltration rate of 1.70mm/hr and a cumulative infiltration of 122.81 mm. Point B had a steady infiltration rate of 1.62 mm/hr and a cumulative infiltration of 101.39 mm. At point C the steady infiltration rate is 1.08 mm/hr and the cumulative infiltration is 134.66 mm. Points D and E have steady infiltration rate range of 1.83 mm/hr to 1.88 mm/hr and a cumulative infiltration range of 97.30 mm to 108.04 mm respectively. The correlation analysis done shows that there is a positive correlation between soil texture and infiltration $r = 0.705$ and between bulk density and infiltration $r = 0.743$, while there is a negative correlation between moisture content and infiltration $r = -0.433$. It is therefore concluded that soil texture and bulk density have positive effect on infiltration while moisture content have a negative effect on infiltration rate. Crops like maize should be cultivated in areas with moderate infiltration, while crops like rice to be cultivated in the areas with low infiltration.

Keywords: Water logging, Infiltration rate, Cumulative Infiltration, Soil textural classification, Soil physical properties

1 INTRODUCTION

Infiltration is defined as the process by which a fluid passes through or into another substance travelling through pores and interstices [1]. For surface irrigation, that fluid, water, is ponded on the soil surface and the infiltration rate, intake rate or infiltrability describes the flux into the soil profile. For many types of irrigation systems and natural rainfall events the application rate does not exceed the potential for infiltration. In these circumstances, the water flux is governed by, and limited to, the water application rate. As long as this application rate remains appreciably below the infiltration potential and the soil characteristics is non-limiting, the uniformity of water applied should be distinctly defined by the irrigation system design. Where this is not the case, such as for surface irrigation, the soil hydraulic properties will govern the infiltration rate and surface ponding. The water volume that does not infiltrate immediately remains on the soil surface and can then move under gravity to other parts of the field. In this way, the distribution of water will be partly determined by the infiltration at other locations in the field. Water movement within the soil is governed by

Darcy's law, which states that the flux is equal to the hydraulic conductivity multiplied by the hydraulic gradient. The hydraulic gradient is comprised of the gravity, pressure, osmotic and metric (movement of water from wet or full pores to dry soil) potentials [2]. Starting with a dry soil the suction gradient (metric potential) is high causing a high infiltration rate. As the pores fill with water the suction gradient decreases and time permitting approaches zero [3]. The infiltration rate experiences a similar reduction until at saturation when it is almost entirely reduced to that caused by the forces of gravity and pressure. Inherent factors affecting soil infiltration, such as soil texture, cannot be changed. Soil texture (percentage of sand, silt, and clay) is the major inherent factor affecting infiltration. Water moves more quickly through large pores of sandy soil than it does through small pores of clayey soil, especially if clay is compacted and has little or no structure or aggregation depending on the amount and type of clay minerals, some clayey soils develop shrinkage cracks as they dry. The cracks are direct conduits for water entering the soil, causing clayey soils to have high infiltration rates under dry conditions. Where cracks do not occur, clayey soils have slow infiltration rates. Also the majority of factors influencing the infiltration rate have a direct effect on the soil structure namely the soil porosity. Soil porosity refers to the fraction of the total soil volume that is taken up by the pore space. Mainly, pore spaces facilitate the availability and movement of air or water within the soil environment. Porosity refers to the ratio between the volume of voids and total volume of a soil sample. However, for infiltration the average pore size, distribution of pore sizes and connectivity of pores are of greater importance. The soil pores must be large enough and offer sufficient continuity in order for infiltration to occur [4]. According to [5], Isolation of the effects of land use treatments will enable an assessment of infiltration capacity under different land uses in a given watershed. Such effects are realizable by the two terms of Sorptivity, S and the Transmission properties of the soil, A . Parameter of the Philips equation state that:

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

Where: I = the infiltration rate in mm/hr, S = sorptivity and, A = transmission properties of the soil. The problems of water logging and drainage characteristics of a particular area can partly be solved by understanding the Infiltration characteristics of the area.

2 THE STUDY AREA

Lake Geriyo irrigation scheme is located between Latitude $9^{\circ} 16'$ and $9^{\circ} 19'$ North of the equator and Longitude $12^{\circ} 00'$ and $12^{\circ} 28'$ East of Greenwich meridian. It is between 150 and 180m above sea level. Lake Geriyo covers a total landmass of 300hac which is cultivated for rice and to a lesser extend maize production. This total Landmass is divided into phase 2B, 2C and 3C for easiness of irrigation. It is bounded in the north-east by river Benue, Jimeta in the south west and Namtari forest reserve in the west. Phase 2B where the research was carried out is 50ha in size. The State is in the Sahel region of Nigeria which is generally Semi-arid with low rainfall, low humidity and high temperature. The area experiences wet and dry seasons, the wet season starts from April to October while the dry season starts from November to April. Recorded mean daily temperature normally changes with season and ranges from 25°C to 45°C . The mean annual rainfall received is in the range of 250 to 1000 mm. The Climate is characterized by high evapotranspiration especially during dry season [6].



Figure 1. Map of Lake Geriyo (Source; ArcGis 10.6 pro U.R.P Department MAU, Yola)

3 MATERIALS AND METHODS

3.1 Field work and sample collection

The study area is Phase 2B which is 50ha in size and is divided approximately into 5 sampling points and ten soil samples were collected from a depth of 0-15cm and 15-30cm so as give a good representation of the surrounding soil of uncultivated farmland with an auger from the 5 different points within the study area. 2 samples were collected from each point. The soil samples were put into polythene bags and were properly labeled and taken to the laboratory.

3.2 Infiltration rate

Double-ring infiltrometers were used. The rate of reduction of water level was measured in the inner ring. A double-ring Infiltrometer was set up at each plot. The diameters of the inner and outer rings were 30 cm and 60 cm respectively [7, 8, 9]. They were driven into the ground to about 15 cm and 30 cm depth respectively. The inner and outer edges were tamped to seal possible cracking. Generally, the water level was measured at an interval of 5 minutes. The rate of fall of the water level in the inner cylinder was measured at 0, 5, 10, 15, 20, 25, 30, 35, 40, 45, 60 minutes etc., to determine the rate of water intakes of the soil. This rate becomes constant when the saturated infiltration rate for the particular soil has been reached.

3.3 Particle size analysis

The hydrometer method was used for determining the particles sizes analysis. 50g of soil sample from a 2 mm sieve was poured in a conical flask. 50 ml of sodium hexametaphosphate was added to the soil sample in the flask after which 100 ml of distilled water was added. The solutions were mechanically shaken and stirred to allow the particles to disperse well but not done in such a manner as to reduce the sizes of soil particles, and was allowed to stand for 24 hours. This is in accordance with the works of [10]. After 40s, the hydrometer was introduced into the cylinder and allowed to stabilize before taking the reading. The solution was kept for 2 hours after which another reading was taken using the hydrometer. The temperature readings were taken for each of these two processes. The first reading of temperature (T_1) and hydrometer (H_1) were used to calculate the percentage sand content, while the second reading of temperature (T_2) and hydrometer (H_2) were used in calculating the percentage clay content. This is in accordance with the work of [11]. According to [12] a correction factor in relation to the temperature is added to the hydrometer readings giving new values of H_3 and H_4 respectively.

$$\% \text{Sand} = 100 - \frac{(H_3 \times 100)}{\text{Weight of soil}} \quad (2)$$

$$\% \text{Clay} = 100 - \frac{(H_4 \times 100)}{\text{Weight of soil}} \quad (3)$$

$$\% \text{Silt} = 100 - (\% \text{sand} + \% \text{Clay}) \quad (4)$$

3.5 Bulk Density

Using a core sampler, soil samples were collected at depths 0 - 30cm and 30- 60cm depths respectively on the sites to give a good representation of the soil conditions around the sampling point. The total samples in the core samplers were transferred into nylon bags and conveyed to the laboratory. In the laboratory, the mass of each empty crucible was found, (M_1). The soil sample was then transferred from the nylon into the crucible and then reweighed as (M_2). The crucible with the soil samples were kept in the oven for 24 hrs at 105°C for total dryness of the moisture in the soil sample. After, which the crucibles were then removed from oven and then reweighed as (M_3). From this, the bulk density was calculated as mass of oven dried soil per volume of core (g/cm^3) and gravimetric water content as mass of water in the soil sample per mass of the oven dried soil.

$$\text{Bulk density} = \frac{\text{mass of oven dried soil}}{\text{volume of core}} \quad (5)$$

3.6 Moisture content

Determination of water content in the various soil samples were carried out using gravimetric method. A 60g portion of the samples collected were oven dried at a temperature of 105°C for 24 hrs. This is in accordance with the work of [13]. The initial weight of the container W_1 was determined and 60g soil sample put up to half of the container and was weigh again as W_2 . And it was put in the oven for 24 hrs at a constant temperature of 105°C. After which the soil sample and the container were weighted as W_3 . The moisture content was calculated using the following relation.

$$\text{MC}\% = \frac{W_2 - W_3}{W_3 - W_1} \times 10 \quad (6)$$

Where; Mc = moisture content, W_1 = weight of container, W_2 = weight of container and sample, W_3 = weight after oven drying.

4 RESULTS AND DISCUSSION

4.1 Physical Properties of Soil

Table 1 presents the results of the soil aggregates for the selected plots within the study areas of phase 2B at Lake Geriyo Irrigation project, Yola. Placing the respective percentages of sand, silt and clay particles on a textural triangle, the soil in the selected is classified into appropriate textural classes. The results obtained from hydrometer method showed that sample A1 has higher percentage of sand compared to the others. The percentage of sand of each soil sample from sample A2 to E2, range from 75% to 89%. Similarly, the clay content of samples C2 and E1 is higher than that of other samples while the silt contents of sample C2 is higher than that of the other samples. Due to the presence of fine grained soils in some plots that can retain more water, it follows that some plots are most suitable for rice production than others this agrees with [2].

Table 1. Soil particle size distribution

Sample Name	Depth (cm)	Sand	Silt (%)	Clay (%)	Textural Classes
A1	0-15	93	4	3	Sandy
A2	15-30	86	8	6	Loamy Sand
B1	0-15	89	5	6	Sandy
B2	15-30	87	5	8	Loamy Sand
C1	0-15	85	8	7	Loamy Sand
C2	15-30	75	15	10	Sandy loam
D1	0-15	85	8	7	Loamy Sand
D2	15-30	83	11	6	Loamy Sand
E1	0-15	87	3	10	Loamy Sand
E2	15-30	86	6	6	Loamy Sand

The highest value of soil bulk density is found in A1 and it ranges between 1.58 to 1.73 g/cm³ while the moisture content of the soil range between 19.15 to 53.85% (Table 2), which may be good for crops that need water always, that is crops that can do very well under waterlogged conditions in line with [3].

Table 2. Soil Bulk Density

Sample Name	Moisture Content (%)	Bulk Density (g/cm ³)
A1	19.15	1.73
A2	40.35	1.67
B1	21.31	1.68
B2	53.85	1.63
C1	53.85	1.65
C2	42.86	1.58
D1	33.33	1.65
D2	29.81	1.67
E1	28.44	1.60
E2	33.45	1.63

4.2 Infiltration parameters

Figure 2 shows the infiltration rate at point A. At first it shows the soil has a very high intake rate which is higher than all the points, this is because the top soil is mostly sandy soil but then falls rapidly to a steady infiltration rate of 1.70 mm/hr and this may be due to the fact that the top soil is dryer. The cumulative infiltration of this point is 122.81 mm.

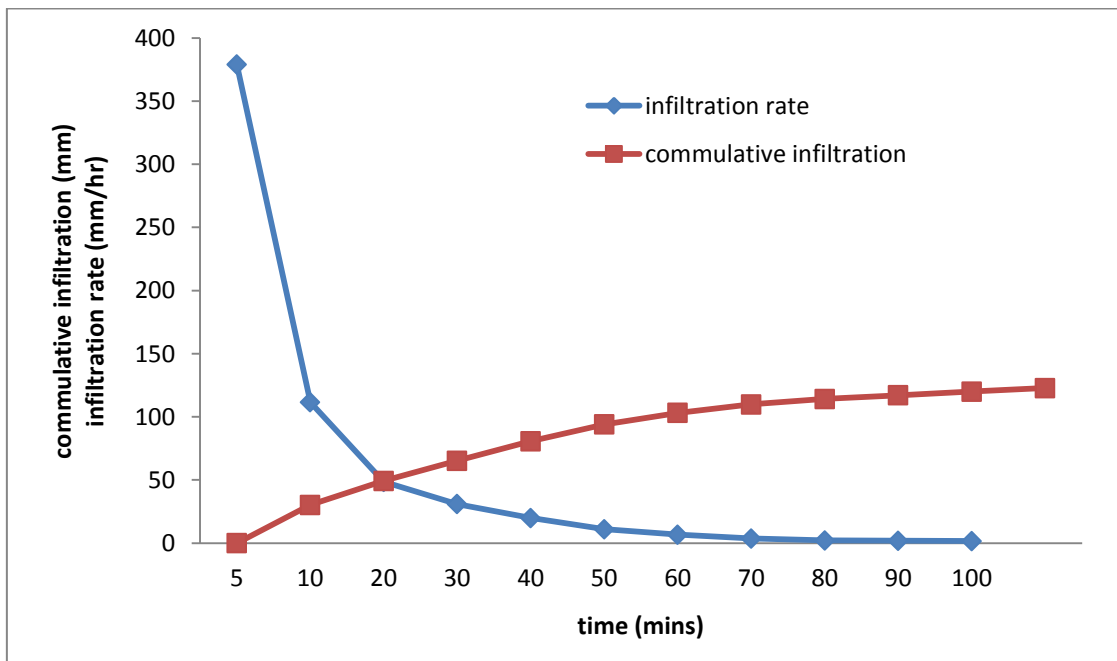


Figure 2. Infiltration curve at point A

Figure 3 shows the infiltration rate and cumulative infiltration curves of point B. it shows the soils have a very high intake rate at first and this reduces with time. Finally, it falls to a steady rate of around 1.67 mm/hr after about 100 minutes and it has a cumulative infiltration of 101.39 mm. This rapid decrease of intake rate may be due to the water level in the area or the type of soil present in the area.

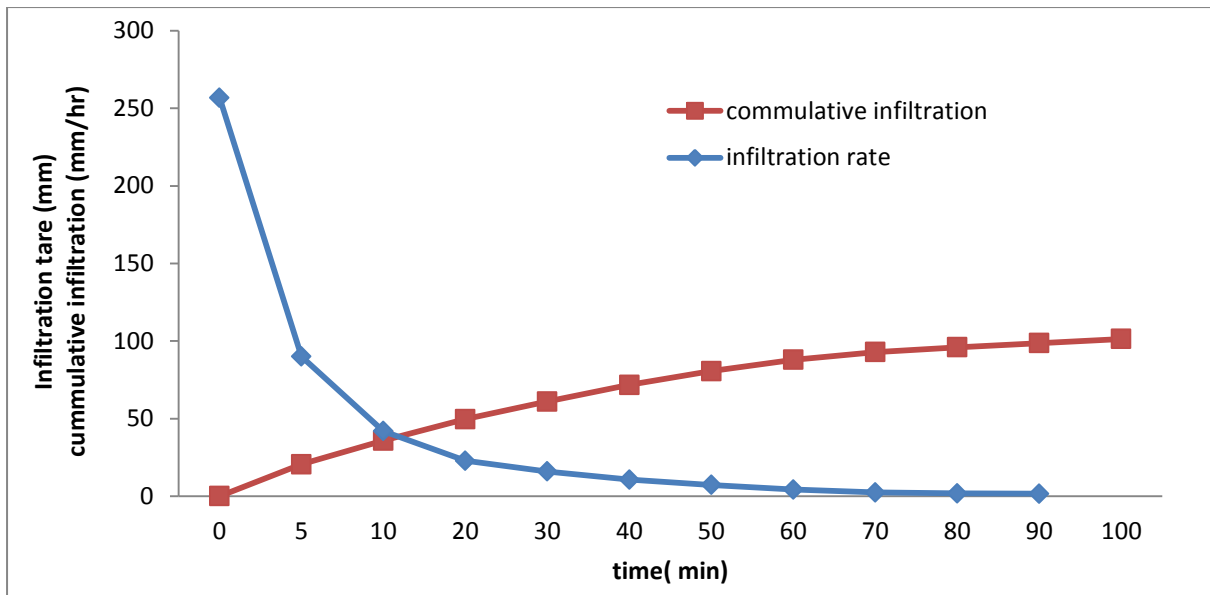


Figure 3. Infiltration Curve at point B

Figure 4 shows cumulative infiltration and infiltration rate curves of point C. it has a high infiltration rate. This is also due to the type of soil present but later falls to a steady rate of about 1.075 mm/hr. the cumulative infiltration rate of 134.66 mm.

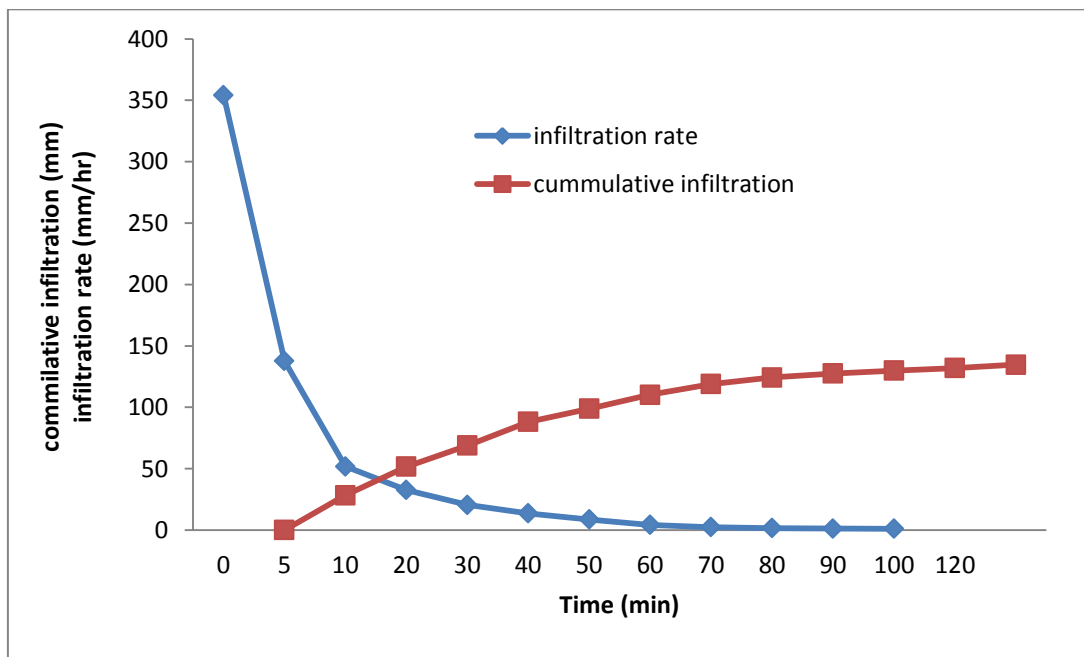


Figure 4. Infiltration Curve at point C

Figure 5 shows the infiltration rate and cumulative infiltration curves of point D. it shows the soils have a very high intake rate at first but this reduces with time. Finally, it falls to a steady rate of around 1.88 mm/hr after about 100 minutes with a cumulative infiltration of 97.30 mm. This rapid decrease of intake rate may be due to water level in the area or the type of soil present in the area.

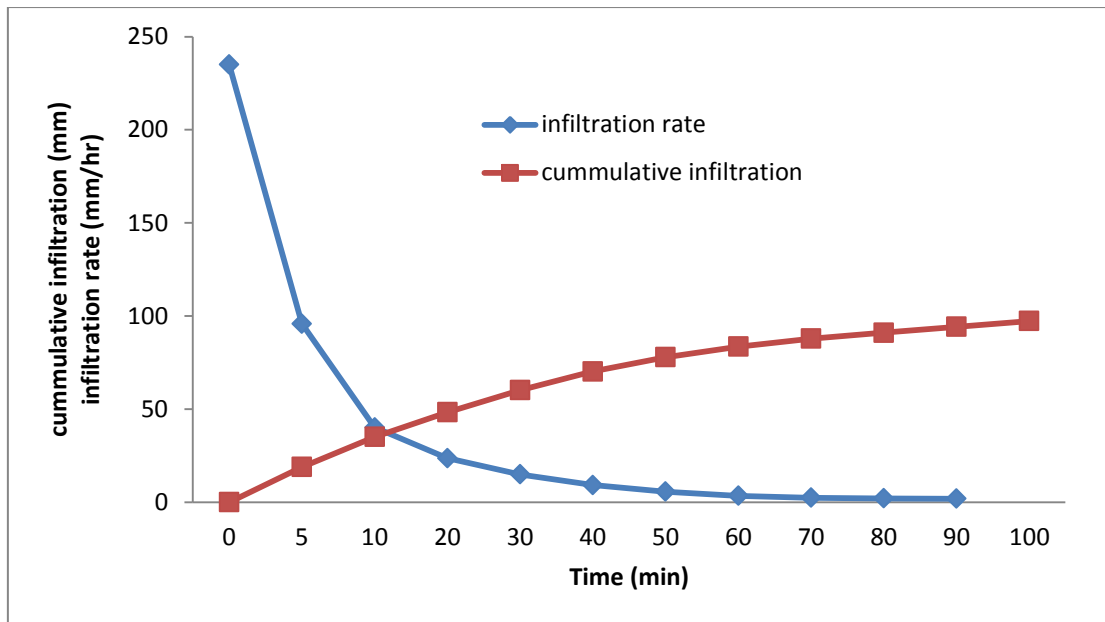


Figure 5. Infiltration Curve at point D

Figure 6 below shows the infiltration rate at point E. This point has the least infiltration rate of all the points. At first it shows the soil has a very high intake rate which falls to steady rate of 1.83 mm/hr, this may be due to the type of soil or water level of the area. The cumulative infiltration of this point is 108.04 mm.

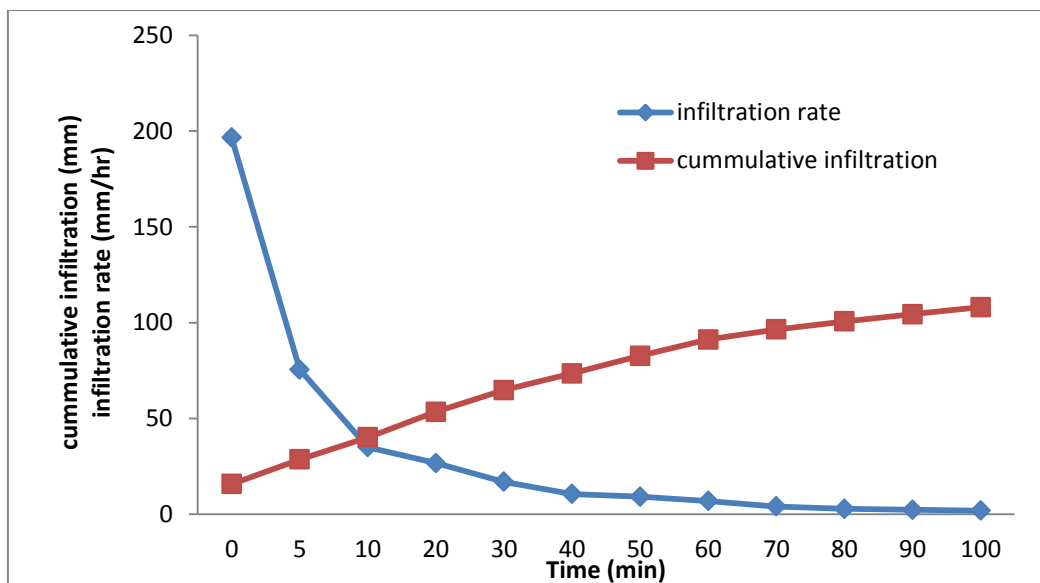


Figure 6. Infiltration Curve at point E

4.3 Infiltration Curves

Figures 2 to 6 shows the infiltration curves corresponding to the average infiltration rate and cumulative infiltration. It was observed that point B and C infiltrates water faster than other points, because the soil particles were dryer when compared to the other points. Thus Shape, size and stability of soil aggregates may affect the absorbance rate of water and hence infiltration rate. Coarse-grained sandy soils are known to have large spaces between each grain which allows water to infiltrate quickly, this is in accordance with the work of [9]. Infiltration rates of soil decrease over time until a steady state is reached. In addition, the infiltration is dependent on several factors, including soil texture, structure, initial soil water content, pore size, soil metric potential and vegetation [14]. This behavior is also reflected in the cumulative infiltration which shows a rapid

increase in the volume of water infiltrated within a short time, and increases gradually to a nearly linear rate over the period of time as shown in all the Figures. Several researchers have shown that sandy soil has a higher infiltration rate than clay soil under identical conditions in agreement with [15]. The available space for additional water in the soil depends on the porosity of the soil and the rate at which infiltration occurs from the surface of the soil. If the amount of the water at the soil surface is less than the infiltration capacity, all of the water will infiltrate. If rainfall intensity at the soil surface occurs at a rate that exceeds the infiltration capacity, ponding begins and is followed by runoff over the ground surface which will eventually bring about the washing away of the soil particles.

Table 3. Analysis of variance for Infiltration Rate

Source	Sum of Squares	Df	Mean Square (SS/Df)	F	Sig
Between Groups	12444832.4	4	3111208	0.936	0.451
Within Groups	172933888	52	3325652		
Total	185378720	56			

The working principles of the variance are shown below:

$$S.S_{Treatment} = r \sum_i^t (\bar{X}_i - \bar{X}_{..})^2$$

$$S.S_{Error} = \sum_i^t \sum_j^r (X_{ij} - \bar{X}_i)^2$$

$$S.S_{Total} = \sum_i^t \sum_j^r (X_{ij} - \bar{X}_{..})^2$$

The ANOVA table above shows the mean difference of infiltration rate at five different point itemize as: Point A, B, C, D and point E. from the table, the F and P-value at 4 degree of freedom were 0.936 and 0.451 respectively. The P-value is greater than the specified α -value of 0.05 by implication, the null hypothesis of no difference in mean among the five different infiltration rate capacity should be retained and as such we conclude that the mean different between the five stages of infiltration rate are statistically insignificant at 5% level. A post hoc test Duncan and LSD was employ to further verify the differences as shown in Table 4.

Table 4. Duncan range multiple test for Infiltration Rate

Point	N	Subset for alpha = 0.05
		1
E	12	32.3292
D	11	39.4882
B	11	41.4055
A	11	56.0855
C	12	1188.0825
Sig.		0.185

Duncan^{a,b}; a. Uses Harmonic Mean Sample Size = 11.379; b. The group sizes are unequal. The harmonic mean of the group sizes is used. Type I error levels are not guaranteed

The Duncan table above reveal that since Table1 shows insignificant different between infiltration rate at different point it is clear to also say that infiltration rate is higher at point C followed by point A, B, D in that order and least at point E.

Table 5. Summary of the correlation result

Dependent variable	Independent variables	Correlations Value	P-value	Sig Level
Infiltration Rate	Soil Texture	0.705	0.044	Sig.
	Bulk Density	0.743	0.014	Sig.
	Moisture Content	-0.433	0.212	Insig.

Table 5 shows the relationship between the independent variables and a dependent variable infiltration rate. The correlation was used to determine the effect of these independent variables on infiltration rates of different soils. Base on the correlation result, we observed that there is high and positive correlation between Soil texture, Bulk Density and Infiltration rate while a weak-negative correlation exists between Moisture content and inflation rate. Furthermore, for a unit increase in Soil texture, the infiltration rate increases by 70.5% and for a unit increase in Bulk Density the infiltration rate increases by 74.3% and finally for a unit increase in Moisture content the infiltration rate decreases by 43.3%. This shows that Soil Texture and Bulk Density have positive and significant impact on infiltration rate in the study area with P-values of 0.044 and 0.014 respectively while Moisture content have negative and insignificant impact on infiltration rate in the study area with P-value of 0.212.

5 CONCLUSIONS

The particle size analysis showed that the soils in the area were mostly sandy loam which may be the reason for relatively moderate infiltration rate obtained around the area. The double ring infiltrometer used in the determination of the infiltration rate shows that points B and C have a high rate of infiltration compared to the other points. The sample with the least moisture content was obtained at point A, having average moisture content of 19.15%. The analysis of variance (ANOVA) conducted for the different infiltration rates taken in the study area show that there is no significant difference between the infiltration rates at different points in the study area at 5% level which is statistically insignificant. The correlation analysis done using excel shows that there is a very high coefficient of correlation between soil texture and infiltration, $r = 0.705$ which can be considered to have a high influence on infiltration rate of the study area. The correlation between bulk density of the soil and infiltration is high with $r = 0.743$ which also shows that bulk density highly affects infiltration, on the other hand moisture content have a negative effect on infiltration with $r = -0.433$ which is insignificant for that area. It is therefore concluded that soil texture and bulk density have greater effect on infiltration rate than moisture content and the study area have moderate to poor infiltration rate which leads to the water logging at some points. Therefore, cultivation of rice crop is recommended in the water logged area because rice needs a lot of water and can do well in water logged conditions, while crops like maize can be planted in the remaining areas with moderate infiltration rates.

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