Journal of Research in Forestry, Wildlife & Environment Vol. 10(3) September, 2018
http://www.ajol.info/index.php/jrfwe
jfewr ©2018 - jfewr Publications
E-mail: jfewr@yahoo.com
ISBN: 2141 – 1778
Yusuf et al., 2018

DETERMINATION OF SORPTIVITY, INFILTRATION RATE AND HYDRAULIC CONDUCTIVITY OF SOIL USING A TENSION INFILTROMETER

***[1]Yusuf K. O., [1]Ejieji C. J. and [2]Baiyeri M. R.**
[1]Department of Agricultural and Biosystems Engineering, University of Ilorin, Ilorin, Nigeria
[2]Department of Agricultural and Bio-Environmental Engineering Technology. Institute of Technology, Kwara State Polytechnic, Ilorin, Nigeria
* = **Corresponding author:** *kamaru.yusuf@yahoo.com; yusuf*.ok@unilorin.edu.ng

ABSTRACT

This study was conducted in June-July 2018 to determine hydraulic properties of soil mainly: sorptivity (S); infiltration rate (I); hydraulic conductivity (K) and water diffusivity (D) using a tension infiltrometer. These soil properties are required during the design of irrigation and drainage projects. The Experimental site was the Demonstration Farm of Department of Agricultural and Biosystems Engineering (DFDABE), University of Ilorin, Ilorin, Nigeria. The soil was loamy sand with mean porosity of 42.90%, percentage contents of sand, silt and clay were 84.35, 5.41 and 10.24%, respectively. A tension infiltrometer which restricts preferential flow of water in the soil was used to measure the infiltration rates. Water potentials of -0.02, -0.05, -10 and -0.15 m were used but -0.05 m was found to be most appropriate for tension infiltrometer. Potential -0.02 m could not control preferential flow of water during infiltration test. The infiltration data were used to determine S, I, K and D of the soil. The mean values of S, I, K and D at -0.02 m in 2018 were 63.50 mm/h$^{1/2}$, 176.84 mm/h, 22.42 mm/h and 171,092.46 mm^2/h, respectively. The corresponding values at -0.05 m were 29.90 mm/h$^{1/2}$, 71.32 mm/h, 24.67 mm/h and 72,871.29 mm^2/h. Corresponding values at -0.10 m were 19.88 mm/h$^{1/2}$, 32.76 mm/h, 13.02 mm/h and 26,309.80 mm^2/h and at -0.15 m were 15.41 mm/h$^{1/2}$, 28.54 mm/h, 15.02 mm/h and 23,041.13 mm^2/h. The values of infiltration rates and hydraulic conductivities of the soil can be used for design of an irrigation project in the study area.

Keywords: Hydraulic conductivity, infiltration rate, sorptivity, soil porosity, tension infiltrometer, water diffusivity,

INTRODUCTION

Movement of water in the soil is governed by hydraulic properties of soil which vary from place to place depending on soil texture and porosity. When water is supplied to soil either by rainfall or irrigation, it infiltrates and moves down through the soil profile by percolation and part of it flow on the soil surface as runoff to the streams. Application rate of water during irrigation must be less or equal to the infiltration rate of the soil to prevent runoff and erosion (Hillel, 1980). Movement of water in the soil depends on sorptivity, infiltration rate and hydraulic conductivity of soil. These soil properties vary from place to place depending on the soil texture, porosity and level of compaction of the soil. Sorptivity is a property that determines the ability of soil to attract water by capillary action and it has a unit of m/s$^{1/2}$ or mm/h$^{1/2}$ (Arntzen and Ritter, 1994). Infiltration rate is the rate at which water enters through the soil surface and it has the same unit of velocity (m/s) but it is normally given in practical term as mm/h. Hydraulic conductivity is the property of soil which determines the ease with which water moves in the soil, it is the ability of soil to allow water to pass through the pores and voids within the soil. Hydraulic conductivity is expressed as the ratio of soil water flux to the potential gradient and it has a unit of m/s or mm/h, it influences movement of soil water and chemical/plant nutrients (Hillel, 1998).

Sorptivity could be used to characterize the infiltration rate of soil as a function of time and water content (initial and final water contents). It could also be used to predict unsaturated hydraulic conductivity of soil (Moldrup *et al*., 1994). Landson (1991) also pointed out that information on infiltration rate, hydraulic conductivity and type of crop to be grown are needed in the design stage of an irrigation project for determining the most efficient method of water application (irrigation type), furrow/border length and application rate of water for a sustainable irrigated agriculture.

Measurement of sorptivity, infiltration rate and hydraulic conductivity of soil using a double ring infiltrometer could be affected by preferential water flow. This preferential water flow is phenomenon in which ponding water in the double ring infiltrometer during infiltration test over flow through worm's holes, cracks and root channels resulting to over estimation of infiltration rate and other hydraulic properties of soil. The preferential water flow in the soil could be controlled by using a tension infiltrometer which allows application of water to soil at zero or negative water potential (Wyseure *et al*., 1997 and Yusuf, 2006). Tension infiltrometer is also called disc permeameter, when it is used for measuring infiltration rate; it gives reliable results of hydraulic properties of soil when compared to double ring infiltrometer (Perroux and White, 1988; Casey and Derby, 2002). Cook and Broeren (1994) compiled six methods which were equations for determining sorptivity and hydraulic conductivity of soil. The data of the infiltration rates and other hydraulic properties of the soil of Demonstration Farm of Department of Agricultural and Biosystems Engineering, University of Ilorin, Ilorin, Nigeria **(**DFDABE) are not available. These data are needed during the design of an irrigation project of the study area. Therefore, there is need to determine the infiltration rates and other hydraulic properties of the soil of DFDABE using a tension infiltrometer which could prevent preferential flow of water in the soil and give accurate values of hydraulic properties of soil. The objectives of this study were to determine the sorptivity, infiltration rate, hydraulic conductivity, water diffusivity and soil porosity of the DFDABE.

Theory of Sorptivity

According to Arntzen and Ritter (1994) Sorptivity, is a term defined by Philip in 1975 as a soil hydraulic property which describes the movement of water in the soil at early stage of infiltration by capillary action. The infiltration rate is governed by Equation (1). The first term ($St^{1/2}$) of Equation (1) is the gravity free absorption of water into soil due to capillary and adhesive forces to soil solid surfaces. The second term (At) of Equation (1) represents the infiltration due to downward force of gravity after the soil has been wetted. At the early stage of infiltration, the second term (At) is zero and Equation (1) becomes Equation (2) from which sorptivity could be determined according to Hillel (1980) and Arntzen and Ritter (1994).

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

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

where, I is the cumulative infiltration (mm), Sorptivity ($mm/h^{1/2}$ or $mm/s^{1/2}$), t is the time (h or s) and A is the empirical constant of the soil related to unsaturated hydraulic conductivity.

Cook and Broeren (1994) reported that sorptivity should be determined from Equation (2) as the slope of the straight portion of the graph of cumulative infiltration (I) against square root of time ($t^{1/2}$) at early stage of infiltration. Cook and Broeren (1994) also reported that the early stage of infiltration is normally occur between 1 and 400 second (s) which is equivalent to square root 1 to 20 $s^{1/2}$. Steady state infiltration rate which is simply called infiltration rate is determined as the slope of cumulative infiltration (I) against time (t) where the flow rate is steady and the curve is linear. Casey and Derby (2002) reported that steady flow rate usually occur between 10 and 20 minutes when tension infiltrometer is used to determine infiltration rate of soil.

MATERIALS AND METHODS

Location of the Study

The location of the study was the Demonstration Farm of Department of Agricultural and Biosystems Engineering (DFDABE), University of Ilorin, Ilorin, Nigeria. Ilorin lies on the latitude 8°30′N and longitude 4°35′E at an elevation of about 340 m above mean sea level (Ejieji and Adeniran, 2009). Ilorin is in the Southern Guinea Savannah Ecological Zone of Nigeria with annual rainfall of about 1300 mm. The wet season begins towards the end of March and ends in October while the dry season starts in November and ends in March (Ogunlela, 2001).

The infiltration test was conducted twice in this study, the first experiment was carried out from 10th February to 6th April 2005 and the second (fresh) infiltration test was conducted from 8th June to 20th July 2018 to validate the results of the hydraulic properties obtained in 2005 in the same study area. The land was left fallow for about 4 years before the infiltration test was conducted in 2005 and the land had been left fallow for about 10 years before the study was conducted in 2018. The infiltration test was conducted when the soil was dry or relatively dry for accurate measurement of hydraulic properties of soil using a tension infiltrometer. Tension infiltrometer was used in this study to determine the infiltration rate of soil of the study area. Four different water potentials (-0.02, -0.05, -0.10 and -0.15 m) were used to determine the infiltration rate of the soil.

Experimental Site

The experimental site was 20 by 20 m which had been left fallow for four years before the study was conducted in 2005. The site was carefully cleared, divided into 10 lines which are 2 m apart and each line was also divided into 10 equal part. Each line has 10 grid points demarcated by pegs which were 2 m apart and the grid point serves as a reference point for the measurement. Perroux and white (1988) reported that preferential water flow could be prevented by using a potential less than or equal to -0.04 m (tension of 0.04 m and above) and variation in sorptivity and infiltration rate could only occur due to inherent soil variability or measurements error. Therefore, four water potentials of -0.02, -0.05, -0.10 and -0.15 m were used during the infiltration measurements. The infiltration test points were 60 cm (away) due north, due east, due south and due west of the grid point for the water potentials -0.02, -0.05, -0.10 and -0.15 m, respectively. At -0.05 m water potential, a total of 100 infiltration tests were successfully conducted. At -0.02 m water potential, a total of 16 infiltration tests were successfully conducted and 22 infiltration tests were conducted for both water potentials of -0.10 and -0.15 m given a total of 160 infiltration test points in 2005.

A fresh infiltration test was conducted in 2018 to validate or compare the infiltration rate and other hydraulic properties of soil of the study area with the results obtained in 2005. A total of 20 infiltration tests were conducted between 8th June and 20th July, 2018 using -0.02, -0.05, -0.10 and -0.15 m water potentials with 5 replications for each water potential during the infiltration tests.

Field Measurement of Infiltration Rate and Operating Principle of a Tension Infiltrometer

The soil surface of the test point was carefully cleared to remove the dry grasses on the soil. A cylinder of 275 mm diameter and 100 mm high was put on the soil and the diameter was marked round. A cutlass was used to cut down and trim the soil to have a soil column. This method was adopted to reduce the effect of disturbing the soil by hammering the cylinder. The cylinder was placed on the soil, driven and pressed down on the soil column to a depth of 80 mm. This cylinder would ensure downward flow of water and prevent lateral flow of water from the soil surface. Fine freely running moistened sand sieved through 2 mm sieve was put on the soil surface of the cylinder as the contact material (5 mm thickness) to ensure that the soil surface was properly leveled and to allow free flow of water from the tension infiltrometer into the soil.

The bubble tower of the tension imfiltrometer was filled with water to a level that gives the desired water potentials (-0.02, -0.05, -0.10 and -0.15 m) using Equation (3) after which the air-inlet tube was corked. The water potential is adjustable because Z_1 could be varied depending on level of water in the bubble tower but Z_2 is fixed based on the design and construction of the tension infiltrometer as shown in Figure 1. The head of the tension infiltrometer was put in a basin containing water, the cork of the water reservoir was removed and water was sucked into the reservoir with mouth. The reservoir which is 900 mm long and has internal diameter of 95 mm was filled to a level of 700 mm within thirty seconds (30 s). The top of the reservoir was immediately corked and the water level in the reservoir would not fall and there would be no flow of water from the reservoir unless there is air-leakage into the reservoir that would initiate flow of water.

Soil sample was taken for initial water content beside the infiltrometer. The tension infiltrometer was gently placed on the contact material and air-inlet tube on the bubble tower was opened by removing the cork. Air enters the bubble tower through the air-inlet tube which bubbles through the water, come out through the air-exit tube and finally enter the water reservoir. The bubbling of air into the reservoir initiates the flow of water and infiltration commenced immediately as shown in Figure 2 which was monitored for 20 minutes for the study conducted in 2005 but 15 minutes was used in 2018. The reduction of water levels in the reservoir (rate of infiltration) was recorded at 20 s interval. For a tension infiltrometer, 2 to 4 litres of water is enough to attain a steady state infiltration rate. The infiltrometer was removed and soil sample was taken with a core sampler for the determination of final water content and bulk density. This method was used to measure the infiltration rate of 160 points at DFDABE in 2005 and 20 infiltration test points was conducted in 2018. Magnification of the water reservoir in relation to the disc or cylinder driven into the soil was 8.4. The actual infiltration in the soil was multiplied by the reciprocal of the magnification (1/8.4 = 0.11905).

$$\psi_o = Z_2 - Z_1 \tag{3}$$

where, Ψ_o is the desired water potential (m), Z_1 is the height of water in the bubble tower between the air-inlet tube end point in the bubble tower and water above the air-inlet tube end point (m) and Z_2 is the distance from the air-exit tube entering the reservoir to the membrane (m)

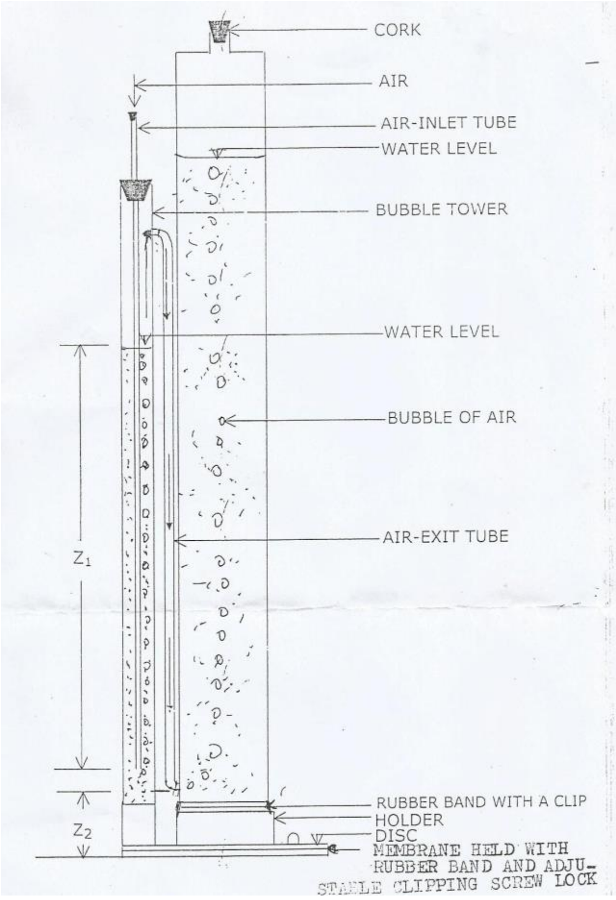

Figure 1 A sketch of side view of the tension infiltrometer
Source: Yusuf (2006)

Figure 2 Tension infiltrometer in operation
Source: Yusuf (2006)

Determination of Sorptivity and Infiltration rate

Sorptivity which was expressed in Equation (2) was determined at the early stage of the infiltration as the slope, S (mm/s$^{1/2}$ but converted to mm/h$^{1/2}$) of the graph of cumulative infiltration versus square root of time which normally occurred between 5 s$^{1/2}$ and 20 s$^{1/2}$ as shown in Figure 3. The equivalent quadratic equation for the parabolic equation for the curve ($I = St^{1/2}$) that described the sorptivity curve was shown on the graph in Figures 3 and 4. The steady state infiltration rate was determined from the graph as the slope of cumulative infiltration versus time when the curve was linear and the infiltration rate was constant as shown in Figures 5 and 6.

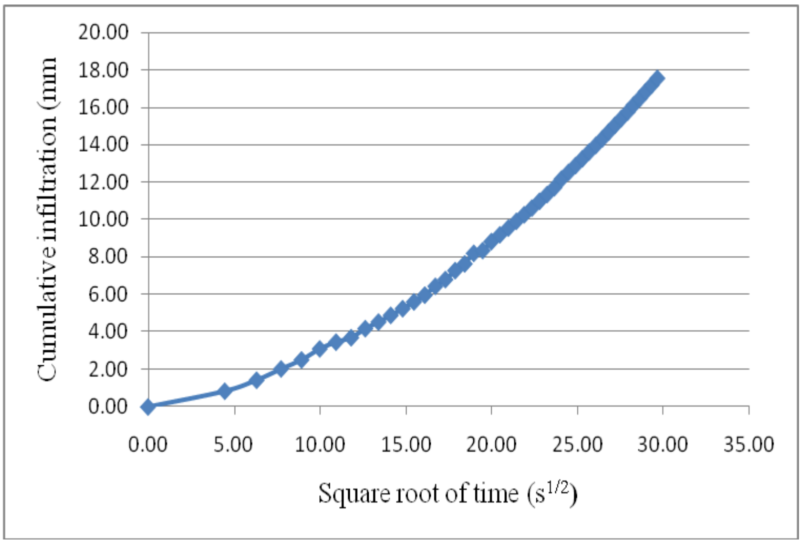

Figure 3 Cumulative infiltration versus square root of time for sorptivity in 2018

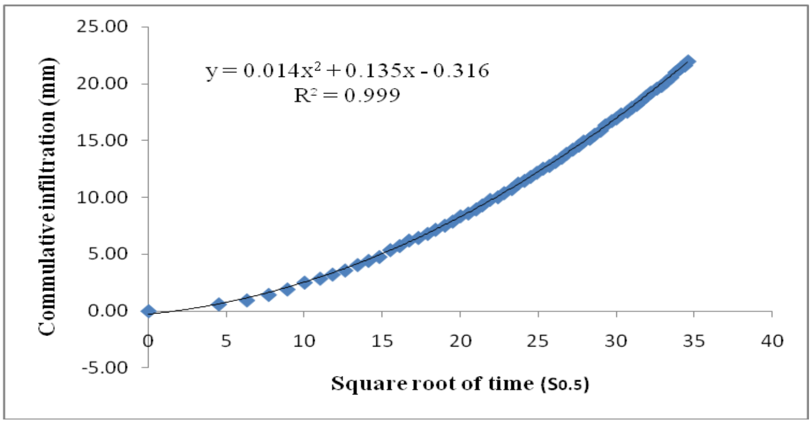

Figure 4 Cumulative infiltration versus square root of time for sorptivity in 2005

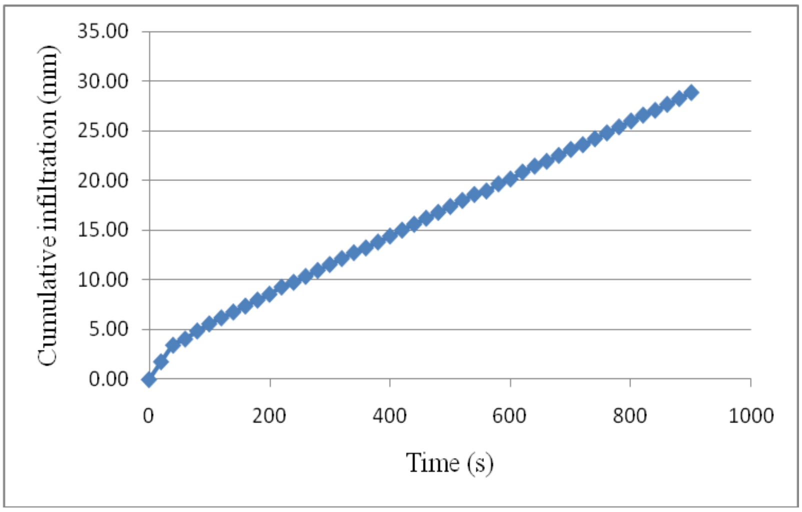

Figure 5 Cumulative infiltration versus time for infiltration rate in 2018

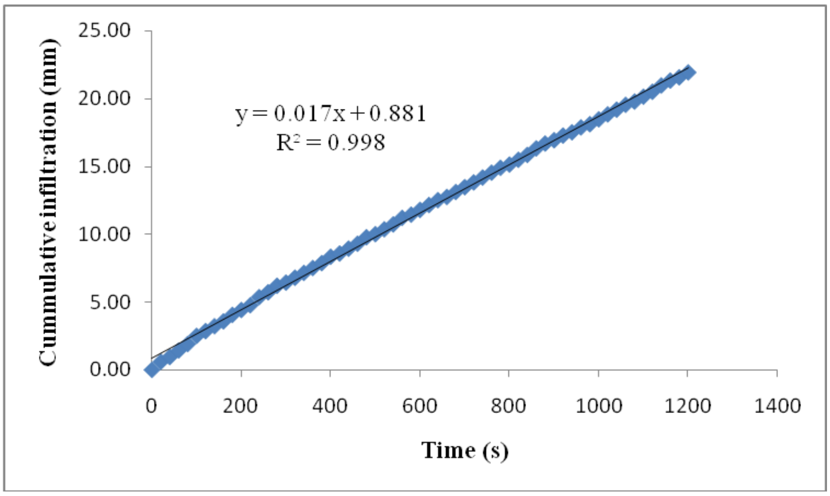

Figure 6 Cumulative infiltration versus time for infiltration rate in 2005

Determination of Hydraulic Conductivity and Water Diffusivity

Cook and Broeren (1994) reported that if there is a relationship between hydraulic conductivity and infiltration rate of soil as given in Equations (4), (5) and (6), then, hydraulic conductivity of soil could be determined using Equation (7b).

$$I = \frac{S}{2t^{1/2}} \qquad (4)$$

$$I = \Delta K\left(1 + \frac{4\lambda_c}{\pi r}\right) \qquad (5)$$

Cook and Broeren (1994) also reported that White and Sully (1987) found out that macroscopic capillary length scale (λ_c) could be determined from Equation (6).

$$\lambda_c = \frac{bS^2}{\Delta K \Delta\theta} \qquad (6)$$

where b is $0.5 \leq b$ 0.25π. for most soils, b is about 0.55 and for every water potential (Ψ_o), $\Delta K = K$ and putting Equation (6) into Equation (5), the resulting equation is Equation (7a) or (7b) from which hydraulic conductivity at steady flow rate was determined.

$$I = K_s + \frac{2.2S^2}{\pi r(\theta_2 - \theta_1)} \qquad (7a)$$

$$K_s = I - \frac{2.2S^2}{\pi r(\theta_2 - \theta_1)} \qquad (7b)$$

where I is the steady state infiltration rate (m/s which was converted to mm/h), K_s is the hydraulic conductivity of soil at the steady state infiltration rate (m/s, converted to mm/h), S sorptivity (m/s½, converted to mm/h$^{1/2}$), r is the radius of the disc or cylinder driven into the soil (m), θ_1 and θ_1 are the initial and final volumetric water contents of the soil (m³/m³).

The weighted mean diffusivity or simply called water diffusivity (D) through the soil was determined from sorptivity as a function of water content using Equation (8) given by Bonsu (1993).

$$D = \frac{\pi S^2}{4(\theta_2 - \theta_1)^2} \qquad (8)$$

where, D is the water diffusivity (m^2/s, converted to mm^2/h), π is equal to 3.142, θ_1 and θ_1 have been defined in Equation (7a or 7b).

Determination of Specific Gravity and Particle Density of the Soil

Specific gravity of soil particle (soil solid) is the ratio of mass of soil to the mass of equal volume of water displaced by soil in the bottle. The specific gravity of soil particle was determined using the procedure given by Sutton (1993). A 50 cl of plastic bottle of Eva table water was improvised as the pycnometer (density bottle). A hole of 3 mm diameter was drilled on the cover of the bottle to allow escape of bubbling air from the soil when water is added to the soil. The specific gravity and particle density of soil were determined using Equations (9) and (10), respectively given by Sutton (1993). The soil particle density (ρ_d) and bulk density (ρ_b) were required for the practical determination of soil porosity.

$$G_s = \frac{m_2 - m_1}{(m_4 - m_1) - (m_3 - m_1)} \qquad (9)$$

$$\rho_d = G_s \times \rho_w \qquad (10)$$

where m_l is the mass of empty plastic bottle (g), m_2 is the mass of empty bottle and dry soil half-filled the bottle (g), m_3 is the mass of empty bottle, mass of dry soil half-filled the bottle and mass of water added to fill the bottle (g) and m_4 is the mass of empty bottle and mass of water only added to fill the bottle (g).

Determination of Porosity and Volumetric Moisture Content of the Soil

Porosity of the soil was determined from bulk density and particle density of the soil using Equation (11) given by Bonsu (1993).

$$P = \left(1 - \frac{\rho_b}{\rho_d}\right)100 \qquad (11)$$

where P is the porosity of the soil (%), ρ_b is the bulk density (kg/m³) and ρ_d is the particle density or density of soil solid (kg/m³ or g/cm³).

The volumetric water (moisture) content was determined using Equation (12).

$$\theta = M.C \times \frac{\rho_b}{\rho_w} \qquad (12)$$

where θ is the volumetric water or moisture content (m³/m³), M.C is the moisture content of the soil (%), ρ_b is soil bulk density (g/cm³), ρ_w is the density of water (g/cm³).

RESULTS

The top soil (0 – 10 cm) of the experimental site was found to be loamy sand. The average contents of sand, silt and clay were 84.35%, 5.41% and 10.24%, respectively. The results of sorptivity, infiltration rate, hydraulic conductivity, water diffusivity, soil porosity, initial and final volumetric moisture contents for DFDABE soil were presented in Tables 1, 2 and 3. Table 1 shows the hydraulic properties of the soil obtained in 2005 from each line when the water potential of -0.05 m was used. Each of the lines contain ten results given a total of 100 results but only the range for each line and mean values of the hydraulic properties of the soil were presented in Table 1. The values of sorptivity, steady state infiltration rate, hydraulic conductivity and water diffusivity on Table 1 vary from point to point but all the values were within the range given by (Perroux and White, 1988, Bonsu, 1993 and Wilkie, 1999).

Table 2 shows the range and mean values of the sorptivity, steady state infiltration rate, hydraulic conductivity water diffusivity, porosity, initial and final volumetric water content using water potentials of -0.02, -0.05, -0.10 and -0.15 m for 2005. Table 3 shows the results of hydraulic properties of the soil obtained in 2018. Hydraulic properties of the soil obtained with -0.10 m and -0.15 m potentials were lower than that of -0.05 m potential as shown in Tables 2 and 3. Infiltration rates for the two potentials were slow because more energy was required by the soil to attract water from the infiltrometer. Potentials of -0.10 m and -0.15 m were characterized by large bubbles of water during the infiltration tests due to absorption of large quantity of water by the soil after the needed energy to overcome by attraction of soil by capillary action had been built up.

The results obtained in the study as shown in Tables 1, 2 and 3 were consistent and satisfactory using a tension infiltrometer but -0.05 m water potential was found to be appropriate for using a tension infiltrometer. The water potential of -0.05 m could prevent preferential flow of water in the soil; the bubbling was not associated with large bubbles that could result to measurement error of infiltration rate and it easy to monitor during infiltration test as reported by Perroux and White (1988) that preferential flow could be controlled using water potential of ≤ -0.4 m.

Table 1 Value of sorptivity (S), infiltration rate (I), hydraulic conductivity (K), water diffusivity (D), Soil porosity (P), initial water content (θ_1) and final water content (θ_2) of a loamy sandy soil at water potential of -0.05 m

Line	Value	S (mm/h$^{1/2}$)	I (mm/h)	K (mm/h)	D (mm^2/h)	P (%)	θ_1 (m^3/m^3)	θ_2 (m^3/m^3)
1	Range	17.40 -33.60	37.08 -87.12	9.36 -79.20	4,680-35,964	42.32-49.98	0.0027-0.0050	0.1223-0.2304
	Mean	**24.36**	**55.44**	**34.81**	**18,324**	**46.74**	**0.0044**	**0.1777**
2	Range	16.20 -40.20	33.12 -93.60	16.20 -57.60	6,984-13,500	40.69-50.19	0.0028-0100	0.1392-0.2361
	Mean	**29.34**	**58.68**	**29.66**	**23,832**	**47.08**	**0.0053**	**0.1862**
3	Range	16.20 -39.00	36.00 -65.88	15.48 -46.80	8,172-35,672	37.85-50.32	0.0005-0.0144	0.1360-0.2082
	Mean	**25.20**	**51.48**	**28.37**	**19,404**	**44.29**	**0.0074**	**0.1748**
4	Range	12.00 -42.00	23.40 -68.04	8.64 -28.80	3,600-35,820	40.51-49.32	0.0066-0197	0.1568-0.2071
	Mean	**25.74**	**41.76**	**17.93**	**19,512**	**44.45**	**0.0124**	**0.1827**
5	Range	18.00 -48.00	32.40 -198.36	17.64 -126.00	10,980-49,032	40.75-46.71	0.0072-0.0175	0.1599-0.2224
	Mean	**31.86**	**67.32**	**34.52**	**24,444**	**43.44**	**0.0131**	**0.1986**
6	Range	9.00 -53.40	21.24 -104.76	18.00 -50.40	2,556-57,060	37.94-45.47	0.0089-0.0257	0.1737-0.2245
	Mean	**35.46**	**72.00**	**30.20**	**31,068**	**43.17**	**0.0164**	**0.2023**
7	Range	10.20 -56.40	20.86 -146.52	10.08-93.60	5,724-51,624	40.47-50.82	0.0070-0.0420	0.1345-0.2573
	Mean	**33.00**	**79.92**	**43.20**	**36,072**	**45.60**	**0.0160**	**0.2068**
8	Range	26.40 -72.00	57.96 -155.88	25.20 -75.60	3,600-75,060	38.32-46.50	0.0071-0.0248	0.1763-0.2543
	Mean	**45.48**	**107.28**	**49.07**	**18,324**	**41.91**	**0.0145**	**0.2250**
9	Range	24.60 -66.00	64.44 -146.16	9.00 -79.20	980-51,876	40.65-43.38	0.0068-0.0267	0.1997-0.2479
	Mean	**43.26**	**105.84**	**51.01**	**28,944**	**42.11**	**0.0113**	**0.2157**
10	Range	22.20 -60.00	32.40 -188.68	12.96 -90.00	8,748-91,764	39.93-46.30	0.0065-0.0366	0.1668-0.2380
	Mean	**42.48**	**100.44**	**41.47**	**43,416**	**42.40**	**0.0166**	**0.2045**

Table 2 Value of sorptivity (S), infiltration rate (I), hydraulic conductivity (K), water diffusivity (D), Soil porosity (P), initial water content (θ_1) and final water content (θ_2) of a loamy sandy soil at water potentials (ψ_o) of -0.02, -0.05, -0.10 and -0.15 m for 2005

ψ_o (m)	Value	S (mm/h$^{1/2}$)	I (mm/h)	K (mm/h)	D (mm^2/h)	P (%)	θ_1 (m^3/m^3)	θ_2 (m^3/m^3)
-0.02	Range	33.00 -90.00	80.28 -253.44	19.80 -133.20	20,196-149,400	37.30-47.60	0.0049-0.0300	0.1900-0.3050
	Mean	**58.02**	**148.32**	**64.33**	**62,460**	**41.92**	**0.0138**	**0.2356**
-0.05	Range	9.00 -72.00	20.88 -188.64	8.64 -126.00	900-91,761	37.85-50.19	0.0005-0420	0.1223-0.2573
	Mean	**33.60**	**74.16**	**36.00**	**26,964**	**44.12**	**0.0118**	**0.1974**
-0.10	Range	5.46 -33.00	21.60 -103.65	13.68 -75.60	1,368-39,600	36.67-48.97	0.0054-0.0342	0.1015-0.2294
	Mean	**19.08**	**54.72**	**41.11**	**13,104**	**42.23**	**0.0188**	**0.1877**
-0.15	Range	3.48 -25.80	25.92 -109.80	20.16 -97.20	684-28,080	39.27-46.63	0.0058-0321	0.1313-0.2299
	Mean	**16.26**	**56.16**	**46.98**	**8,244**	**42.90**	**0.0136**	**0.1955**

Table 3 Values of sorptivity (S), infiltration rate (I), hydraulic conductivity (K), water diffusivity (D), Soil porosity (P), initial water content (θ_1) and final water content (θ_2) of a loamy sandy soil at water potentials (ψ_o) of -0.02, -0.05, -0.10 and -0.15 m for 2018

ψ_o (m)	S (mm/h$^{1/2}$)	I (mm/h)	K (mm/h)	D (mm^2/h)	P (%)	θ_1 (m^3/m^3)	θ_2 (m^3/m^3)
	46.10	102.98	25.12	86,400.93	35.50	0.1167	0.2557
	70.71	196.20	12.77	203,858.55	33.48	0.1170	0.2558
-0.02	61.09	165.60	19.00	173,727.73	33.93	0.1347	0.2646
	73.96	200.88	15.18	190,966.63	33.93	0.1106	0.2606
	65.63	218.52	40.05	200,508.47	32.46	0.1035	0.2264
Mean	**63.50**	**176.84**	**22.42**	**171,092.46**	**33.86**	**0.1165**	**0.2526**
	34.19	86.04	23.97	100,889.89	36.00	0.1257	0.2211
	28.14	85.88	46.62	58,973.04	39.91	0.1142	0.2169
-0.05	35.12	78.84	19.86	85,419.30	40.09	0.1101	0.2166
	28.13	47.16	8.04	58,588.34	39.74	0.1280	0.2310
	23.92	58.68	24.88	60,485.88	36.96	0.1160	0.2022
Mean	**29.90**	**71.32**	**24.67**	**72,871.29**	**38.54**	**0.1188**	**0.2176**
	20.11	31.62	12.37	27,746.15	37.65	0.0945	0.2015
	18.32	35.20	15.56	22,067.69	41.32	0.0852	0.1945
-0.10	21.10	28.70	08.00	29,166.40	38.31	0.1010	0.2105
	20.40	34.50	12.02	30,515.87	36.87	0.1010	0.2045
	19.47	33.78	17.17	22,052.91	40.20	0.0961	0.2123
Mean	**19.88**	**32.76**	**13.02**	**26,309.80**	**38.87**	**0.0956**	**0.2047**
	14.40	27.50	17.15	15,655.64	35.78	0.0800	0.1820
	15.21	26.80	12.52	26,699.11	38.42	0.0920	0.1745
-0.15	15.50	29.40	16.01	22,590.05	40.10	0.1020	0.1934
	16.74	30.50	13.82	28,489.14	41.20	0.0971	0.1850
	15.20	28.50	15.61	21,771.67	39.20	0.0987	0.1900
Mean	**15.41**	**28.54**	**15.02**	**23041.12**	**38.94**	**0.0940**	**0.1850**

DISCUSSION

The values of sorptivity, steady state infiltration rate and hydraulic conductivity of lines 8, 9 and 10 were higher than the other lines because the soil appeared to be looser (pulverized) than the lines 1 to 7. This might be responsible for higher hydraulic properties of the soil obtained in lines 8, 9 and 10. The result of hydraulic properties of the soil obtained in 2018 in Table 3 were slightly lower than the results obtained in 2005 in Tables 1 and 2 because the land had been left fallow for about 10 years where cattle could follow when grazing. Movement of cattle on the land and soil being left for about 10 years increased the level of compaction which could lead to low infiltrate rate. The results of the hydraulic properties of soil in 2018 were within the range of the results obtained in 2005. A potential of -0.02 m was difficult to use during the infiltration rate measurement because it could not control preferential flow of water in the soil, the rate of infiltration was rapid and difficult to be recorded within 20 s interval when compared with -0.05 m water potential.

The values of hydraulic properties of the soil measured in 2005 and 2018 at -0.02 m water potential were higher than the other values with water potentials of -0.05 m, -0.10 m and -0.15 m. This indicated that the results of infiltration rates using water potential of -0.02 m might have been affected by preferential water flow which could not be avoided on a fallow land due to worm holes and cracks in the soil. Perroux and white (1988) pointed out that preferential water flow could be prevented by using a potential less than or equal to -0.04 m (tension of 0.04 m and above) and variation in sorptivity and infiltration rate could only occur due to inherent soil variability or measurements error. For values of potential greater than -0.04 m (tension less than 0.04 m) for the soil, variation might be due to macro pores and preferential water flow simply called preferential water flow. A -0.05 m water potential was found to be appropriate for the infiltration measurement using a tension infiltrometer because preferential water flow could be controlled and infiltration rate could be accurately measured.

Hydraulic properties of the soil obtained with -0.10 m and -0.15 m water potentials were lower than that of -0.05 m potential as shown in Tables 2 and 3. Infiltration rates for the two potentials were slow because more energy was required by the soil to attract water from the infiltrometer. Potentials of -0.10 m and -0.15 m were characterized by large bubbles of water during the infiltration tests due to absorption of large quantity of water by the soil after the needed energy to overcome by attraction of soil by capillary action had been built up. The water potential of -0.05 m could prevent preferential flow of water in the soil; the bubbling was not associated with large bubbles that could result to measurement error of infiltration rate and it easy to monitor during infiltration test as reported by Perroux and White (1988) that preferential flow could be controlled using water potential of ≤ -0.4 m.

CONCLUSION

Hydraulic properties of soil of the DFDABE were successfully measured using a tension infiltrometer. Water potential of -0.02 m could not control preferential water flow in this study which gave a higher mean infiltration rate of 148.32 mm/h in 2005 and 176.84 mm/h in 2018. A water potential of -0.05 m was found to be appropriate for using a tension infiltrometer which gave mean infiltration rate of 74.16 mm/h in 2005 and 71.32 mm/h in 2018. Water potentials of -0.10 m and -0.15 m were inappropriate for the measurement of infiltration rate using a tension infiltrometer because high energy was required to overcome the water potential and this led to large bubbles in the reservoir before the soil absorbed water and this could create error during the measurement. The results of hydraulic properties of soil obtained in this study using -0.05 m water potential was consistent, satisfactory and the results could be used for design of an irrigation project. The soil of DFDABE was found to be loamy sand.

REFERENCES

Arntzen, C. J. and Ritter, E.M. (Ed) (1994). Encyclopedia of Agricultural Science. Academic Press inc. California, 4: 151 – 168.

Bonsu, M. (1993). Field determination of sorptivity as a function of water content using a tension infiltrometer. *Journal of Soil Science.* 44: 44 – 415.

Casey, F.X.M and Derby, N.E (2002). Improved designed for an automated tension Infiltrometer. *Soil Science society of America journal*. 66: 64 – 67.

Cook, F.J and Broeren, A. (1994). Six methods for determining sorptivity and hydraulic conductivity with disc permeameter. *Journal of Soil Science,* 157 (1): 2 – 11.

Ejieji, C.J and Ajayi, A.S. (2001) Relation of some soil water transmission characteristics to some soil physical properties in a tropical alfisol. *Journal of Agricultural Research and Development*, University of Ilorin. 1: 9 – 22.

Hillel, D. (1980). Application of Soil Physics. Academic press, Inc. New York, 5-21.

Hillel, D. (1998). Environmental Soil Physics: Fundamentals, Applications, and Environmental Considerations. Academic Press, Oval Road, London, UK, 775.

Landson, J.R (Ed) (1991). Tropical Soil Manual: A hand book for soil survey and agricultural land evaluation in tropics and subtropics. John Wiley and Sons Inc. New York, 59 – 60.

Moldrulp, P., Yamaguchi, T. Ralston, D.E and Hansen, J.A. (1994). Estimation of the soil-water sorptivity from infiltration in vertical soil columns. *Journal of Soil Science*, 157: 12-18.

Ogunlela, A. O. (2001). Stochastic analysis of rainfall event in Ilorin, Nigeria. *Journal of Agricultural Research and Development.* Nigeria, 39-49.

Perroux, K.M. and White, J. (1988). Design for disc permeameters. *Soil Science Society of America Journal*, 52 (5): 1205 – 1215.

Sutton, B. H. C. (1993). Solving problems in soil mechanics. 2nd Edition, Addison Wesley Longman Limited, London, 3-4.

Wilkie, A. (1999). Water infiltration rates into unponded and pounded soil in Central Australia. Technote of Australia. Range Land Production, 105: 1- 8.

Wyscure, G.C.L, Satter, M.G.S, Adey, M.A and Rose, D.A (1997). Determination of unsaturated hydraulic conductivity in the field by a Robust tension infiltrometer. Department of Agricultural and Environmental Science, University of New Castle Upon Tyne, U. K, 1-4.

Yusuf, K.O. (2006). Design and construction of a tension infiltrometer for the determination of sorptivity and hydraulic conductivity of soils. Unpublished M.Eng. Thesis, Department of Agricultural and Biosystems Engineering, University of Ilorin, Ilorin, Nigeria.