Determination of Sorptivity, Infiltration Rate and Hydraulic Conductivity of Loamy Sand using Tension Infiltrometer and Double-Ring Infiltrometer

1Kamorudeen O. Yusuf, 2Rasheed O. Obalowu, 1Gideon T. Akinleye and 1Selia I. Adio-Yusuf

1Department of Agricultural and Biosystems Engineering, University of Ilorin, Ilorin, Nigeria
2Department of Agricultural and Bio-Environmental Engineering Technology, Institute of Technology, Kwara State Polytechnic, Ilorin, Nigeria

Received: 13-APR-2020; Reviewed: 16-MAY-2020; Accepted: 04-JUN-2020

http://dx.doi.org/10.46792/fuoyejet.v5i2.501

Abstract- This study was conducted to assess the effectiveness and accuracy of tension infiltrometer (TI) over double ring infiltrometer (DI) for determining infiltration rate (I) of loamy sand. Sorptivity (S), infiltration rate and hydraulic conductivity (K) are soil properties that govern the rate of entry of water into the soil and its movement within the soil. The ease and accurate measurement of these properties depend on the instruments used. DI operates by ponding water and could be affected by preferential water flow during infiltration test which could not be avoided especially on a fertile soil. DI and TI at water potentials of -0.02, -0.04, -0.05 and -0.06 m were used to determine infiltration rate of the soil. The mean values of sorptivity for DI and TI at water potentials of -0.02, -0.04, -0.05 and -0.06 m were 847.02, 63.50, 33.15, 29.90 and 19.46 mm/h1/3, respectively. Mean values of infiltration rates for DI and TI at -0.02, -0.04, -0.05 and -0.06 m water potentials were 471.26, 176.84, 73.73, 71.32 and 37.73 mm/h, respectively. Mean values of hydraulic conductivity for DI and TI at -0.02, -0.04, -0.05 and -0.06 m were 344.45, 22.42, 18.61 and 16.83 mm/h, respectively. DI required 100-150 litres for the infiltration test, difficult where water is very scarce and gave higher values of infiltration rate. TI saved water (2-3 litres), controlled preferential water flow and values of S, I and K were within the range obtained by other researchers. TI is more effective for measuring hydraulic properties of soil than DI.

Keywords: Double ring infiltrometer, tension infiltrometer, sorptivity, infiltration rate, hydraulic conductivity

1 INTRODUCTION

Double ring infiltrometer is a simple instrument and the most commonly used instrument in the developing countries like Nigeria for the determination of infiltration rates of soils. It is a cylindrical metal that open at both ends of the inner ring (30 cm diameter) and outer ring (60 cm) and is normally 25 cm high. DI operates by ponding water on the soil surface and the infiltration rate could be affected by preferential water flow during infiltration test in which water flow through worm holes, soil cracks and cracks by roots of plants or decay of plant root which cannot be avoided on a fertile fallow land (soil) on the field. This preferential water flow could lead to over-estimating infiltration rate (high value of infiltration rate) and other hydraulic properties of soil (Perroux and White, 1988).

A tension infiltrometer also called disc permeameter normally requires little quantity of water for the measurement of infiltration rate and could control preferential water flow during infiltration test by using negative water potentials (tensions) that restrict abnormal flow of water in the soil (Wyscrete et al., 1997; Perroux and White, 1988; Casey and Derby, 2002). Soils that contain organic matter normally contain worm holes and soil cracks and this usually result to preferential flow of water through the holes during infiltration test. Preferential flow of water could not be totally avoided on a fertile fallow land and this could result to high values of sorptivity, infiltration rate and hydraulic conductivity.

Both DI and TI could be used for the measurement of sorptivity and infiltration rate but the ease and accurate measurement of these hydraulic properties of soil depend on the type of infiltrometer used. Tension infiltrometer is more portable than double ring infiltrometer, saved water, easy to read during infiltration test (error due to parallax reading could be avoided) and preferential water flow could be controlled and avoided.

Sorptivity (S) is related to infiltration rate and is the soil hydraulic property that determines the rate of flow of water through the soil at early stage of infiltration by capillary action (Arntzen and Ritter, 1994). S is gravity free absorption of water into soil due to capillary and adhesive forces of soil solid surfaces. According to Cook and Broeren (1994), S could be determined from Equation (1) as the slope of the straight portion of the graph of cumulative infiltration (I) versus square root of time (t1/2) at early stage of infiltration. Casey and Derby (2002) pointed out that I could be determined as the slope of cumulative infiltration (I) against time (t) where the flow rate is steady and the curve is linear. Steady state infiltration rate is normally occurring between 10 and 20 minutes when TI is used to determine infiltration rate of soil (Cook and Broeren, 1994; Casey and Derby, 2002; Yusuf, 2006 and Yusuf, et al., 2018).

\[ I = \frac{S}{t^{0.5}} \]  

(1)

where, \( I \) is the cumulative infiltration (mm), Sorptivity (mm/h1/2) and \( t \) is the time (h).

Double ring infiltrometer is cumbersome to use because it is heavy, required large quantity of water (100 to 150
litres), high value of infiltration rate due to preferential water flow and is time consuming. DI normally gives young researchers in Soil and Water Engineering problem especially where water is scarce during dry season because it requires large quantity of water to perform the infiltration test. TI is an alternative instrument that is very simple to use but not popular; it is not commonly used especially in Nigeria. Again, available data of 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 adequate. The soil hydraulic properties are needed in Soil and Water Engineering to understand the flow of water in the soil and the data are also needed for the design of an irrigation project in the area. Therefore, there is need to determine the infiltration rates and other hydraulic properties of the soil of DFDABE using a TI is easy to use. In view of its aforementioned merits, the objectives of this study were to determine the sorptivity, infiltration rate and hydraulic conductivity of soil of the DFDABE using tension and double ring infiltrometers.

2 MATERIALS AND METHODS

2.1 LOCATION OF THE STUDY

The location of this 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. 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 on the land that had been left fallow for about 10 years before the study was conducted between April and May, 2018. The infiltration test was conducted on loamy sandy soil using tension and double infiltrometers. For the tension infiltrometer, water potentials used were -0.02, -0.04, -0.05 and -0.06 m.

2.2 EXPERIMENTAL SITE

The experimental site where the infiltration test was conducted was 15 by 15 m. The test points were randomly selected on the site for both double ring and tension infiltrometers. Perroux and white (1988) stated that preferential flow of water during infiltration test could be avoided by using a water potential less than or equal to -0.04 m (tension of 0.04 m and above). Variation in infiltration rate and other hydraulic properties of soil could only be due to inherent soil variability and measurement error. Therefore, four water potentials of -0.02, -0.04, -0.05 and -0.06 m were used in this study for measurement of infiltration rate. A total of 25 infiltration tests were conducted with 5 tests (replications) for each water potential using tension infiltrometer and 5 replications for double ring infiltrometer.

2.3 OPERATING PRINCIPLES OF A TENSION INFILTROMETER AND METHOD USED IN THIS STUDY

The soil surface where the infiltration was carried out was carefully cleared to remove the weeds and organic matter on the soil. A cylinder of 275 mm diameter and 100 mm high was put on the soil and hammered down through the soil profile to a depth of 50 mm. This cylinder would ensure downward flow of water and prevent lateral flow of water from the soil surface. Sand sieved through 2 mm sieve was put on the soil surface of the cylinder as the contact material (3 mm thickness) to allow free flow of water from the tension infiltrometer into the soil.

The bubble tower of the tension infiltrometer was filled with water to a level that gives the desired water potentials (-0.02, -0.04, -0.05 and -0.06 m) using Equation (2) given by Perroux and White (1988). The air-inlet tube was corked to prevent entry of air into the air inlet tube that could initiate flow of water in the reservoir. The water potential is adjustable because Z₀ could be varied depending on the level of water in the bubble tower but Z₁ (8 cm) is fixed for 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 (900 mm high and internal diameter of 95 mm) was filled to a level of 700 mm within forty seconds (40 s). The top of the reservoir was corked immediately to make it air-tight and prevent flow of water out of the reservoir. Flow of water can only occur if there is air-leakage into the reservoir that could initiate movement of water.

Soil sample was taken for the initial water content beside the infiltrometer. The tension infiltrometer was gently placed on the contact material and the cork air-inlet tube on the bubble tower was carefully opened to allow movement of air into the bubble tower. The air that enters the bubble tower bubbles through the water, comes out through the air-exit tube and the air finally enter the water reservoir. The bubbling of air into the reservoir initiates the flow of water through the reservoir and infiltration commenced immediately as shown in Figure 2. The infiltration test was monitored for 15 minutes because steady state infiltration rate was attained at 10 – 12 minutes when the tension infiltrometer was used. The reduction of water levels in the reservoir which is the rate of infiltration was recorded at 20 s interval. For the tension infiltrometer, 2 to 3 litres of water was used to attain the steady state infiltration rate. The infiltrometer was gently removed and soil sample was taken with a core sampler for the determination of final water content and bulk density. Magnification of the water reservoir in relation to cylinder that was driven into the soil profile was 8.4. The actual depth of infiltration in the soil was multiplied by the reciprocal of the magnification (1/8.4 = 0.11905).

\[ \psi' = Z_2 - Z_1 \]  \hspace{1cm} (2)

where, \( \psi' \) 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 is the distance from the air-exit tube entering the reservoir to the membrane (m).

Fig. 1: A sketch of side view of the tension infiltrometer (Yusuf, 2006)

Fig. 2: Tension infiltrometer in operation (Yusuf, 2006)

2.4 OPERATING PRINCIPLES OF DOUBLE RING INFILTROMETER AND METHOD USED

The operating principles of single ring infiltrometer (Figure 3) or double ring infiltrometer (Figure 4) is by ponding of water and it does not require water potential (zero water potential) during infiltration test that could restrict preferential water flow. Double ring infiltrometer (inner ring 30 cm diameter, outer ring 60 cm diameter and 25 cm high) was used to determine the infiltration rate of 5 points in the study area. Water was poured in the inner ring and in between the inner and outer rings. A metre rule was put in the inner ring where reading was recorded. The water in between the inner and outer rings would provide water for lateral flow and ensure downward flow of water in the inner ring. The decrease in the level of water was recorded at 2 minutes interval for 90 minutes. The cumulative infiltration was plotted against time and the steady state infiltration rate was determined from the graph for each point.

Fig. 3: Single ring infiltrometer

Fig. 4: Double ring infiltrometer used for the measurement of the infiltration rate

2.5 DETERMINATION OF SORPTIVITY & INFILTRATION RATE

Sorptivity given in equation (1) 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 cumulative infiltration versus square root of time which normally occurs between 6 s^{1/2} and 18 s^{1/2} as shown in Figure 5. The steady state infiltration rate (I) was determined from the graph as the slope of cumulative infiltration versus time when the curve was linear and the infiltration rate was constant (which occurs at 400 – 900 s) as shown in Figure 6.

Fig. 5: Cumulative infiltration versus square root of time for sorptivity

Fig. 6: Cumulative infiltration versus time for infiltration rate
2.5 Determination of Hydraulic Conductivity

Cook and Broeren (1994) reported that if there is a relationship between hydraulic conductivity and infiltration rate of soil as given in Equations (3), (4) and (5), then, hydraulic conductivity of soil was determined using Equation (6b).

\[ I = \frac{S}{2t^{1/2}} \]  
\[ I = \Delta K \left( 1 + \frac{4\lambda_c}{\pi r} \right) \]

Cook and Broeren (1994) also reported that macroscopic capillary length scale \( \lambda_c \) could be determined from Equation (5).

\[ \lambda_c = \frac{bS^2}{\Delta K \Delta \theta} \]  

where \( b \) is 0.5 ≤ \( b \) ≤ 0.25\( \pi \) for most soils, \( b = 0.55 \) and for every water potential \( \psi \), \( \Delta K = K \) and putting Equation (4) into Equation (5), hydraulic conductivity at steady flow rate was determined using Equation (6a) or (6b)

\[ I = K_s + \frac{2.2S^2}{\pi r (\theta_1 - \theta_i)} \]
\[ K_s = I - \frac{2.2S^2}{\pi r (\theta_1 - \theta_i)} \]

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 \( (m/s) \), \( S \) sorptivity \( (m/s^{1/2}) \) converted to \( mm/h^{1/2} \), \( r \) is the radius of the disc or cylinder driven into the soil \( (m) \), \( \theta_1 \) and \( \theta_i \) are the initial and final volumetric water contents of the soil \( (m^3/m^3) \).

2.6 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 density bottle. The specific gravity of soil particle was determined using the method given by Sutton (1993). A 50 cm³ of plastic bottle of University of Ilorin water (Unilorin water) was improvised as the pycnometer or density bottle. A hole of 4 mm diameter was drilled on the cover of the bottle to allow escape of bubbling air from the soil when water was added to the soil. The specific gravity and particle density of soil were determined using Equations (7) and (8), respectively given by Sutton (1993), Yusuf and Murtala (2020). The soil particle density \( (\rho_p) \) and bulk density \( (\rho_b) \) were required for the practical determination of soil porosity.

\[ G_s = \frac{m_s - m_i}{(m_s - m_i) - (m_t - m_i)} \]  
\[ \rho_s = G_s \times \rho_w \]

where \( m_s \) is the mass of empty plastic bottle \( (g) \); \( m_t \) is the mass of empty bottle and dry soil half-filled the bottle \( (g) \); \( m_i \) 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 \( m_i \) is the mass of empty bottle and mass of water only added to fill the bottle \( (g) \).

and \( m_i \) is the mass of empty bottle and mass of water only added to fill the bottle \( (g) \).

2.7 Determination of Porosity and Volumetric Moisture Content of the Soil

Porosity of the soil was calculated using the values of bulk density and particle density of the soil from Equation (9) given by Bonsu (1993).

\[ P = \left( 1 - \frac{\rho_p}{\rho_w} \right) \times 100 \]

where \( P \) is the porosity of the soil \( (\%) \), \( \rho_b \) is the soil bulk density \( (kg/m^3) \) and \( \rho_w \) is the particle density of soil \( (kg/m^3) \) or \( g/cm^3 \). The volumetric moisture content was computed using Equation (10).

\[ \theta = M.C \times \frac{\rho_b}{\rho_w} \]

where \( \theta \) is the volumetric moisture content \( (m^3/m^3) \), \( M.C \) is the moisture content of the soil \( (\%) \), \( \rho_b \) is soil bulk density \( (g/cm^3) \), \( \rho_w \) is the density of water \( (g/cm^3) \).

2.8 Statistical Analysis of Infiltration Rates by Paired T-Test

A pair t-test statistical analysis was used in this study to determine the effect of preferential water flow and the accuracy of the results of infiltration rates obtained using a tension infiltrometer (at -0.02, -0.04, -0.05 and -0.06 m water potentials) and double ring infiltrometer. The statistical analyses were done by comparing the results of infiltration rates from tension infiltrometer with different water potentials versus double ring infiltrometer. The mean, standard deviation, standard error and t-test values were determined using Equations (11), (12a) or (12b), (13) and (14), respectively as given by Montgomery et al. (1998) and Yusuf and Ogunlela (2016). The calculated values of the t-test and that of table values were compared and presented in Tables 6 and 7.

\[ \bar{d} = \frac{\sum d}{n} \]
\[ \delta = \sqrt{\frac{\sum (d - \bar{d})^2}{n - 1}} \]
\[ \delta = \sqrt{\frac{\sum d^2 - n(\bar{d})^2}{n - 1}} \]
\[ \delta_{Er} = \frac{\delta}{\sqrt{n}} \]
\[ t_{cal} = \frac{\bar{d}}{\delta_{Er}} \]

where \( \bar{d} \) is the mean of the difference from the data \( x_i \) and \( x_2 \), \( \sum d \) is the summation of \( d \), \( n \) is the number of the treatments (observations), \( \delta \) is the standard deviation, \( \delta_{Er} \) is the standard error and \( t_{cal} \) is the calculated value of \( t \) which was compared with the Table value of \( t_{tab} \) at \( \alpha = 5 \% \) significant level but 2.5 % (\( \alpha = 0.05/2 = 0.025 \)) for paired t-test.
3 RESULTS AND DISCUSSION

The top soil (0 – 30 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, soil porosity, initial and final volumetric moisture contents for the soil of DFDABE were presented in Table 2. The values of sorptivity, steady state infiltration rate and hydraulic conductivity on Table 2 varied from point to point because soil porosity and level of soil compaction could not be uniform but all the values were within the range given by Bonsu (1993), Perroux and White (1988) and Wilkie (1999). The mean values of the sorptivity, steady state infiltration rate, hydraulic conductivity, porosity, initial and final volumetric water contents using water potentials of -0.02, -0.04, -0.05 and -0.06 m for tension infiltrometer were within the range by other researchers (Wyscure et al., 1997; Casey and Derby, 2002; Yusuf et al., 2018).

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 manually within 20 s interval when compared with -0.04 and -0.05 m water potentials. This indicated that the results of infiltration rates using -0.02 m water potential might be affected by preferential water flow. Perroux and White (1988) showed that preferential water flow could be prevented by using a potential less than or equal to -0.04 m and variation infiltration rate could only occur due to inherent soil variability or measurements error.

Water potentials of -0.04 and -0.05 m were found to be appropriate for the infiltration measurement using a tension infiltrometer because preferential water flow could be prevented and infiltration rate could be accurately measured. Hydraulic properties of the soil obtained using -0.06 m potentials gave the least values. The results obtained in the study as shown in Tables 2 were satisfactory using a tension infiltrometer but -0.04 and -0.05 m water potentials were found to be more appropriate for measuring infiltration rate of soil using a tension infiltrometer. The results of hydraulic properties of soil with double ring infiltrometer are presented in Table 3. The mean values of the sorptivity, steady state infiltration rate, hydraulic conductivity, initial and final volumetric water contents were all higher for double ring infiltrometer. Infiltration rate of soil using double ring infiltrometer could be affected by preferential water flow which led to higher values of infiltration rate and other hydraulic properties of soil. The volume of water required to attain steady state infiltration rate for DI ranged from 100 - 150 litres compared to 2 - 3 litres by tension infiltrometer. Mean result of hydraulic properties of the soil using DI and TI is shown in Figure 7.

The paired t-test statistical analysis on the infiltration rate of the soil in Table 4 revealed that double ring infiltrometer gave higher infiltration rate of soil due to preferential water flow. The results of I using DI were statistically significant when compared with the results obtained using TI at -0.04 and -0.05 m water potentials because the calculated value of paired t-test were 4.419 and 4.642 which were higher than the table value t-test 2.776 at α ≤ 5% (2.5% for paired t-test). The results of infiltration rate with TI using -0.04 and -0.05 m water potentials were consistent and appeared to be more accurate because there was no abnormal bubbling of air and the infiltration was steady and easily read from reservoir. The calculated value of paired t-test using the TI between -0.04 and -0.05 m water potentials was 0.443 which is less than the table value of t-test 2.776 at α ≤ 5%. This means that the effect of water potentials of -0.04 and -0.05 m was not significant on infiltration rate and preferential water flow was controlled as reported (Perroux and White, 1988 and Yusuf, 2006).

The calculated value of paired t-test with tension infiltrometer using -0.02 and -0.04 m water potentials was 3.901 which is greater than the table value of 2.776 at α ≤ 5%. This means that -0.02 m water potential had significant effect on infiltration rate of the soil due to preferential flow which was in agreement with Yusuf et al. (2018) that water potential higher than -0.04 m could not control preferential water flow. Again, -0.06 m water potential required more energy to absorb water from the reservoir of the TI to initiate infiltration. This normally associated with large abnormal bubbling of air through the reservoir causing error during measurement.

| Table 1. Data of infiltration rate used for computation of paired t-test was obtained from DI and TI with water potential -0.04 m as an illustration for the calculation |
|---------------------------------|-----------------|-----------------|-----------------|
| DI (X1) | TI at -0.04m (X2) | d = X1 - X2 | d² |
| 345.00 | 85.32 | 259.68 | 67,433.70 |
| 358.10 | 83.88 | 274.34 | 75,262.44 |
| 342.00 | 88.20 | 253.80 | 64,414.44 |
| 388.20 | 65.88 | 322.32 | 103,890.18 |
| 723.00 | 45.36 | 677.64 | 459,195.97 |
| n = 5 | | | |
| | Σd = | Σd² = |
| | 1,787.78 | 770,196.76 |

\[
\bar{d} = \frac{1787.78}{5} = 357.56 \quad (12)
\]

\[
\delta = \sqrt{\frac{77017676 - 5(357.56)^2}{5 - 1}} = 180.94 \quad (13b)
\]

\[
\delta_{es} = \frac{180.94}{\sqrt{5}} = 80.92 \quad (14)
\]

\[
t_{calc} = \frac{357.56}{80.92} = 4.419 \quad (15)
\]

But table value of t-test = 2.776
Table 2. Values of sorptivity (S), infiltration rate (I), hydraulic conductivity (K), Soil porosity (P), initial water content (θ₁) and final water content (θ₂) of a loamy sandy soil using a tension infiltrometer at water potentials (ψ₀) of -0.02, -0.04, -0.05 and -0.06 m

| ψ₀ (m) | S (mm/h·m⁻¹²) | I (mm/h) | K (mm/h) | P (%) | θ₁ (m³/m³) | θ₂ (m³/m³) |
|--------|---------------|----------|----------|-------|------------|------------|
| -0.02  | 46.10         | 102.98   | 25.12    | 35.50 | 0.1167     | 0.2557     |
|        | 70.71         | 196.20   | 12.77    | 33.48 | 0.1170     | 0.2558     |
|        | 61.09         | 165.60   | 19.00    | 33.93 | 0.1347     | 0.2646     |
|        | 73.96         | 200.88   | 15.18    | 33.93 | 0.1106     | 0.2606     |
|        | 65.63         | 218.52   | 40.05    | 32.46 | 0.1035     | 0.2264     |
| Mean   | 63.50         | 176.84   | 22.42    | 33.86 | 0.1165     | 0.2526     |
| -0.04  | 37.01         | 85.32    | 20.37    | 36.00 | 0.1047     | 0.2121     |
|        | 35.39         | 83.88    | 12.38    | 39.91 | 0.1368     | 0.2260     |
|        | 39.55         | 88.20    | 20.18    | 40.09 | 0.1047     | 0.2218     |
|        | 29.40         | 65.88    | 27.30    | 39.74 | 0.1218     | 0.2359     |
|        | 24.40         | 45.36    | 12.83    | 36.96 | 0.1279     | 0.2211     |
| Mean   | 33.15         | 73.73    | 18.61    | 38.54 | 0.1192     | 0.2234     |
| -0.05  | 34.19         | 86.04    | 23.97    | 36.00 | 0.1257     | 0.2211     |
|        | 28.14         | 85.88    | 46.62    | 39.91 | 0.1142     | 0.2169     |
|        | 35.12         | 78.84    | 19.86    | 40.09 | 0.1101     | 0.2166     |
|        | 28.13         | 47.16    | 8.04     | 39.74 | 0.1280     | 0.2310     |
|        | 23.92         | 58.68    | 24.88    | 36.96 | 0.1160     | 0.2022     |
| Mean   | 29.90         | 71.32    | 24.67    | 38.54 | 0.1188     | 0.2176     |
| -0.06  | 17.69         | 40.68    | 22.81    | 39.13 | 0.1390     | 0.2282     |
|        | 17.69         | 35.28    | 12.59    | 34.96 | 0.1257     | 0.1968     |
|        | 19.39         | 28.08    | 10.07    | 34.96 | 0.1513     | 0.2107     |
|        | 18.54         | 39.60    | 21.88    | 36.56 | 0.1076     | 0.2064     |
|        | 23.97         | 45.00    | 16.81    | 36.40 | 0.1088     | 0.2126     |
| Mean   | 19.46         | 37.73    | 16.83    | 36.40 | 0.1265     | 0.2109     |

Table 3. Values of sorptivity (S), infiltration rate (I), hydraulic conductivity (K), Soil porosity (P), initial water content (θ₁) and final water content (θ₂) of a loamy sandy soil using a double ring infiltrometer (DI)

| DI     | S (mm/h·m⁻¹²) | I (mm/h) | K (mm/h) | P (%) | θ₁ (m³/m³) | θ₂ (m³/m³) |
|--------|---------------|----------|----------|-------|------------|------------|
| 722.20 | 345.00        | 252.16   | 39.39    | 0.1633 | 0.3253     |
| 1071.40| 558.10        | 407.92   | 45.46    | 0.1620 | 0.3251     |
| 642.90 | 342.00        | 249.97   | 45.22    | 0.1028 | 0.3713     |
| 687.50 | 388.20        | 283.74   | 43.84    | 0.1804 | 0.3486     |
| 1111.10| 723.00        | 528.44   | 38.22    | 0.1543 | 0.3715     |
| Mean   | 847.02        | 471.26   | 344.45   | 42.43 | 0.1526     | 0.3484     |

Fig. 7: Results of Sorptivity (S), Infiltration rate (I), Hydraulic conductivity (K), Porosity of the soil (P) using double ring and tension infiltrometers at 4 different water potentials.
The calculated value of t-test using -0.04 and -0.06 m water potentials was 3.448 which is greater than the table value of 2.776 at α ≤ 5%. This means that -0.06 m water potential was significant, it had effect on preferential water flow and the water potential was not adequate for TI as shown in Table 4. The values of all hydraulic properties of the soil measured using -0.02 m water potential were higher than the values obtained using water potentials of -0.04 m, -0.05 m and -0.06 m as shown in Table 1.

Measurement of infiltration rate of soil using DI required large quantity of water (100 – 150 litres depending on the diameter of infiltrometer) and this could be a serious problem in area (s) where water is very scarce. DI is normally heavier than the TI which requires 2 - 3 litres of water.

4 Conclusion
The soil of DFDABE was loamy sand. Both double ring and tension infiltrometer could be used to measure infiltration rate of soil on the field. Double ring infiltrometer required 100 - 150 litres of water to attain steady state infiltration rate compared to tension infiltrometer which required about 2 - 3 litres of water. Tension infiltrometer prevents or reduces preferential water flow, easy to use, effective, gives consistent and accurate values of sorptivity and infiltration rate of soils. The results of hydraulic properties of soil obtained in this study using -0.04 and -0.05 m water potentials were consistent, satisfactory and the results could be used for design of an irrigation project in the study area. Water potential of -0.02 m could not control preferential water flow in the study area. Tension infiltrometer is more effective and more accurate for measuring infiltration rate of soil than the double ring infiltrometer.

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.
Montgomery, D. C, Runger, G. C and Hubele, N. F. (1998). Engineering statistics John Wiley and Sons, Inc, New York, pp. 135-248, 1998.
Ogunlela, A. O. (2001). Stochastic analysis of rainfall event in Ilorin, Nigeria. Journal of Agricultural Research and Development 3: 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, C. G. L, Satter, 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. M.Eng. Thesis, Department of Agricultural and Biosystems Engineering, University of Ilorin, Ilorin, Nigeria.
Yusuf, K. O and Ogunlela, A. O (2016). Effect of magnetically treated water on the quality of tomato. Katmandu University Journal of Science, Engineering and Technology, 12 (2): 29-33.
Yusuf, K. O, Eijeji, C. J and Baiyeri, M. R (2018). Determination of sorptivity, infiltration rate and hydraulic conductivity of soil using a tension infiltrometer. Journal of Research in Forestry, Wildlife and Environment 10 (3): 99-108.
Yusuf, K. O and Murtala, M. O (2020). Development and performance evaluation of a portable household ceramic water filter with activated carbon and magnetic treatment unit. International Journal of Environmental Science and Technology, 17 (5): 1–10.