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# Effect of Soil Texture on Soil Infiltration Rate

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***Authors' contributions***

*This work was carried out in collaboration between both authors. Both authors read and approved the final manuscript.*

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## ABSTRACT

The process of infiltration may be quite complex due to non-uniformity of the initial moisture content and soil properties and it is a process governed by force of gravity and capillary action. This process affects surface runoff, soil erosion, and groundwater recharge. It is important therefore to measure the rate of infiltration to balance the ecosystem. This work assesses the performance of a locally fabricated double-ring infiltrometer for infiltration rate measurement using selected locations within the Ekiti State University, Nigeria. The double-ring infiltrometer test is a well-recognized and documented technique for directly measuring soil infiltration rate. From the observation of the study, the soil location can be texturally classified as sandy clay, the infiltration depths obtained from the double ring infiltrometer test are $0.97t^{1.22} - 2.9$ and $0.25t^{1.22} - 2.0$. The result demonstrates that the intake rate of soil depends on the texture of soil, surface condition of the soil and time of pounding.

*Keywords: Infiltration rate; infiltrometer; measurement; surface runoff; soil texture; ecosystem.*

## 1. INTRODUCTION

Infiltration, according to [1,2], is the process whereby water enters the soil uniformly through its matrix, or through pores or crevices. This implies that entry of water into soil is affected by soil surface conditions as well as inherent properties and water supply [3,4,5,6,7]. It has

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been observed that infiltration is essentially a surface process in which porosity distribution of the soil material is the determining factor.

Infiltration capacity is the maximum rate at which the soil can take in water [8,9,10]. Infiltration capacity can be reduced by compaction (human, animal or vehicular traffic). It can be determined using infiltrometers (Fig. 1), drainage basins rainfall- runoff- analysis, inflow- outflow measurements, volume balance technique, index method and the far method. When water from rainfall or irrigation is applied to the surface of the soil, some of it may enter the soil where it may percolate to groundwater table or may become distributed within the soil and is stored for plant use [3,11,12,13]. Part of it may runoff causing erosion while part may evaporate.

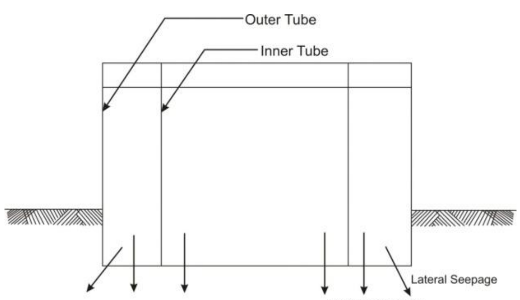


**Fig. 1. Section double ring infiltrometer**

The process of infiltration under conditions may be quite complex due to non-uniformity of the initial moisture content and soil properties. In the early stages of infiltration into a uniformity dry soil, the matrix suction gradient in the surface layer will be very high and is likely the most important factor determining the amount of infiltration and downward movement of water. In a dry soil, suction gradients can be much greater than gravitational gradient [2,14,15]. And infiltration rates can be attributed to the suction gradient. In wet soils, suction gradients are small from the start and become negligible sooner. The rate of infiltration and obvious characteristics of infiltration process is the rapid decrease in rate with time. Generally, infiltration rate is initially high, decreasing rapidly and then moves slowly to a constant rate known as the steady state [2].

The factors that affect infiltration include crop root system, organic debris, mulching, burrowing animals, insects, surface moisture content. Others are frost heave, salts, digging cracks, interstitial air, temperature, etc. all these factors mentioned above can be divided into 3 groups namely; surface conditions, soil characteristics and cultural practices.

The rate at which water passes through the soil surface is highly dependent on the conditions of the soil surface. Materials such as clay, polythene and mulch may seal the surface of soil so that infiltration rates are low and even when the underlying soils are highly permeable. If, however, the soil surface is rough, it will permit high infiltration but if the surface is smooth with tiny pores, infiltration rate would be low.

Soil characteristics include soil texture, soil structure, swelling and shrinkage etc. cultural practices tillage vegetative cover, trash and organic matter.

Parr and Bertrand (1960) published a thorough review of field methods for measuring infiltration capacity. Basically, some types of devices have been used as sprinkling infiltrometer and flooding infiltrometer, it is always advantageous to use a sprinkling infiltrometer for irrigation purpose, while flooding infiltrometer would be more appropriate for soils that are to be furrow for flood irrigation [6,16,17,18]. However, the double rings infiltrometer devices are far more frequently used because they require less equipment and are easier to install and operate than the other types. This work, therefore, aims at designing and constructing a double ring infiltrometer using local materials to measure infiltration rate.

## 2. MATERIALS AND METHODS

The double ring infiltrometer is an instrument which is in form of concentric cylinder described in detail by [2]. According to him, for any two cylinders to be called concentric cylinder, the center from where the radii of the two cylinders are measured to their circumference must be the same. In other words, the two cylinders must have the same center of producing their circular edges as shown in Fig. 2. The infiltrometer is produced from 2 mm thick rolled steel as shown in Fig. 2. The two cylinders are of same height of 40 cm (Fig. 2). The inner cylinder from where the infiltrometer measurements are taken is 30cm in diameter while the outer cylinder which is used to form the buffer pond is 60 cm in diameter.

With the above two diameters, the circumference of each of the cylinders can be obtained mathematically as shown below:

Circumference of a circle = πd, where, d is the diameter. For the circumference of the inner cylinder = πd = 94.30 cm, similarly for the circumference of the outer cyclinder = πd = 188.60 cm.

The Cylinders were installed 10 cm deep into the soil for all experiments carried out.

Soil samples used for this work were collected at different depths; 0.30 cm, 30-60 cm, from the faculty of Engineering and at the Entrepreneur building of Ekiti State University. In what follows, these are designated as location 1 and 2 respectively. The samples collected were analyzed to determine the particle size distribution of the soils.

Infiltration rate was determined using the fabricated double ring infiltrometer of inner diameter 30 cm and outer ring diameter of 60cm and 40 cm deep (Fig. 3). The infiltrometer is installed to a depth of 10 cm, water is poured into the infiltrometer and pressure head kept at the same level and measurements made at two different locations on the field with the aid of the steel rule (Fig. 3).

The outer cylinder (buffer) prevents lateral seepage thereby ensuring only vertical movement of water in the inner cylinder into the soil. A stopwatch is used to take the reading at five minutes interval which is later varied as the experiment progresses.

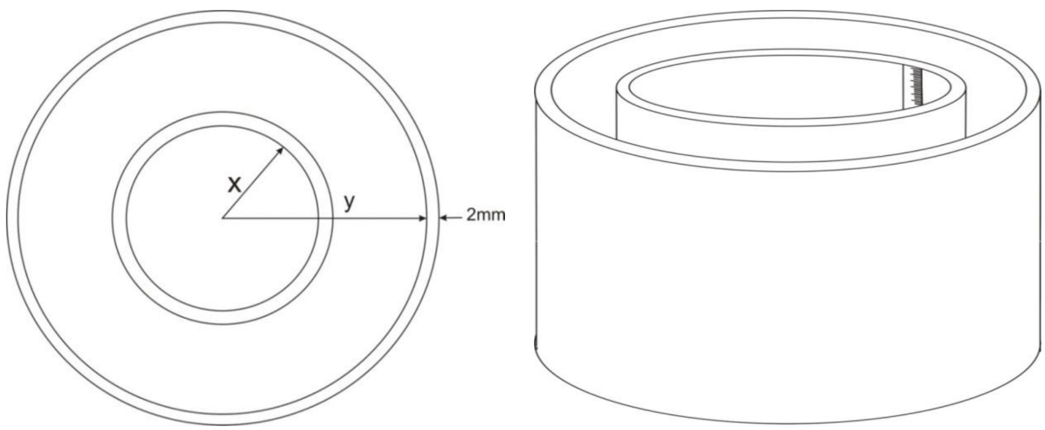


**Fig. 2. Double ring infiltrometer plan and assembling**

**Fig. 3. Infiltrometer**

## 3. RESULTS AND DISCUSSION

The preliminary soil test carried out to determine the particle size distribution gave the results as shown in Tables 1 to 4. Using the soil texture triangle (Fig. 4), the soil has more of sand particles at location 1 at 30 cm depth and 60cm depth falls into the class of sandy clay, while the soil particle at location 2 at depth 60cm falls into the class of clay. Results from the double ring infiltrometer test using Equation (1) is shown in Table 7 and 8 for locations 1 and 2.

$$\text{Average infiltration rate} = \frac{it - i_o}{t - t_o} \quad (1)$$

Where,

it = depth after filling, $i_o$= depth before refilling, t = time (min), $t_o$ = initial time (min)

The cumulative infiltration depth (cm) is obtained by summing up the values of depth of water infiltrated in the infiltrometer one after the other, from the calculated data the values of

**Table 1. Sieve analysis for soil sample at depth 30cm for location 1**

| Sieve size (mm) | Mass of sieve (g) | Mass of sieve + soil (g) | Mass of soil retained | Percentage retained (%) | Cumulative % retained | Finer percentage |
|---|---|---|---|---|---|---|
| 2.36 | 420 | 834 | 414 | 41.4 | 41.4 | 58.6 |
| 1.18 | 377 | 557 | 180 | 18.0 | 59.4 | 40.6 |
| 0.60 | 371 | 566 | 195 | 19.5 | 78.9 | 21.1 |
| 0.43 | 365 | 416 | 51 | 5.1 | 84.0 | 16.0 |
| 0.30 | 370 | 407 | 37 | 3.7 | 87.7 | 12.3 |
| 0.15 | 347 | 418 | 70 | 7.0 | 94.7 | 5.3 |
| 0.075 | 341 | 374 | 30 | 3.0 | 97.7 | 2.3 |
| Pan | 307 | 330 | 23 | 2.3 | 100 | 0 |
| | | | Wt =1000 g | | | |

**Table 2. Sieve analysis for soil sample at depth 60cm for location 1**

| Sieve size (mm) | Mass of sieve (g) | Mass of sieve + soil (g) | Mass of soil retained | Percentage retained (%) | Cumulative % retained | Finer percentage |
|---|---|---|---|---|---|---|
| 2.36 | 420 | 894 | 474 | 47.4 | 47.4 | 52.6 |
| 1.18 | 377 | 513 | 136 | 13.6 | 61 | 39 |
| 0.60 | 371 | 524 | 153 | 15.3 | 76.3 | 23.7 |
| 0.43 | 365 | 415 | 50 | 5.0 | 81.3 | 18.7 |
| 0.30 | 370 | 409 | 39 | 3.9 | 85.2 | 14.8 |
| 0.15 | 347 | 427 | 80 | 8.0 | 93.2 | 6.8 |
| 0.075 | 341 | 379 | 38 | 3.8 | 97.0 | 3.0 |
| Pan | 307 | 339 | 30 | 3.0 | 100 | 0 |
| | | | Wt =1000 g | | | |

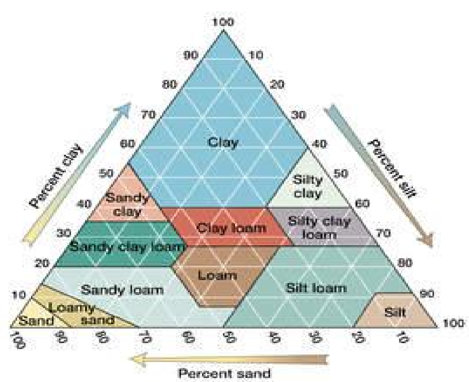


**Fig. 4. Soil Texture Triangle**

accumulated infiltration rates are plotted as a function of the elapsed time as shown in Figures 5 and 6. The relationship of accumulated infiltration 'y' with respect to time't' can be mathematically defined by the following equation known as modified kostiakov method [8]:

$$Y = at^{\alpha} + b \quad (2)$$

The values a, ∝ and b are three characteristic constants which were be obtained by the procedures suggested by Davis [8] as follows for locations 1 and 2 respectively.

Location 1:

a = 0.97, b = -2.90, and $\propto = 1.22$ given a relationship $\mathbf{Y = 0.97t^{1.22} - 2.90}$.

Location 2:

a = 0.25, b = 2.00, $\propto = 1.22$ given relationship $\mathbf{Y = 0.25t^{1.22} - 2.00}$

**Table 3. Sieve analysis for soil sample at depth 30cm for location 2**

| Sieve size (mm) | Mass of sieve (g) | Mass of sieve + soil (g) | Mass of soil retained | Percentage retained (%) | Cumulative % retained | Finer percentage (%) |
|---|---|---|---|---|---|---|
| 2.36 | 420 | 781 | 361 | 45 | 45 | 55 |
| 1.18 | 377 | 501 | 124 | 15.5 | 60.5 | 39.5 |
| 0.60 | 371 | 456 | 85 | 10.6 | 71.1 | 28.9 |
| 0.43 | 365 | 404 | 39 | 4.9 | 76 | 24 |
| 0.30 | 370 | 404 | 34 | 4.3 | 80.3 | 19.7 |
| 0.15 | 347 | 445 | 98 | 12.3 | 92.6 | 7.4 |
| 0.075 | 341 | 371 | 50 | 6.3 | 98.9 | 1.1 |
| Pan | 307 | 316 | 9 | 1.1 | 100 | 0 |
| | | | Wt =800 g | | | |

**Table 4. Sieve analysis for soil sample at depth 60cm for location 2**

| Sieve size (mm) | Mass of sieve (g) | Mass of sieve + soil (g) | Mass of soil retained | Percentage retained (%) | Cumulative % retained | Finer percentage (%). |
|---|---|---|---|---|---|---|
| 2.36 | 420 | 972 | 552 | 55.2 | 55.2 | 44.8 |
| 1.18 | 377 | 497 | 120 | 12.0 | 67.2 | 32.8 |
| 0.60 | 371 | 489 | 118 | 11.8 | 79 | 21 |
| 0.43 | 365 | 404 | 39 | 3.9 | 82.9 | 17.1 |
| 0.30 | 370 | 399 | 29 | 2.9 | 85.8 | 14.2 |
| 0.15 | 347 | 411 | 62 | 6.2 | 92 | 8 |
| 0.075 | 341 | 380 | 39 | 3.9 | 95.9 | 4.1 |
| Pan | 307 | 348 | 41 | 4.1 | 100 | 0 |
| | | | Wt =1000 g | | | |

**Table 5. Particle size analysis of soil at different depths and locations**

| | | 1 | | | 2 | |
|---|---|---|---|---|---|---|
| **Depth (cm)** | **% Sand** | **% Silt** | **% Clay** | **% Sand** | **% Silt** | **% Clay** |
| 0-30 | 56.3 | 2.3 | 0 | 53.9 | 1.1 | 0 |
| 30-60 | 49.6 | 3.0 | 0 | 40.7 | 4.1 | 0 |

**Table 6. Textual classes of the above soil**

| | | 1 | | | 2 | |
|---|---|---|---|---|---|---|
| **Depth (cm)** | **% Sand** | **% Silt** | **% Clay** | **% Sand** | **% Silt** | **% Clay** |
| 0-30 | Sandy clay | | | Sandy clay | | |
| 30-60 | Sandy clay | | | Clay | | |

**Table 7. Infiltration readings for location 1**

| Time (mins) | Depth after filling (cm) | Depth before refilling (cm) | Depth of water infiltrated (cm) | Average infiltration rate (cm/hr) | Average accumulated infiltration |
|---|---|---|---|---|---|
| 0 | 30 | 0.0 | 0.0 | 0.0 | 0 |
| 5 | 30 | 25.6 | 4.4 | 52.8 | 4.4 |
| 10 | 30 | 22.2 | 7.8 | 93.6 | 12.2 |
| 15 | 30 | 19.4 | 10.6 | 127.2 | 23.0 |
| 20 | 30 | 17.2 | 12.8 | 153.6 | 36.0 |
| 25 | 30 | 15.2 | 14.8 | 177.6 | 50.4 |
| 30 | 30 | 13.6 | 16.4 | 196.8 | 67.0 |
| 40 | 30 | 10.6 | 19.4 | 116.4 | 86.2 |
| 60 | 30 | 5.0 | 25.0 | 75.0 | 111.2 |

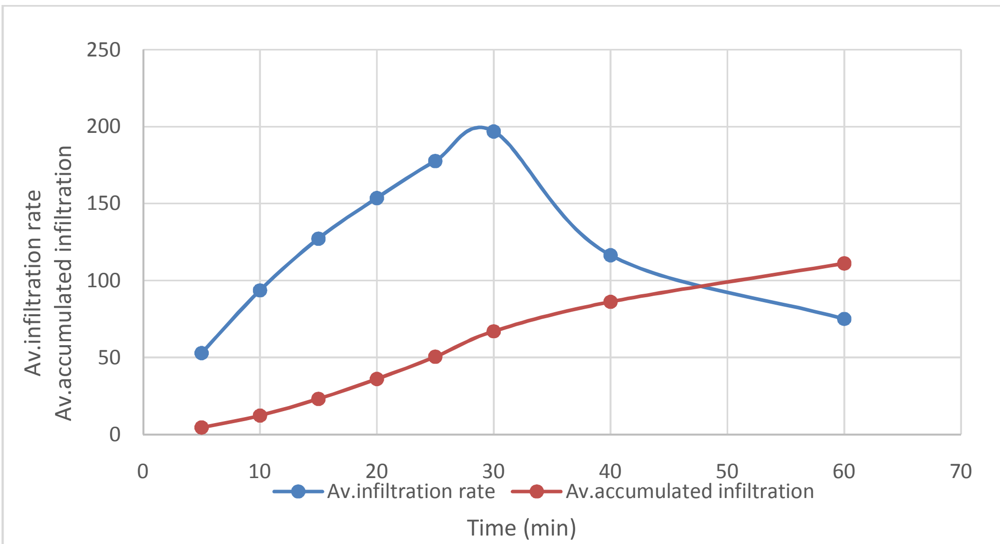


**Fig. 5. Graph of infiltration rate for location 1**

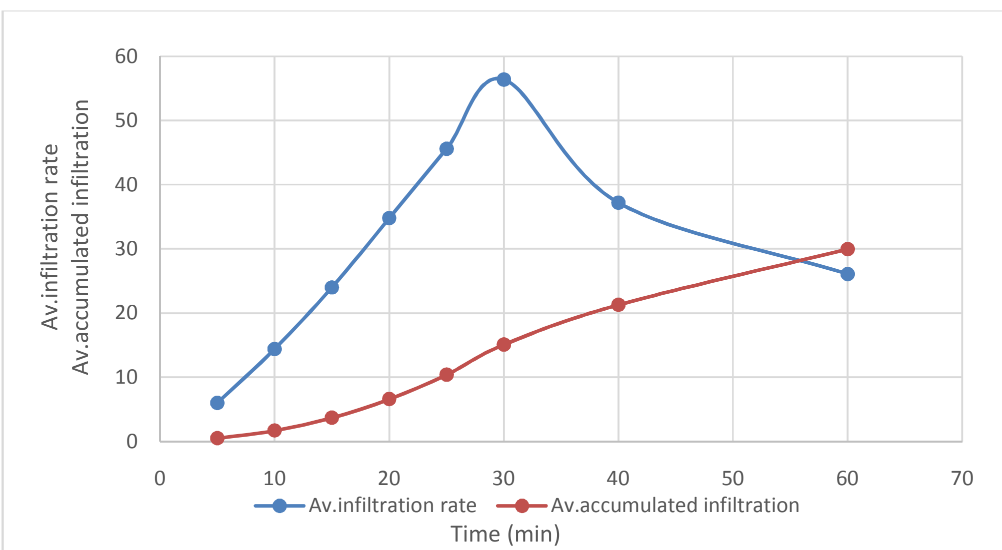


**Fig. 6. Graph of infiltration rate for location 2**

**Table 8. Infiltration readings for location 2**

| Time (mins) | Depth after filling (cm) | Depth before refilling (cm) | Depth of water infiltrated (cm) | Average infiltration rate (cm/hr) | Average accumulated infiltration |
|---|---|---|---|---|---|
| 0 | 30 | 0.0 | 0.0 | 0.0 | 0.0 |
| 5 | 30 | 29.5 | 0.5 | 6.0 | 0.5 |
| 10 | 30 | 28.8 | 1.2 | 14.4 | 1.7 |
| 15 | 30 | 28.0 | 2.0 | 24.0 | 3.7 |
| 20 | 30 | 27.1 | 2.9 | 34.8 | 6.6 |
| 25 | 30 | 26.2 | 3.8 | 45.6 | 10.4 |
| 30 | 30 | 25.3 | 4.7 | 56.4 | 15.1 |
| 40 | 30 | 23.8 | 6.2 | 37.2 | 21.3 |
| 60 | 30 | 21.3 | 8.7 | 26.1 | 30.0 |

In the use of double ring infiltrometer, water impound in the outer cylinder is to prevent lateral flow from the inner cylinder or to serve as a buffer to ensure vertical flow in the inner cylinder. The infiltration rate represents primarily vertical flow in the soil.

From Table 7 and 8, the infiltration rate (cm/hr) for the two points on the field were initially high and decreases sharply with time.

Similarly, Fig. 5 and Fig. 6 shows the graph of average infiltration rate and average accumulated infiltration against time for location 1 and location 2. The cumulative infiltration (cm) which designates the total quantity of water that enters the soil in a given time increased as more time elapsed and also as high rate of sun evaporates the water. However, the fall in infiltration rate with time could be attributed to the attainment of saturated point by the soil as more water was applied. As the soil approaches saturated points, less water infiltrates into the soil because both micro-pores and macro-pores were almost filled up with water, thereby allowing for less infiltration to take place. The infiltration rate decreases with increase in time.

It is observed that the infiltration rate at the locations 2 is low, because of the predominant existence of clay in the soil which transmits water slowly.

The presence of dense cover vegetation, such as grass or forest tends to increase infiltration. The vegetation not only provides protection from erosion and compaction due to due to rain but also provides a layer of decaying organic matter which promotes the activity of burrowing insects and animals.

The field capacity varied at different points of location and depths. It increased with depth. The rate at which soils approach an average field capacity is slower with clayey soils.

## 4. CONCLUSION

From observation of the study and particle size analysis of soil samples at different depths and locations of field site as shown in table 7, the soil can be texturally classified as sandy clay and clay as shown in Table 8.

The infiltration depths Y obtained from the double ring infiltrometer test are as follows;

$$Y = 0.97t^{1.22} - 2.9 \text{ and } Y = 0.25t^{1.22} - 2.0.$$

The result shows that the intake rate of soil depends on the texture of the soil, the surface condition of the soil and time of pounding.

The textual class and infiltration rate obtained from the test is good for furrow irrigation and the figures can be utilized for the efficient design of irrigation design on the field site.

The results obtained from the field test of the local fabricated double ring infiltrometer agrees with the findings of many researchers who have discovered that the rate of infiltration for various soil texture is high at the initial stage and later begins to fall as more water infiltrates into the soil.

## COMPETING INTERESTS

Authors have declared that no competing interests exist.

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