

DOUBLE RING INFILTROMETER FOR MEASURING SOIL INFILTRATION RATE

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 ground water 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.

Introduction

Infiltration, according to Hillel (1980), 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 (Biswas, et al, 1969). It has 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 (Rowland, 1993).

Infiltration capacity can be reduced by compaction (human, animal or vehicular traffic). It can be determined using infiltrometers (figure 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 ground water table or may become distributed within the soil and is stored for plant use. Part of it may runoff causing erosion while part may evaporate.

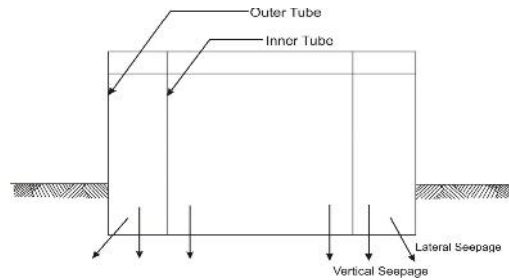


Fig 1: Section double ring infiltrometer

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 (Hillel, 1980). And infiltration rates can be attributed to 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 (Hillel, 1980).

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.

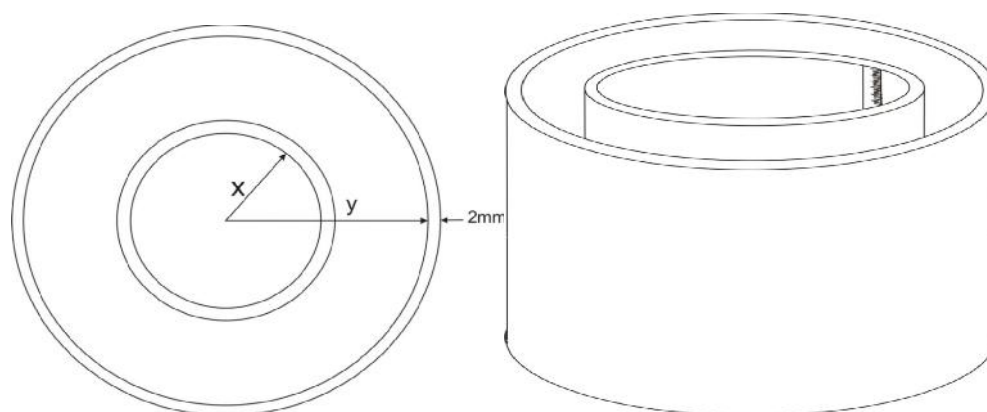
Parr and Bertrand (1960) published a thorough review of field methods for measuring infiltration capacity. Basically, some types of devices have been used as sprinkling infiltrometer and flooding infiltrometer, it is always advantageous to use a sprinkling infiltrometer for irrigation purpose, while flooding infiltrometer would be more appropriate for soils that are to be furrow for flood irrigation. However, the double rings infiltrometer

60 devices are far more frequently used because they require less equipment and are easier to
61 install and operate than the other types. This work therefore aims at designing and
62 constructing a double ring infiltrometer using local materials to measure infiltration rate.

63 **Material and Methods**

64 The double ring infiltrometer is an instrument which is in form of concentric cylinder
65 described in detail by Haise et al 1956. According to him, for any two cylinders to be called
66 concentric cylinder, the center from where the radii of the two cylinders are measured to their
67 circumference must be the same. In other words, the two cylinders must have the same center
68 of producing their circular edges as shown in Figure 2. The infiltrometer is produced from
69 2mm thick rolled steel as shown in Figure 2. The two cylinders are of same height of 40cm
70 (Figure 2). The inner cylinder from where the infiltrometer measurements are taken is 30cm
71 in diameter while the outer cylinder which is used to form the buffer pond is 60cm in
72 diameter.

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Figure 1: double ring infiltrometer plan and assembling

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

78 Circumference of a circle = πd , where, d is the diameter. For the circumference of the inner
79 cylinder = $\pi d = 94.30\text{cm}$, similarly for the circumference of the outer cylinder = $\pi d =$
80 188.60cm .

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

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

86 Infiltration rate was determined using the fabricated double ring infiltrometer of inner
87 diameter 30cm and outer ring diameter of 60cm and 40cm deep (Figure 4). The infiltrometer
88 is installed to a depth of 10cm, water is poured into the infiltrometer and pressure head kept
89 at the same level and measurements made at two different locations on the field with the aid
90 of the steel rule (Figure 4).



Figure 4

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

96 Results and Discussion

97 The preliminary soil test carried out to determine the particle size distribution gave the results
98 as shown in Table 10. Using the soil texture triangle (Figure 5), the soil has more of sand
99 particles at location 1 at 30cm depth and 60cm depth falls into the class of sandy clay, while
100 the soil particle at location 2 at depth 60cm falls into the class of clay. Results from the
101 double ring infiltrometer test using Equation (1) is shown in Table 11 and 12 for locations 1
102 and 2.

$$103 \quad \text{Average infiltration rate} \quad = \quad \frac{it - i_o}{t - t_o} \quad (1) \text{ where}$$

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

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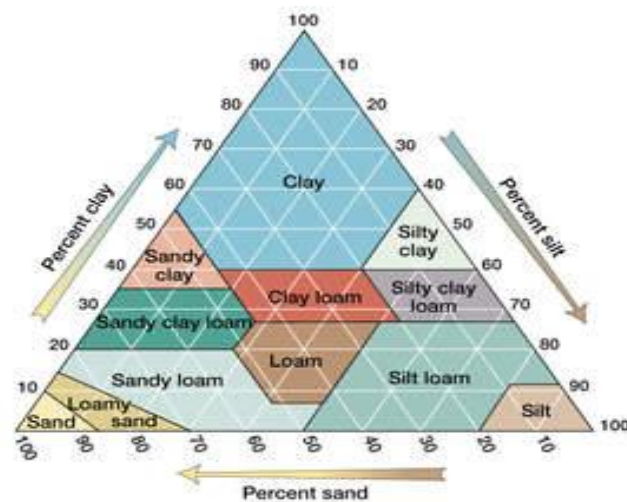


Fig-5

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 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 (Davis, 1943): $Y = at^{\alpha} + b$
(3)

The values a, α and b are three characteristic constants which were be obtained by the procedures suggested by Davis (1943) as follows for locations 1 and 2 respectively. Location 1: $a = 0.97$, $b = -2.90$, and $\alpha = 1.22$ given a relationship $Y = 0.97t^{1.22} - 2.90$. Location 2: $a = 0.25$, $b = 2.00$, $\alpha = 1.22$ given relationship $Y = 0.25t^{1.22} - 2.00$

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=1000g			

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Table 5: 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	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 =1000g			

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Table 6: 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	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 =800g			

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Table 7: Sieve analysis for soil sample at depth 30cm for location 2

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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 =1000g			

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126 Table 8: Sieve analysis for soil sample at depth 60cm for location 2

	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

127 Table 9: Particle size analysis of soil at different depths and locations.

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

128 Table 10: Textual classes of the above soil

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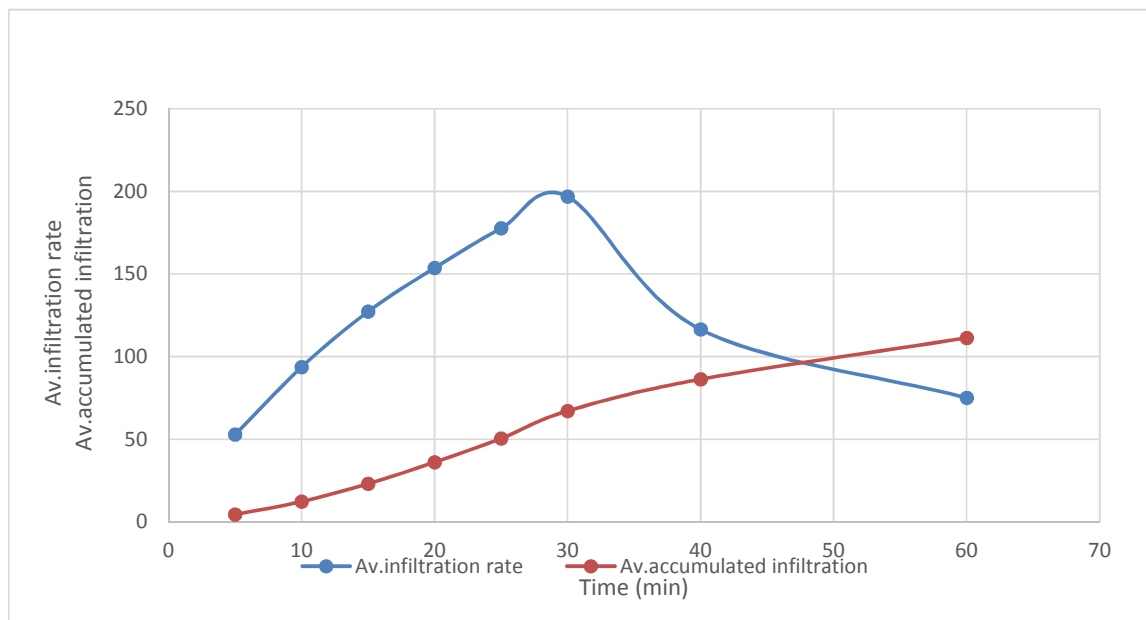
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Time (mins)	Depth after filling (cm)	Depth before refilling (cm)	Depth of water infiltrated (cm)	Average infiltration rate (cm/hr)	Average accumulated infiltration
0	30	0.0	0.0	0.0	0
5	30	25.6	4.4	52.8	4.4
10	30	22.2	7.8	93.6	12.2
15	30	19.4	10.6	127.2	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

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133 Table 11: Infiltration readings for location 1

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136 Fig 14: Graph of infiltration rate for location 1

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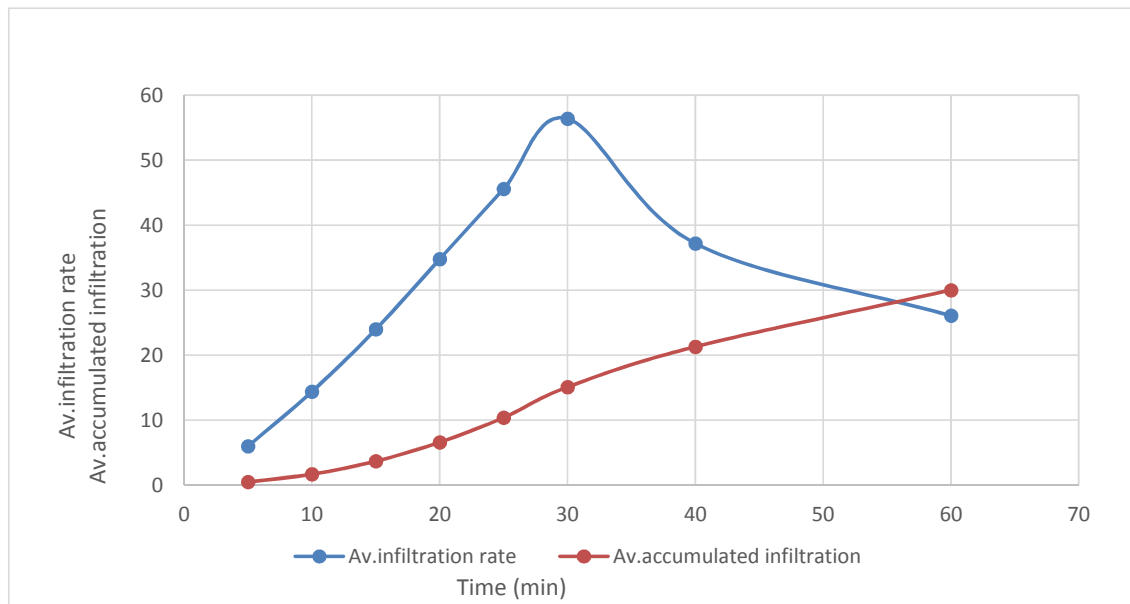
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Time (mins)	Depth after filling (cm)	Depth before refilling (cm)	Depth of water infiltrated (cm)	Average infiltration rate (cm/hr)	Average accumulated infiltration
0	30	0.0	0.0	0.0	0.0
5	30	29.5	0.5	6.0	0.5
10	30	28.8	1.2	14.4	1.7
15	30	28.0	2.0	24.0	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

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140 Table 12: Infiltration readings for location 2

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143 Fig 15: Graph of infiltration rate for location 2

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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 11 and 12, the infiltration rate (cm/hr) for the two points on the field were initially high and decreases sharply with time.

Similarly, Fig.14 and Fig.15 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.

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 9, the soil can be texturally classified as sandy clay and clay as shown in table 10.

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

$Y = 0.97t^{1.22} - 2.9$ and $Y = 0.25t^{1.22} - 2.0$. The result shows that the intake rate of soil depends on the texture of soil, 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 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.

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