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Original Article

Aboufayed Method for Measuring Infiltration Rates and Identification of Profile Features Influencing Them

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Abstract

Aboufayed method is a simple procedure for measuring infiltration rate using single ring infiltrometers consisting of 50 cm long stainless steel tubes of 11 cm diameter. Water was supplied to the infiltrometer rings from glass reservoir bottles (approximate volume - 1100 cm^3) to which clear plastic rulers had been attached. The bottles were fitted with narrow-bore delivery tubes of a length that ensured the establishing of a constant head inside the infiltrometer rings. The developed procedure for measuring infiltration is simple and practical and permit measurement of the infiltration rate at different depths simultaneously. It could be carried out under light rainfall events because the infiltrometer ring is covered by the reservoir bottle and therefore not exposed to the atmosphere. It was found to be adaptable for use under different land - use in different geographic regions.

Key words: Infiltration, Infiltration rate, Infiltration rate measurement.

Introduction

The phenomenon of infiltration is a very important element in the hydrologic cycle, in that it determines whether water reaching the soil surface at a particular place, enters the soil at that place, moves to another place before entering the soil, or becomes surface water in streams, rivers, lakes, seas or oceans. Infiltration rate and surface topography control the occurrence of these processes, while infiltration rate itself is determined by soil characteristics. In coarse textured and/or well-structured soils, infiltration rates are high and overland flow only arises under extreme rainfall intensities or durations. In contrast, the infiltration rates for fine textured and/or poorly structured soils can be low enough to make overland flow a common occurrence. While layers with low porosities and small pore size at any depth can influence infiltration, such layers have greater effects when they occur at the soil surface since their effects are then immediate. Such is the situation when the soil surface structure breaks down due to the impact of falling water drops, compaction due to traffic or the clogging of soil pores by suspended solids (organic or inorganic) that accumulate on the surface. Taket and Person (1965) reported that crusts, only l to 3 mm thick, formed subsequent to structural breakdown by raindrop impact were 5 times less permeable than the underlying soil, effectively sealing the surface.

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In the unsaturated (vadose) zone of soil the preferred path of movement of moisture is vertical, by percolation, toward the saturated zone. Infiltration is the passage of water through the soil surface, and the infiltration rate (i) is the velocity with which it occurs. The rate may depend on precipitation/irrigation intensity in which case it is said to be supply controlled, or it may depend on the physical properties of the soil (porosity, grain and pore size, soil moisture, etc) in which case it is profile controlled. Infiltrability is the term used to describe the infiltration rate when the supply of water is not limiting. A dry soil has a high initial in-filterability that declines when the soil is wetted, eventually falling to a more or less steady rate referred to as the final infiltrability- a rate that is close to the saturated hydraulic conductivity of the soil. Since the latter property is closely related to porosity, pore size distribution and pore continuity, properties that are greatly influenced by soil use and management, useful measurement of infiltration rates can only be accomplished under field condition.

Soil compaction occurs when soil particles are pressed together, reducing both the size and volume of pores. Compacted soil layers have reduced rates of saturated hydraulic conductivity and hence reduced rates of both water infiltration and drainage. Soil is rarely homogenous vertically and as a consequence infiltrability is often influenced by the porosities and pore—size distributions of layers within the soil profile. Identification of restricting layers is important in interpreting infiltration measurements and predicting their influence on soil hydrology. There may be value for measuring and comparing the infiltration rate at different depths within a soil profile.

Layering, or horizonation, that influences or determines porosity and pore-size distribution in natural soil profiles, is often further affected by agriculture and other human activities with consequences for the preferred path of movement of soil moisture and its dissolved and suspended constituents. Thus, surface runoff; and/or interflow (lateral subsurface flow) may be quite different than would be predicted by the natural profile characteristics.

The compaction could also be by animal treading in winter conditions when soils are moist and more susceptible to compaction and received relatively little attention. The development of new pasture species and cultivars and intensive fertilization have resulted in increased animal stocking rates which in turn cause greater compaction forces on the soil, increase bulk densities and reduce pore space (Langland and Bennett, 1973). Significant losses of pores > 60µm were reported by a number of authors (Gradwell, 1960; Climo and Richardson, 1984; Greenwood and McNamara, 1992) on Pukemutu and Waikiwi soils under intensive sheep winter grazing systems reported that macro porosity (macropores > 30µm) in the 0-5 cm soil depth was significantly reduced from 16.4% to 12.1%. Since macro pores are the primary pathway for water movement in wet soil so the reduction in these can restrict the rate of water flow (infiltration rate) and nutrients transmission to the root zone and this could encourage the overland flow and pollutants transports toward inland waters. By measuring the infiltration rate at the soil surface and at other depths below, it may be possible to predict the risk of runoff and/or interflow from precipitation events and the associated risk of off-site contamination of inland water resources by suspended soil or solutes.

The vertical water flow (infiltration rate) could be restricted at the interface of A/B or B/C horizons diverting the flow laterally as interflow and treated as a component of subsoil hydrology. When interflow occurs in the pollutant rich layer below the soil surface and over the interface of A/B horizons, it may be the most important water flow type in respect of pollutant transport towards inland waters and their eutrophication. There is a need to measure the infiltration rate at different depths where the change in soil horizons and compaction layers expected under different soil moisture content condition, to be able to predict risk of off-site contamination through overland and interflow water.

The simplest way of measuring the infiltration rate is using a single ring infiltrometer, which is flooded with water and the rate at which water moves into the ground is measured. Many different sizes of ring have been used and there is a huge amount of literature on the use of single ring infiltrometer under constant and falling head in the measurement of infiltration rate. In an example of the latest ones ponded infiltration rates were measured with a single-ring infiltrometer designed to pond water on the soil surface to a constant height of 5 cm, where the inner diameter of the metal ring was 10.2 cm with the edge pressed into soil surface by about 10 mm (Pricksat ***et al.,*** 1992).

The objective of this experiment was to develop a simple means of measuring infiltration rates at different depths, with the overall purpose of using it to help characterize the hydrology of the Hill Field at the UCD Research Farm at Lyons Estate. The procedure was developed and assessed at sites in the semi-arid region of Libya as well as in Ireland.

Material And Methods

Study areas location:

As farm tractors and field equipment become larger and heavier, there is growing concern from soil compaction and formation of impermeable layers at depth within the soil profile over the whole world. In humid region in Ireland an over three years study in the effect of cattle treading in winter and early spring on soil physical properties in the UCD farm research station in Lyon estate shows increase in soil bulk density and surface roughness and decrease aggregate stability and soil penetrability (Mullen ***et al.,*** 1974). Therefore, Hillfield in UCD farm research station in Lyon estate were chosen to study impact of animal treading on top 5 cm and soil layers below soil surface on infiltration rate. Therefore infiltration rate was measured at soil surface and at 5, 15 and 30 cm below it. In semi arid region in Libya continuous ploughing or disking at the same depth will cause serious tillage pans just below the depth of blowing layer in tillage soils. Such tillage pans may not have a significant effect on crop production but can restrict the vertical water flow (infiltration rate) and divert the flow laterally as interflow. This is a common occurrence in the semiarid regions of Libya, particularly under dry farming condition in the north western zone (Jebel Nefusa upland), where continuous ploughing (yearly) at the same depth has resulted in serious tillage pans. Secretariat of Agriculture, Reclamation and land development, (1980) soil study showed that the predominated soils in the area are Reddish Brown soil, Saillatic Cinommon soil and Lithosols, or according to the American classification, Entisols, Inceptisols and Aridisols. Therefore the proposed method for infiltration measurement were made in the surface and at the bottom of the ploughing layer for the three dominated soil within Gharian area.

Infiltration measurement method:

Infiltration rates were measured using single ring infiltrometers consisting of 50 cm long stainless steel tubes of 11 cm diameter. Water was supplied to the infiltrometer rings from glass reservoir bottles (approximate volume - 1100 cm^3) to which clear plastic rulers had been attached. The bottles were fitted with narrow-bore delivery tubes of a length that ensured a constant water level inside the infiltrometer rings when set up as shown in Plate 1.

Plate.1 Items used in making single ring intiltrometer measurements.

Delivery of water from the reservoir bottles was calibrated by measuring the volume collected as a function of water depth on the attached ruler (Table 1).

The relationship between the depth of water in the bottle and the volume delivered was established by regression analysis (Fig 1). In the field the steel pipes were embedded to a depth of approximately 2 cm, either in the soil surface, or in the base of a hole excavated to. In the Hill Field, pipes were embedded in the surface and at 5, 15 and 30 cm below it, as shown in plate 2.

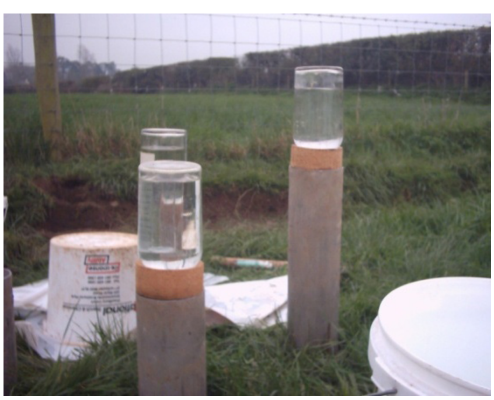

Plate 2. Developed Procedure during measurement in Hill Field.

In the Libyan soils, pipes were embedded in the surface and at the bottom of the plough layer. After filling the reservoir bottles with water, and installing their delivery tubes the bottles were upended and inserted into the steel pipes and supported on a collar consisting of a large cork ring. Depths of water in the reservoirs were recorded as a function of time.

After the initial delivery to establish a constant head, the volumes of water infiltrated were evaluated from the regression equation given in Fig (1). Infiltration rates were calculated from dividing the volume estimates by the cross section area of the pipe (95 cm^2) and by time.

Table 1. Calibration of delivery reservoirs (Bottles, Bi) volume of water versus depth.

Depth	Volume delivered from bottles(cm^3)				
(cm)	B_1	B_2	B_3	B_4	Mean
0-1	54	54	54	56	54
1-2	66	66	66	70	67
2-3	66	68	68	70	68
3-4	68	68	68	70	68
4-5	68	68	68	72	69
5-6	70	70	70	72	70
6-7	70	70	70	74	71
7-8	72	72	72	74	72
8-9	74	74	74	74	74
9-10	74	74	74	76	74
10- 1	74	74	74	76	74
11-12	76	76	76	78	76
12-13	76	76	76	78	76
13+	210	202	198	169	201

Statistical analysis:

Since the experiment aimed to study the effect of season on the infiltration rate at three sites, the top, middle and bottom of Hill Field, and at different depths (5, l5 and 30 cm) in addition to soil surface itself it was analysed as a 2x3x4 factorial design experiment. The 24 treatments were replicated three times. The design of the Libyan experiment was a 3x2 factorial with three soil types and two depths, namely, at the surface and below ploughing layer.

Results And Discussion

Bottle calibration:

Table.1 shows the volume delivered from each bottle used in measuring infiltration for each cm increment for each bottle used. Due to the curvature change in the shape of bottles after 13 cm the whole of volume from that point was measured. Mean volume delivered by the four bottle used in measurement was also estimated.

The relation between the mean water volumes delivered and scale depth was very highly correlated (r=0.99); and the coefficient of determination (r^2=0.99). The regression equation was V= 71.8 d - 27.4. Where V is the volume of water delivered, and d is the depth of water infiltrated from scale attached on the bottle as in the Fig (1).

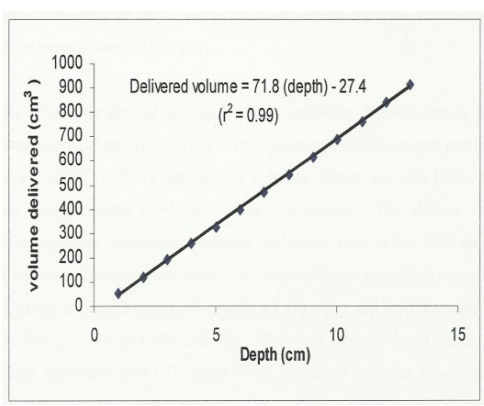

Figure 1. Relationship between volume of water and depth from ruler attached on bottle.

Infiltration rate:

The developed procedure for measuring infiltration rate experiment was carried out during the last three days in March 2005 when soil conditions were wet, and on 10th July 2005 when they were dry. Because the UCD Research Farm lies in the lowest rainfall area in Ireland, and because soils are normally at their driest in July, very high rates of infiltration were recorded. Indeed, under such dry conditions the whole volume of water in the bottles was infiltrated within the first l0 minutes at most depths. To simplify and standardize the measurements, comparison between the wet and dry soil conditions, at different depths, was made on the basis of the first l0 minutes of measurements only. Values for all the depths, under the different seasonal conditions were obtained in this way.

Analysis of variance showed that the three way interaction between season, site and depth was not significant (P>0.05). The only significant interaction was that between season and depth (P<0.05). Interactions between season and site (P>0.05), and between site and depth (P>0.05) were not significant. The absence of these interactions justifies comparisons between infiltration rates at the different depths within the two seasons. These show that rates differed significantly at different depths, except at depth 30 cm (iw=0.43 and id=l.49) where soil moisture content were similar (SMCw=2l.5% and SMCd=26.4%). Statistical analysis shows that the depth factor was significant (P<0.05), which could be due to variation in soil moisture content.

The results show that the mean infiltration rate was high at depth 5 and 15 cm (4.57 and 3.76 cm/10min). Both these depths were within the plough layer and had almost the same moisture content. Lower values were recorded at the surface, especially in winter time. This could be related to the high MC% which were recorded in the top 5 cm, clogging of pores by organic material, or compaction of wet soil by sheep, which grazed the field at the time of measurement, or to a combination of all these factors. Infiltration rates were low at depth 30cm, which was below the plough layer, and at the interface of the A and B horizons (0.43 and 1.49 cm/10min). According to the least significant difference test there was no difference between infiltration rates at the soil surface and at depth 30 cm (i0 v i30, P>0.05), but the difference between rates at the surface and at 5cm depth was significant (i0 v i5, P<0.05). This suggests that the top 5cm was a restricting layer to water infiltration. The fact that infiltration was higher below the surface confirms the importance of identifying restricting soil layers in interpreting infiltration data as pointed out by Bouwer (2002). While the difference in rates between the surface and depth 15cm was not significant (i0 v i15, P>0.05), there was a significant difference between rate of infiltration at depth 5cm and at depth 30cm (i5 v i30, P<0.05). Rates were not significantly different between 5 and 15 cm depths (i5 v i15, P>0.05), but significant between 15 and 30 cm (i15 v i30, P<0.05) as shown in the Table 2.

The main effect of soil moisture conditions (season) was highly significant (P<0.001). The soil moisture contents for the days of infiltration measurement were the top 0-5cm soil layer and the other underlying layers (5-15, 15-30 and 30+ cm) as shown in the Table 3.

Due to the significant interaction between season and the depth, the least significant difference test (LSD) was used to compare between infiltration rates at the same depth within the different seasons. The difference between seasons within the same depths is significant except at depth 30 cm as shown in Fig (2). The LSD test shows that in the wet season infiltration rates were not significantly different at any of the depths. They were not significantly different in the dry season either at the surface and at depth 30 cm, nor at depth 5 and 15cm depths.

Table 2. Mean infiltration rate (first 10 min) at different depths in 3 sites in the Hill Field under wet (winter) and dry (summer) conditions

		Depth (cm)				Site mean	Season Mean
Season	Site	0	5	15	30		
	Top	0.14	0.97	0.97	0.66	0.56	
Wet	Mid	0.10	1.81	1.47	0.29	0.92	0.56
	Bottom	0.10	0.20	0.16	0.35	0.21	
Mean of depths/winter		0.11a	0.91a	0.78a	0.43a		
	Top	6.61	7.08	4.67	2.90	5.32	
Dry	Mid	4.04	11.3	6.90	2.25	5.3	5.12
	Bottom	0.73	5.51	6.20	2.50	3.91	
Mean of depths/summer		3.79b	7.96c	6.16c	2.55a		
Overall mean of depths		1.95e	4.44d	3.47d	1.49c		

Table 3 Mean gravimetric moisture content at different depths in 3 sites at the time of infiltration measurement in the Hill Field.

		Depth (cm)				Site mean	Season Mean
Season	Site	0-5	5-15	15-30	30+		
	Top	60.0 0.14	28.0	21.4	13.1	30.6	
Wet	Mid	64.0	32.8	27.3	25.6	37.4	36.5
	Bottom	68.2	40.5	31.6	25.9	41.6	
Mean of depths/winter		64.1	33.8	26.8	21.5		
	Top	37.6	24.1	23.0	15.1	25.0	
Dry	Mid	42.3	20.4	19.5	18.2	25.1	26.4
	Bottom	43.3	27.9	23.4	22.3	29.2	
Mean of depths/summer		24.1	22.0	18.5	26.4		
Overall mean of depths		52.6	29.0	24.4	20.0		

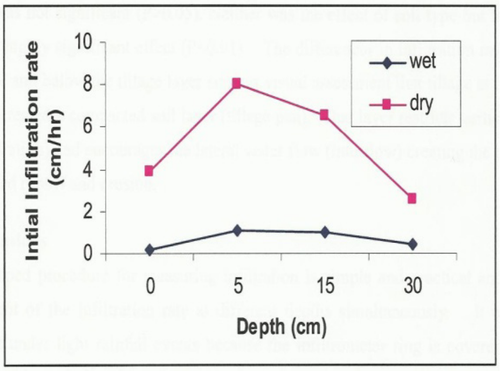

Figure 2. Mean initial infiltration rates (within first l0 min) at different depths under wet and dry season.

These results show that there was variation in infiltration rates between summer and winter conditions. They also show that the top 5 cm surface soil layer had a lower infiltration rate than the underlying layer despite having a higher porosity (62%). Lower infiltration rates at 30 cm depth under both wet and dry conditions suggests that interflow could occur at the interface of A/B horizons. Other workers, including, Cox and McFarlane (1995), Fleming and Cox (1998) and Stevens ***et al.,*** (1999) have reported that interflow can occur in the pollutant rich layer below the soil surface or at the interface of the A/B horizon.

The infiltration measurements in Libya were carried out to test the procedure under contrasting conditions and to assess its capacity to identify layers within soil profiles that restrict water movement. The results obtained are shown in Table 4.

Table 4 Mean infiltration rate for 3 Libyan soils at the surface and below the tillage layer.

Depth (cm)	Soil Type		
	Entisols	Inceptisols	Aridisols
0cm	6.7a	10.3a	7.6a
15-25cm	1.7b	0.3b	0.56b

Statistical analysis for the Libyan results showed that the interaction between depth and soil type was not significant (P>0.05). Neither was the effect of soil type but the depth factor was highly significant effect (P<0.01). The differences in infiltration rates at the soil surface and below the tillage layer support visual assessment that tillage at the same depth had created a compacted soil layer (tillage pan). That layer restricts vertical water flow (infiltration) and encourages the lateral water flow (interflow) creating the potential for increased runoff and erosion.

Conclusions

The developed method for measuring infiltration is simple and practical and allows measurement of the infiltration rate at different depths simultaneously. It could be carried out under light rainfall events because the infiltrometer ring is covered by the reservoir bottle and therefore not exposed to the atmosphere. It was found to be adaptable for use under different land-use in different geographic regions.Under Irish conditions there were differences in infiltration rates between wet and dry seasonal conditions at different soil depths down to 30 cm. This was due to variation in soil moisture content down to that depth where soil moisture content was almost the same in both summer and winter. Although the top 5 cm layer had low bulk density and high porosity its infiltration rate was low compared to the underlying soil layers at 5 and 15 cm. Hence, the measurement procedure is a practical way of identifying restricting layers in relation to water flow.

The relatively low surface infiltration may have been due to the higher MC% associated with higher organic matter at the surface, or clogging of pores with organic matter, or treading by grazing sheep stocking on wet soil resulting in the closure of macro soil pores which are the primary pathway of infiltrated water and nutrients transmission to the root zone. The overall effect is to encourage overland flow and pollutant transport toward inland waters bodies in winter, whereas there is little or no risk of overland flow in summer due to infiltration excess. The low infiltration rate at depth 30 cm restricts vertical flow and encourages lateral flow downslope as interflow even in summertime because the difference in moisture content is not significant at that depth.

The procedure effectively identified that in Libyan soils ploughing at the same depth caused a hard, dense pan layer that restricted vertical flow and encouraged lateral flow and increased the potential for surface runoff and erosion. Therefore, the simple infiltration measurement technique and its suitability for measurement at different depths makes it a practical and useful means of identifying restricting layers within soil profiles. Knowledge of the presence of these layers should give a better understanding and prediction of the conditions under which overland and interflow are likely to occur in the field.

References

1. Climo, W., and Richardson, M. (1984). Factors affecting the susceptibility of threesoils in the Maanawatu to stock treading. New Zealand Journal of Agricultural Research. 27:247-253.
2. Cox, J .W. and McFarlane, D. J. (1995) The causes of water logging in shallow soils and their drainage in south western Australia. Journal of Hydrology 167; 175-194.
3. Fleming, N.K. and Cox, J .W.(1998). Chemicl losses off dairy catclnrnents located on texture-contrast soil: carbon, phosphorus, sulphur, and other chemicals. Australian Journal of Soil Research 36; 979-995.
4. Gradwell, M. W (1965) Soil physical conditions of winter and the growth of ryegrass plants. New Zealand Journal of Agricultural Research 8:238-269.
5. Greenwood, P.B., and McNamara, R.M. (1992). An analysis of the physical condition of two intensively grazed Southland soils. Proceedings of the New Zealand Grassland Association. 54; 71-75.
6. Langland, J, P., and Bennett, I. L. (1973). Stocking intensity and pastoral production.I. Changes in the soil and vegetation of a sown pasture grazed by sheep at different stocking rates. Journal of Agricultural Science, Cambridge. 81; 193-204.
7. Mullen, G. J., Jelley, R. M. and McAleese, D. M. (1974). Effect of animal treading on soil properties and pasture production. Ir. J Agric. Res.13: 171- 180.
8. Prieksat, M,A., Znkeny, M. D. and Kaspar, T.C. (1992) Design for an automated self-regulating ponded infiltrometer .Soil Sci. Soc. Am. J. 56; 1409-1411.
9. Stevens, D. P., Cox, J. W. and Chittleborough, D.J. (1999). Pathways of phosphorus, nitrogen and carbon movement over and through texturally differential soils. South Australia. Australian Journal of Soil Research. 37; 679-693.
10. Soil ecological expedition v/o (Selkozprom Export) USSR. (1980) Soil studies in the western zone of libya. Secretariat for Agriculture Reclamation and land Development. Tripoli.
11. Taket, J. L., and Person, R.W. (1965) Some characteristics of soil crusts formed by simulated rainfall. Soil Sci.99; 407-413.