Determination of Soil Unsaturated Hydraulic Conductivity using the AIM Automatic Infiltration Meter

Introduction

Unsaturated hydraulic conductivity refers to a measure of soil's water-retaining ability when soil pore space is not saturated with water. Measurement of unsaturated conductivity with the AIM Automatic Infiltration Meter is achieved by maintaining a small negative pressure of the water as it moves out of a highly permeable membrane/infiltromenter disc into the soil. By doing so, water does not enter the large cracks or wormholes but instead infiltrates into the true soil matrix.

Photo 1. The AIM Automatic Infiltration Meter consists of a tension infiltrometer, pressure transducer and data logger.

Knowledge of the soils' hydraulic properties is important in many applications including in: a) designing of sustainable irrigation and effluent disposal schemes, b) assessment and management of surface run-off and erosion risks, c) evaluation of movement of pesticides and nutrients through the soil, d) characterisation of soil structure and d) mine site management among others.

The AIM has been designed to measure unsaturated flow of water into the soil rapidly, easily and with great precision. To this end, the AIM has been uniquely designed to automate the collection of data. The automated collection of data relieves researchers of having to manually monitor with a stop watch, the water level in the supply tower over fixed time and record the data on a notepad. Automated collection of data is achieved through connection of a differential pressure transducer near the bottom of the infiltrometer and is inserted in the tubing between the top of the water tower and the bottom of the water tower. The fitting of a pressure transducer also reduces the effects of air bubble induced noise therefore increasing measurement precision. The transducer is then connected to a data logger via a break out box supplied with the system.

Principle: Three dimensional (3-D flow)

Wooding's (1968) equation for steady state unconfined infiltration rates was used in the calculation of unsaturated hydraulic conductivities. Briefly, the flow of water underneath the disc is axisymmetric and three-dimensional. To describe the three-dimensional flow underneath the disc, Wooding (1968) proposed the following algebraic approximation of steady-state unconfined infiltration rates into soil from a circular source of radius r (cm):

1) $$Q = \pi r^2 K \left[1 + \frac{4}{\pi r \alpha} \right]$$

Where Q is the volume of water entering the soil per unit time ($cm^3\ hr^{-1}$), K ($cm\ hr^{-1}$) is the hydraulic conductivity, is a parameter, and h (cm) is the matric potential or tension at the source. The value of h will normally be negative corresponding to a tension at the water source; however, it can also be zero. lt is assumed that the unsaturated hydraulic conductivity of soil varies with matric potential h (cm) as proposed by Gardner (1958).

2) $$K(h) = K_{sat} \exp(\alpha h)$$

Where Ksat is the saturated hydraulic conductivity (cm hr $^{-1}$). Although (1) can be used for unsaturated and ponded infiltration, (2) applies only for h <= 0. With the tension infiltrometer one measures the volume of water (Q) entering the soil per unit time through the porous membrane at a minimum of two tensions, e.g. h1 and h2.

For unsaturated soil, and upon replacing K in (1) with Ksat exp (αh), and after substitution of h1 and h2, respectively for h in the combined equation one obtains:

3) $$Q(h_1) = \pi r^2 K_{sat} \exp(\alpha h_1) \left[1 + \frac{4}{\pi r \alpha} \right]$$

4) $$Q(h_2) = \pi r^2 K_{sat} \exp(\alpha h_2) \left[1 + \frac{4}{\pi r \alpha} \right]$$

Dividing (4) by (3) and solving for α yields:

5) $$\alpha = \frac{\ln[Q(h_2)/Q(h_1)]}{h_2 - h_1}$$

Because Q(h1) and Q(h2) are measured, and h1 and h2 are known, α can be computed directly from (5). With α known, one can now calculate Ksat from (3) or (4). Once Ksat and α are known, their values can be substituted in (2), yielding the relationship between hydraulic conductivity and tension for the soil. This relationship can be used to calculate the unsaturated conductivity at the desired tensions. Note however, that the Ksat value obtained with the above method may be different from the value obtained for Ksat if measured directly. One reason is that the relationship of K(h) versus h is often not linear near h=0.

This application note examines the measurement of soil unsaturated hydraulic conductivity in a clay soil. The measurement procedure including field set up of AIM, data collection and analysis are discussed below.

Measurement procedure

Field set up

a) The soil surface where a measurement was to be made was cleaned of debris and levelled without disturbing the surface structure;
b) A ring of 20 cm (comes with the AIM system) was placed on the levelled surface. Fine and moist sand was evenly spread on the soil within the ring. The sand was levelled by means of a ruler. The fine moist sand is crucial to ensure a good and level contact between the membrane/infiltrometer disc of the tension-infiltrometer;
c) The AIM was set up following procedures detailed in the AIM manual (refer to manual http://www.ictinternational.com/products/aim1/aim-automatic-infiltration-meter/);
d) The AIM was then pushed vertically onto the sand with some degree of force (bring careful not to disrupt the membrane) to give good contact; and
e) Any excess sand around the circumference of the disc was removed by running a finger through. This ensures the contact sand has exactly the same radius as the membrane/disc infiltrometer.

Data collection

a) The tension to be maintained at the bottom of the membrane/disc infiltrometer was set by beginning with the highest tension. In this study, the measurement runs were conducted by successive determinations at two tensions of -10 and -15 cm. Consequently, we began taking measurements from the highest tension, which was done by raising the tube in the bubble tower to -15 cm.
b) It is worth noting that at the highest tension, the hydraulic conductivity is the lowest, and thus it may take some time for the AIM to start "bubbling".
c) The data set from the infiltration measurement is presented in Table 1.
d) A plot of cumulative infiltration versus time is presented in Figure 1 and 2.

Table 1: Tension infiltrometer data from a clay soil. Radius of the disc =10 cm and the inside diameter of the water supply tube of the tension infiltrometer =4.45

	Supply potential (-15 cm)			Supply potential (-10 cm)		
Time (hr)	Scale reading (h) (cm)	Infiltration (cm)	Cumulative Infiltration (cm)	Scale reading (h) (cm)	Infiltration (cm)	Cumulative Infiltration (cm)
0.00	0	0	0	0.00	5.41	5.41
0.08	7.44	1.47	1.47	27.30	1.78	7.19
0.17	8.71	0.25	1.72	36.29	2.23	9.41
0.25	9.79	0.21	1.94	47.53	2.54	11.95
0.33	10.64	0.17	2.11	60.34	2.62	14.57
0.42	11.70	0.21	2.32	73.57	1.27	15.84
0.50	12.47	0.15	2.47			
0.58	13.07	0.12	2.59			
0.67	13.75	0.13	2.72			
0.75	14.49	0.15	2.87			
0.83	15.16	0.13	3.00			
0.92	15.69	0.11	3.11			
1.00	16.37	0.13	3.24			
1.08	16.69	0.06	3.31			
1.17	17.45	0.15	3.46			
1.25	18.07	0.12	3.58			
1.33	18.66	0.12	3.69			
1.42	18.84	0.04	3.73			
1.50	19.29	0.09	3.82			
1.58	20.19	0.18	4.00			
1.67	20.71	0.10	4.10			
1.75	20.95	0.05	4.15			
1.83	21.50	0.11	4.26			
1.92	21.85	0.07	4.33			
2.00	22.33	0.10	4.42			
2.08	22.61	0.06	4.48			
2.17	23.02	0.08	4.56			
2.25	23.34	0.06	4.62			
2.33	23.41	0.02	4.64			
2.42	23.52	0.02	4.66			
2.50	24.23	0.14	4.80			
2.58	24.56	0.06	4.86			
2.67	24.73	0.03	4.90			
2.75	25.28	0.11	5.01			
2.83	25.40	0.02	5.03			
2.92	25.47	0.01	5.04			
3.00	25.74	0.05	5.10			
3.08	26.03	0.06	5.15			
3.17	26.21	0.04	5.19			
3.25	26.47	0.05	5.24			
3.33	26.69	0.04	5.29			
3.42	26.81	0.02	5.31			
3.50	26.94	0.02	5.33			

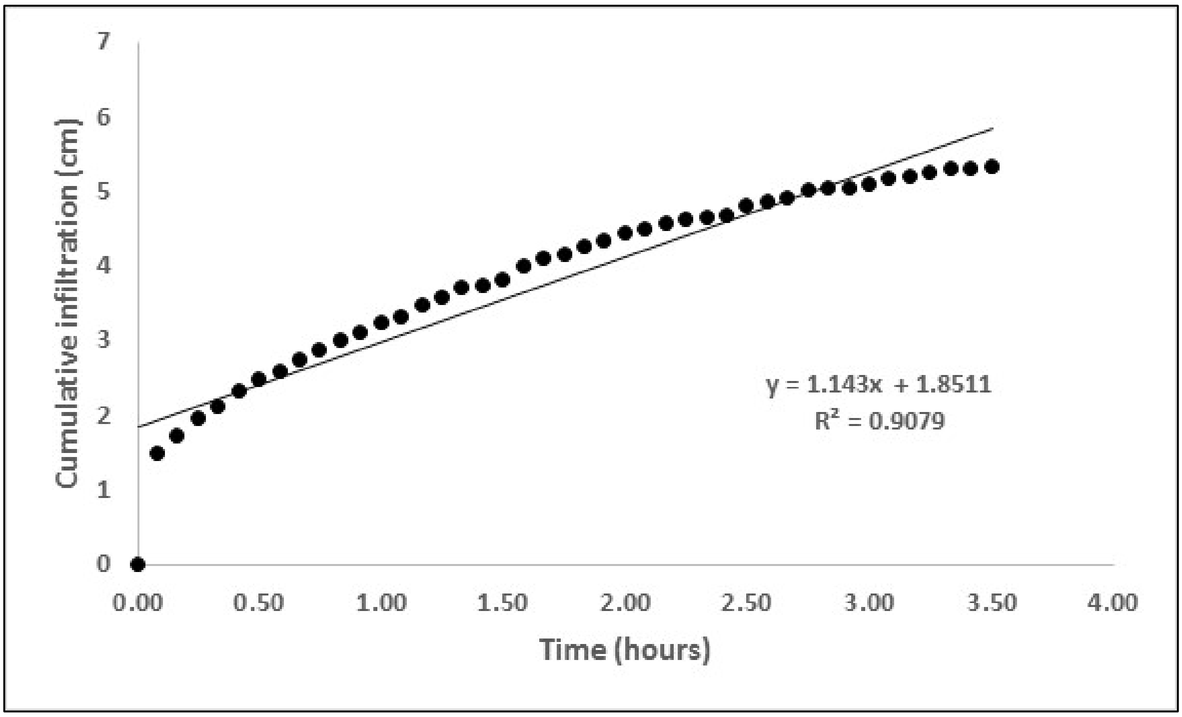

Figure 1: Cumulative infiltration versus time for -15 cm suction in tension infiltrometer

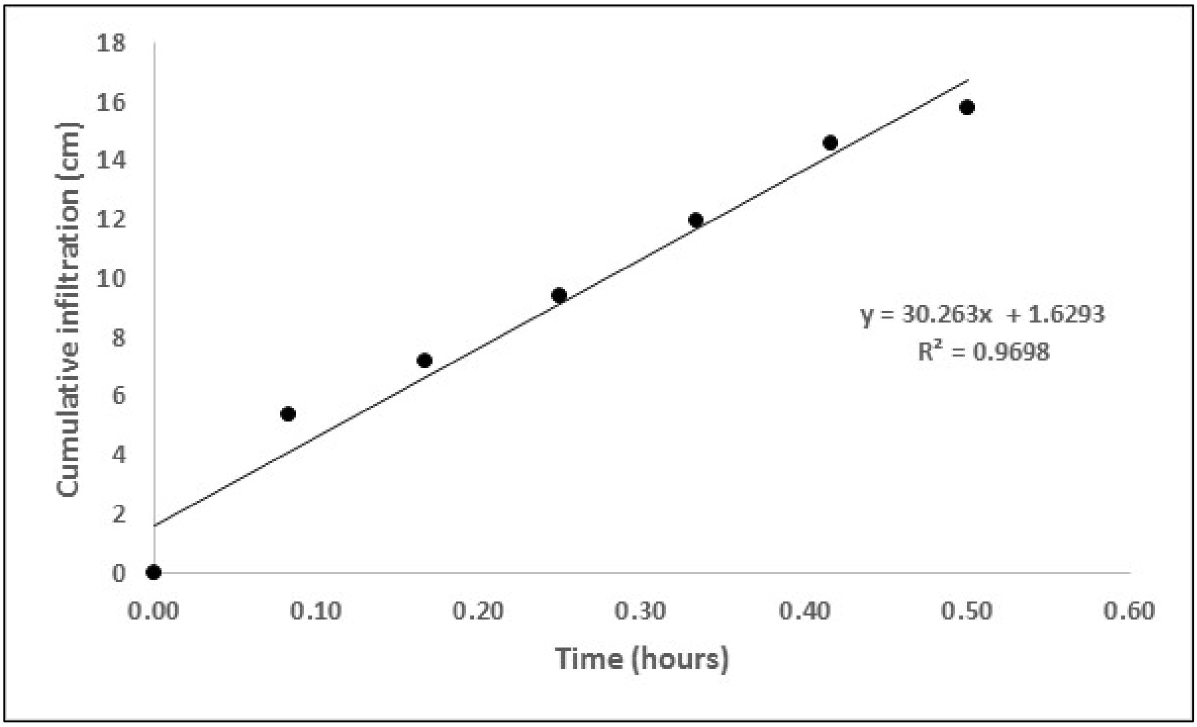

Figure 2: Cumulative infiltration versus time for -10 cm suction in tension infiltrometer

Data analysis

The steady state flow rate was calculated using the average flow rate when steady state was reached. The steady state was determined by taking eight (8) to ten (10) consecutive readings that showed about the same infiltration rate, hence steady state. The steady-state flows calculated from Table 1 for -15 cm and -10 cm were 0.60 cm/hr and 31 cm/hr respectively.

Accordingly, Wooding's (1968) equations for steady state was used in the calculation of unsaturated hydraulic conductivities as described above. Thus based on the above data, the unsaturated hydraulic conductivities at the two tensions of -15 and -10 cm were:

h=-10cm,   K (-10) = 1.32 cm/hour

h=-15cm,   K (-15) =0.026 cm/hour

References

Gardner, W.R. Some steady-state solutions of the unsaturated moisture flow with application to evaporation from a water table. 1958. Soil Sci. 85: 228-232.

Wooding, R.A. Steady infiltration from a shallow circular pond. 1968. Water Resour. Res. 4: 1259-1273.