DETERMINATION OF UNSATURATED HYDRAULIC CONDUCTIVITY OF ALFISOL SOIL IN GUINEA SAVANNAH OF NORTHERN NIGERIA

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Abstract

The hydraulic conductivity of soil measures the ease at which water moves through the soil by determining the flux density of water passing through the soil. The estimation of hydraulic conductivity indicates how fluids flow through a substance and thus determine the water balance in the soil profile. The trend lines of hydraulic conductivity with its trend regression r = 0.9548 and 0.9120 respectively and its unsaturated hydraulic conductivity was found to be 0.2640.

Keywords: *Capacitance probe, diviner 2000, volumetric water contents*

Introduction

The hydraulic conductivity of a soil is a measure of the ease at which water moves through the soil. The soil-water transmission properties of a soil are measured by its hydraulic or proportionality constant. The estimation of hydraulic conductivity is essential for the determination of soil water fluxes and hence e.g. water balance in the soil profile (Vose, 1980). Hydraulic conductivity indicates how well fluid will flow through a substance, e.g. rock or gravel. Accurate soil water content measurements are required for measuring crop water use and of the hydraulic characteristics of soils. Soil hydraulic conductivity () and water content () are key parameters for crop growth, irrigation, drainage, and modeling water flow and chemical transport through the soil. A sound irrigation management program considers the soil water holding capacity and hydraulic conductivity to determine the timing and amount of irrigation water to be applied (Faers *et al.*, 2000).

A capacitance probe with trade name *Diviner 2000* was used for this experiment, which took place at the farm site of Centre for Energy Research and Training (CERT), Ahmadu Bello University, Zaria. The method utilizes the high dielectric constant of water compare to soil and air to determine water content of the soil. A pair of electrodes or electrical plates (which can be parallel spikes or circular metal rings) was used as capacitor. When activated, the soil-water-air matrix around the PVC tube forms the dielectric of a capacitor and completes the oscillating circuit. Changes in the resonant frequency of the circuit depend on changes in the capacitance of the soil access tube system (Dean *et al.*, 1987; Paltineau and Starr, 1997; Fares and Alva, 1999; Fares and Alva, 2000; Heng *et al.*, 2002).

Material and Methods Field site and experimental procedures

In determining the unsaturated hydraulic conductivity of soil, five plots of 5.0 x 4.0 m were prepared with a PVC access tube installed in each plot. A PVC access tube (5.1 cm of internal diameter (ID) and 5.5 cm of outer diameter (OD)) was installed to a depth not less than 30 cm in each plot using hand held auger. The furrows of the ridges were ponded with 120 litres of water each. The soil surface was covered with grass to prevent water loss by evaporation or water input by rain. Soil water content was measured at 10, 20 and 30 cm soil depths over a 5 days period. The readings were taken twice daily, one at about 9.00 am and the other at about 3.00 pm. This was done with an instrument, a capacitance probe with a trade name called *Diviner 2000*.The *Diviner 2000* is a hand-held, portable soil moisture-monitoring device consisting of a portable display/logger unit, connected by cable to an automatic depth sensing probe. The probe is usually inserted into an access tube to take the measurement; a high frequency electrical field (100 MHz) is created around the sensor extends through the access tube allowed the moisture to be determined.

Theory of Hydraulic Conductivity

The hydraulic conductivity is the volume of flow in unit time per unit cross-section area divided by the hydraulic gradient. Expressions for hydraulic conductivity is derived from Darcy's equation (Rose *et al.*, 1965; Genutchen van, 1980; Marshall *et al.*, 1988),

$$q_L = -K(\theta)\frac{dH}{dz} \qquad (1)$$

where, K(θ) = hydraulic conductivity at depth Z=L

q_L= steady state flux of water passing through a Unit soil surface per unit time

$\frac{dH}{dz}$ = total water potential gradient.

For non-steady conditions, the rate of change in water contents $\frac{d\bar{\theta}}{dt}$ is

$$\frac{d\bar{\theta}}{dt} = \frac{d}{dz}\left[K(\theta)\frac{dH}{dz}\right] \qquad (2)$$

which, on integration gives (Libardi *et al.*, 1980; Genutchen van, 1980; Das *et al.*, 2002)

$$L\frac{d\bar{\theta}}{dt} = \left[K(\theta)\frac{dH}{dz}\right]_{z=L} - \left[K(\theta)\frac{dH}{dz}\right]_{z=0} \qquad (3)$$

where, $\bar{\theta}$ = mean soil water contents (cm^3cm^{-3}), the first term on the is the water flux across depth L ($cm^3cm^{-2}day^{-1}$) and the second term is the water flux across the soil surface ($cm^3cm^{-2}day^{-1}$).It is however clear that, in many cases after irrigation or heavy precipitation the major part of the water will be drained out of the profile at depth L, while water evaporating at the soil surface will be small in comparison, and the second term is therefore ignored. And equation(3) takes the form

$$L\frac{d\bar{\theta}}{dt} = \left[K(\theta)\frac{dH}{dz}\right] \qquad (4)$$

it is shown in practice that little is lost by estimating $\frac{dH}{dz}$ as -1 (Libardi *et al.*, 1980; Vose, 1980), giving:

$$K(\theta) = -L\frac{d\bar{\theta}}{dt} \qquad (5)$$

There are several approaches to the measurement of soil hydraulic conductivity in the field (Libardi *et al.*, 1980; Genutchen van, 1980; Kirda, 1990). However is related to as describe by (Libardi *et al.*, 1980; Jones and Wagenet, 1984) with the following equation:

$$K(\theta) = K_o \exp[\beta(\theta_o - \theta)]$$

where β is constant and K_o and θ_o are the values of K and θ at saturation, respectively.

The data in Table 1 are enough to estimate unsaturated hydraulic conductivity which is assumed to be adequately described by eqn. (6) and also gives the major steps involved in the calculations. The slope dθ/dt given in column 3 of Table 1 is calculated using an exponential curve fitted for the pot of volumetric water content (θ) versus time (t) as shown in Fig.1.

$$\theta = 85.533t^{-0.056} \qquad \text{and } r = 0.955$$

$$\frac{d\theta}{dt} = -4.79t^{-1.056}$$

Table 1: Basic data for estimation of $K_o(z = 30cm, \theta_o = 84.03)$

Time (t) (h)	Vol.water contents (θ) cm cm^{-3}	$\frac{d\theta}{dt}$	$z\frac{d\theta}{dt}$	$\ln[z\frac{d\theta}{dt}]$	Diff.in vol. water cont. $(\theta_o - \theta)cm^3cm^{-3}$
0	84.03	-	-	-	0
6	82.43	-0.72	-21.7	3.076	1.6
24	80.95	-0.17	-5.01	1.612	3.08
30	80.47	-0.13	-3.96	1.376	3.56
48	77.06	-0.08	-2.41	0.88	6.97
54	78.15	-0.07	-2.13	0.755	5.88
72	77.71	-0.05	-1.57	0.452	6.32
78	76.95	-0.05	-1.44	0.367	7.08
96	75.78	-0.04	-1.16	0.148	8.25
102	76.69	-0.04	-1.09	0.084	7.34
120	73.81	-0.03	-0.92	-0.09	10.22
126	74.14	-0.03	-0.87	-0.14	9.89
144	72.64	-0.03	-0.76	-0.28	11.39
150	74.31	-0.02	-0.72	-0.32	9.72
168	72.13	-0.02	-0.64	-0.44	11.9

$\ln[z(d\theta / dt)] = -0.2856(\theta_o - \theta) + 2.6393 \qquad r = 0.927$

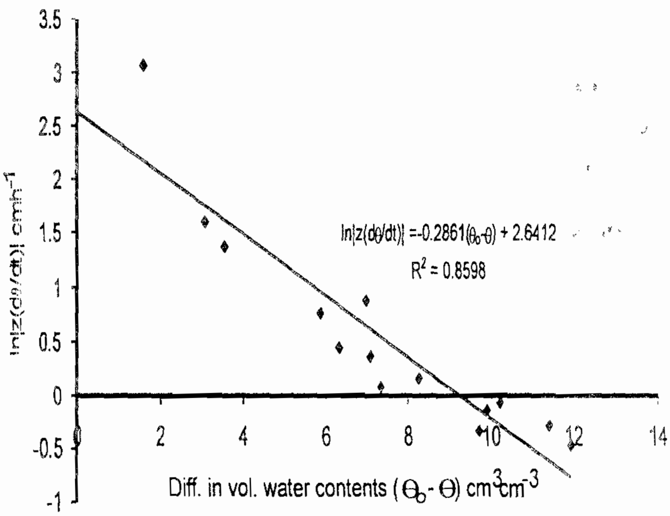

Fig. 2 Semi log plot of ln[z(dθ/dt)] vs (θ_o-θ)

Therefore, the exponential eqn. (6) describing unsaturated hydraulic conductivity is given as

$$K(\theta) = 2.64 \exp[-0.2856(84.03 - \theta)]$$

Result and Discussion

From Figs. 1 and 2, the trend lines of hydraulic conductivity with its regression line, shows soil water infiltration rate with regression r = 0.9548 and 0.912 respectively and its unsaturated hydraulic conductivity was found to be 0.264. With good data of hydraulic conductivity, the experimental work on plant water consumption, infiltration characteristics of soils and drainage work of wetland could easily be calculated. The data of this experiment in alfisol could be used for crops that have no more than 30 cm roots in the soil.

Conclusion

Unsaturated hydraulic conductivity is an important soil property affecting water and solute transfer rate in soil. However, is very difficult to accurately measure soil hydraulic conductivity, special in field. Hence indirect methods to estimate soil hydraulic properties become a critical technology to predict the unsaturated hydraulic conductivity from more easily measured soil properties (Wang Quajiun, 1991). The important task to the indirect method is to establish a theoretical model to describe soil water transfer process or develop between the soil water retention curve and hydraulic conductivity function. In this paper a method used by Lirbadi, *et al.*, (1980), is used in determining the unsaturated hydraulic conductivity and soil water retention curve. Since it is assumed that matric potential gradient is zero, the estimate of may differ from reality at each site. For soils having distinct layers or horizons of greatly differing hydraulic conductivity, it may be necessary to solve eqn. (3) with more reliable estimates of the hydraulic gradient. Calculations of the soil water flux within fields managed similarly, or mathematical simulations of the same rely on estimates of soil water properties whose accuracy and precision must be judged upon the variance of the structure of the observations. It is believed that from large number of observations, an opportunity exists to statistically analyze the data from several theoretical viewpoints.

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