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Soil-Water Sorptivity Estimation for Some Nigerian Soils

J.O. Aribisala
University of Ado-Ekiti, Department of Civil Engineering,
P.M.B. 5363, Ado-Ekiti, Nigeria

Abstract: Soil-water Sorptivity (S) is a single parameter that can be used to measure infiltrated water into the soil at a particular time, predict groundwater recharge and soil erosion, predict unsaturated hydraulic conductivity, determine saturated hydraulic conductivity and predict soil water diffusivity. This paper presents a simple method of estimating soil-water sorptivity. The experiment was carried out using some selected Nigerian soils. The infiltration experiment allows water to pass through a soil column. The volume of water infiltrating through a soil column at a particular time was measured. The infiltrated water (cm) was plotted against square root of time. Soil-water sorptivity was estimated as the slope of the graph.

Key words: Sorptivity, infiltration, soil, water content

INTRODUCTION

Soil-water sorptivity is a single parameter that contains the influence of matric suction and conductivity on the transient flow process[1]. For horizontal and constant head infiltration at non-ponding conditions i.e., ($\iota = 0$, $z = 0$, $t = 0$),[2] defined sorptivity as

$$S = I.t^{-1/2} \quad (1)$$

Where S is the sorptivity ($cmh^{-1/2}$), I is accumulated infiltration (cm) and t is time (h). Sorptivity is used to characterize the infiltration capacity for a given soil as a function of time and initial soil-water content. It measures the amount of water that has infiltrated into the soil. Hydrological processes in the soil, such as infiltration, groundwater recharge and soil erosion can be predicted if the sorptivity is known. Sorptivity is meaningful when estimated in relation to initial state of the soil.

Sorptivity is related to the slope of the curve representing the unsaturated hydraulic conductivity versus the soil-water potential. This explains why sorptivity can be successfully used to predict the unsaturated hydraulic conductivity. Unsaturated hydraulic conductivity determination had been found to be associated with experimental and theoretical difficulties[3]. Sorptivity can be used to predict unsaturated hydraulic conductivity[4] and soil water diffusivity[5].Klute[6] demonstrated how sorptivity can be used to determine saturated hydraulic conductivity.

Using Eq. 1 sorptivity can be estimated from infiltration experiment, as the slope of the relationship between accumulated infiltration and square root of time[6,7].Klute[6] validated experimental infiltration method used in this study using a mathematical method.

Theory: Philip[8] gave the expression for vertical unsaturated water flow through soil as

$$\frac{\partial\theta}{\partial t} = \frac{\partial}{\partial z}\left(\frac{Kd\psi}{d\theta}\frac{\partial\theta}{\partial z} - K\right) \quad (2)$$

Where θ is the soil-water content (cm^3cm^{-3}), ι is the soil-water potential (cm), K is the soil hydraulic conductivity (cmh^{-1}) and z is soil depth (cm). Jacobsen[2] solution of the flow equation describes the time dependence of cumulative infiltration I in terms of a power series:

$$I(t) = \sum_{n=1}^{\infty} jn(\theta)t^{n/2} = St^{1/2} + (A_2 + Ko) t + A_3 t^{3/2} + \ldots\ldots. A_n t^{n/2} \quad (3)$$

The coefficient S is the sorptivity. Equation (3) can be described approximately by two – parameter equation as

$$I(t) = St^{1/2} + Kt \quad (4)$$

For horizontal infiltration, Eq. 4 becomes

$$I = St^{1/2} \quad (5)$$

Equation 5 corresponds to the first term of the well-known semi-analytical solution of[9] to the governing differential equation for one-dimensional, unsaturated water flow.

Table 1: Sample description and location

Soil type	Description	Depth of collection	
Laterite (Type1)	This is an engineering soil usually used for road pavements	90 cm	Along Ado-Aramoko road
River sand (Type 2)	This is a cohesionless soil, brownish in colour. Usually used in civil and concrete works	25 cm	Ado-Ekiti
Sharp sand (Type 3)	This is a coarse grained cohensionless soil. It is used in civil and concrete works	25 cm	Ado-Ekiti
Sandy loam (Type 4)	This is an agricultural soil. It is dark in colour and used in agricultural farms	25 cm	Faculty of Agriculture Farm Land, University of Ado-Ekiti

Table 2: Measured values of soil parameters

Soil type	Moisture content (%)	Bulk density (g cm^{-3})	Hydraulic conductivity (mm sec^{-1})
Type 1	7.26	2.10	0.29
Type 2	5.79	2.69	0.49
Type 3	1.56	2.83	0.46
Type 4	9.20	2.13	0.37

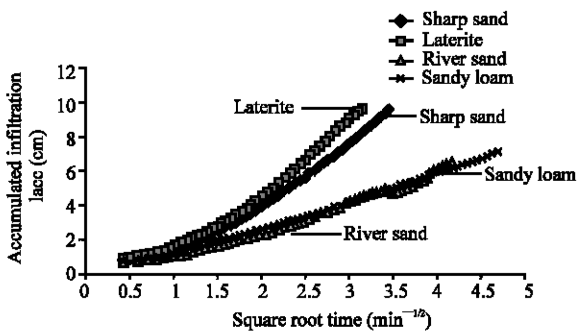

Fig. 1: Accumulated infiltration of water

MATRIALS AND METHODS

The samples for the experiment were taken from Ado-Ekiti, in Ekiti state, Nigeria. A brief description of the samples and locations are shown in Table 1.

Properties of the samples such as soil moisture content, bulk density, hydraulic conductivity, saturated moisture content were determined using well known laboratory procedures. The results are shown in Table 2.

Lund[10] presented the complete experimental procedure for estimating sorptivity. A summary of the procedure is outlined briefly.

Soil cores were taken out using a core soil sampler of stainless steel. Inside the steel sampler is a separate plexi-glass column (4 cm in outside diameter,3.4 cm in inside diameter, 20 cm in length) for containing the soil core . After the sampler has been used and removed from the sampling site, the plexi-glass column containing the soil core is removed from the sampler, a new plexi-glass column is inserted into the sampler and the sampler glass column containing the soil cores (soil columns) were placed in a soil core dryer and dried to a constant, initial soil-water content (θ_o). In the soil core dryer, atmospheric air was led through the soil columns at a suction of 20 cm.

Table 3: Estimated values of sorptivity

S/N	Soil type	Sorptivity (cm $min^{-1/2}$)
1	Type 1	2.67
2	Type 2	2.5
3	Type 3	3
4	Type 4	1.72

The atmospheric air was first cleaned and dried by leading it through concentrated sulphuric acid at 20°C. after approximately two days, a constant (in depth) soil water content of 2-4 cm^3cm^{-3} was obtained in the soil columns. After drying the columns, horizontal infiltration experiments were carried out using the set-up in[5].

SORPTIVITY DETERMINATION

Recall Eq. 5, i.e $I = St^{1/2}$. Using the result of horizontal infiltration experiment, accumulated infiltration was plotted against the square root of time as shown in Fig. 1. The slope of the graph is the estimated value for the sorptivity. The estimated sorptivity values are presented in Table 3.

CONCLUSION

Soil-water sorptivity if correctly estimated can be used to estimate a number of other parameters. One of such parameters is the unsaturated hydraulic conductivity. Unsaturated hydraulic conductivity had been found to be associated with experimental and theoretical difficulties.

A simple experiment was used to estimate soil-water sorptivity for four selected soils. This is one of the few attempts at determining soil water sorptivity for Nigerian soils. The experimental technique which had been validated[6] provided reliable estimated sorptivity values for samples such as Laterite, River Sand, Sharp sand and Sandy loam. Comparing the sorptivity values in Table 3 and the hydraulic conductivity values in Table 2 shows a good agreement as infiltration depends on hydraulic conductivity. The hydraulic conductivity for sand samples were higher than that of sandy loam and laterite. As revealed in Table 3, sandy soil transmits water faster than laterite and sandy loam. The estimated values can be used to monitor irrigation systems, groundwater recharge, soil erosion and to choose suitable construction materials for water related construction works.

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