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Experimental determination of hydraulic conductivity at unsaturated soil column

Maria Sakellariou-Makrantonaki[a,*], Anastasia Angelaki[a], Christos Evangelides[b], Vasiliki Bota[a], Evangelia Tsianou[a], Nikolaos Floros[a]

[a]*University of Thessaly, School of Agricultural Sciences, Department of Agriculture, Crop Production and Rural Environment, Agriculture Hydraulics Laboratory, Fytokou, Volos 38446, Greece*
[b]*Aristotle University of Thessaloniki, School of Rural and Surveying Engineering, Thessaloniki 54124, Greece*

Abstract

Hydraulic Conductivity (K) is an important hydraulic parameter as it affects the environment by controlling infiltration, irrigation rate, and consequently the water movement through the ground. In order to determine Hydraulic Conductivity in a soil column during unsaturated flow, experiments were performed in the laboratory. A sandy (S) soil sample of known Hydraulic Conductivity at saturation (K_S) was placed uniformly in a transparent column. Using a pump, water was applied at the surface of the soil column in certain supplies (Q_i), while soil moisture (θ) was measured using TDR probes. At the same time, soil pore pressure (h) was measured using pressure transducers. The cumulative volume of the outgoing water (V) of the column was measured. Experimental data were fitted by Van Genuhten's Hydraulic Conductivity model. The results of the above experimental procedure constitute useful tools for the simulation of water movement in unsaturated soils and can be the outset for further research.

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Keywords: hydraulic conductivity; unsaturated flow; soil moisture; soil pore pressure; soil column

* Corresponding author. Tel.: +30-242-109-3059; fax: +30-242-109-3060.
E-mail address: msak@agr.uth.gr

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1. Introduction

The rational use in agricultural crops, depends on the knowledge of the phenomenon which determines the movement of water in soil. The ability of soils to retain and carry water is regulated by hydraulic properties one of which is the hydraulic conductivity in relation to soil moisture K(θ) or in relation to water pressure K(h).

Generally, the movement of water in soil is three-dimensional, but in most cases can be considered as two-dimensional because of the axial symmetry and in many cases can be considered as one-dimensional. The vertical movement of water in soil is found in irrigation systems and in the enrichment of aquifers.

The study of the movement of water in unsaturated soil launched in 1907 by Buckingham who tried to give a detailed analysis of the unsaturated flow as it mentioned by Swartzendruber, [18]. Richards [12] extended the law of Darcy and unsaturated flow. But Childs [5] started a systematic research of water movement in the soil and gave a complete description of the physical phenomena governing the movement of water in soil.

Many scientists who dealt with the systematic study of unsaturated flow are Childs and Collis-George [6], Vachaud [20], Philip [11], Swartzendruber [18], Parlange [9], Sakellariou-Makrantonaki et al. [13].

A significant prediction model of Hydraulic Conductivity in unsaturated condition of the soil is van Genuchten's model:

$$K(\theta) = K_s \Theta^{\frac{1}{2}} \left[1 - \left(1 - \Theta^{1/m}\right)^m\right]^2 \quad (1)$$

where K is the hydraulic conductivity, K_s is the hydraulic conductivity at saturation, m = 1 – 1 / n (0<m<1; n>1) is a parameter which is related to curve deformation and Θ is the soil moisture, which is defined as:

$$\Theta = \frac{\theta - \theta_r}{\theta_s - \theta_r} = \frac{1}{((1+(ah)^n)^m} \quad (2)$$

where θ_r is the residual moisture, θ_s is the soil moisture at saturation, h is the soil pore pressure and a is an adjustment parameter.

The development of computer science contributed to a more detailed approach to the movement of water in unsaturated zone. At the same time, computers helped researchers in the development and presentation of mathematical models that describe the movement of water in unsaturated zone with the ability of automatic data recording. There are many researches in the international literature and indicatively examples are Sakellariou-Makrantonaki and Hajiyiannakis [14], Sakellariou-Makrantonaki [15], Vogel et al. [21], Angelaki et al. [1, 2], Or and Tuller [8], Mertens et al. [7], Šimůnek et al. [17], Vogel and Ippisch [22], Touma [19], Carrick et al. [4], Pfletschinger et al. [10], Shein et al. [16].

2. Methodology

Granulometric analysis and Hydraulic Conductivity at saturation (Ks) of the soil sample, were measured at the laboratory, using the constant head method (ASTM, [3]). The method operates in accordance to the direct application of Darcy's law to a soil liquid configuration representing a one-dimensional, steady flow of a percolating liquid through a saturated column of soil from a uniform cross-sectional area. This procedure allows water to move through the soil under a steady state head condition while the quantity (volume) of water flowing through the soil specimen is measured over a period of time. By knowing the quantity of water measured, length of specimen, cross-sectional area of the specimen, time required for the quantity of water to be discharged and constant head difference, the Hydraulic Conductivity at saturation can be calculated:

$$K_s = \frac{QL}{A\Delta H} = \frac{VL}{At\Delta H} \quad (3)$$