

MONITORING SYSTEM FOR UNSATURATED SOILS HYDRAULIC PARAMETERS

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Lucrarea descrie o instalație de laborator realizată cu scopul de a măsura în timp real parametrii hidraulici ai unui sol nesaturat. Instalația permite monitorizarea continuă a continutului volumic de apă dintr-un sol nesaturat precum și a presiunii din pori. Metodele de măsurare utilizate sunt moderne pe plan mondial și permit studierea influenței irigațiilor, evaporației și a dezvoltării plantelor asupra continutului de apă din sol. Sistemul de monitorizare realizat conține un umidimetră de tip capacativ, conectat printr-un convertor analogic la un sistem de achiziție de date. Presiunea apei din porii solului se măsoară cu un tensiometru de tip tensionic și un traductor de presiune electronic. Acest tip de tensiometru permite atât măsurarea presiunii cât și prelevarea apei din porii solului, în vederea analizării calității chimice a acesteia.

The goal of our work is to realize an experimental monitoring system to measure the hydraulic parameters of unsaturated soils. We continuously measured the volumetric soil water content θ and soil pressure head h , to determine the soil pedotransfer functions (absolutely necessary in the modeling process). The laboratory experiments developed a modern method to survey the real time behavior of an agricultural soil, the influence of irrigations, evaporation and crop life on the soil water content. The soil water content monitoring system based on a capacitive device is connected through a convertor to a PC. A hardware interface is used for data acquisition. The soil water pressure can be measured with a special tensiometer (tensionic) connected to an electronic transducer. The tensionic device can be used for soil solution extraction too.

Keywords: Unsaturated soils, water content, pressure head, monitoring system.

1. Introduction

The vadose zone plays an important role in many aspects of hydrology, including infiltration, soil moisture storage, evaporation, plant water uptake, groundwater recharge, runoff and erosion.

Due to agricultural, industrial and municipal activities, the soil and groundwater pollution has increased in the last decades. Fertilizers and pesticides

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applied to agricultural lands can be transported by water below the soil root zone and may contaminate underlying groundwater reservoir.

The conceptual understanding of water flow and solute transport processes in the unsaturated zone represented the subject of a large number of theoretical and experimental researches [1], [2].

Richards equation and the Fickian - based convection-dispersion equation are the most popular models describing the flow in the unsaturated soils and the chemicals migration toward the groundwater.

Usually the two equations are numerically solved with different software packages. For example HYDRUS code [7] may be used to analyze water and solute movement in unsaturated, partial saturated, or fully saturated porous media.

The models have to be calibrated using soil hydraulic and solute transport parameters from measured transient or steady-state flow and transport data [6].

The goal of our work is to realize an experimental monitoring system to measure the hydraulic parameters of unsaturated soils. We continuously measured the volumetric soil water content (θ) and soil pressure head (h), to determine the soil pedotransfer functions (absolutely necessary in the modeling process).

Two laboratory experiments were developed to survey the real time behavior of an agricultural soil, the influence of irrigations, evaporation and the plants uptake during the crop life, on the soil hydraulic parameters.

2. Unsaturated soil hydraulic properties

The equation describing the behavior of one-dimensional uniform water movement in a partially saturated rigid porous medium (Richards equation) is:

$$\frac{\partial \theta}{\partial t} = \frac{\partial}{\partial z} \left[K(h) \left(\frac{\partial h}{\partial z} + 1 \right) \right] - S \quad (1)$$

where h is the water pressure head [L], t is time [T], z is the spatial coordinate [L], positive upward, $\theta(h)$ is the volumetric water content [$L^3 L^{-3}$], S is the sink term [$L^3 L^{-3} T^{-1}$], and $K(h)$ is the unsaturated hydraulic conductivity function [LT^{-1}].

The unsaturated soil hydraulic properties $\theta(h)$ and $K(h)$, are highly nonlinear functions of the pressure head. For example mathematical relationship for soil water retention and hydraulic conductivity proposed by van Genuchten [4] describes the total soil water-retention curve. The soil water retention curve is given by:

$$\theta(h) = \theta_r + (\theta_s - \theta_r) \left[\frac{1}{1 + (\alpha|h|)^n} \right]^m, \quad (2)$$

where: θ ($cm^3 cm^{-3}$) is the soil volumetric water content, θ_r ($cm^3 cm^{-3}$) – the residual soil water content θ_s ($cm^3 cm^{-3}$) – saturated soil water content, h (cm) is

the pressure head in the soil's pores, and α , n , m are parameters defining the moisture retention characteristic's (MRC) shape.

Unsaturated soil hydraulic conductivity, K , can be expressed as a function of soil volumetric water content:

$$K(\theta) = K_s \left(\frac{\theta - \theta_r}{\theta_s - \theta_r} \right)^{\frac{1}{2}} \left[1 - \left(1 - \left(\frac{\theta - \theta_r}{\theta_s - \theta_r} \right)^{\frac{1}{m}} \right)^m \right]^2. \quad (3)$$

with K_s - soil hydraulic conductivity at saturation. Mualem proposed the relation:

$$m = 1 - 1/n. \quad (4)$$

The above equations contain five independent parameters θ_r , θ_s , α , n , K_s which can be estimated from laboratory or field measurements [6].

3. Monitoring system of water content in unsaturated soils

Soil's gravimetric water content (ω), can be determined either by direct or indirect methods. Gravimetric method (direct method) involves weighing a wet soil sample ($m_w + m_s$), removing the water (m_w) by oven-drying it, and reweighing the sample (m_s).

$$\omega = m_w/m_s. \quad (5)$$

The volumetric water content (θ) is defined as the volume of water (V_w) divided by the total volume of the sample (V_t):

$$\theta = \frac{V_w}{V_t} = \omega \frac{\rho_b}{\rho_w}, \quad (6)$$

where ρ_w is the water density and $\rho_b = m_s/V_t$ is called bulk density.

Indirect methods consist of measuring a soil property considering the soil water influence on that property. Specially, electrical and thermal conductivity and electrical capacitance of porous materials vary with water content.

Using two columns with agricultural soil (Fig.1) we observed in our experiment the variation of soil physical properties for different watering condition. In one of the reservoirs we studied the influence of plant (corn) growth on soil water content and on pores pressure head.

We measured the soil volumetric water content, the pressure head and the nitrates concentration at different depths.

The soil volumetric water content was measured using a moisture sensor, coupled to a reading device (Fig.2). The sensor measures the soil electrical capacity (Fig.3). Between the dielectric soil permittivity (ε) and its volumetric water content (θ), a linear relationship:

$$\varepsilon = A\theta + B \quad (7)$$

can be expected. The constants A and B have to be calculated for each soil type as part of the system calibration [5]. The calibration coefficients can be introduced into the probe by using reading device which enables the user to read directly the volumetric water content (θ).



Fig. 1. Laboratory monitoring system.

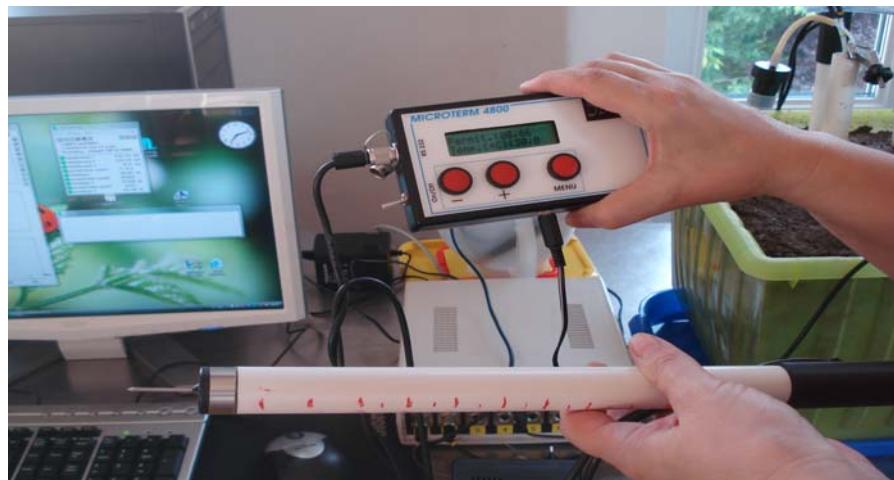


Fig. 2. Soil humidimeter connected to the reading device.

The soil moisture humidimeter can be connected to a PC, using a high-resolution converter.

Pico Log is a data acquisition tool that collects, records, displays and analyses measured data. It offers continuous recording over long periods. The data

can be displayed in graphical or spreadsheet format during data collection. The fastest sampling rate in real time mode depends on the speed of the computer and the operating system.

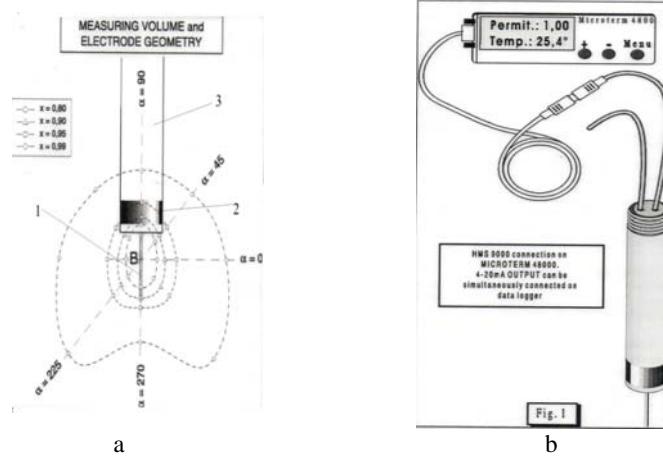


Fig. 3. Soil humidimeter [8]:

a) humidimeter components: 1 – rod sensor; 2 – ring sensor; 3 - tube PVC containing the electronic components; b) humidimeter connection to the reading device.

The high-resolution converter offers eight analogue input channels. It is a high-accuracy data logger for use with PCs, connected to the RS-232 serial port, and requiring no external power.

4. Water pressure measuring system

The water pressure in unsaturated soil's pores can be measured using tensiometric tubes and electronic pressure transducers (Fig.4), [5].

A porous ceramic cup is glued to the bottom of a PVC tube filled with water, which will be set into the soil.

The measuring technique consists in piercing through a silicon bung closing the tensiometer tube, using a hypodermic needle, connected to a electronic pressure transducer. The vacuumometer measures the air pressure decrease created in an airtight system (at the top of the tensiometric tube) when water transfers through the porous ceramic toward the unsaturated soil.

The electronic device provides directly the negative relative air pressure (p_{air}) inside the top of tensiometric tube. If d is the height of the water column

above the soil surface and ρ_w the water density, the pressure (suction) in N/m^2 , at a depth z below soil surface, is given by:

$$p = p_{\text{air}} + \rho_w g(z + d), \quad (8)$$

while the same relative pressure, p , expressed in $\text{cm H}_2\text{O}$ is:

$$h = (p_{\text{air}} / \rho_w g) + (z + d) < 0. \quad (9)$$

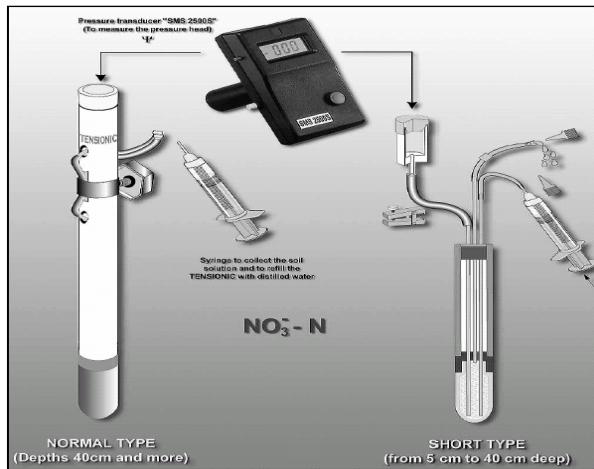


Fig. 4. Tensiometer and electronic transducer [8].

The pressure head value given by equation (9) and the measured volumetric water content values can be used to calibrate the moisture retention characteristic (eqs.2 and 3) with an inverse method [6].

5. Experimental results

In two columns with loam clay soil (36 % clay, 36.1 % silt and 27.9 % sand) we observed the variation of soil physical properties for different watering condition. We studied the influence of plant growth on soil water content and on pores pressure head. The monitoring system is shown in fig.1.

Sampling the soil profiles we measured for each sample: total volume - V_t , pores water volume - V_w , soil particles volume - V_s , dry weight of the sample - m_s , and m_w - the mass of water. We calculated: (Table1) bulk density - ρ_b at different depth, grain density - ρ_s , volumetric water content at saturation, - θ_s (%), gravimetric water content at saturation - ω_s (%), volumetric water content (spatial and temporal variation) - $\theta(z, t)$ (%), gravimetric water content (spatial and temporal variation) - $\omega(z, t)$ (%).

The calibration curve for one of ours humidimeters is presented in the figure (5). For each soil sample gravimetric method was used to calculate (ω), and (θ) with the relations 5 and 6. Between the volumetric water content and the permeability value the device showed for each sample the best linear correlation was computed.

Table 1: Soil properties.

Properties	bulk density g/cm ³	grain density g/cm ³	volumetric water content at saturation (%)	gravimetric water content at saturation (%)
Definition	$\rho_b = \frac{m_s}{V_t}$	$\rho_s = \frac{m_s}{V_s}$	$\theta_s (\%) = \frac{V_w}{V_t} 100$	$\omega_s = \frac{m_w}{m_s} 100$
Values	1.17	2.418 g/cm ³	50.35	43.034

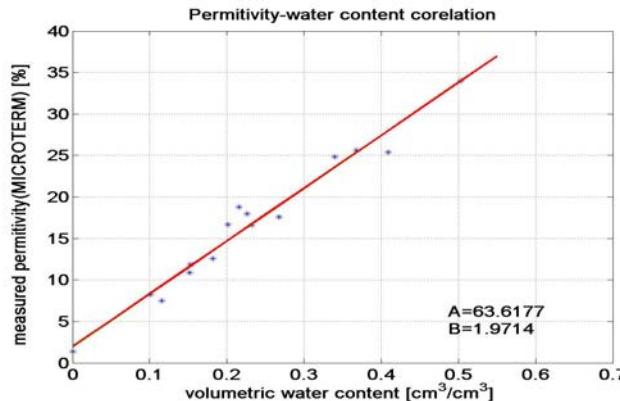


Fig. 5. Soil humidimeter calibration.

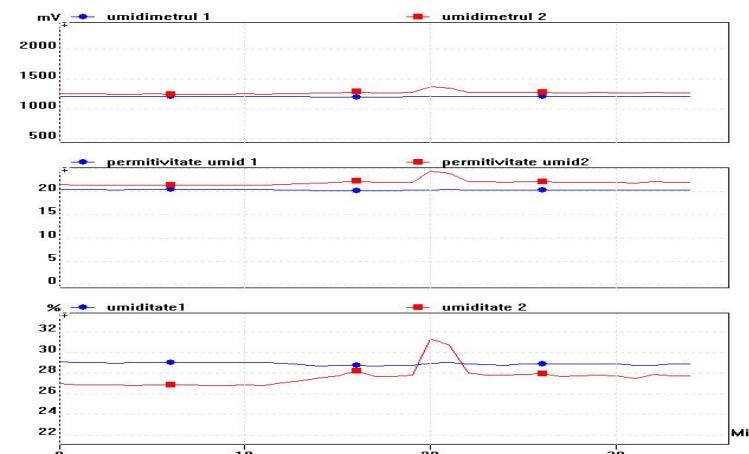


Fig. 6. Volumetric water content monitoring results. (tension, permittivity and humidity)

Fig. 6 shows some results of a real time monitoring of soil volumetric water content, in two experiments. One of the two humidiometers measures the time variation of volumetric water content in the soil column without plants and the other one the influence of corn crop on the humidity behavior

4. Conclusions

We designed an experimental monitoring system to measure the hydraulic parameters of unsaturated soils. We continuously measured the volumetric soil water content θ and soil pressure head h , to determine the soil moisture retention characteristic, useful in the modeling process.

Two experiments were developed to survey the real time behavior of an agricultural soil, the influence of irrigations, evaporation and the plants uptake during the crop life, on the soil hydraulic parameters.

The tensiometer was used to measure the water pressure and to extract soil solution. The measured values will be used for a model calibration.

This monitoring system can be used for field agricultural research.

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