STUDY OF CAPILLARY HYSTERESIS IN MEDIUM TEXTURE SOIL USING PREISACH MODEL

STUDIUL HISTEREZISULUI CAPILAR ÎN SOLURI CU TEXTURA MEDIE FOLOSIND MODELUL PREISACH

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***Abstract**. The purpose of this paper is to study the physical properties of the soil using a phenomenological model which should be able to describe the capillary hysteresis of water from pores of the medium-textured soil. The proposed model is Preisach type and has been used successfully to describe the hysteresis of nonlinear phenomena in physics, biology or economics. This model has the advantage of being easily adapted. We had expanded this model to study the pressure exerted by water in the processes of drying and wetting of the soil. The developed and implemented model, unlike other models, takes into consideration the way in which interconnected pores are filled and emptied. Our study presents a new method of assessing the water circulation in soil pores with medium texture from greenhouses. The results are useful to make the irrigation systems used in gardening more efficient, from economical point of view.*
Keywords: drying-wetting process, water hysteresis, Preisach model, irrigation

***Rezumat**. Scopul acestei lucrări este de a studia proprietățile fizice ale solului utilizând un model fenomenologic capabil să descrie histerezisul apei din porii capilari ai solului cu textură medie. Modelul propus este de tip Preisach, fiind folosit cu succes pentru a descrie histerezisul fenomenelor neliniare din fizică, biologie sau economie. Acest modelul prezintă avantajul de a putea fi uşor adaptat. Noi am extins acest model pentru a studia presiunea exercitată de apă în procesele de uscare şi umezire ale solului. Modelul dezvoltat şi implementat, spre deosebire de alte modele, ia în considerare modul de umplere şi golire al porilor în cazul în care aceştia sunt interconectați. Studiul nostru prezintă o nouă metodă de evaluare a circulația apei în porii solului cu textură medie din sere. Rezultatele sunt utile pentru a eficientiza, din punct de vedere economic, sistemele de irigații utilizate în grădinărit.*
Cuvinte cheie: procesul de uscare-umezire, histerezisul apei, modelul Preisach, irigare

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INTRODUCTION

The soil is described as a porous medium where all the phases (liquid, solid and gas) coexist and presents a memory effect in unsaturated state. The memory effect is highlighted by hysteresis loop. In soil, it is important to know the relationship between capillary pressure and saturation to understand the unsaturated behavior of this type of system. Water-soil characteristic curves (WSCC) have been used to estimate the hydraulic conductivity, pores volume variation, shears strength or diffusion phenomena in soil.

The hysteretic behavior of soil is given by a sum of factors, the most important being the irregular pore space geometry, a different contact angle for the two directions of water content evolution , the air entrapped inside the medium, the shrinking and swelling of pores (Nimmo, 2006), and the thermal effect.

- The 'ink bottle effect' is the effect given by geometric non-uniformity of individual pores when the water passes the smallest cross-sections of pores.
- The variation of contact angle between advancing interface (wetting of pore) and receding (drying of pore) is described by unequal values. The advancing angle is larger than the receding one, thus the suction at drying is greater than the wetting.
- The proportion of liquid and gas of soil is inverted when the state of pore is changed. If the liquid phase is dominant in pores, then the air trapped inside slows pore filling.
- In fine grained medium, the swelling of pore due to wetting and shrinkage due to drying changes the diameter of pores.
- The variation of temperature affects the retention relation by changing the fluid viscosity and density.

In the last five decades, the science community has been developed numerous models widespread used for water retention estimation in soil. For a model to be useful, it should satisfy three conditions: to respect the law of water mass conservation, to respect Darcy's law regarding the flow of water through a porous medium and to describe relationship between water content and pressure head.

Therefore, these models have been categorized into *conceptual* and *empirical* models. These theories are based on domain theory of capillary hysteresis that can be *independent* and *dependent.* The domain theory takes into account the small area of pores that have the same state.

An *independent* model considers the pore as a single component (mono-domain) that is filled with water or air and cannot be influenced by the surrounding pore state. On the contrary, in the *dependent* model the pores are connected by small tubes creating a network of pores, in the same way like in the percolation theory (Bollobás and Riordan, 2006).

Recently, a mathematical approach of Preisach model was developed in a series of papers in order to simulate the experimental curves of water soil retention (Krejci *et al.*, 2012). This type of model is using the domain theory, where each domain exists in one of the two states: empty or filled with water.

In real porous medium, the pores go through partially full state in wetting or drying processes. The processes in intermediary states are considered as reversible process. Those are associated with instantaneous exchange and linear variation of head pressure. The reversible processes do not depend on the history of water content, only on the actual value of it (Bodale *et al.*, 2011). Instead, the irreversible processes are given by internal variable that are associated with the dissipation of energy. For example, the processes occurring at the two bottleneck of pore are irreversible (Iwata *et al.*, 1994). These processes depend on moisture 'history' of porous medium (soil).

In this paper we adapted a Preisach model that includes the transition states and the jumps of state pores in order to describe the water circulation in real soil pores.

MATERIALS AND METHOD

The classical Preisach model was developed by Mayergoyz (2003) based on Preisach formalism (1935) in order to describe the hysteresis behavior. Initially, their model explained the hysteresis behavior of standard samples of ferromagnetic medium, but it was easily extended to describe all systems with a hysteresis behavior (materials engineering, electrical engineering, geology, biology, economy and water cycle in porous medium as soil).

In this model each element is in one of the two states: empty (filled with air) or full (water flooded) state. The transition of pore between one state to the other depends on the moisture history described by a small hysteresis, named hysteron. The sum of all hysterons of a system is given by the hysteresis of the whole system.

In the Preisach model, each hysteron has a single point associated in half Preisach plan where the coordinates ((*f,d); f = filling*, d = *draining*) are the pore switching values on wetting and on drying processes, respectively. In Preisach plan area, which has physical signification, it is described by a right triangle (Fig.) limited by the first bisector and the two extremely lines: no water (x) and saturation (x_{max}). In a porous medium, the pores are not identical according to the switching values and can be described by two statistically independent distributions. The product of the two distributions gives the Preisach distribution that is found in the triangle area from Preisach plan (Bodale and Stancu, 2013):

$$p(f,d) = p(f) \cdot p(d) \tag{1}$$

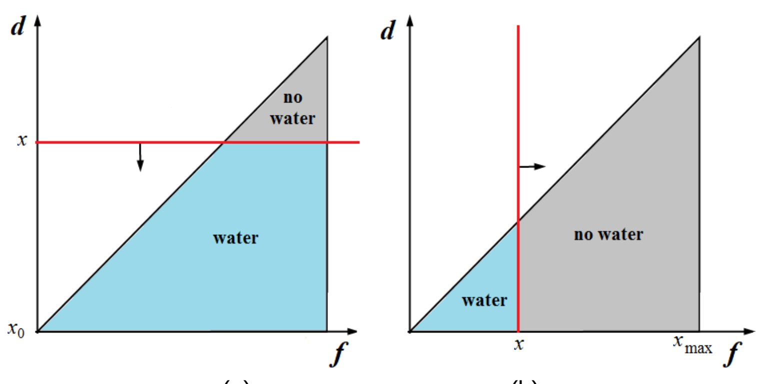

Fig. 1 The Preisach plan swept by *x* for (a) drying and (b) wetting processes.

The main drying curve (MDC) is obtained starting from the *saturate state* (where all pores are filled with water and no bubbles air entrapped inside) towards complete dry medium (x_0). The line of actual value of water content moves down in Preisach plan (fig.1a) and all points with *d* value smaller that water content value switches into dry state. This moving down of the line is determined by hydrologic continuous movement of water caused by infiltration, desorption, evaporation and drainage. On the other hand, main wetting curve (MWC) is obtained starting from *no water state* and *x* swept of the Preisach plan from left to right (fig.Fig. 1b). The increasing of water content from porous medium is determined by infiltration, surface runoff, irrigation/precipitation, suction and condensation.

The model is based on the integration of Preisach distribution ($p(f,d)$) into the two regions of Preisach plane:

$$I = \left[\iint_{S_W} p(f,d)\,\mathrm{d}f\,\mathrm{d}d - \iint_{S_{noW}} p(f,d)\,\mathrm{d}f\,\mathrm{d}d \right] \quad (2)$$

In moisture hysteresis or capillary hysteresis from porous media not all situations satisfy the two properties because there is a *pumping effect*, mainly generated by the thermal effect (Wei and Dewoolkar, 2006). This aspect is not the topic of the present paper and will be the subject of a future paper.

In order to take into account all characteristics of porous medium behavior given by jumps and the intermediary states of pores we used generalized Preisach model (GPM) that include reversible and irreversible processes (Stoleru *et al*., 2010).

The reversible variation (*R*) is determined similarly to equation (2) as a difference of the two intervals of reversible distribution $p_{rev}(x_{rev})$:

$$R = \left[\int_{C_W} p_{rev}(x_{rev})\,\mathrm{d}x_{rev} - \int_{C_{noW}} p_{rev}(x_{rev})\,\mathrm{d}x_{rev} \right] \quad (3)$$

In generalized type models, the irreversible and reversible weights are defined by a squareness factor (*S*) of hysteresis (Mayergoyz and Friedman, 1988). The proportion between the two components is calculated using:

$$Y = S \cdot I + (1-S) \cdot R \quad (4)$$

In literature this model was developed in an advanced version, but we used this version because is able to explain the water circulation in medium texture soil.

RESULTS AND DISCUIONS

We used the above phenomenological model to simulate the water circulation in soil during both processes; drying and wetting based on a set of experimental data published by Morrow and Harris in (1965).

In our simulation, the irreversible process from soil pores was performed using Preisach distribution obtained as a multiply of two Gaussian distributions. Moreover, the squareness factor of hysteresis behavior of experimental data shows a significant reversible component (*S*=0.75). The reversible component was evaluated as initial slopes in starting point of each experimental scanning curves. We identified the reversible component as a Gaussian function obtained by interpolation of experimental values (fig. 2), as in the equation below:

$$f_{rev} = f_0 + A_{rev} \cdot e^{-(x-\mu_{rev})^2/2\sigma_{rev}^2} \quad (5).$$

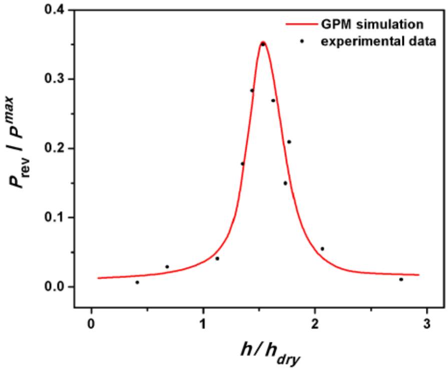

Fig. 2 Reversible distribution identified from experimental data

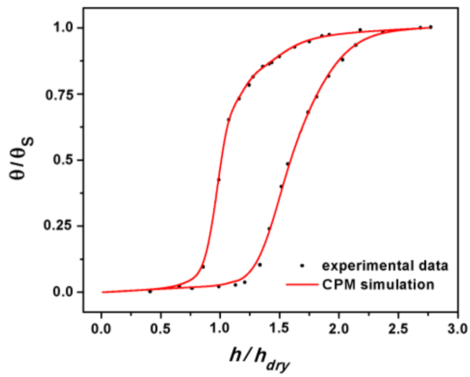

Fig. 3 Simulation of soil-water hysteresis braches by using Preisach model vs. experimental data (Morrow and Harris,1965)

We used the above Preisach model in order to simulate the behavior of water circulation in the interconnected pores. As is shown in figure 3, the simulated results fit the experimental points (continuous red lines) only if the model includes the reversible process during water movement and if the interconnectivity of pores is considered. By including in Preisach model the reversible variation of water as a Gaussian function (fig. 2), the errors of simulation decreased with 23%.

In order to compare the simulations with the experimental results, we normalized the water content (θ) from soil at the saturation water value (θ_S) and the current pressure head of water (h) at the pressure head of water, since most pores jump from a filled to empty state (h_{dry}). The reversible probability was normalized at the maximum value of probability distribution identified in the experimental data.

The above results were used to evaluate the available water of soil as difference between field capacity and wilting point. Understanding the physical mechanism by which the water fills the pores or not is an important aspect in order to evaluate the available water of soil necessary to improve water efficiency of irrigation.

CONCLUSION

1. In soil with medium texture cannot be ignored the effect of unsaturated pores because it influences the shape of water characteristics curves. This effect can be explained only by adding in model the reversible variation of water during filling and drying processes.

2. A good technique to identify the reversible component is based on the geometrical evaluation method of the scanning curves initial slopes which show nonzero values.

3. From the water consumption point of view, the results are useful for designing more efficient irrigation systems to be used in soils with medium texture from greenhouses and gardening.

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