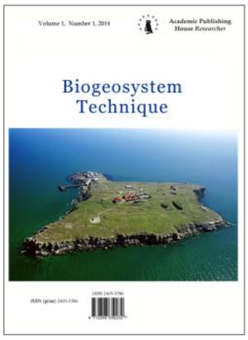

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Soil Water Retention Curve: Experimental and Pedotransfer Data to Forecast Water Movement in Soils*

[1] Evgeny V. Shein
[2] Natalia S. Kukharuk
[3] Sofia S. Panina

[1, 3] Lomonosov Moscow State University, Russian Federation
119991, Moscow, Leninskie Gory
Faculty of soil science
[2] Belgorod State University, Russian Federation
E-mail: evgeny.shein@gmail.com

Abstract

Soil water retention curve (WRC) - the most important hydrological characteristics of soils, which determines the movement of moisture and soluble substances in soils. This relationship between soil moisture and capillary pressure of moisture, is included in all forecasting mathematical models of moisture movement in the soils. To assess the adequacy of model calculations with using the WRC, obtained by different methods, WRC was defined by experimental laboratory methods, or was calculated by using pedotransfer functions (PTF). Then the calculated data and field nature experiments on the movement of moisture were compared with. The precision of moisture movement modeling in the soil was significantly determined by the method of obtaining WRC. The results of the experimental modeling of soils water regime, significantly the results of the simulation were located in the following descending order of precision: regional PTF > WRC (water retention curve), obtained by the method of sand-kaolin boxes > WRC, obtained using capillarimeters > PTF used in the program Agrotool (on the basis of the experimentally obtained hydrological constants) > PTF using as predictor of granulometric structure (from the data base ROSETTA) > WRC obtained using the centrifuge method > PTF based on Voronin's «secants». It is recommended to create regional hydrophysical data base to calculate pedotransfer functions for forecasting modeling of soil water movement.

Keywords: hydrophysics of soils; mathematical model; water retention curve; experimental software; pedotransfer functions.

Introduction

Problems of the elaborate study and forecast of substances movement in the soils - currently are highly relevant [1, 2]. This is primarily due to the fact that at the present stage of development of the land hydrology and using the natural waters it is necessary to know and to quantitatively predict the development of one or another natural process, in order to timely and accurately solve the question of their management. Governance issues are always based on the preliminary forecast

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calculations that are performed on the basis of mathematical models. Now the procedure of predictive modeling is required for registration of pesticides [12, 15], while forecasting the effects of flooding, the development of the urban and agricultural water supply systems, the management of water resources, etc. [17] It is considered that at the current moment the management of water using is not directed at the construction of new systems, but on the accurate management of existing ones [18].

The main difficulties in the application of mathematical physically-based models are primarily associated with the obtaining the adequate experimental material on hydrophysical properties of soils [11, 14]. That is why presently the most topical issues related to obtaining and using of experimental support for that kind of models.

As an experimental support of the model the hydrophysical properties of soils, first of all, water retention curve (WRC), and primarily the moisture permeability function are used. Modern soil physics uses a variety of methods for determination: the direct experimental determination of WRC by various methods [3, 4, 6, 7], and various calculation methods (pedotransfer functions) [10, 16, 22]. This fact poses a researcher with the task of selecting the most appropriate method of obtaining experimental support of the model.

The objective research is a quantitative comparative evaluation of experimental and calculation dynamic data on soil moisture in conditions of non-pressure and low - debit infiltration and analysis of the most suitable method of obtaining experimental support for the using model (program HYDRUS-1D).

Research tasks: (1) experimental study of the soil moisture dynamics at non-pressure and low-debit infiltration and subsequent evaporation in the field condition; (2) a description of the process of water transfer using physically-based model HYDRUS, (3) failure analysis and modeling (4) substantiation of the optimum way of getting hydrophysical properties for predictive mathematical models

Objects and methods. The object of the study is middle-loamy soil on the carbonate loess-like loams of the Vladimir Opol'e . These agrosoils are described in detail in the literature [5, 13].

Some physical properties, which were subsequently used in calculating of pedotransfer functions, are presented in Table 1.

Table 1: Some physical properties of grey forest soils of Vladimir Opol'e

Depth, cm	Granulometric composition, %			Soil density, g/cm³	Field capasity, %	Filtrstion coefficient, cm/day	Organic carbon conc, %
	<0.002	0.002-0.05	>0.05				
0-5	17,39	80,66	1,95	1,10	37,34	60	1,91
5-10	17,35	80,21	2,44	1,16	37,21	58	1,86
10-20	17,21	80,00	2,79	1,21	37,08	52	1,78
20-30	17,63	81,62	0,75	1,33	38,58	26	1,76
30-40	16,00	82,43	1,57	1,36	38,20	32	1,63
40-50	17,35	81,76	0,89	1,33	37,37	35	1,42
50-60	17,32	82,09	0,59	1,39	35,26	35	0,72

In the framework of this study the experimental (field experience) and calculated (using predictive mathematical model) and study of the moisture movement in the conditions of low pressure infiltration were conducted.

In the field conditions in 2009 and 2010, the movement of moisture by a special technique on soil monoliths was explored. According to the scheme of experience two identical in size (42 cm in diameter) and soils monoliths have been prepared. The side walls of the monoliths were wrapped in foil and covered with mounting foam and then they have been buried to prevent the moisture loss and heat. This technique allowed us strictly to meet the condition of one-dimensional (vertical) moisture moving in the soil profile and accurately use all balance-sheet ratios, as due to the isolation of the walls the difficult-to-estimate moisture loss on lateral lamination was liquidated

The experiment was set so that at the same time in both monoliths was held the absorption of water from the surface, but in one case on the surface the constant pressure of 5 cm was maintained and in the other case the water absorption was no pressure (fine-dispersed sprinkling without the formation of the water layer on the surface top). It is assumed that the presence of even a small (3-6 cm of column of water) pressure may change the type of moisture transfer from capillary front with non-pressure absorption to influctional, on a separate preferential pathways of transfer, when low-debit absorption is taken place. [9]. The difference of the conditions at the upper border (non-pressure and low-debit of infiltration) had to confirm/refute noted previously fact [9], that for the formation of preferential moisture fluxes, in addition to the availability of macropores, cracks, or other inherent soil features of the pore space, the necessary condition is the presence on the soil surface the additional hydraulic pressure.

For the determination of moisture content in monoliths the daily layerwise (0, 5, 10, 20, 30, 40, 50, 60 cm) drilling for the study of the dynamics of moisture has been conducted. At the end of the experiment on the horizontal grid at these depths the samples (25 experimental points at each layer) for determining the spatial distribution of humidity have been taking. Evaporation from the surface of the soil during the entire period of the experiment was determined with using the small (about 83 cm^3) monoliths.

Computational study of the moisture movement in the conditions of low - debit and non-pressure infiltration was conducted with using the mathematical model of moisture transfer - HYDRUS-1D [20, 21]. For the experimental support of the model (first of all, WRC) the following methods were used [7, 11]:

I. Empirical method

1. Method of capillarimeters. The method is based on the fact that in the soil sample the finely porous ceramic filter is inserted. In the filter the controllable rarefaction is formed. This rarefaction is equal to the pressure of moisture. Through some time the balance between the pressure of the moisture in the soil and the controllable pressure in the filter is established. At this point, the equilibrium humidity of the soil is measuring. In turn, setting the rarefaction in the filter and measuring the equilibrium humidity receive the water retention curve for this sample.

2. Method of tenziostates or sand - kaolin boxes. This is a widely used method. In this method use boxes in which as saturated membrane is fine sand, or clay. In the sand boxes the rarefaction 30, 100 is supported, and in the kaolin ones - 300 and 500 cm of the water column. On the membrane the undisturbed structure samples are placed and achieve the balance. At this point, the humidity as experimental point on the water retention curve is measuring.

3. The method of centrifugation (centrifuge). In the centrifuge glass put the saturated sample of the soil. The rarefaction is created in a centrifuge, and the excess water is drained by special tray in the centrifuge tube.

II. Semi-empirical methods (restoration of WRC with hydrological constants and properties of soils – pedotransfer functions, PTF):

1. PTF using in the program Agrotool (PTF_Hydr-const)[19]);

2. PTF on the basis of Voronin's «secants» (PTF_Voronin) [7];

3. On PTF of granulometric structure (PTF_gran). It was used database Rosetta in HYDRUS);

4. On the regional PTF (PTF_region) received by O.A. Troshina [8]. These PTF were obtained by the regression method on the basis of a large number of experimental data on the complex of gray forest soils of the Vladimir Opol'e on the basis of the density of the soil organic matter content and the definitions of WRC by the capillarimetrical method.

One of the tasks of the research is modeling of the mentioned processes, the comparison of the calculated and experimental data in order to characterize what experimental support of the model is the most adequate: WRC obtained by the experimentally above-listed common methods, or using PTF and any the above (1-4) semiempirical approaches.

Results and discussion

We have investigated the distributions of humidity along the profile of agro-gray soil prove that in the absence of pressure on the soil, the moisture after the process of infiltrationhas has been moved to a depth of 30 cm, and in the presence of a hydraulic pressure - up to 40 cm. The spatial distribution of moisture in the end of the experiment (Fig. 1) shows that, for the low-debit infiltration the statistics of humidity varying is more significant (at depths of 50 and 60 cm quartile and range were about 4–6 and 15–18 %). This is due to the fact that in low-debit infiltration the preferred flows of moisture are manifested. In this context the substance is carried over the separate water «tension bars», channels of macrospores and cracks. The unstable border of moistening with the more rapid movement of water than in the main soil is formed. So in the bottom of the profile there are areas with high humidity. When the non-pressure infiltration there is less variation of humidity (at depths of 50 and 60 cm quartile and range were about 2–4 and 5–10 %), as the water slowly moves through soil and drenches the entire profile evenly.

Modeling of these processes in the program HYDRUS 1D showed that by gravity filtration the model with the introduction of WRC obtained by the methods of capillarimeters and tenziostates and also the regional PTF better than others described the behavior of water in the soil better than others – the average square error of the modeling in this case was the lowest and for the monolith with the presence of pressure on the surface the model with the introduction of WRC received by the tenziostates method, and also taking into account the granulometric composition is the most suitable (Table 2).

Table 2: Quadratic average errors of modeling in using the different experimental support

Experimental suppott variant	The method of obtaining WRC	Quadratic average error	
		by gravity irrigation	by low-debit irrigation
(1) Method of capillarimeters	experimental	0,0586	0,0541
(2) Method of tenziostates	experimental	0,0536	0,0335
(3) Method of centrifugation	experimental	0,0856	0,0862
(4) On Agrotool programe [17]	PTF based on the data on FC* and WP*	0,0649	0,0541
(5) Method of Voronin's «secants»	Based on the data of porosity , WP and FC**	0,0863	0,0794
(6) On PTF of granulometric structure	On ROSETTA database (in HYDRUS)	0,0724	0,0345
(7) Regional PTF [5]	According to the data for the soils of the Vladimir Opol'e on the basis of density and organic matter content [6]	0,0473	0,0581

*LWC - lowest water-absorbing capacity, WP–wilting point, FC – field capacity

Probably the appreciable errors when using the model of an experimental WRC obtained by the centrifuge method are connected with the fact that when determining WRC occurs the great inaccuracy, which is connected with the using of the small sizes disturbed samples and with the insufficiently accurate setting initial conditions of the experiment (the storage of samples, their drying, various preliminary saturation of the sample by water). In the method of tenziostates the samples of undisturbed composition are used, providing the most accurate determination of hydro-physical characteristic of the soil. The stable and accurate method for the determination of the granulometric composition gives the more reliable results. The worst were the model with using the WRC renewal by Voronin as experimental supply and the method of centrifugation.

Statistical analysis of the inaccuracies (the total errors of humidity calculation along the profile, i.e. for all investigated layers of the monolith) of the models showed that in the case of non-pressure infiltration the smallest errors and their varying occur when using PTF data for Vladimir Opol'e (Fig.2).

For low-debit infiltration the lowest total errors of simulation and their variations are observed when using PTF of granulometric composition. Also among the experimental methods of obtaining WRC the method of tenziostates is the best. The maximal variation of the errors occurs when using the method of centrifugation in both cases under given conditions at the upper border of the soil profile. Note also that deviation of the central mean of the inaccuracy from zero indicates the possible presence of systematic errors: apparently, in the case of non-pressure infiltration this type of error is the most likely when using PTF on granulometric composition, Voronin's «secants» and the experimental centrifuge method, and when the pressure infiltration of the simulation - when using as a predictor of granulometric composition and using the regional PTF (Fig. 2). We emphasize that extra researches and calculations are needed for the final conclusions about the presence of systematic errors when using different experimental support in the predictive modeling of water regime.

Comparison of models with nonparametric Williams-Klute criterion showed that the best experimental support of the mathematical model HYDRUS-1D is the use of regional PTF.

On the results of the modeling of water regime of soils all experimental support of the model can be arranged in the following order: better suited the use of regional PTF > then WRC obtained by the method of tenziostates > WRC obtained by the method of capillarimeters > PTF which use in the program Agrotool (on the basis of the experimentally obtained hydrological constants) > PTF that use as predictors of granulometric structure (from the ROSETTA data base > WRC obtained by centrifuging > PTF, on the basis of Voronin's «secants».

Apparently, from conducted researches the following methodical recommendation for researchers of water regime of soils can be done: in regional studies, forecasts, optimization of water regime of soils, it is necessary to create their own regional hydrological databases, which, even in the case of a small number of predictors (as in this case, only the density and organic matter content) provides with physically based models the sufficiently accurate and reliable description of one-dimensional water regime in the scale of soil profile.

Resume

1. The transference of moisture considerably differs, even for small changes of the conditions at the upper border, primarily due to the mechanism of the moisture transference. In the presence of the head of moisture on the soil surface can occur the preemptive streams of moisture, that essentially changes the physical mechanism of the transference of moisture and, accordingly, the mathematical description and the using models.

2. Different experimental support gives the significantly different errors of the modeling. All studied methods of obtaining WRC give the great dispersion of the modeling errors. Among experimental methods the smallest errors can occur when using the methods of capillarimeters and tenziostates, and with using PTF – in the case of regional PTF with density of soils and organic matter content as predictors.

3. The using of the regional PTF is the most adequate experimental support for the mathematical model HYDRUS-1D, describing the processes of non-pressure and low-debit infiltration and the further redistribution of moisture in the soil profile

Conclusion

In this article the approach of the comparative evaluation of different methods of obtaining hydrophysical information for accurate predictive modeling in scale of pedon is suggested. It should be noted that all the results are given only for one type of the soil; therefore it is impossible to affirm with confidence about the suitability of similar data for other soils.

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Figures

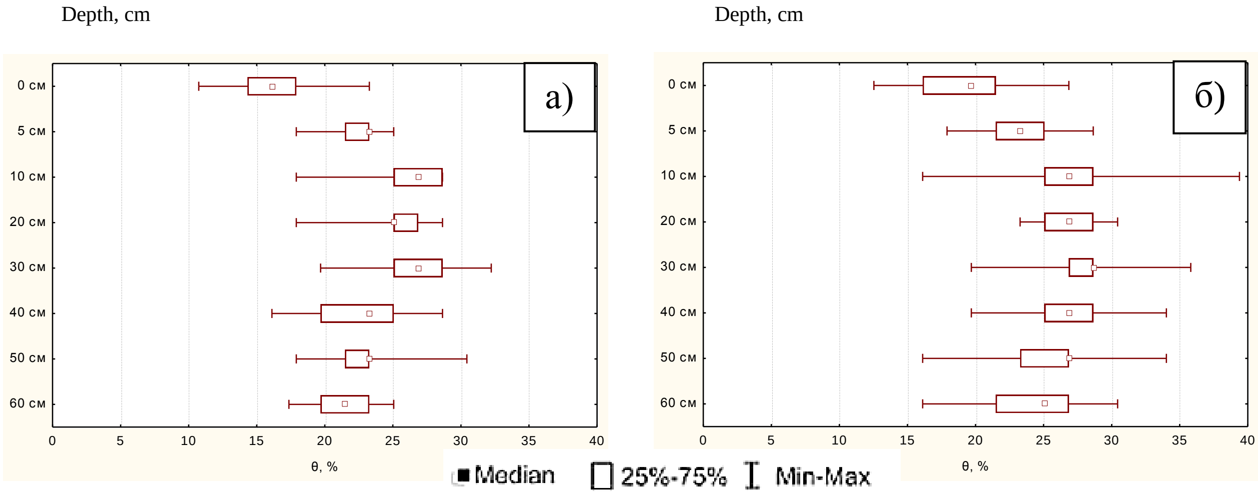

Fig. 1. Statistics of the humidity distribution on the layers of the soil profile in 5 days after irrigation (a – by gravity filtration, b – by low-debit iltration)

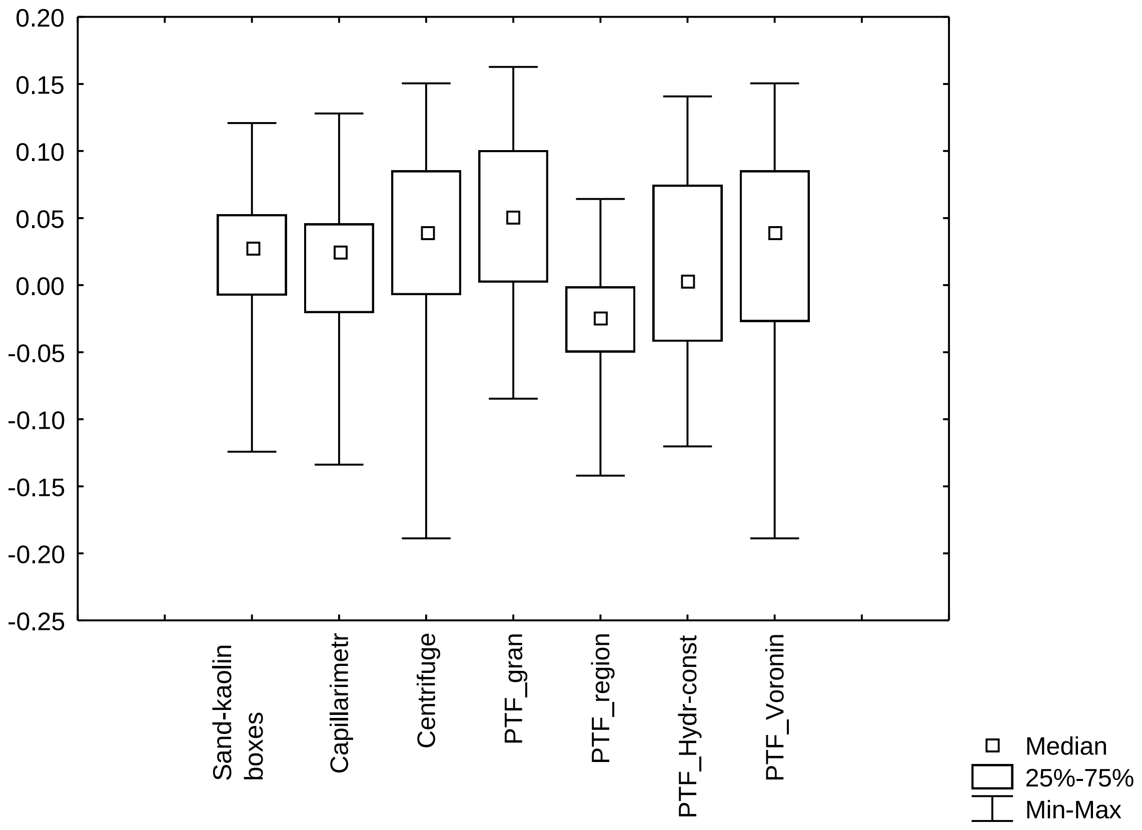

Fig. 2. Inaccuracies (the total errors of humidity calculation along the profile, i.e. for all investigated layers of the monolith) of the model for watr retention curve derived by different experimental data and PTF calculations

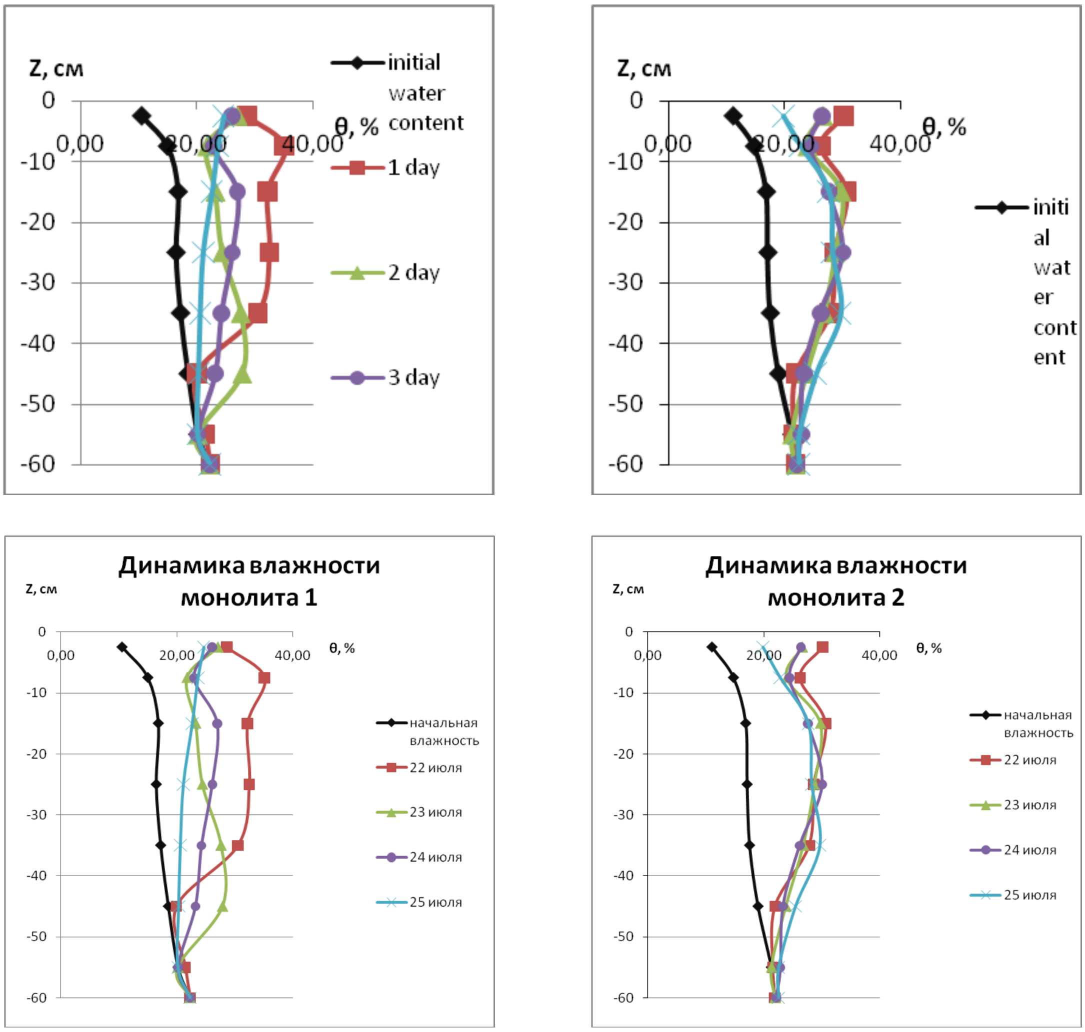

Fig. 3. Humidity distribution along the soil profile before and after irrigation
(a – by gravity filtration, b – by low-debit iltration)