HYDRO-DEPOSITARY AND HYDRO-TRANSMITTING PROPERTIES OF SODDY-PODZOLIC SOILS IN THE COURSE OF SIMULATING THE WATER TRANSFER BY PHYSICALLY-GROUNDED MODELS

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The results of field experiments conducted on the medium-loamy agro soddy-podzolic soil showed that in the presence of the hydraulic head of water at the soil surface the water is moving predominantly through migration ways, thus decreasing the hydro-depositary properties of soils. The water movement was studied by a special method performed in two soil monoliths identical in size (42 cm in diameter and 60 cm high). The monolith walls were covered by a film, foamed and buried to avoid the lateral water loss. The monoliths were simultaneously saturated with water: one of them – with the constant head of water in 5 cm, the other monolith - with fine-dispersed sprinkler without the formation of the water layer at the soil surface. The objectives of this study were to simulate the water movement under conditions of small headed infiltration and without head of water as well as to compare the calculated and experimental data with the view of assessing the most adequate experimental material - the main hydro-physical characteristics obtained experimentally by empiric methods or those calculated by hydrological constants and soil properties (pedo-transmitting functions). It seemed reasonable to conclude that the use of regional pedo-transmitting functions provides better results as compared to main hydrophysical characteristics, the latter being obtained by tensiometers and capillarimeters are better than the pedo-transmitting functions used the particle-size distribution as a prediction in Agrotool program (ROSETTA database) and pedo-transmitting functions on the basis of Voronin's "secant"

Keywords: soil hydrophysics, mathematical model, experimental provision, pedo-transmitting functions.

INTRODUCTION

The soil performs the most important depositary function in global cycle of water. Just thanks to the water retention capacity of soil the major part of water doesn't flow into the catchment area; being filtered through the soil cover it remains in soil. The soil forces by different nature (capillary, adsorption, osmotic, etc.) retain the water, thus forming the soil moisture storage vital for plants, microorganisms, terrestrial and soil biota on the whole. This depositary hydrological role of soil and soil cover is a basis of the production function, biosphere functions capable to create and maintain the biodiversity, to conserve the wealth of biosystems and the health of population as well as many other functions, the performance of which is possible only due to the definite moisture storage.

How is formed and discharged this moisture storage in soil and how does it contribute to the agricultural produce? This question has become very acute long ago. For today, there are several approaches to the study of the problem relating to the formation and discharge of depositary soil moisture storage. At the current stage of the world science development two trends are used in studying the water-holding and water-conducting properties of the soil cover with the view of optimizing the water nutrition for plants. The first trend is based upon the study of water retention function as the main hydrophysical soil characteristic and the water conductivity function. The other approach involves the experimental determination of soil-hydrological constants – characteristics of the moisture status in soil to create the conditions for water supply of plants. This approach is based on field studies of such important soil-hydrological constants as the minimum field capacity, wilting moisture, infiltration coefficient. At present, the study of hydro-depositary and hydro-transmitting functions as a base for governing the soil hydrology is mainly associated with simulation of the moisture movement in soil as the main soil hydrophysical characteristic. However, the preliminary forecasting calculations are required for mathematical models. The simulation procedure is obligatory now in recording the pesticides, forecasting the floods, elaborating the systems of municipal and agricultural water supply and efficient use of the water resources. It is rather difficult to apply mathematical physically-grounded models if they are not provided with adequate experimental data about the hydrophysical soil properties.

In view of this, the experimental material obtained to provide such models is a problem of today. As experimental materials the hydro-physical properties of soils and the major hydrological characteristics of the water-holding and water-conducting functions in particular are used. The modern soil physics reveals a diverse set of methods to determine the main hydro-physical soil characteristics and the pedo-transmitting function. The task of every researcher is only to find the most adequate method for obtaining the experimental material to provide the forecasting models.

The aim of this study is to give a comparative assessment of experimental and calculated dynamic data about the soil moisture under conditions of small headed infiltration and without head of water and to use the method as themost suitable to provide the model HYDRUS ID with experimental materials.

Throughout the research process the following activities have been undertaken to solve the objectives of the present study:

– Field experiment with the view of studying the dynamics of the soil moisture under conditions of small headed infiltration and without head of water and the consequent evaporation under field conditions;

– Description of the water transfer process by using the physically-grounded HYDRUS model;

– Analysis of errors in modeling and substantiating the optimal way to determine the soil hydrophysical properties for forecasting mathematical models.

OBJECTS AND METHODS

The object of research is an agro soddy-podzolic soil at the territory of Zelenogradsky experimental station of the V.V. Dokuchaev Soil Science Institute (Pushkinsky district in the Moscow region). Some physical properties of this soil are presented in Table 1.

In 2010 and 2013 the field experiments permitted to study the water movement by using a special method with soil monoliths. According to the experiment scheme two soil monoliths identical in size (42 cm in diameter) have been prepared. The monolith walls were covered by a film, foamed and buried into the soil to avoid the lateral water and heat loss. This method allowed creating the conditions for vertical water movement throughout the soil profile.

Table 1. Physical properties of agro soddy-podzolic soil (Zelenogradsky experimental station of the V.V. Dokuchaev Soil Science Institute in the Moscow region)

Depth, cm	Particle size distribution, % from soil sample mass			Bulk density, cm^3	Minimum field capacity, %	Infiltration coefficient cm/24 hours	C org, %
	<0.002	0.002–0.05	>0.05				
0–5	10.50	84.78	4.72	1.37	31.1	21.6	1.23
5–10	10.79	86.27	2.94	1.36	27.4	21.6	1.18
10–20	11.39	87.70	0.91	1.34	26.5	21.6	1.26
20–30	11.13	87.49	1.38	1.49	24.2	21.6	1.00
30–40	10.99	86.61	2.40	1.52	21.3	12	0.23
40–50	10.03	85.44	4.53	1.55	23.7	12	0.18
50–60	10.37	86.48	3.15	1.56	24.3	12	0.14

The monoliths were simultaneously saturated with water: one of them – with the constant head of water in 5 cm, the other monolith – without head of water (fine-dispersed sprinkler and no water layer at the soil surface). It is supposed that due to the even small head of water (3–6 cm of water column) the water transport seems transformed from capillary frontal type in case of the absent head of water into the influx along preferential transfer ways in the presence of small headed infiltration. The different conditions at the soil surface (small headed infiltration and the absent head of water) can evidence or disprove the fact that apart from macropores, fissures and the other components of the pore space an additional hydraulic head is required for the formation of preferential water flows.

In the course of this experiment the monoliths were bored every day at a different depth (0, 5, 10, 20, 30, 40, 50, 60 cm) in order to study the moisture dynamics. With the view of studying the moisture distribution in space at the end of this experiment the soil samples were taken at the above mentioned depth (25 experimental points in every soil layer). Microevaporators helped to determine the surface evaporation.

The water movement under conditions of small headed infiltration and without head of water was calculated by means of mathematical model HYDRIS ID. Under use were the methods presented in Table 2 to obtain the experimental material providing this model (first of all, the main hydrophysical characteristics of soil).

Table 2 Analytical empiric methods to determine the main hydro-physical soil characteristic and those to determine pedo-transmitting functions

Empiric method	Half-empiric method (the main hydro-physical characteristic by means of soil constants and properties– pedo-transmitting function)
1. Capillarimeters	4. Pedo-transmitting function according to Agrotool program (Poluektov, Terleev, Agrophysical Institute)
2. Tensiometers	5. Pedo-transmitting function as based upon Voronin's "secant"
3. Centrifugation	6. Pedo-transmitting function according to the particle size distribution (Rosetta database used in HYDRUS)
	7. Regional pedo-transmitting functions obtained in field experimental studies of the soil physical properties and detection of the main hydro-physical soil characteristic in laboratory; they were obtained by regressive method using a great amount of experimental data about the soddy-podzolic soils at the territory of Zelenogradsky experimental station of the V.V. Dokuchaev Soil Science Institute

One of the objectives of the given study was modeling of the above processes, comparison of calculated and experimental data to identify the most adequate for providing the models – the main hydro-physical soil characteristics experimentally determined by methods presented in Table 2.

RESULTS AND DISCUSSION

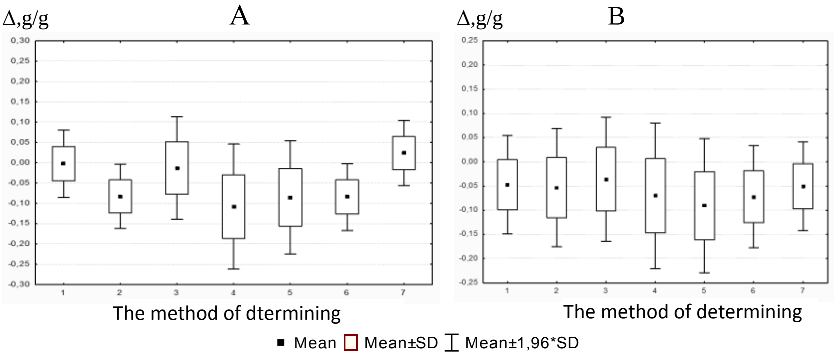
The moisture distribution along the profile of agro soddy-podzolic soil showed that after infiltration the water penetrated to the depth of 30 cm in case of the absent head of water and to the depth of 40 cm in the presence of hydraulic water head. The spatial distribution of moisture at the end of experiment served as evidence that due to small headed infiltration the statistical indices of moisture variability seemed considerably higher at the depth of 50 and 60 cm accounting for 4–6 and 15–18%. This is explained by occurrence of preferential water flows due to the small headed infiltration. The water penetrated along separate channels of macropores and fissures, thus forming an instable moistening front, in which the water moves more quickly than in the soil mass and the lower part of the soil profile becomes moist. In case of the absent headed infiltration the moisture variability is rather low (2–4 and 5–10% at the depth of 50 and 60 cm) because the water moves slowly throughout the soil and provides evenly moistening of the soil profile.

Modeling of these processes in HYDRIS ID showed that the water behavior in soil is described best of all by the model for the monolith with the absent headed infiltration and provided with the main hydro-physical soil characteristics obtained by methods of capillarimeters and tensiometers as well as regional pedo-transmitting function, thus minimizing the average error of modeling. The model with the main hydro-physical soil characteristic obtained by tensiometers with account of the particle-size distribution seemed suitable for the monolith with the present head of water. Significant errors in models with the main hydro-physical soil characteristics obtained by centrifugation are explained by destroying of small soil samples, the latter being incorrectly dried or saturated with water. Using the method of tensiometers the undisturbed soil samples permit to determine more exactly the hydro-physical soil characteristics. The detection of pedo-transmitting function taking into account the particle-size distribution reveals the most reliable results. The model experimentally provided with the main hydrophysical soil characteristic determined by Voronin’s secant and that constructed by the method of centrifugation didn’t allow obtaining the required results.

The statistic analysis of errors in modeling (total mistakes in calculation of moistening throughout the soil profile, i.e. in all the studied monolith layers) showed that in case of the absent headed infiltration the errors are rather small when the data of regional pedo-transmitting function are used (Fig.).

Under conditions of small headed infiltration the minimal total errors of modeling and their variability are observed in case of using pedo-transmitting functions with account of the particle-size distribution.

Among the experimental methods the application of tensiometers proved to be the most suitable for determining the main hydro-physical soil characteristics. The method of centrifugation displayed a great variability of errors in modeling of the water behavior in both monoliths.



Statistics of modeling errors (difference between real and calculated moisture, Δ, g/g) in case of the absent headed infiltration (A) and small headed infiltration (B) for agro soddy-podzolic soils by using different experimental materials (method of determining the main hydro-physical characteristics of soil, see Table 2).

It is worth emphasizing that the deviation of the average value from zero indicates possible systematic errors -in case of the absent headed infiltration they are probably observed in determining the pedo-transmitting function with the use of particle-size distribution, Voronin's secants and the method of centrifugation. In case of headed infiltration such errors in modeling are observed in the use of the particle-size distribution as a predictor as well as regional pedo-transmitting function. It must be made clear that the further studies and calculations are required to draw final conclusions about systematical errors in obtaining experimental materials for forecasting models of the moisture regime.

When comparing the models according to Williams-Klyute criterion, it seemed reasonable to show that the mathematical model HYDRUS ID was best provided with experimental materials by using regional pedo-transmitting functions.

Based upon these studies it is feasible to give the following methodical recommendation for researchers of the moisture regime in soil – in investigations, forecasts and optimization of the moisture regime at regional level it is necessary to elaborate regional hydrological databases that even in case of a small amount of predictors (in the given case only the bulk density and the content of the organic matter) allow obtaining rather exactly the reliable description of the water regime along the soil profile by using physically-grounded models.

CONCLUSIONS

1. The water transport in soil is quite different even under conditions of small changes at the soil surface; it happens at the expense of differences in the mechanism responsible for water transfer. When the head of water is present, the preferential water flows occur in soil and change the physical mechanism of water transfer as well as the mathematical description and the used models.

2. Differences in the obtained experimental materials reveal different errors in modeling. Among the methods performed in these studies the errors are rather minimal in case of using the capillarimeters and tensiometers as well as the pedo-transmitting function with predictors of the particle-size distribution and the organic matter content.

3. The use of regional pedo-transmitting functions is the most adequate method to provide the experimental material for the mathematical model HYDRUS ID describing the processes of the small headed infiltration, the absent head of water and the consequent water redistribution throughout the soil profile.

An approach is offered to give a comparative assessment of different methods to obtain the information on the hydrophysical soil characteristics for forecasting modeling at a pedon level. One should notice that the results have been obtained only for one soil type. By this reason, it is impossible to be sure that the analogous data can be suitable for the other soils.

REFERENCES

1. Bouma J. Hydropedology as a powerful tool for environmental policy research, *Geoderma*, 2006, Vol. 131, pp. 275–280.
2. Catchment water balance modelling in Australia1960–2004, *Bougton. Agricultural Water management*, 2005, Vol. 71, pp. 91–116
3. Globus A.M. *Experimental hydrophysics soil*, Lenngrad, 1969, 356 p.
4. Harou J.J., Pulido-Velazkes M., Rosenberg D.E., Azuara J.M., Lund J.R., Hiwitt R.E. Hydro-economic models: Concepts, design, application atd future prospects, *J. Hydrology*, 2009, Vol. 375, pp. 627–643.

5. Poluektov R.A., Fintushal S.M., Oparina I.V., ShatskikhD.V., Terleev V.V., Zakharova E.T. Agrotool – a system for crop simulation, *Archves Agronomy Soil Sci*., 2002, Vol. 48, Issue 6, pp. 609–635.
6. Shein E.V., Arkhangel'skaya T.A., Goncharov V.M., Guber A.K., Pochatkova T.N., Sidorova M.A., Smagin A.V., Umarova A.B. *Field and laboratory methods for studying the physical properties of soils and conditions*, Moscow, 2001.
7. Shein E.V., Gudima I.I., Mokeichev A.V. Methods for determination of hydro-core functions for modeling purposes, *Vest. Mosk. un-ta*. Ser.17, Pochvovedenie, 1993, № 2, S. 18–24.
8. Shein E.V., Kokoreva A.A., Gorbatov V.S., Umarova A.B., Kolupaeva V.N. Evaluation of the sensitivity setting and compare migration patterns of pesticides in the soil according to lysimetric experiment, *Eurasian Soil science*, 2009, Vol. 42(7), pp. 824–833.
9. Shein E.V., Pachepskii Ya.A., Guber A.K., Chekhova T.I. Features of the experimental determination of the hydrophysical and hydrochemical parameters of mathematical models of moisture and salt transport in soils. *Eurasian Soil science*, 1995, No. 12, pp. 1479–1486.
10. Shein E.V., Spiridonov Yu.A., Smetnik A.A. *The migration of pesticides in soil*, Moscow, 2005, 336 p.
11. Šimůnek J., van Genuchten M. Th. and Šejna M. *The HYDRUS-1D Software Package for Simulating the One-Dimensional Movement of Water, Heat, and Multiple Solutes in Variably-Saturated Media*, Department of Environmental Sciences University of California Riverside, 2005.
12. *Theories and techniques of soil physics* (Ed.) Shein E.V., KarpachevskiiL.O., Moscow, Kiev, 2007, 616 p.
13. Troshina O.A. *The physical properties of the elements and hydrothermal regime of integrated soil Vladimir plain field (for example, an agricultural field VNIISKH)*: Extended abstract of candidate's thesis, Moscow, 2009. 30 c.
14. Umarova A.B. *Preferential flow of moisture in the soil and the importance of forming patterns in the functioning of the soil*, Moscow, 2011. 266 p.
15. Vadyunina A.F., Korchagina Z.A. *Methods for studying the physical properties of soils*, Moscow, 1986.
16. Van Genuchten M.T., Leij and Yates S.R. *The RETC code for quantifying the hydraulic functions of unsaturated soils*, US Salinity Lab, Riverside, CA (1991).
17. Wilding L.P., Lin H. Advancing the frontiers of soil science towards a geoscience, *Geoderma*. 2006. Vol. 131, pp. 257–274.