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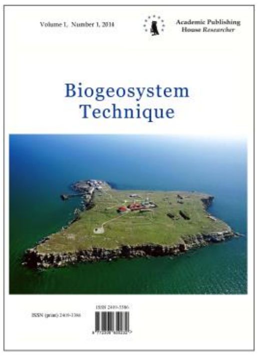

Validation of HYDRUS-1D for Predicting of Soil Moisture Content with Hysteresis Effect

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Abstract

HYDRUS-1D program is commonly used to estimate soil moisture, solute, and temperature flow in saturated and unsaturated zone under different initials and boundary conditions. The aim of the work was to validate the efficiency of HYDRUS-1D program for predicting soil moisture and temperature dynamics with hysteresis using HYDRUS-1D for clay loam Albic Glossic Retisols (Lomic, Cutanic) soils. The efficiency of HYDRUS-1D was determined by comparing field experiment measurements of soil moisture and temperature dynamics with its calculated soil moisture and temperature dynamics by HYDRUS-1D based on soil physical properties. The distribution and the values of measured soil moisture and temperature dynamics in the field were close to its calculated soil moisture and temperature using HYDRUS-1D with hysteresis effect of soil water retention. HYDRUS-1D program can be used for simulation of soil moisture and temperature dynamics, but more accurate calculations are possible when using the hysteresis effect of soil moisture retention curve for Clay loam and silty Clay loam soils.

Keywords: water retention, irrigation, field experiments, experimental and modelling data, water and temperature dynamics.

1. Introduction

Soil moisture and temperature dynamics are forming the soil hydro and thermal regimes. It is used for modeling water and heat flux in the soil, plant production, evapotranspiration, irrigation and drainage designs, groundwater contamination, soil evaluation, soil biota, and environmental processes. Although the field measurements of soil moisture and temperature regimes are accurate, they are time-consuming and costly. The dynamics of soil moisture and temperature may be calculated using mathematical models, which are involving the quantitative description of the hydro and thermal-physical properties based on fundamental of soil physical parameters as predictors. The information of soil hydro and thermal-physical properties is

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required to accurately predict modeling soil moisture and temperature dynamics (Mady, Shein, 2018; Shein, Mady, 2016). Several methods used for estimation and measurement of soil hydro and thermal-physical properties, they have divided into direct and indirect methods. Some attempts have been made to predict indirectly soil hydro and thermal-physical properties from the easily available soil physical parameters using mathematical models and pedotransfer functions (PTFs) (Mady, Shein, 2018). The majority of PTFs can be estimated from proxy variables of soil physical properties those are easily available, such as soil texture components, organic matter content, and soil bulk density (Jarvis et al., 2013; Jorda et al., 2015; Shein et al., 2015).

HYDRUS-1D, a software package for simulating water, heat and solute movement in one-dimensional variably saturated and unsaturated media. The software consists of the HYDRUS computer program, and the HYDRUS-1D interactive graphics-based user interface. The HYDRUS program numerically solves the Richards' equation for variably saturated water flow and convection-dispersion type equations for heat and solute transport. The flow equation incorporates a sink term to account for water uptake by plant roots. The flow equation may also consider dual-porosity-type flow with a fraction of water content being mobile, and fraction immobile (Gerke, van Genuchten, 1993a, 1993b; Simunek et al., 2008). The heat transport equation considers transport due to conduction and convection with flowing water (Simunek et al., 2001, 2003). So it is important to evaluate the efficiency of HYDRUS-1D program for forecasting soil moisture and temperature dynamics for clay soil of podzolic genesis.

2. Materials and methods

The field experiment was carried out in Albic Glossic Retisols (Lomic, Cutanic) (WRB, 2014), Moscow region, Russia, during the period from 2 to 7 August, 2017. The dataset of soil moisture, soil potential, soil temperature and meteorological data was collected and measured for program HYDRUS-1D at soil depths 10, 15, 20, 30, 40, 50 and 60 cm. The cylindrical monolith of Albic Glossic Retisols was dug, with a diameter of 1 m and a height of 60 cm. Moreover, the walls of the monolith were isolated by foam from the horizontal flow of soil moisture and heat movement in Albic Glossic Retisols.

2.1 Soil moisture dynamics

a) Soil moisture was measured daily at soil depths (0, 10, 20, 30, 40, 50, and 60 cm) using direct method (weight method)

b) Soil water pressure was measured daily using the digital tensiometers at soil depths (0, 10, 15, 20, 30, 40, 50, and 60 cm) for 3 days before and after irrigation.

2.2. Soil temperature dynamics

a) Soil temperature was measured daily using digital temperature sensors or digital recorder (EC LERK-USB-RHT-K1), with isolated from the horizontal flow soil walls monolith of Albic Glossic Retisols, at soil depths (0, 10, 15, 20, 30, 40, 50, and 60 cm).

2.3. Efficiency of program HYDRUS-1D

In order to estimate the efficiency of program HYDRUS-1D for prediction soil moisture and temperature dynamics in Albic Glossic Retisol, its results were compared with the field experiment. The dataset of soil water content, soil temperature, and meteorological data was measured for program HYDRUS-1D at soil depths 10, 15, 20, 30, 40, 50 and 60 cm. When reaching moisture equilibrium in the process of draining the monolith (according to long-standing tensiometric observations), the soil moisture content was determined by drilling. The density of the soil was determined with repetition and presented in Table 1.

Table 1. Statistical characteristics of some soil properties (Mady, Shein, 2018)

Soil properties	Medium	Min	Max	Standard deviation
Sand, 2-0,05 mm, %	5.50	1.80	8.91	2.01
Silt, 0,002-0,05 mm, %	67.58	59.01	76.35	4.96
Clay <0,002 mm, %	26.90	17.65	35.29	5.50
Soil density, g/cm^3	1.35	1.19	1.49	0.10
Organic matter content, %	1.37	0.34	2.97	0.77

Soil moisture hysteresis was determined in spesial laboratory experiment with tensimeters in the range of soil water pressure form −30 to −800 cm on soil undistributed samples for the layers 0–10, 10–30, 30–40 and 40–60 cm (Shein, Mady, 2018). During field experiment meteorological data for the calculation of evaporation from the surface soil was measured for the HYDRUS-1D program from 2 to 7 August 2017 based on the average of daily temperature, wind speed, and relative humidity using the Penman-Monteith equation. The upper and lower boundary conditions for soil moisture and temperature are shown in Table 2 for modeling soil moisture and temperature dynamics which was used in HYDRUS-1D program.

a) Soil moisture dynamics: Pre-processing for HYDRUS-1D program depended on the parameters of van Genuchten (1980) (θr, θs, α_d and n) which were determined based on the particle size distribution and soil bulk density. Also, water flow simulation was determined with hysteresis based on the model of Kool and Parker (1987), α_w for the wetting branch.

b) Soil temperature dynamics: Pre-processing for HYDRUS-1D program depended on the parameters of Chung and Horton (1987) which were determined based on the soil the particle size distribution (soil texture).

Table 2. Boundary conditions for soil water and heat transport

Parameter	Boundary condition	
Water flow	Upper	Atmospheric BC with surface layer. Evapotranspiration was calculated the average of daily temperature, wind speed, and relative humidity using the Penman-Monteith equation.
	Lower	Free drainage
Heat transport	Upper	Soil temperature BC (measured, on the surface)
	Lower	Soil temperature BC (constant, jn the depth 60 cv)

3. Results and discussion

3.1. Simulation soil moisture dynamics

As the result of the conducted field experiment with artificial irrigation of the dried monolith of Albic Glossic Retisols, the dynamics of soil moisture and temperature were measured, and calculations of these dynamics under really initial and boundaries conditions were estimated. Figure 1 shows the differences of real and calculated soil moisture without and with hysteresis. Figure 2 shows the distributions of measured soil moisture in the field were usually different from its calculated soil moisture by the HYDRUS-1D program. However, the difference between measured soil moisture in the field and its calculated soil moisture by program HYDRUS-1D was small at soil depths (10, 20, 30, 40) cm, whereas those difference were large at bigger soil depths (50 and 60) cm as Figure 3. The reason of that due to the lower boundary condition was free drainage at soil depth 60 cm, but those boundary conditions are usually used at depths bigger than that, reach to 150 cm.

3.2. Simulation soil moisture dynamics with hysteresis

The differences on Figure 1 shows the difference between calculated soil moisture without hysteresis and its calculated soil moisture with hysteresis by HYDRUS-1D were small at soil depths (10, 20, 40 and 60) cm, but the difference was larger at shallow soil depths 20 and 40 cm, especially in case soil moisture calculation without hysteresis of soil moisture retention. The differences on Figure 1 are usually real but less than 0,01cm^3/cm^3. The reason for the difference related to the hysteresis degree which depended on, the value of soil bulk density and the percentage of clay. The higher degree of hysteresis was at the surface soil layers, but the lower degree of hysteresis was at soil depth 60 cm.

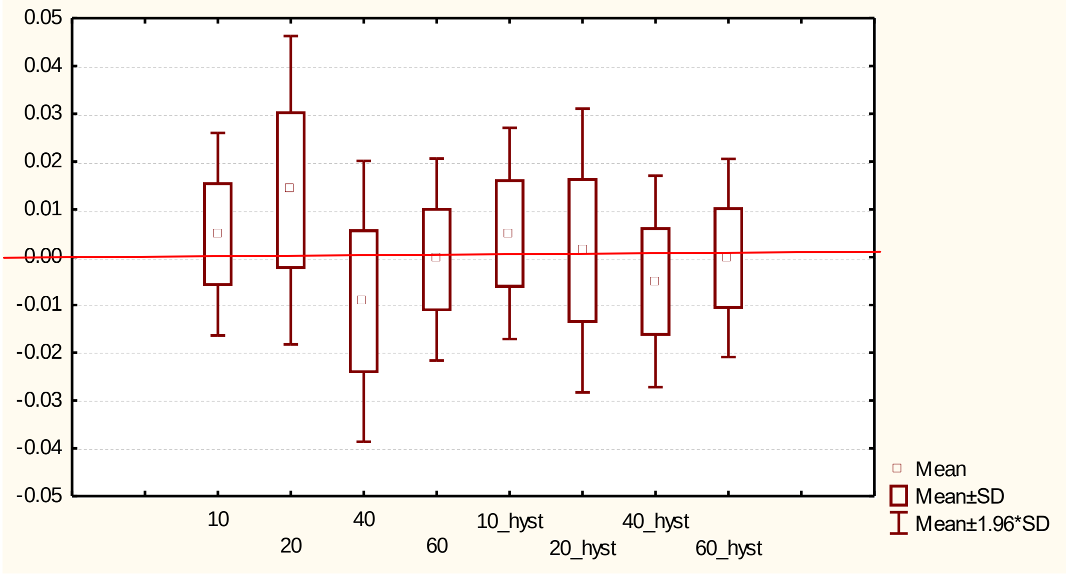


Fig. 1. Statistics of the difference between measured and calculated soil moisture content (by volume) using program HYDRUS-1S for the depths 10, 20, 40 and 60 and calculated with soil moisture hysteresis (10_hyst, 20_hyst, 40_hyst and 60_hyst) of agro-podzolic soil

HYDRUS-1D is commonly used for simulation soil moisture dynamics with hysteresis based on the model of Kool and Parker (1987) $\alpha_w = 2\alpha_d$. The above calculations and the good agreement between the calculated and real values of humidity indicate in favor of this dependence. However, in some cases, and in some soils, a different model can be used on the same theoretical basis. Apparently, for each soil in study, the hysteresis of water retention can be described by close regression functions of the bubbling pressure of the drying and wetting curves. For example, for clay structured Albic Glossic Retisols the hysteresis can be calculated on the model $\alpha_w = 0.13 + \alpha_d$, (Shein, Mady, 2018).

3.3. Simulation soil temperature dynamics

It is known that water and thermal regimes are closely related. Therefore, an adequate water regime estimation in the HYDRUS-1D program with the use of hysteresis data should be adequately reflected in the restoration of the temperature regime. Figure 2 shows the differences between measured in the field and calculated by program HYDRUS-1D soil temperatures which was small at soil depths (0–10) cm, but it was larger at soil depths (10–15) and (15–20) cm. The reason of that may be related to the sinusoidal equation which used by HYDRUS-1D; this commonly used for simulation soil temperature in the surface layer. theoretical equation in real conditions has noticeable deviations. But the profile distributions of soil temperatures (Figure 3) shows that the distributions of really measured soil temperature in the field conditions did not differ from its calculated soil temperature by program HYDRUS-1D. The range of temperature values and their profile distributions are close and adequate in dynamics.

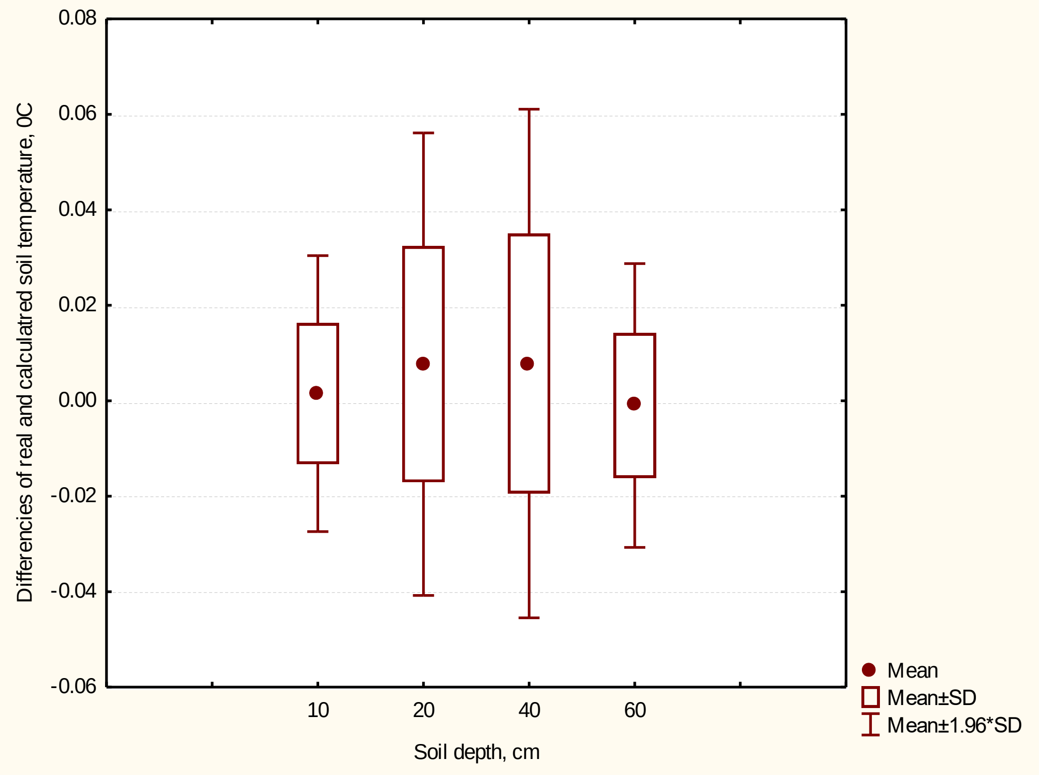
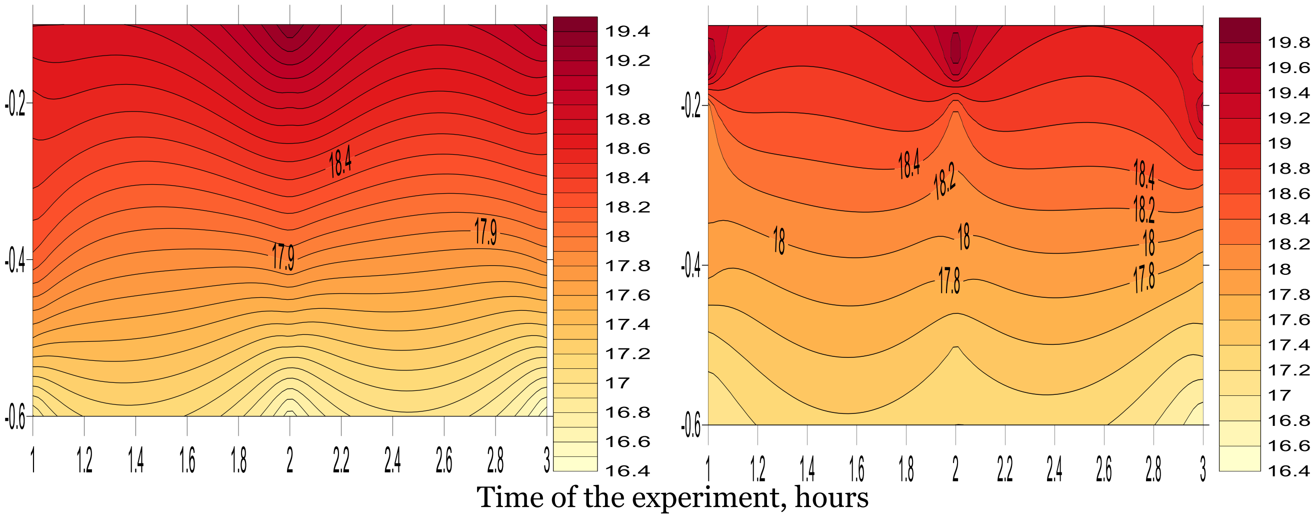


Fig. 2. Statistics of the differences between measured and calculated soil temperature using HYDRUS-1D for different depths of Albic Glossic Retisols



a) b)

Fig. 3. Soil temperature dynamics (a) in the field experiment and (b) calculated using the HYDRUS -1D program

4. Conclusion

HYDRUS-1D program is commonly used to estimate soil moisture and temperature dynamics. The efficiency of HYDRUS-1D increases at surface soil depths (0–15) cm. The efficiency of HYDRUS-1D depended on used initial and boundary conditions and the use of the hysteresis effect in case of irrigation of the dried soil. The difference between the field experimental data based on the dynamics of measured soil moisture and temperature in the field and its calculated soil moisture and temperature by HYDRUS-1D were small, which indicates to the possibility usage

HYDRUS-1D program for simulation of soil moisture and temperature dynamics (with hysteresis) for Albic Glossic Retisols.

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References

Chung, Horton, 1987 – *Chung S.O., Horton R.* (1987). Soil heat and water flow with a partial surface mulch. *Water Resour. Res.,* 23(12): 217-2186.

Gerke, van Genuchten, 1993a – *Gerke H.H. and van Genuchten M.Th.* (1993a). A dual-porosity model for simulating the preferential movement of water and solutes in structured porous media. *Water Resour. Res.*, 29: 305-319.

Gerke, van Genuchten, 1993b – *Gerke H.H., van Genuchten M.Th.* (1993b). Evaluation of a first-order water transfer term for variably saturated dual-porosity flow models. *Water Resour Res.*, 29: 1225-1238.

Jarvis et al., 2013 – *Jarvis N., Koestel J., Messing I., Moeys J. and Lindahl A.* (2013). Influence of soil, land use and climatic factors on the hydraulic conductivity of soil. *Hydrol Earth Syst. Sci.*, 17: 5185-5195. DOI: https://doi.org/10.5194/hess-17-5185–2013

Jorda et al., 2015 – *Jorda H., Bechtold M., Jarvis N. and Koestel J.* (2015). Using boosted regression trees to explore key factors controlling saturated and near-saturated hydraulic conductivity. *European Journal of Soil Science*, 66(4): 744-756. DOI: https://doi.org/ 10.1111/ejss.12249

Kool, Parker, 1987 – *Kool J.B.,Parker J.C.* (1987). Development and evaluation of closed-form expressions for hysteretic soil hydraulic properties. *Water Resour. Res.*, 23(1): 105-114.

Mady, Shein, 2018 – *Mady A.Y., Shein E.V.* (2018). Modelling and validation hysteresis in soil water retention curve using tomography of pore structure. *Int. J.* Water,12(4): 370-381. DOI: 10.1504/IJW.2018.10016241

Shein, Mady, 2016 – *Shein E.V., Mady A.Y.* (2016). Soil Thermal Parameters Assessment by Direct Method and Mathematical Models. *Journal of Soil Science and Environmental Management,* 7(10): 166-172. DOI: 10.5897/JSSEM2016.0585

Shein and Mady, 2018 – *Shein E.V., Mady A.Y.* (2018). Hysteresis of the water retention curve: wetting branch simulation based on the drying curve. *Moscow University Soil Science Bulletin*, 73(3): 124-128. DOI: 10.3103/S0147687418030080

Shein et al., 2015 – *Shein E.V., Mady A.Y., El Hassna A. Mohamed.* (2015). Soil Saturated Hydraulic Conductivity Assessment by Direct and Pedotransfer Functions Methods. *Biogeosystem Technique*, 6(4): 396-400. DOI: 10.13187/bgt.2015.6.396

Simunek et al., 2001 – *Simunek J., Wendroth O., Wypler N., van Genuchten M.Th.* (2001). Non-equilibrium water flow characterized by means of upward infiltration experiments. *Europ. J. Soil Sci.*, 52: 13-24.

Simunek et al., 2003 – *Simunek J., Jarvis N.J., van Genuchten M.T., Gardenas A.* (2003). Nonequilibrium and preferential flow and transport in the vadose zone: review and case study. *J. Hydrology,* 272: 14-35.

Simunek et al., 2008 – *Simunek J. van Genuchten M.Th., Sejna M.* (2008). Development and Applications of the HYDRUS and STANMOD Software Packages and Related Codes. *Vadose Zone J.,* 7(2): 587.

Van Genuchten, 1980 – *Van Genuchten M.Th.* (1980). A closed-form equation for predicting the hydraulic conductivity of unsaturated soils. *Soil Sci. Soc. Am. J.,* 44(5): 892-898.