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Modeling of vertical moisture transfer in agricultural soils under two land use types

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Abstract

The intensive exploitation of soils leads to deterioration of their water and nutrient regime, soil erosion, salinization and desertification. The atmospheric moisture is only source of water supply of the dry steppe's soils. Taking into account the expected climate warming and changes in precipitation, the process of water infiltration and distribution in steppe soils is of particular interest. The moisture regime of chernozems in the Uymon intermountain depression landscapes with different agricultural use types was investigated. The parameters of approximation of water retention curve (WRC) by the Van Genuchten function were determined by semiempirical computational method based on data of the particle size distribution soil, soil density, moisture of withering and the lowest moisture capacity, in RETC. It was shown that all measured soil-hydrological parameters of chernozems well coincided with WRC built at RETC using only the particle size distribution , density, porosity, TH33 and TH1500. In HYDRUS-1D we calculated the volume of reduction of moisture reserves in the upper soil horizons as a result of water infiltration into the lower layers. According to the results, the moisture content in agricultural soils depends on the land use type: for example, saturated soil moisture is higher in the soil with no-till practice than in annually plowed soil. It is shown that in the chernozem of arable land (with oat crops) there is a faster soaking of all soil layers than in the chernozem under the mixed grass, in which the transpiration factor corrects the dynamics of humidity to a greater extent.

Keywords: Chernozem, land-use, water retention, hydraulic conductivity, soil moisture, HYDRUS-1D

Introduction

Sustainable management of soils is an important global issue of the 21st century. Providing approximately 8 billion people with an environmentally sustainable production system is a serious necessity (Ussiri and Lal, 2018). On the other hand, the ecological condition and quality of natural water are determined by the catchment area state, as the main processes forming the chemical composition of water take place here (Ikem and Adisa, 2011; Andrade *et al*., 2018). Infiltration water to the soils is a key process that partitions precipitation to the surface runoff and water that enters the soil profile (Vereecken *et al*., 2019). In soils of dry steppes, the atmospheric moisture is the only source of water supply practically and the process of water absorption and its further redistribution in dry soil (infiltration) is of particular interest (Shein, 2005). Expected climate warming and changes in precipitation emphasize the importance of understanding how the land surface transports and stores surface water (Seaton *et al*., 2019).

To study and adequately assess the quantitative and qualitative effects of runoff from the catchment to the watercourse, it is necessary to be able to perform calculation and modeling of moisture transfer processes in soils. The modern models relying on special hydro-physical experimental support allow calculating the processes of moisture transfer in soils (Simunek *et al*., 2003). Obtaining adequate support for such model is very important for hydrological research (Schindler *et al*., 2010; Shein *et al*., 2012; Shein, 2015; Bezerra-Coelho *et al*., 2018). A quantitative characteristic of the water-retaining capacity of soils is the water retention function (curve) (WRC), as a relationship between the capillary-sorption moisture pressure (P) and soil moisture. The vertical movement of moisture in the unsaturated steppe soils is characterized by the function of hydraulic conductivity – the relationship between the hydraulic conductivity coefficient (K) and P (Shein, 2005).This parameter significantly determined by soil physical properties – density, porosity, granulometric composition.

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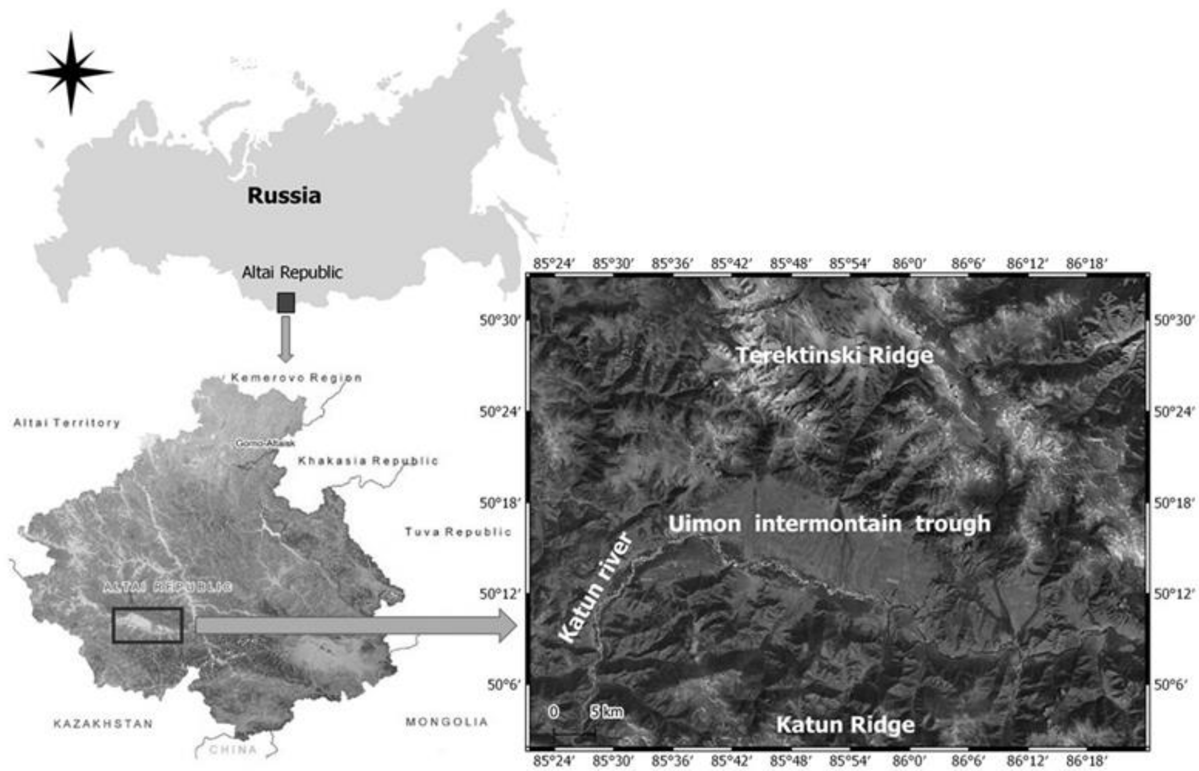

Figure 1. The map of the study area: Uimon intermountain depression (Altai, Russia)

Currently in Soil Science there is a concept of "physical quality of the soil", which is crucial for achieving optimal crop yields (Anghinoni *et al*., 2019). It is believed that the moisture content in agricultural soils depends on the method of plowing it and on the cultivated crop (Mohammad *et al*., 2014). Type of tillage affects its physical and chemical properties, determines the values of the main soil and hydrological characteristics and the moisture transfer (Fer *et al*., 2020).

The modeling of the moisture infiltration in the different land type use chernozems of the Uimon intermountain depression was the aim of the present research. The objectives of the study were: to investigate the main hydro physical properties of chernozems of arable land and hayfields, to simulate the downward movement of moisture in soils for a 10-day period without precipitation, and to establish the differences in moisture retention and moisture transfer depending on the type of land use.

Materials and Methods

The Uimon intermountain depression is located in Central Altai (mountain system in the South of Western Siberia), at the altitude of about 900 m above sea level, in the Altai Republic (Russia) (Figure 1). Its area is 400 km^2, its extent is about 35 km, and width about 10-12 km. From the south, the Uimon intermountain depression is bordered by the Katunsky Range, and from the north – by the Terekhtinsky Range. The average annual rainfall norm in the Uimon trough is 450-500 mm, the main amount falls from May to July, the humidification coefficient at this time is 0.7-0.8 (Khmelev, 1989). The bottom of the depression is a wide slightly undulating plain, its relief is complicated by the riverbeds of the Katun River tributaries, flowing from the tops of the framing ridges.

Sandy-pebble quaternary deposits of the Uimon depression are overlapped by carbonate loam and sandy loam. The soil cover is presented by Ordinary and Southern chernozems (Haplic chernozems), and now they are almost completely plowed, only small areas are occupied by hayfields. General and physical properties of the Uymon steppe soils were previously studied by V.A. Khmelev (1989), the biogeochemistry of these soils was studied by D.N. Balykin (2009).

Ordinary chernozems under two different land use types were studied. These soils were formed on loamy-gravelly lacustrine-deluvial deposits which are the products of the destruction of calcareous sandy-clayey and chloritesericite schists of the southern slopes of the Terekhtinsky mountain range.

The considered agricultural landscapes occupy an aligned and topographically homogeneous area with a surface slope of about 0°. The first plot was the arable land under oat crops to the stage of pulling. The second plot was the hayfield under the forb-cereal plant association. Soil sections were excavated on these two fields at a distance of not more than 100 m from each other. Soil samples were taken from genetic soil horizons, for arable chernozem: A(0-26 cm) B (26-40 cm) and C (40-60 cm), for hayfield chernozem: A(0-16 cm) B (16-26 cm) and C (26-40 cm) on July 8, 2014. According to archival data (www.rp5.ru), on July 5, 2014, 14 mm of precipitation fell; in the period from July 6 to July 8, 3.5 mm of precipitation fell. Therefore, at the time of observations, the upper horizon of the studied chernozems was distinctly more humid than the lower layers.

The field moisture was determined by the thermostatic-weight method. The density of soil composition was determined by the cutting ring method. The density of the solid phase was determined pycnometrically. The granulometric composition of the soils was determined by the pipette method according to Kachyńsky. The total porosity was determined through the ratio of the soil density and the density of its solid phase (Sokolov, 1975). The determination of the minimum moisture capacity in the field was carried out 24 hours after the completion of the experiments on water permeability (Sokolov, 1975). Wilting moistures were determined by the method of vegetation miniatures (seedlings) according to GOST 28268-89. The determination of the maximum soil hygroscopicity was carried out by the method of soil saturation by the vaporous moisture according to GOST 28268-89. The method of Tyurin was followed for the determination of organic matter contents, the pH was determined potentiometrically (Arinushkina, 1970).

To approximate the WRC, the most widely known Van-Genuchten equation was used [11]: $\theta(P) == \frac{\theta_s - \theta_r}{(1+(\alpha P)^n)^m} + \theta_r$, where m = 1-1/n, θ is the equilibrium moisture (corresponding to a certain soil moisture pressure P), θ_s is the moisture close to saturation humidity, θ_r is the residual moisture, α is the inverse of the capillary-sorption pressure (reciprocal to the bubbling pressure), approaching the pressure of the air inlet, n - the slope of the curve (Van Genuchten,1999; Scaap at al., 2001; Radcliffe and Simunek, 2010; Shein *et al*., 2012; Bezerra-Coelho *et al*., 2018).

The WRC recovery was carried out by a semi-empirical calculation method using pedotransfer functions (PTF) - dependencies which make it possible to construct the WRC according to the traditionally determined basic properties of soils (Shein, 2009; Radcliffe and Simunek, 2010). In this paper, PTF Rosetta Lite 1.1 was used, incorporated in the RETC program. To calculate the WRC approximation parameters for the Van-Genuchten function, experimentally obtained particle size distribution (SSC), density (BD), minimum moisture capacity (TH33) and wilting moisture (TH1500) were used. The fractions boundaries of granulometric composition were reduced to the international classification of FAO by the method of linear graphical interpolation (Shein, 2009).

The process of vertical moisture transfer in the ordinary chernozems of the Uimon steppe in case of initial saturation of only the upper horizons with moisture (in July, after rains) was described using a computer simulation system for moisture transfer in soils HYDRUS-1D (USA, authors: J. Simunek, M.Th. Van-Genuchten, M. Seina, www.hydrus2d.com). The HYDRUS-1D model is the most widely used and verified code for unsaturated flow modeling in soil science. Modeling of the moisture infiltration process in agrochernozems was carried out taking into account the physico-chemical properties and structure of each soil horizon. In the calculations, the connectivity parameter of the pores l=0.5 was assumed (Smagin, 2011). We didn`t consider macropores and hysteresis.

Modeling of the vertical moisture movement in the Uimon depression chernozems was carried out for a period of 10 (July) days without precipitation in two variants 1) simple vertical movement of moisture (Water transport), and 2) taking into account the absorption of water by plant roots – motley grass (hayfield) and oats (arable land). In the second course, the submodel was selected in the "Main process" directory, and in "The Root Water Uptake Parameters" the parameters of the root consumption for a certain type of culture were selected from the built-in database. The most suitable option in the case of arable land was the "Corn – vegetative period", in which P*0* (the pressure value below which the roots of cereals begin to draw water from the soil) is -10 cm water column, and the optimum absorption of water (between the pressure of P_{opt} and P*2*) occurs in the range pressure moisture from -10 to -400 cm water column. With hayfield, the parameter *"Grass"* was chosen with P*0* = -10 cm water column and the optimal absorption range from -25 to -300 cm water column. The distribution of root systems was built in a graphical editor (Soil Profile). In case of arable land with oat crops, the constant root density of 0-15 cm and the linear decrease with layer depth of 15-55 cm were given. In the hayfield soil with forb-grass, a greater density and depth of the root mass penetration was chosen. Further, in the *Water Flow (Constant Boundary)* command, the intensity of potential transpiration was set at the upper boundary (Radcliffe and Simunek, 2010) – the maximum evaporation that can occur under given weather conditions over a specific agricultural crop under optimal agronomic conditions (without stresses). These values were taken based on the values of potential transpiration (as well as evapotranspiration, evaporation, productivity, water consumption coefficients) published in the works of other authors.

For example, Smagin (2011) chose the intensity of potential transpiration for the grass-moss cover of forest ecosystems equal to 3 mm/day. According to Arkhangelskaya *et al*. (2016), potential transpiration for maize in June, calculated according to the Penman-Monteith equation (Allen *et al*., 1998), was 1.59 mm day^{-1}. Assuming that the value of transpiration for oat crops should be lesser than for maize and forest grass, the potential transpiration of oats can be taken as not more than 1.5 mm day^{-1}. In addition, according to Kozyreva *et al.* (2013) evapotranspiration from the oat field surface at noon on 08.06.2011 was 2.8 mm day^{-1}. If the moisture consumption for transpiration and physical evaporation can be equal when there is not enough moisture, because the atmosphere and plants compete for moisture (Gnatovskiy, 2010), then, the potential transpiration for oats in June-July in the absence of precipitation may be 2.8/2=1.4 mm day^{-1}. In this case, Root water uptake for the hayfield soil under the forbgrass can be set from 1.4 mm day^{-1} and more.

Results and Discussion

The upper horizon of ordinary (Haplic) chernozem of hayfield was characterized by a higher content of sand fraction then B and C horizons. Horizon A of hayfield chernozem is more friable, less dense, the most porous (Table 1). With depth, in the chernozem of hayfield the density and the content of clay and silt fractions increased. In arable soils, on the contrary, the content of clay fraction was the highest in the upper horizon, and with depth the granulometric composition is changed from loam to sandy loam, although the density and porosity did not decrease. It should be noted that in a number of works (Chenu *et al*., 2000; Lisetskii, 2008; Bertolino *et al*., 2010; Khokhlova *et al*., 2015; Indoria *et al.*, 2017) the authors registered a more density and higher content of clay and silt fractions in arable soils because of the effect of agricultural use. For example, several long-term studies (Yadav *et al*., 2020) concluded that agricultural vehicles traffic reduced soil water retention,

Table 1: Measured physico-mechanical and physico-chemical parameters of ordinary (Haplic) chernozems of the Uimon intermountain depression (Altai, Russia)

Object	Horizon	Granulometric composition by FAO: particle size %,				Density g cm^{-3}	Porosity %	Humus content, %	pH
		Clay <0,002 (mm)	Silt 0,002-0,05 (mm)	Sand >2 (mm)	Textural class				
Chernozem (hayfield)	A	12.0	51.1	36.9	Silt loam	0.88	62.9	4.7	7.1
	B	19.8	42.6	37.6	Loam	1.26	51.1	2.1	8.0
	C	21.0	40.2	38.8	Loam	1.36	48.0	1.1	7.9
Chernozem (arable land)	A	15.3	45.0	39.7	Loam	1.07	58.7	9.5	6.8
	B	13.0	41.9	45.1	Loam	1.14	55.4	5.4	6.6
	C	10.0	33.4	56.6	Sandy loam	1.17	57.8	1.6	7.7

Table 2: Optimized parameter of Ordinary (Haplic) chernozem of hayfield and arable land of Uimon depression (Altai, Russia)

Horison (depth, cm)	Θ_s, cm^3 cm^{-3}	Θ_r, cm^3 cm^{-3}	*n*	*α*	C_f, cm day^{-1}
Chernozem of hayfield					
A (2-16)	0.50	0.026	1.320	0.0245	161.2
B (16-26)	0.42	0.037	1.415	0.0112	31.4
C (26-40)	0.41	0.056	1.423	0.0165	23.72
Arable chernozem					
A (0-26)	0.46	0.035	1.536	0.0054	88.2
B (26-40)	0.446	0.028	1.392	0.013	76.9
C (40-55)	0.426	0.019	1.428	0.010	84.6

plant available water and air porosity in agricultural soils compared to that of the wooded soils.

Chernozems of Uimon depression differ significantly in the content of humus – in arable soil it is 2 times higher than in hayfield chernozem. In this case, the soil under the oats was distinguished by neutral reaction, whereas in chernozem with natural vegetation the reaction was slightly alkaline, and the pH values was higher.

Obtained in the program RETC V.6.02 hydrophysical properties (parameters of the WCR approximation by the Van Genuchten function and filtration coefficients, C_f) of Ordinary (Haplic) chernozems of various agricultural uses are given in Table 2. These data were used for modeling the with the increase of soil density and decrease in porosity. The residual moisture Θ_r varied from 0.019 to 0.056 $cm^3\ cm^{-3}$ and increased with depth in the hayfield soil profile but decreased down the profile in the arable soil. The parameter α (the inverse of the capillary-sorption pressure approaching the air input pressure) in the horizon A was noticeably lower than in the over soil layers. It determined the higher position of the inflection point in the water retention curve (Figure 2). This means that the retention of moisture in large capillaries will be longer and stronger at a decreasing (from 0 cm of water column) pressure, when only the curvature of the meniscus in the capillaries changes, but water is not released from them.

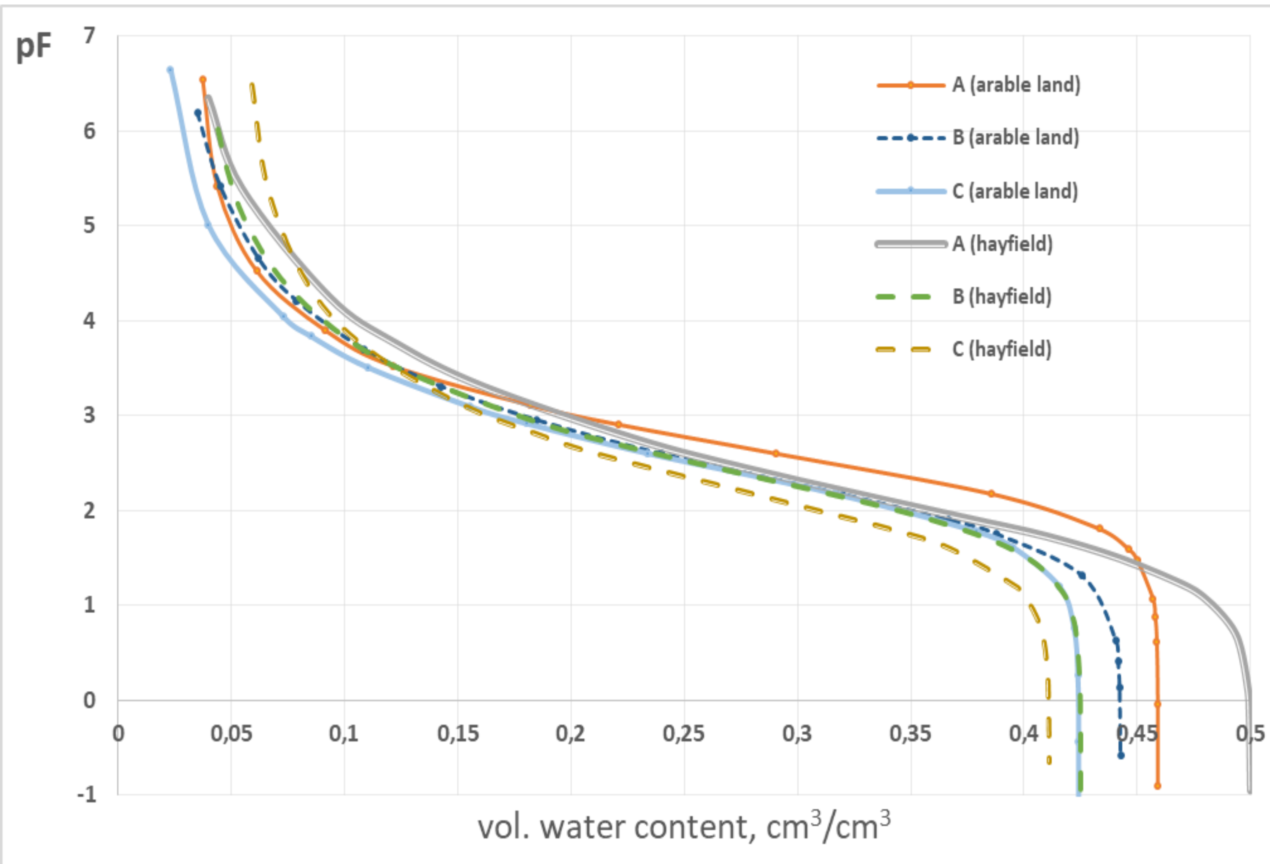

Figure 2: Water retention functions as the relationships between the volume water content and capillary-sorption potential of the ordinary chernozems of arable land and hayfield of Uimon intermountain depression, Central Altai, Russia (parameters of the WRC approximation by the Van Genuchten function were obtained in the program RETC V.6.02)

process of moisture movement in soils in the HYDRUS program. It showed that the moisture in the saturation state (Θ_s) in the studied soils decreased with depth in accordance

It is believed that the moisture content in agricultural soils depends on the method of plowing it and on the cultivated crop (Mohammad *et al*., 2014). Indeed, according to the results of our study, the value α (the reciprocal of the air-entry pressure head or bubbling pressure) was noticeably higher in soil that was not plowed annually (under haymaking) than in soil under arable land (with traditional annual plowing) - 0.0245 and 0.0054, respectively (Table 2). A reduced value of the parameter α may indicate to the physical soil degradation (Bolotov *et al*., 2020). The content of saturated soil moisture was higher in the soil with no-till practice (under haymaking, Θ^s = 0.50 cm^3 cm^{-3}) than in annually plowed soil (Θ^s = 0.459 cm^3 cm^{-3}) also. These results are consistent with the conclusions of other researchers. Thus, Fér, *et al*. (2020) showed that the value of α is higher in soils without annual tillage (α = 0.0227) than in soils with continuous conventional farming (α = 0.0187), as well as the the saturated soil water content (Θs) was higher in the no-till field than in the continuous conventional farming field (0.4 and 0.32 cm^3 cm^{-3}, respectively).

The water retention curves of the different plots chernozems of Uimon steppe had evident S-shape and differed significantly, particularly in the lower parts, corresponding to the capillary and gravitational forms of

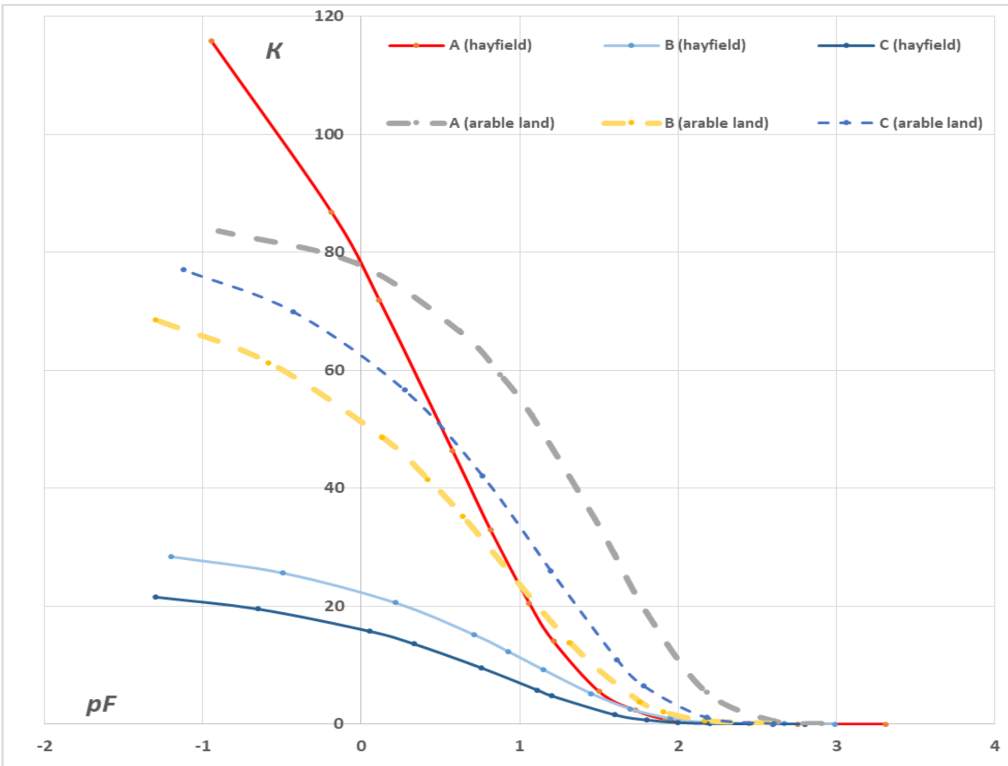

Figure 3: Hydraulic conductivity functions as a dependences of the coefficient of moisture conductivity (unsaturated hydraulic conductivity, K) on the capillary-sorption (P) pressure of A, B, C horizons of ordinary (Haplic) chernozems of the Uimon depression agricultural landscapes (Central Altai, Russia)

Table 3: Soil-hydrological parameters of the different land-use type chernozems (arable land and hayfield) of the Uimon depression, in % of moisture

Object	Horizon	MG	WM	MMC	FP	TMC
Hayfield chernozem	A	8.2 (0.07)	9.7 (0.09)	31 (0.27)	36 (0.33)	58 (0.51)
	B	4.7 (0.06)	6.5 (0.08)	21 (0.26)	26 (0.33)	34 (0.43)
	C	5.1 (0.07)	5.8 (0.08)	18 (0.25)	23 (0.32)	30 (0.41)
Arable chernozem	A	6.1 (0.065)	9.0 (0.08)	33 (0.35)	43 (0.39)	43 (0.47)
	B	5.2 (0.060)	6.1 (0.07)	23 (0.26)	33 (0.38)	38 (0.44)
	C	4.3 (0.05)	5.5 (0.06)	21 (0.25)	28 (0.33)	36 (0.42)

Note: MG – maximum soil hygroscopicity, pF=4.5; WM –wilting moisture, pF=4.18; MMC - minimum moisture capacity, pF=2.52; FP – fluidity point pF=2.17; FMC - total moisture capacity, pF=0. There are volumetric values of moisture, cm^3 cm^{-3} in parentheses.

moisture (Figure 2).

When the soil was close to saturation by moisture (*p*<-50 cm of water column or pF<1.7), the upper humus-accumulative horizon of hayfield chernozem had the most moisture-retaining ability (Figure 2), as it was the silt loam, the most porous, the least dense. The lowest water retention capacity at P<-50 cm of water column was established for the C horizon in the hayland soil (Figure 2), which, on the contrary, had the least porosity but the greatest composition density.

The medium-loam, most humus containing and porous upper A horizon of arable land was distinguished by the most moisture-retaining ability on the curve section corresponding to capillary (pF = 1.7-3, P = -50 – -1000 cm of water column) and film-capillary low-mobility moisture (pF = 3-4.5) (Figure 2). The lowest moisture-retaining is detected in the sandy loam, carbonate soil-forming rock (C horizon) of arable chernozem. The shift of the WRC of saline soil to the left, towards a lower moisture, is explained by the decrease in the thickness of the double diffuse ion layer, which occurs when the mineralization of the pore solution increases. At the same time the wedging pressure due to which water is "pumped" between the soil particles, decrease (Shein, 2015).

On the curve section corresponding to film form of moisture and adsorbed form of moisture (pF> 4.5, P>-35000 cm of water column), the moisture-retaining capacity was most evidenced in the soil-forming rock of hayfield – its C horizon was the most dense, containing more silt and clay fractions, which determined here a large number of fine pores providing moisture retaining when pressure was low (Shein, 2015).

Soil-hydrological parameters of chernozems of two different types of land use are shown in Table 3. All these moisture constants were determined by instrumentically. Theoretically, each of them should correspond to a certain moisture pressure (see Table 3, Note) (Shein, 2012). These pressure-moisture pairs matched well with the corresponding pressure-moisture points on the WRC plotted by RETC using only soil particle size distribution, density, porosity, TH33 and TH1500. This confirms that the approximation parameters of the WRC of the studied chernozems obtained in the RETC are a suitable variant of the input data for the model; they can be used for modeling of the movement in moisture in soils.

The hydraulic conductivity coefficients (K) for A, B, C horizons of studies soils are expressed on a logarithmic scale on the diagram (Figure 3). According to the diagram, the loosest A horizon of hayfield soil had the largest hydraulic conductivity on the curve section corresponding to complete soil saturation with moisture (Figure 3). At the same time, considerably denser B and C horizons of hayfield chernozem were characterized by the lowest moisture-conducting properties. Obviously, in hayfield chernozem the vertical downward moisture transfer will not be very fast.

During the capillary mechanism of moisture retention (P = -10 to -100 cm of water column), the hydraulic conductivity coefficients (K) were highest in arable chernozem for oats. In the curve section of low pressures (P <-100 cm of water column) and low moisture content the soil under oats had the most pronounced moisture-conducting properties (Figure 3).

The hayfield chernozem (with the highest filtration coefficient of its upper A horizon) under drying conditions will conduct moisture down more slowly than the arable soil. Therefore, it can be assumed, that a vertical downward moisture flows will be more noticeable in the arable soils.

Table 4: Initial conditions of water content and moisture pressure in arable and hayfield Ordinary (Haplic) chernozem of Uimon intermountain depression

Horison (depth, cm)	ρ, g cm^{-3}	Water content			pF	P, cm of water column
		Field description	Gravimetric, %	Vol., $cm^3\ cm^{-3}$		
Arable chernozem						
A (0-26)	1.07	wet, up to damp	30.4	0.325	2.46	-289
B (26-40)	1.14	dry	18.1	0.206	2.808	-643
C(40-55)	1.17	dry, cold	12.1	0.142	3.195	-1567
Hayfield chernozem						
A (0-16)	0.88	wet	31.8	0.279	2.447	-274
B (16-26)	1.26	dry	16.0	0.202	2.821	-662
C (26-40)	1.36	dry	8.1	0.11	3.710	-5128

To simulate the process of vertical moisture movement in the investigated chernozem, vertical moisture transfer in layered soils was analyzed in HYDRUS-1D reproduces isothermal mass transfer in a porous medium (Radcliffe and Simunek, 2010; Smagin, 2011, Šimůnek *et al.*, 2016). The upper boundary condition was set as "Constant flow". The "Constant pressure" was taken as the lower boundary. The evapotranspiration was not taken into account in the first version of the simulation.

The natural field situation was taken as the initial condition to calculate the moisture movement. At the time of sampling (on July 8, 2014), the moisture of the upper horizons of the arable soil and hayfield soil was about 30%. Water content of sub-arable B horizons was 16-18% (Table 4). According to the WRC (Figure 2) and RETC matrix, this moisture values corresponded to the pressures of -270 to -290 cm of water column in the upper horizons and -640 to -660 cm of water column in the sub-arable B horizons of these soils. With such capillary-sorption pressure values, a more loamy, humus and denser soil horizon under oats contained more voluminous moisture (cm^3 cm^{-3}) and was characterized by a greater moisture capacity. The values of the initial pressure in the C horizon of arable soil and in the C horizon of hayfield soil differed essentially: P = -1587 cm of water column in the C horizon of arable chernozem (the percentage water content was 12%) and P = -5128 cm of water column (the percentage water content was 8%) in the C horizon of hayfield chernozem (Table 4).

The nature and dynamics of moisture distribution in chernozems of various agricultural uses in the considered conditions differed significantly (Figure 4). During 10 days without precipitation, the studied soils lost moisture gradually. However, the decrease of water content (in volumetric values) in the hayfield soil was not as significant as in the arable chernozem. According to the diagram (Figure 4.1 B), the moisture in the A horizon of hayfield soil on the first day decreased from 0.278 to 0.255 cm^3 cm^{-3}, or by 0.0185 cm^3 cm^{-3}, thus the moisture was lost from the entire upper horizon (16 cm depth) total amount was 3 mm of water layer for the first day. In the A horizon of arable chernozem on the first day the moisture content decreased from 0.325 to 0.290 cm^3 cm^{-3} (Figure 4.1 A), or by 0.035 cm^3 cm^{-3}, which corresponds to the moisture loss of 9.1 mm of the water layer from the soil horizon depth of 26 cm. The moisture loss will be 5.6 mm of the water layer if will take for comparison the same as of hayfield soil thickness of the horizon – 16 cm.

It can be noted that the profile of arable soil was rapidly saturated with water for the entire thickness on the first day (Figure 4.1 A) due to greater hydraulic conductivity coefficients (K) of its horizons B and C. So, in the sub-arable horizons B and C moisture reserves increased noticeably on the first day: in B horizon – by 4 mm, and in C – by 3.75 mm of the water layer due to the flow from the horizon A. However, in the following days in the absence of additional atmospheric humidification, the underlying horizons B and C of the arable soil gradually lost moisture obtained from the upper horizon. All the soil layers gradually dried up to values below the initial. The moisture content of the soil profile of arable land decreased and level by the end of the period under consideration.

As for the chernozem of hayfield, on the first day after precipitation the moisture did not penetrate the entire depth of the soil profile, but only to 32 cm (Figure 4.1 B), despite the large proportion of sand fraction in the granulometric composition of the upper A horizon. Obviously, a much higher density and a lower porosity of B and C horizons with lower hydraulic conductivity coefficients (K) impeded the vertical runoff. The soil-forming rock (horizon C) of hayfield chernozem was moistened very slowly, during the whole period. For 10 days in the C horizon of hayfield soil, the volumetric moisture content increased gradualy – from 0.11 cm^3 cm^{-3} to 0.16 cm^3 cm^{-3}; water penetrated from 32 cm to 38 cm. By the end of the period, the moisture of the entire hayfield soil profile decreased, but became more evenly distributed. Moisture of the B horizon of hayfield chernozem did not fall below the initial value (0.2 cm^3 cm^{-3}) at the end of the period under review.

According to model, for 10 days without precipitation, in total, the moisture of the upper A horizon of arable chernozem decreased from 0.325 to 0.232 cm^3 cm^{-3}, or from 30.4% to 24.8%. The moisture losses of this horizon as a whole amount to 24 mm water column (or 15 mm of water column, if calculations for the thickness of 16 cm to be compared with the hayfield soil variant). During this same time, the moisture of the A horizon of hayfield soil decreases from 0.279 to 0.225 cm^3 cm^{-3}, or from 31.8% to 19.8%, the moisture was lost only 8.6 mm water column. Thus, changes in the percentage (or weight) moisture in the chernozems of the Uimon depression of different agricultural uses during the period without precipitation differ insignificantly, while the volumes of moisture lost differed noticeably and in the arable soil they are much larger than in the hayfield soil.

The high water capacity of only the upper horizon of arable chernozem with oat crops does not provide an optimal water regime for the entire soil profile, because the vertical gradients of capillary-sorption pressure can neutralize the increased water retention of a single layer during vertical moisture transfer (Smagin, 2011).

Obviously, in the loose and porous arable soil, more favorable conditions are formed for vertical moisture runoff, and hence for leaching of various salts and compounds, which is expressed in lowering the pH level of this soil. Note, that the soil pH is a very important property: for example, a minor alteration in soil pH significantly impacts the release of micronutrients in the soil and changes their bioavailability (Hussain *et al*., 2020).

In the hayfield soil, the loss of moisture resulting from vertical runoff is generally less significant and the pH of this soil higher.

We complicate the model and add the root water uptake item (Figure 4.2 A, B). According to model the root water uptake in the hayfield soil changes the moisture dynamics

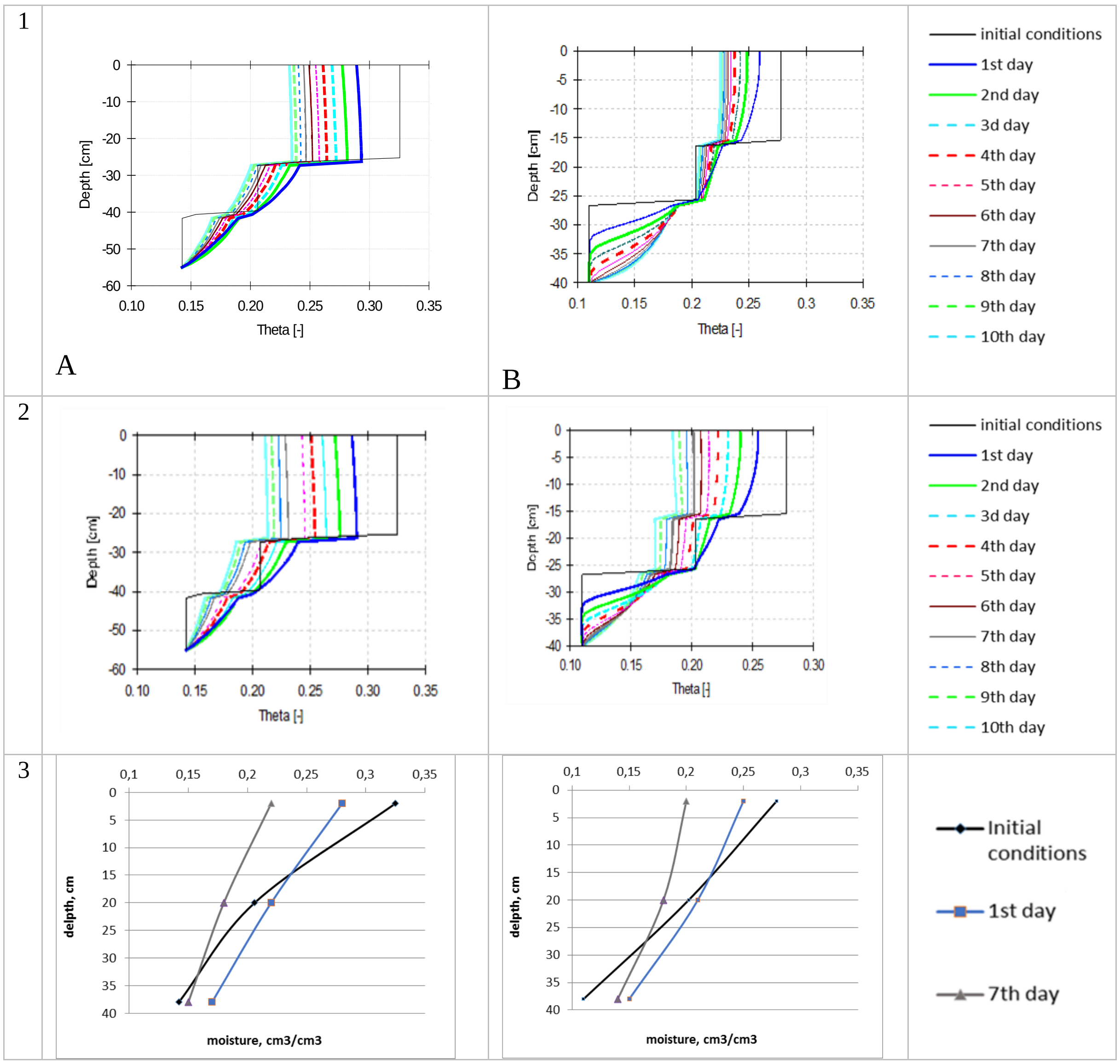

Figure 4: Depth distribution of volumetric water content (cm^3 cm^{-3}) in Ordinary (Haplic) chernozems of different agricultural landscapes (A – arable chernozem, B – hayfield chernozem) of the Uimon intermountain depression. 1, 2 - the results of modeling in HYDRUS 1D 1 - estimated value of simple vertical water transfer for a 10 day without precipitation and without taking evapotranspiration into account, 2 - and considering the moisture consumption of plant roots. 3 - measured daily moisture content in soil of two land use

and decreases in the water content in the soil profile significantly (Figure 4.2). At the same time, for the first day moisture losses in the upper horizon of arable soil (less porous and loamier) were less visible, taking into account the water root consumption.

It is shown that the model, taking into account the transpiration factor, is more effective and better reflects the real picture of the change in moisture content in the different land use type soils of the Uimon steppe for 10 days of the period without precipitation (Fig 4.3 A, B), provided that the initial moisture of soil is not so lower than the level of the minimum moisture capacity.

In general, for 10 days, taking into account the root consumption of moisture by the plants, the arable soil loses 0.114 cm^3 cm^{-3} of moisture from the upper A horizon 26 cm depth, or 29.5 mm of the water layer, which is 5.5 mm larger than the simple vertical intrasoil runoff. The volumetric moisture changes in the upper layer of arable soil (taking into account the root consumption) from 0.325 to 0.211 cm^3 cm^{-3}, or (for weight moisture) from 30.4% to 22.5%. Loss of moisture in the hayfield soil, especially in the A horizon were more significant. It is more porous, more sandy and with a more dense distribution of roots than the A horizon of arable soil. For 10 days, the moisture of the upper horizon of hayfield soil, taking into account the root consumption, will change from 0.279 cm^3 cm^{-3} to 0.183 cm^3 cm^{-3} (or from 31.8% to 16.1%), the moisture loss is 0.096 cm^3 cm^{-3} or 15.4 mm of water column (for 16 cm of soil thickness). It is 6.8 mm (almost 2 times) higher if the water consumption by the roots is not taken into account. Taking into account the root consumption, the B horizon of hayfield soil also loses moisture, to values much lower than the initial ones (Figure 4. 2 B), while the moisture content of the B horizon of arable chernozem varies insignificantly. Thus, the upper A horizon of arable soil will be able to compensate for the requirements of sowing plants in moisture during the dry period, despite a significant vertical flow of water into the depth layers at the initial stage of sufficient moisture. In the hayfield soil the vertical runoff into its deeper layers is prevented by the compacted B and C horizons, but the root water uptake adjustments to the soil water balance significantly. Thus, the water reserves in the A horizon of soil under oats in the summer rainless period may by higher than in the soil under the motley grass, which is explained among other things by the increased root water uptake in the soils of hayfields. Our conclusions are consistent with the works of other authors, which show that in the summer, the moisture content in different soils decreases with an increase in the number of roots in them (Arkhangelskaya and Khokhlova, 2019).

Conclusions

Modeling of the vertical moisture movement in the loamy Ordinary chernozems of Uimon intermountain depression (Altai, Russia) using the HYDRUS-1D program revealed that the hydrological regime of this unsaturated by moisture soils depended on their agricultural uses type. It was shown that vertical moisture transfer after atmospheric precipitation in the arable land chernozem was a faster than in the chernozem of hayfield. The model taking into account the transpiration factor was more effective and better reflected the real change of moisture content in the different land use type soils of the Uimon steppe for 10 days of the period without precipitation. The transpiration factor most significantly changed the moisture dynamics and water reserve in a horizon of hayfield chernozem: It’s drying out was affected by the root water uptake more obvious than in arable soil.

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