SOIL WATER RETENTION OF THE ODRA RIVER ALLUVIAL SOILS (POLAND): ESTIMATING PARAMETERS BY RETC MODEL AND LABORATORY MEASUREMENTS

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(Received 29th Mar 2018; accepted 12th Jun 2018)

Abstract. The paper presents water retention of alluvial soils in the Odra valley. Floodplain soils are one of the most fertile intrazonal soils in Europe. The relevant field studies and laboratory tests were carried out during the vegetation seasons (2012 and 2013) on arable lands located in Tworków (south of the Silesian Province, Poland). A three pedotransfer functions (PTFs) parameter van Genuchten type model was used to describe the water retention curves of alluvial soils. Fitted soil water retention curve (SWRC) parameters were regressed linearly with a different number of soil physical properties in the RETC and Rosetta. The first model (PTF-1) uses soil textural classes, consisting of a lookup table that provides parameter averages for each USDA textural class. The second model (PTF-2) uses sand, silt, and clay percentages as input, and the third model (PTF-3) includes bulk density as a predictor. The simulation results were considered for each layer separately and as a whole for all soil profiles. The predicted values of water content of the RETC and Rosetta for each soil layer are close to the measured values (R^2 = 0.825–0.995). Simulated values of water content (all soil profiles) by PTF-3 are very similar to the measured values. The predicted values of the residual soil water content (θr) and the saturated soil water content (θs) by PTF-3 provided good simulation results R^2 = 0.860 and R^2 = 0.667, respectively. The specific alluvial soil conditions affect the high water content in the soil, which is reflected in the content of water available for plants. This information should contribute to the rational management of water resources in the agricultural area, what can be used to mitigate the effects of drought.

Keywords: *water properties of soil, floodplain soil, RETC program, Poland*

Introduction

Soil is a non-renewable natural resource that is essential to life. Water movement, water quality, land use, and vegetation productivity all have relationships with soil (Schoonover and Crim, 2015). Diversity of alluvial soil types has been the subject of much less study than typical mineral soils. Thus, studies focused on physical and hydraulic parameters of alluvial soils are essential for a better understanding of how alluvial ecosystems function (Ľuptáčik et al., 2012).

Alluvial soils have the highest productivity with respect to other soils (Huong et al., 2013). They are present mostly along rivers and are carried by its streams during weathering of rocks. Most vegetable production is on alluvial soil generally succeed. The key role in creating alluvial soil is a high ground water level (Dobrovol'ski et al., 2011; Pirastru and Niedda, 2013; Liu et al., 2015; Dwevedi et al., 2017; Yassoglou et al., 2017).

River alluvial soils are formed from silts deposited chiefly by flood-waters, from here are often called floodplain soils. Soil formation is in this case very long, in consequence, alluvial soils have, as a rule, an undeveloped profile. The natural soils in river-valley bottoms are almost wholly used for meadows, pastures and tilled fields (Szafer, 1966). According to Bednarek and Prusinkiewicz (1999) alluvial soils constitute about 5% of Poland's area.

As a result of soil cultivation, farmers can change some of its physical and hydraulic parameters, such as: soil compaction, soil water permeability, relations between water and air (Cameira et al., 2003; Pagliai et al., 2004; Hakl et al., 2007; Nawaz et al., 2013; Bogdał et al., 2014; Kahlon and Khurana, 2017). Soil compaction is a significant problem of agriculture nowadays. It is directly connected with the mechanization of field treatments. Compaction is a physical form of soil degradation: it changes the soil structure, water and air permeability, porosity, and it inhibits penetration by plant roots (Hakl et al., 2007; Nawaz et al., 2013).

Knowledge of the soil hydraulic properties is indispensable to solve many soil and water management problems related to agriculture, ecology, and environmental issues. The most important hydraulic properties of soils are the soil water retention curve (SWRC) and soil water permeability (Shwetha and Varija, 2015; Qanza et al., 2015). Soil hydraulic properties depend mainly on soil texture, organic matter content and bulk density (Hillel, 1998). In scientific research, many methods and types of models are used to determine the hydraulic parameters of soils (Minasny et al., 2004; Šimůnek et al., 2005; Pandey et al., 2006; Nasta et al., 2013). The role of water retention in soil has been analyzed and reviewed in many scientific studies (Van Genuchten et al., 1991; Minasny et al., 2003; Merdun et al., 2006; Wassar et al., 2016; Nguyen et al., 2017).

Modeling water flow in soil requires knowledge of soil hydraulic properties, which are water retention curves. As an alternative to direct measurement, indirect determination of these functions from basic soil properties using pedotransfer functions (PTFs) has attracted the attention of researchers in a variety of fields such as soil scientists, hydrologists, and agricultural and environmental engineers (Merdun et al., 2006; Fashi et al., 2016).

Water retention characteristics are fundamental input parameters in any modeling study on water flow and solute transport. These properties are difficult to measure and for that reason, we usually need to use direct and indirect methods to determine them. An extensive comparison between measured and estimated results is needed to determine their applicability for a range of different soils (Wassar et al., 2016).

The RETC can be useful for estimating the hydraulic parameters from retention data only with laboratory, or simultaneously from observed retention and hydraulic conductivity data and other physical parameters (Van Genuchten et al., 1991).

The objective of this study is to evaluate the water retention of the alluvial soil and the estimation of van Genuchten parameters by the three intelligent pedotransfer models RETC.

Materials and methods

Study area

The study area lies on alluvial soils located in the catchment of the Odra River on arable land in Tworków, in the south of Poland (the Racibórz District, the Silesian Province) (*Fig. 1*).

The average altitude of the object is 190.00 m a.s.l. According to the geographical division by Kondracki (2011), the object is situated in the Central European Lowlands province (31), in the macroregion of the Silesian Lowlands (318.5) and in the mesoregion of the Raciborska Basin (318.59), in terms of climate is considered as one of the warmest areas in this region. In general, Poland has mostly temperate climate, in transition between oceanic climate dominating in the north and west of the country, and continental climate in the south and east (Kundzewicz et al., 2017). In the multiannual period 1971–2000, average annual air temperature was 8.5 °C and total precipitation was 616 mm (according to the IMGW – Institute of Meteorology and Water Management – station in Racibórz). Depending on changes in meteorological conditions, there are periodically too high moisture contents in soil. The characteristics of meteorological conditions are shown in *Table 1.*

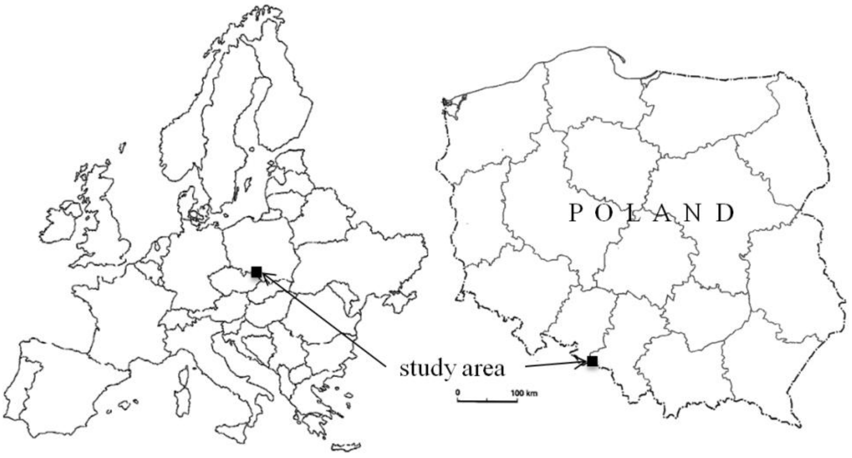

Figure 1. *Location of the study area*

Table 1. *The characteristics of meteorological conditions of the study area*

Period	**Months**												
	I	**II**	**III**	**IV**	**V**	**VI**	**VII**	**VIII**	**IX**	**X**	**XI**	**XII**	
Year	**Average monthly precipitation totals [mm]**												**Sum I–XII**
2012	41	24	18	41	35	75	89	69	58	81	37	18	586
2013	44	29	36	21	132	110	14	48	99	24	31	9	597
2014	21	16	23	27	137	75	58	92	127	35	18	16	645
1971–2000	28	26	32	45	67	79	94	74	56	41	40	34	616
	Average monthly air temperatures [°C]												**Average I–XII**
2012	-0.3	-5.6	5.4	9.9	15.3	17.7	19.9	19.1	14.7	9.0	6.5	-1.1	9.2
2013	-2.2	-0.2	0.1	9.0	13.8	16.9	19.7	19.1	12.6	10.8	5.5	2.7	9.0
2014	0.6	4.0	6.9	10.8	13.8	16.3	20.4	17.4	15.6	11.1	7.1	1.6	10.5
1971–2000	-1.3	-0.2	3.8	8.2	13.5	16.1	17.8	17.7	13.6	9.0	3.6	0.2	8.5

Field analysis

The field soil tests were carried out in the two agricultural seasons: 2012 and 2013 on arable lands. The alluvial soils are the predominant soil type here on account of height of the region’s surface water, which makes them good/very good in terms of soil fertility classes.

In field four soil pits were made up to a depth of 150 cm (*Fig. 2; Table 2*). Undisturbed soil samples were taken from each genetic horizons using Kopecky’s cylinders (in 3 replications) to find the soil water content (SWC), bulk density (BD), total porosity and soil water potential. Also, approximately 1 kg, disturbed soil from each genetic horizons to find the soil texture and other laboratory analysis were taken.

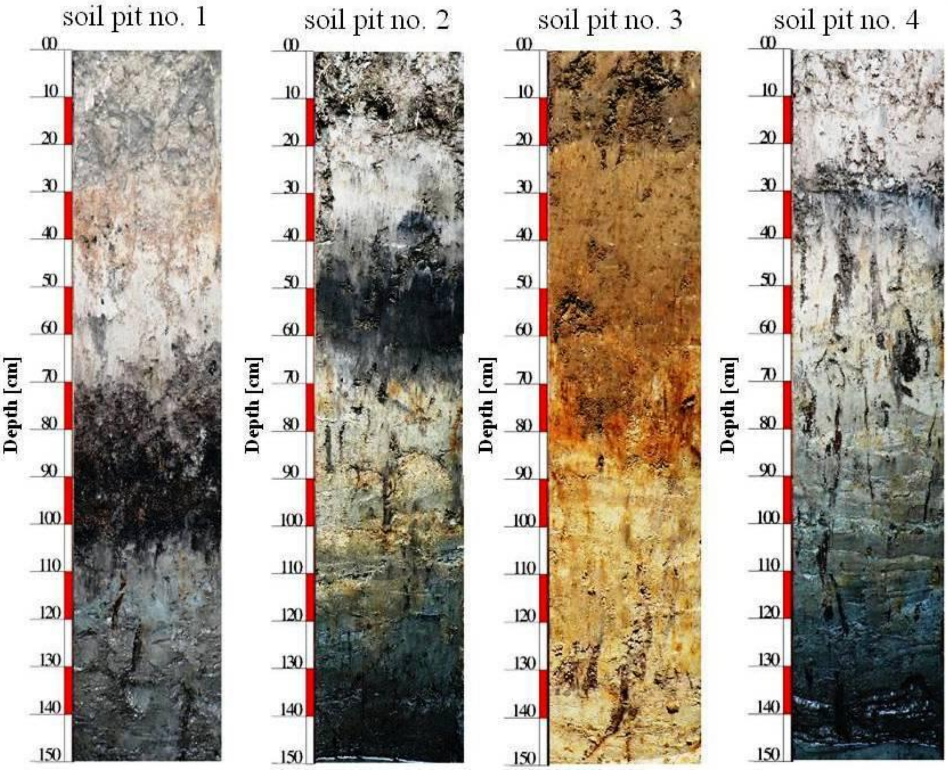

Figure 2. *Characteristics of soil pits for the Tworków object*

Table 2. *Place of soil pits and sampling*

Place of soil pits	Number of soil pits	Position of soil pits	
		N	E
Tworków	1	50°01’02.43”	18°14’20.50”
	2	50°01’03.08”	18°14’17.87”
	3	50°01’25.47”	18°14’25.56”
	4	50°00’57.90”	18°14’21.68”

Laboratory analysis

From the soil samples that were collected the following properties were determined:

- Soil texture by the Bouyoucose-Casagrande areometric method modified by Prószyński. The modification consisted in measurement of suspension of soil by Prószynski’s hydrometer, which gives percentages sedimentation fraction content between the two readings in the time. Suspension density is read in the terms, which set out in the tables developed by Prószyński. The content of particle size classes (sand, 2.0–0.05 mm; silt, 0.05–0.002 mm; clay, <0.002 mm) is determined according to the Soil Taxonomy system that was made known by the United States Department of Agriculture (USDA) (Soil Survey Staff, 1999).

- Particle density (ρ_s) by the pycnometer method as average density of the mineral grains of the soil (*Eq. 1;* Mocek and Drzymała, 2010; Phogat et al., 2015):

$$\rho_s = \frac{M_s}{V_s}\left(g \cdot cm^{-3}\right) \qquad \text{(Eq.1)}$$

  where M_s is the mass of mineral grains of the soil sample (g) and V_s is the volume of the mineral grains of the soil (cm^3).

- Soil bulk density (ρ_b) by the gravimetric method in Kopecky's cylinders (100 cm^3) as the mass of dry soil per volume. The weight of this soil core is then determined after drying in an oven at 105 °C for about 18–24 h. The dry bulk density for each core sample was then calculated using equation (*Eq. 2;* Hao et al., 2008; Phogat et al., 2015):

$$\rho_b = \frac{M_s}{V_t}\left(g \cdot cm^{-3}\right) \qquad \text{(Eq.2)}$$

  where M_s is the mass of dry soil weight (g) and V_t is the soil volume (cm^3).

- Soil moisture (volume wetnees) by the gravimetric method in Kopecky's cylinders (100 cm^3) as the ratio of the amount of water in the soil sample to the dry weight of the soil, after drying in an oven at 105 °C for about 18–24 h, then calculated using *Equation 3* (Mocek and Drzymała, 2010; Phogat et al., 2015):

$$\theta_v = \left[\frac{V_w}{V_t}\right] \cdot 100\left(cm^3 \cdot cm^{-3}\right) \qquad \text{(Eq.3)}$$

  where V_w is the volume of water in the soil sample (cm^3) and V_t is the volume of soil sample (cm^3).

- Water storage in layer as (*Eq. 4;* Mocek and Drzymała, 2010):

$$S_w = \frac{\theta_V \cdot h}{10}\,(mm) \qquad \text{(Eq.4)}$$

  where θ_v is soil moisture (% cm^3·cm^{-3}), *h* is thickness of the soil layer (cm), *10* – water conversion from Mg·ha^{-1} to mm water.

- Soil water retention using set for pF determination with ceramic plates in the 5 and 15 Bar Pressure Plate Extractor. The pressure plate equipment used in this study is made by the American Soil Moisture Equipment Corporation. In engineering practice, soil suction has usually been calculated in *pF* units (*Eq. 5;* Schofield, 1935):

$$pF = log\ h\ \left(cm\ H_2O\right) \qquad \text{(Eq.5)}$$

where *h* is the suction of water (in cm).

In laboratory the soil water potentials were measured at pF: 0.0, 2.0, 2.2, 2.5, 2.7, 3.0, 3.4, 3.7 and 4.2 (*Table 3*). The total available water capacity (TAWC) was determined as a difference between the moisture retained at pF 2.5–4.2. Easily and hardly available water were determined as a difference between the moisture retained at pF 2.5–3.7 and at pF 3.7–4.2, respectively. The field capacity (FC) was considered at pF 2.5 and the permanent wilting point (PWP) at 4.2 (Mocek and Drzymała, 2010).

Table 3. *The pressure applied to determine the pF curves*

Number of measurements	pF	cm H_2O	kPa	bar	mm Hg
1	0.0	0	0.00	0.0000	0.0
2	2.0	100	9.81	0.0981	73.6
3	2.2	159	15.54	0.1554	116.6
4	2.5	316	30.99	0.3099	232.4
5	2.7	500	49.03	0.4903	367.8
6	3.0	1000	98.07	0.9807	735.6
7	3.4	2500	245.17	2.4517	1838.9
8	3.7	5000	490.33	4.9033	3677.8
9	4.2	15849	1554.26	15.5426	11657.9
10	7.0	10 000 000	1 000 000	10 000	735538.1

- Total organic carbon (TOC) content by the Tiurin's method, then converted to soil organic matter content (SOM) according to the formula (*Eq. 6;* Mebius, 1960; Mocek and Drzymała, 2010):

$$SOM = TOC \times 1.724\ (\%) \qquad \text{(Eq.6)}$$

- pH value by means of the potentiometric method in KCl of 1 $mol \cdot dm^{-3}$ concentration in one repetition (Mocek and Drzymała, 2010).
- On the basis of results obtained total porosity was calculated from bulk density and particle density, as (*Eq. 7;* Mocek and Drzymała, 2010; Phogat et al., 2015):

$$f = \left[1 - \frac{\rho_b}{\rho_s}\right] \cdot 100(\%) \qquad \text{(Eq.7)}$$

Soil classification was established according to the Polish Soil Classification (PTG, 2011), the World Reference Base for Soil Resources – IUSS Working Group WRB (2006) and USDA soil taxonomy (Soil Survey Staff, 1999).

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Modeling the soil water retention in the RETC program

The RETC (*Retention Curve Program*) is a computer program which may be used to analyze the soil water retention and hydraulic conductivity functions of unsaturated soils, especially to predict the hydraulic conductivity from observed soil water retention data assuming that one observed conductivity value (not necessarily at saturation) is available (Van Genuchten et al., 1991; Hollenbeck et al., 2000).

The shape of water retention curves (pF) can be characterized by several models, one of them known as the van Genuchten model (1991) (*Eq. 8*):

$$\theta_{(h)} = \theta_r + \frac{\theta_s - \theta_r}{[1 + (\alpha |h|^n)]^m} \qquad \text{(Eq. 8)}$$

where, $\theta_{(h)}$ is the soil water content ($cm^3 \cdot cm^{-3}$), θ_r is the soil residual water content at pF > 4.2 ($cm^3 \cdot cm^{-3}$), θ_s is the soil saturated water content at pF 0.0 ($cm^3 \cdot cm^{-3}$), h is soil water potential (kPa), α is a scale parameter inversely proportional to mean pore diameter (cm^{-1}), n and m are the shape parameters of soil water characteristic

$$m = \frac{1}{n};\ 0 < m < 1.$$

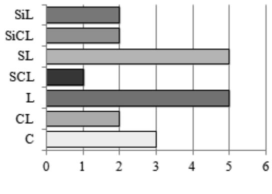
Retention curves (pF) were compared against those obtained from the RETC program estimations and laboratory measurements. The water retention parameters according to Van Genuchten (1980) with predicted hydraulic functions were estimated by a published neural networks program *Rosetta Lite v. 1.1*. The necessary input data for the RETC model (e.g. % soil texture and bulk density) were determined in laboratory analysis of soil samples from different soil horizons (*Tables 2, 3* and *4*). The unknown parameters (θ_s, θ_r, n, α) were determined in the RETC program (Van Genuchten et al., 1991) using measured soil water retention data. *Rosetta* offers five pedotransfer functions (PTFs). To estimate of the water retention parameters (θ_r, θ_s, α, n), were used only three of them with limited or more extended sets of predictor. The first model (PTF-1) uses soil textural classes, consisting of a lookup table that provides parameter averages for each USDA textural class. The second model (PTF-2) uses sand, silt, and clay percentages as input, and in contrast to PTF-1, provides hydraulic parameters that vary continuously with texture. The third model (PTF-3) includes bulk density as a predictor (Schaap et al., 1998, 2001).

Statistical analysis

The data set consisted of analytical results of soil samples collected at the four soil pits located in the Odra River valley during two vegetation seasons (2012 and 2013). For statistical analysis, the procedures provided by the program *Statistica PL version 12.5* were used. A 5% significance level was used. A statistical method was chosen after checking data normality (Shapiro-Wilk test). For each analysed physical and water parameters of soil its minimum and maximum values were determined its arithmetic mean, median, standard deviation (SD) and coefficient of variation (CV) were computed. The performances of the RETC model and laboratory measurements in predicting measured data were assessed using a coefficient of determination (R^2).

Moreover, the Spearman’s correlation relationship (r) between the granulometric composition and the organic matter of soils and their physical and water values were calculated. The correlation strength and direction of a linear relationship between two variables were determined based on a scale (Rumsey, 2016): exactly ±1 – a perfect downhill/uphill (negative/positive) linear relationship; ±0.70 – a strong downhill/uphill (negative/positive) linear relationship; ±0.50 – a moderate downhill/uphill (negative/positive) relationship; ±0.30 – a weak downhill/uphill (negative/positive) linear relationship; 0 – no linear relationship.

Table 4. *Granulometric composition of soils and basic descriptive statistics*

Profile number	**Depth (cm)**	**Genetic horizons** ***(acc. to PTG)***	**Percentage fraction with diameter (mm)**			**Soil texture group** ***(acc. to USDA)***
			Sand 2.0–0.05	**Silt 0.05–0.002**	**Clay <0.002**	
1	0–30	Ap	18	47	35	Silty clay loam (SiCL)
	30–46	AC	31	26	43	Clay (C)
	46–63	OCg	16	19	65	Clay (C)
	63–94	2O	57	29	14	Sandy clay loam (SCL)
	94–150	3G	19	62	19	Silty loam (SiL)
2	0–18	Ap	25	35	40	Clay loam (CL)
	18–34	AC	18	21	61	Clay (C)
	34–52	G	32	44	24	Loam (L)
	52–85	Cg1	55	33	12	Sandy loam (SL)
	85–150	2G	76	16	8	Sandy loam (SL)
3	0–25	Ap	43	35	22	Loam (L)
	25–47	A/Bw	45	33	22	Loam (L)
	47–75	Bw	58	24	18	Sandy loam (SL)
	75–117	Cg	40	43	17	Loam (L)
	117–150	2Cg	41	45	14	Loam (L)
4	0–30	Ap	22	40	38	Clay loam (CL)
	30–42	O	17	55	28	Silty clay loam (SiCL)
	42–71	Bw	27	53	20	Silty loam (SiL)
	71–100	Cg	54	33	13	Sandy loam (SL)
	100–150	2Cg	67	25	8	Sandy loam (SL)
Basic descriptive statistics						
Index value:		Minimum	16.0	16.0	8.0	
		Maximum	76.0	62.0	65.0	
		Mean	38.0	35.9	26.1	
		Median	36.0	34.0	21.0	
		SD	18.4	12.6	16.3	
		CV (%)	48.2	35.1	62.4	

Results

Physical properties of soils

As shown in *Table 4* and *Figure 2*, the alluvial soils are heterogeneous in terms of texture. In each soil profile, five genetic levels were specified. The granulometric composition of the profiles was classified into to seven soil texture groups (acc. to

DOI: http://dx.doi.org/10.15666/aeer/1604_46814699
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USDA) as: silty loam (SiL), silty clay loam (SiCL), loam (L), sandy clay loam (SCL), sandy loam (SL), clay (C) and clay loam (CL). The high coefficient of variation (CV) values was observed, which is the measure of empirical data deviations from average values. The highest CV was in silt (62.4%). Sand content in the profiles was between 16 and 76%, silt content between 16 and 62%, and clay content between 8 and 65%. Finally, according to the Polish Soil Classification (PTG, 2011), World Reference Base for Soil Resources – IUSS Working Group WRB (2006) and USDA soil taxonomy (Soil Survey Staff, 1999), examined soils were classified as:

- Order 7. Chernozemic soils (Polish: Gleby czarnoziemne; WRB: Chernozems, Phaeozems; ST: Mollisols – Aquolls, Udolls).
- Type 7.4 “Chernoziemic fluvisols” (Polish: Mady czarnoziemne; WRB: Mollic Fluvisol, Endofluvic Phaeozem; ST: Fluvaquentic Endoaquolls)

The soils formed mostly in recent alluvium on flood plains. Many of the soils have been artificially drained and are used as cropland, but some are used as pasture or forest (Soil Survey Staff, 1999).

The basic physical and chemical properties of soils with descriptive statistics for each sites is given in *Table 5*.

Table 5. *Basic physical and chemical properties of soils and descriptive statistics*

Profile number	**Depth**	**Soil moisture**	**Bulk density**	**Particle density**	**Total porosity**	**Soil organic matter**	**pH**	**Water storage in layer**
	(cm)	**($cm^3 \cdot cm^{-3}$)**	**($g \cdot cm^{-3}$)**		**(%)**		**(KCl)**	**(mm)**
1	0–30	0.3087	1.44	2.53	43.08	3.7	6.29	93
	30–46	0.4644	1.12	2.62	57.25	2.4	6.22	74
	46–63	0.4844	1.06	2.43	56.38	4.0	6.02	82
	63–94	0.6684	0.44	1.69	73.96	7.5	5.61	207
	94–150	0.4622	1.40	2.63	46.77	1.8	7.27	259
2	0–18	0.4016	1.32	2.54	48.03	3.3	6.59	72
	18–34	0.4247	1.29	2.56	49.61	2.3	6.45	68
	34–52	0.3740	1.52	2.57	40.86	2.2	6.67	67
	52–85	0.3363	1.75	2.64	33.71	0.7	6.61	111
	85–150	0.3941	1.61	2.63	38.78	1.1	3.71	256
3	0–25	0.2734	1.65	2.53	34.78	1.8	5.83	68
	25–47	0.2330	1.81	2.66	31.95	1.0	6.16	51
	47–75	0.3197	1.66	2.68	38.06	0.4	6.40	90
	75–117	0.3500	1.68	2.70	37.78	0.3	6.42	147
	117–150	0.3678	1.68	2.67	37.08	0.2	6.29	121
4	0–30	0.5145	1.11	2.56	56.64	4.0	6.49	154
	30–42	0.3943	1.51	2.48	39.11	1.9	6.53	47
	42–71	0.4028	1.56	2.65	41.13	0.7	6.37	117
	71–100	0.3241	1.65	2.67	38.20	0.4	6.53	94
	100–150	0.3159	1.62	2.69	39.78	0.8	4.95	158
Basic descriptive statistics								
Index value:	Minimum	0.2330	0.44	1.69	31.95	0.2	3.71	47
	Maximum	0.6684	1.81	2.70	73.96	7.5	7.27	259
	Mean	0.3907	1.44	2.56	44.15	2.0	6.17	117
	Median	0.3841	1.54	2.63	40.32	1.8	6.39	94
	SD	9.71	0.32	0.22	10.31	1.8	0.74	63
	CV (%)	24.85	22.27	8.49	23.36	88.54	12.02	53.81

High soil moisture values were observed in soil profiles. The average soil moisture content was 0.3907 $cm^3 \cdot cm^{-3}$, which means it is very close to average value of water content at the field's water capacity (*Table 6*). Bulk density (BD) was in range 0.44–1.81 $g \cdot cm^{-3}$ and predominantly increasing with a depth and yielding a very high value for total porosity from 31.95% to 73.96%. Mean particle density value is very similar in whole profiles about 2.56 $g \cdot cm^{-3}$, only in profile no. 1 in fourth genetic horizon (rich in organic matter) it is much smaller (1.69 $g \cdot cm^{-3}$). According to coefficient of variation (CV), the behaviour in the soil profiles can be considered as a low variability (see *Table 5*). Mean organic matter content, about 2.03%, was highest in top layers and decreasing with depth. The pH values were in a wide range from 3.71 to 7.27, which corresponds to very acidic to alkaline soils. The high values of water storage ranged 477–715 mm in soil profiles was observed.

Table 6. *Retention of available water in soil*

Profile number	Depth [cm]	Maximum retentive capacity	Field water capacity	Permanent wilting point	Available water for plants	Easily accessible water	Hardly accessible water
		pF 0.0	**pF 2.5**	**pF 4.2**	**pF 2.5–4.2**	**pF 2.5–3.7**	**pF 3.7–4.2**
		($cm^3 \cdot cm^{-3}$)					
1	0–30	0.4995	0.4289	0.2690	0.1599	0.0529	0.1070
	30–46	0.5618	0.5280	0.3166	0.2114	0.1235	0.0879
	46–63	0.6242	0.6119	0.3314	0.2805	0.2247	0.0558
	63–94	0.7936	0.6784	0.3092	0.3692	0.3437	0.0255
	94–150	0.5203	0.4894	0.1915	0.2979	0.2877	0.0102
2	0–18	0.5117	0.4759	0.2466	0.2293	0.0808	0.1485
	18–34	0.5282	0.5177	0.2894	0.2283	0.1486	0.0797
	34–52	0.4687	0.4502	0.2557	0.1945	0.1150	0.0795
	52–85	0.4080	0.3556	0.1327	0.2229	0.1839	0.0390
	85–150	0.4253	0.3467	0.1034	0.2433	0.2145	0.0288
3	0–25	0.4052	0.3770	0.2500	0.1270	0.1214	0.0056
	25–47	0.3211	0.2985	0.1503	0.1482	0.0879	0.0603
	47–75	0.3823	0.3345	0.1576	0.1769	0.1465	0.0304
	75–117	0.3689	0.3484	0.1306	0.2178	0.1858	0.0320
	117–150	0.3962	0.3417	0.0886	0.2531	0.2135	0.0396
4	0–30	0.5760	0.5663	0.2943	0.2720	0.1764	0.0956
	30–42	0.4514	0.4386	0.2870	0.1516	0.1304	0.0212
	42–71	0.4394	0.4225	0.1873	0.2352	0.2131	0.0221
	71–100	0.3948	0.2690	0.0737	0.1953	0.1352	0.0601
	100–150	0.4314	0.3094	0.0649	0.2445	0.2442	0.0003
Basic descriptive statistics							
Index value	Minimum	0.3211	0.2690	0.0649	0.1270	0.0529	0.0003
	Maximum	0.7936	0.6784	0.3314	0.3692	0.3437	0.1485
	Mean	0.4754	0.4294	0.2065	0.2229	0.1715	0.0515
	Median	0.4454	0.4257	0.2191	0.2256	0.1625	0.0393
	SD	0.11	0.11	0.08	0.06	0.07	0.04
	CV (%)	22.64	25.81	42.84	25.72	41.97	74.66

Hydraulic properties of soils

The data of soil water retention, incuded available water for plants, from laboratory analysis are presented in *Table 6*. The water retention curve for the studied soils showed a mean value of soil moisture of about 0.4754 $cm^3 \cdot cm^{-3}$ at saturation (pF 0.0), 0.4294 $cm^3 \cdot cm^{-3}$ at field water capacity (pF 2.5), and 0.2065 $cm^3 \cdot cm^{-3}$ at permanent wilting point (pF 4.2). Mean share of easily accessible water for plants contributed 77% of the total available water for plants (TAWC), whereas hardly accessible water accounted 23% TAWC.

The determination coefficient (R^2) of observed and fitted values in each layers of soil profiles ranges from 0.825 to 0.995. These results are very satisfactory and show that the estimation procedure works well (*Tables 7, 8* and *9*). *Tables 7, 8* and *9* present different values of the van Genuchten parameters (θ_r, θ_s, α, n) obtained.

Table 7. *Characteristic parameters of soil water content from model PTF-1 with soil USDA textural classes*

Profile number	Depth [cm]	θ_r ($cm^3 \cdot cm^{-3}$)	θ_s ($cm^3 \cdot cm^{-3}$)	α (cm^{-1})	n (–)	R^2
1	0–30	0.0901	0.4820	0.0084	1.5202	0.978
	30–46	0.0982	0.4588	0.0150	1.2529	0.993
	46–63	0.0982	0.4588	0.0150	1.2529	0.987
	63–94	0.0633	0.3837	0.0211	1.3298	0.979
	94–150	0.0645	0.4387	0.0051	1.6626	0.955
2	0–18	0.0792	0.4418	0.0158	1.4145	0.825
	18–34	0.0982	0.4588	0.0150	1.2529	0.995
	34–52	0.0609	0.3991	0.0111	1.4737	0.989
	52–85	0.0387	0.3870	0.0267	1.4484	0.979
	85–150	0.0387	0.3870	0.0267	1.4484	0.965
3	0–25	0.0609	0.3991	0.0111	1.4737	0.969
	25–47	0.0609	0.3991	0.0111	1.4737	0.989
	47–75	0.0387	0.3870	0.0267	1.4484	0.985
	75–117	0.0609	0.3991	0.0111	1.4737	0.987
	117–150	0.0609	0.3991	0.0111	1.4737	0.979
4	0–30	0.0792	0.4418	0.0158	1.4145	0.995
	30–42	0.0901	0.4820	0.0084	1.5202	0.979
	42–71	0.0645	0.4387	0.0051	1.6626	0.981
	71–100	0.0387	0.3870	0.0267	1.4484	0.978
	100–150	0.0387	0.3870	0.0267	1.4484	0.956

Table 8. *Characteristic parameters of soil water content from model PTF-2 with % sand, silt, and clay*

Profile number	Depth [cm]	θ_r ($cm^3 \cdot cm^{-3}$)	θ_s ($cm^3 \cdot cm^{-3}$)	α (cm^{-1})	n (–)	R^2
1	0–30	0.0891	0.4665	0.0096	1.4593	0.978
	30–46	0.0886	0.4484	0.0184	1.2893	0.993
	46–63	0.0990	0.4950	0.0209	1.1936	0.987
	63–94	0.0493	0.3884	0.0217	1.4033	0.979
	94–150	0.0683	0.4340	0.0048	1.6502	0.955

DOI: http://dx.doi.org/10.15666/aeer/1604_46814699
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2	0–18	0.0893	0.4586	0.0136	1.3573	0.825
	18–34	0.0979	0.4899	0.0205	1.2075	0.995
	34–52	0.0710	0.4228	0.0080	1.5222	0.989
	52–85	0.0456	0.3889	0.0189	1.4229	0.979
	85–150	0.0417	0.3841	0.0386	1.5283	0.965
3	0–25	0.0656	0.4064	0.0128	1.4469	0.969
	25–47	0.0654	0.4042	0.0144	1.4294	0.989
	47–75	0.0564	0.3888	0.0240	1.3761	0.985
	75–117	0.0574	0.4019	0.0084	1.5280	0.987
	117–150	0.0518	0.3992	0.0079	1.5455	0.979
4	0–30	0.0896	0.4631	0.0117	1.4001	0.995
	30–42	0.0812	0.4516	0.0068	1.5501	0.979
	42–71	0.0664	0.4215	0.0054	1.6101	0.981
	71–100	0.0477	0.3894	0.0181	1.4251	0.978
	100–150	0.0380	0.3876	0.0355	1.4168	0.956

Table 9. *Characteristic parameters of soil water content from model PTF-3 with % sand, silt, clay and bulk density (BD)*

Profile number	**Depth [cm]**	θ_r **($cm^3 \cdot cm^{-3}$)**	θ_s **($cm^3 \cdot cm^{-3}$)**	**α (cm^{-1})**	**n (–)**	R^2
1	0–30	0.0978	0.5650	0.0112	1.4528	0.978
	30–46	0.1035	0.5774	0.0195	1.3542	0.993
	46–63	0.1146	0.6102	0.0282	1.2495	0.987
	63–94	indicates the parameter cannot be estimated (too low bulk density value)				
	94–150	0.0780	0.5163	0.0046	1.6932	0.955
2	0–18	0.1014	0.5727	0.0156	1.3894	0.825
	18–34	0.1130	0.6064	0.0271	1.2618	0.995
	34–52	0.0807	0.5199	0.0073	1.5678	0.989
	52–85	0.0535	0.4896	0.0115	1.4812	0.979
	85–150	0.0475	0.5235	0.0353	1.4232	0.965
3	0–25	0.0753	0.5160	0.0094	1.5163	0.969
	25–47	0.0749	0.5178	0.0102	1.5004	0.989
	47–75	0.0658	0.5208	0.0159	1.4322	0.985
	75–117	0.0663	0.4917	0.0063	1.6010	0.987
	117–150	0.0602	0.4791	0.0058	1.6215	0.979
4	0–30	0.1000	0.5696	0.0137	1.4136	0.995
	30–42	0.0897	0.5450	0.0073	1.5529	0.979
	42–71	0.0757	0.5068	0.0051	1.6576	0.981
	71–100	0.0577	0.4921	0.0111	1.4871	0.978
	100–150	0.0454	0.5010	0.0231	1.4086	0.956

The graphs of the fitted the van Genuchten model with the RETC to the soil water retention data with laboratory measurements for soil pit no. 1 – from depth of 0–30 cm and for soil pit no. 2 – from depth of 34–52 cm are illustrated in *Figure 3,* as examples. It is observed that both the results of research fit well.

DOI: http://dx.doi.org/10.15666/aeer/1604_46814699
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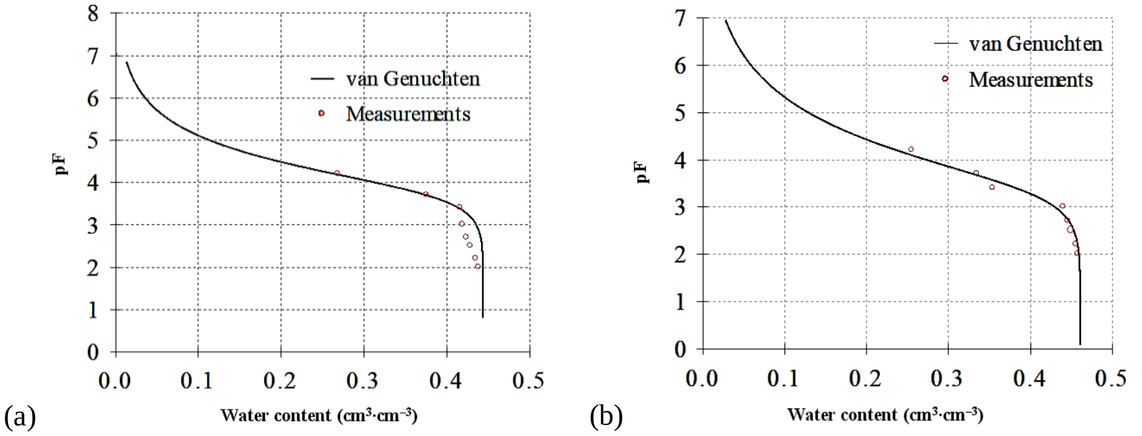

Figure 3. *Water retention curve (pF): a) – soil pit no. 1; b) – soil pit no. 2*

Figures 4 and *5* illustrate the comparison of the predicted water content of the RETC and Rosetta with that of measurement for three pedotransfer models (PTF-1, PTF-2 and PTF-3). The measured results from all soil profiles for θ_s and θ_r were compared with fitted results those of the RETC and Rosetta.

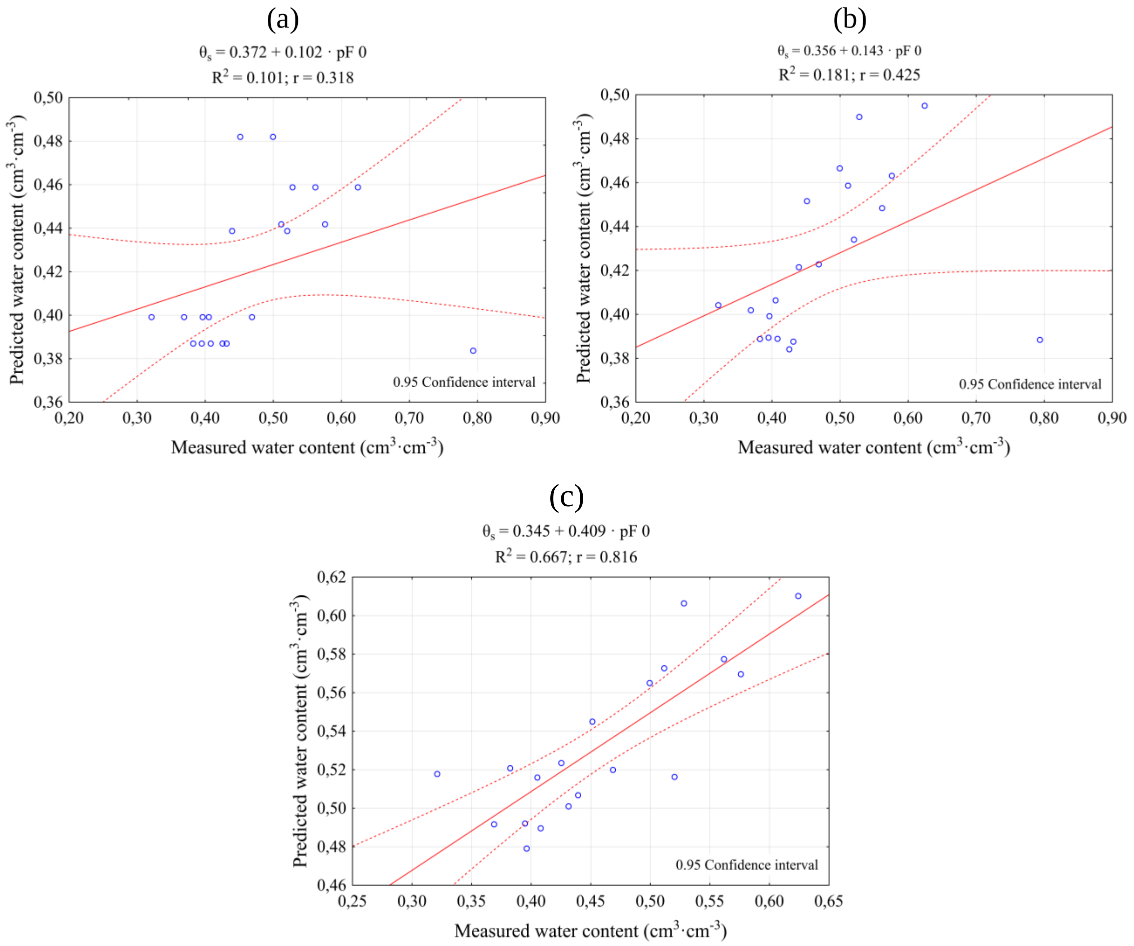

Figure 4. *Estimated vs. measured water contents (θ_s) of the RETC a) for first model (PTF-1), b) second model (PTF-2), c) for third model (PTF-3)*

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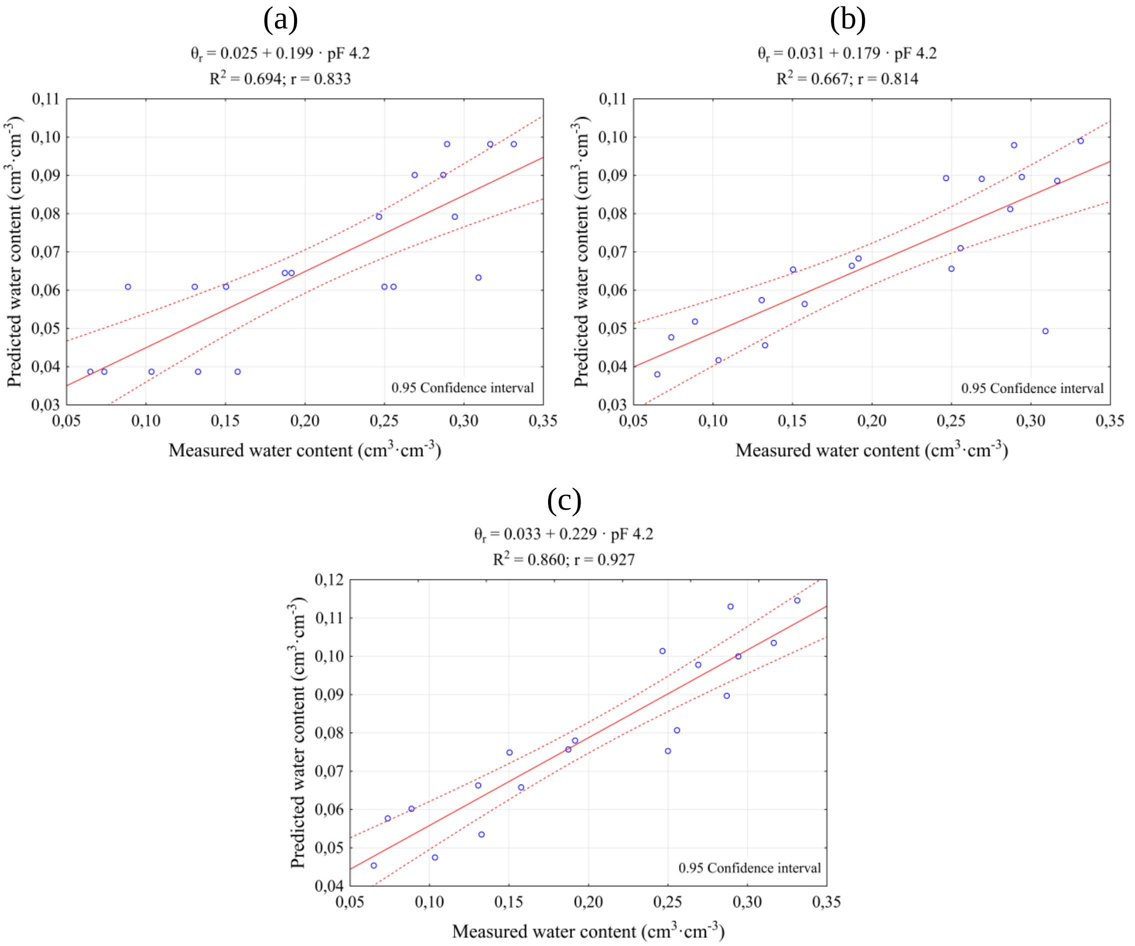

Figure 5. *Estimated vs. measured water contents (θr) of the RETC a) for first model (PTF-1), b) second model (PTF-2), c) for third model (PTF-3)*

The results of the three pedotransfer functions show statistically increase in the R^2 for θ_r (PTF-1 – R^2 = 0.694, $p < 0.05$; PTF-2 – R^2 = 0.667, $p < 0.05$ and for PTF-3 – R^2 = 0.860, $p < 0.05$). On the other hand two neural network models show statistically low R^2 and also no statistically significant for θ_s (PTF-1 – R^2 = 0.101, $p > 0.05$ and for PTF-2 – R^2 = 0.181, $p > 0.05$) only in case of PTF-3 results was high and statistically significant (R^2 = 0.667, $p < 0.05$).

In order to find interrelations of soil properties a correlation R Spearman analysis was conducted. The correlation (*Table 10*) displayed significant correlation between particle size distribution (i.e. sand, silt, clay content) and soil organic matter (SOM) content, and physical and water properties of soil.

Sand content was statistically significance ($p < 0.05$) negatively correlated with field capacity (FC), hardly accessible water and pH, whereas silt content was statistically significance positively correlated with pH. Also clay content was statistically significance positively correlated with FC and hardly accessible water. Soil organic matter was statistically significance positively correlated with water content, total porosity, FC and available water but statistically significance negatively correlated with BD and particle density. The correlation strength between SOM and soil moisture, BD, particle density, total porosity and FC was statistically very high ($r > 0.7$), while between SOM and available water was statistically high ($0.5 < r < 0.7$).

Table 10. *Correlation coefficient (r) between the granulometric composition and organic matter of soils and selected physical and water properties*

Variables:	**Percentage fraction with diameter (mm)**			**SOM (%)**
Physical and water properties of soils:	**Sand 2.0–0.05**	**Silt 0.05–0.002**	**Clay <0.002**	
Water content (% $cm^3 \cdot cm^{-3}$)	r = -0.2134 p = 0.366	r = -0.0488 p = 0.838	r = 0.2785 p = 0.235	**r = 0.7597*** **p = 0.000**
Bulk density ($g \cdot cm^{-3}$)	r = 0.2540 p = 0.280	r = 0.1771 p = 0.455	r = -0.4236 p = 0.063	**r = -0.9220** **p = 0.000**
Particle density ($g \cdot cm^{-3}$)	r = -0.0108 p = 0.964	r = 0.1185 p = 0.619	r = -0.0795 p = 0.739	**r = -0.8707** **p = 0.000**
Total porosity (% $cm^3 \cdot cm^{-3}$)	r = -0.2545 p = 0.279	r = -0.1965 p = 0.406	r = 0.4392 p = 0.053	**r = 0.8747** **p = 0.000**
pH (–)	**r = -0.6649** **p = 0.001**	**r = 0.6055** **p = 0.005**	r = 0.2810 p = 0.230	r = -0.0278 p = 0.907
Field capacity (pF 2.5)	**r = -0.5138** **p = 0.020**	r = -0.0367 p = 0.878	**r = 0.6079** **p = 0.004**	**r = 0.8723** **p = 0.000**
Available water (pF 2.5–4.2)	r = 0.0551 p = 0.817	r = -0.0984 p = 0.680	r = 0.0140 p = 0.953	**r = 0.5163** **p = 0.020**
Easily accessible water (pF 2.5–3.7)	r = 0.2828 p = 0.227	r = -0.0287 p = 0.904	r = -0.2968 p = 0.204	r = 0.2377 p = 0.313
Hardly accessible water (pF 3.7–4.2)	**r = -0.4477** **p = 0.048**	r = -0.0931 p = 0.696	**r = 0.5770** **p = 0.008**	r = 0.3251 p = 0.162

*Values in bold indicate that correlation relationships are statistically significant ($p < 0.05$)

Discussion

The examined alluvial soils are very specified and diversity in terms of texture (Iqbal et al., 2005; Bullinger-Weber et al., 2007; Ľuptáčik et al., 2012) and showed high water content values (at saturation 0.4754 $cm^3 \cdot cm^{-3}$ and wilting point 0.2065 $cm^3 \cdot cm^{-3}$). This feature may be related to the high silt (35.9%) and clay (26.1%) for all soil profiles and also mean organic matter content about 2.03% (Rawls et al., 2003; Rubio and Poyatos, 2012). Minasny et al. (2003) reported. that the hydraulic parameters are mostly sensitive to sand content and saturated water content. Gama-Castro et al. (2000) found, that the high productivity of alluvial soils is largely due to the plant available water. According to Hong et al. (2013) the most important values for agricultural use is a field water capacity (at pF 2.5), which in this case ranged between 0.2690 and 0.6784 $cm^3 \cdot cm^{-3}$.

The maximum retentive capacity (at pF 0.0) measured in laboratory was slightly different than total porosity calculated from bulk density and particle density. Paluszek (2011) stated that the difference between maximum retentive capacity and total porosity may be especially visible in the soils with high content of swelling clay minerals because maximum retentive capacity was directly determined after capillary rise to the state of full saturation, while total porosity was calculated on the basis of the particle density and bulk density.

Bulk density (BD) is one of important physical soil properties that characterizes soil compaction (Reynolds et al., 2002). The BD range of alluvial soils can be very wide – smaller values were observed in the Ap horizons and increased with depth (Gama-Castro et al., 2000). We observed that bulk density was related to organic matter contents, which is not in agreement with the findings of Gama-Castro et al. (2000), where they assumed that the presence of more noncrystalline material due to increased pumice weathering contributes to the low bulk density through the development of a porous soil structure.

Used the pedotransfer models of artificial neural network program Rosetta in this case, produces promising results only for sand, silt, and clay percentages and bulk density as data input. This might be due to the fact that the van Genuchten’s parameters. which express the shape of the water retention curve, are sensitively affected by the wide ranges of soil properties as in this alluvial soil. Even though the data used in this study was obtained from a relatively small area, large spatial and temporal variability in physical and hydraulic properties of this alluvial soil may cause such a low performance in predictions. Similar results were observed by Minasny et al. (1999), Nemes et al. (2002) and Merdun et al. (2006).

Conclusions

In conclusion the course of the water retention curves obtained on the basis of non-linear regression analysis (R^2) for each layers of soil profiles indicates a good adjustment of the approximating functions used to the retention capacity obtained from the measurements. The pedotransfer models of artificial neural network program RETC and Rosetta in this case produces promising results and its advantages can be utilized by developing of water hydraulic characteristics of alluvial soils in future studies. The simulation of the RETC using the van Genuchten equation with a percentages of sand, silt and clay and also bulk density entry value was adequate to estimate soil water contents for four soil profiles located in the Odra River valley, in spite of the differences obtained between observed and predicted data.

On the basis of the conducted research it can be concluded that share of easily accessible water for plants was higher of the hardly accessible water for plants. It is very important from the viewpoint of the production and cultivation. Alluvial soil can hold moisture and is very fertile so in dry years plants do not suffer from a shortage of water.

Studies on water retention of alluvial soils should be extended in order to obtain more data that will be used for proper statistical inference. Other properties of alluvial soils, e.g. water permeability, should also be carried out.

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