ASSESSMENT OF SOIL HYDROLOGIC COEFFICIENTS BY PEDOTRANSFER FUNCTIONS

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Abstract: Soil hydrologic coefficients, that we also call hydrolimits, are soil water contents defined for certain values of water potentials. Closer attention is paid to three hydrolimits: field capacity, point of decreased availability and wilting point. The hydrolimits can be found out by various ways. Their assessment under natural conditions should be seen as laboratory assessment of hydrolimit values or use of soil water retention curves for reading of hydrolimits. Therefore, some methods for indirect assessment of the water retention curve from basic soil characteristics such as soil texture, bulk density and $CaCO_3$ content were devised. They are generally called pedotransfer functions (PTFs). Aim of the study is to calculate values of some important hydrolimits using PTFs. The hydrolimits calculated by this way are compared to hydrolimits determined from another measured water retention curves. The presented study documents a convenience of PTFs using for dynamics evaluation of water storage in the soil aeration zone considering the water supply of plants.
Key words: water storage, hydrolimit, water retention curve, pedotransfer function

DIE BESTIMMUNG DER HYDROLOGISHEN BODENSKOEFFIZIENTEN DURCH DIE PEDOTRANSFERFUNKTIONEN

Zusammenfassung: Die hydrologischen Koeffizienten des Bodens, die auch Fixpunkte der Wasserbewegung genannt werden, sind die bei dem konkreten Feuchtepotenzial definierten Wassergehalte. Nähere Aufmerksamkeit wird den drei Fixpunkten, und zwar der Feldkapazität, dem Punkte niedrigerer Erreichbarkeit und dem Welkepukte gewidmet. Die Fixpunkte kőnnen entweder in den Natur- oder Labor-bedingungen, oder durch die Benűtzung von Wasserretentionscurven (WRC) festgestellt werden. Deshalb wurden die Methoden auf indirecte Feststellung von WRC aus den grundlichen Feldcharakteristiken und zwar, Korngrőssenzusammensetzung, Dichte des trockennen Bodens und $CaCO_3$ Inhalt, vorgeschlagen. Diese Methoden werden in Allgemeinen Pedotransferfunktionen (PTF) genannt. Das Ziel des Beitrags ist die Berechnung der Werte irgendeinen wichtigen Fixpunkten mit Hilfe PTF. Die soweise ausgerechneten Fixpunkte werden mit den Fixpunkten verglichen, welche aus den gemessenen WRC bestimmt wurden. Der praäsentierte Beitrag dokumentiert die Eignung der Verwendung PTF fűr die Bewertung der Dynamik des Wasservorrats in der Aerationszone des Bodens von dem Gesichtspunkt der Wasserpflanzenversorgung.
Schluesselworte: Wasservorrat, Fixpunkte, Wasserretentionscurve, Pedotransferfunktion

1. Introduction

Water regime of soil aeration zone, which determines production ability of soil, depends on inflow into or outflow from the area. Because of the plants are supplied by water from the soil aeration zone, it is necessary to know the water amount that the soil can provide the plants with. The water amount (or water storage) in the soil aeration zone reacts to weather changes and to technical impacts realised within the area from the long-term point of view (Kopecký, 2002). For estimation of water storage in the soil aeration zone in relation to plants the hydrologic coefficients, which are also called hydrolimits, can be used.

Hydrolimits are soil water contents defined for certain values of water potentials. Closer attention is paid to three hydrolimits: field capacity Θ_{FC}, soil water content defining point of decreased availability Θ_{PDA} and wilting point Θ_{WP}. The hydrolimits can be found out by various ways. Their assessment under natural conditions should be seen as laboratory assessment of hydrolimit values of the individual soil samples. The assessment is a little bit lengthy and it has only one-sided use. Use of soil water retention curves for reading of hydrolimit values for respective water potentials is another possibility. And then the problem of hydrolimit assessment is concentrated on assessment of dependence of a soil water potential on volume soil water content $h_w(\Theta)$ in balanced state, that is the water retention curve (WRC).

Measuring of the dependence $h_w(\Theta)$ is very expensive, time consuming and labor intensive. An obvious relationship between $h_w(\Theta)$ and soil texture has led to formulation of models that are trying to put into relation e.g. sand, clay and dry bulk density with $h_w(\Theta)$, etc. and they are generally called pedotransfer functions (PTFs) (Gupta, Larson, 1979; Rawls, et al. 1982; Bouma, Van Lanen, 1987; Šútor, Štekauerová, 1999; Šútor, et al. 2001; Gomboš, Burger, 2001).

Aim of the study is to calculate values of some important hydrolimits using pedotransfer functions that were devised from a smaller file of water retention curves, but calcium content was determined in soil samples too. The hydrolimits calculated this way are compared to the hydrolimit values determined from another measured water retention curves. Suitability of the method for its using in practice is verified this way.

2. Material and methods

A data file consists of measuring results on 57 soil samples. The soil samples come from regions of The Rye Island and Záhorie namely from localities of Kráľovská lúka, Baka, Horný Bar, Šamorín, Gabčíkovo, Čilistov, Čiližská Radvaň, Šintava, Gáň, Sereď, Trakovice, Bučany, Šulekovo, Lošonec, Sekule. Drying branches of water retention curves (WRC) were measured on soil samples under laboratory conditions by overpressure apparatus Soil Moisture Equipment, Santa Barbara, California. Soil water contents were determined at water potentials of -3, -30, -300, -800, -1300 cm. Particle size distribution was determined by Cassagrande's method. Content of $CaCO_3$ was determined for each sample as well as dry bulk density ρ_d.

Pedotransfer functions (PTFs) were obtained by sextuple linear regression for volume soil water contents Θ_{hw} at water potentials h_w = -3, -30, -300, -800, -1300 cm depending on percentage content of I., II., III. and IV. grain category according to Kopecký, on percentage content of $CaCO_3$ and on dry bulk density. Resultant PTFs have the general form:

$$\Theta_{hw} = A(I.cat) + B(II.cat) + C(III.cat) + D(IV.cat) + E(CaCO_3) + F\rho_d + G \qquad (1)$$

where A, B, C, D, E, F, G are regression coefficients, I., II., III. and IV. grain categories: I.cat. - percentage of clay (< 0.01 mm), II.cat. - percentage of silt (0,01–0.05 mm), III.cat. - percentage of fine sand (0.05–0.10 mm), IV.cat. - percentage of sand (0.1–2.0 mm), $CaCO_3$ in mass % and ρ_d is dry bulk density in $g.cm^{-3}$.

Regression coefficients A, B, C, D, E, F, G are presented in table 1 for all water potentials together with a correlation coefficient R. Coefficients A, B, C, D, E, F and G can be used for calculation of water retention curves points i.e. volume water contents θ at respective water potential h_W.

Table 1. Coefficients A,B,C,D,E,F,G and correlation coefficient R

h_w (cm)	*Coefficients of regression relations*							*R*
	A	*B*	*C*	*D*	*E*	*F*	*G*	
-3	0.309	0.222	0.232	0.164	-0.038	-28.953	67.504	0.9032
-30	0.212	0.135	0.032	-0.049	0.032	-17.464	58.398	0.8309
-300	0.267	0.081	-0.512	-0.054	-0.137	-7.159	48.034	0.8188
-800	0.270	0.049	-0.610	-0.023	-0.126	-5.487	42.921	0.8095
-1300	0.261	0.033	-0.562	-0.037	-0.118	-6.303	42.287	0.8002

A new data file of drying branches of WRC measured on 9 soil samples was obtained from the same localities from which the data file of 57 drying branches of WRC appointed for PTFs quantification was obtained. The WRC of the 9 samples were measured using the same above-mentioned method for water potentials of -3, -30, -300, -800, -1300 cm (Table 3). They were approximated using a relation by van Genuchten (1980) and thereby the values of coefficients α_m and n_m where *m* stands for coefficients obtained for measured drying branches of WRC, were obtained. A value of residual moisture Θ_r was calculated for the soil samples using the relation (Šútor, Majerčák, 1988):

$$\Theta_r = 0,20058\ (\%\ \text{I.cat}) + 1,03747 \tag{2}$$

The data file of the approximated WRC was labelled as S_m. Point values of WRC at water potentials of -3, -30, -300, -800, -1300 cm were calculated from the grain categories of the soil samples, $CaCO_3$ content and from values of dry bulk densities ρ_d (Table 2) using the PTFs (eq.1, Table 1). The above-mentioned point values were also approximated according to van Genuchten and so the coefficient values α_{PTF} and n_{PTF} were obtained. The PTF index means that the coefficients were obtained from WRC calculated using PTFs. The file of approximated WRC was labelled as S_{PTF}. The hydrolimits field capacity Θ_{FC}, the soil water content defining point of decreased availability Θ_{PDA} and the wilting point Θ_{WP} were determined from the WRC approximated according to van Genuchten for both files S_m and S_{PTF}.

3. Results and discussion

Main parameters obtained by approximation of WRC using the van Genuchten relation for both files S_m and S_{PTF} are presented for 9 soil samples A1 - A9 (Table 2).

Table 2. Van Genuchten parameters of the water retention curves α, n, Θ_S is the saturated water capacity and Θ_r is residual volume water content equal for the files S_m and S_{PTF} (S_m stands for measured WRC, S_{PTF} stands for WRC calculated using PTFs)

WRC	S_m			S_{PTF}			
	α_m	n_m	Θ_S	α_{PTF}	n_{PTF}	Θ_S	Θ_r
A1	0.00308	1.43009	0.4357	0.00087	1.77630	0.4105	0.0230
A2	0.00125	1.59781	0.5275	0.00131	1.61913	0.5175	0.0438
A3	0.00238	1.47283	0.4493	0.00087	1.77924	0.4117	0.0217
A4	0.00262	1.45777	0.5199	0.00190	1.65047	0.4549	0.0256
A5	0.00211	1.50287	0.4771	0.00096	1.72924	0.4258	0.0238
A6	0.00243	1.45779	0.4482	0.00106	1.67931	0.4657	0.0451
A7	0.00476	1.38122	0.4838	0.00145	1.57888	0.4805	0.0292
A8	0.00261	1.45047	0.5418	0.00135	1.60629	0.4619	0.0228
A9	0.00300	1.43083	0.4821	0.00118	1.65143	0.4898	0.0492

The hydrolimit values are dependent on time variability throughout a year that is related to soil bulk changes. Therefore the hydrolimit values are always within certain intervals of soil water content. They are not specific values. The soil water content defining point of decreased availability and the wilting point are dependent on a type of growth. Therefore the hydrolimits Θ_{FC}, Θ_{PDA} and Θ_{WP} were obtained from water retention curves of the file S_{PTF} and from measured WRC (the file S_m) for mean values of water potentials namely for $pF_{FC} = 2.5$, $pF_{PDA} = 3.3$ and $pF_{WP} = 4.18$. The results are presented in Table 3.

Figure 1 shows the water retention curves of soil samples A1 to A9 from the both files and the values of three presented hydrolimits are displayed too. It is also possible to determine a value of another hydrolimit Θ_S from representation of WRC. The hydrolimit is characterised by the soil water content at complete soil pore saturation by water and it expresses the maximum water amount that can be found in soil. It is defined for the water potential that equals 0 cm. Figure 1 represents its measured and also using PTFs calculated soil water value for the water potential of –3 cm.

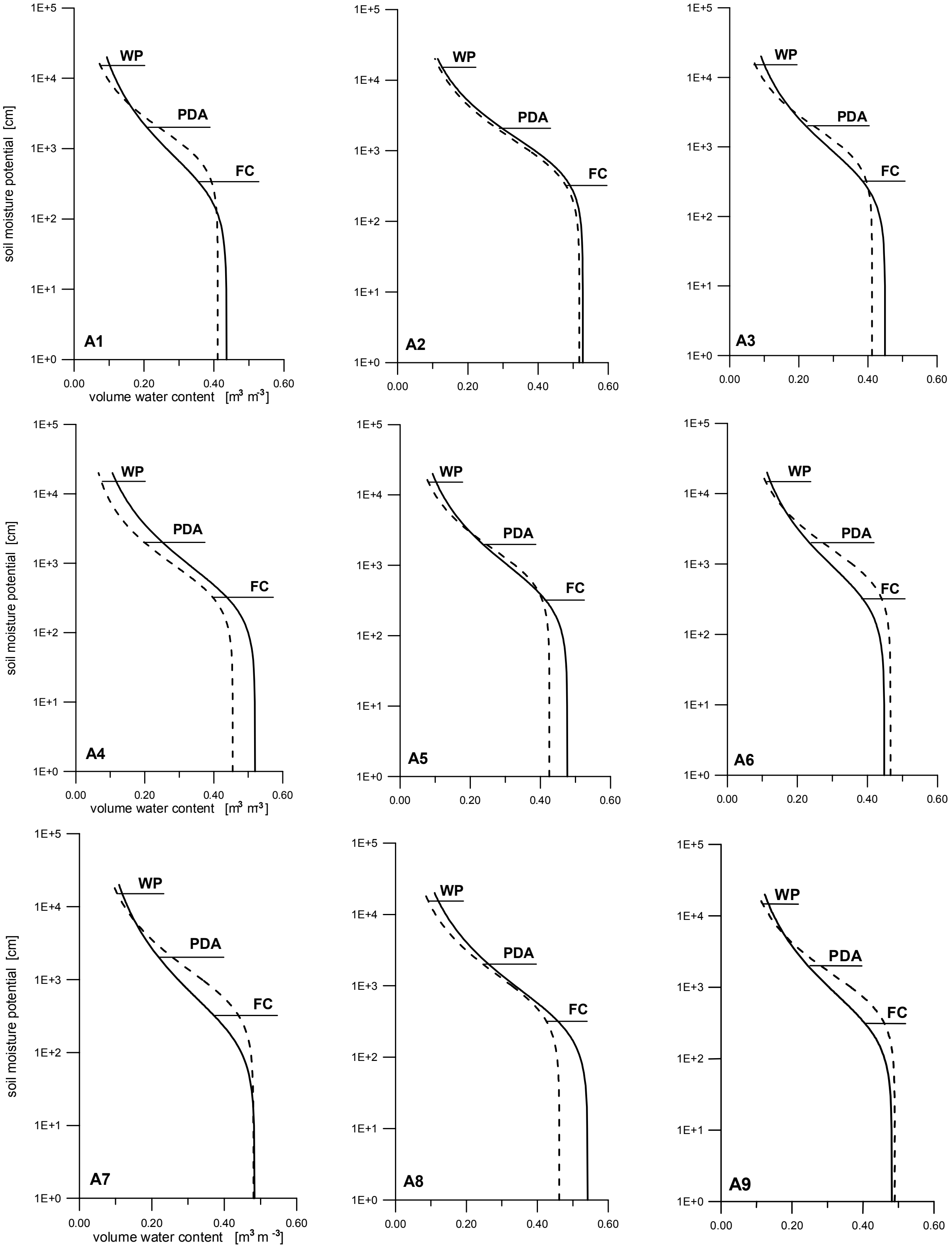

Figure 1. Water retention curves (—— measured, – – – calculated by PTFs) approximated using van Genuchten relation (FC, PDA and WP are marked hydrolimit values in order of the field capacity, the soil water content defining point of decreased availability and the wilting point)

Table 3. Hydrolimits calculated from WRC approximated using van Genuchten relation for both files S_m and S_{PTF}. Θ_{FC}, Θ_{PDA}, Θ_{WP} are marked hydrolimit values in order of the field capacity, the soil water content defining point of decreased availability and the wilting point. Δ is difference between hydrolimit values from the files S_{PTF} and S_m

WRC	S_m			S_{PTF}			$\Delta = f\ (S_{PTF} - S_m)$		
	Θ_{FC}	Θ_{PDA}	Θ_{WP}	Θ_{FC}	Θ_{PDA}	Θ_{WP}	Θ_{FC}	Θ_{PDA}	Θ_{WP}
	pF=2.5	*pF=3.3*	*pF=4.18*	*pF=2.5*	*pF=3.3*	*pF=4.18*	*pF=2.5*	*pF=3.3*	*pF=4.18*
A1	0.3500	0.2080	0.1020	0.3946	0.2427	0.0752	0.0446	0.0347	-0.0268
A2	0.4919	0.3029	0.1269	0.4801	0.2067	0.1081	-0.0118	-0.0162	-0.0088
A3	0.3852	0.2199	0.0998	0.3957	0.2425	0.0738	0.0105	0.0226	-0.0260
A4	0.4395	0.2513	0.1172	0.3984	0.1987	0.0738	-0.0411	-0.0526	-0.0434
A5	0.4158	0.2359	0.1031	0.4060	0.2461	0.0807	-0.0098	0.0102	-0.0224
A6	0.3876	0.2350	0.1224	0.4413	0.2736	0.1087	0.0537	0.0386	-0.0137
A7	0.3728	0.2196	0.1182	0.4401	0.2584	0.1045	0.0673	0.0388	-0.0137
A8	0.4585	0.2630	0.1217	0.4259	0.2473	0.0931	-0.0326	-0.0157	-0.0286
A9	0.4045	0.2450	0.1327	0.4598	0.2807	0.1164	0.0553	0.0357	-0.0163

A close agreement is evident when comparing WRC measured and calculated using PTFs as it is displayed in Figure 1. Correctness of the calculated WRC is quantified with the mean difference (MD) and with the root of mean squared difference (RMSD):

$$MD = \frac{1}{b-a}\int_a^b \left(\theta_p - \theta_m\right) d\psi \qquad (4)$$

$$RMDS = \left[\frac{1}{b-a}\int_a^b \left(\theta_p - \theta_m\right)^2 d\psi\right]^{1/2} \qquad (5)$$

MD and RMSD are calculated using the method of numerical quadrature within an interval of soil moisture potentials <a;b> ≡ <-74130 cm; 0 cm> using integrals, where Θ_m stands for a measured water content, Θ_p stands for an equivalent water content calculated from PTFs and $d\psi$ is a soil moisture potential increment. RSMD values determine the closeness between measured values of a water retention curve and its values obtained using PTFs. Tietje – Tapkenhinrichs (1993) present results of PTFs evaluation by 13 authors and 100% applicability is evident at 5 authors, RMSD values occur between 1.29 and 6.11 % of the volume water content. The results of MD and RMDS values for soil samples A1 – A9 are in the table 4 and they occur between 0.76 and 3.7 % of the volume water content.

Table 4. Mean difference (MD) and root of mean squared difference (RMSD) for comparison of the measured values with the calculated values of WRC for soil samples A1 – A9

WRC	*MD* *($100\ m^3\ m^{-3}$)*	*RMSD* *($100\ m^3\ m^{-3}$)*
A1	-0.0226	0.0266
A2	-0.0071	0.0076
A3	-0.0218	0.0241
A4	-0.0362	0.0370
A5	-0.0188	0.0199
A6	-0.0118	0.0177
A7	-0.0130	0.0195
A8	-0.0249	0.0252
A9	-0.0144	0.0197

Close agreement is also obvious between hydrolimit values of the field capacity, the soil water content defining point of decreased availability for plants and the wilting point determined from measured WRC and from WRC calculated using PTFs (Table 3). Difference between values of the hydrolimit Θ_{FC} from data files S_m and S_{PTF} ranges from 0.98 to 6.73 % of the volume water content. Difference between values of the hydrolimit Θ_{PDA} from data files S_m and S_{PTF} ranges from 1.02 to 5.26 % of the volume water content. Difference between values of the hydrolimit Θ_{WP} from data files S_m and S_{PTF} ranges from 0.88 to 4.34 % for all the cases.

Assessment of WRC or the hydrolimits by this simplified way is advantageous for a water regime management of areas and for soil water regime interpretation using mathematical models.

4. Conclusion

Pedotransfer functions were obtained from 57 drying branches of water retention curves.. The PTFs were used for a calculation of 9 water retention curves (data file S_{PTF}) that were measured too (data file S_m) and were not included in the foregoing data file. The WRC were approximated using van Genuchten relation in the both cases. Figure 1 and Table 6 clearly demonstrate a close agreement for all 9 WRC. Measured and calculated WRC were used for hydrolimit values assessment of the field capacity Θ_{FC}, the soil water content defining point of decreased availability Θ_{PDA} and the wilting point Θ_{WP}. It was found out, that differences between hydrolimit values Θ_{FC} and Θ_{PDA} determined from approximated WRC measured and calculated from PTFs did not exceed 6.38 % of volume water content and a difference Θ_{WP} did not exceed 2.57 % for all the cases.

The presented study documents an efficiency and promptness of PTFs using for a region of interest for dynamics evaluation of water storage in the soil aeration zone considering the water supply of plants.

5. References

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