Indirect estimation of plant-available water limits in selected soils of Wielkopolska Province (Poland)

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Introduction

Hydropedology provides detailed information on soil hydraulic properties which is indispensable to solve water management problems related to environmental, agricultural and ecological purposes. For small area direct determination of hydraulic parameters, on field or laboratory, are preferred. For larger area these time consuming and expensive measurements can be substituted by indirect estimation, using a chosen pedotransfer function (PTF). Published evaluations of accuracy of plant available water capacity (PAWC) estimation did not show the most appropriate single PTF and reveal specific limitations in its application in various soil conditions.

The objective of this study was to develope functions for estimating both upper and lower limits of PAWC, i.e. field capacity (FC at 10 kPa) and permanent wilting point (WP at 1500 kPa) from standard soil survey data (texture, organic carbon, bulk density, porosity).

Materials and Methods

The analysis were carried out on methodologicaly uniform training data set of 167 horizons taken from 39 soil profiles including Luvisols, Albeluvisols and Mollic Gleysols formed from glacial tills, as well as Arenosols and Podzols formed from fluvioglacial materials. The water retention curves were determined using 1 and 15 bar ceramic plates on four times repeated undisturbed soil samples (50cm^3). Wilting point was also determined on disturbed soil samples using exiccator methods (Kędziora 1971; 21°C, 10mm Hg suction, above water solution of H_2SO_4 with ratio of 96% acid to water as 1:2,107). Other soil characteristics were determined using standard methods. For evaluation of modeling accuracy compilation of published data from Poland as well as six other published data sets were used (Table 1).

Table 1
Sizes and mean values of basic characteristics of training and validation data sets

Data set	Data set size	Bd	ϕ	Corg	Sand	Silt	Clay	Dg3f	FC mean	FC Variance	WP mean	WP Variance	PAWC mean	PAWC Variance
		Mg/m³	v/v	%	%	%	%	mm	v/v	-	v/v	-	v/v	-
Training data set														
Kaźmierowski (2007)	167	1.677	0.368	0.70	71.1	18.1	10.8	0.104	0.266	0.004	0.059	0.002	0.168	0.003
Validation data sets														
Poland - FC	97	1.558	0.411	0.70	67.7	23.0	9.3	0.116	0.231	0.009	-	-	-	-
Poland - WP	90	1.556	0.411	0.66	65.9	24.5	9.5	0.109	-	-	0.078	0.003	-	-
Poland - PAWC	76	1.567	0.407	0.71	63.1	26.6	10.3	0.101	-	-	-	-	0.165	0.005
Mohanty et al. (1999)	128	1.402	0.466	0.76	46.8	36.9	16.3	0.048	0.289	0.003	0.123	0.002	0.165	0.002
Denton et al. (2004)	97	1.625	0.387	0.06	69.5	25.2	5.4	0.118	0.237	0.010	0.131	0.008	0.107	0.007
Tempel et al. (1996)	1570	1.424	0.458	0.72	46.4	29.5	24.1	0.050	0.334	0.013	*(0.154)*	*(0.008)*	0.181	0.006
Tempel et al. (1996)	22948	1.414	0.462	0.76	37.8	37.1	25.2	0.034	-	-	0.166	0.007	-	-
Nemes et al. (1999)	338	1.464	0.445	0.70	49.9	33.0	17.2	0.076	0.294	0.016	0.147	0.009	0.150	0.007
Stolbovoy (2002)	682	1.367	0.476	1.22	31.3	46.6	22.1	0.021	0.338	0.004	0.100	0.001	0.288	0.004
Batjes (2002) - FC	1010	1.381	0.478	0.89	43.4	24.3	32.3	0.041	0.295	0.018	-	-	-	-
Batjes (2002) - WP	3807	1.412	0.463	0.99	38.2	30.0	31.7	0.033	-	-	0.163	0.009	-	-
Batjes(2002) - PAWC	900	1.356	0.487	0.95	41.9	24.1	33.9	0.038	-	-	-	-	0.127	0.004

where Bd is the bulck density, Dg3f is the geometric mean diameter (Shirazi and Boersma 1984) calculated on the basis of sand, silt and clay contents (sieving and hydrometer methods) with lower clay size limit at 0,00004 mm (Scheinost et al. 1997); ϕ is the porosity; Corg is the organic carbon (Walkeley-Black method).

PTF developed by stepwise multiple linear regression (SPSS v.12) and the other twelve published point and parametric PTF's (Table 2) were tested and their goodness-of-fit criteria and bias was evaluated (mean error ME, root mean square error RMSE, its relative value RRMSE and modelling efficiency index EF after Loague and Green, 1991).

$$ME = \frac{1}{n}\sum_{i=1}^{n}(P_i - O_i) \qquad RMSE = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(P_i - O_i)^2} \qquad RMSRE = \frac{100}{\overline{O}} \times RMSE \qquad EF = 1 - \frac{\sum_{i=1}^{n}(P_i - O_i)^2}{\sum_{i=1}^{n}(O_i - \overline{O}_i)^2}$$

Results

Among published PTF the models of Hudson (1986) and Wösten et al. (1999) give the best estimation of FC (RMSE of 0,04 and 0,042 m^3×m^3, respectively). Rosetta model (Schaap et al. 2001) and equation of Batjes (1996) estimated well the WP (RMSE of 0,028 and 0,032 m^3×m^{-3}, respectively). For estimation of PAWC the smallest RMSE and the highest EF value were indicated for PTF developed by Vereecken et al. (1989) and Wösten et al. (1999), but corresponding RMSE are relatively higher than for specific water content limits (0,055 and 0,062 m^3×m^{-3}, respectively).

Equation proposed in this paper (Sa, Cl – sand and clay content respectively) explained of 79 %, 46 % and 47% of total variance of FC, WP and PAWC, respectively. Application of these equations increase the accuracy of FC, WP and PAWC estimation with corresponding RMSE of 0,029, 0,024 and 0,037 m^3×m^{-3}, and EF of 0,79, 0,61 and 0,49 respectively.

$$\text{FC (v/v; if Corg} \le 3\%) = 0{,}190 - 0{,}911 \times Dg3f + 0{,}337 \times \phi + 0{,}0155 \times Corg$$

$$\text{FC (v/v; if Corg} > 3\%) = 0.279 - 0.659 \times Dg3f + 0.179 \times \phi + 0.014 \times Corg - 0.001 \times Sa$$

$$\text{WP (v/v)} = 0.006 - 0.068 \times Dg3f + 0.058 \times \phi + 0.004 \times Cl$$

Table 2
Goodness-of-fit criteria of FC, WP and PAWC estimation of analysed PTF on training data set

Pedotransfer function	PTF type	FC ME	FC RMSE	FC RRMSE	FC EF	WP ME	WP RMSE	WP RRMSE	WP EF	PAWC ME	PAWC RMSE	PAWC RRMSE	PAWC EF
		v/v	v/v	% of mean	-	v/v	v/v	% of mean	-	v/v	v/v	% of mean	-
RTEC [1]	Optim. VGM [2]	0.007	0.012	5.5	0.96	0.010	0.018	30.9	0.78	-0.003	0.019	11.1	0.86
Vereecken et al. (1989)	VGM par.	0.032	0.054	24.1	0.27	0.027	0.041	69.7	-0.12	0.006	0.055	33.0	-0.21
Scheinost et al. (1997)	VGM par.	0.061	0.096	42.3	-1.24	0.051	0.061	104.1	-1.51	0.010	0.095	56.3	-2.52
Wösten et al.. (1999)	VGM par.	-0.009	0.042	18.4	0.58	0.020	0.045	76.1	-0.34	-0.029	0.062	37.1	-0.53
ENR 6 (Minasny et al.1999)	VGM par.	-0.002	0.046	20.3	0.48	0.035	0.047	80.2	-0.49	-0.038	0.072	42.9	-1.04
Mayr and Jarvis (1999)	BC[3] par.	0.009	0.050	22.0	0.40	0.043	0.061	104.6	-1.53	-0.034	0.063	37.8	-0.59
Schaap et al. (2001)	VGM par. ANN	-0.042	0.055	24.5	0.25	0.012	0.028	47.0	0.49	-0.054	0.069	41.0	-0.87
Minasny McBratney (2001)	VGM par. ANN	0.027	0.058	25.8	0.17	0.025	0.040	68.8	-0.09	0.002	0.068	40.3	-0.81
Hudson (1986)	point, mult. reg.	-0.003	0.041	17.9	0.60	0.057	0.070	119.3	-2.29	-0.062	0.078	46.5	-1.40
Batjes (1996)	point, mult. reg.	-0.075	0.087	38.6	-0.86	0.013	0.033	55.8	0.28	-0.088	0.097	57.9	-2.72
Katterer et al. (2005)	point, mult. reg.	-0.003	0.054	23.9	0.29	0.013	0.031	52.6	0.36	-0.015	0.066	39.5	-0.73
Walczak et al. (2006)	point, mult. reg.	-0.115	0.126	55.7	-2.52	-0.033	0.047	79.7	-0.07	-0.099	0.111	66.3	-3.07
Giltrapp i Hewitt (2003)	point, mult. reg.	-	-	-	-	-	-	-	-	-0.071	0.083	49.8	-1.76
FC - Hudson (1986) WP- Katterer et al. (2005)	point, mult. reg.	-	-	-	-	-	-	-	-	-0.017	0.045	27.1	0.19
Presented in the paper	point, mult. reg.	0.003	0.030	13.3	0.78	0.005	0.024	41.1	0.61	-0.002	0.038	22.5	0.44

[1] - RTEC code by van Genuchten et al. (2001), [2] – van Genuchten- Mualem SWRC model (m=1-1/n), [3] – Brooks-Corey SWRC model.

The best estimation of PAWC value on the basis of published PTF's was achieved using compilation of equation of Hudson (1986) for FC and Katterer et al. (2005) for WP, with corresponding RMSE of 0,045 m^3×m^{-3} and EF of 0,184.

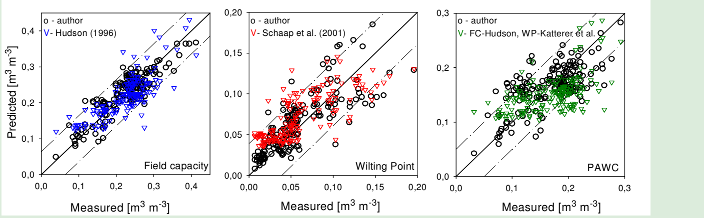

Fig. 1. Measuded vs. predicted values of FC, WP and PAWC on training data set

Validation on slightly more silty soils from independent Polish data set indicated an increase of estimation errors of proposed PTF (Fig. 2), which are comparable with the corresponding values for the best published models. Analysis of modeling accuracy on eight different data sets (Fig. 4) indicated generally high values of efficiency index (EF) for proposed equations.

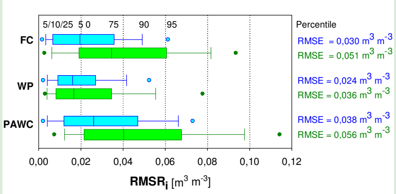

Fig. 2 . Boxplots of RMSE$_i$ for FC, WP and PAWC estimation on **training** and **Polish validation** data sets of proposed PTF

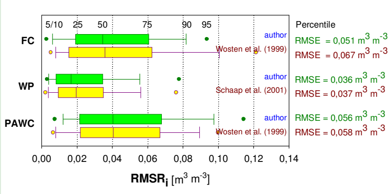

Fig. 3 . Boxplots of RMSE$_i$ for FC, WP and PAWC estimation of proposed and the best published PTF on Polish validation data set

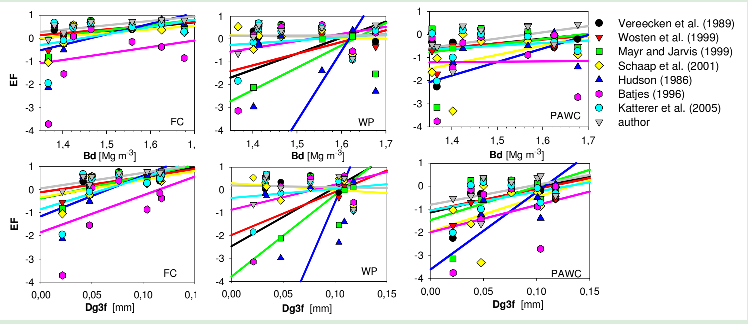

Fig. 4. Comparision of modeling efficiency index values for selected PTF on eight data sets

Conclusion

The results of the study sugest so the findings of regional PTF is still neded. Analysys of goodnes-of-fit criteria of present and published PTF on eigth data sets indicated so proposed equations are effective also in various soils outside the study region.