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Attempt of water retention characteristcs estimation as pedotransfer function for organic soils**

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A b s t r a c t. This paper presents the results of statistical-physical modelling (pedotransfer function) relating soil water content at defined values of soil water potential to selected physical and chemical parameters of organic soils. The two models were developed as the result of the modelling. The independent variables of equations of both models are: ash content, specific surface area, bulk density, pH in KCl and Fe content. The following ranges of determination coefficient values between the measured and predicted water content were estimated for the models: $0.67 < R^2 < 0.81$ for the first and $0.68 < R^2 < 0.91$ for second one.

K e y w o r d s: organic soils, pedotransfer functions, water retention

INTRODUCTION

Among hydrophysical properties of soils there are two properties which play a fundamental role in forming the water balance of regions. They are the water capacity and the water permeability (Hillel, 1998; Kutilek and Nielsen, 1994). It has been established that through the knowledge of these properties and their dependence upon various factors it is possible to control the processes of water circulation in the biosphere. Therefore, they are responsible for the amount of water in the river systems, surface and underground water reservoirs, and for the proper conditions of plant growth and development with consideration of the most efficient consumption of water. It is especially important for organic soils, because these are under intensive anthropogenic evolution since the 70's of the 20th century. The transformation of organic soils as a result of drainage and agricultural use leads to changes in their physical characteristics such as increase of bulk density and ash content, decrease of total porosity as well as of the quantity of macro- and mezopores (Rovdan *et al*., 2002; Sokołowska *et al*., 2005; Sokołowska and Józefaciuk, 2004; Włodarczyk and Kotowska, 2005).

The measurements of soil hydrophysical characteristics are time and labour consuming and they require special equipment. An alternative to the direct measurements is to estimate these characteristics with the use of pedotransfer functions. Whereas for the mineral soils there are many models (Gupta and Larson, 1979; Kern, 1995; Rawls and Brakensiek, 1982; Walczak *et al*., 2002, 2004, 2006; Wosten and Nemes, 2004) which enable derivation of the water retention curve and determination of the coefficient of water conductivity on the basis of knowledge of easily measurable physical parameters of the soil such as bulk density, aggregate size distribution, *etc*., for organic soils these models cannot be used due to differences in physical properties between these soils (Bambalov, 2000; Brandyk *et al*., 1996; Rovdan *et al*., 2002). Furthermore, pedotransfer functions for organic soils are mostly developed for specific soils (Gnatowski, 2001; Paivanen, 1973; Weiss *et al*., 1998, Zawadzki, 1970). Therefore, a necessity exists to continue investigations to find the relations between physicochemical parameters and hydro-physical characteristics of organic soils for pedotransfer functions elaboration.

The aim of the investigation was an attempt to estimate water retention characteristics as pedotransfer functions for organic soils *ie* the determination of the dependence between the physicochemical properties of organic soils and their hydrophysical characteristics.

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MATERIALS AND METHODS

The static hydrophysical characteristics were determined for soil samples from 11 genetic horizons of organic soils which were taken from the typical landscape of the Polesie region (Dorohucza, Rogóźno) (Gawlik, 1992; Okruszko and Zawadzki, 2000; Rovdan *et al.*, 2002; Zaidelman, 2001). A short description of the soil profiles is given below:

- Sites I and II (samples 1.1-3 and 2.1-2) are located in a floodplain. Both of them are the deep organic soils, intensively drained and transformed. They are used as an opencast peat mines. Sample 1 (depth – 5-10 cm) is moorsh derived from reed-sedge peat with higher iron content. Sample 2 (depth 30-35 cm) is moorsh formed from reed-sedge peat with higher calcium and iron content;
- Sites III and IV (samples 3.1-2 and 4.1-2) are shallow reclaimed peat soils. Both of them are used as permanent grasslands. They have the same botanic composition but different intensity of drainage. The site III is heavily humified, whereas the site IV is moderate humified meadow. Sample 3 (5-10 cm) is the peat moorsh developed from sedge peat and sample 4 (40-45 cm) is the medium decomposed sedge peat;
- Sites V and VI (sample 5.1-3 and 6.1-3) are: samples 5 (5-10 cm) are the humic moorsh and samples 6 (40-45 cm) are the sedge peat with the high degree of decomposition.

The physical and chemical properties of the investigated soil samples were measured by standard methods and are within the following limits: ash content from 33 to 48%, specific surface area (measured by water vapour adsorption - BET method): 193-243 m^2g^{-1}, bulk density: 0.20-0.58 g cm^{-3}, pH in H_2O: 5.1-7.4, pH in KCl: 4.6-6.8, and Fe content: 4.5-20.9 g kg^{-1} (Table 1).

Measurements of static hydrophysical characteristics of the studied soils *ie* the relation between soil water potential and water content (moisture), were made for 11 points during the drying process according to the Richards procedure (Hillel, 1998; Kutilek and Nielsen, 1994). These are points in the range of ψ from 1 to 15 000 hPa (98.1 to 1.5 10^6 J m^{-3}), namely 1, 10, 31, 100, 160, 310, 500, 1 000, 1 600, 5 000 and 15 000 hPa (Table 2). The standard pressure chambers, manufactured by SOILMOISTURE Equipment, Santa Barbara, California USA, were used (Catalog Nos 1500 and 1600).

For statistical analysis, the Gauss-Newton multiple non-linear regression method was used and calculations were performed using statistical software STATISTICA 6.0. All the statistical analyses were performed with a significance level value α =0.05. As a result of the statistical analysis two models were developed.

RESULTS

The following input parameters were assumed in the modelling:

- ash content in dry matter (*AC*) as a physical parameter informing about the quantity of mineral matter of the soil,
- specific surface area (*SSA*), a physical parameter informing about the soil mineralogical composition,
- soil bulk density (*BD*), a physical parameter informing about the maximum soil porosity and thus directly influencing the ability of water accumulation,
- pH in KCl of soil solution (*KCl*) and pH in H_2O,
- Fe content in dry matter (*Fe*) as a physical parameter informing about the soil solution properties and peat degradation degree.

T a b l e 1. Basic properties of the investigated soils

Site	Sample No.	Depth (cm)	Ash content (% d.m.)	Specific surface area (m^2g^{-1})	Bulk density (g cm^{-3})	pH in		Fe (g kg^{-1} d.m.)
						H_2O	KCl	
I	1.1	5-10	45	202	0.37	6.9	6.6	13.7
	1.2	5-10	42	195	0.50	6.9	6.6	13.9
	1.3	5-10	43	197	0.40	7.1	6.7	13.6
II	2.1	30-35	40	196	0.41	7.3	6.7	20.0
	2.2	30-35	38	193	0.40	7.4	6.8	20.9
III	3.1	5-10	44	200	0.41	5.4	4.7	10.0
	3.2	5-10	41	207	0.35	5.1	4.6	9.9
IV	4.1	40-45	35	223	0.27	5.9	5.3	4.8
	4.2	40-45	33	210	0.20	6.0	5.4	4.7
V	5.1	5-10	42	213	0.58	6.4	6.0	4.5
	5.2	5-10	39	197	0.49	6.6	6.1	4.7
	5.3	5-10	40	209	0.51	6.5	5.9	4.6
VI	6.1	40-45	48	234	0.34	6.8	6.4	7.0
	6.2	40-45	45	243	0.35	6.9	6.4	6.5
	6.3	40-45	47	231	0.55	6.7	6.5	6.6

T a b l e 2. Water content values corresponding to the studied values of soil water potential for investigated soils

Site	Sample No.	Depth (cm)	Water content (% m^3m^{-3}) at the studied soil water potential (hPa)										
			1	10	31	100	160	310	500	1000	1600	5000	15 10^3
I	1.1	5-10	84.7	82.2	58.9	48.4	45.4	43.7	42.6	39.8	38.5	30.3	24.3
	1.2	5-10	81.6	79.7	72.3	60.7	57.2	54.6	52.5	49.9	49.1	50.4	33.8
	1.3	5-10	79.8	76.9	63.2	52.8	49.4	47.2	45.2	42.4	41.4	40.1	27.6
II	2.1	30-35	82.8	81.6	74.7	67.4	64.6	64.3	61.6	58.2	56.4	38.7	34.7
	2.2	30-35	82.4	79.4	74.8	67.6	63.5	59.6	57.5	53.9	53.0	50.9	33.3
III	3.1	5-10	83.0	80.7	77.6	66.3	60.9	59.2	58.8	54.3	52.7	39.6	36.0
	3.2	5-10	85.9	83.6	77.6	66.3	61.6	60.6	60.1	55.9	54.8	33.5	29.5
IV	4.1	40-45	95.3	93.2	86.1	73.0	65.0	58.6	58.2	54.2	53.5	31.7	22.8
	4.2	40-45	91.2	89.6	81.2	68.0	60.2	55.3	54.3	51.2	50.4	21.5	15.5
V	5.1	5-10	84.9	83.4	80.8	74.4	70.8	67.0	63.5	60.2	59.7	58.1	40.8
	5.2	5-10	75.9	73.3	67.8	62.6	59.5	56.2	55.5	53.1	52.4	34.6	34.1
	5.3	5-10	82.6	80.7	76.5	69.8	65.4	63.4	62.5	59.0	58.3	57.6	57.0
VI	6.1	40-45	86.7	84.3	80.7	70.1	66.2	64.3	63.4	60.1	59.4	36.3	29.8
	6.2	40-45	83.7	81.6	74.9	67.5	64.5	63.6	63.0	60.1	59.3	46.3	44.8
	6.3	40-45	80.8	79.0	76.8	71.2	67.9	63.7	61.2	58.0	57.1	54.8	48.1

T a b l e 3. Regression and determination (R^2) coefficients for Model 1

Soil water potential (hPa)	Regression coefficients						R^2
	a_0	a_1	a_2	a_3	a_4	a_5	
1	**82.58***	-0.47	0.17	-14.70	-1.81	0.18	0.69
10	**78.37**	-0.54	0.19	-12.04	-1.95	0.21	0.67
31	38.32	**-1.29**	0.51	34.42	-6.25	0.73	0.73
100	7.84	**-1.49**	0.58	**56.67**	-5.37	0.80	0.77
160	-8.13	**-1.29**	0.56	**61.33**	-4.55	**0.83**	0.76
310	-14.88	**-1.00**	0.54	**59.02**	-5.02	**0.92**	0.69
500	-10.20	-0.91	0.52	**52.29**	-5.38	0.84	0.68
1000	-13.15	-0.88	0.49	**50.26**	-4.42	0.74	0.67
1600	-14.71	-0.91	0.49	**50.82**	-4.18	0.69	0.68
5000	**-73.25**	-0.93	0.52	**114.08**	-1.93	1.01	0.81
15000	-66.39	-0.46	0.43	**99.64**	-2.83	0.60	0.72

*Statistically significant parameters are written by bold font style.

Model 1

This model is based on the following multiple linear regression Eq. (1):

$$\theta p = a_0 + a_1\ AC + a_2\ SSA + a_3\ BD + a_4\ KCl + a_5\ Fe \quad (1)$$

where: θp is the predicted soil water content corresponding to a given value of water potential (%, m^3m^{-3}); *AC* – ash content in % of dry matter; *SSA* – specific surface area (m^2g^{-1}); *BD* – bulk density (g cm^{-3}); *KCl* – pH in KCl; *Fe* – Fe content (g kg^{-1} d.m.); a_0, a_1, a_2, a_3, a_4 and a_5 – regression coefficients.

For each value of the soil water potential values of regression coefficients and determination coefficient R^2 were calculated (Table 3). The correlation between the predicted and measured water content values is shown in Fig. 1.

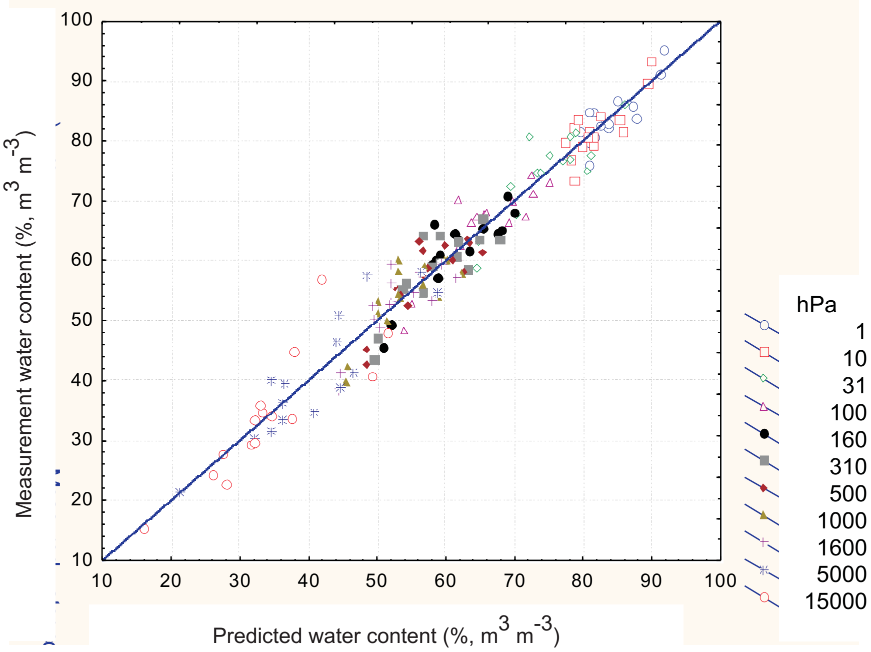

Fig. 1. The measured versus predicted values of water content for the studied soil water potential range by Model 1.

Model 2

As the determination coefficient values of Model 1 are not very high, multiple non-linear modelling was applied. As result of this modelling the following multiple non-linear regression equation was obtained Eq. (2):

$$\theta p = \left| a_0 + a_1\ AC + a_2\ SSA + a_3\ BD + a_4\ KCl + a_5\ Fe \right|^{a6} \quad (2)$$

where: θp is the predicted soil water content corresponding to a given value of water potential (%, m^3m^{-3}), *AC* – ash content in % of dry matter, *SSA* – specific surface area (m^2g^{-1}), *BD* – bulk density (g cm^{-3}), *KCl* – pH in KCl, *Fe* – Fe content (g kg^{-1} d.m.), a_0, a_1, a_2, a_3, a_4, a_5 and a_6 – regression coefficients (to samo co pod wzorem 1).

For the model, for each value of water potential values of regression coefficients were calculated and determination coefficient R^2 was found (Table 4). The performance of Model 2 is shown in Fig. 2.

Comparison of both elaborated models shows that Model 1 is simpler than Model 2. Model 1 is a linear regression and the values of the regression coefficients of Model 1 are not as large as the values of the regression coefficients of Model 2, but Model 2 has a number of advantages. The water content values referring to 1 hPa and 10 hPa are not statistically significant parameters for both models. But the transformation of Model 1 in to Model 2 caused an increase of the determination coefficients R^2 value for the soil water potential value of 1 hPa from 0.69 to 0.7. A similar increase of R^2 value from 0.67 to 0.68 was noted for 10 hPa. For Model 1, for the water content referring to range 31-600 hPa, statistically significant are different sets of parameters *ie* for the value of soil water potential of 31 hPa statistically significant parameters are ash content, specific surface area and pH in KCl, for 100 hPa: ash content, specific surface area, bulk density and pH in KCl, for 160 hPa and 310 hPa: ash content, specific surface area, bulk density and Fe content, for 500 hPa: specific surface area, bulk density and pH in KCl, for 1 000 hPa and 1 600 hPa: specific surface area and bulk density. Whereas for Model 2 in this range of soil water potential values statistically significant parameters are all the parameters of the model. The differences in the values of the determination coefficient R^2 of both models in this range are significant. As the transformation of Model 1 in to Model 2 caused the increase of the determination coefficient (R^2) values for water potential value of 31 hPa from 0.73 in Model 1 to 0.83 in Model 2, for 100 hPa – from 0.77 to 0.91, for 160 hPa – from 0.76 to 0.91, for 310 hPa – from 0.69 to 0.87, for 500 hPa – from 0.68 to 0.88, for 1 000 hPa – from 0.67 to 0.88 and for 1 600 hPa – from 0.68 to 0.90, respectively. In Model 1, for the soil water potential value of 5 000 hPa statistically significant parameters are specific surface area and bulk density, for 15 000 hPa – only bulk density. In Model 1 for this value of soil water potential there are no statistically significant parameters. The increase of the determination coefficient (R^2) values for these water potential values are insignificant *ie* for 5 000 hPa are 0.81 for both models, and for 15 000 hPa – from 0.72 to 0.74, respectively.

T a b l e 4. Regression and determination (R^2) coefficients for Model 2

Soil water potential (hPa)	Regression coefficients							R^2
	a_0	a_1	a_2	a_3	a_4	a_5	a_6	
1	1.86E+00	-1.46E-03	5.36E-04	-4.54E-02	-5.71E-03	5.74E-04	7.09E+00	0.70
10	1.69E+00	-1.32E-03	4.73E-04	-2.91E-02	-4.85E-03	5.11E-04	8.36E+00	0.68
31	**-9.55E+20***	**-4.14E+19**	**1.67E+19**	**7.53E+20**	**-1.70E+20**	**2.31E+19**	**9.18E-02**	0.83
100	**-7.86E+19**	**-1.52E+18**	**7.30E+17**	**5.31E+19**	**-4.69E+18**	**8.43E+17**	**9.58E-02**	0.91
160	**-2.11E+21**	**-2.47E+19**	**1.46E+19**	**1.32E+21**	**-6.90E+19**	**1.76E+19**	**8.86E-02**	0.91
310	**-4.41E+24**	**-4.34E+22**	**2.87E+22**	**2.75E+24**	**-1.50E+23**	**3.99E+22**	**7.55E-02**	0.87
500	**-4.03E+23**	**-4.02E+21**	**2.72E+21**	**2.68E+23**	**-1.72E+22**	**3.53E+21**	**7.84E-02**	0.88
1000	**-7.22E+24**	**-6.39E+22**	**4.53E+22**	**4.35E+24**	**-2.04E+23**	**5.00E+22**	**7.34E-02**	0.88
1600	**-5.49E+23**	**-4.73E+21**	**3.38E+21**	**3.22E+23**	**-1.30E+22**	**3.34E+21**	**7.67E-02**	0.90
5000	-1.34E+02	-1.64E+00	8.96E-01	1.98E+02	-3.23E+00	1.73E+00	8.94E-01	0.81
15000	-1.15E+03	-8.57E+00	6.50E+00	1.52E+03	-3.67E+01	7.35E+00	6.12E-01	0.74

*Statistically significant parameters are written by bold font style.

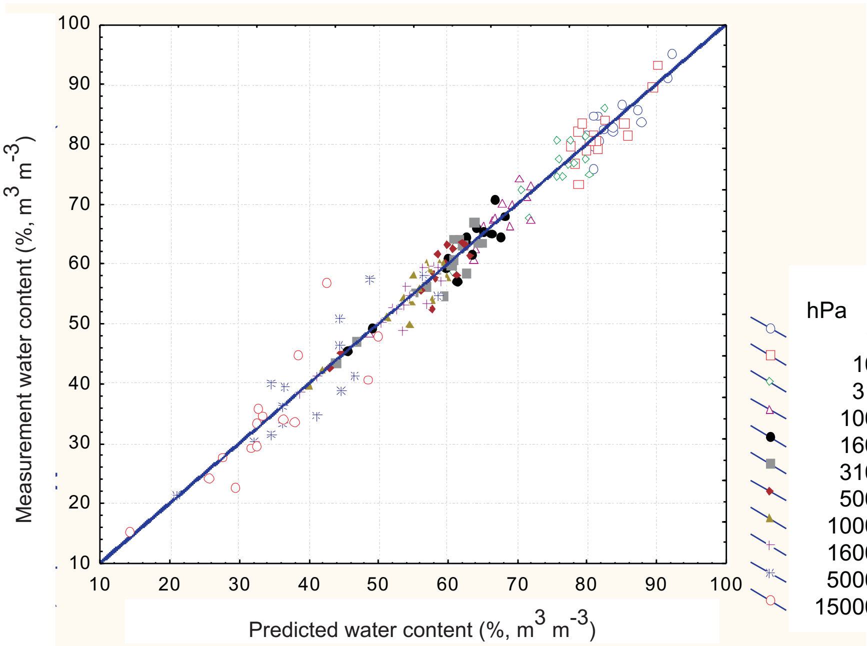

Fig. 2. The measured versus predicted values of water content for the studied soil water potential range by Model 2.

It should be noted that the use of pH in H_2O instead of pH in KCl in the models caused an insignificant increase of the determination coefficient (R^2) values for the water potential values of 1 hPa and 10 hPa, but a decrease of R^2 values in the range from 31 to 15 000 hPa.

CONCLUSIONS

1. It is possible to elaborate pedotransfer models for the prediction of soil water retention characteristics with acceptable accuracy using easily measurable physical-chemical parameters of organic soils.

2. Comparison of the elaborated models (Eqs (1) and (2)) shows that the best fit between measured and predicted water content values is obtained by Eq. (2) - the proposed Model 2. For this model the determination coefficient (R^2) values for all water potential values are higher than for Model 1.

3. The best results of soil water content prediction were obtained by Model 2 application for water potential values in the range from 31 to 1 600 hPa.

4. The use of pH in KCl as a parameter in the developed models showed better results than the use of pH in H_2O.

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