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VERIFICATION OF APPROPRIATENESS OF SELECTED PEDOTRANSFER FUNCTIONS FOR THE BASIC USE IN AGRICULTURE OF THE CZECH REPUBLIC

Vítězslav Vlček[1], Vítězslav Hybler[1]

[1] Department of Agrochemistry, Soil Science, Microbiology and Plant Nutrition, Faculty of Agronomy, Mendel University in Brno, Zemědělská 1, 613 00 Brno, Czech Republic

Abstract

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Soil is a huge reservoir of water used by plants in periods without precipitation and significantly affects the hydrological balance of any territory. To evaluate the hydrological balance of any piece of the land given, it is therefore necessary to carry out the analysis of the hydro-physical conditions. To speed up and simplify the determination of basic hydro-physical properties of soil man developed and began to use the so-called pedotransfer functions (PTF). Comparison of domestic and foreign works, however, faces problems such as the definition of available water supplies in different countries. In the research project "Specification of the available supplies of nitrogen and water in the soil profile and determining the effective depth of crops' roots" we have dealt with the selection of suitable pedotransfer functions necessary for basic agricultural production with the requirement of minimal amount of input data. For our research we chose several PTFs developed and used in the Czech Republic for a long time, with a minimum of input data, and several new PTFs from foreign authors with greater correlation, but also a greater need of input data, and we compared each other. The best correlation between values and the pedotransfer function for the field water capacity and for the wilting point seems to be the PTF according to Tomasella and PTF according to Batjes. Pedotransfer function according to Váša, in terms of volume of input data, appears better.

Keywords: PTF, wilting point, water holding capacity, water retention

INTRODUCTION

Soil as a much larger reservoir of water compared to surface water in the form of rivers and reservoirs, significantly affects the hydrological balance of the target area. But soil is also a complex three-phase system, where water movement is influenced by lot of factors. Pedotransfer functions have been developed to speed up and simplify the determination of basic hydro-physical properties of soil (Wosten *et al.*, 1985). Basically, this is a mathematical derivation of soil properties (in our case, hydrophysical properties) usually using the regression equations from the most commonly determinable soil properties (particle size, bulk density, porosity, content of Cox, etc.). As we needed to select suitable pedotransfer functions necessary for basic agricultural production, i. e. with the requirement of minimal amount of input data, we chose several PTFs developed and used in the Czech Republic for a long time, with a minimum of input data, and several newer PTFs from foreign authors with greater correlation, but also a greater need of input data, and we compared each other.

MATERIAL AND METHODS

One of the first PTF is probably the work of Lyman *et al.* (1907) for the determination of wilting point/ wilting coefficient (equation 1) as a function of the grain size:

Wilting coefficient = 0.01 sand + 0.12 silt + 0.57 clay. [Eq. 1]

There is a certain dependence among the forces by which is water tied to solid particles and water content in the soil, and it can be expressed by the retention curve (pF curve). The range of humidity for the different hydrolimits is given by the agreement, it means we can find different values for different countries. Comparison of works logically faces problems such as the definition of available water supply in different countries (Vogel, 1994; Shouse *et al.*, 1995, 1996 Batjes etc.). For example, the pF range, generally used to define the available water supply, is in the United Kingdom in the range from 1.7 to 4.2 pF, in the Netherlands only 2.0 to 4.2 pF or pF from 2.5 to 4.2 in the USA.

Wilting point (WP) is one of the most important soil hydrolimits and ranks among so called spot hydrolimits. Soil is in the WP when the plants are consistently under-supplied with water and wilt. Value of humidity is 4.18 pF potential (which corresponds to the pressure of 1.5×10^6 Pa, namely 1500 kPa). It expresses the amount of water in the soil, tied stronger than the suction power of plant roots is. Other previously used names are moisture unusable or moisture inaccessible to plants. For these hydrolimits there are several possible methods of **direct determination**:

Vegetation method of analysis of disturbed samples (Briggs, Shantz, 1912; Veihmeyer, Hendrickson, 1927) can be, to a certain extent, set as a reference, although they are mostly pot experiments, which do not reflect realistic physical conditions in the soil (real porosity, saturation of subsurface profile, capillary elevation etc.). An advantage is that it works with living plants as an indicator – they are the direct values.

Wilting point (Váša, 1959) is the technical analytical method based on a disturbed sample after experiments of Dolgov (1948), or based on the use of pressure devices.

Indirect methods of determination by pedotransfer functions:

For the indirect assessment, the relationships between each individual hydrolimits or relationships among different soil characteristics are used. These relationships are very complicated, which is one of the reasons why they are not expressed clearly enough. They are depending mostly on the value of the grain size composition of the soil (which can be changed within the profile). With the growth of amount of fine particles generally increases the value of WP. Thevalue of the WP was also dependent on the soil structure, organic matter, bulk density etc. According to different authors we can see these PTFs for calculation of WP:

- One of our oldest and also the most widely used, is calculation according to Váša (in Kutílek, 1978). Its advantage is the relative simplicity and it is not demanding big amount of input data. The disadvantage is certain disproportion in clay soils and sandy soils:

WP [vol. %] = 0.3 × (I. grain category content in %) + 4; [Eq. 2]

- or older by Váša 1958:

WP [vol. %] = 0.88 × of physical clay content (for sandy soil);

or 0.77 × of physical clay content (loam soil);
or 0.75 × of physical clay content (clay soil); [Eq.3]

- WP by Solnář:

[vol. %] = content of I. grain category/2.4. [Eq. 4]

Currently are mostly used the continuous PTFs. It is a set of regression equations with continuous output in the form of an estimated hydraulic property for specific soil with known (measured) variables. For the determination, a range of measured values are used, such as clay content [%], silt content [%], the organic matter content [%], bulk density of dry soil [$g.cm^{-3}$] etc. These values are difficult to observe for the average farmer. As an example, here are some continuous PTF for pF = 4.2:

- **Batjes** (1996):

$WP = 0.3624 \times C + 0.1170 \times S + 1.6054 \times O$
($r = 0.88$, $n = 3860$), [Eq. 5]

- **Tomasella, Hodnett** (1998):

$WP(\%) = 0.763 - 0.170 \times S + 0.402 \times C$
($r = 0.895$, $n = 416$), [Eq. 6]

- **Moreno *et al.*** (2014):

$WP = -560.9 + 5.61 \times CS + 5.61 \times FS + 5.61 \times S + 5.61 \times C - 0.0095 \times GSD - 0.071 \times \rho b.$
($r = 0.899$, $n = 72$), [Eq. 7]

where
C..........clay,
S..........silt,
O.........organic carbon,
CS.......coarse sand,
FS........fine sand,
GSD....geometrical standard deviation,
ρb........bulk density.

New equations No. 5 and 6 were choosen from reasons: high number of observations (3 860 and 416), high correlation coefficient and relatively „low“ data input.

Textural PTFs estimate the average of hydraulic characteristics for given grain size classes. Spot PTFs are empirical functions that estimate the moisture in the predefined values of potentials. The most common are −10, −33, −1500 kPa respectively (corresponding to the agreed WP). They are needed for example for determining the amount of water available for the plants (Tomasella *et al.*, 2003).

Water holding capacity (WHC)/Field water capacity (FC) is the soil moisture on the border between the capillary and gravitational water and indicates the maximum amount of water suspended in the capillaries, and which is held against the action of gravity after irrigation. It is expressed particularly in volume percentage, or in the pF value in the range from 2.0 to 2.9 pF. Usually we use (in the Czech republic) a center of this interval, 2.5 pF. In clay soils the water retention capacity (WHC) value is close to 2.9 pF, within sandy soils it is significantly lower. The water retention capacity determined in the field conditions is called the field water capacity (FC). Through the difficulty of determining the FC in field it is for practical purposes usually determined in the laboratory from undisturbed soil samples (steel cylinders). Probably the most common PTF function used to determine WHC is reported by:

- **Váša** (1960):

$$= \sqrt{(\textit{supply of grain size under } 0.01\,\text{mm} + 18) \times 20}$$

for 2.5 pF. [Eq. 8]

Among the other PTFs for the calculation we can also include:

- **Batjes** (1996):

$$FC = 0.46 \times C + 0.3045 \times S + 2.0703 \times O$$

(r = 0.90, n = 2949); 2.5 pF, [Eq. 9]

- **Tomasella, Hodnett** (1998):

$$FC = 25.76 - 0.26 \times SA + 0.36 \times C + 2.99 \times O$$

(r = 0.893, n = 416); 2.5 pF, [Eq. 10]

- **Moreno *et al.*** (2014):

$$FC = 0.702 - 0.0016 \times CS - 0.00077 \times FS - 0.201 \times GPD - 0.163 \times \rho b$$

(r = 0.871, n = 72); 2.5 pF, [Eq. 11]

where
C..........clay,
S..........silt,
SA.......sand,
O.........organic carbon,
CS.......coarse sand,
FS........fine sand,
GPD ...mean particle diameter,
ρb........bulk density.

I: *Basic soil properties of selected soil pits*

No.	Clay (%)	Silt (%)	Sand (%)	Grain size < 0.01 mm (%)	Organic carbon (%)	Texture class
1	12.2	20,7	67.2	22.3	1.17	Sandy loam
2	13.2	21.7	65.2	23.4	0.95	Sandy loam
3	10.1	17.5	72.4	18.5	0.32	Sandy loam
4	17.5	67.1	15.5	46.4	1.37	Silt loam
5	18.6	65.0	16.5	45.8	1.16	Silt loam
6	18.5	70.8	10.7	49.6	0.93	Silt loam
7	19.7	54.1	26.2	62.8	1.48	Silt loam
8	31.5	53.0	15.5	74.2	1.47	Silty clay loam
9	39.6	50.3	10.1	78.5	1.23	Silty clay loam
10	11.1	55.2	33.7	26.7	1.57	Silt loam
11	19.3	70.9	9.8	43.9	2.74	Silt loam
12	13.6	66.3	20.1	39.4	2.34	Silt loam
13	20.1	68.4	11.5	43.0	2.34	Silt loam
14	14.9	60.6	24.5	39.1	2.46	Silt loam
15	35.4	47.8	16.8	42.8	2.43	Clay loam
16	22.8	62.3	14.9	41.1	2.65	Silt loam
17	17.0	48.3	34.7	32.3	2.38	Loam
18	12.4	34.1	53.5	26.8	2.15	Sandy loam
19	12.4	44.9	42.7	29.1	1.78	Loam
20	16.4	50.5	33.1	35.4	1.86	Silt loam/loam
21	19.7	63.8	16.5	30.2	1.31	Silt loam
22	22.4	66.4	11.2	43.5	2.12	Silt loam
23	20.5	38.1	41.4	36.2	2.03	Loam
24	19.5	64.8	15.7	37.1	1.70	Silt loam
25	20,2	64.4	15.4	45,3	2.92	Silt loam
26	6.8	14.3	78.9	17.0	1.90	Loamy sand
27	13.8	28.3	57.9	26.3	2.28	Sandy loam

Equations No. 9 and 10 were chosen from the same reasons like equations No. 5 and 6.

For comparative evaluation the 27 areas in southern and central Moravia on different soil types were selected: cambisol (10), chernozem (8), fluvisol (3), regosol (1), haplic luvisol (5), with different texture and chemical characteristics – see Tab. I.

Particle size analysis were analyzed by pipetting method (Gee, Bauder, 1986) and the content of oxidizable carbon using methods Walkley and Black (1934) with modifications of Novák and Pelíšek.

For technical determination of water holding capacity steel cylinders taken from the topsoil horizons were used. The standard laboratory method for soil moisture measurement was used, with drying by 105 °C in laboratory dryer. To determine the wilting point, the device WP4T (Dewpoint Potentiameter) from Decagon was used to check the soil moisture amount within pF 4.18.

For comparison mostly older PTFs were selected, they were analyzed from soil samples of our soils without significant demands to the input data, and newer PTFs used abroad. The comparison was carried out with technical data identified for water holding capacity and wilting point. The aim was to choose PTF with a good correlation to technically determined hydrolimits and with minimum requirements on the input data set.

RESULTS AND DISCUSSION

The average grain size was a silty clay. The average content of clay was 18.5 ± 1.4%, the average content of silt was 50.7 ± 3.4% and the average content of sand was 30.8 ± 4.1%. The variance of clay content ranged from 6.8 to 39.6%. The variance of the silt content ranged from 14.3 to 70.9%. The variation range of the sand was wider, from 9.8 to 78.9%. The average content of particles lower than 0.01 mm is 39.1 ± 2.9% with variation range from 17.0 to 78.5%.

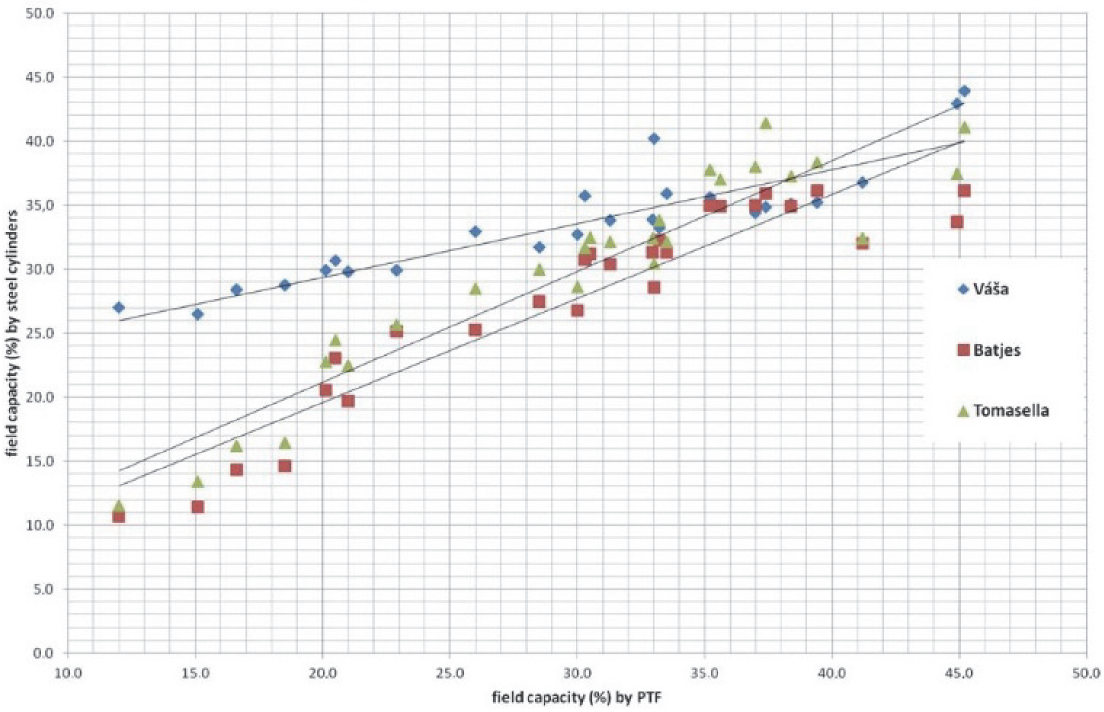
The average content of organic matter in the observed data set (n = 27) was only 1.82 ± 0.12%, which can be assessed as a low content. The variance of soil organic matter content ranged from 0.32 to 2.92% (the content is from very low to moderate).

Selected PTFs to Calculate Field Water Capacity/Water Holding Capacity and their Correlation with Technically Measured Values

The average values of field water capacity by the technically specified values were 30.01 ± 1.74 vol. %. The average values of field water capacity

II: *Correlation between selected PTF for field water capacity (N = 27)*

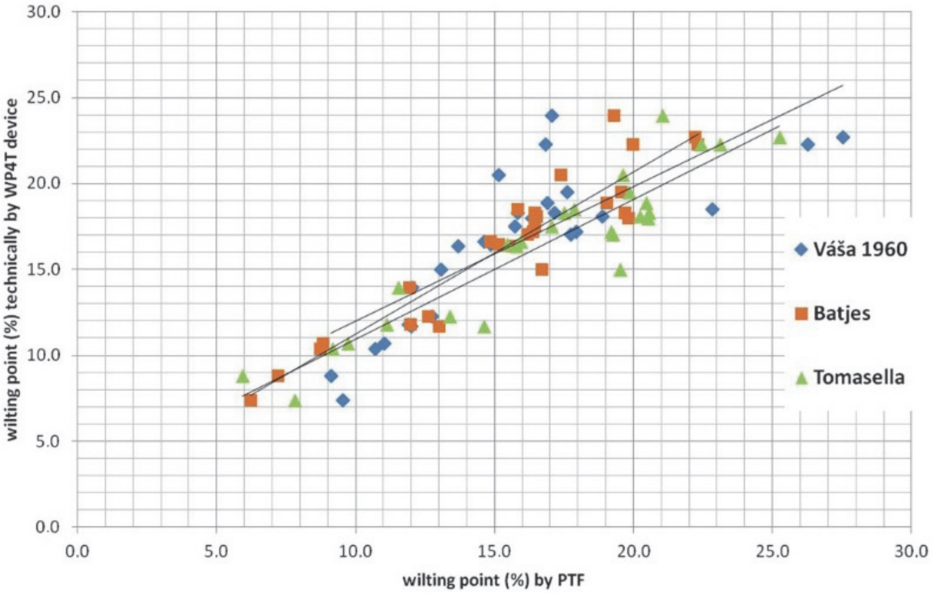
	Technically	Váša	Batjes	Tomasella
Technically	1			
Váša	0.891	1		
Batjes	0.937	0.773	1	
Tomasella	0.942	0.791	0.990	1



1: *Correlation between selected pedotransfer function for field water capacity and technically established field capacity*

III: *Correlation between selected PTF for wilting point (N = 27)*

	Technically	Váša 1960	Solnář	Váša 1958	Batjes	Tomasella
Technically	1					
Váša 1960	0.805	1				
Solnář	0.805	1	1			
Váša 1958	0.793	0.802	0.802	1		
Batjes	0.939	0.768	0.768	0.813	1	
Tomasella	0.927	0.815	0.815	0.816	0.974	1



2: *Correlation between selected PTF for wilting point and technically established wilting point (for the example, the same PTFs as in the Fig. 1 are used)*

in the calculation by Váša were 33.54 ± 0.82 vol. % (with a value of reliability R^2 = 0.794, N = 27), in the calculation according to Batjes 27.71 ± 1.51 vol. % (r^2 = 0.878, N = 27), in the calculation according to Tomasella 29.84 ± 1.60 vol. % (r^2 = 0.888, N = 27).

Correlation is indicated in Tab. II. The strongest correlation (very strong correlation) to technical determination has PTFs of Tomasella and Batjes, the worst was Váša's, in point of view of the minimum volume of input data to the contrary seems to be the best the function by Váša.

Selected PTFs for Calculating of the Wilting Point and their Correlation with Technically Measured Values

The average values of the wilting point by the technically specified values were 17.07 ± 0.96 vol. %. The average values of the wilting point for the calculation according to Váša (1960) were 15.74 ± 0.86 vol. % (with a value of reliability r^2 = 0.648, N = 27), for the calculation according to Solnář 16.31 ± 1.20 vol. % (r^2 = 0.648, N = 27), by calculating according to Váša (1958) 14.12 ± 1.06 vol. % (r^2 = 0.629, N = 27), for the calculation according to Batjes 15.55 ± 0.83 vol. % (r^2 = 0.881, N = 27), for the calculation according to Tomasella 16.82 ± 0.95 vol. % (r^2 = 0.860, N = 27). Correlation between individual PTFs is indicated in Tab. III. The strongest correlation (very strong correlation) with technical determination had again the PTF of Batjes and Tomasella, worst was Váša's 1958 (strong correlation).

CONCLUSION

In the framework of the project „Specification of the available supplies of nitrogen and water in the soil profile and determining of the effective depth of root of crops" we examined the selection of appropriate PTFs for the needs of agricultural practice with the requirement to minimize the amount of input data, or using the data easily measurable. For our research we chose several PTFs developed and used in the Czech Republic for a relatively long time (Váša, Solnář), with minimum of input data, and several new PTF of foreign authors, with greater correlation assumption but with need of more input data, and we tried to compare them with each other. In terms of best correlation between technically observed values and the pedotransfer function for the field water capacity seems to be the PTF according to Tomasella with correlation of 0.94; for the wilting point it is PTF according to Batjes with correlation of 0.94. Pedotransfer function according to Váša, despite its „age", we cannot completely ignore because of its strong correlation (correlation 0.89, respectively 0.81). In terms of volume of input data, this PTF appears to agricultural production as incomparably better than PTF according to Batjes and Tomasella, where is necessary to analyze the proportions of each grain size (silt, clay and sand) and organic matter.

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Contact information

Vítězslav Vlček: xvlcek1@mendelu.cz
Vítězslav Hybler: hybler@mendelu.cz