

STATISTICAL ASSESSMENT OF RELATIONSHIP BETWEEN WATER REPELLENCY AND SELECTED PROPERTIES OF FOREST TOPSOIL IN THE WHITE CARPATHIAN MTS.

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Abstract This study investigates the relationship between water repellency and selected physical and chemical characteristics of topsoil in the area of White Carpathian Mts. (Slovakia). WDPT and MED tests were used for the purpose of water repellency assessment. It was found that particular type of landuse is an important factor for water repellency development. None of the topsoils taken from agricultural land or grassland exhibited any water repellency, and at the same time, all samples which showed some water repellency were forest soils. However, within the category of forest A-horizons, soil wettability varied greatly: wettable, slightly, strongly, severely, and extremely water repellent samples were rated. Therefore, regression analysis was aimed on WDPT and MED variances of forest soils predominantly. Unlike WDPT, MED test provided a good range of normally distributed values and a high level of discrimination between soils of different wettability. From soil variables tested as possible predictors (content of organic carbon and CaCO₃, pH and contents of three textural fractions), all were proved to affect soil wettability significantly. There was a tendency for sandy soils to show greater repellency than heavier soils. The number of water repellent soils also increased with increasing organic carbon content. Repellency was higher at lower pH values. The largest proportion of repellent soils contained no CaCO₃. The results of regression analysis showed that majority of mentioned soil variables helped to explain substantial part of water repellency variance by using multiple linear approaches.

Keywords: CaCO₃, MED, regression analysis, soil organic carbon, water repellency, WDPT

1. INTRODUCTION

It has been observed that soil, in spite of being a porous material, is not always wetted readily. Under certain conditions, some soils resist or retard water infiltration into soil matrix, sometimes to the extent that they remain dry even after a wet season or prolonged irrigation. The amount and type of organic matter present (DeBano, 1981; Imeson et al., 1992; Doerr et al., 1998) soil texture (DeBano, 1981), soil pH values (Wang et al., 2003) and CaCO₃ content belong among soil properties that affect water repellency. In most cases, low wettability in soils can be attributed to coatings on the soil particles of hydrophobic substances of organic origin. Thus, it follows that soils rich in organic matter (Jaramillo et al., 2003; Barton & Colmer, 2011) and a low specific surface area (surface area per unit of mass), i.e. coarse textured soils (Scott,

2003; Nadav et al., 2013) should develop the phenomenon more readily. Repellency mostly intensifies with decreasing pH, probably because of a sufficient number of proton accepting surface sites with a significant amount of positive surface charge (Diehl et al., 2010). The presence of carbonates in soil leads to enlargement of the hydrophilic/hydrophobic surface ratio and to the pH increase, which causes enhanced dissociation of carboxylic groups and by this way also overall hydrophilicity of soil organic matter (Orfanus et al., 2010). Water repellency often has a negative impact on the surrounding environment, such as reduced infiltration capacity, enhanced overland flow and soil erosion, reduced microbial activity, creation of unstable, irregular wetting fronts, development of preferential flow paths and associated leaching of nutrients and agrochemicals which can lead to poor seed germination and crop growth. To

characterize water repellency, a wide range of approaches were used. Besides evaluating traditional methodologies and utilizing new analytic techniques to better describe and assess overall water repellency under field-scale conditions (DeBano, 2003), statistical sampling designs are being applied for studies that involve making an inference about the population as whole. There is an emerging interest in characterizing water repellency on a landscape basis. Such a relationship would involve first relating specific soil properties to water repellency (McKissock et al., 1997), and then using the spatial distribution of these diagnostic soil parameters to predict the occurrence of water repellency over large landscapes. In spite of extensive research which have been carried out in order to explain reduced wettability of soil material, papers in which water repellency of soil within large area would be investigated in systematic manner are still lacking. There are very few studies which would attempt to explain variable wettability of topsoil at the scale of a regional soil survey. For this reason we decided to perform sampling in the area of several hundreds of km², with sufficient diversity of geomorphic and soil conditions, where repellency data would be possible to confront with number of other soil variables.

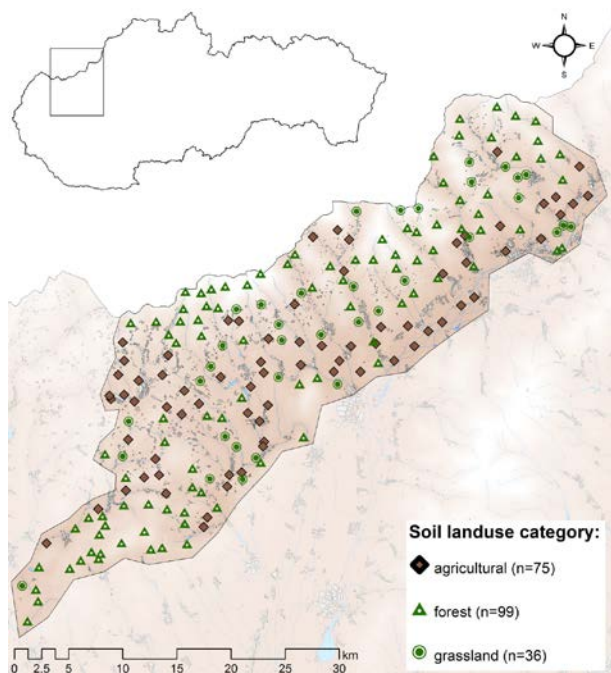


Figure 1. The map of the White Carpathians area with soil pits localization.

Harper & Gilkes (1994) showed that the combination of numerous soils characteristics better explains the variation of water repellency than single variables, and that multi-variable regression could be used successfully to predict the risk of repellency at the scale of a regional soil survey. In this context, to

find out the extent to which the variation of repellency may be explained by use of different soil characteristics, a multiple linear approach was employed. The regression output may not only be used in prediction of water repellency, but it may also provide hints towards explanation of its origin.

2. MATERIALS AND METHODS

2.1. Soil sampling and sample preparation

Overall 210 samples of topsoil (depth interval 0-20 cm) were taken from the area of 890 km², where forested area of White Carpathian Mts. (Slovakia) corresponds approximately to 435 km² of extent. This population comprised 75 agricultural, 36 grassland and 99 forest soils (Fig. 1). Individual sampling spots were distributed in quasi-regular pattern, taking into account geomorphic and pedologic characteristics, as well as current landuse. In order to cover soil diversity (at least partially), one sample was taken per 5 km² approximately. As it was found later in water repellency testing, from the total number of collected soils, samples belonging into agricultural (tilled) and grassland category were all wettable. In this study we therefore focus on remaining 99 soils taken from forest sites, as these show variable repellency, ranging from wettable to extremely water repellent.

Prior to analysis, all samples were dried at room temperature (25°C) in order to achieve constant weight, then gently grinded, sieved through a 2-mm mesh, the gravel and large plant debris was discarded and the remaining fine-earth fraction gently mixed until it appeared to be homogeneous. This homogenized fine soil was stored in the dark polyethylene bags and prepared for further analyses. Water repellency was determined in sieved samples in order to get standard data and compare the results with other authors' findings.

2.2. Laboratory analyses of selected physical and chemical soil properties

Soil texture was determined by pipette method (Fiala et al., 1999) and results were classified according to USDA-FAO texture triangle (FAO, 2006). Soil pH was measured potentiometrically in deionized water and in 1M KCl with a soil: solution ratio of 1:2.5; CaCO₃ content using a Janko's calcimeter (Fiala et al., 1999), soil organic carbon (SOC) content by rapid oxidation of organic carbon with KCr₂O₇ - H₂SO₄ and titration of non-reduced dichromate (Walkley & Black, 1934). The persistence of soil water repellency was indicated by water drop penetration time (WDPT) test (Letey, 1969) and

severity of water repellency by molarity of an ethanol droplet (MED) test (Watson & Letey, 1970; King, 1981). The severity of water repellency of 46 dried soil samples (previously found repellent on the base of the WDPT test) was measured using increasing ethanol concentrations (0.5, 1, 2, 3, ... 32% by volume). The volume of solution in a droplet was 0.05 ml. All measurements were performed at room temperature, in triplicate.

2.3. Statistical assessment

As a first step, basic parameters of descriptive statistics (mean, median, standard deviation, mean deviation, coefficient of variation) were calculated. In case of each measured variable, distribution of the obtained values was checked by Kolmogorov-Smirnov test. If significant deviation from normality was detected, a simple transformation of values was applied by using logarithms or exponents. Pearson's coefficients of correlation were calculated for particular couples of soil properties. Prior to performing regression analysis, water repellency datasets representing dependent variable (WDPT and MED) were tested for presence of outliers by use of Laplace function. No outliers were detected. In case of other properties which were perceived as independent, identification of the outliers was not performed. The approach applied in regression analysis was in case of this study based on assumption that water repellency of soil is controlled by more than one soil variable.

Soil water and organic matter contents, its textural composition or soil reaction are properties which have been reported to be partaking on soil wettability (Doerr et al., 2006; Hurraß & Schaumann, 2006). In this context, selected soil variables (SOC and CaCO₃ contents, soil reaction, and content of individual textural fractions) were tested as possible predictors of water repellency. In general, function of simple and also multiple regression can be assumed as:

$$y = f(x_1, \dots, x_m; b_0, b_1, \dots, b_m), \quad (\text{Eq.1})$$

where x_1, \dots, x_m are values of particular explanatory variables; b_1, \dots, b_m are regression coefficients of variables which are approximating shape of the function, and b_0 is the intercept. Here for purpose of multiple regression the function f was considered as a sum of weighed terms (selected soil variables). Significance of partial regression coefficients b_m was assessed by testing the $t = b_m / se(b_m)$ value according to Student probability distribution (two tailed) at particular degrees of freedom (v). If the error probability value was less than 0.05, the regression coefficient was considered to be partaking on shape of particular function significantly. For each of the

obtained equations and particular coefficients of multiple determination (r^2) the F value was calculated as follows:

$$F = [r^2 / k] / [(1 - r^2) / (n - k - 1)], \quad (\text{Eq.2})$$

where n is the number of cases (samples), k is the number of terms in equation, and the expression $(n - k - 1)$ signifies degrees of freedom (v). Calculated F value was tested according to Fisher-Snedecor probability distribution at particular degrees of freedom (v) and expressed as error probability. Residuals (absolute value of difference between observed and predicted MED value) were calculated for selected equations and tested for normality of distribution.

3. RESULTS AND DISCUSSION

3.1. Relationship between water repellency and selected properties of forest soils

Samples taken from the White Carpathian Mts. region comprise soils of different origin and hence diverse characteristics. Focus area extends on tens of thousands of hectares and concerns various soil types, differing soil parent materials, and types of landuse. Variability of one particular variable (e.g. water repellency) is, in case of such statistical population of soils, controlled by great number of factors. This fact inherently complicates the process of regression analysis. Attempts to explain variability of water repellency results by applying certain mathematical relation in order to describe the effect of predictors which would be valid for either agricultural as well as forest soils may provide misleading and/or ambiguous conclusions. The mechanism which controls susceptibility of soil to become water repellent may be different for forest and agricultural soils. Firstly, there is a significant difference in quality of organic matter of agricultural and forest soils. For example, forest topsoils in moderate climate are in general characterized by a higher portion of particulate organic carbon. This is favoured by fresh organic inputs of plant and microbial biomass which are entering the topsoil throughout the year. On the other hand, in agricultural soils raw organic matter is typically absent or far less abundant, and more humified, microbially resistant, aromatic organic matter is prevailing. Besides differences in soil organic matter quality, there are also other substantial differences between agricultural and forest topsoils, including their management, nature of soil parent material or soil structure. Although we think that mentioned characteristics probably affect or control soil wettability, their quantification would require specific measurements to be performed. In case of

210 soils this would be laborious and expensive task. In order to propose meaningful regression relation which would explain varying wettability of soil material by use of properties measured in this study we decided to focus on forest samples only.

From all topsoil samples, 99 represented forest soils, from which 46 were found water repellent (WR). These were further classified as slightly (25), strongly (10), severely (5) and extremely (6) WR (Table 1A). Soil groups most affected by repellency accommodated Cambisols (44% were WR), Leptosols (50% were WR), Luvisols (54% were WR) and Regosols (100% were WR), although these results may be conditioned by the different numbers of samples in particular soil groups. WDPT proved to be a useful screening test in that it was quick and easy to test for the presence or absence of repellency (Scott, 2000). However, WDPT has a limited ability to distinguish between WR samples, particularly in case of longer time intervals when evaporation is affecting results. In this context, MED test is more suitable as it measures the degree (severity) of water repellency (Table 1B) The longest time required for water penetration was 22 hours (*haplic Cambisol* with 60.72% of sand, SOC: 9.05%, carbonate free, pH: 3.46) and the highest ethanol concentration used 32% (*rendzic Leptosol*: 61.52% of sand, SOC: 7.45%, CaCO₃: 1.2%, pH: 7.06).

SOC content ranged from 0.66 to 20.94%, and there were wettable soils present in each category distinguished (Table 1C). The highest SOC content in WR soil was 20.94% (*cambic Leptosol*), in wettable soil 11.16% (*Cambisol eutric*); except this case, all soils with SOC above 8.06% were found WR. Generally, in all soil groups containing WR soils the number of these soils increased with increasing SOC content.

In 30% of soils, (30 samples) a certain portion of CaCO₃ was detected (Table 1D). CaCO₃ contents ranged from 0 to 51%. There was one WR sample with a high CaCO₃ content of 51%, *Cambisol calcaric* with a high SOC content (6.35%) and a high portion of sand fraction (74.68%). The findings presented here suggest inverse relation between water repellency and carbonate content (83% of studied WR soils contained no CaCO₃), which is in contrast to results of Dekker & Jungerius (1990) who found no relation between CaCO₃ content and water repellency of dune sands.

Besides soil moisture, CaCO₃ content and the amount and quality of soil organic matter, there are indices that also soil pH may affect the wettability (Wallis & Horne, 1992). In studied soils, soil reaction varied from very strongly acidic (2% of soils) to slightly alkaline (20% of soils) values (Table 1E). A broad pH range (3.46 to 8.31) is related to differing

pedogenic substrates and altitudes of individual sampling spots as well as the presence of particular vegetation community. WR soils were present within the quite large pH interval extending from 3.46 to 8.05. There were no wettable samples below pH of 4.1. Three of six extremely WR soils had pH values between 3.46 and 3.64. Although several authors (Roberts & Carbon, 1971; Steenhuis et al., 2001) suggested that hydrophobicity does not appear under alkaline conditions, WR was detected in 29% of slightly alkaline soils. There was one slightly alkaline soil sample (pH of 7.45, CaCO₃ content: 19.8%) classified as being extremely WR (*Cambisol calcaric*); it contained 83.16% of sand.

pH was lower when determined with KCl than with H₂O, values ranged from 2.92 to 7.96. Most WR soils (33 samples, representing 72% of WR samples) had pH/KCl values lower than 4.31. Below 3.34, there were no wettable samples. Generally, in all soil groups containing repellent soils an increasing soil pH led to a decrease of water repellency. This is in accordance e.g. with Ritsema & Dekker (1998) and Hurraß & Schaumann (2006) that found interrelations between soil acidity and water repellency.

Similarly as other discussed properties also soil texture varied greatly. Content of sand fraction ranged between 18.60 and 86.60%, with mean being equal to 52.76. Samples were wettable when the sand contribution was lower than 32.68%. The highest detected sand content was 86.60%, however, this sample (*haplic Fluvisol*) was wettable probably due to significant amount of CaCO₃ (11%) and a low portion of SOC (0.66%). Although it is apparent from the correlation—matrix that the risk of repellency occurrence is affected not only by soil texture (though it may be a minor contributory factor), in general the repellency increased with increasing sand content. However, some medium-textured soils, such as loam and sandy clay loam, were highly repellent. With respect to clay content, the values ranged from 0.82 to 38.64%. Most of the WR soils contained less than 12.32% of clay (30 samples), and, at the same time, no repellency was detected if the amount of clay exceeded 22.32 % (Table 1F).

Although results presented here suggest that contents of individual textural fractions are important for soil wettability, there are some studies (Scott, 2000), which report an insignificant role of textural composition in repellency development. Different findings should be assessed in context of particular conditions in which the research was carried out. Since number of variables or factors may affect wettability, it is not surprising that under different circumstances studies may come up with dissimilar conclusions.

Table 1. Number of samples in particular categories of A) WDPT - water drop penetration time (King, 1981), B) MED - molarity of ethanol droplet (Doerr, 1998), C) SOC - soil organic carbon (Jones et al., 2005), D) CaCO₃ (Barančíková et al., 2009), E) pH/H₂O (Čurlík et al., 2003), F) soil texture (FAO, 2006).

Reference soil group (WRB,2006)		Cambisols	Leptosol	Luvisols	Fluvisol	Regosols	Total	Total WR
Total number of samples		50	26	13	7	3	99	46
Number of WR samples		22	13	7	1	3	46	
A) WDPT (s)	< 5	28	13	6	6	0	53	0
	5-60	17	6	1	1	0	25	25
	60-600	1	2	4	0	3	10	10
	600-3600	0	4	1	0	0	5	5
	> 3600	4	1	1	0	0	6	6
B) MED (mol.l ⁻¹)	< 0.85	38	18	10	7	0	20	20
	0.85-1.45	6	1	1	0	0	7	8
	1.45-2.22	2	0	0	0	3	6	5
	2.22-3.07	1	3	1	0	0	5	5
	3.07-6.14	3	4	1	0	0	8	8
C) SOC (%)	< 1	0	0	0	1	0	1	0
	1-2	1	0	3	3	0	7	1
	2-5	28	9	4	3	0	44	15
	5-10	18	13	6	0	3	40	24
	10-25	3	4	0	0	0	7	6
D) CaCO ₃ (%)	0	43	12	12	0	2	69	38
	0.1-1	4	9	0	0	1	14	2
	1-5	0	1	1	0	0	2	1
	5-20	1	3	0	7	0	11	3
	20-60	2	1	0	0	0	3	2
E) pH/H ₂ O	< 3.5	1	1	0	0	0	2	2
	3.6-4.5	17	5	4	0	0	26	18
	4.6-5.5	15	4	6	0	2	27	15
	5.6-6.5	11	3	2	0	0	16	4
	6.6-7.2	3	5	0	0	0	8	1
	7.3-8.5	3	8	1	7	1	20	6
F) Soil texture	loamy sand	1	0	0	3	0	4	2
	sandy loam	21	12	6	3	1	43	30
	loam	23	8	4	1	1	37	11
	silt loam	3	2	3	0	1	9	3
	sandy clay	2	3	0	0	0	5	0
	clay loam	0	1	0	0	0	1	0

Moreover, if the effect of several variables on soil wettability is judged by purely statistical means, more variable property will appear to have a greater effect in comparison to less variable parameter. For example, the influence of some property related to vegetation cover on water repellency may be higher if all soil samples would have similar texture.

3.2. Relationship between water repellency and measured soil properties - Correlation and regression analysis

Since there was no variability in WDPT or MED data corresponding to agricultural and grassland soils, there was no reason to perform

regression analysis or to calculate correlation coefficients. It was the group of forest soils where wettability varied. 73 forest samples out of 99 were found to be wettable according to results of MED test and wettability of 53 forest topsoil samples was confirmed by using WDPT test. Calculated coefficients of correlation are presented in tables 2 and 3. It should be noted that use of simple correlation for the assessment of relation between two variables is underlined by an approximate normal (Gauss) distribution of considered sets of values. Values of all variables fulfilled this condition except CaCO₃ contents, whose distribution showed significant skewness (with exponential character, Fig. 2) and common transformations did not

improved the situation. This was caused by the fact that from 99 forest soils, 69 did not contain any CaCO_3 at all. In spite of this limitation, from simple descriptive assessment of the data follows that the effect of CaCO_3 content on soil water repellency is rather negative. Dividing the group of forest samples according to CaCO_3 content into calcite-free soils and those containing CaCO_3 indicated that inverse relation between soil water repellency and content of CaCO_3 may be the case.

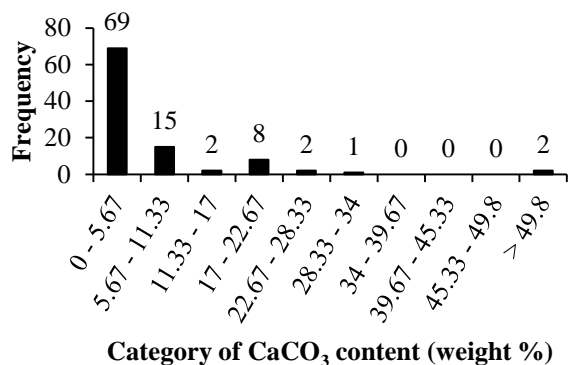


Figure 2. Histogram of CaCO_3 contents concerning forest topsoil samples ($n = 99$).

Soil which were classified as rendzic subtypes ($n=14$) exhibited ease wettability or only slight water repellency except one severely WR sample. Moreover, WDPT results obtained for samples containing ≥ 0.5 % of CaCO_3 showed strong, severe or extreme water repellency only in case of three soils (one sample per each class). The remaining soils were mostly wettable.

Soil water repellency is possible to express in form of various indexes, which may be used in correlation and/or regression analysis. Besides WDPT and MED, approximate values of surface tension γ_{sa} (in mN m^{-1}) were calculated according to equations presented in works of Regalado & Ritter (2005) or King (1981). From the three considered expressions of water repellency we found the MED value to be the most suitable for correlation and regression analyses because its distribution was closest to normal. For instance, square or cubic roots of MED led to normally distributed data in case of complete population of forest soils ($n=99$) or calcite-free forest soils ($n=69$), respectively. In case of WDPT, logarithms still showed substantial skewness, and normality was achieved after ninth root. We did not use the surface tension values as they are calculated from MED data and hence their distribution show similarities.

Correlation and regression analysis differ in conditions for their correct application. A prerequisite for correlation analysis is that both variables which the relation is investigated between are distributed normally (when calculating r value). For this reason,

the interpretation of r values was problematic in some cases (CaCO_3). On the other hand, in the regression analysis the condition of normal distribution concerns only values of variable that is being explained. Square roots of MED results (distributed normally) were used as representative of soil water repellency for the purpose of calculating correlation coefficients and regression statistics. The r values presented in correlation matrix suggest that water repellency of studied topsoils is controlled by number of variables. SOC content, pH value, contents of particular textural fractions, all of these were significantly correlated with MED values considering forest soils (Table 2). Similarly significant were the correlations between water repellency and variables concerning forest samples with no CaCO_3 content (Table 3). In general, the r values were significant in more cases when correlation coefficients were calculated for all 99 forest soils. This suggests that multivariate model is more appropriate for the expression of the wetting process as it proceeds in the field where the effect of individual properties is synergic.

Majority of properties which were significantly correlated with water repellency (except clay content) were also successfully tested as partial predictors of water repellency in regression analysis. This accounts also for the amount of CaCO_3 (Fig. 3), although it did not show significant correlation with repellency. Positive or negative value of partial regression coefficient in the equation suggests either positive or negative contribution of particular property on overall MED value. With respect to calcite content, the positive effect related to positive regression coefficient is however quite disputable and it is in contradiction with certain findings presented in particular works (Mataix-Solera & Doerr, 2004). However, there are some facts which are worth to be mentioned with respect to presented results of regression analysis. Higher content of CaCO_3 in soil is often associated with higher amount of organic carbon.

Stabilization of organic matter against microbial degradation is facilitated by sufficient amount of Ca^{2+} present in soil solution. Calcium cations form relative stable complexes with organic matter and also positively affect absorption of organic matter onto mineral surfaces (Mikutta et al., 2007). Prevailing accumulation of organic inputs in calcareous soils might be hence associated with their WR behaviour. Moreover, soils with higher CaCO_3 content are often coarse-textured. An increasing portion of sand in textural composition has been reported to affect soil water repellency positively. For these reasons it is possible that content of CaCO_3 is in fact reflecting some other characteristics of soil, and its role in the equation is purely statistical with no physico-chemical background.

Table 2. Pearson's coefficients of correlation calculated for particular couples of soil properties considering all forest topsoil samples (n = 99).

	MED ^{1/3}	Log SOC	pH/H ₂ O	pH/KCl	Sand	Silt	Clay
MED ^{1/3}	1						
Log SOC	0.51***	1					
pH/H ₂ O	-0.35***	-0.25*	1				
pH/KCl	-0.28**	-0.22*	0.98***	1			
Sand	0.34***	-0.01	0.14	0.21*	1		
Silt	-0.28**	-0.08	-0.22*	-0.25*	-0.86***	1	
Clay	-0.22*	0.19	-0.03	-0.09	-0.66***	0.20*	1

*, **, *** indicate statistical significance at 0.05, 0.01 and 0.001 level

Table 3. Pearson's coefficients of correlation calculated for particular couples of soil properties considering only forest topsoil samples with zero CaCO₃ content (n = 69).

	MED ^{1/2}	Log SOC	pH/H ₂ O	pH/KCl	Sand	Silt	Clay
MED ^{1/2}	1						
Log SOC	0.61***	1					
pH/H ₂ O	-0.41***	-0.14	1				
pH/KCl	-0.29*	-0.02	0.95***	1			
Sand	0.42***	0.18	-0.13	-0.08	1		
Silt	-0.44***	-0.24	0.11	0.08	-0.88***	1	
Clay	-0.08	0.05	0.06	0.03	-0.51***	0.03	1

*, **, *** indicate statistical significance at 0.05, 0.01 and 0.001 level

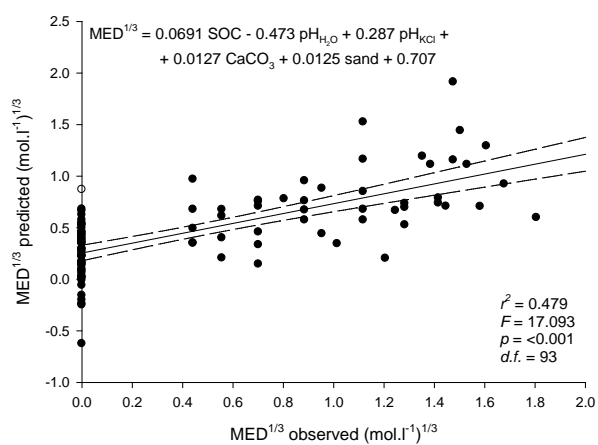


Figure 3. The relation between observed and predicted water repellency (MED) according to presented regression equation proposed for explanation of water repellency variance in case of 99 forest soils (SOC - soil organic carbon, r^2 - coefficient of multiple determination, F - observed value of the F statistic, p - error probability value of F statistic, $d.f.$ - degrees of freedom).

The effect of other soil variables implemented as predictors in the regression equations is in accordance with theoretical basis and information given in various literary sources. It is suggested that regression analysis provides more relevant results when performed on separated populations of forest

samples, e.g. according to CaCO₃ content. Similar type of regression equation as was acquired for the whole population of forest samples (same explanatory variables except CaCO₃) is describing variation of repellency in case of 69 calcite-free forest topsoils. Scatter plots of observed versus predicted MED values are depicted in figure 4.

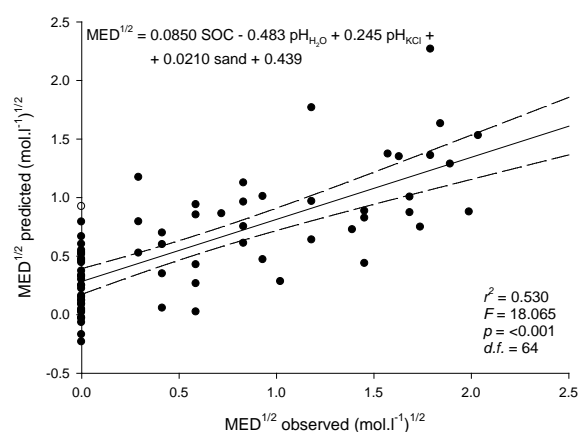


Figure 4. The relation between observed and predicted water repellency (MED) according to presented regression equation proposed for explanation of water repellency variance in case of 69 forest calcite-free soils (SOC - soil organic carbon, r^2 - coefficient of multiple determination, F - observed value of the F statistic, p - error probability value of F statistic, $d.f.$ - degrees of freedom).

Positive effect of SOC content on water repellency applied in the regression equations is, at least to some extent, related to the degree of accumulation of mainly plant and also microbial inputs which enter the topsoil. It is hypothesized that the balance between accumulation, humification and mineralization of biomass is the important factor for water repellency development. Prevalence of cold and wet conditions within forest floor at higher altitudes throughout the year favours accumulation of organic inputs in the humus horizon. If for some reason water content of soil decreases under critical level, water repellency appears. In contrast, a study of water repellency in transects in a dune sand of the Netherlands (Dekker & Ritsema, 1994) showed no relationship between soil organic matter and the persistence of water repellency.

Positive effect of SOC content on the WDPT or MED values is related to negative effect of soil reaction. As mentioned already, humus horizons of forest soils are commonly rich in particulate organic material and hence exhibit relatively acidic character. Negative correlation between SOC and pH was significant at 0.05 level (Table 2). Connection between acidity of topsoil and water repellency is not new, it has already been mentioned in some papers (Hurraß & Schaumann, 2006; Horne & McIntosh, 2000; Šimkovic et al., 2009). Plant and microbial biomass contain relative large portion of organic (e.g. carboxylic) acids which contribute to acid reaction of soil environment. Acidity of topsoil partially reflects raw character of soil organic matter and hence the degree of accumulation of organic (plant and microbial) inputs. Besides that it can be expected that acidic character of soil is additionally accentuated due to chemical composition and overall amount of atmospheric precipitation. This however cannot be quantified on the basis of results presented in this study. Furthermore, in such case even greater water repellency might be expected. Slower mineralization rates and hence higher amount of accumulated carbon in surface horizon, in relation to accelerated soil acidification, have been reported from various forest ecosystems of northern and central Europe (Prietz et al., 2006).

Similarly as in the case of other works also in this study it was proved that results of water repellency testing were affected by sand fraction content. Detected amounts of sand were positively correlated with MED values (Table 3). Besides other soil variables, sand fraction content was positively tested as partial predictor in multiple regression analysis with positive effect on resulting MED value (tendency for water repellency to increase with increasing content of sand). Coarse-textured soils have been reported to exhibit water repellency more frequently in comparison to fine-textured. With respect to such observation, there are two factors that are worth to be mentioned. Smaller specific

hydrophilic mineral surface of e.g. sand grains are covered more easily by organic coatings (McGhie & Posner, 1980). Moreover, the organic matter of coarse-textured soils contains more alkyl compounds in comparison to loamy or clayey soils, and at the same time it is deficient in labile organic substances such as proteins and carbohydrates (Capriel et al., 1995). In sandy soils, these are degraded predominantly by soil microorganisms, whereas in fine-textured soils they are stabilized against biodegradation due to absorption onto clay mineral particles.

Considering two regression models, the first which resulted from analysis performed on 99 samples of all forest soils and the second which concerned 69 calcite-free forest topsoils, both explained similar portions of $MED^{1/3}$ and $MED^{1/2}$ variance. From these two, the latter is preferred (in spite of lower number of cases - samples) because of ambiguities associated with the effect of $CaCO_3$ content on water repellency. This regression model explains 55% of $MED^{1/2}$ variance as a linear function of particular soil properties. General trend of water repellency variation resulting from change of other soil properties is visualized in figure 4. However, the great portion (45%) of variance still remains unexplained. Relatively low portion of elucidated variability of soil wettability by means of regression analysis was reported also in other studies with similar character. For example, Scott (2000) explained 46% of variability of critical surface tension and 27% of apparent contact angle values by variability of soil organic matter content and soil textural composition. Also Doerr et al. (2006) reported limited explanation of water repellency by use of supposedly influential parameters (soil texture, organic matter and water content) as predictors. In general, studies in which area greater in extent is subjected to sampling and subsequent statistical analysis report rather low portion of explained variability. On the other hand, plot-scale studies often provide relatively good explanation of varying repellency. This is related to differing diversity of soil characteristics of samples which are included in the investigated population.

4. CONCLUSION

Since the area subjected to research is rather large, water repellency of studied soils is controlled by great number of factors which complicate the regression analysis. There are differences in soil types and fabric, geology, and landuse. Therefore, only populations of soils having some particular feature in common were analyzed. Hence, regression analysis and calculation of correlation coefficients were performed for forest soils only, because soils under other landuse types were wettable. Furthermore, the group of forest samples was

divided according to CaCO₃ content into calcite-free soils and those containing certain amount of CaCO₃. The latter group comprised only eight water repellent samples, whereas soils from the former showed water repellency in 38 cases; content of CaCO₃ was successfully tested as a term with negative effect on repellency. It is probable that instead of direct effect of CaCO₃ content on either WDPT or MED values, various other aspects associated with calcareous soils (there is frequently the lack of adequate soil moisture, they are often rich in organic carbon and also coarse-textured) are in fact responsible for higher water repellency of particular soils. Positive effect of SOC content on the WDPT or MED values is associated with accumulation of various organic inputs and also with negative effect of soil reaction. The acidic character of calcite-free soils is determined by the presence of organic acids coming from decomposing plant and microbial biomass, bedrock composition, and the chemical composition and amount of atmospheric precipitation. The content of sand fraction was successfully tested as partial predictor affecting water repellency positively. Besides regression analysis, the relation between water repellency and particular soil properties can be characterized by coefficient of correlation. Achieving relevant *r* values was however problematic for some couples of soil characteristics (e.g. in case of WDPT and CaCO₃ content) due to their non-normal distribution. For this reason, square roots of MED results (distributed normally) were used as representative of soil water repellency either for the purpose of calculating correlation coefficients or explaining variability in regression analysis. Since soil water repellency is controlled by number of variables, performing multiple regression analysis became more appropriate way of elucidating water repellency variance in comparison to simple regression or correlation analysis. It is also worth to mention that studies dealing with larger areas report rather low portion of explained variability in comparison to plot-scale studies. This is related to considerable diversity of soil characteristics of samples comprised in the investigated population.

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