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Assessment of soil water repellency in reclaimed soils under different land use

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Abstract

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Study on soil water repellency in reclaimed Technosols from the area of Obruchishte village, Maritsa-Iztok Mines has been carried out. Sampling sites cover several regions with different land use – stubble site (without vegetation), acacia and pine plantations. Surface soil layers and those of deeper depths in the soil profile were investigated. Soil water repellency was determined by water drop penetration time (WDPT) test at ambient conditions and after heating in an incubator at 65°C. It was found that before heating, extreme water repellency prevails in the surface soil layers of the studied sites compared to the subsurface. It also covers the highest share of all soil samples. Water drop penetration time significantly correlates with the extracted organic carbon (EOC) content and the % sand fraction of soil samples. The decrease of the water drop penetration time after heating leads to an increase in the number of wettable and slightly water repellent soil samples and reduced the share of extremely water repellent samples.

Keywords: soil water repellency; reclaimed soils; water drop penetration time; soil organic carbon; soil texture; correlation

Introduction

Jaramillo et al. (2000) report that soil water repellency (SWR) is the subject of research by many scientists around the world. Over the years, this is due to its gradual separation as a part of science (DeBano, 2000). SWR occurs in soils under the influence of various factors (Lozano et al., 2013) and varies with changes in environmental conditions (Diehl, 2013). Therefore, SWR is considered as a variable property (Dekker & Ritsema, 2000; Sepehrnia et al., 2017) that is difficult to be predicted and is interrelated with different soil characteristics, climate and land use (Müller & Deurer, 2011; Diehl, 2013). Many soil types including surface soil layers and the deeper soil profile horizons were studied (Hurraß & Schaumann, 2006; Dekker & Ritsema, 1996; Sepehrnia et al., 2017). Just like natural soils, the Technosols as a reference soil group (IUSS Working Group WRB, 2015) have been studied for determination of different soil characteristics and establishment of their relationship to SWR. Some studies draw attention to the physical and chemical characteristics of reclaimed mine spoils (Atanassova et al., 2018a, b; Simeonova et al., 2018). Others emphasize the microbiological indices of the Technosols (Nedyalkova et al., 2018a, b), changes in water repellency during different seasons, before and after laboratory heating (Ivanov et al., 2019), and relationships between soil characteristics and SWR in depth of soil profile (Atanassova et al., 2020). A feature of the listed Technosols studies is that they were carried out during the spring and summer season and cover sample sites with pine plantation, without vegetation or with tussock grass vegetation.

To complement the information on the occurrence of SWR in studied Technosols, a new field study was conducted during the autumn season, including new vegetation types.

Materials and Methods

The soil samples were collected in the beginning of October 2019 from several sites at reclaimed Technosols in the region of Obruchishte village, Maritsa-Iztok Mines. A stubble site without vegetation was selected for sampling. It had tussock grass vegetation during the study in the summer of 2017. Sampling is carried out at two depths (0-20 cm and 20-40 cm) of the pre-constructed grid points with coordinates: N 42.1442; E 25.9541. The total number of soil samples from the grid is 16. In the stubble site, a soil pit was further dug to detect the availability of water repellency in depth of the reclaimed soil. Six soil layers up to a depth of 85 cm are defined and sampled. Other soil samples were collected from sites with acacia (N 42.14456; E 25.95278) and pine trees (N 42.14857; E 25.95304). Grids Δ2 m, ~ 40 m^2 were constructed and sampling was at two depths where water repellency was demonstrated on the field 0-5 cm and 5-15 cm. At the reclaimed sites of Obruchishte, soils were of *sandy loam* (USDA Soil Survey Staff, 1975; FAO, 2006) texture mixed with degraded lignite and coal ash, and of *clay loam* texture in afforested acacia and pine sites. Layers of greyish-green and yellow clays had been mixed with black clays containing coal and ash in the 1970s. The number of soil samples from the reclaimed sites analysed from pooled samples at each point is 34.

The presence of SWR was determined by the water drop penetration time test (WDPT) (Dekker & Ritsema, 1996; Doerr et al., 2002). For this purpose, the preliminary preparation of soil samples for the analysis was carried out at room temperature drying in the laboratory (18-20°C and air humidity 68-82%). The samples were further homogenized and ground to a particle size of 2 mm. Three drops of 80 µl distilled water were placed on the surface of each sample and the time for their full absorption into the soil was measured.

After WDPT measurements, the soil samples were heated at 65°C for 24 hours in an incubator NUVE, EN500 and the WDPT test was repeated again (Ivanov et al., 2019).

The discussions of SWR in the Technosols studied are based on the medians that were determined between the three water drops for each sample (before and after heating). Thus, the soil samples are classified on a five-class scale, as presented in studies by Dekker & Ritsema (1996; 2000): 0 – wettable (< 5 s); 1 – slightly (5-60 s); 2 – strongly (60-600 s); 3 – severely (600-3600 s); 4 – extremely water repellent (> 3600 s).

The collected samples were additionally studied for determination of the following chemical and physical properties:

– pH (H_2O) – potentiometrically (Arinushkina, 1970);

– Cation exchange capacity (CEC) by the method of Ganev & Arsova (1980);

– Textural composition (%) by the method of Kachinski (1965), with calculation of textural fractions and classes according to Soil Taxonomy (USDA Soil Survey Staff, 1975) and FAO (2006);

– Extracted organic carbon (EOC) by the Tyurin's method for total organic carbon and the EOC content by the method of Kononova-Belchikova (Kononova, 1966), modified by Filcheva & Tsadilas (2002), with 0.1M $Na_4P_2O_7$+0.1M NaOH extraction;

– Soil bulk density (D_b) according to the ISO 11272 (1998) with 100 cm^3 rings in four replicates;

– Soil particle density (D_s) according to ISO 11508 (1998) with 100 cm^3 pycnometers;

– Soil total porosity (P_t) was calculated using the data for bulk density and particle density;

The soil samples were further combined into two groups depending on the land use of the studied sites for correlation of WDPT with EOC and textural fractions: without vegetation (stubble site plus soil profile layers to a depth 0-40 cm) and with afforestation (acacia and pine sites). Statistical data processing was performed using SPSS 22 for MS Windows.

The sites without vegetation have very low pH (mean ± stdv) (3.72 ± 0.24) and 47.72 ± 0.67 CEC (cmol.kg^{-1}). The pH in afforested sites is 4.59 ± 0.67 with 35.45 ± 3.30 CEC (cmol.kg^{-1}) (mean ± stdv).

Results and Discussions

The overview of data on SWR measurements presents extreme hydrophobicity and time for infiltration of water drops between 3 hours to almost 5 hours (point 2/3, 20-40 cm = 3 h 16 min 20 s; point 2/2, 0-20 cm = 4 h 45 min 20 s) in soil samples from the stubble site (Figure 1). This is typical for both the surface and subsurface layers of the grid, before heating of the soil samples in the incubator. Extreme water repellency is also typical for half of the surface sampling points (0-10 cm) surveyed during the summer season, on a site without vegetation in the area of Obruchishte village, Maritsa-Iztok Mines (Nedyalkova et al., 2018a; Ivanov et al., 2019). On the other hand, before heating, three grid points in our study (1/1, 1/2, 1/3) demonstrate clear pattern in the presence of strong to severe SWR in the surface layer (0-20 cm) and its lack to slight extent, in depth of these points (Figure 1). Such a trend is more pronounced at time interval at several points from a pine vegetation site studied during the spring season (Nedyalkova et al., 2018b; Ivanov et al., 2019).

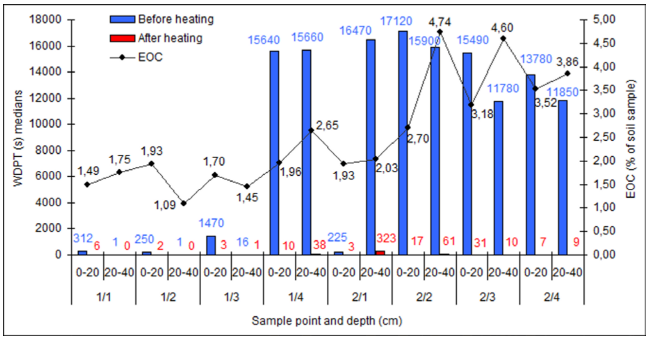

Fig. 1. WDPT and EOC content in soil samples from the stubble site

The soil profile from the stubble site is characterized by sharp differentiation of water repellency between the surface soil layers and those in depth. While in the surface, before heating of samples, the SWR is extreme, it is slight or absent below 30 to 85 cm (Figure 2). For another soil profile from the studied site where tussock grass vegetation was developed (in July, 2017), extreme water repellency was typical for soil layers between 10 and 80 cm, before heating of samples (Atanassova et al., 2020). We found positive correlation between the WDPT and EOC for the samples before heating (Figure 3), but after heating at some sites, the relationship was lost. The fact that the positive correlation between the WDPT and EOC is preserved after heating supports the statement that organic compounds causing hydrophobicity in these reclaimed Technosols are rather similar in composition and organo-mineral interactions, therefore their behaviour after heating is similarly influenced.

The physical characteristics of the stubble site (mean ± stdv) are the following: D_b (g/cm^3) = 0.89 ± 0.19; D_s (g/cm^3) = 2.36 ± 0.23; P_t (%) = 62.24 ± 7.05. A significant negative correlation was observed between the WDPT before heating and the studied soil physical characteristics: WDPT-D_b R = -0.333, WDPT-D_s R* = -0.658 (Figure 4). No correlation was observed between WDPT and total porosity Pt.

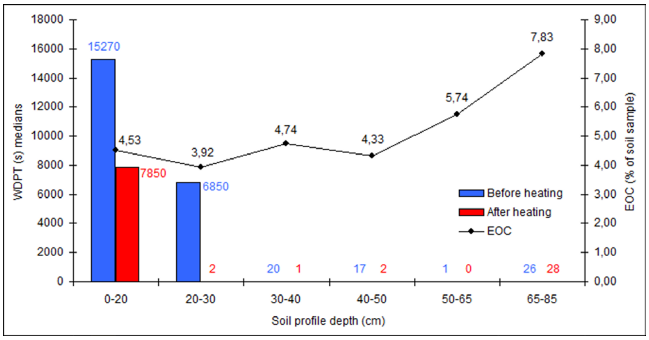

Fig. 2. WDPT and EOC content in soil profile layers

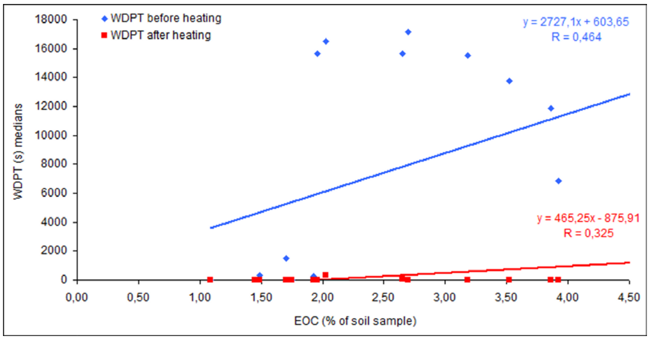

Fig. 3. Correlation between the WDPT and EOC in studied site without vegetation (stubble site plus 0 – 40 cm soil profile layers)

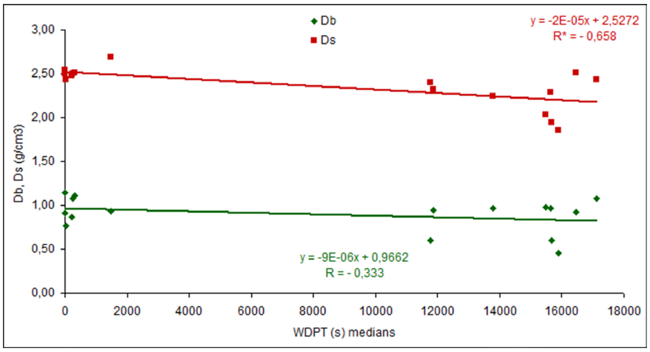

Fig. 4. WDPT correlation with soil bulk density (D_b) and soil particle density (D_s) in stubble site before heating of soil samples

Significant at *p < 0.05

The particle density of the soil represents the mass of the soil sample in a given volume of the particles. This physical characteristic describes the soil particles and not the total volume that the soil particles and pore spaces occupy in the soil, expressed as bulk density D_b. Unlike the bulk density representing the total volume of the mineral plus organic matter in the soil with the pore spaces, the particle density is a result of the chemical composition and structure of the soil particles.

Textural composition (%) of the stubble site, plus soil profile layers from 0 to 40 cm, shows that the sand fraction predominates (mean ± stdv) 58.14 ± 6.18, followed by the silt (21.97 ± 4.57) and the clay (19.89 ± 3.00) fractions. The correlation between the WDPT before heating and textural fractions is significant and is positive for the sand fraction (WDPT-sand R* = 0.687) and negative for the silt (WDPT-silt R* = -0.569) and clay fractions (WDPT-clay R* = -0.547) (Figure 5).

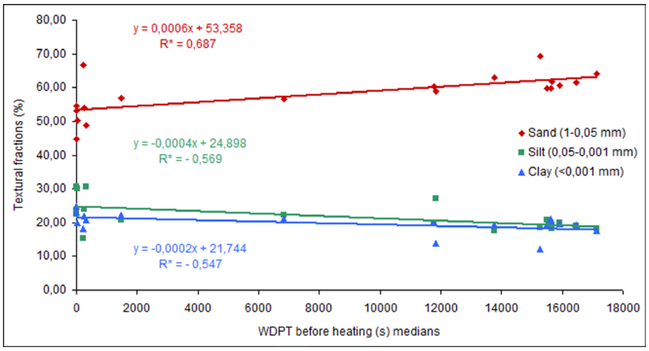

Fig. 5. WDPT correlation with textural fractions in studied site without vegetation (stubble site plus 0 – 40 cm soil profile layers)
Significant at *p < 0.05

The predominant extreme water repellency in the surface layers of the stubble site is also inherent in the afforested reclaimed areas. Here, however, the sampling depth differs from the other sites in the studied mine spoil because of the specific conditions and processes of soil formation typical for areas with tree species. The total thickness of the two depths in the studied afforested sites is 15 cm and is close to the surface layer of sampled points at the stubble site (20 cm). Under these conditions, within the acacia site, the recorded WDPT at 0-5 cm depth classifies the soil samples before heating in class 4 (extremely water repellent) based on the respective scale (Dekker & Ritsema, 1996, 2000). The established water repellency is also characteristic of both depths of point 1/1 (Figure 6). For the rest subsurface layers (5-15 cm) of the acacia site, the WDPT characterizes the soil samples as strongly water repellent to wettable.

In contrast to the acacia site, the differentiation between the surface and subsurface layers in the pine site, before heating of the soil samples, is well demonstrated for all sample points studied (Figure 6). These differences are significant in WDPT between the two depths, which range from 4 h 3 min 30 s to 18 min 50 s at point 1/1 and from 3 h 56 min to 8 s at point 1/3. The correlation between WDPT and EOC in afforested sites is also positive and higher than the area without vegetation (R* = 0.740) (Figure 7).

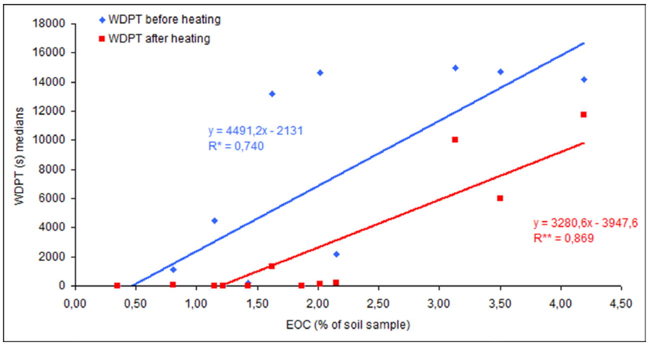

Fig. 7. Correlation between the WDPT and EOC in afforested acacia and pine sites
Significant at *p < 0.05, **p < 0.01

Regarding the textural composition (%), the quantity of different fractions in afforested sites decreases gradually in the following sequence (mean ± stdv): sand 38.08 ± 13.24; silt 33.63 ± 4.37; clay 28.24 ± 10.55. Here, we will note that the correlation between the WDPT before heating of soil samples and textural fractions is significant and stronger than that in the area without vegetation. It is positive for the sand fraction (WDPT-sand R** = 0.891) and negative for the silt (WDPT-silt R* = -0.602) and clay (WDPT-clay R** = -0.864) fractions (Figure 8).

Previous studies of surface and subsurface layers from the sampling points in the area have shown that heating of

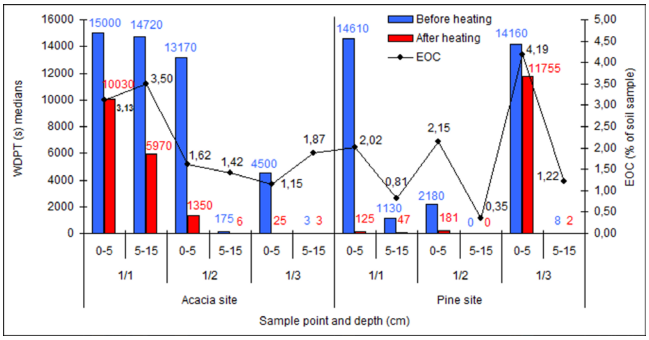

Fig. 6. WDPT and EOC content in soil samples from afforested sites

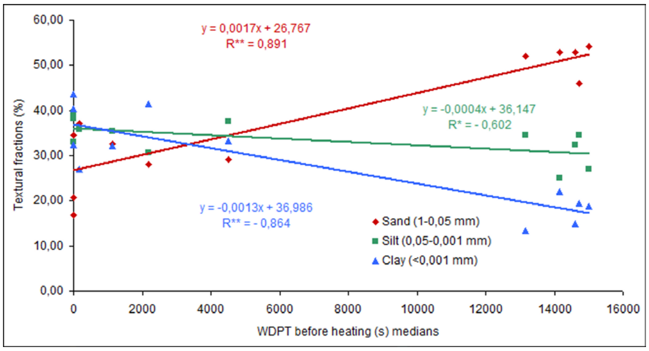

Fig. 8. WDPT correlation with textural fractions in afforested acacia and pine sites
Significant at *p < 0.05, **p < 0.01

soil samples in an incubator generally leads to decreasing of WDPT, regardless of vegetation and season (Ivanov et al., 2019). The same trend is typical for a depth of up to 100 cm in a reclaimed soil profile from the area of Obruchishte village, Maritsa-Iztok Mines (Atanassova et al., 2020). In the present study, the established trend is most pronounced from the results of the laboratory heating of soil samples from the stubble site. For soil samples with extreme water repellency, the reduction of WDPT leads to their classification as slightly water repellent (Class 1). The other points, where the hydrophobicity was slight to severe, become wettable (without point 1/1, 0-20 cm) (Figure 1).

After heating, the soil profile layers from the same stubble site also show reduced values of the WDPTs. Here, however, the surface layer (0-20 cm) retains its extreme water repellency, although twice decreased. The water repellency is highly reduced in the subsurface layer, which becomes wettable (Class 0). The other profile layers absorb the water drops for 0 to 2 s, even though they were slightly water repellent before heating. The exception is the deepest layer (65-85 cm), which retains the degree of water repellency (Figure 2). Under these conditions, the correlation between WDPT and EOC in the site without vegetation is also positive although the lower value than that before heating (R = 0.325) (Figure 3).

Extreme water repellency characterizes one of the sample points (1/1) from the acacia site after heating at 65°C, where the WDPT becomes shorter in the surface layer (0-5 cm) and shortened more than twice to a depth of 5-15 cm. For the remaining (0-5 cm) points, the decrease is significantly larger. There, the initial extreme water repellency is reduced to slight (Class 1) and severe (Class 3). The change in the degree of water repellency after heating the soil samples varies also over a wide range at the surface (0-5 cm) of the points from the pine site (Figure 6).

After heating, significant correlation was observed between the WDPT and EOC (R** = 0.869) in afforested sites, which is higher than before heating (Figure 7). This may be related to increases in the formation of organic carbon coatings responsible for soil water repellency after drying at higher temperatures (Dekker et al., 1998).

So far, the discussions of WDPT have revealed differences in the measured soil samples, which sometimes express SWR without a clear pattern between the sample sites and soil layers. Therefore, we made two comparisons of the % distribution of soil samples between the SWR classes (Dekker & Ritsema, 1996, 2000). In the first comparison, we juxtapose the WPDT data between the surface and subsurface layers of the studied sites, without inclusion of the soil profile depths.

The percentage of all soil samples from the surface layers of studied sites (0-5 cm in afforested areas, 0-20 cm in other sites) shows that, before heating, they are not divided into the five SWR classes (Dekker & Ritsema, 1996, 2000). More than a half of the samples are in Class 4 (extremely water repellent: 67%). Wettable and slightly water repellent are missing. After heating in the incubator, the observed distribution of surface samples has changed. Wettable and slightly water repellent samples comprise 60%, in replacement of the other reduced SWR classes (Figure 9a).

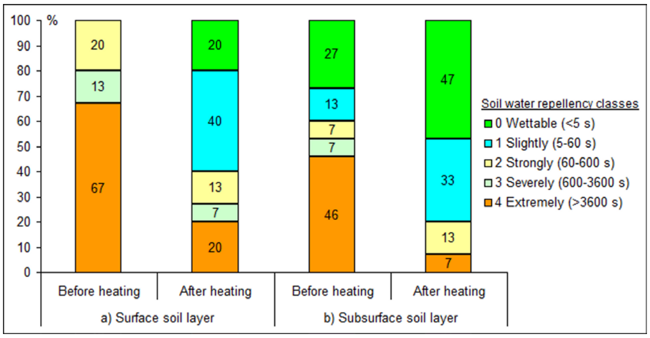

Fig. 9. Water repellency ratio in surface and subsurface soil layers of all studied sites

Different is the grouping of soil samples from subsurface layers, whose depth varies between 5-15 cm in afforested areas, 20-40 cm in stubble site and 20-30 cm in the soil profile (excluding layers below 30 cm). In this case, the samples are distributed in all divided classes of SWR before heating of soil samples (Dekker & Ritsema, 1996, 2000). Those with extreme water repellency (> 3600 s) again occupy the highest share, even though they are less in comparison with surface layers. On the other hand, we will note here that 40 % of samples in the subsurface layers are represented in both wettable and slightly water repellent SWR classes. After heating, the shortening of WDPT is also evident with a sharp decrease of soil samples in class 4 and an increase of wettable samples and those in class 1 (Figure 9b).

In the second comparison, the total distribution of soil samples measured from all sites and depths of the soil profile confirms that extremely water repellent samples have the highest share before heating in the incubator (49 %). The rest are separated between other classes of SWR (Dekker & Ritsema, 1996, 2000), of which the higher equal shares have wettable and slightly water repellent samples, followed by the strongly water repellent ones. Logically, heating of the soil samples in the incubator redistributes them, with sharp decline in extremely water repellent class (> 3600 s) and reduction of its share by nearly 4 times. On the other hand, the wettable samples increase more than twice as well as the slightly water repellent ones in class 1 (Figure 10a). The decrease of WDPT after heating at 65°C can be attributed to conformational changes in organic compounds distribution. Dekker et al. (1998) also emphasizes the possible connection between changes in organic substances and SWR.

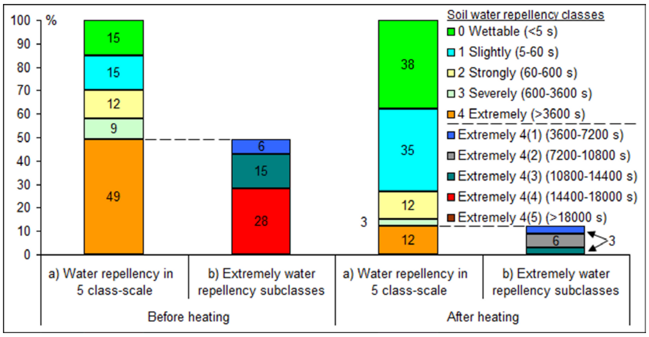

Fig. 10. Water repellency ratio in all soil samples from studied sites

The classification of different levels of SWR (Dekker & Ritsema, 1996, 2000) used in our study groups the soil samples in which the WDPT is more than 1 hour (> 3600 s) into one general class – extremely water repellent (Class 4). Therefore, we decided to separate these samples in accordance with additional subdivision of WDPT (> 3600 s) at equal one-hour intervals until reaching of more than 5 hours WDPT (3600-7200 s; 7200-10800 s; 10800-14400 s; 14400-18000 s; > 18000 s) (Doerr et al., 2002). Thus, the extremely water repellent class is split into five subclasses, which allows significantly longer measurements of WDPT and more detailed visualization of the results. Jaramillo et al. (2000) present similar longer-term measurements of the WDPT between 1-2 h, 2-3 h, and > 3 h. Other authors also divide the extremely water repellent class (> 3600 s) into 3 subclasses but with longer WDPT intervals to more than 6 hours (1-3 h, 3-6 h, > 6 h) (Dekker et al., 2000; Oostindie et al., 2013). In our study, there are no soil samples with recorded WDPT > 5 h.

The general overview of the distribution of all soil samples by the WDPT (> 3600 s) indicates that, before heating in the incubator, they are not divided between the 5 extremely water repellent subclasses (Doerr et al., 2002), but only in some of them. Water repellent samples with WDPT between 4 and 5 hours occupy the highest share of differentiated degrees of SWR (28%). The remaining soil samples are grouped according to the time for absorption of the water drops typical for subclasses 4(1) and 4(3). After heating, the reduction in the WDPT is further evident in the separation of the extremely water repellent samples, which, in addition of their reduction, they can now be classified in up to class 4(3) (Figure 10b).

Conclusions

The differences of the WDPT in the soil samples studied sometimes represent the SWR without a clear pattern between the different sites and soil layers. Before heating, the extreme water repellency occupies the highest share of all soil samples from the studied sites and is predominant in the surface layers compared to the subsurface ones. The WDPT lasts between 4 and 5 hours for the extremely water repellent samples. Soil heating coincides with the previously established reduction of the WDPT to varying degrees, regardless of vegetation and season and is caused by conformational changes of organic compounds causing water repellency. In the present study, the decline in WDPT after heating mainly leads to increasing of wettable and slightly water repellent soil samples. The WDPT is < 4 hours reflecting a reduced share of the extremely water repellent class. Before heating, the WDPT correlates positively with extractable organic carbon content and the sand content and negatively with the contents of the silt and clay fractions in the surface 40 cm of the stubble site, and the afforested sites. After heating, the established correlation varies, depending on the extent and orientation of organic matter coatings on soil particles.

Acknowledgements

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