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Influence of Abandoning Agricultural Land Use on Hydrophysical Properties of Sandy Soil

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Abstract: Soil water repellency can significantly degrade its agricultural utility and bring about negative environmental consequences (i.e., reduced infiltration capacity, enhanced overland flow, increased erosion rates, and water infiltration occurred in irregular patterns). The presented study aimed to establish whether excluding albic Podzols from agricultural production and their spontaneous inhabitation by a pine tree stand affected their hydrophysical properties. Studies with the application of the water drop penetration time (WDPT) test showed that a change in the land use increased the potential water repellency of the surface layer (horizon A) and caused its changeover from strongly repellent class (Class 2) to extremely repellent (Class 5). The relationship between soil moisture content and wettability made it possible to determine the critical soil moisture content (CSMC) for the occurrence of the phenomenon of water repellency. It was confirmed that the CSMC value increased along with a change in use. For the site under arable use, it was 9–10 vol.%, whereas for the site formerly under arable use and currently covered predominantly by a pine tree stand, a value in the range of 14–16 vol.% was reached. A laboratory experiment on surface runoff of the soil formerly under arable use showed that over half of the rainfall may be transformed into surface runoff as a result of occurring water repellency. This means that exceeding the critical soil moisture content makes the recharge of soil retention difficult and may significantly influence the water balance of soil, as well as increasing its susceptibility to drought.

Keywords: soil water repellency; land use change; agrohydrology; water retention; surface runoff

1. Introduction

The amount of water which sandy soil can retain is low and results from the distribution of soil pores, which is dominated by large pores that do not contribute to water storage. This phenomenon is described by the soil water desorption curve. In soils characterized by a high contact angle, the London dispersion forces make the wetting of soil difficult to different degrees. As a result, full use may not be made of the potential retention ability of soil, seeing as how rainwater, instead of infiltrating, will gather on the surface of the soil and run off. In connection with the above, some researchers [1,2] treat soil water repellency (SWR) as one of the most important properties of soil, which determines its physical and chemical properties, and is decisive to its production and regulation functions. Water repellency may have significant agrohydrological consequences by increasing the susceptibility of soils to drought. The reasons behind water repellency are being identified to an increasingly wider extent and are related to the occurrence of organic carbon, especially humic and fulvic acids, as well as waxes and lipids of different origins [2–6]. Water repellency also occurs following forest fires and the burning of grasses [7–11] as well as soil contamination with crude oil derivatives [12–15]. Water repellency is of a seasonal nature and is strictly connected with soil moisture content [16–21]. Many authors [22–27] draw attention to the connection of water repellency with the type of soil use. A deciding factor when it comes to the ability of soil to absorb and retain rainwater is the wettability of the soil material, which depends on the level of humification of soil organic matter [28]. In Poland, a common phenomenon connected with political transformation is abandoning agricultural production on sandy soils characterized by low productivity [29]. These areas are intentionally afforested or, most often, become spontaneously covered by forest plants with a large share of pine trees.

The dimension of the agricultural areas abandoned or converted into production forests in Europe varies widely between scenarios [30]. According to intermediate scenarios in Verburg and Overmars [31], between 10 and 29 million ha of land will be released from agriculture between 2000 and 2030.

Water infrastructure (drainage system) for purposes of agricultural production undergoes fast degradation in these areas. As a result of changing agrohydrological conditions and the balance of organic substances, the areas that once had been an agricultural ecosystem undergo fast transformations, and soil properties may change the ecosystem services [32]. The complexity of the planning process is increasing, especially in the context of the sustainable use of forest resources and its adaptation to climate change [33,34]. To avoid further land degradation and promote land restoration, multifunctional use of land is needed within the boundaries of the soil–water system [35]. A robust soil–water system is essential for achieving most of the UN sustainable development goals [36,37], as interlinked goals. Moreover, sustainable solutions need to embed short-term management in long-term landscape planning in the direction of long-term sustainability. The aim of this study was to assess whether resigning from agricultural production on sandy (nutrient-poor) soil and the uncontrolled succession of a pine stand can significantly influence the shaping of hydrophysical properties of soil. Identification of the main parameters driving system dynamics is essential to solve land and water-management related problems [38].

2. Materials and Methods

2.1. Description of the Study Site

The study site is located in central Poland in the Mazowieckie Province, Stanisławów Commune. Sandy soils, mainly albic-Podzols [39] with a low production potential, are found here and are the reason behind the significant limitation or abandonment of agricultural production. This is, at the same time, influenced by the proximity of Warsaw, which is an attractive job market. Prior to ceasing plant production at the beginning of the 90s, mainly rye and potatoes had been grown here. Currently, part of the site is covered by self-sown Scots pine (*Pinus sylvestris* L.) 80%, silver birch (*Betula pendula Roth)* 15%, and aspen poplar *(Populus tremula* L.*)*. Grasses, blackberry (*Rubus* L.), wood club-rush (*Scirpus sylvaticus* L.*)*, and European goldenrod (*Solidago virgaurea* L.) are found in the poorly developed undergrowth. The drainage system has been overgrown and has undergone partial degradation. The land is flat, with local denivelations of approx. 5–10 cm. This leads to long-term high soil moisture content, usually in Spring, with the level of the water table at 5–10 cm below the surface in a formerly arable area. In the Summer, upon the falling of the water table, the soil becomes more susceptible to drought. On part of the site of the same soil unit, the land remains under arable use. The study was carried out at two points. The first was located in a formerly arable area (Site 1, N 52°28′28.21″ and E 21°21′72.78″), while the latter remains under active extensive agricultural use (Site 2, N 52°28′39.52″ and E 21°52′29.16″). All samples were collected from the top layer (horizon A, 0–10 cm) during a wet period at the beginning of April 2018. At this term, soil moisture content was approximately at the level of field capacity.

2.2. Evaluation of Soil Water Repellency

The soil water repellency (SWR) was determined using the water drop penetration time (WDPT) test. This test is the most widespread [5,16] and the most suitable [40] method, as it is relatively simple and cheap. In order to determine the potential SWR value, the soil samples were dried at room temperature (20 °C) to a constant weight. Triplicate samples of about 20 g of soil were placed in Petri dishes and 5 drops (the volume of water in a droplet was equal to 60 μL), using a standard medicine dropper, of distilled water were deposited onto smoothed soil samples. The sample surfaces were gently smoothed by hand for these tests. The median values of the WDPT test were used to assess the SWR class. The classification of SWR presented in Table 1 was proposed by Dekker and Jungerius [41] and comprises up to 5 classes, further subdividing the extremely repellent class into 2 classes [16]. In order to establish the relationship between soil moisture content and SWR, the WDPT test was performed for different moisture contents that had been adjusted by equilibrating the material at 7 pF levels (i.e., 2.0, 2.3, 2.7, 3.0, 3.3, 3.7, 4.2) in triplicate on undisturbed soil samples (100 cm^3).

Table 1. Classification of soil water repellency using the water drop penetration time (WDPT) test., Dekker et al. [16,41].

Classification	Threshold WDPT Test	Class
Hydrophilic	≤5 s	0
Slightly water repellent	5–60 s	1
Strongly water repellent	60–600 s	2
Severely water repellent	600 s–1 h	3
Extremely water repellent	1–3 h	4
Extremely water repellent	3–6 h	5
Extremely water repellent	>6 h	6

2.3. Determination of Basic Physical and Chemical Properties of Soil

The particle size distribution was assessed using the Bouyoucos method with modifications by Casagrande and Prószyński (the aerometric method) for particles smaller than 0.1 mm, and the sieve method for particles larger than 0.1 mm [42]. The bulk density was assessed by dividing the core samples at 105 °C. Measurement of this parameter was conducted in five replicates. Total porosity (p) was calculated as $= 1 - \frac{\rho_b}{\rho_s}$, where ρ_b is the dry bulk density of the soil (kg m^{-3}) and ρ_s is the particle density assumed to be 2650 kg m^{-3}. Soil pH was measured in a 1:5 soil:water suspension using a standard potentiometric method. Organic carbon content was determined using Tiurin's method [43], with total carbon measured with the Kjeldahl method (Kjeltec–Tecator analyser). Measurements of pH, organic carbon, and total nitrogen were done in triplicates.

2.4. Determination of Soil Hydraulic Properties

Soil moisture retention characteristics were measured in a laboratory in triplicate on undisturbed soil samples (100 cm^3) using a reference method [44]. The saturation of soil to its full water-holding capacity was carried out in laboratory for three days by gradually increasing the water table upwards from the bottom of each sample. The moisture content values of pF between 0.4 and 2.0 were determined in a standard sand box, whereas the amounts of water at pF 2.3, 2.7, 3.4, and 4.2 were measured in pressure chambers. Laboratory measured saturated hydraulic conductivity (K_s) was determined by the constant head method. Metal cores (7.3 cm diameter, 6 cm height) were used to collect undisturbed samples of soil. In the laboratory, the samples were saturated with water from bottom up (capillary rise) for 3 days prior to measurements. The amount of surface runoff was tested on disturbed samples in the laboratory, maintaining a bulk density (ρ_s) similar to the natural one. A rainfall intensity of 2 mm lasting 420 min., which corresponds to a total dose of 14 mm, at a terrain slope of 5‰, was simulated. Surface runoff was captured by an open drain located on the border of the tested microplot, perpendicularly to the slope. Next, water was directed to a measurement tank, where registration of the volume of surface runoff was carried out every 30 min.

3. Results

3.1. Basic Soil Properties

Basic physical and chemical properties of soil are presented in Table 2. According to the USDA classification [45], the analyzed soil was classified as fine sand. Soil bulk density and total porosity were practically the same at the post-arable site and the site remaining under extensive arable use. However, formerly arable land was characterized by a lower (pH = 4.7) than soil of the same complex still under cultivation (pH = 5.3). Soil organic carbon content also varied, amounting to 1.25% in the surface layer of formerly arable land (0–10 cm), as compared to cultivated soil (0.89%).

Table 2. Basic properties of genetic horizon A (0–10 cm) of soil of the two study sites, (± = standard deviation).

Characteristic	Site 1 Forest (after Arable Usage)	Site 2 Extensive Arable Usage
Sand (%)	94	94
Silt (%)	4	4
Clay (%)	2	2
Soil bulk density, n = 5 (kg m^{-3})	151040.1	1490 ± 45.2
Total porosity, n = 5 (%)	43.01 ± 0.16	43.8 ± 1.7
Soil organic carbon n = 3 (%)	1.25 ± 0.19	0.89 ± 0.13
Nitrogen total n = 3 (%)	0.0939 ± 0.0007	0.0676 ± 0.0003
C:N	13.3	13.2
pH (H_20) n = 3 (−)	4. 7 ± 0.1	5.3 ± 0.1

3.2. Saturated Hydraulic Conductivity and Water Retention

Samples taken from the surface layer of soil (genetic horizon A) were characterized by soil moisture content similar to that of field capacity at the time of sampling, at which the analyzed soil was wettable (Class 0). The obtained soil saturation was 0.98 ± 0.01 of total porosity. For Site 1, the average value of saturated hydraulic conductivity for n = 6 was $K_s = 2.66 \times 10^{-5} \pm 0.45 \times 10^{-5}$ ms^{-1} at a coefficient of variation v = 16.9%, and for site 2: $K_s = 3.44 \times 10^{-5} \pm 0.66 \times 10^{-5}$ ms^{-1}, v = 19.2%. The obtained conductivity results were similar to those provided in literature for albic Podzols [46,47], and the coefficients of variation indicate low variability of data. Extensive research on the saturated soil conductivity under conditions of abandonment of agricultural use was conducted by Di Prima et al. [48] and methods, with a characterization based exclusively on a stabilized infiltration process, yielded also an appreciably low variability of the conductivity results. The pF curves measured for both sites (Figure 1), as well as saturated water conductivity K_s, did not vary by the manner of soil use. The total water content available to plants indicated from the retention curve was 0.13 cm^3 cm^{-3}.

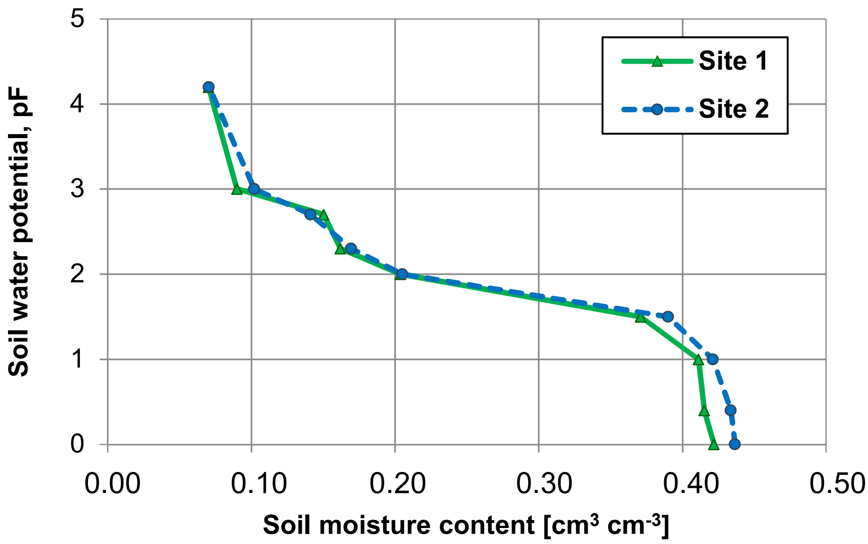

Figure 1. pF curves for post-arable land site (Site 1) and site under arable use (Site 2).

3.3. Assessment of Soil Water Repellency

The basic statistic measures of potential water repellency for the n = 15 number of replicates are presented in Table 3. The median of measured WDPT values for Site 1 was 17,700 s, which classifies Site 1 as an extremely repellent class (Class 5). The measured extreme WDPT values were max = 19,200 s and WDPT min = 16,080 s, which also belong to Class 5. The median of measured WDPT values for Site 2 was 90 s, which classifies the soil as being strongly repellent (Class 2). The maximum value was 284 s which still was Class 2, while the minimum value of 38 s belongs to Class 1 (slightly water repellent).

The relationship between soil water potential (in terms of pF) and the share of WDPT classes found for the respective soil water potential is presented in Figure 2. With rising pressure heads, SWR increased significantly in both A horizons. In the case of low soil water tension up to field capacity on Site 1 and up to pF = 3.0 on Site 2, the soils were wettable. At higher pF the soil became increasingly repellent with decreasing soil moisture content.

The critical moisture content for repellency (CSMC), delivered from the relationship between WDPT and soil water potential, on the site formerly under arable use was 0.16–0.14 $cm^3\ cm^{-3}$ which corresponds to pF = 2.3–2.7. At the same time, the value of CSMC for extensive arable use was 0.10–0.09 $cm^3\ cm^{-3}$, which corresponds to a pF = 3.0–3.3.

Table 3. Values of potential soil water repellency as derived from water drop penetration time (WDPT) test under forest following arable use (Site 1) and under arable use (Site 2), n = 15.

WDPT Characteristic	Site 1	Site 2
Median (s)	17,700	90
Average (s)	17,760	123
Max (s)	19,200	284
Min (s)	16,080	38
Range (s)	3120	246

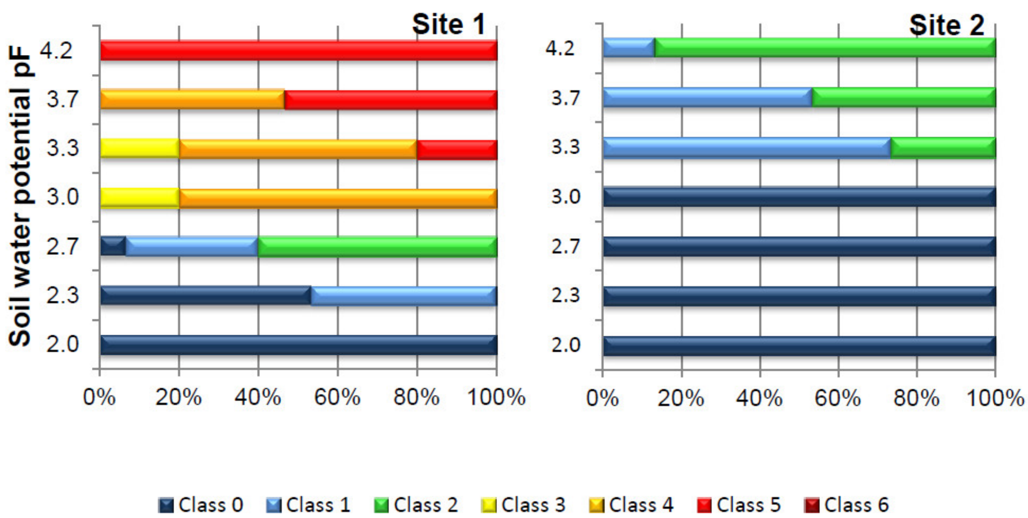

Figure 2. Soil water repellency, in terms of WDPT classes [16], of the A horizons of Site 1 and Site 2, as a function of soil water potential in terms of pF.

3.4. Surface Runoff in Soil Formerly under Arable Use

Taking into account the extreme potential SWR of the Site 1 A horizon, surface runoff was analyzed with this material. A visualization of the wetting of the soil surface is presented in Figure 3. What is characteristic is the uneven wetting of the surface. Soil surfaces of high moisture content, from which surface runoff takes place, as well as completely dry surfaces are noticeable. The thickness of the wetted layer after completion of the experiment was approximately 5 mm, while the soil below was completely dry. The course of runoff during the experiment is presented in Figure 4. The measured total runoff was 6.72 mm, meaning that, of the total rainfall, the soil retained merely 48%. The obtained results of surface runoff confirm that high water repellency can significantly affect the agrohydrological regime. It can significantly decrease the amount of water available to plants, causing increased susceptibility to drought, accelerated mineralization of organic substances, and additional CO_2 emissions [21,49].

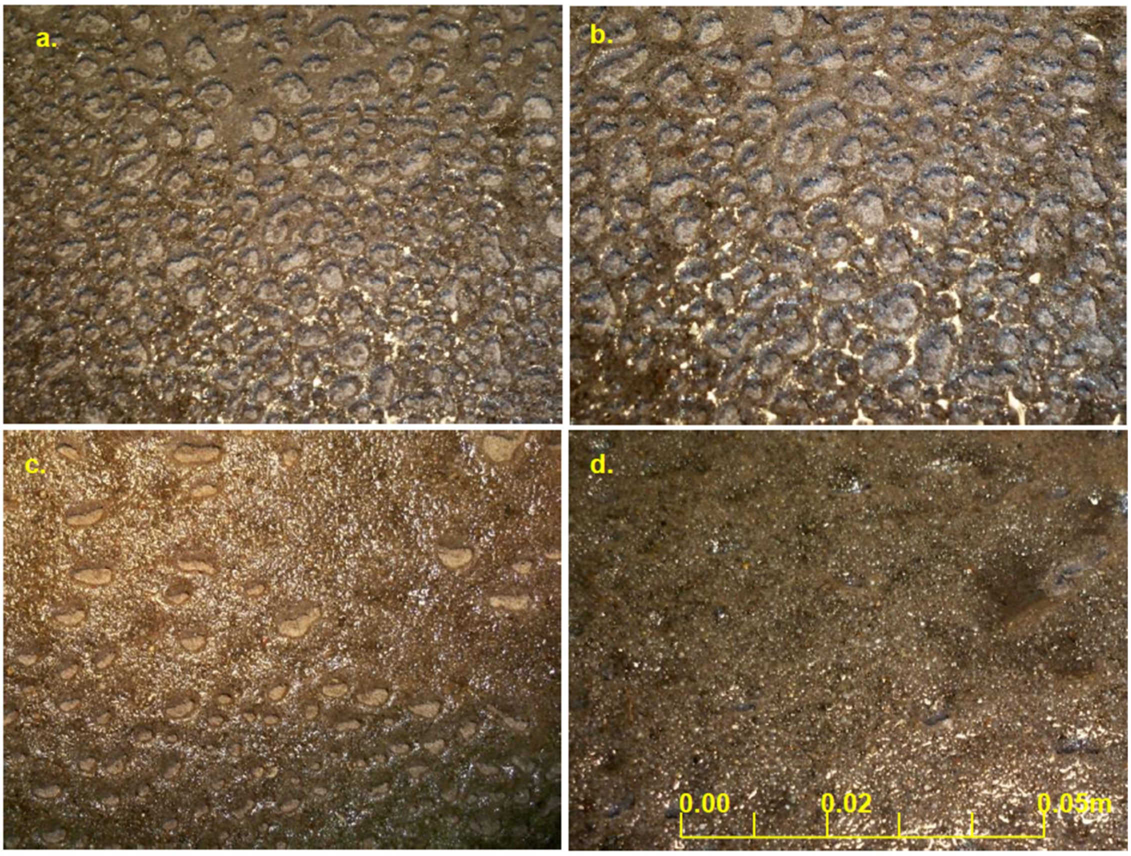

Figure 3. Visualization of wetted surface area over time during simulated rainfall, Site 1: (**a**) after 1 h; (**b**) after 2 h; (**c**) after 4 h; and (**d**) after 7 h.

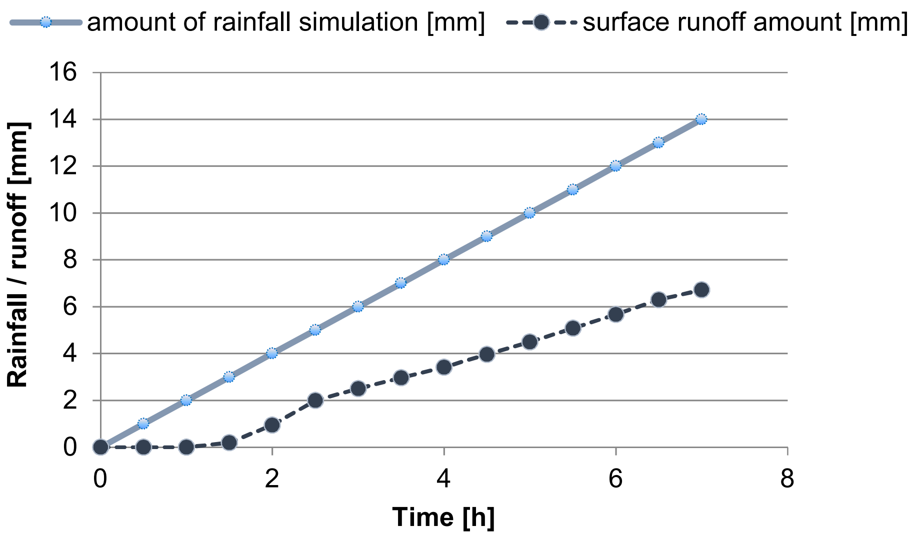

Figure 4. Course of rainfall and surface runoff caused by soil water repellency (Site 1).

4. Discussion

Global warming is causing severe soil droughts to occur more and more often in the continental climate [50–52]. Thus, risk connected with the occurrence of water repellency increases, especially in sandy soils. This contributes, especially, to increasing surface runoff and decreasing periodical soil water retention [53,54]. The degree of retention capabilities of forest soils are much less known than the retention of land used for agriculture [55,56]. On the other hand, pedotransfer functions have a local nature, as a result of which differences in precision of retention assessment may be significant [57]. Additionally, the development of a new methodology to compare the connectivity processes at the catchment with the pedon scale indicates the possibility of allowing inclusion of the absent micro-topographical information (e.g., [58]). Abandoning agricultural production on soils characterized by low productivity potential and their transformation into forests is economically and environmentally ratified, but should be preceded by an individual analysis of each case. The study site was characterized by a low nitrogen content, typical of albic Podzols. The soil organic content (SOC) content (1.25%) was significantly higher on the post-arable site, spontaneously afforested with a dominance of pine, in relation to cultivated soil (0.89%). Sibielec et al. [59], on the base of many-year studies, states that sandy soils in Poland contain SOC in a range from 1.01% to 2% in 63% of their data set. The C:N ratio for both sites was the same and amounted to 13.3–13.2, similar to average for sandy soils in Poland. Abandoning arable use along with changes in the air–water ratios lead resulted in a decrease in pH, from acidic to highly acidic. Afforestation with *Pinus sylvestris* (80%) also affected the SOC composition, enriching the soil in waxes [26,28]. Many authors (e.g., [17,18,60]) indicate waxes as one of the reasons for the water repellency of forest soils. The strongest SWR under thicker layers of litter was reported by Buczko et al. [17,61], and the authors [61] suggested that it is caused by the changing chemistry of the soil organic matter, along with depth, and/or varied bonding of this organic matter to the soil particles.

The deposit of organic matter in the soil on Site 1 is dominated by *Pinus silvestris* trees, its decomposition and penetration into A horizon is the most likely cause for the observed distinct water repellency, as indicated from the WDPT test. A very distinct difference in water repellency was; however, observed in the surface layer of soil between the two sites. The reduction in organic matter content due to soil tillage promotes the reduction in repellency by reducing the CSMC, beyond which hydrophobic soils become hydrophilic as well as persistence of water repellency [62]. Repellency on the post-arable site occurred during drought, that is at higher moisture content than on the site under arable use. Critical soil moisture content (CSMC) for the occurrence of water repellency in post-arable, afforested land was 0.14–0.16 cm cm^{-3}, as compared to 0.09–0.10 cm cm^{-3} in arable soil. Here, increased CSMC and distinct increase in water repellency on the afforested post-arable site was classified in Class 5 (i.e., extremely repellent), while arable soil was found to fall into Class 2 (i.e., strongly water repellent).

In literature on the subject, variability in CSMC values can be found in relation to the type of soil (i.e., 2% for dune sand [63], 9.3%–15% for sand [64], 14%–27% for loamy sand [19], 3%4–38.5% for clayey peat [65], 41%–49% for moorsh formations, 64%–69% for alder peats, and 83%–86% in reed peats [20]). CSMC results obtained in this study confirm the reports presented by Ziogas et al. [64] for sandy soils.

On the other hand, in the analyzed case, increasing the values of CSMC and the high increase in water repellency occurred as a result of abandoning agricultural production and the succession of forest vegetation with a dominance of pine. The hydrological consequences of SWR have also been indicated by other authors [66–72]. According to studies of Butzen et al. [73] on coniferous forest sites in Germany, water repellency effects were an important factor triggering overland flow generation. For the post-agricultural site, from the experiment with simulated rainfall, a surface runoff of 50% was indicated. Despite simplifications in reflecting field conditions (e.g., the lack of vegetation), the obtained results indicate the direction of changes in the rainfall–runoff relationship when the phenomenon of water repellency occurs. Water repellency was characterized by seasonality, which was also observed by Buczko et al. [17,18], Leighton-Boyce et al. [26], and Hewelke et al. [11,15]. On the analyzed site, the soil was wettable in the period of early spring, whereas the phenomenon of water repellency occurred after a longer period without rainfall. The persistency and the severity of water repellency is decisive to the shaping of the dynamics of soil moisture content and requires further research.

5. Conclusions

The present study confirmed that abandoning arable use and allowing for spontaneous afforestation with the succession of pine had a negative influence on soil hydraulic properties. Changes in use led to a decrease in the CSMC and a significant increase in water repellency. The basic strategy of preventing water repellency, and its consequences, is maintaining an adequately high moisture content of soil. In the case of excluding land from agricultural production, its afforestation with a dominance of pine should not be allowed, and introducing, rather, a mixed stand of trees, appropriate for the soil type and climate conditions, should be considered. It should be kept in mind that progressing climate change and the increased frequency of the occurrence of soil droughts may lead to an increased significance of water repellency in the water management of soils. The overview of studies on water repellency, caused by both natural as well as anthropogenic factors, indicates that it ought to be treated as one of the indicators of soil quality, with the present work indicating the linkages of soil properties to ecosystem services and to UN sustainable goals for development.

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References

1. Czachor, H.; Flis-Bujak, M.; Ksiezpolska, A.; Niewczas, J.; Falski, M. Analysis of factors affecting the wettability of mineral soils. *Acta Agrophys*. **2009**, *2*, 84.
2. Goebel, M.O.; Bachmann, J.; Reichstein, M.; Janssens, I.A.; Guggenberger, G. Soil water repellency and its implications for organic matter decomposition—Is there a link to extreme climatic events? *Glob. Chang. Biol.* **2011**, *17*, 2640–2656.
3. Franco, C.M.M.; Michelsen, P.P.; Oades, J.M. Amelioration of water repellency: Application of slow-release fertilisers to stimulate microbial breakdown of waxes. *J. Hydrol.* **2000**, *231*, 342–351.
4. Franco, C.M.M.; Tate, M.E.; Oades, J.M. Studies on non-wetting sands. 1. The role of intrinsic particulate organic-matter in the development of water-repellency in non-wetting sands. *Soil Res.* **1995**, *33*, 253–263.
5. Doerr, S.H.; Shakesby, R.A.; Walsh, R. Soil water repellency: Its causes, characteristics and hydro-geomorphological significance. *Earth-Sci. Rev.* **2000**, *51*, 33–65.
6. Lachacz, A.; Nitkiewicz, M.; Kalisz, B. Water repellency of post-boggy soils with a various content of organic matter. *Biologia* **2009**, *64*, 634–638.
7. Moody, J.A.; Kinner, D.A.; Úbeda, X. Linking hydraulic properties of fire-affected soils to infiltration and water repellency. *J. Hydrol.* **2009**, *379*, 291–303.
8. Certini, G. Effects of fire on properties of forest soils: A review. *Oecologia* **2005**, *143*, 1–10.
9. Granged, A.J.; Jordán, A.; Zavala, L.M.; Bárcenas, G. Fire-induced changes in soil water repellency increased fingered flow and runoff rates following the 2004 Huelva wildfire. *Hydrol. Process.* **2011**, *25*, 1614–1629.
10. Bogacz, A.; Łabaz, B.; Woźniczka, P. Impact of fire on values of organic material transformation Indicators. *Rocz. Glebozn. Soil Sci. Annu.* **2013**, *64*, 88–92.
11. Hewelke, E.; Oktaba, L.; Gozdowski, D.; Kondras, M.; Olejniczak, I.; Górska, E.B. Intensity and persistence of soil water repellency in pine forest soil in a temperate continental climate under drought conditions. *Water* **2018**, *10*, 1121.
12. Adams, R.H.; Osorio, F.G.; Cruz, J.Z. Water repellency in oil contaminated sandy and clayey soils. *Int. J. Environ. Sci. Technol.* **2008**, *5*, 445–454.
13. Takawira, A.; Gwenzi, W.; Nyamugafata, P. Does hydrocarbon contamination induce water repellency and changes in hydraulic properties in inherently wettable tropical sandy soils? *Geoderma* **2014**, *235*, 279–289.
14. Klamerus-Iwan, A.; Błońska, E.; Lasota, J.; Kalandyk, A.; Waligórski, P. Influence of oil contamination on physical and biological properties of forest soil after chainsaw use. *Water Air Soil Pollut.* **2015**, *226*, 389.
15. Hewelke, E.; Szatyłowicz, J.; Hewelke, P.; Gnatowski, T.; Aghalarov, R. The Impact of Diesel Oil Pollution on the Hydrophobicity and CO_2 Efflux of Forest Soils. *Water Air Soil Pollut.* **2018**, *229*, 51.

16. Dekker, L.W.; Ritsema, C.J.; Oostindie, K.; Moore, D.; Wesseling, J.G. Methods for determining soil water repellency on field-moist samples. *Water Resour. Res.* **2009**, *45*, doi:10.1029/2008WR007070.
17. Buczko, U.; Bens, O.; Hüttl, R.F. Variability of soil water repellency in sandy forest soils with different stand structure under Scots pine (*Pinus sylvestris*) and beech (*Fagus sylvatica*). *Geoderma* **2005**, *126*, 317–336.
18. Buczko, U.; Bens, O.; Hüttl, R.F. Changes in soil water repellency in a pine–beech forest transformation chronosequence: Influence of antecedent rainfall and air temperatures. *Ecol. Eng.* **2007**, *31*, 154–164.
19. Leighton-Boyce, G.; Doerr, S.H.; Shakesby, R.A.; Walsh, R.P.D.; Ferreira, A.J.D.; Boulet, A.K.; Coelho, C.O.A. Temporal dynamics of water repellency and soil moisture in eucalypt plantations, Portugal. *Aust. J. Soil Res.* **2005**, *43*, 269–280.
20. Hewelke, E.; Szatyłowicz, J.; Gnatowski, T.; Oleszczuk, R. Effects of soil water repellency on moisture patterns in a degraded Sapric Histosol. *Land Degrad. Dev.* **2016**, *27*, 955–964.
21. Urbanek, E.; Doerr, S.H. CO_2 efflux from soils with seasonal water repellency. *Biogeosciences* **2017**, *14*, 4781–4794.
22. Imeson, A.C.; Verstraten, J.M.; Van Mulligen, E.J.; Sevink, J. The effects of fire and water repellency on infiltration and runoff under Mediterranean type forest. *Catena* **1992**, *19*, 345–361.
23. Harper, R.J.; McKissock, I.; Gilkes, R.J.; Carter, D.J.; Blackwell, P.S. A multivariate framework for interpreting the effects of soil properties, soil management and landuse on water repellency. *J. Hydrol.* **2000**, *231*, 371–383.
24. Mataix-Solera, J.; Arcenegui, V.; Guerrero, C.; Mayoral, A.M.; Morales, J.; González, J.; García-Orenes, F.; Gómez, I. Water repellency under different plant species in a calcareous forest soil in a semiarid Mediterranean environment. *Hydrol. Process.* **2007**, *21*, 2300–2309.
25. Zavala, L.M.; González, F.A.; Jordán, A. Intensity and persistence of water repellency in relation to vegetation types and soil parameters in Mediterranean SW Spain. *Geoderma* **2009**, *152*, 361–374.
26. Lichner, L.; Holko, L.; Zhukova, N.; Schacht, K.; Rajkai, K.; Fodor, N.; Sándor, R. Plants and biological soil crust influence the hydrophysical parameters and water flow in an aeolian sandy soil. *J. Hydrol. Hydromech.* **2012**, *60*, 309–318.
27. Orfánus, T.; Dlapa, P.; Fodor, N.; Rajkai, K.; Sándor, R.; Nováková, K. How severe and subcritical water repellency determines the seasonal infiltration in natural and cultivated sandy soils. *Soil Tillage Res.* **2014**, *135*, 49–59.
28. Prusinkiewicz, Z.; Kosakowski, A. The wettability of soil organic matter as the forming factor of the water properties of forest soils. *Rocz. Glebozn.-Soil Sci. Annu.* **1986**, *37*, 3–23.
29. Pudełko, R.; Kozak, M.; Jędrejek, A.; Gałczyńska, M.; Pomianek, B. Regionalisation of unutilised agricultural area in Poland. *Polish J. Soil Sci.* **2018**, *51*, 119.
30. Navarro, L.M.; Pereira, H.M. Rewilding abandoned landscapes in Europe. In *Rewilding European Landscapes*; Springer: Cham, Switzerland, 2015; pp. 3–23.
31. Verburg, P.H.; Overmars, K.P. Combining top-down and bottom-up dynamics in land use modeling: Exploring the future of abandoned farmlands in Europe with the Dyna-CLUE model. *Landsc. Ecol.* **2009**, *24*, 1167–1181.
32. Schwilch, G.; Lemann, T.; Berglund, Ö.; Camarotto, C.; Cerdà, A.; Daliakopoulos, I.N.; Kohnová, S.; Krzeminska, D.; Marañón, T.; Rietra, R.; et al. Assessing impacts of soil management measures on Ecosystem Services. *Sustainability* **2018**, *10*, 4416.
33. Borecki, T.; Łopiński, Ł.; Kędziora, W.; Orzechowski, M.; Wójcik, R.; Stępień, E. The Concept of Regulating Forest Management in a Region Subject to High Environmental Pressure. *Forests* **2018**, *9*, 539.
34. Borecki, T.; Orzechowski, M.; Stępień, E.; Wójcik, R. Expected impact of climate change on forest ecosystems and its consequences in forest management planning. *Sylwan* **2017**, 161, 531–*538*.
35. Keesstra, S.; Mol, G.; de Leeuw, J.; Okx, J.; de Cleen, M.; Visser, S. Soil-related sustainable development goals: Four concepts to make land degradation neutrality and restoration work. *Land* **2018**, *7*, 133.
36. Griggs, D.; Stafford-Smith, M.; Gaffney, O.; Rockström, J.; Öhman, M.C.; Shyamsundar, P.; Steffen, W.; Glaser, G.; Kanie, N.; Noble, I. Policy: Sustainable development goals for people and planet. *Nature* **2013**, *495*, 305–307.
37. Steffen, W.; Richardson, K.; Rockström, J.; Cornell, S.E.; Fetzer, I.; Bennett, E.M.; Biggs, R.; Carpenter, S.R.; de Vries, W.; de Wit, C.A.; et al. Planetary boundaries: Guiding human development on a changing planet. *Science* **2015**, *347*, 1259855.

38. Keesstra, S.; Nunes, J.P.; Saco, P.; Parsons, T.; Poeppl, R.; Masselink, R.; Cerdà, A. The way forward: Can connectivity be useful to design better measuring and modelling schemes for water and sediment dynamics? *Sci. Total Environ.* **2018**, *644*, 1557–1572.
39. IUSS Working Group WRB. *World Reference Base for Soil Resources 2014, Update 2015 International Soil Classification System for Naming Soils and Creating Legends for Soil Maps*; World Soil Resources Reports No. 106; IUSS: Austria Vienna, 2015; p. 192.
40. Papierowska, E.; Matysiak, W.; Szatyłowicz, J.; Debaene, G.; Urbanek, E.; Kalisz, B.; Łachacz, A. Compatibility of methods used for soil water repellency determination for organic and organo-mineral soils. *Geoderma* **2018**, *314*, 221–231.
41. Dekker, L.W.; Jungerius, P.D. Water repellency in the dunes with special reference to The Netherlands. *Catena* **1990**, *18*, 173–183.
42. Ryżak, M.; Bartminski, P.; Bieganowski, A. Method for determination of particle size distribution of mineral soils. *Acta Agrophys.* **2009**, *175*, 1–84.
43. Lityński, T.; Jurkowska, H.; Gorlach, E. *Chemical and Agriculture Analysis*; PWN: Warszawa, Poland, 1976; pp. 129–132.
44. Klute, A. *Methods of Soil Analysis. Part 1. Physical and Mineralogical Methods. Agronomy Monographs*; ASA and SSA, A. Klute: Madison, WI, USA, 1986; Volume 9.
45. Soil Survey Division Staff. *Soil Survey Manual*; United States Department of Agriculture: Washington, DC, USA, 1993; p. 315.
46. Buczko, U.; Bens, O.; Huttl, R.F. Water infiltration and hydrophobicity in forest soils of a pine–beech transformation chronosequence. *J. Hydrol.* **2006**, *331*, 383–395.
47. Lichner, Ľ.; Capuliak, J.; Zhukova, N.; Holko, L.; Czachor, H.; Kollár, J. Pines influence hydrophysical parameters and water flow in a sandy soil. *Biologia* **2013**, *68*, 1104–1108.
48. Di Prima, S.; Lassabatere, L.; Rodrigo-Comino, J.; Marrosu, R.; Pulido, M.; Angulo-Jaramillo, R.; Úbeda, X.; Keesstra, S.; Cerdà, A.; Pirastru, M. Comparing transient and steady-state analysis of single-ring infiltrometer data for an abandoned field affected by fire in Eastern Spain. *Water* **2018**, *10*, 514.
49. Tezza, L.; Vendrame, N.; Pitacco, A. Disentangling the carbon budget of a vineyard: The role of soil management. *Agric. Ecosyst. Environ.* **2019**, *272*, 52–62.
50. Boczoń, A.; Kowalska, A.; Dudzińska, M.; Wróbel, M. Drought in Polish Forests in 2015. *Polish J. Environ. Stud.* **2016**, *25*, 1857–1862.
51. Stojanovic, M.; Drumond, A.; Nieto, R.; Gimeno, L. Anomalies in Moisture Supply during the 2003 Drought Event in Europe: A Lagrangian Analysis. *Water* **2018**, *10*, 467.
52. Koutroulis, A.G.; Papadimitriou, L.V.; Grillakis, M.G.; Tsanis, I.K.; Wyser, K.; Betts, R.A. Freshwater vulnerability under high end climate change. A pan-European assessment. *Sci. Total Environ.* **2018**, *613*, 271–286.
53. Ferreira, C.S.S.; Walsh, R.P.D.; Shakesby, R.A.; Keizer, J.J.; Soares, D.; González-Pelayo, O.; Ferreira, A.J.D. Differences in overland flow, hydrophobicity and soil moisture dynamics between Mediterranean woodland types in a peri-urban catchment in Portugal. *J. Hydrol.* **2016**, *533*, 473–485.
54. Rye, C.F.; Smettem, K.R.J. The effect of water repellent soil surface layers on preferential flow and bare soil evaporation. *Geoderma* **2017**, *289*, 142–149.
55. Hewelke, P.; Gnatowski, T.; Hewelke, E.; Tyszka, J.; Zakowicz, S. Analysis of Water Retention Capacity for Select Forest Soils in Poland. *Polish J. Environ. Stud.* **2015**, *24*, 1013–1019.
56. Hewelke, P.; Hewelke, E.; Chołast, S.; Żakowicz, S.; Lesak, M. Assessment of the possibility of applying selected pedotransfer functions for indicating the retention of forest soils in Poland. *Sci. Rev. Eng. Environ. Sci.* **2017**, *26*, 336–345.
57. Hewelke, P.; Hewelke, E.; Oleszczuk, R.; Kwas, M. The application of pedotransfer functions in the estimation of water retention in alluvial soils in Żuławy Wiślane, northern Poland. *Soil Sci. Annu.* **2018**, *69*, 3–10.
58. Rodrigo Comino, J.; Keesstra, S.D.; Cerdà, A. Connectivity assessment in Mediterranean vineyards using improved stock unearthing method, LiDAR and soil erosion field surveys. Earth Surface *Process. Landf.* **2018**, *43*, 2193–2206.

59. Siebielec, G.; Smreczak, B.; Klimkowicz-Pawlas, A.; Kowalik, M.; Kaczyński, R.; Koza, P.; Ukalska-Jaruga, A.; Łysiak, M.; Wójtowicz, U.; Poręba, L.; et al. *Report on the Third Phase of the Contract "Monitoring of Arable Soil Chemistry in Poland in 2015–2017"*; IUNG-PIB: Puławy, Poland, 2017; p. 190.
60. Orfánus, T.; Bedrna, Z.; Lichner, L.; Hallet, P.D.; Kňava, K.; Sebíň, M. Spatial variability of water repellency in pine forest soil. *Soil Water Res.* **2008**, *3*, 123–129.
61. Buczko, U.; Bens, O.; Fischer, H.; Hüttl, R.F. Water repellency in sandy luvisols under different forest transformation stages in northeast Germany. *Geoderma* **2002**, *109*, 1–18.
62. Vogelmann, E.S.; Reichert, J.M.; Prevedello, J.; Consensa, C.O.B.; Oliveira, A.É.; Awe, G.O.; Mataix-Solera, J. Threshold water content beyond which hydrophobic soils become hydrophilic: The role of soil texture and organic matter content. *Geoderma* **2013**, *209*, 177–187.
63. Dekker, L.W.; Doerr, S.H.; Oostindie, K.; Ziogas, A.K.; Ritsema, C.J. Water repellency and critical soil water content in a dune sand. *Soil Sci. Soc. Am. J.* **2001**, *65*, 1667–1674.
64. Ziogas, A.K.; Dekker, L.W.; Oostindie, K.; Ritsema, C.J. Soil water repellency in north-eastern Greece with adverse effects of drying on the persistence. *Soil Res.* **2005**, *43*, 281–289.
65. Dekker, L.W.; Ritsema, C.J. Variation in water content and wetting patterns in Dutch water repellent peaty clay and clayey peat soils. *Catena* **1996**, *28*, 89–105.
66. Cerdà, A.; Doerr, S.H. Soil wettability, runoff and erodibility of major dry-Mediterranean land use types on calcareous soils. *Hydrol. Process*. **2007**, *21*, 2325–2336.
67. Miyata, S.; Kosugi, K.I.; Gomi, T.; Onda, Y.; Mizuyama, T. Surface runoff as affected by soil water repellency in a Japanese cypress forest. *Hydrol. Process. Int. J.* **2007**, *21*, 2365–2376.
68. Neris, J.; Tejedor, M.; Rodríguez, M.; Fuentes, J.; Jiménez, C. Effect of forest floor characteristics on water repellency, infiltration, runoff and soil loss in Andisols of Tenerife (Canary Islands, Spain). *Catena* **2013**, *108*, 50–57.
69. Olorunfemi, I.E.; Fasinmirin, J.T. Land use management effects on soil hydrophobicity and hydraulic properties in Ekiti State, forest vegetative zone of Nigeria. *Catena* **2017**, *155*, 170–182.
70. Hejduk, L.; Hejduk, A.; Baryła, A.; Hewelke, E. Influence of selected factors on erodibility in catchment scale on the basis of field investigation. *J. Ecol. Eng.* **2017**, *18*, 256–267.
71. Cerdà, A.; Rodrigo-Comino, J.; Novara, A.; Brevik, E.C.; Vaezi, A.R.; Pulido, M.; Giménez-Morera, A.; Keesstra, S.D. Long-term impact of rainfed agricultural land abandonment on soil erosion in the Western Mediterranean basin. *Prog. Phys. Geogr. Earth Environ.* **2018**, *42*, 202–219.
72. Mao, J.; Nierop, K.G.; Dekker, S.C.; Dekker, L.W.; Chen, B. Understanding the mechanisms of soil water repellency from nanoscale to ecosystem scale: A review. *J. Soils Sediments* **2019**, *19*, 1–15.
73. Butzen, V.; Seeger, M.; Marruedo, A.; de Jonge, L.; Wengel, R.; Ries, J.B.; Casper, M.C. Water repellency under coniferous and deciduous forest—Experimental assessment and impact on overland flow. *Catena* **2015**, *133*, 255–265.