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Water repellency as conditioned by physical and chemical parameters in grassland soil

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ABSTRACT

The occurrence and consequences of soil water repellency (SWR) have been reported in many parts of the world, but little is known on the reasons and mechanisms of SWR in grasslands. Although considerable advances have been made in the past 10 years in understanding the impact of hydrophobic organic compounds on water repellency, there is still a considerable amount to be learnt. Of particular importance is the interaction between soil chemical characteristics and SWR in soil. The research gaps and seeks to understand how soil water repellency in grasslands of Inner Mongolia is influenced by soil chemical properties. The SWR of soil samples ($n = 80$) at the surface of the grassland (0–10 cm) collected in Xi Linhot was measured using the Water Drop Penetration Time Test (WDPT), and the relationship between soil chemical properties (e.g. soil organic matter, SOM) and SWR was studied in grassland soils. Results showed that SWR reached a peak value with an average of 80 s when the soil water content was 10.7%, the relationship between WDPT values and soil water contents showed a one-peak distribution. Soil water repellency increased exponentially with organic matter contents, total N, and available N and poorly correlated with carbonate, available P, available K and pH in grassland soils. Our results can provide the influencing factors of soil water repellency and promote soil amelioration.

1. Introduction

Soil water repellency (SWR) is a physical phenomenon that water cannot or hardly wet the soil surface of the mineral particles. As early as the 11th century, the Dutch found the phenomenon of soil water repellency in the reclamation of soil (Wallach and Jortzick, 2008). The most typical phenomenon of soil drought in the grassland called “mushroom circle” and “dry spots” was caused by water-repellent in fungal hyphae (Lozano et al., 2013). The typical steppe soils in Inner Mongolia, secondary salinized soils in Xinjiang, tropical soils in Xishuangbanna, *Pinus massoniana* forest soils, degraded sand land, and the arid valley of the upper Minjiang River existed water repellent in different extent (Zhang et al., 2014; Qin et al., 2012; Yang et al., 2012; Li et al., 2010).

Australia and the United States are the earliest countries to study soil water repellency, and especially in Australia soil water repellency of the census and classification work has been carried out, and results showed that there is strong water repellency about 10 million hm^2 soil in western and southern Australia, with a trend of water repellent area increasing year by year (Doerr et al., 2005; Roper et al., 2013). Approximately 75% of the Netherlands agriculture has shown moderate or severe water repellency, and 95% of the natural topsoil shows water repellency (Goebel et al., 2011).

Water-repellent soils are widely distributed all over the world, from the tropics to sub-Arctic regions, including different soil types, different texture and soil organic matter (SOM) content, different parent materials, different clay mineralogical characteristics, different Vegetation types, different soil uses and management practices (Martínez-Murillo et al., 2013; González-Peñaloza et al., 2012). Links between hydrophobic compounds in soil and the development of water repellency have not been convincing. While Mainwaring et al. (2004) detected a greater abundance of high molecular mass polar compounds in water repellent soils. Work by Morley et al. (2003) showed that it was poorly related to water repellency. Although considerable advances have been made in the past 10 years in understanding the impact of hydrophobic organic compounds on water repellency, there is still a considerable amount to be learnt. Of particular importance is the interaction between chemical characters and SWR in soil. In a review summarizing remedies for SWR, Müller et al. (2011) suggested that a better understanding of the fundamental mechanisms of how and why SWR develops was needed.

In grasslands of Inner Mongolia, China, from June to the end of

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September, the soil moisture fluctuated because of the strong evaporation at this time (Chen and Wang, 2003). Soil texture, clay minerals, helps to decrease soil WR by coating hydrophobic surfaces (Ward and Oades, 1993), and soils containing 25–40% clay showed extreme WR (Dekker and Ritsema, 1996b). Study area is affected by banning grazing and over grazing that have resulted in more or less vegetation cover. We know that the majority of hydrophobic substances are released into soils, as exudate of roots (Doerr et al., 1998), organic residues in decomposition (McGhie and Posner, 1981) or excreted by fungi and other microorganisms (Schaumann et al., 2007). In all, soil moisture, soil texture, and soil hydrophobic substances could be mostly responsible for the water-repellent condition of certain soils (Rumpel et al., 2004; Lozano et al., 2013). In this paper, we conducted multivariate statistical analysis to address the urgent need of a more comprehensive in-depth understanding of the complex interplay of SWR and soil properties in grasslands of Inner Mongolia, China. Our multivariate statistical analysis focused on the relationship between SWR and soil water content, SOM, soil pH and also taking into account total Nitrogen, alkali hydrolyzable N, available phosphorus, available potassium. Hence, we specifically wanted to answer these questions: (1) is SWR correlated with soil properties? (2) do soil pH and soil water content affect SWR? (3) is SWR positively correlated to SOM?

2. Materials and methods

2.1. Study area

The study area is located in Xilinhot, Inner Mongolia. The geographical coordinates of the study area are 41° 40′ 38″ − 46° 12′ 02″ N and 114° 57′ 16″ − 1119° 38′ 57″ E (Table 1). The area is formed on the basalt platform gentle hilly valley, at an elevation of 1200–1250 m, a relative hill height of 20–30 m, and with the round top and long valley slope < 5°, bordering on the flat valley (http://ngcc.sbsm.gov.cn/). In general, the area is characterized by a temperate semi-arid grassland climate (mean annual precipitation 350 mm yr − 1; mean annual temperature 0.57 °C) (Wang et al., 2010), and land uses including grazing, banning grazing land, conventional tillage, and no tillage.

The highest precipitation for the year was 645 mm, the precipitation was mainly concentrated in July to September, the lowest precipitation was 182 mm, and the evaporation was 1600–1800 mm (http://www.nmgtj.gov.cn/nmgttj/index.htm).

Chestnut soil was the main soil type in this area, under different vegetation covers: *Lemus chinensis* (80% of the total biomass of the community), *S. gradis*, *Agropyron cristatum*, and *Cleistogenes squarrosa*, with grass group height of 50–60 cm and coverage from 30%–40% to 60%–70% in the rainy season. A significant accumulation of organic matter and calcium carbonate was observed in the upper part of the soil of the chestnut humus layer, the middle part of the gray calcareous layer, and the lower part of the weathered parent material layer. The humus layer thickness was generally in the range of 30–45 cm, and an organic matter content of 2.0%–4.0% (Wang et al., 2010). The texture was lighter, mostly consisting of sand and silt loam. The clay minerals were mainly montmorillonite and hydromica.

2.2. Soil sampling and sample preparation

Eighty site locations and characteristics of repellent and wettable control samples were sampled and summarized in Table 1. In August 2015, three sub-samples were taken from the 0–10 cm soil layers in each site at three locations (size 1 × 1 m), representing relative spatial consistency and homogeneity and mixed into a composite sample per site, which transported to the laboratory in sealed plastic bags. Before water repellency assessments, a composite sample was made for each site by thoroughly mixing the three sub-samples and sieved through a 2 mm sieve to remove gravel and other non-soil materials.

2.3. Water repellency assessments

After equilibrating the samples in a controlled atmosphere of 20 °C and 45–55% relative humidity for 24 h in order to avoid any influence of changing atmospheric conditions on measurement results (Doerr et al., 2002), water repellency was assessed using the Water Drop Penetration Time (WDPT) method. This test involves placing 5 drops of distilled water (80 μL) onto the sample surface and recording the time for complete droplet penetration (Letey, 1969). Repellency values were recorded according to distinct repellency classes and are based on the median class of the drops (Bisdom et al., 1993). According to Bisdom et al. (1993), soil samples were classified as wettable when the water drop infiltrated within 5 s, (class 1), slightly water repellent (5–60 s; class 2), strongly water repellent (60–600 s; class 3), severely water repellent (600–3600 s; class 4) and extremely water repellent (> 3600 s; class 5).

2.4. Physical and chemical analysis

Soil pH values in 1:1 ratio of soil to deionized water were measured by a Hachsens ION 1 pH meter, soil organic matter (SOM) by $K_2Cr_2O_7$–H_2SO_4 volumetric method, Total Nitrogen (TN, micro-Kjeldahl), available phosphorus (0.5 M $NaHCO_3$), and available potassium (NH_4OAc) using the methods described by Sparks et al. (1996), for carbonates (1.0 M HCL) was determined using the method described by Loeppert et al., 1984and for alkali hydrolyzable N (AH-N, NaOH) using the method described by Cornfield (1960).

2.5. WDPT in different soil sieve sizes

After drying the samples in a controlled atmosphere of 20 °C and 45–55% relative humidity for a week (Doerr et al., 2002), 30 samples were selected randomly and each composite sample was carefully divided in five sieve size fractions (0.5–2, 0.25–0.5, 0.15–0.25, 0.1–0.15, and < 0. 1 mm) by dry sieving. Then, water repellency was assessed using the Water Drop Penetration Time (WDPT) method described in Section 2.2.

Derived from a model for soil particle size distribution by Tyler and Wheatcraft (1992a), to soil sieve size, it appears more appropriate to investigate the soil texture in terms of mass, a more easily measured quantity. Soil sieve size fractal dimension is described as follows:

$$\frac{M\,(r < R)}{M_T} = \left(\frac{R}{R_L}\right)^{3\text{-}D} \tag{1}$$

where the sieves of size diameter *r* lower than a specific or adjacent measuring scale diameter, *R*. *M* and M_T are constants relating to the shape factors and total range of scale (mass), and *D* is the fractal dimension. R_L is the maximum diameter of the soil sieve size; when the sieve size is lower than 0.1 mm, *R* is assumed to be 0.1 mm.

For our studied soils in the textural triangle, the size of the fragments ranges from 2 mm to < 0.1 mm. For a given soil sample, one can expect to find the mass of solids to be distributed within this range. In, general, coarse-textured soils are more likely to have fragments of 2-mm size comprising a large percentage of the total mass, while fine-textured soils may have very little mass concentrated at the 2-mm size (Tyler and Wheatcraft, 1989, 1992b). In present study, for soils with coarsest fragments (coarse sand) at the 2-mm diameter, strict self-similar or scale-invariant behavior follows a path of texture from sand to clay soils (Tyler and Wheatcraft, 1990).

2.6. Soil moisture

Take 200 g of soil with 105 °C oven-drying for 24 h to constant weight to calculate of soil moisture content. Designed WDPT tests as following were carried out after air-drying (20 °C and 45–55% relative humidity) for a 1-week period.