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Seasonal changes in soil water repellency of different land use types in Inner Mongolia grassland

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A B S T R A C T

Soil water repellency (SWR) is a physical phenomenon in which the rate of wetting is restricted and water beads are formed on the soil surface where the soil is called water-repellent soil. SWR analysis is necessary to interpret nonuniform wetting and preferential flow for site-specific ecosystems. This study aims to investigate the effects of soil water conditions and land use types on SWR in *Leymus chinensis* steppe soil in Xilinhot, Inner Mongolia, China. The main objective is to determine how SWR in soils in Inner Mongolia is influenced by different grassland utilization types, including no grazing since 1979 and 1999, winter grazing, and continuous grazing, by using water drop penetration time (WDPT). Results show that a slightly hydrophobic or hydrophilic soil behavior was often observed, and SWR was most evident in the months with the highest evaporation despite heavy rainfall. Changes in SWR in different seasons were affected by grazing intensity. The highest number of hydrophobic soil samples was found in the continuous grazing sites, followed by that in the winter grazing sites. Few hydrophobic soil samples were detected in the ungrazed sites since 1979, and the lowest number of samples was observed in the ungrazed sites since 1999. The SWR of different particle size classes decreased with increasing particle size. Therefore, SWR was significantly correlated with soil particle size class at 0–0.05 and 0.05–0.1 mm. These results emphasized the need to consider SWR in soil utilization because grazing intensity affects the soil repellent properties in steppe soil and provided a basis for the development of grassland management.

1. Introduction

Soil water repellency (SWR) is a physical phenomenon in which the rate of wetting is restricted and water beads form on the soil surface where the soil is called water-repellent soil (Anderson, 1986). The soil in this state is called water repellent soil (Yang et al., 1996). SWR causes precipitation or irrigation water to flow along preferential flow paths into the soil, leading to the uneven distribution of soil moisture, seriously affecting the emergence rate of seeds and eventually resulting in the reduction of crop production (Dekker and Ritsema, 1994; Yang et al., 2003). Moreover, SWR enables water to carry solutes along preferential flow paths to reach groundwater rapidly, increasing groundwater contamination risk and causing a series of environmental problems (Carrillo et al., 2000; Liu et al., 2016a). In addition, SWR reduces water infiltration and when a part of the surface soil remains dry it may lead to erosion in rainy seasons (Witter et al., 1991). Water is the main limiting factor of grassland productivity in semi-arid areas. The effects of grazing intensity on soil physical and mechanical properties, such as soil water content (SWC), hydraulic conductivity (K), water drop penetration time (WDPT), soil organic carbon (SOC) concentration, bulk density (BD), and soil texture, in the *Leymus chinensis* steppe in Inner Mongolia, China have been reported (Zhao et al., 2007). Studies on the water-repellent properties of steppe soils will help examine the influence of grazing intensity on soil water cycle and utilization in grassland, thereby providing a scientific basis for the development of reasonable grassland management measures.

Studies on SWR in grasslands mainly include the analysis of basic grass characteristics, influencing factors on SWR, and strategies to decrease or prevent SWR in practice. Dekker and Jungerius (1990) and Dekker and Ritsema (2000) investigated the SWR characteristics of sand dune grass that has not been cultivated for at least a few decades in the southwest of the Netherlands. They considered the critical soil moisture content and explained the relationship between SWR and soil water content. Their results revealed no relationship between organic matter content and SWR. Newton et al. (2003) evaluated the rangelands located in the Western North Island of New Zealand and found that the increase in soil organic matter (SOM) contents remarkably strengthened SWR in fields, but SWR decreased as the amount of carbon dioxide

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in air increased (Liu et al., 2016b). SWR is affected by land use types, vegetation distribution and soil moisture content, soil texture, soil organic matter, and other physicochemical properties (Keizer et al., 2007; Mataix-Solera et al., 2013). SWR also exhibits strong temporal and spatial variability (Czachor et al., 2010), which is especially obvious in different land use types. For example, the soil properties of orchards and cultivated lands differ significantly from other land use types (Sharpley and Menzel, 1987). Soil erosion not only leads to nutrient loss and reduced soil productivity but also induces nutrient transport through the surface runoff into the water body, thereby causing water pollution and eutrophication, which is a non-point source pollution factor that limits agricultural activities (Gomi et al., 2008). The effects of water repellency on soil erosion are affected by their spatiotemporal changes (Jordan et al., 2008), and previous studies only revealed the characteristics of SWR for single land use (Lemmnitz et al., 2008; Benito et al., 2003). However, the spatial distribution of SWR under different land uses (Harper and Gilkes, 1994) and its influencing factors have not been considered.

Grassland is the main land use type in northern China and in the semi-arid areas of Eurasia. Grassland degradation resulted in grassland productivity decline and ecosystem deterioration because of improper management and overgrazing (Tong et al., 2004). Uneven soil wetting and limited water retention in these soils caused poor crop and pasture establishment, resulting in increased susceptibility to wind and water erosion (Tate et al., 1989). Reduced tillage practices have been enthusiastically adopted by farmers in southern Australia, which is associated largely by well-documented reductions in soil erosion (Flower et al., 2008). The benefits of no-tillage include high soil carbon contents (Bachmann et al., 2008), which led to remarkable water and nutrient holding capacity of many soil types (Lal and Kimble, 1997). The impact of reduced tillage and no-tillage practices on SWR in fields has been examined (Blanco-Canqui and Lal, 2009; González-Peñaloza et al., 2012; Roper et al., 2013; Ward et al., 2015) but has yet to be investigated in grasslands.

In this research, the influence of different grassland uses in China on the original physical soil and its chemical and biological characteristics was investigated. This study also briefly described the benefit of water retention characteristic, water infiltration and redistribution in grassland soils, and soil water movement patterns that are closely related to SWR properties. The main objectives of this study are as follows: (1) to evaluate the SWR of grassland soil in Inner Mongolia under different land use types through a field experiment; (2) to examine the characteristics of the SWR of different land use types under different seasons; and (3) to investigate the effects of different particle sizes under different land use types on SWR.

2. Methods

2.1. Study area

The study area is located in the Inner Mongolia grassland ecosystem in Baiyinxile pasture station in Xilinhot, Inner Mongolia. The geographical coordinates of the study area are 43° 32′ 45″ −43° 33′ 10″ N and 116° 40′ 30″−116° 40′ 50″ E (Fig. 1), located on the south bank of the Xi lin River in the hilly area. 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 a round top and long valley slope of less than 5°, bordering on flat valley (http://ngcc.sbsm.gov.cn/). The study area has a temperate semi-arid grassland climate (Wang et al., 2010), the annual average temperature is 0.57 °C, the coldest month is January with an average temperature of −21.4 °C, the hottest month is July with an average temperature of 18.5 °C, and an extreme minimum temperature of −30.6 °C (http://www.zhongguotianqi.com.cn). The annual average rainfall is approximately 350 mm, and the precipitation is mainly concentrated in July to September, with a high rainfall interannual variation coefficient of more than 30%. The highest precipitation for the year is 645 mm, the lowest precipitation is 182 mm, and the potential mean annual evapotranspiration is 1600–1800 mm (http://www.nmgtj.gov.cn/nmgttj/index.htm). The plant growth period is from May to September of each year (Wang et al., 2009). By the end of September, the temperature suddenly drops with the rapid death of grass plants in the short growing season (Wang et al., 2013).

The area is typical temperate grassland. The *Leymus chinensis* community and the *Stipa grandis* community are the most widely distributed plant community in the area, and they are extensively present in the Eurasia temperate grassland. *Leymus chinensis* is the dominant species in the grassland, followed by *S. gradis*, *Agropyron cristatum*, and *Cleistogenes squarrosa*. *L. chinensis* contributes to 80% of the total biomass of the community. The *S. grandis* community, consisting of *S. grandis*, *Koeleria cristata*, *A. cristatum*, and *C. squarrosa*, has a significant advantage that accounts for 85% of the total biomass with a grass group height of 50–60 cm and coverage from 30 to 40% to 60–70% in the rainy season with the remaining bare soil. The surface layer of the bare soil is covered with thin litter.

Chestnut soil is the main soil in this area, which was characterized by the significant accumulation of organic matter and calcium carbonate 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 layer. The humus layer thickness was generally in the range of 30–45 cm, and had an organic matter content of 2.0-4.0%. The texture mostly consists of sand and silt. The clay minerals are mainly montmorillonite and hydromica. The dynamic change of grassland soil moisture in a year is divided into four periods. From March to early April with the melting of snow and ice and the dissolution of permafrost, the soil has a short wetting period. From the beginning of April to the end of June, the probability of precipitation is small and the soil experiences a dry period with the rising temperature and frequent winds. By the end of June, the soil moisture fluctuates because of the strong evaporation and rising temperature. From the beginning of September to the end of the freezing month (December), the soil moisture content is constant low because of the low temperature and evaporation (Chen and Wang, 2003).

2.2. Sampling sites

Before 1979, the whole experimental area was lightly grazed, with 70–90% of sheep livestock and 10–30% of goats. The test included four fence plots (Fig. 1). Sample site A has fencing and has been ungrazed since 1979; this site has an area of 24 ha, grassland native vegetation, high grass group, lush growth, and a large material coverage of approximately 3–5 cm thickness on the surface. Sample site B has fencing and has been un grazed since 1999; it has an area of 35 ha, which is basically for native vegetation, high grass group, lush growth, and a large continuous coverage. Sample site C is an area of 40 ha, and the grazing intensity is 0.5 sheep unit/(ha a). Sample site D is an area of 250 ha, and the grazing intensity is 2.0 sheep units/(ha a). Cold-song and wheatgrass are the vegetation group, and the ground material is discontinuously distributed. The organic carbon contents of the four sites at 0–5 cm soil layers are 31.0, 25.5, 25.9, and 23.0 mg/g of organic matter. As shown in Fig. 1, grazing site (A) and forbidden grazing site (B) are located in the lower part of the hilly valley, the winter grazing site (C) on the higher parts of the valley, and the continuous grazing site (D) in a flat wide valley.

An area of 105 m × 135 m was selected from each sample site, and was divided into 15 m × 15 m grids, 80 sampling sites were established, and 20 other samples were set with a spacing of 5 m according to the terrain conditions between the two sampling sites of 80 locations. A total of 80 + 20 samples were taken in each site (the origin of the continuous grazing site was the southeast corner and the rest was the northwest corner). When present, litter was gently brushed off or removed by hand. A total of 100 samples were taken from the 0–5 cm soil