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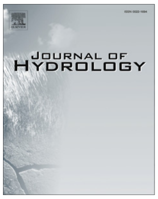

Mixed artificial grasslands with more roots improved mine soil infiltration capacity

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SUMMARY

Soil water is one of the critical limiting factors in achieving sustainable revegetation. Soil infiltration capacity plays a vital role in determining the inputs from precipitation and enhancing water storage, which are important for the maintenance and survival of vegetation patches in arid and semi-arid areas. Our study investigated the effects of different artificial grasslands on soil physical properties and soil infiltration capacity. The artificial grasslands were *Medicago sativa*, *Astragalus adsurgens*, *Agropyron mongolicum*, *Lespedeza davurica*, *Bromus inermis*, *Hedysarum scoparium*, *A. mongolicum* + *Artemisia desertorum*, *A. adsurgens* + *A. desertorum* and *M. sativa* + *B. inermis*. The soil infiltration capacity index (SICI), which was based on the average infiltration rate of stage I (AIRSI) and the average infiltration rate of stage III (AIRS III), was higher (indicating that the infiltration capacity was greater) under the artificial grasslands than that of the bare soil. The SICI of the *A. adsurgens* + *A. desertorum* grassland had the highest value (1.48) and bare soil (−0.59) had the lowest value. It was evident that artificial grassland could improve soil infiltration capacity. We also used principal component analysis (PCA) to determine that the main factors that affected SICI were the soil water content at a depth of 20 cm (SWC20), the below-ground root biomasses at depths of 10 and 30 cm (BGB10, BGB30), the capillary porosity at a depth of 10 cm (CP10) and the non-capillary porosity at a depth of 20 cm (NCP20). Our study suggests that the use of Legume-poaceae mixtures and Legume-shrub mixtures to create grasslands provided an effective ecological restoration approach to improve soil infiltration properties due to their greater root biomasses. Furthermore, soil water content, below-ground root biomass, soil capillary porosity and soil non-capillary porosity were the main factors that affect the soil infiltration capacity.

1. Introduction

Mining and related activities have led to severe soil degradation and soil disturbance through mining operations that change soil properties and destroy soil structure (Shrestha and Lal, 2011; Yang et al., 2015). Surface mining operations should be followed by soil reclamation and/or the reestablishment of vegetative cover. Reclamation involves replacing top soil that was removed and homogenized followed by seeding. The most common post-mining land uses were for hay production and for providing pasture (Jeffrey et al., 2008). In abandoned quarries or surface mines, recolonization by plants was very difficult (Ballesteros et al., 2012) because of the destruction of the natural soil structure and of the seed bank, as well as the limitations of nutrients and water (Haritash et al., 2007). Soil water is one of the most critical limiting factors affecting plant growth and distribution patterns in semi-arid regions (Wang et al., 2008). Rainfall is the only source of soil water replenishment in desert ecosystems (Wang et al., 2007). Soil infiltration capacity plays a critical role in determining the precipitation inputs to the soil and in enhancing soil water storage, which is important for the maintenance and survival of vegetation patches in arid and semi-arid areas (David et al., 2015). Thus, soil infiltration capacity is an important soil hydrological parameter that can be used as an indicator of soil degradation and drought potential (Zhang et al., 2010). Therefore, it is very important to quantify the soil infiltration capacity.

Infiltration is the movement of water into the soil from the surface by downward or gravitational flow. The rate at which this occurs is known as the infiltration rate (Osuji et al., 2010). Several past studies have been conducted to determine infiltration rates in soil vegetated with different vegetation types in order to evaluate

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the soil infiltration capacity during the course of rainfall events. Soil infiltration capacity can determine, for example, the initial and steady infiltration rates, the mean infiltration rate, the water infiltration depth and accumulated infiltration (Zhao et al., 2013; Li et al., 2013; Bi et al., 2014 Liu et al., 2015). Christine et al. (2014) used a hood infiltrometer for in situ infiltration measurements and evaluated the infiltration capacity of grassland indirectly through different parts of the pore spectrum. However, the use of only one or two parameters could not comprehensively evaluate the soil infiltration capacity. In view of these issues, a better understanding of the infiltration capacity under different grasslands during vegetation restoration is considered important to the sustainable eco-environmental construction on reclaimed mine soils.

Many studies have found that the infiltration capacity of soil was mainly controlled by both vegetation characteristics and soil physical properties (Wang et al., 2003; Christine et al., 2014; Leung et al., 2015). Li et al. (2013) reported that the soil permeability had significant positive linear correlations with the total porosity, non-capillary porosity, initial water content, and water holding capacity of the soil, and a significant negative linear correlation with soil bulk density. Scanlan and Hinz (2010) found that plant roots could clog soil pores and decrease the soil infiltration rate. However, previous studies on the relationship between soil infiltration capacity and structural properties were mostly based on laboratory experiments using disturbed and sieved-soil. Quantitative information about the soil infiltration capacity as affected by the structural properties under field conditions is scarce.

In view of the close relationship between soil physical properties and soil infiltration capacity, we assumed that (1) artificial grassland with a greater root biomass could more effectively improve soil infiltration capacity by improving soil infiltration rates; and (2) we studied soil infiltration rates and soil physical properties to find the main factors that affected soil infiltration. The results should provide new insights into the effects of vegetation restoration on infiltration and further provide a baseline reference for rational vegetation restoration and soil–water conservation in the mining areas.

2. Materials and methods

2.1. Study sites

The present study was conducted in the dump area of the Yongli coal mine, Inner Mongolian Autonomous Region, which is located on the northern Loess Plateau (110°16′30″E, 39°41′52″N, H: 1026–1304 m) in China. The area is characterized by a semiarid climate, with a mean annual temperature of 7.2 °C and a mean annual precipitation of 404.1 mm, which mostly occurs from July to September and accounts for about 80% of the annual rainfall. The annual evaporation is 2082.2 mm. The annual cloud-free solar radiation is about 3119.3 h. The climate is cold and dry in the winter and spring, and hot and rainy in the summer. The main soil type is a sandy soil (Calcaric Cambisols, FAO) and the thickness of the soil layer is about 50 cm. The main plant species in the region are *Artemisia sacrorum*, *Stipa capillata*, *Artemisia desterorum*, and *Lespedeza bicolor*.

2.2. Experiment design

Nine-types of artificial grasslands were established on the reclaimed land: *Medicago sativa*, *Astragalus adsurgens*, *Agropyron mongolicum*, *Lespedeza davurica*, *Bromus inermis*, *Hedysarum scoparium*, *A. mongolicum* + *Artemisia desertorum*, *A. adsurgens* + *A. desertorum* and *M. sativa* + *B. inermis*. *M. sativa* and *B. inermis*. These are the most common species used in vegetation restoration and can improve soil properties relatively quickly. *A. adsurgens*, *A. mongolicum*, *L. davurica* and *H. scoparium* are also dominant native species of this region and are adapted to survive in arid environments. *A. desertorum* is a pioneer species of community succession, which can be used as an indicator of the soil status. Six replicate plots (3 m × 5 m) were established in each grassland type. Seeding was carried out with a row spacing of 50 cm and at a sowing rate 0.07 kg/m^2. Due to the barrenness of the soil, the sowing rate was a little higher than usual in order to guarantee an adequate emergence rate, which would also increase the population density that could rapidly cover and protect the soil surface. Revegetation of the various grasses used the same planting density and the plants were irrigated to ensure grass survival during the beginning of the restoration period. Later on, grass growth entirely depended on rainfall, without fertilization or human intervention. This ensured that the conditions in all of the plots were similar during the experiment but also that any differences were solely due to the grassland type. Hence, it could be assumed that any differences in soil infiltration could be attributed to the type of artificial grassland.

From the beginning of the growing season, we randomly selected three parallel 1 m × 1 m quadrats in each of the plots at two-month intervals. Aboveground biomass was harvested from each quadrat by cutting the plant stems at the soil level, and was then sealed in an envelope. Each envelope was weighed while the plant material was fresh and then re-weighed after drying at 65 °C for 48 h. To measure the below-ground root biomass, a 9-cm diameter root augur was used to remove three soil samples from each soil depth of 0–10, 10–20, and 20–30 cm. The three samples collected from the same layer were then mixed to create a single composite sample. A 2-mm sieve was used to separate most of the plant roots from the soil. No attempt was made to distinguish between living and dead roots. The separated roots were oven-dried at 75 °C for 48 h and then weighed.

2.3. Soil properties analysis

The thickness of mine soil is about 50 cm and plant roots are mainly distributed in the 0–30 cm soil layer (Leung et al., 2015) and the depth of rainfall infiltration is about 30 cm (Liu et al., 2015). Therefore, we investigated soil properties in the 0–30 cm layer. The soil bulk density of each layer (0–10, 10–20, 20–30 cm) was measured for soil samples using a stainless steel cutting ring, 5 cm in diameter and 5 cm in depth (3 replicates) to collect a known volume of undisturbed soil. The dry mass was measured after oven-drying at 105 °C and the bulk density was calculated. Soil water content was measured gravimetrically and expressed as a ratio of soil water to dry soil mass. Total soil porosity (TP) was calculated using Eq. (1) based on the measured bulk density and assuming a soil particle density of 2.65 g cm^{-3}. Soil capillary porosity (CP) was subsequently calculated using Eq. (2) and the bulk density and soil capillary water capacity data (Jiao et al., 2011). Soil non-capillary porosity (NCP) was calculated using Eq. (3) (Huang, 2003).

$$\mathrm{TP} = \left(1 - \frac{\mathrm{BD}}{ds}\right) \times 100 \tag{1}$$

where TP is the total soil porosity (%); BD is the soil bulk density (g cm^{-3}); and ds is the soil particle density (g cm^{-3})

$$\mathrm{CP} = W_c \times \frac{\mathrm{BD}}{V} \times 100 \tag{2}$$

$$\mathrm{NCP} = \mathrm{TP} - \mathrm{CP} \tag{3}$$

where CP is the soil capillary porosity (%); NCP is the soil non-capillary porosity (%); W_c is the soil capillary water content (%); and V is the volume of the soil core (cm^3).