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Temporal variations in infiltration properties of biological crusts covered soils on the Loess Plateau of China

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ABSTRACT

Biological soil crusts (BSCs) are widespread in abandoned farmlands over the Loess Plateau after the "Grain for Green" project was implemented in 1999. However, few studies have been carried out to quantify the effects of BSCs on temporal variations of soil infiltration properties. This study was conducted to investigate the effects of two typical BSC (moss and cyanobacteria) on the temporal variations of soil infiltration properties reflected by soil sorptivities under different pressures of 0 (S_0) and − 3 (S_3) cm, saturated hydraulic conductivity (K_s), and wetting front depth (*WFD*) on the Loess Plateau. Two BSC-covered sites and one bare soil site (as control) were selected to measure soil infiltration properties using a disc infiltrometer under two consecutive pressure heads of 0 and − 3 cm, and then the S_0, S_3, and K_s were calculated. The *WFD* was measured quickly by a ruler after the measurement of soil infiltration. The experiments started from May 9 to October 8, 2015 for 7 times at approximately 3 weeks interval. Soil physicochemical properties and BSC thickness were also measured to explain the temporal variations of soil infiltration properties. The results showed that the thickness of moss and cyanobacteria crusts increased continually during the experimental period. BSC affected top-soil (0–5 cm) properties (soil water content, bulk density, texture, and organic matter content) significantly, and the effects of moss were greater than those of cyanobacteria. BSC was effective to impede soil infiltration. Compared to the control, the mean S_0, S_3, K_s, and *WFD* of moss-covered soil reduced by 31.4%, 25.2%, 39.0%, and 22.7%. While, S_0, S_3, K_s, and *WFD* of cyanobacteria-covered soil declined by 21.5%, 18.2%, 29.3%, and 11.9%, respectively. The temporal variations in infiltration properties of both moss- and cyanobacteria-covered soils were similar. S_0, S_3, K_s, and *WFD* generally decreased over time. However, the related infiltration properties of bare soil fluctuated over time with no distinguish trend. The temporal variations in infiltration properties were closely related to the seasonal variations in BSC thickness and soil water content.

1. Introduction

Soil infiltration properties are needed for studying hydrological processes, soil erosion, migration of nutrients, pesticides and contaminants transport, and design and monitoring of irrigation and drainage systems (Bagarello et al., 2005; Alletto and Coquet, 2009). Soil infiltration properties generally consist of soil sorptivity, soil hydraulic conductivity and the wetting front depth (Eldridge et al., 1997; Zhang, 1997; Li et al., 2010; Lichner et al., 2013). They are controlled by soil physicochemical properties (e.g. texture, structure, bulk density, soil water content, organic matter content) (Eldridge and Greene, 1994; Chamizo et al., 2012a, b; Wang et al., 2013; Gao et al., 2017) and biological soil crusts (BSCs) growth within the surface soil layer (Eldridge and Greene, 1994; Kidron and Yair, 1997; Kidron, 1999; Belnap, 2006; Wang et al., 2007; Kidron, 2007; Lichner et al., 2012; Chamizo et al., 2012a; Wang et al., 2013; Kidron, 2016; Wang et al., 2017).

BSCs are important and typical ubiquitous components of the ground flora in arid and semi-arid regions (Eldridge, 1993a). As one of the integral components of near soil surface characteristics, BSCs form through intimate relationships between biotic community (cyanobacteria, lichens, mosses, liverworts, fungi and bacteria) and abiotic conditions of the uppermost millimeters of soil (soil water, texture and mineral components) (West, 1990; Zaady et al., 1997; Eldridge et al., 2000). As a boundary between the biosphere and the atmosphere, BSCs play a major role in ecosystem processes, particularly in soil physicochemical properties and soil infiltration properties (Kidron and Yair, 1997; Kidron, 1999, 2007; Wang et al., 2013; Zhao et al., 2014; Liu

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et al., 2016; Kidron, 2016).

In the past several decades, in order to quantify the effects of BSCs on soil infiltration, a large number of studies have been performed. However, the influences of BSCs on soil infiltration are still not fully understood and ambiguous. A considerable study showed that the presence of some BSCs impeded infiltration (Graetz and Tongway, 1986; Yair, 1990; Verrecchia et al., 1995; Kidron and Yair, 1997; Kidron, 1999: Eldridge et al., 2000; Li et al., 2002; Kidron et al., 2003; Wang et al., 2007; Lichner et al., 2012). They argued that BSCs could close the conducting pores at the soil surface and form a relatively non-porous layer compared with the below soil, which is the most important reason for BSCs impeding soil infiltration (Eldridge and Greene, 1994; Verrecchia et al., 1995; Mazor et al., 1996; Kidron et al., 1999; Belnap, 2006; Wang et al., 2009; Wang et al., 2017). Meanwhile, the dry BSCs have a strong water repellency at the beginning of rainfall leading to more runoff and less soil infiltration (Malam et al., 2009; Lichner et al., 2012; Zhang et al., 2014; Wang et al., 2017). The water repellency ceases when BSCs became wet (Kidron et al., 1999), but the low water-holding capacities of BSCs also generates more runoff and less water to be infiltrated (Malam et al., 2009; Lichner et al., 2012; Bu et al., 2013). In contrast, some other studies revealed that BSCs could be expected to increase soil infiltration via absorbing water (Eldridge, 1993b; Belnap, 2006; Bu et al., 2013), increasing the availability of entry points for water into the soil (Eldridge and Greene, 1994; Bu et al., 2013), and promoting surface retention result from the increasing soil surface roughness (Eldridge and Greene, 1994; Kidron, 2007; Bu et al., 2013).

The contradicting results regarding the effect of BSCs on soil infiltration are likely attribute to the interaction of some factors as review by Belnap (2006). Firstly, the lack of information about soil features and BSCs characteristics make it impossible to quantify the relative contribution of BSCs to soil infiltration. Secondly, to test the effect of BSCs on soil infiltration compares are made between crusted soils (undisturbed) and soils where the crusts were removed by various methods, which have different soil features, consequently, the results are likely different each other. Finally, the application of different methods, variables, and instruments may complicate the comparisons of different studies. Meanwhile, it seems that the influences of BSCs on soil infiltration processes are closely depend on the BSCs compositions (Kidron et al., 2003: Rodríguez-Caballero et al., 2013), cover (Eldridge et al., 2010; Wang et al., 2017), moisture status (Chamizo et al., 2012a), microtopography (Kidron and Yair, 1997; Belnap, 2006), roughness (Kidron et al., 2003; Kidron, 2007; Kidron et al., 2012a), disturbances (Bu et al., 2013), and rainfall characteristics (Kidron et al., 2012b; Rodríguez-Caballero et al., 2013), as well as soil properties (Eldridge and Greene, 1994; Kidron et al., 2012a; Wu et al., 2013).

The growth of BSCs is influenced significantly by soil temperature and moisture, which exhibit great seasonal variation and lead to temporal variations in cover of biological soil crust, especially in the arid and semi-arid regions (Chamizo et al., 2012a; Kidron et al., 2012b; Belnap et al., 2013). Eldridge (1993a) found that the cover of BSCs increased continually during the whole growing season, and the proportion of moss increased significantly with the increasing BSCs cover. Aguilara et al. (2009) revealed that the cover of BSCs after the wet season was significantly higher than that in the dry season. Belnap et al. (2005) pointed out that sufficient water and appropriate temperature could stimulate C and N fixation to be used to create more BSCs biomass during the wet season. Kidron et al. (2012b) demonstrated that chlorophyll, total carbohydrates and species composition of BSCs increased significantly following a rainy season.

The Loess Plateau in northwestern China is one of the most eroded regions in the world due to high erodible soil, steep slope, short heavy storm, sparse vegetation cover, and irrational land use (Zhang et al., 2008). Great efforts have been paid in the past several decades to reduce soil and water losses on the Loess Plateau, China (Chen et al., 2007). Especially, the “Grain for Green” project was launched in 1999. As a result, more than two million hectares of steep farmlands have been converted to woodland or grassland, which has led to significant changes in near soil surface characteristics and produced available conditions for BSCs development. Zhao et al. (2006) found that the development of BSCs in the rehabilitated grasslands have experienced three stages on the Loess Plateau. In the first two or three years after rehabilitation, cyanobacteria colonized. In the next four to eight years, the dominant BSCs are cyanobacteria and mosses. After 10 years succession, the large mosses colonize the soil. Several investigations results showed that the mean cover of BSCs can up to 60% to 70% in the abandoned farmlands on the Loess Plateau (Zhao et al., 2014). A recent study of Xiao et al. (2014) found that the density and thickness of BSCs increased over time, and the related soil hydrological processes also changed significantly over time on the Loess Plateau.

As mentioned above, the effects of BSCs on soil infiltration properties are closely related to the properties of BSCs (i.e. compositions, cover and richness). The expected temporal variations in BSCs properties are likely to cause the temporal variations in soil infiltration properties for the lands covered by BSCs. However, few studies have been performed to investigate the potential effects of BSCs on the temporal variations in soil infiltration properties under the field conditions. Therefore, the objectives of this study were to quantify the temporal variations in soil infiltration properties of moss- and cyanobacteria-covered lands and to identify the factors influencing these variations during a growth period on the Loess Plateau of China

2. Materials and methods

2.1. Study area

The study was performed in Xiannangou small watershed (36°42′42″–36°46′28″N 109°13′46″–109°16′03″E) with a drainage area of 119.5 km^2. The elevation ranges from 1010 to 1440 m. The watershed locates in a typical loess-hilly region with a typical semi-arid continental climate. The mean annual temperature is 8.8 °C. The mean annual precipitation is 505 mm, and > 60% concentrating in the period from June to September as short heavy storms (Zhang et al., 2009). The vegetation zones are warm shrub and meadow steppe. The major species are *Artemisia capillaris Thunb*, *Artemisia giraldii*, *Artemisia sacrorum*, *Lespedeza davurica*, *Stipa bungeana and Caragana microphylla*. BSCs are extensively are evenly developed on the abandoned farmlands after the “Grain for Green” project was implemented. Moss crust and cyanobacteria crust are two dominant BSCs types distributed on the abandoned farmlands in the watershed, and the mean coverage was approximately 70% for each crust type (Zhao et al., 2006) (Fig. 1).

2.2. Sites and locations

A completely field survey was carried out shortly after a rainfall event to ensure maximal visibility of the BSCs (Knapen et al., 2007). Two abandoned hill slopes (slope gradient < 5°) covered by moss-dominated crust and cyanobacteria-dominated crust (the coverage was approximately 75% for each slope), and a nearby bare slope (as control) with at most 10% cyanobacteria cover were selected as the test sites. The dominated species of moss are Didymodon tectorum (C. Mull.) Saito. and *Didymodon vinealis* (Brid.) Zander (Zhang et al., 2007). While, the major species of cyanobacteria are Phormidium calcicola, Lyngbya allorgei, and Phomidium tenue (Yang et al., 2013). The area of each site was approximately 100 m^2, and the distances between the different sites were < 200 m. The two selected BSCs sites and the control had similar microtopography. While the control located near a path, thus its disturbance intensity caused by the activities of the human and livestocks was severe than those of moss- and cyanobacteria-covered sites. The dominated vascular plant is *Artemisia capillaris Thunb* for cyanobacteria-covered site and control site. For moss-covered site, the dominated vascular plant is *Artemisia sacrorum*. The coverage of all three sites were < 25%.