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Moss-dominated biological soil crusts significantly influence soil moisture and temperature regimes in semiarid ecosystems

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ABSTRACT

Biological soil crusts (BSCs) have been recognized as a vital influence factor to desert terrestrial ecosystems under semiarid climate. However, their effects on soil moisture and temperature, which play very important roles in many ecological and hydrological processes, have not yet been well understood. To provide more insight into this issue, we conducted a five-year monitoring experiment for moisture (0–150 cm) and temperature (0–30 cm) of soil with or without moss-dominated BSCs in a semiarid ecosystem on the Loess Plateau of China. The results showed that: (1) the BSCs significantly increased soil moisture by up to 7.6% at 5 cm depth, and significantly decreased soil moisture by up to 3.1%, 6.1%, and 8.1% at 15, 30, and 50 cm depths, respectively; while they had nearly no influence on soil moisture at 70–150 cm depths; (2) the BSCs significantly decreased soil temperature by up to 11.8, 7.5, 5.4, and 3.2 °C at 0, 5, 15, 30 cm depths, respectively, under wet and hot conditions in summer; whereas they significantly increased soil temperature by up to 8.0, 3.7, 2.9, and 1.9 °C, respectively, under dry and cold conditions in winter; and (3) the effects of the BSCs on soil moisture and temperature were significantly correlated with each other, and both of them were significantly driven by solar radiation and precipitation. We concluded that soil moisture and temperature regimes were significantly changed by moss-dominated BSCs in semiarid ecosystems, however, their effects mostly depended on seasons and soil depths.

1. Introduction

Biological soil crusts (BSCs) are widely distributed around the globe and usually cover 40–100% of the open ground in dry climate areas (Belnap and Lange, 2003). The ecological functions of BSCs and their potential utilization in conserving soil and water to restore vegetation and control desertification are attracting more attention (Xiao et al., 2015), and recently, they have been recognized as a vital influence factor to dryland ecosystems (Belnap, 2006; Tisdall et al., 2012; Su et al., 2013). It has been reported that some physical, chemical, and biological properties of the surface soil, such as color (Xiao et al., 2013), roughness (Rodríguez-Caballero et al., 2012), stability (Chamizo et al., 2012c), porosity (Menon et al., 2011), organic carbon (Drahorad et al., 2013), fertility (Zhao et al., 2010), hydraulic parameters (Fischer et al., 2010; Rossi et al., 2012), and microbial biodiversity and activity (Liu et al., 2013), are greatly influenced by BSCs. However, their effects on soil moisture and temperature, which play very important roles in many ecological processes, including soil water cycling (Belnap, 2006), soil chemical reactions (Hu et al., 2014) and microbial interactions (Louge et al., 2013), plant growth and vegetation succession (Li et al., 2002), have not yet been well understood (especially for soil temperature) or show contrasting results (Belnap, 2006; Xiao et al., 2013, 2014).

Although there were some positive effects of BSCs on soil moisture, including increasing infiltration (Xiao et al., 2011b; Chamizo et al., 2012b) and dew formation (Zhang et al., 2009; Fischer et al., 2012) as well as reducing runoff (Chamizo et al., 2012a; Kidron et al., 2012b) and evaporation (Xiao et al., 2010; Chamizo et al., 2013a), the negative effects of BSCs on soil moisture have also been noted or speculated by some researchers. For example, the smooth BSCs reduced the amount and depth of water infiltration (e.g., in hyperarid regions) (Belnap, 2006) as well as increased water evaporation (Kidron and Tal, 2012), and ultimately, they deteriorated deep soil water conditions (Li et al., 2004) which were originally available for vascular plant growth. Generally, the greater infiltration of BSCs has been attributed to their enhanced aggregate stability (Chamizo et al., 2012c), increased soil porosity (Menon et al., 2011), and improved physical structure (Zhang, 2005); whereas the reduced infiltrability has been attributed to their water repellency and pore clogging, which is caused by the swelling of extracellular polymeric substances and sheath materials during the imbibition of water (Issa et al., 2009; Fischer et al., 2010). Similarly, the higher evaporation rate of BSCs may be caused by their greater water holding capacity (Xiao et al., 2010), higher soil temperature (Kidron and Tal, 2012), and fast channels for water vapor

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movement (Li et al., 2005); whereas the lower evaporation rate of BSCs may be caused by the capping soil surface (George et al., 2003) and their high proportion of finer particles (Zhang et al., 2008).

At present, the results of BSC's effects on soil temperature are not only limited but also conflictive. It is generally believed that BSCs would increase soil temperature due to their dark colors. The increasing effects from cyanobacteria- or lichen-dominated BSCs on soil temperature were confirmed by a few studies with more or less differences in extent (Belnap, 1995; George et al., 2003; Kidron and Tal, 2012). However, Xiao et al. (2010) reported that the moss-dominated BSCs averagely decreased soil temperature by 0.4, 0.9–1.5, and 0.8–1.1 °C at surface, 5, and 10 cm depths, respectively. It has been reported that the increasing effects of BSCs on soil temperature were mostly attributed to their dark colors and increased surface roughness, which resulted in decreasing surface albedo (>50%) and increasing adsorption of solar radiation (Belnap, 1995; Kidron and Tal, 2012); whereas the decreasing effects of BSCs on soil temperature were possibly related to their accelerated soil evaporation rate, which took more heat out of soil during soil water evaporation (Xiao et al., 2013).

The conflictive results of BSC's effects on soil moisture and temperature may be firstly caused by the differences in BSC types, which have significant different functions in soil water and heat transport processes (Eldridge et al., 2000; Belnap, 2006; Chamizo et al., 2013a), and secondly caused by the differences of climate conditions (Belnap, 2006), which are remarkably different in solar radiation, rainfall regimes, air temperature, and humidity. Moreover, the seasonal variations in characteristics and functions of BSCs (Darby et al., 2011; Johnson et al., 2012; Kidron et al., 2012a) made the problems further complicated. Thus, it would be worthy to conduct more investigations for understanding the effects of BSCs on soil moisture and temperature as well as their relationships.

In this study, we hypothesized that moss-dominated BSCs could significantly influence soil moisture and temperature regimes in different seasons in semiarid ecosystems, and their effects on soil moisture and temperature were closely correlated with each other. Based on these hypotheses, we conducted a five-year monitoring experiment for moisture (0–150 cm) and temperature (0–30 cm) of soil with or without moss-dominated BSCs in a semiarid climate area

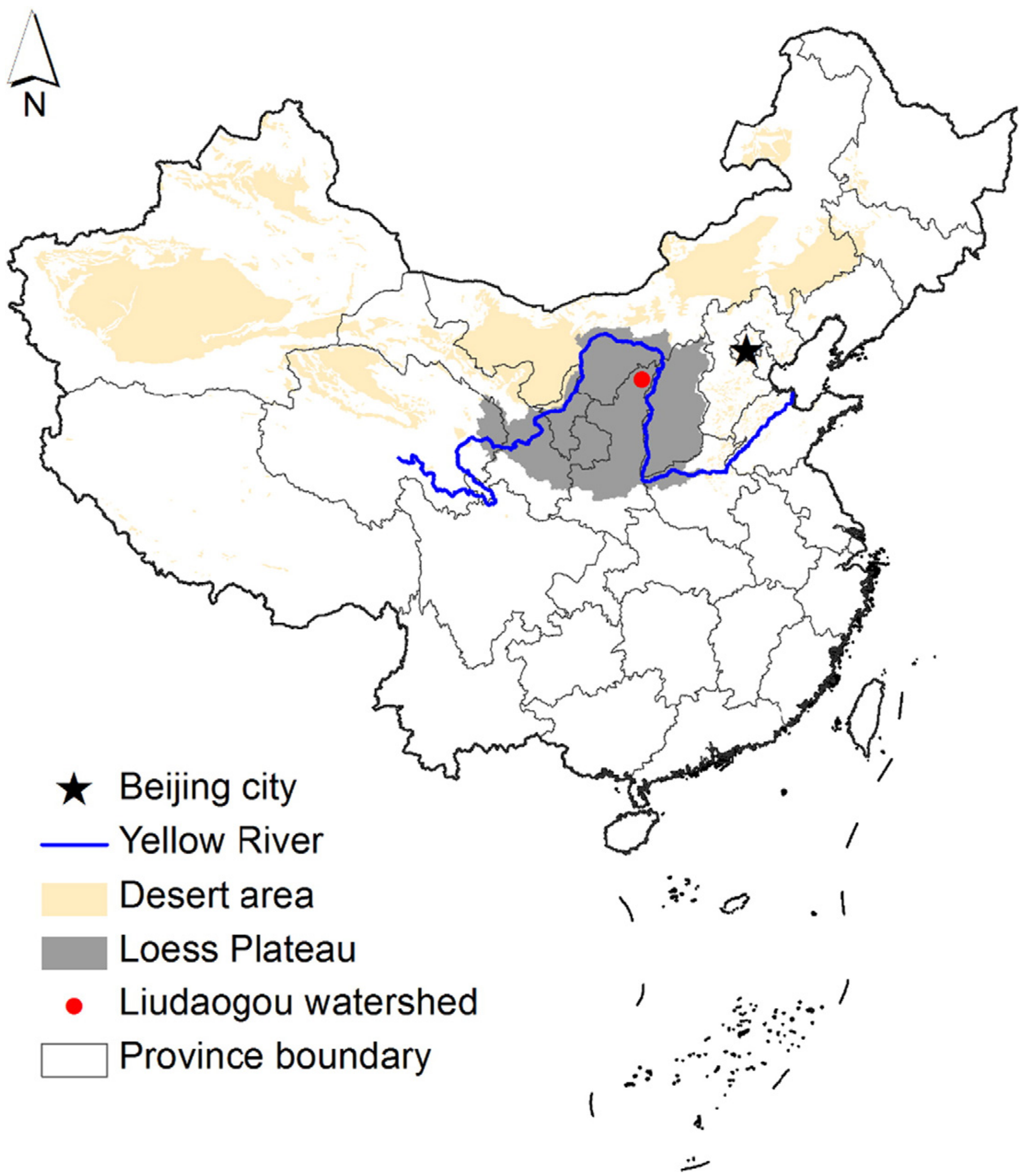

Fig. 1. The location of the study site in the Liudaogou watershed on the Loess Plateau in China.