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Small-scale observation on the effects of the burrowing activities of mole crickets on soil erosion and hydrologic processes

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A B S T R A C T

Soil-dwelling insects create continuous biopores when making their nests. Such burrowing activities alter soil structure and increase water infiltration. As fresh soil is brought onto the surface, sediments become available for erosion. Limited attention has been given to the ecological function of mole crickets on the Loess Plateau. In this study, the nest characteristics of adult and immature mole crickets (*Gryllotalpa unispina*) and their effects on soil hydrologic processes were investigated. Thin slurry of orthodontic plaster was used to fill the subterranean nests in the field to generate 3D renderings of the nest architecture. Dyeing and rainfall simulation experiments were conducted in a nest scale to quantify the effects of mole cricket burrows on the runoff and water infiltration on the slopes. *G. unispina* burrows consisted of horizontal and vertical parts. The mean diameter and depth of the vertical burrows created by adult mole crickets were 1.51 and 46.3 cm, which were significantly ($P < 0.05$) greater than those of immature ones (0.96 and 30.0 cm). Adult *G. unispina* exerted a more distinct effect on soil hydrologic processes than their immature counterparts. The horizontal burrows intercepted rainfall and promoted runoff reduction and infiltration, particularly in crusted soil. The mean amount of runoff in the crusted soil with adult nests (549.3 g) was significantly ($P < 0.01$) lower than that with no-nest (1039.6 g). Preferential flow in the nests resulted in high water content in the deep soil. In the semi-arid area, moderately improving the density of hypogeal animals and their nests might benefit to the soil moisture. However, the risk of soil erosion cannot be neglected.

1. Introduction

The Chinese Government launched the Grain for Green Project in 1999 to control the severe and widespread soil erosion on the Loess Plateau in northwest China. The mean vegetation coverage across the Loess Plateau reached 60.2% by the end of 2013 (Gao et al., 2017). The substantial increased vegetation markedly consumed soil water and result in severe soil desiccation, which is a main obstacle for the sustainable development of vegetation recovery in this region (Wang et al., 2010). Therefore, efforts to increase the rainwater infiltration and storage of rainwater in the soil have become more urgent.

Soil macropores can greatly improve soil infiltration despite accounting for less than 5% of the soil volume (Beven and Germann, 1982). The substantial increase in vegetation cover promoted soil animal diversity by providing abundant food sources and suitable habitats. Macropores created by soil macroinvertebrates increase water infiltration and reduce runoff by forming preferential flow at a fine scale (Capowiez et al., 2014; Li et al., 2017). In view of the water-stable structure of biopores (Friend and Chan, 1995), the tunnels become saturated and effectively increase the infiltration rates during heavy rainfall. Particularly in crusted soil, macroinvertebrate burrows penetrated the soil surface, weakened the rainfall interception by the crust, and markedly improved the infiltration and deep soil moisture (Li et al., 2014), all of which promoted the vegetation growth and succession. Compared with familiar soil engineers of earthworms, ants, dung beetles and termites (Bastardie et al., 2005; Brown et al., 2010; Evans et al., 2011), mole crickets have bigger body width and tend to make larger diameter of nest entrance. Herbivorous mole crickets tend to create abundant horizontal burrows which close to the soil surface. Obviously, mole crickets could be regarded as another kind of "soil engineer". With the increasing of mole cricket communities in the Liudaogou Catchment, especially in the farmland, their ecological function should receive more attention. However, unlike those of other soil-dwelling insects, limited works have been devoted to the hydrological functions of

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mole cricket nests.

The *Gryllotalpidae* includes over 100 species and is widespread worldwide (Eades et al., 2014). Mole crickets create tunnels for feeding, protection, and mating, and they spend most of their lives underground. Herbivorous mole crickets damage crops by feeding on roots, leaves and emerging shoots (Endo, 2007). Herbivorous mole crickets make abundant horizontal burrows which are suitable for feeding on roots in soil shallow layer. Without external appendages, earthworms construct tunnels that are equal to or slightly less than their body width (Joschko et al., 1991). As hypogeal insects, mole crickets possess sclerotized and fossorial forelegs for digging. Mole crickets can produce branching tunnels that are twice up to thrice of their body width (Villani et al., 2002; Endo, 2007). Mole crickets are solitary, and they develop individual tunnels depending on their life stage (Bailey et al., 2015). The species and feeding behavior also influenced the architecture of mole cricket tunnels. Herbivorous mole crickets tend to create deep burrows, whereas predominantly carnivorous ones tend to make shallow burrows (Villani et al., 2002). Brandenburg et al. (2002) demonstrated that mole crickets in the field could dig tunnels up to 70 cm deep.

Earthworms could reduce surface runoff and soil erosion by increasing water infiltration and roughness because of the accumulation of water-stable aggregates on the soil surface (Blanchart et al., 2004; Evans et al., 2011; Jouquet et al., 2012). Similarly, ants increase infiltration and reduce erosion losses, particularly in vegetation-removed soil and burn forests, which induce water repellency (Shakesby et al., 2003). However, unstable aggregates, such as fresh earthworm casts (Blanchart et al., 2004), ants made pellets (Li et al., 2017), and termite sheeting (Jouquet et al., 2012), are easily hydrolyzed, leading to soil detachment during heavy rains (Cerdà and Doerr, 2007). By contrast, mole crickets remove soil particles from the underground onto the ground, and loosen the surface soil by creating horizontal burrows (Endo, 2007). Although the increasing of vegetation coverage can control the soil erosion, prolonged soil desiccation could lead to regional vegetation die-off (García et al., 2008). Moreover, soil animals, such as herbivorous mole crickets (Brandenburg et al., 2002) and rodents (Herbst and Bennett, 2006), feed on roots of creeping and graminoid plants, which would inhibit plant development around the burrows and reduce the coverage of vegetation. The effects of the burrowing activities of mole crickets on soil hydrology and erosion should be thoroughly examined on the slopes.

Identifying the structure of mole cricket nest is important in understanding their effects on the soil properties. Although nests can be readily excavated from some types of soils, this strategy cannot make voids visible. Tschinkel (2003) used orthodontic plaster to produce a potentially 3D rendering of the voids to study the nest architecture. Brandenburg et al. (2002) used fiberglass resin for the tunnel casting of mole crickets. Furthermore, X-ray CT method has been used for structural studies on earthworms, termites, and ants (Capowiez et al., 2016; Rab et al., 2014). However, CT is not widely applied in remolding the nest architecture in the field. In this study, thin slurry of orthodontic plaster was filled mole cricket nests to investigate the actual architecture in the field.

The studied species was is *G. unispina*. The objectives of this study were to (1) evaluate the nest characteristics of *G. unispina*; (2) determine the impact of *G. unispina* on water runoff and soil detachment; and (3) characterize the preferential water flow in the nest of *G. unispina* and the effects on soil moisture.

2. Materials and methods

2.1. Experimental site

The Liudaogou Catchment is located on the northern Loess Plateau and is approximately 14 km west of Shenmu County, Shaanxi Province, China (Fig. 1). This catchment is located at 110° 21′–110° 23′ E and 38° 46′–38° 51′ N at an elevation of 1094–1274 m. The region is characterized by a temperate, semiarid zone with a mean annual precipitation of 430 mm, of which 77% occurs between July and September. The average annual temperature is 8.4 °C, and the mean annual potential evapotranspiration is 785 mm (Jia et al., 2013). The study area is situated in the center of a water–wind erosion crisscross region, which sustains serious soil erosion (Fu et al., 2011).

2.2. Nest characteristics of G. unispina

The nest architecture of mole crickets depends on their body type and life stage (Bailey et al., 2015). The biological soil crusts are important factor that affecting water infiltration. Thus, the immature nests and adult nests in the bare soil and crusted soil were the research objects in this study. After conducting a field survey in the Liudaogou Catchment, twelve mole *G. unispina* nests in bare soil and crusted soil were selected to investigate the nest architecture. We washed away the loose soil around the nest entrance and then filled the horizontal and vertical burrows with thin slurry of orthodontic plaster to produce a 3D rendering of the nest voids. The horizontal burrows are shown in Fig. 2. When filling ant nests, heavy clay soils prevent air from being displaced from chambers and tunnels, thereby producing incomplete casts and voids within the plaster (Tschinkel, 2003). In the present study, the thin slurry could fill all of the voids and create an intact cast because of the large diameter of the tunnels in the nests of *G. unispina*. Two days after filling the nest, the hardened casts of the horizontal and vertical burrows were excavated and photographed. The area of the horizontal burrows as well as the diameter and length of the vertical burrows were analyzed by using Image-J and Photoshop (version CS6.0). The volume and surface area of the vertical burrows were calculated from the diameter and length of the vertical burrows in the laboratory.

2.3. Rainfall simulations

Six treatments (bare soil with no-nest, bare soil with immature nest, bare soil with adult nest, crusted soil with no-nest, crusted soil with immature nest, and crusted soil with adult nest) with three replications each were designed in the rainfall simulation experiment. Other eighteen nests of mole crickets were selected in this experiment. A PVC cylinder (diameter: 30 cm; length: 75 cm) without caps (Fig. 3) was inserted 3 cm into the soil at a slope of 5°–10°. The cylinder was not high to provide enough energy as the raindrop in natural rainfalls. It is difficult to provide the raindrop enough energy by using PVC cylinder in this study. We used same height and rainfall intensity to compare the difference of runoff and sediment loss among different treatments. The horizontal burrows with loose soil were included in the cylinder. A 2 cm hole was made on the cylinder near the bottom, and a pipe was connected to the hole to collect the runoff. A slight compaction was made on the soil along the cylinders and sharpened the edges of the cylinder bottom to reduce the disturbance on the soil structure. A circular tank (diameter: 29.5; length: 10 cm) with 240 droplets through 240 hypodermic needles connected to the bottom was inserted on the top of the PVC cylinder. A markov bottle was used to ensure a constant water head (9 cm) in the tank during rainfall. The rainfall amount was calculated basing on the reduction of solution in the markov bottle. The mean amount of erosive rainfall which is more than 12 mm (Xie et al., 2000) in the Liudaogou Catchment was 35.6 mm in the year of 2016. In this study, the rainfall amount was set as 36 mm (1130 g). The rainfall duration was 60 min similar with other studies of rainfall simulation (Capowiez et al., 2014; Wen et al., 2017). Thus, the rainfall density of was 0.6 mm min^{-1}, which was reasonable according to the standard of rainfall density (0.1-3.2 mm min^{-1}, Wang et al., 2013). Purified water was used to avoid blocking the needles. Fine powder of brilliant blue was added in the water at a concentration of 4 g/L to trace the preferential flow in the nest.