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Effects of activities of ants (*Camponotus japonicus*) on soil moisture cannot be neglected in the northern Loess Plateau

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ABSTRACT

Ants can create abundant and continuous soil macropores by burrowing their nests. The hydrological processes in ant nests for different soil types and the effects of ant activities on soil water evaporation are unclear. In this study, we assessed the effects of ant (*Camponotus japonicus*) nests on preferential flow in the loam and sand soils and on soil water evaporation. First, 12 plots in the sand and loam soils with and without ants were selected for the preferential flow measurements in the field. Second, 200 worker ants and the queen ant were introduced to abandoned cropland plots, and the comprehensive effects of ants on soil moisture down to 340 cm were measured using neutron probes. Third, at the Shenmu Erosion and Environment Research Station, 18 iron buckets (20 cm in diameter, 20 cm high) were filled with disturbed loam soil, and a different number of ants was used to assess the effects of ant activities on soil evaporation. The infiltration rate in areas with a nest was approximately 20 times higher than that in no-nest areas. Moreover, the dyeing depths in loam and sand soil with a nest were 47 ± 4.6 and 34 ± 1.5 cm, which were significantly greater than those without a nest (13 ± 2.7 and 23 ± 2.3 cm). Ant nests reached a depth of 60 cm in the field. The effects of a nest on soil moisture existed between 0 and 120 cm deep. Moreover, by moving a high number of "homemade soil aggregates" (1.6 ± 0.18 mm in diameter) onto the soil surface, ants reduced soil evaporation. Ant activities improved soil moisture around the nest by increasing rainfall infiltration and reducing soil water evaporation, which increased the variation in soil water distribution in the soil profile and may benefit the general restoration of vegetation on the Loess Plateau.

1. Introduction

The Chinese government started the Grain for Green Project in 1999 by planting trees and grasses on barren croplands on the Loess Plateau to control the severe and widespread soil erosion. By the end of 2005, this project had covered some 87,000 km^2 of land on the plateau and had planted approximately 400–600 million trees (Zhou et al., 2009). The substantial increase in vegetation cover markedly affected the soil properties of the soil, including the deep soil profile water content (Wang et al., 2010; Jia and Shao, 2014). Because of the severe water consumption by the plants, soil desiccation is a main obstacle for vegetation growth and succession in this region (Chen et al., 2008; Wang et al., 2010). Moreover, the heavy and concentrated rainfall in the summer impeded water infiltration and resulted in very high surface runoff. Therefore, increasing the rainwater infiltration and storage in the soil is urgent.

A substantial increase in vegetation could promote the development of soil-dependant animals by providing abundant food and suitable habitats (Wang et al., 2010). When the Grain for Green Project was conducted in 1999, the ant communities in the Liudaogou Catchment developed rapidly. The physical activities of ants dramatically alter the soil physical properties (Whitford, 2002; Jouquet et al., 2006) and ecological processes in the fine spatial scales (Huntley and Inouye, 1988). Ant colony organisation can create abundant macropores, galleries and chambers within their nests (Karlen et al., 2003). Furthermore, constructing a nest enables the movements of air, water and solutes into the soil (Cerdà and Jurgensen, 2008). Nests could dramatically increase water infiltration rates, drainage and reduce the runoff by

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improving soil porosity at the fine scale (Jouquet et al., 2006; Benckiser, 2010; Li et al., 2014; Brevik et al., 2015). Within a landscape, ant nests also affect surface hydrological processes and increase the heterogeneity of infiltration rates (Cammeraat and Risch, 2008). Li et al. (2014) argued that ants are key regulators of rainfall reallocation in soil and increase rainfall transport to deep soil via influencing infiltration, further stabilising the vegetation in arid sandy ecosystems. Despite their potentially large impact on the soil, ants still receive less attention than other macro-faunistic taxa, such as earthworms or termites (Léonard et al., 2004; Six et al., 2004).

On the other hand, studies on the effects of ant activities on soil water evaporation are scarce. Ants could make and carry spherical soil aggregates onto the soil surface with their mandibles when burrowing a nest. These aggregates are stacked around the nest entrance and are relatively stable when the wind blows. In the dry season, new layers form on the soil surface as these aggregates accumulate. This layer might affect soil evaporation, just as artificial mulching such as the gravel, sand, cobble (Xu et al., 2005), basaltic tephra (Diaz et al., 2005) and soil biocrust covering (Rasiah et al., 2001; Li, 2003; Ma and Li, 2011; Xiao et al., 2010) and reduce the exchange of water vapour between soil surface and atmosphere, although the magnitude of these effects depends on particle size and layer thickness (Yuan et al., 2009; Qiu et al., 2014; Wang et al., 2014).

The studied species in this research is *C. japonicus*, which has a larger body than other ant types (such as *Messor aciculatus*, *Formica sinensis* and *Tetramorium caespitum*) in the Liudaogou Catchment. This study (1) evaluated the characteristics of preferential water flow in the soil with the nest of *C. japonicus* and its effects on soil moisture; and (2) explored the effects of different sizes of ant colonies on soil water evaporation.

2. Materials and methods

2.1. Experimental site

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

2.2. Source of test ants

Numerous ants were found in the sand and loam soils at the Liudaogou Catchment. After a field survey, we dug the soils using a small shovel along the tunnels of ant nests. Once the nest was destroyed, soldier and worker ants came out to defend the nest and were collected using a modified dust catcher. A total of more than 1770 ants and three queens ant were brought to the lab. Ant samples were stored in a refrigerator at a constant temperature of 1 °C, which could reduce their activities and make them convenient to count. Ants could be revived in 2 h upon warming.

2.3. Experimental designs

Experiment 1: The dyeing method was used to estimate the effects of the ant nest on preferential water flow from September 20 to October 26 at the Liudaogou Catchment. Firstly, a survey was conducted to search for *C. japonicus* nests in the sand and loam soils. Second, we used a tape to measure the nest entrance diameter in each plot. Litter around the nest entrance was removed and a PVC cylinder (11 cm in diameter, 25 cm long) with no caps was inserted 3 cm into the soil. To not destroy the structure and connectivity of the ant nests, we sharpened the edges of the PVC cylinders and gradually pushed them vertically and into the ground. The length of the sharpened edge was 3 cm. An edge longer than 3 cm would be too soft to be inserted into the soil. Inserting PVC cylinders into the soil surely caused soil disturbance on the surface. A little compaction of the soil inside the cylinders prevented the disturbed soil particles from blocking the nest entrance when filling PVC cylinders with brilliant blue solution. Soil outside the PVC cylinders was also slightly compacted to prevent the brilliant blue solution from leaking. A plastic board (10.5 cm in diameter) with 200 holes (2.5 mm in diameter) was put into the cylinder to reduce the destruction and blocking of the solution on the ant nest entrance. Each site was filled with 2000 ml of a solution of brilliant blue solution at a concentration of 4 g L^{-1}

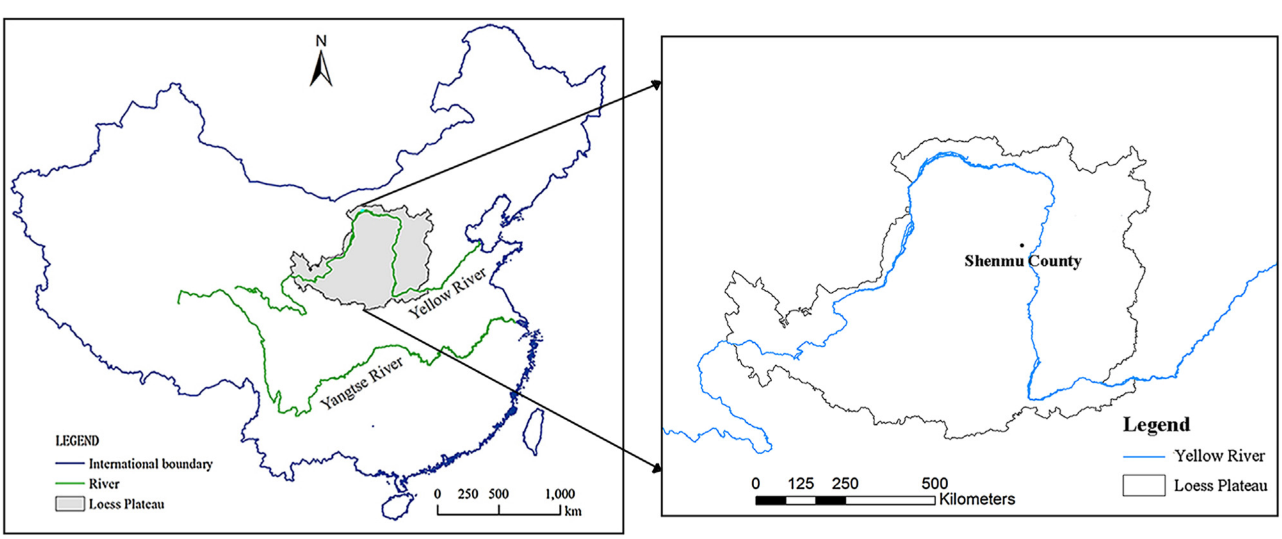

Fig 1. The location of the study area in the Loess Plateau of China.