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Ants mediate soil water in arid desert ecosystems: Mitigating rainfall interception induced by biological soil crusts?

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ABSTRACT

As vital components of desert systems, the roles of ants in arid ecological processes have been well documented, while little attention has been given to their effects on soil water. We conducted a six-year investigation in sand dune systems stabilized via revegetation, to explore the hydrological role of ants through comparing the influence of ant nests on rainfall infiltration in different-aged revegetated dunes. The presence of ant nests markedly enhanced infiltration due to weakening the rainfall interception by biological soil crusts (BSCs) in revegetated dunes. The distribution of ant nest was denser in older revegetated areas, due to better developed BSCs of later successional stages, compared to younger revegetated areas. Ants prefer later to early successional BSCs because the later lichen–moss dominated crusts were thicker and their surface was more stable than the early cyanobacteria dominated crusts. Conversely, the crustal rainfall interception was positively correlated with BSC thickness. These findings suggest that the occurrence of ant nests in older revegetated areas benefited to the planted shrubs with deeper root systems and maintain a relative constant cover of shrubs in artificial sand-binding vegetation following an increase in infiltration to deeper soil layers.

1. Introduction

Numerous studies have predicted that the large area of woody sand-binding vegetation will degrade or become extinct due to soil water depletion and underground water decreasing in sandy areas of northern China (Cao, 2008; Wang et al., 2010). However, in some cases, sand-binding vegetation can sustainably develop even for annual precipitation <200 mm (SDRES, 1991; Li et al., 2004; Wang et al., 2004; Li et al., 2007a). Amongst these debates, ecologists and land managers have become interested in the hydrological role of biological soil crusts (BSCs) (Li et al., 2010), which are widespread and develop in the processes of dune stabilization from revegetation and sand-binding vegetation succession (Li et al., 2002; Su et al., 2007). The occurrence of BSCs in stabilized dunes, and the conversion of early cyanobacteria to the later lichen–moss dominated crusts (Li et al., 2011), markedly increases the interception of rainfall (Belnap et al., 2005; Fischer et al., 2010). This favors annual plants (Su et al., 2007) and disadvantages woody plants with deeper root systems due to increasing shallow soil water and reducing infiltration to deeper soil (Li et al., 2007a). BSCs enhance the water-holding capacity of topsoil via increasing the clay and silt proportion content in topsoil thus stabilizing the dune surface and entrapping dust-fall in topsoil with the succession of artificial sand-binding vegetation (Li et al., 2007b). Therefore, BSCs alter the pattern of rainfall infiltration in soil (Maestre et al., 2002) and result in deep-rooted woody species disappearing from current communities and developing of shallow-rooted herbaceous species and, in particular, establishment of annual plants (Su et al., 2007; Li et al., 2007a). We want to determine how artificially established sand-binding vegetation systems respond and adapt to the changes induced by BSCs; and whether such ecosystems can maintain stability via systematic self-adjustment such as via altering species composition and performance, including invertebrate disturbance.

The presence and development of BSCs create safe sites for ants (Perfecto and Vandermeer, 1996; Bestelmeyer, 1997; Retana and Cerda, 2000) in wind erosion environments; and the distribution of ant nests is closely related to the successional stages of BSCs in the Tengger Desert (Li et al., 2011; Chen and Li, 2012). As ecosystems engineers, ants are abundant and conspicuous components of

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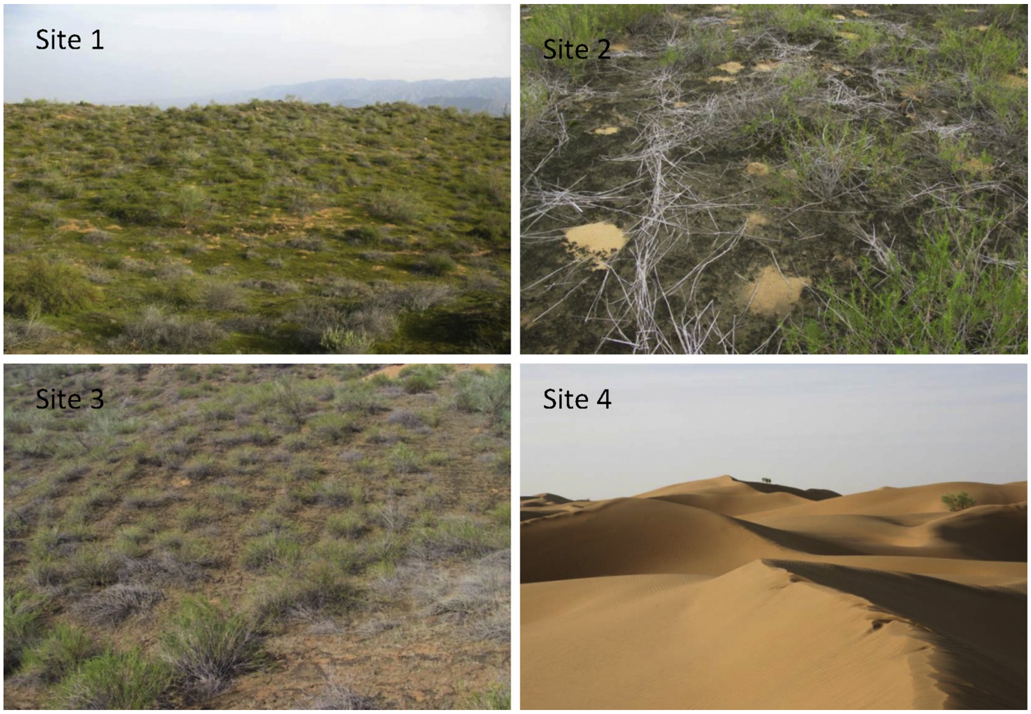

Fig. 1. The distributions of BSCs and ant nests in different-aged sand-binding vegetation in the Tengger Desert (moss dominated crusts and abundant ant nests in site 1; lichen–moss dominated crusts and ant nests in site 2; cyanobacteria–lichen mixed crusts with rare ant nests in site 3; photos were taken after 17.3 mm of rainfall on 4 July 2013).

desert ecosystems and are known to contribute to the heterogeneity or patchiness of landscapes and to pedogenesis (Whitford, 2002; Cerda and Jurgensen, 2008; Cerda et al., 2009). They especially influence belowground processes through altering the abiotic environment and through their effects on plants, microorganisms and other soil organisms (Folgarait, 1998). With the exceptions of the abovementioned functions, we hypothesize that ants serve as a key regulator to mediate and reallocate the rainfall in soil, and increase the supplement of rainfall to deep soil via influencing infiltration, further facilitating stability of artificial vegetation in arid sandy ecosystems. The objectives of this study are to test this hypothesis to explore hydrological role of ants and partly answer how artificial vegetation systems realize self-adjustment under moisture stress in arid desert regions. Specifically, this study examines two questions: (1) is there a significant difference in soil moisture between the crust-covered soils and those disturbed by ant nests? (2) Do ant nests influence the deeper soil moisture that determines the presence of shrubs in the composition of sand-binding vegetation?

2. Materials and methods

2.1. Study site

The study sites were located at the southeast fringe of the Tengger Desert in the Shapotou region of the Ningxia Hui Autonomous Region (37°32′ N and 105°02′ E), northwestern China. The mean annual temperature is 10.6 °C and the mean annual precipitation is 186 mm, of which approximately 80% falls during May–September. The annual potential evaporation is 2800 mm. The landscape of the Shapotou region is characterized by large and dense reticulate barchan chains of sand dunes (SDRES, 1991; Li et al., 2004). The dunes have consistent gravimetric water contents in the range of 3–4% (Li et al., 2007a). The groundwater in the study area is deeper than 60 m. The predominant native plants are *Hedysarum scoparium* Fisch., *Agriophyllum squarrosum* Moq. and *Psammochloa cillosa* Bor., which have a scattered distribution and cover about 1% of the entire study area (SDRES, 1991). Ants were almost nonexistent before revegetation (Chen and Li, 2012).

In order to fix mobile dunes, thus protecting steppe and main lines of communication from sand burial, the same revegetation approach was employed over different years (Li et al., 2007a,b). The revegetation processes were described in detail by Li et al. (2004). We chose the revegetated areas established respectively in 1964, 1982 and 1992 as study sites (Fig. 1), which have mainly developed with moss dominated crusts (site 1), lichen–moss mixed crusts (site 2) and cyanobacteria–algal crusts (site 3), while sharing the same geomorphological, climatic and soil characteristics. BSCs fill an important niche in development of sand-binding vegetation where extreme climatic conditions and shifting surfaces of dunes lead to an absence of, or inaccessibility for, invertebrates. Ants prefer to dig and burrow in crustal habitat and therefore the distributions of nests are affected by soil surface characteristics (Li et al., 2010). The distribution of ant nests is closely associated with crustal successional stages in the stabilized dunes of the Tengger Desert, and a total of seven ant species are found in soils covered by moss dominated crusts: *Proformica jacoti* Wheeler, *Cataglyphis aenescens* Nylander, *Formica cinerea* Mayr, *Formica clara sinae* Emery, *Formica cunicularia* Latreille, *Tetramorium caespitum* L. and *Messor aciculatus* Smith (Li et al., 2011; Chen and Li, 2012).

2.2. Methods

Investigation of the influence of ants on infiltration was conducted during April–September of 2008–2013 in the above sites. A total of 41 investigations were conducted (Appendix 1). There were 30 plots (each 5 m × 5 m) in each of three sites. With regard to the micro-geomorphological effects on infiltration, all plots were randomly allocated in the hollow of stabilized dunes of each site, which were within a 1 km^2 area. As a control site, 10 observation plots