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# Hydrological behaviour of microbiotic crusts on sand dunes: Example from NW China comparing infiltration in crusted and crust-removed soil

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ABSTRACT

Biological soil crusts are important microbiotic communities which are considered a key factor in combating desertification in terms of sand dune remobilitation. Because of their greater concentration of clay, silt and hydrophobic organic matter, they create a physical discontinuity in surface profile which potentially contribute to variability in soil hydrology of arid and semiarid land and should be considered in the development of hydrological and erosion models. However, until recently limited inconclusive research has been conducted to determine the functional relationship between soil and microbiotic crusts. We investigated the influence of microbiotic crust on hydrological behaviour of crusted sand dunes in NW China. The infiltration data on a crusted and crust-removed sand dune were obtained with dish permeameter which was not moved during the measurement at a sequence of nominal pressure head values, $h$, of −1, −4, −7, −10, −18 cm. Hydraulic conductivity $K(h)$ was measured by steady-state infiltration experiments and piece-wise application of the exponential relation between $K$ and $h$, according to Wooding's analytical solution of a three-dimensional flow field. The transient experimental infiltration data, along with initial and final water contents were used for numerical analysis within sand profiles without and with microbiotic crust. Specifically, we provided evidences that the main physical and hydrological consequences occurring locally, always cause lower unsaturated fluxes in the sand beneath the crusted layer. Nevertheless, due to the effective rainfalls regime, it has insignificant effects on the local soil water regimes with unchanged storage and deep fluxes.



## 1. Introduction

Crusting of the soil surface has been observed in many parts of the world in soils with different textures. Generally, crust formation occurs under the influence of rain storms and drying weather. In this type of crust a disturbed level of variable thickness, illuviated by the material in suspension, follows a very superficial real crust. The disturbed layer can be characterized by vertical dishomogeneity in porosity, with a progressive transition towards the properties of the lower undisturbed layer (Coppola et al., 2004; Kutilek and Nielsen, 1994).

Less understood and discussed is how the presence of biological soil crusts consisting of soil surface cyanobacteria, green algae, microfungi, lichens and bryophytes (Belnap, 2006; Fischer et al., 2010a,b) influences local hydrological behaviour. Biotic crusts form at the soil surface of arid and semiarid land in the interspaces between shrubs and contribute to stabilization of soil surfaces. However, the effect of biotic crusts on soil hydrology is often contradictory.

Biotic crusts are often associated to rain-induced crusts, which are known to restrict soil water infiltration. Nevertheless, biotic–physical interaction produces crusts with atypical characteristics compared to the classical rain-induced crusts, as they can imbibe water and swell, thus potentially restricting water flow along the soil profile. On the other hand, as pointed out by Belnap and Gardner (1993), the additional structure provided by the microbiotic activity via soil carbon addition would enhance the hydraulic conductivity rather than reduce it through new micropore channels (Eldridge et al., 2001).

In arid north-west China, changes in landscape from desert dunes to artificially stabilized shrub-covered dunes have strongly enhanced the formation of biotic crusts. Studies by Wang et al. (2006) showed that this could result in a reduction of soil water replenishment, especially important where groundwater does not support the natural vegetation cover. In these conditions, the local hydrological regime might change significantly.

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Micromorphological analysis approaches have been applied to study microstructure of microbiotic crusts in different desert landscapes (Malam Issa et al., 1999; Zhang et al., 2006) in order to clarify the roles of these crusts in soil stabilization of the environments under study. Nevertheless, until recently, limited and conflicting research has been conducted to determine the influence of biotic crusts on soil hydrological processes.

To partially fill the gap this study aims (i) to measure at different sites the soil physical and hydraulic properties of biotic crusts commonly found in an arid area of the north-west China, (ii) to provide an accurate characterization of the pore architecture of these crust formations by non-destructive imaging X-ray microtomography (XMT) (Menon et al., 2011) and specific procedures of 3D pore image analysis and (iii) to evaluate the effects of these measured properties on the hydrological behaviour of such soils by numerically simulating water flow processes naturally occurring in the area. The final aim will be (iv) to establish whether and to what extent the biotic crust affects soil water storage and deep water fluxes in these crusted soil profiles.


**Fig. 1.** View of a typical crust of the examined soil.

## 2. Materials and methods

### 2.1. Study site

This study was conducted in the Shapotou region, which is located in Zhongwei County in the Ningxia Hui Autonomous Region at the southeastern edge of the Tengger Desert (37°32′N, 105°02′E). It is an ecotone between steppified desert and desertified steppe and also a transitional zone between sandy desert and oasis (Li et al., 2002; Shapotou Desert Research and Experiment Station, CAS, 1991). Natural vegetation in the sandy desert region is dominated by the psammophytes, such as *Hedysarum scoparium* Fisch., *Agriophyllum squarrosum* Moq., *Stilpnolepis centiflora* Krasch and *Pugionium calcaratum* Kom., with coverage of about 1% (Li et al., 2003). Based on long-term measurements from 1955 to 2001, the mean temperature in January is −6.1 °C and in July 24.7 °C. Mean relative humidity varies from 31% (April) to 54% (August). The first frost occurs in late September and the last frost ends in mid April. Annual mean precipitation is 191 mm, about 80% of which falls between June and September. Annual class A pan evaporation is about 2400 mm. The area has large and dense reticulate dune chains. The main dune crest migrates southeastward at a velocity of 0.3–0.6 m $year^{-1}$. The soil is loose and impoverished mobile sand classified as Typic Psammaquents (Berndtsson et al., 1996). The groundwater is between 50 and 80 m and is thus unable to support the natural vegetation. Rainfall is the only source of fresh water. The natural predominant plants are *H. scoparium* and *A. squarrosum* with a cover of approximately 1–2% (Shapotou Desert Experimental Research Station, Chinese Academy of Sciences, 1991). A 16 km-long vegetated protection system was established in the 1950s. Initially, a sand barrier was established with woven willow branches or bamboos to reduce wind erosion. Behind the sand barrier, straw chequerboards (wheat or rice straw) were installed, usually with sections of 1 $m^2$ area. The straw structures remain intact for 4–5 years, facilitating the establishment of planted xerophytic shrubs which are typical in this highly eroded environment (Wang et al., 2006). The fixed sand surface has led to the formation of microbiotic soil crusts (see Fig. 1). Details on the soil composition analysis of the stabilized dune sand with and without microbiotic soil crust can be found in Wang et al. (2006).

### 2.2. Hydraulic measurements

Infiltration measurements were performed at supply potential of −1, −4, −7, −10, −18 cm using a tension disc infiltrometer


**Fig. 2.** Pictures of an infiltration experiment on crusted soil and on crust-removed soil.