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Effects of sand burial on dew deposition on moss soil crust in a revegetated area of the Tennger Desert, Northern China

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SUMMARY

Sand burial and dew deposition are two fundamental phenomena profoundly influencing biological soil crusts in desert areas. However, little information is available regarding the effects of sand burial on dew deposition on biological soil crusts in desert ecosystems. In this study, we evaluated the effects of sand burial at depths of 0 (control), 0.5, 1, 2 and 4 mm on dew formation and evaporation of three dominant moss crusts in a revegetated area of the Tengger Desert (Northern China) in 2010. The results revealed that sand burial significantly decreased the amount of dew deposited on the three moss crust types by acting as a semi-insulator retarding the dew formation and evaporation rates. The changes in surface temperature cannot fully explain the variations of the formation and evaporation rates of dew by moss crusts buried by sand. The extension of dew retention time was reflected by the higher dew ratios (the ratio of dew amount at a certain time to the maximum value in a daily course) in the daytime, and may to some extent have acted as compensatory mechanisms that diminished the negative effects of the reduction of dew amount induced by sand burial of moss crusts. The resistances to reduction of dewfall caused by sand burial among the three moss crusts were also compared and it was found that *Bryum argenteum* crust showed the highest tolerance, followed by crusts dominated by *Didymodon vinealis* and *Syntrichia caninervis*. This sequence corresponds well with the successional order of the three moss crusts in the revegetated area, thereby suggesting that resistance to reduction of dewfall may act as one mechanism by which sand burial drives the succession of moss crusts in desert ecosystems. This side effect of dew reduction induced by sand burial on biological soil crusts should be considered in future ecosystem construction and management of desert area.

1. Introduction

The availability of water largely determines the ecological processes of arid areas and ancillary water from sources other than rainfall, e.g. dew, fog and atmospheric water vapor, serves as an important additional source of moisture for organisms. Although usually smaller in quantity, ancillary water wets and dries the upper soil surface more frequently than rainfall in arid areas, and strongly influences organisms that dwell on the soil surface (Agam and Berliner, 2006; Kaseke et al., 2012).

Biological soil crusts (BSCs) are comprised mostly of cryptogams, such as moss, lichen, and algae. They dominant the soil surface in arid areas and have critical roles in determining the composition, structure, and function of many desert ecosystems (Belnap and Lange, 2003). In addition to strongly increasing the stability and nutritional levels of upper soil layers, BSCs also provide a favorable micro-habitat for other organisms. However, the functions of BSCs are very sensitive to changes in water availability, sourced not only from rainfall (Belnap et al., 2004; Coe et al., 2012), but also from fog and dew (Csintalan et al., 2000; Jacobs et al., 1999; Kidron et al., 2002; Wilske et al., 2008). Considering the poikilohydric features, small-size with low growth habit, and overall small biomass of BSCs, dew may have very strong influences on crust biota and may further have critical roles in arid ecosystems. Dew provides short-term amelioration of vapor-pressure deficits, maintains a pre-activated state for subsequent rainfall events (Wilske et al., 2008), activates photosynthesis (Jacobs et al., 1999), and prolongs metabolic activity (eg. Lange et al., 1998). Dew may also influence the growth (Pan et al., 2013), distribution, development and succession of BSCs in the long-term (Kidron et al., 2002; Liu et al., 2006; Prado and Sancho, 2007). Thus,

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a mutually enhanced effect occurs between dew availability and BSCs development in many desert areas (Kidron et al., 2002; Liu et al., 2006; Zhang et al., 2009).

BSCs dominated by mosses are usually the last successional stage in arid areas and they harvest the largest amount of dew (Liu et al., 2006; Zhang et al., 2009). The stable, continuous occurrence of dew deposition is vital for the daily functions of mosses. Dewfall can directly wet moss caulidium (Kidron et al., 2002), resulting in photosynthetic biomass accumulation in the early-mornings (Csintalan et al., 2000; Stradling et al., 2002; Tuba et al., 1996), and the production of mature sexual organs (Kidron et al., 2002) when its amount is large. When dewfall is small it is still able to reduce transpiration stress and results in a pre-activated state for crust mosses to respond to the next rainfall event, thus enhancing the utilization efficiency of rainfall (Wilske et al., 2008). The long-term consequences of decreases in dew availability and quantity would indirectly induce imbalances of carbon gains and modify the distribution and succession of crust mosses in arid desert ecosystems (Alpert and Oechel, 1985; Kidron et al., 2002; Proctor, 2003). The effects of dew on moss soil crusts are highly susceptible to changes in environmental factors (eg. angle and aspect, see Kidron, 2005) and disturbances such as trampling (Lalley and Viles, 2006).

Burial of BSCs by wind-blown sand is common in many desert areas. Through bringing about changes in physical factors such as moisture, temperature, aeration, and other aspects of the plant and the soil micro-environment, sand burial may act as a filter eliminating sensitive species, and thereby determining the composition and distribution of desert vegetation to a large extent (Harris and Davy, 1988; Maun, 1994, 2004). Crust cryptogams are very susceptible to stress by sand burial because of their occurrence on the surface and short stature, even when the burial depth is shallow (Jia et al., 2008).

In the Tennger Desert, the fourth largest desert of China (location of the present study), dewfall and sand burial are two common natural phenomena and are reported to be closely related to the development and succession of BSCs (Jia et al., 2008; Liu et al., 2006). Dewfall is beneficial for BSCs organisms (Pan et al., 2013) and its amount corresponds well with increasing developmental levels of BSCs, from algal crust to moss crust (Liu et al., 2006). Burial by sand is detrimental to BSCs development and determines the succession of species in BSCs, in the sequence dominated by: *Bryum argenteum* Hedw., *Didymodon vinealis* (Brid.) Zand. [(Syn. *D. constrictus* (Mitt.) Saito, *D. tectorum* (C. Muell.) Saito)], *Syntrichia caninervis* Mitt. and *Collema tenax* (Swartz) Ach., respectively. The first three are moss crusts, and the last is a lichen crust (Jia et al., 2008). This raises two questions: (1) Does sand burial affect dew availability to BSCs, and if so, how and to what extent? (2) Are there differences between the responses to dew availability among different crust types? Specifically, do the earlier successional stages of moss crust types have advantages, or higher resistance to losses or reduction of dew harvest ability when subject to sand burial than the later ones? In general, sand cover improves the water status and extends moisture retention in buried soil (Meng et al., 2011; Li et al., 2014). However, less information is available regarding the influence of sand burial on dew availability at the micro-hydrological scale relevant to BSC. Although some studies have been conducted to determine the effects of sand burial or gravel mulch on dew condensation on bare (abiotic) soil surfaces (Graf et al., 2008; Kaseke et al., 2012; Li, 2002), little information is available for BSCs and BSCs-covered soils. This study is a further development of our previous study (Jia et al., 2008) and aimed to investigate the effects of sand burial on dew trapped by three moss crust types. In addition, the resistances to reduction of dewfall of three types of moss crust when subject to sand burial were compared, and the corresponding mechanisms discussed. Our initial hypotheses are that sand burial reduces the amount and retention duration of dew by three moss crusts, and that their resistance to loss of dew absorption by burial by sand is in accordance with their succession sequence.

2. Materials and methods

2.1. Study area

The study site is 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), Northern China. This area belongs to the transitional zone from desert steppe to steppified desert and the transitional belt between desert and oasis. The mean annual temperature is 10.6 °C and the mean annual precipitation is 186 mm, approximately 80% of which falls from May to September. The landscape forms of the study region are large and dense reticulate barchan chains of sand dunes where the predominant native plants are *Hedysarum scoparium* Fisch. and *Agriophyllum squarrosum* Moq. that cover about 1% of the surface. No BSC is found on the surface of the mobile sand dunes (Li et al., 2010, 2014).

An unirrigated vegetation system was originally established in 1956 to stabilize mobile dunes through a combination of wind-breaks, straw checkerboard barriers and planted xerophytic shrubs, and the treated area was expanded in 1964, 1981 and 1987. Crust organisms began to colonize and develop progressively and the surface became increasing stabilized. Wind-blown sand and its re-deposition gradually reduced, reducing sand burial stress on BSCs growth. In this process, dew was found to be an important source of water for xerophytic plants, especially in the inter-spaces between re-vegetated plants that were inhabited by BSCs, where it benefited the formation and succession (Liu et al., 2006; Pan et al., 2010). For this study, we chose the revegetated area established in 1981 as the study site as it is the most recent area among the four revegetated areas where the three moss crusts emerged in the sequence of those dominated by *B. argenteum*, *D. vinealis* and *S. caninervis*. Information regarding the three types of moss crusts is shown in Table 1.

2.2. Sampling and treatments

There is no internationally accepted standard method or instrument for measuring dew (Agam and Berliner, 2006; Liu et al., 2006). In our study area, dewfall accounts for about 92% of the total dew amount, and its active layer is limited to the upper 0–3 cm depth of the upper soil (Feng et al., 1998; Liu et al., 2006). The soil surface temperature usually cannot drop below the estimated dew-point during the growing season (Pan et al., 2010). In this study, dew is defined as atmospheric moisture condensed at a substrate surface (Li, 2002).

The total amount of dew deposited on moss crusts, which are subject to being buried with varying depths of sand, consists of two parts: one is the amount of dew intercepted by the sand-mulch layer covering moss crusts, and the other is the quantity of dew trapped by the crust underlying the sand layers. It is very difficult to directly measure the amount of dewfall of either part separately without disturbing the integrity of the materials. In order to quantify the effects of burying BSCs with sand on dewfall, we developed the following protocol. The net dew amount harvested by a moss crust (the latter part) was determined by the difference between the dew amount deposited on a moss crust buried with a certain depth of sand (the total amount) and the dew amount intercepted by the sand-mulch layer covering the moss crust (the former part).