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Research papers

Increasing effect of biocrusts on evaporation is evidenced by simulating evaporation and diffusion experiments and water stable isotope analysis

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ABSTRACT

Evaporation, one of the main components of the water and energy balance between soil and atmosphere, plays a key role in hydrological processes particularly in semi-arid and arid climate regions. As critical living organism communities inhabiting the soil-atmosphere boundary, biocrusts are capable of modifying near-surface soil properties and structure in drylands. However, the roles of biocrusts in mediating soil evaporation still remain greatly controversial, and the literature yet lacks in a systematic assessment. In this study, evaporation experiments were conducted under simulated isothermal and non-isothermal conditions for bare soil and three types of biocrusts (cyanobacterial, moss, and their mixture) sampled from a semi-arid climate region of the Chinese Loess Plateau. During the evaporation, soil temperature and moisture were measured at depths 2, 5, 10, and 15 cm for those biocrusts and bare soil. Their water vapor diffusion process and stable isotopic composition were also analyzed in the laboratory. We found that the measured evaporation yielded 4.9%, 17.5%, and 31.6% higher average evaporation rate for cyanobacterial, cyano-moss, and moss crusts, respectively, when compared to the bare soil. In comparison to bare soil, all types of biocrusts markedly reduced the rate of temperature rise, prolonged the duration of wetting time, and delayed the formation of dry surface layer. The largest regulating effects on soil temperature and moisture were found in the moss crusts instead of cyanobacterial or cyano-moss crusts. The increasing evaporation in biocrusts was attributed to their higher fine particle content, lower bulk density, and greater water holding capacity. Moreover, the water vapor diffusion rate and diffusivity of biocrusts were 18.2% and 16.4% higher than those of bare soil, respectively, which is attributable to the increased total porosity and better soil structure. Additionally, the isotopic composition of soil water (0–50 cm) in bare soil and moss crusts was distributed below the local meteoric water line. The mean $\delta^{18}O$ and $\delta^{2}H$ in soil water gradually decreased with increasing soil depth, and the moss crusts were more isotopically enriched than bare soil. Based on the enhanced soil evaporation rate, improved vapor diffusivity, and enriched isotopic composition of biocrusts in contrast to bare soil, we conclude that biocrusts exacerbate vapor transport and evaporative loss, and consequently they are crucial surface cover in rebalancing surface ecohydrological and biochemical processes in global drylands. These findings improve our understanding of the complexity of dryland hydrology, and a full consideration should be given in future biocrust studies.

1. Introduction

Biocrusts are photoautotrophic communities of cyanobacteria, algae, liverworts, lichens, and bryophytes that co-occur with heterotrophic bacteria, archaea, and fungi, forming a special encrusted layer within or immediately on the uppermost few millimeters or even centimeters of the soil surface (Belnap et al., 2003). According to recent studies, biocrusts are especially prevalent in water-limited ecosystems and currently cover ~30% of global dryland soil (Rodríguez-Caballero et al., 2018) and ~14% of China's dryland soil (Qiu et al., 2023). Biocrusts are

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