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Insights about biocrust effects on soil gas transport and aeration in drylands: Permeability, diffusivity, and their connection to hydraulic conductivity

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ABSTRACT

Soil gas transport properties and aeration are essential influencing factors of soil chemical and biochemical reactions, especially the respiration processes of plant roots and microorganisms. As ecosystem engineers in drylands, biocrusts may greatly alter surface soil gas transport properties and aeration, but their influences remain unclear and understudied. In a semiarid dryland ecosystem on the Chinese Loess Plateau, the air permeability of bare soil and three types of biocrusts (cyanobacterial, cyanobacterial-moss mixed, and moss crusts) were measured in-situ with naturally changing soil water content. Undisturbed soil samples were also taken for each treatment, and their air permeability and relative gas diffusivity at air-dried and near-saturated conditions, as well as saturated hydraulic conductivity, were determined in the laboratory. We further analyzed the relationship between saturated hydraulic conductivity and air permeability or relative gas diffusivity and calculated the gas and permeability continuity (specific air permeability and specific gas diffusivity) and tortuosity indexes at air-dry and near-saturation. Our results showed that biocrusts were associated with a significantly higher air permeability in contrast to bare soil, and the in situ mean air permeability ranked in order of moss crusts > mixed crusts > cyanobacterial crusts > bare soil. At air-dried condition, biocrusts increased surface soil air permeability by 26% and relative gas diffusivity by 46% as compared with bare soil through decreased surface soil bulk density. In contrast, at near saturation biocrusts decreased air permeability and relative gas diffusivity by 33% and 20%, respectively, which was attributed to pore-clogging by extracellular polymeric substances of biocrusts (3.37 vs. 2.27 mg g^{-1}). Accordingly, at air-dried condition biocrusts increased specific air permeability by 11% and specific gas diffusivity by 30% but decreased tortuosity by 7%. In contrast, they decreased specific air permeability by 76% and specific gas diffusivity by 39% but increased tortuosity by 28% at near-saturated condition. Additionally, the saturated hydraulic conductivity of cyanobacterial, cyanobacterial-moss mixed, and moss crusts were respectively 77%, 69%, and 61% lower than that of bare soil. We found that the relationship between saturated hydraulic conductivity and air permeability or relative gas diffusivity of biocrusts at air-dried condition can be well fitted with a positive linear log–log model ($R^2 > 0.95$). In general, the improved gas transport properties of surface soil caused by different types of biocrusts leads to better soil aeration, which in turn would facilitate microbial activity, soil respiration, and root growth; and impact surface soil water vapor movement induced by evaporation or condensation processes in drylands. Therefore, biocrusts should be carefully considered in further assessments of global dryland hydrology and carbon or nitrogen cycling under changing climate.

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