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Modelling the exchanges of water, energy and soil carbon in a dryland ecosystem with high plant-interspace heterogeneities

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CO_2 exchange between soil and atmosphere (FS) constitutes a major carbon (C) loss from terrestrial ecosystems. In arid and semiarid (dryland) ecosystems, the dynamics of FS represents the mixed effects of CO_2 production, transportation and surface exchange processes (e.g. biocrust photosynthesis, respiration and photodegradation), which closely link to the plant-interspace heterogeneities of water-energy conditions. Existing models for dryland ecosystems largely overlooked the interaction of water-energy dynamics at plant cover and interspace or the complexity of soil C processes. In this work, a process-based model was developed to simulate the exchanges of water, energy and soil carbon in dryland ecosystems, with focuses on investigating (i) the effects of plant-interspace interactions on water-energy balances, and (ii) the roles of different C processes and plant-interspace heterogeneties in regulating the FS dynamics. The model employed a two dimensional scheme to describe the plant-interspace heterogeneities. The soil-vegetation-atmosphere transportation of water, vapor and energy were integrated with horizontal flows between areas with plant cover and without. To simulate the diurnal and seasonal dynamics of FS, the model considered simultaneously autotrophic-heterotrophic respirations, transportaion of gasous and dissolved CO_2, and the surface exchanges by biocrust and photodegradation, as driven by the water-energy processes. The model was parameterized and validated with multivariate data measured from two nearby sites in a semiarid shrubland ecosystem in Yanchi, northwestern China.

The model simulations showed mixed effects of plant-interspace advections on the simulated water-energy budget. The advections of heat and vapor aboveground significantly enhanced the evapotranspiration rate at the plant cover (PC), whereas the root uptake and horizontal inflows from the interspace compensated over 40% of water loss from PC annually. The presence of plant cover decreased the rate but increase the temperature sensitivity of root-zone respiration, probably due to the shading and cooling effects of foliages. On the other hand, the sensitivity of root-zone respiration to water content were lower under canopy, which may relate to the advection of soil water from the interspace to plant cover. The simulations further showed that, the C processes other than autotrophic and heterotrophic respirations could impact the temporal dynamics of FS. During rewetting, the lichen-crusted soil could shift temporally from net CO_2 source to sink due to the activated photosynthesis of biocrust and enhanced CO_2 dissolution, and the emission of respired CO_2 at rain pulses could be delayed by over 24 hours. Such variability subjected further to soil properties such as hydraulic features, pH and the content of organic matters. To conclude, the complexity and plant–interspace heterogeneities of water-energy-C processes should be carefully considered to extrapolate findings from chamber to ecosystem scales and to predict the ecosystem responses to climate change and extreme climatic events. Our model can serve a tool to simulate the C-water dynamics in sparse-vegetated ecosystems regarding such complexities.