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Grazing modulates soil temperature and moisture in a Eurasian steppe

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ABSTRACT

Few studies have addressed the potential grazing effects on microclimate, such as surface temperature and moisture, and their feedback effects on grassland function. A continuous, approximately three-year long study was conducted in experimental plots of various grazing intensities, and *in situ* soil temperature and moisture were measured. The results indicated that grazing significantly altered soil temperature and moisture. Soil temperature increased exponentially with increasing grazing intensity in the warm season due to the removal of aboveground biomass (AGB) and decreased linearly with increasing grazing intensity in the cold season due to decreases in both AGB and wind-blown snow accumulation. Heavy grazing increased soil temperature (10 cm depth) by an average of 2.6 °C from April to October (the largest hourly temperature increase was 8.8 °C), representing a soil warming effect 3.7 times that of global warming. Our findings showed that, compared with ungrazed plots, grazed plots had decreased soil water storage due to less winter snow accumulation, especially in the early growing season (EGS) because of the smaller amount of winter snow accumulation than in ungrazed plots. In the EGS, the average water storage in the 0–100 cm layer of the ungrazed plots was 23.3%, which was 1.3–1.8 times that of the grazed plots. Our results showed that grazing also produced warming and drying effects on grassland soil. The long-term feedback effects of grazing-induced soil warming and drying on the ecosystem might be an important mechanism accelerating the degradation and desertification of these grasslands.

1. Introduction

Soil temperature and moisture are key variables influencing almost all ecosystem processes and functions. Whereas the *in situ* soil temperature and moisture are constrained by the regional climate, the vegetation, litter layers and soil are the foundations that regulate their magnitudes and dynamics (Geiger, 1965; Aalto et al., 2013). The canopy cover, litter depth and cover are among the most important mediators of soil temperature and moisture because they directly intercept incoming/outgoing radiation (i.e., net radiation, Rn), and they are also indirect regulators of other energy fluxes, such as the sensible heat flux (H), latent heat flux (LE), and soil heat flux (G) (Campbell and Norman, 1998; Chen et al., 1999; Shao et al., 2014, 2017; Han et al., 2014). G directly controls the changes in soil temperature, and LE (i.e., evapotranspiration) determines soil moisture (Fig. 1). Following this conceptual framework, the diel to interannual changes in soil temperature would be magnified significantly by reducing the vegetation cover and litter layer, whereas the changes in soil moisture may be reduced or unchanged.

Grazing is the most significant human practice in dryland ecosystems and has profound consequences for ecosystem functions, including the soil microclimate (Qi et al., 2017). Substantial scientific investigations have been conducted to understand the effects of grazing on grassland composition, structure, and function, as well as associated ecosystem processes (Olofsson et al., 2004; Altesor et al., 2005; Stark et al., 2015; Eldridge et al., 2016), but relatively few studies have considered the potential effects of grazing on surface microclimate factors such as the dynamics of soil temperature and moisture as well as the underlying mechanisms responsible for their changes and their feedback to grassland function. This lack of understanding of the effects of grazing on the soil microenvironment limits our ability to construct sound ecosystem models for ecosystem studies and manage livestock toward the sustainability of ecosystem goods and services without degradation.

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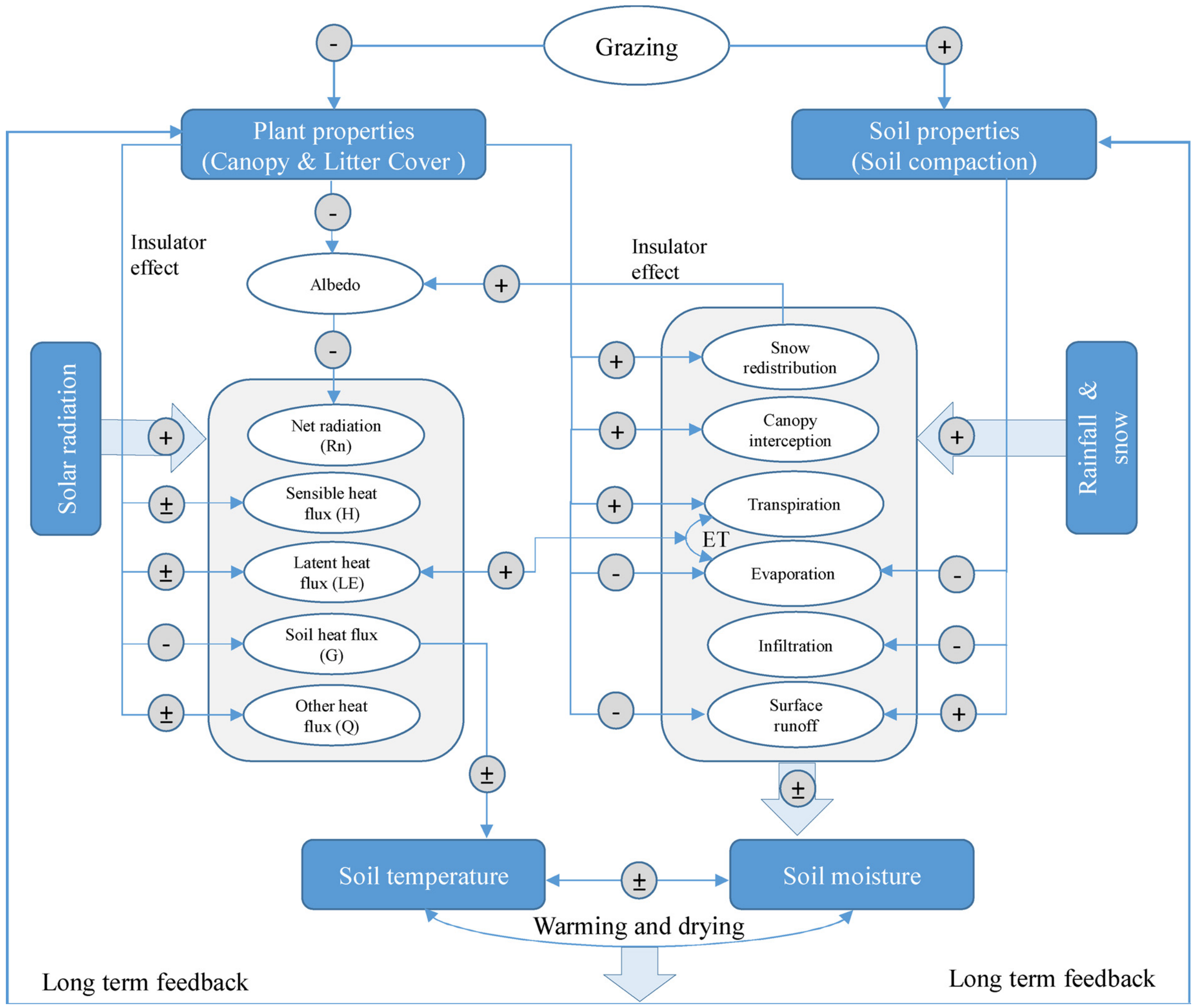

Fig. 1. Conceptual framework of grazing-driven changes to soil temperature and moisture. Grazing resulted in a series of changes to plant and soil properties. We selected the canopy and litter cover and soil compaction as the representative indicators for the plant and soil properties, respectively. We determined the positive or negative effects of these two indicators on the energy process and water process that ultimately influenced soil temperature and moisture. ET represents evapotranspiration. A plus sign surrounded by a circle indicates a positive effect; a minus sign in a circle indicates a negative effect. The presence of both a plus and a minus sign in a circle indicates that the sign (positive or negative) of the effect is unclear or depends on other conditions.

One of the major regulatory mechanisms for the changes in soil temperature by grazing is the reduction in the insulating effect of vegetation and the litter layer on Rn and G (Chen et al., 1999; Aalto et al., 2013; Cheng et al., 2008; Gornall et al., 2009; Hirsch et al., 2014; Savva et al., 2010) (Fig. 1). Decreased canopy cover and litter from grazing may decrease Rn due to increased reflection or albedo (Tian et al., 2017), but can also accelerate the incoming or outgoing of radiation on soil surface due to decreased shelter thus resulting in a higher G flux, which could increase or reduce soil temperatures depending on the direction of heat flux (Fig. 1) (Aalto et al., 2013; Blok et al., 2010; Shao et al., 2017). For example, Aalto et al. (2013) showed that vegetation plays an important role in moderating the variation in soil temperature in an Arctic-alpine system, and Porada et al. (2016) reported that bryophyte and lichen cover reduced the average soil temperature by 2.7 °C in high-altitude regions. Özkan and Gökbulak (2017) demonstrated that the removal of woody vegetation increased the mean daily soil temperatures even at a depth of 40 cm. Our studies in Inner Mongolian grasslands have indicated that grazing can cause changes in Rn by 10% and G by 45% (Shao et al., 2017). In sum, previous reports have focused mostly on the effect of vegetation on energy fluxes and soil temperature in various ecosystems, with relative few studies examining the direct effects of vegetation cover change as a result of grazing's impact on soil temperatures (Zhao et al., 2011; Odriozola et al., 2014). Currently, the quantitative relationship between grazing intensity and soil temperature remains unknown due to a lack of long term and *in situ* experimental data.

The effects of grazing on soil moisture are complex but occur mostly through the reduction in canopy cover and compaction of the litter layer and surface soil, which directly alters a series of thermo-hydrological processes such as transpiration, evaporation, infiltration, and surface runoff (Vandandorj et al., 2017) (Fig. 1). Dense vegetation can increase soil moisture by reducing evaporative losses through shading and by reducing both the horizontal and vertical water flow in the soil (Aalto et al., 2013; Asbjornsen et al., 2011; Naeth et al., 1991). In contrast, plants can also promote soil drying by increasing transpiration and the interception of precipitation (Horton and Hart, 1998; Naeth et al., 1991). Prolonged and heavy grazing can also affect soil hydrologic processes (e.g., infiltration and retention capacity) by altering the physical properties of the soil. For example, increased compaction reduces soil water conductivity, promotes surface runoff, and increases the soil water-holding capacity (Vandandorj et al., 2017) (Fig. 1). Although grazing could influence soil moisture via multiple pathways, long-term continuous soil moisture observations especially under different grazing intensities are still lacking, which hinders our