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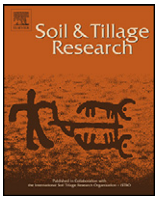

Effects of grazing intensity on soil thermal properties and heat flux under *Leymus chinensis* and *Stipa grandis* vegetation in Inner Mongolia, China

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ABSTRACT

The increase of grazing intensity may alter the fluxes of mass and energy in grassland ecosystem due to fast population growth and distinct land-use change. To understand effects of different grazing intensities on soil thermal properties and heat flux, 5 sites under two representative vegetation types: *Leymus chinensis* (LC) and *Stipa grandis* (SG) in Inner Mongolia, China were investigated: two un-grazed sites since 1979 (LCUG79 and SGUG79), two moderately grazed sites which are winter grazed in LC (LCWG, 0.5 sheep units ha^{-1} year^{-1}) and continuously grazed in SG (SGCG, 1.2 sheep units ha^{-1} year^{-1}), and one heavily grazed site (LCHG, 2.0 sheep units ha^{-1} year^{-1}). Soil water content and temperature were registered in the growing seasons: 2008 and 2009. The results in the more sensitive top 20 cm layer showed that heavy grazing induced the lowest soil water content, followed by winter grazing in the LC region. Continuous grazing caused higher soil moisture compared with un-grazed in SG region, which can be explained by the on site adjusted grazing intensity. For all sites, soil volumetric heat capacity and thermal conductivity increased with depths, which was in accordance with soil moisture. In LC region, the thermal conductivity was greater at the LCHG site than at the LCUG79 and LCWG sites, but the volumetric heat capacity was not significantly different between them. In SG region, these properties were greater at SGCG site than at SGUG79 site. Net soil heat flux generally moved downwards during the growing season. The greatest value was at LCHG site but lowest at LCUG79 site in LC region. On the contrary, a lower value was observed at SGCG site because of higher soil water content compared with SGUG79. For two un-grazed sites, heat flux was greater under SG vegetation than under LC vegetation. The long-term rainfall induced upward heat flux, but short-term rainfall caused a sharply downward increase. Without raining, the daily maximum and minimum of heat flux concurred with those of air temperature at LCHG site, but delayed at other sites. In conclusion, we can state that grazing intensity affects the soil thermal properties and heat flux, but vegetation type was only verified to impact heat flux. An appropriate grazing intensity improves soil water and thermal regimes compared with the long-term un-grazed sites.

1. Introduction

In Inner Mongolia grassland, China, both population growth and a quick land-use change enhanced over the past decades. The traditional extensive, semi-nomadic sheep grazing system changed to a dramatically intensified stationary livestock farming, which resulted in over-grazing and over-cropping in some areas. It is estimated by the UNEP (United Nations Environment Programme) that 60–70% of the grasslands in China are affected by deterioration and desertification mainly due to heavy grazing (Graetz, 1994). Heavy grazing accompanied with animal trampling has detrimental effects on soil hydraulic and mechanical properties especially if soils are either too wet and therefore susceptible to homogenization by puddling or mostly too dry with therefore reduced cohesive forces (Greenwood and McKenzie, 2001; Reszkowska et al., 2011a). Especially in the topsoil, soil deformation results in a decrease of pore volume and an increase in finer pores, i.e. changed soil water retention characteristics (Martinez and Zinck, 2004; Kutílek et al., 2006), and is even more important to the changes in water and air fluxes (Willat and Pullar, 1983; Krümmelbein et al., 2006; Reszkowska et al., 2011b). Heavy grazing also can lead to changes in vegetation cover (Paruelo et al., 2001) and plant community composition in grasslands (Li, 2001; Oba et al., 2001; Zhang and Skarpe, 1996).

An often neglected property concerning plant growth, evapotranspiration and even flux processes is the soil temperature, as it is a primary factor in determining the rates and directions of soil physical processes and of energy and mass exchanges with the

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atmosphere. It varies in response to changes in radiant, thermal, and latent energy exchanges taking place primarily through the soil surface (Tyagi and Satyanarayana, 2010). Soil thermal properties like thermal conductivity and volumetric heat capacity play an important role in the surface-energy partitioning and temperature distribution (de Vries, 1987; Horton and Chung, 1991; Noborio et al., 1996; Tyson et al., 2001), which all are driven by soil moisture distribution and absolute values, and are also influenced by soil composition, soil structure, and vegetation cover (shading, root influence on soil moisture content) (de Vries, 1966; Dec et al., 2009; Ju et al., 2010). Any practice or process which causes changes of the bulk density, porosity as well as pore size distribution and arrangement of particles within aggregates at a given water content have a significant effect on thermal conductivity. Abu-Hamdeh (2000) stated that the thermal conductivity increased with increasing bulk density as a result of particle contact enhancement as porosity decreased. In addition to compaction, tillage can influence soil water content and other physical characteristics which have also an impact on soil thermal conductivity (Al Nakshabandi and Kohnke, 1965; Cochran et al., 1967; Fritton et al., 1974; Dec et al., 2009). Bristow and Horton (1996) and Kustas et al. (2000) demonstrated the effects of partial surface mulch and clustering of the vegetation cover on soil heat flux. Reduced soil disturbance due to long-term no-tillage induced changes in soil organic matter, aggregate size distribution and water storage capacity compared with a conventional tillage system thereby, altering above various factors affecting heat conduction (Arshad et al., 1990; Chang and Lindwall, 1992; Azooz et al., 1997; O'Donnell et al., 2009).

The perennial rhizome grass *Leymus chinensis* and bunch grass *Stipa grandis* (Tong et al., 2004; Chen et al., 2005) cover about 60% of the total land area in the Xilin River catchment in Inner Mongolia grassland (Li et al., 1988). Livestock grazing is however recognized as one of the main causes of soil and vegetation degradation in Inner Mongolia grassland. Grazing associated with animal activity alters soil hydraulic and mechanical properties (Greenwood and McKenzie, 2001) and heat flux by the variety of plant height and vegetation cover which contribute into the change in surface temperature (Li et al., 2000). It is also well known that many arid and semi-arid types of grassland have experienced a shift in dominant vegetative composition from perennial grasses to shrubs and bare soil, a change which coincides with desertification (Daily, 1995; Van Auken, 2000; Scheffer et al., 2001; Jackson et al., 2002). Such extensive shift in vegetation and desertification are caused by stationary livestock farming and the increase of livestock in Inner Mongolia grassland in the past four decades (Cao and Yang, 1999). Some studies have also shown that there are distinct differences in the morphology and photosynthetic physiology between two species *L. chinensis* and *S. grandis* (Du and Yang, 1988; Du et al., 1999; Cui et al., 2001) which also may affect the water use and heat transport of these two species in the semi-arid grassland and may result in different strategies to overcome mechanical and hydraulic stresses under those climatic conditions.

The MAGIM project (Matter fluxes in grasslands of Inner Mongolia as influenced by stocking rate) carried out in Inner Mongolia grassland aims to understand how sheep grazing affects water, carbon and nitrogen fluxes at various spatial and temporal scales (Reszkowska et al., 2011a,b; Wiesmeie et al., 2010; Wittmer et al., 2010). In the following the effect of grazing on soil thermal properties and heat flux as affected by grazing intensity and vegetation cover (*L. chinensis* or *S. grandis)* more controlled in situ conditions will be described based on the hypotheses: grazing will enhance the heat flux compared with un-grazed sites and that soils under *S. grandis* and *L. chinensis* vegetation have different thermal properties and result in different heat fluxes.

Therefore, our objectives were: (i) to characterize the spatial and temporal distribution of soil thermal properties within the soil profiles and (ii) to quantify soil heat flux as affected by different grazing intensities and vegetation type in Inner Mongolia grassland, China.

2. Materials and methods

2.1. Study site description

The research was carried out on a long-term experiment established at the Inner Mongolia Grassland Ecosystem Research Station (IMGERS; 43°37′50″N, 116°42′18″E) situated in the Xilin River catchment, Northern China. The experiment evaluated the effect of grazing intensity on mass flux in the continental semi-arid grasslands of the Central Asian steppe ecosystem, with a dry and cold middle latitude climate (Kawamura et al., 2005). In the last two decades, the annual mean air temperature was 0.7 °C and the annual mean minimum temperature was approx −20 °C. Annual precipitation was 343 mm in which less than 5% fell as snow for the period 1982–2003. More than 85% of the annual precipitation is concentrated during the growing season (May to September). The vegetation is characterized by the perennial rhizome grass *L. chinensis* (LC) and bunch grass *S. grandis* (SG) (Tong et al., 2004; Chen et al., 2005), which cover about 60% of the land area in the Xilin River catchment (Li et al., 1988). Soils were classified as Calcic Chernozems (IUSS Working Group WRB, 2006) developed from aeolian sediments deposited on a pleistocene basalt plateau (Wiesmeier et al., 2009).

In this case study, both representative vegetation types: *L. chinensis* (LC) and *S. grandis* (SG) under different grazing intensities were investigated. In the LC region the following sites were investigated: un-grazed since 1979 (LCUG79, 24 ha), grazed in winter (LCWG, 40 ha) with 0.5 sheep units ha^{-1} year^{-1}, and heavily grazed (LCHG, 100 ha) with 2.0 sheep units ha^{-1} year^{-1}. In the SG region the following sites were investigated: un-grazed since 1979 (SGUG79, 24 ha), and continuously grazed (SGCG, 100 ha) with 1.2 sheep units ha^{-1} year^{-1}. Both LCWG and SGCG were defined as moderate grazing intensity. The distance between LC and SG regions is about 10 km.

2.2. Soil sampling and analyses

At each site three replicate profiles within a distance of 15 m Theta-probes (Type ML2x, Delta-T Devices, Cambridge, UK) were installed at 5, 20 and 40 cm depths to monitor soil moisture and platinum ground temperature probes (Pt-100) within the measurement error of ±0.30 °C at the same depths measured soil temperature. All sensors were connected to one solar powered automatic data-logger, which recorded soil water content and soil temperature at 30-min intervals. The Theta-probes were calibrated for the site-specific soil using the gravimetric method. The technical specification of the Theta-probe has a measurement error of $\pm 0.01\ \text{cm}^3\ \text{cm}^{-3}$ from 0 to 40 °C (Delta-T Devices Ltd., 1999). In winter the top soil was almost frozen at all sites, thus the limitation of Theta-probe might induce the errors of soil water content so that only the data of the growing season were further analyzed and presented in this study. Rainfall was measured by rain gauges (DECAGON DEVICES ECRN-100). The whole study period lasted from 1st of May 2008 to 30th of September 2009, however, some probes and/or data loggers were out of order for 8 weeks at the LCWG site in 2008 and 12 weeks at the LCHG site in 2009, respectively. Thus, we compared the effect of grazing intensity on soil thermal properties and heat flux under LC vegetation using the data of 2008 and under SG vegetation using the data of 2009, respectively. The effect of vegetation type on two un-grazed soil thermal regimes was analyzed using the data of