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Ecosystem responses to mowing manipulations in an arid Inner Mongolia steppe: An energy perspective

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ABSTRACT

Mowing for hay is a widely adopted practice for grasslands utilization and management. However, its effects on energy partitioning have not well been studied. Our primary objective was to examine the role of mowing as a disturbance factor acting on energy partitioning and relationships between community composition/structure and energy fluxes in a typical steppe ecosystem through a long-term field experiment in Inner Mongolia. After four years of annual mowing, dominant species changed from *Stipa krylovii* to *Artemisia frigida*. Mowing decreased hay productivity via the reduction of palatable perennial bunchgrass. During the growing season, soil moisture was 47.5% lower and soil surface temperature was 7.4 °C higher at midday and 2.2 °C lower at predawn, with a 4.2 °C greater diurnal soil temperature range at 2 cm depth in the heavily mowed plots compared to that in the unmowed plots. Heavily mowing lowered 6% net radiation and 98 MJ m^{-2} available energy, but elevated 2.1 times soil heat flux. Heavily mowed plots shared higher sensible heat flux, but similar latent heat flux. The absence of mowing might alleviate the stress of high temperature and drought during the hot and dry periods, leading to a high resistance of vegetation to environmental changes.

1. Introduction

Energy fluxes, such as net radiation, soil heat, latent heat and sensible heat, represent the complex functions of long-term interactions between human disturbances, climate and water cycling, and of short-term interactions between plant physiological processes and the development of the atmospheric boundary layer in terrestrial ecosystems (Wilson et al., 2002). Vegetation, as an intermediary, plays a central role in buffering the mass and energy exchanges of land surfaces and the atmosphere (Baldocchi et al., 1988; Beringer et al., 2005). Species composition, structure and distribution of vegetation could be directly affected by the changes in climate and energy partitioning (Kittel et al., 2000), disturbances and management (Schippers and Joenje, 2002). In return, any changes in vegetation composition and structure would further bring significant influences on the heat and water regimes and budgets (Hernandez-Ramirez et al., 2010; Li et al., 2000), causing significant feedbacks to regional and global climate (Beringer et al., 2005; Eugster et al., 2000; Gu et al., 2005; Kellner, 2001).

Mowing for hay is a widely-practiced human disturbance and a pasture management type in grassland ecosystems (Bao et al., 2004; Luo et al., 2001). It resembles the grazing process in terms of canopy biomass removal in grassland ecosystems, causing substantial changes in the canopy structure, species composition and functional type (Poptcheva et al., 2009) and thereby dramatically affects the ecological and hydrological processes, including aerodynamic characteristics, microclimate, surface resistance to evaporation and soil water holding capacity (Chen et al., 2009; Li et al., 2000). It has been documented that mowing can lead to changes in the variability of environmental resources in an ecosystem (Chen et al., 1999, 2004). Changes in community structure could pose direct effects on soil heat flux, which can account for up to one third of the net radiation in arid and semi-arid grasslands (Li et al., 2006; Shao et al., 2008). Wan et al. (2002) found that mowing could increase the growing season soil temperature range by 4.3 °C in a Great Plains tall grass prairie. Klein et al. (2005) reported that mowing increased soil temperature by 1.7 °C and increased the maximum air temperature by 4.0 °C in the Tibetan Plateau rangeland. All of these studies pointed a conclusion that mowing would exacerbate the effects of climatic warming (Luo et al., 2001) and give evidences of near relationships between mowing disturbance and microclimate. However, significantly less effort had been made to examine the underline processes (i.e.,

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energy fluxes) that determine the microclimatic changes associated with the vegetation change.

The widespread occurrences of changes in microclimate arising from manipulation of terrestrial vegetation require great attention. Climate changes (e.g., temperature increases) caused by extensive land-use alteration may be as substantial at both local and regional scales as the predicted modifications caused by the greenhouse effect (Chen et al., 1999; Schwalm et al., 2010). Despite the important role that grasslands may play in regulating global climate change and the hydrological cycle, manipulative experiments to explore the relationships between energy partitioning and grassland management practices (e.g., mowing) and to reveal the potential contribution of grassland ecosystems to climate change at local scales have been extremely rare in the literature (Rosset et al., 2001).

These kinds of changes in microclimatic measures, such as light input, air temperature and humidity, soil temperature and moisture play important roles in plant growth and community structure, even exotic species invasion. Plant growth is affected directly by temperature change and indirectly by altering the ecosystem's moisture condition, length of its growing season, etc (Shaver et al., 2000). Each kind of plant has its favorable threshold of germination and death in light, temperature and moisture regimes. If extreme conditions exceed tolerance thresholds for certain species, growth patterns and species compositions will likely be altered (Ma et al., 2010; Wayman and North, 2007). We therefore also put the effort in explore plant species composition and growth with microclimate change.

Our objectives then are to examine the effects of mowing as a disturbance agent on energy partitioning and to explore the relationships between different heat fluxes and community composition and structure characteristics at the long-term field experimental site of CAS, located in the Inner Mongolian Autonomous Region of northern China. We hypothesized that mowing would lead to significant changes in energy partitioning, including an increase in soil heat, sensible heat and latent heat fluxes but with a decrease in net radiation due to lowered canopy buffering capacity that can be expressed in canopy architecture and community composition. We further hypothesized that the removal of biomass by mowing would facilitate and maintain plant coexistence and diversity by changing the surface environments.

2. Methods

2.1. Study site

The study was conducted during the 2007 growing season at the mowing plots of the long-term experimental of the Duolun Restoration Ecology Research Station (42° 50′ N, 116° 18′ E, elevation 1380 m asl., Fig. 1). The area belongs to a semi-arid agro-pastoral transitional region in southeastern Inner Mongolia, with a typical continental climate. The mean annual temperature is around 3.3 °C, with a mean monthly temperature ranging from −15.9 °C in January to 19.9 °C in July. The mean annual precipitation is ∼400 mm (375 mm in the study year), which falls primarily from May to October. The mean annual relative humidity is about 61%. Summers are damp and warm while winters are cold, dry and windy (5.2 m s^{-1} in winter and 2.6 m s^{-1} in summer in the study year). The study site was flat with relatively homogenous vegetation of a typical steppe ecosystem dominated by a perennial bunchgrass − *Stipa krylovii* Roshev. Other common species include *Artemisia frigida* Willd., *Potentilla acaulis* Linn., *Cleistogenes squarrosa* Trin., and *Allium bidentatum* Fisch. Ex Prokh.&Ikonn.-Gal. Soil is classified as chestnut soil (Chinese classification) or Haplic Calcisols according to the FAO classification, with 62.75 ± 0.04% sand, 20.3 ± 0.01% silt and 16.95 ± 0.01% clay. Mean bulk density is about 1.31 g cm^{-3} and pH is around 7.12 ± 0.07. The site has been fenced since 2001 to exclude large herbivores such as cattle and sheep, which had been previously grazed for several decades.

2.2. Experimental design

The experiment was designed using a single-factor with five mowing intensities aiming at maintaining post-harvest heights of 2 cm [R_2], 5 cm [R_5], 10 cm [R_{10}], 15 cm [R_{15}], and no mowing [R_c, control], with five replications for each treatment. Usually farmers

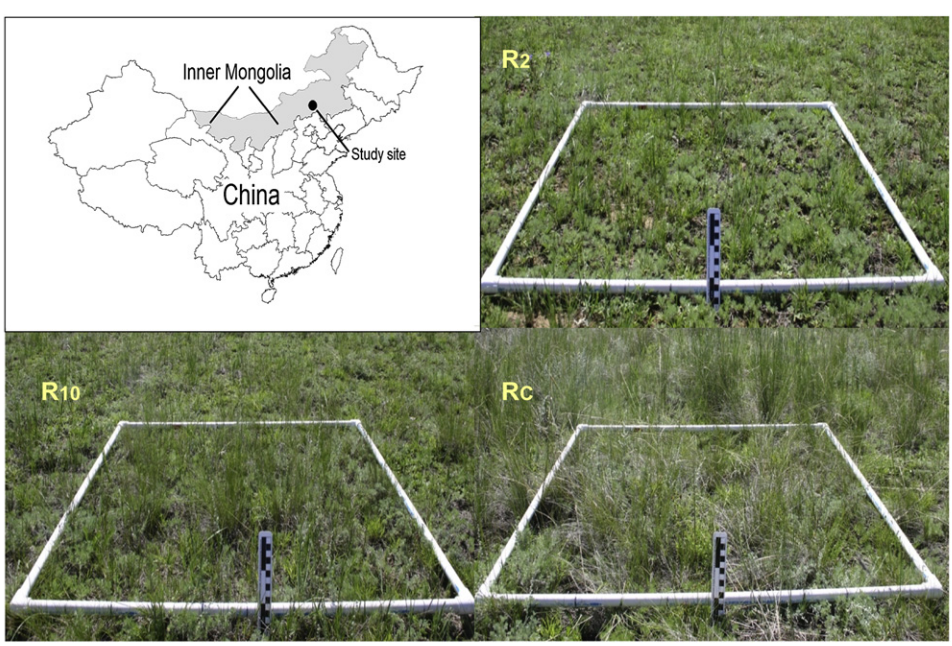

Fig. 1. Our study sites are located in a typical steppe grassland region of Inner Mongolia, China. R_2, R_{10}, and R_c represent three mowing treatments where the steppe was trimmed once a year to a height of 2 cm and 10 cm, or no mowing (i.e., control), respectively.