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Moderate grazing can promote aboveground primary production of grassland under water stress

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ABSTRACT

Comprehensive understanding on the response of net primary production (NPP) to grazing is still elusive. It is necessary to choose a suitable study area with significant differences in climate, landform, diverse grasslands and grazing intensity (GI), to better understand plant–herbivore interactions and what environmental conditions NPP may increase. This study used Biome-BGC model with inclusion of a grazing process and the effects of the excreta on vegetation to investigate the effects of grazing on the aboveground NPP (ANPP) in Tianshan Mountains-Junggar Basin with four grasslands along a climatic gradient from mountain to plain, i.e., alpine meadow (AM), mid-mountain forest-meadow (MMFM), low-mountain dry grassland (LMDG), and plain desert grassland (PDG). The model simulated ANPP agreed well with the measured values for both non-grazed and grazed experiments at four sites, suggesting that the model successfully captured the effects of grazing on ANPP. The model results based on different GI scenarios indicated that ANPP decreased with increasing GI at AM and MMFM. But at LMDG and PDG, ANPP increased when GI was smaller than optimal GI (GI_{opt}). After GI_{opt}, ANPP decreased with the increasing GI. This implied that appropriate GI stimulated ANPP at LMDG and PDG, with magnitude of 4.1–22% at LMDG and 6.6–15.7% at PDG. By investigating the annual evapotranspiration (ET) and soil volumetric water content under non-grazed and grazed conditions, it was found that grazing reduced ET and hence improved soil water at sites LMDG and PDG, which explained the different response of ANPP to GI in different grasslands. We concluded that the response of ANPP to GI highly depended on the climatic conditions in grassland ecosystems over Central Asia, and moderate grazing can promote ANPP under water stress.

1. Introduction

Grazing is a key disturbance that shapes the structure and function of grassland communities (McNaughton, 1983b, 1985). However, comprehensive understanding on the effects of the principle functional processes controlling the response of net primary production (NPP) to grazing is still elusive. The mechanism between grassland NPP and grazing activities under various ecological conditions or grazing intensities is poorly understood (Frank et al., 2002).

There has been a substantial debate about whether or not grazing can increase aboveground net primary productivity (ANPP). Grazing has traditionally been viewed as detrimental to plant growth (Painter and Belsky, 1993; Derner et al., 2006; Mikola et al., 2009), but it has been proposed that grazing, under certain conditions, may lead to compensatory growth (McNaughton, 1979, 1983a; Milchunas and Lauenroth, 1993; McNaughton et al., 1997; de Mazancourt et al., 1998; Schuman et al., 1999). In the North American Great Plains grazing by domestic herbivores has been shown to reduce NPP (Derner et al., 2006). But in European grasslands, the NPP tended to increase when biomass was cut or grazed (Milchunas and Lauenroth, 1993). In Phleum pratense-Festuca pratensis dairy cow pasture in Finland of northern Europe, however, grazing maintained original plant-community structure and decreased shoot mass (Mikola et al., 2009). It has been observed that primary productivity at first increased with grazing intensity (GI), reaching a maximum at a moderate rate of herbivory (McNaughton, 1979; Hilbert et al., 1981; Holland and Detling, 1990; Holland et al., 1992; Dyer et al., 1993; McNaughton et al., 1997) and decreased with further increase in GI. From both empirical (Williamson et al., 1989; Turner et al., 1993) and modeling data (Holland et al., 1992), herbivory often induces biphasic growth and development in plants, and these responses

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translate into a system-level optimization curve, wherein plant community NPP is maximized at a low level of herbivory and is severely reduced at high levels. However Biondini et al. (1998) did not find any consistent effect of grazing on ANPP.

Inconsistencies in the reported responses of NPP to livestock grazing may be the result of a number of factors that differ among studies, including differences in grassland types, environmental variables (climate, landform and soil etc.), plant community composition, and grazing history (Milchunas and Lauenroth, 1993; Li et al., 2005), differences in seasonal grazing frequency, intensity and duration (Reeder et al., 2004), and differences in research methodology (Williamson et al., 1989; Holland and Detling, 1990; Holland et al., 1992; Turner et al., 1993). Plants from areas with a history of heavy grazing, however, have higher ANPP than the same species from infrequently grazed areas (Jaramillo and Detling, 1988; Polley and Detling, 1988). Differences in ANPP between grazed and ungrazed treatments were more sensitive to varying environmental variables than to varying grazing variables (Milchunas and Lauenroth, 1993; Leriche et al., 2001). The geographical location where grazing occurs may be more important than how many animals are grazed or how intensively an area is grazed. Therefore, it is necessary to choose a suitable study area with significant differences in climate landform, and diverse grasslands and grazing systems/intensity, which is helpful to better understand plant–herbivore interactions and what ecological conditions or level of ecological organization NPP may increase, and to further clarify some controversy in whether or not herbivory can increase net primary production.

The Central Eurasia continent, the largest arid land in the world, is such a study area where the landscape was characterized by large mountainous basins and the climate was featured as distinct vertical gradients. Tianshan Mountains-Junggar Basin (TMJB), located in the centre of the Central Eurasia continent, was a representative grassland type in Central Eurasia continent. It consisted of a descending order of an alpine meadow (AM), mid-mountain forest-meadow (MMFM), low-mountain dry grassland (LMDG) and plain desert grassland (PDG). Grass ecosystems in the TMJB were very sensitive to both climate change and human activities (Luo et al., 2010). Grazing is the dominant human activity in the mountainous and desert grasslands over the TMJB. The number of domestic herbivores increased significantly in the grasslands of TMJB over the past two decades. Overgrazing became more and more evident due to increased intensive grassland use in this region (Zhao et al., 2007).

As the vast extent of arid area over Central Eurasia continent, it is of great importance to investigate the response of aboveground net primary productivity (ANPP) to GI for better understanding the interactions between grass and herbivore communities and sustainably maintaining the ecological function in grassland ecosystems. Investigating the response of ANPP to GI can be achieved in a relatively small field. Over larger areas, a simulation model is commonly used (White et al., 1997; Chen et al., 2007). Biome-BGC model has been widely used as a valid tool to simulate the dynamic of grass growth, the fluxes of CO_2 and H_2O between the plant and atmosphere (Running and Hunt, 1993; Running, 1994; Thornton et al., 2002). Biome-BGC did not include grazing process in its original version in the application for grassland ecosystems. However, a defoliation formulation developed by Seligman et al. (1992) was shown to be able to calculate the biomass consumed by animals and to analyze the production potential under grazing condition in grassland.

The objectives of this paper were therefore (1) to integrate grazing process into Biome-BGC model for addressing the effects of grazing on ANPP along the climatic gradients and their variations during the period 1959–2009 in different grasslands from the mountain to basin over the TMJB, (2) to investigate the response of ANPP to grazing intensity and to speculate the possible underlying mechanisms, and (3) to discuss under what ecosystem-environmental conditions grazing can promote ANPP of grasslands in the Central Eurasia continent.

2. Materials and methods

2.1. Study area

The study area is located in the Tianshan Mountains-Junggar Basin (TMJB), including the northern Tianshan Mountains and southern Junggur Basin (Fig. 1). Along the vertical gradients, four bio-geographic types of grasslands occur (Table 1), AM (2700–3500 m a.s.l.), MMFM (1650–2700 m a.s.l.), LMDG (650–1650 m a.s.l.), and PDG with an elevation lower than 650 m a.s.l. The mean annual precipitation and temperature in the MMFM recorded at Tianchi meteorological station are 592 mm and 2.2 °C during the period 1959–2009. 70% of the annual precipitation falls between May and September. Annual mean potential evaporation is 1368 mm. The AM is covered by alpine or sub-alpine meadow. Above the AM belt (3500–4000 m), the ground is bare or covered by modern glacial and permanent snow. In the MMFM, the sunny hillside is mainly covered by grasses with a coverage of larger than 70%. On the shaded hillside, Tianshan Mountain spruce (*Picea schrenkiana* var. tianshanica Cheng et Fu) woodland grows, under which there are skiophyte shrubs and grasses. LMDG, located at the transition between the mountain and basin, is characterized by dry grassland or desert shrubland with coverage of 30–80%. According to precipitation–evaporation ratio, plants growing in the PDF and LMDG are subject to water stress but not ones growing in the MMFM and AM.

Table 1
The information on grasslands and conventional grazing systems during the period of 1959–2009 in the northern Tianshan Mountains and southern Junggur Basin.

Type of grasslands	Altitude (m a.s.l.)	Vegetation coverage (%)	Climate condition				Spring rangeland		Summer rangeland		Autumn rangeland		Winter rangeland	
			T (°C)	P (mm)	E (mm)	P/E	Start/ end day	Days	Start/ end day	Days	Start/ end day	Days	Start/ end day	Days
PDG	<650	20–70	10.33	228	1753	0.13	March 25/ June 15	82	N/A	N/A	August 25/ November 25	92	November 25/ March 25	120
LMDG	650–1650	30–80	8.33	315	926	0.34	N/A	N/A	June 15/ August 25	72	N/A	N/A	November 25/ April 25	150
MMFM	1650–2700	70–90	2.20	592	661	0.90	N/A	N/A	June 15/ August 25	72	N/A	N/A	November 25/ April 25	150
AM	2700–3500	50–90	−1.06	501	748	0.67	N/A	N/A	July15/ August 20	36	N/A	N/A	N/A	N/A

Notes: T, annual temperature; P, annual precipitation; E, potential evaporation.
PDG, plain desert grassland; LMDG, low-mountain dry grassland; MMFM, mid-mountain forest-meadow; AM, alpine meadow.
N/A means 'not applicable'. For example, PDG is not applicable for summer rangeland.