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Forage nutritional characteristics and yield dynamics in a grazed semiarid steppe ecosystem of Inner Mongolia, China

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ABSTRACT

In the steppe of Inner Mongolia, forage is the only source of feed for sheep. The forage intake of sheep can be characterized in both quantity and quality terms, which are determined by environmental and anthropogenic factors and grazing has a strong effect on steppe productivity and the grassland ecosystem. Evaluation of forage quality and quantity is therefore of critical importance. The effects of grazing intensity, interannual variability effects, and species composition on aboveground net primary productivity (ANPP) and forage nutritional characteristics were investigated in a controlled grazing experiment along a gradient of 7 grazing intensities (from non-grazed to very heavily grazed) over six years (2005–2010) on typical steppe in Inner Mongolia. Forage nutritional characteristics were defined by the nutritional value (concentrations of crude protein (CP), cellulase digestible organic matter (CDOM), metabolizable energy (ME) and neutral detergent fibre (NDF)) and the nutritional yield. The forage nutritional yield is a function of ANPP and the forage nutritional value. Forage nutritional value increased but ANPP and nutritional yields decreased with increasing grazing intensity. The inter-annual variation of ANPP, forage nutritional value and yield were weakly linked to the inter-annual variability of precipitation. However, ANPP and nutritional value also varied during the growing season, depending on the seasonal distribution of precipitation and temperature, which influence forage digestibility (CDOM) and metabolizable energy (ME), with higher CDOM and ME under high seasonal precipitation and low seasonal mean temperature. Forage nutritional value and yield, as well as ANPP, were predominantly determined by the dominant species rather than by species diversity. The results suggest that forage nutritional yield in the Inner Mongolian steppe is predominantly determined by the ANPP and only to a minor extent by forage nutritional value, and is predominantly determined by the dominant species and only to a minor extent by species diversity. Therefore, herbage productivity seems to be the most limiting factor in managing this steppe ecosystem as a feeding resource for livestock and to be the best ecological and environmental indicator for grassland management practices.

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1. Introduction

The semi-arid steppe in Inner Mongolia is one of the most important grazing grassland ecosystems in the Eurasian steppe region (Kang et al., 2007). Because of increasing grazing pressure in recent decades, most of this steppe ecosystem is in some state of degradation, which has sharpened the conflict between grassland supply and livestock demand. The ability of grassland to provide forage as the single most important source of nutrients to support livestock productivity depends on both its aboveground net primary productivity (ANPP) and its nutritional value (Snyman, 2002). Both ANPP and forage nutritional value (FNV) determine forage nutritional yield (FNY), i.e., the quantities of crude protein (CP), neutral detergent fibre (NDF), cellulase digestible organic matter (CDOM) or metabolizable energy (ME) per unit area on a seasonal or annual basis, but previous studies did not quantify their respective

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contributions to FNY (Schonbach et al., 2012). Grazing is known to affect ANPP and forage nutritional characteristics and thus animal performance (Schonbach et al., 2009). For example, increasing stocking density and grazing intensity on steppe grassland can improve FNV and animal live weight gain per area, but also decrease forage productivity (Schonbach et al., 2009, 2011). Since FNY determines the quality and quantity of forage available to livestock, it is important to evaluate the effects of grazing on ANPP and FNV in order to understand the effects of grazing on livestock performance. Previous observations have emphasized the effect of grazing intensity on FNV and the effect of animal intake of nutrients on grasslands (e.g. McKown et al., 1991; Wang et al., 2009). However, despite the important role of the Inner Mongolia steppe as a major feed resource for livestock farming, relatively little is known about the effects of grazing on FNY.

ANPP and FNV are affected not only by grazing but also by other factors, including environmental factors, such as topography, botanical composition and diversity (Buxton, 1996; Hooper et al., 2005; Schonbach et al., 2009; Ren et al., 2012). In arid and semiarid grassland ecosystems, mean annual precipitation has been considered to be a highly reliable measure of water availability for community productivity (Bai et al., 2008). Temperature has also been shown to directly affect community productivity and FNV (Auerswald et al., 2012). Inter-annual variations in precipitation and temperature have been reported to be closely correlated to ANPP (Ren et al., 2012; Auerswald et al., 2012). However, little is known about the links between temporal variability in precipitation and temperature and shifts in forage nutritional characteristics. Furthermore, species composition and diversity are likely to influence plant productivity and plant nutrient value in most habitats (Hooper et al., 2005). The mass ratio hypothesis suggests that dominant species rather than diversity manipulate ecosystem functioning and stability (Ren et al., 2012). Each individual species plays a different role in influencing community productivity (Hooper et al., 2005), and it has long been discussed whether the relationship between species diversity and productivity is positive, negative or non-significant (Tilman et al., 2006). However, within grassland ecosystems, it remains uncertain whether species diversity or species composition has the greatest effect on productivity and forage nutrient use, and on the overall FNY, and whether could be considered as most effective indicator.

Based on results reported in the above-mentioned studies, we hypothesized that grazing and environmental factors, such as precipitation and temperature, determine not just the variation of FNV and ANPP, but also of FNY in semi-arid steppe. Furthermore, based on the mass ratio hypothesis framework, we hypothesized that species richness or diversity index rather than species composition will improve FNY. In order to test the effects of different grazing intensities and different years, species composition and species diversity on FNV, ANPP and FNY, we collected data during six consecutive years (2005–2010) from a large-scale controlled grazing experiment in an Inner Mongolian steppe in China. The broad dataset covering six years allows us to combine the effects of grazing and environmental conditions on ecosystem functioning on the one hand, and diversity effects on the other hand. This dataset included much broader data and is able to give more convincing results than a previous study (Schonbach et al., 2012). The primary questions we addressed were: (1) What is the relationship between FNV, ANPP and FNY?; (2) How do grazing intensity, precipitation and temperature affect FNV, ANPP and FNY?; (3) How do species composition and species diversity affect FNV, ANPP and FNY?; and (4) How much contribution do ANPP and dominant species make to FNY? Which index can be used as optimum indicator for guiding grassland management practices?

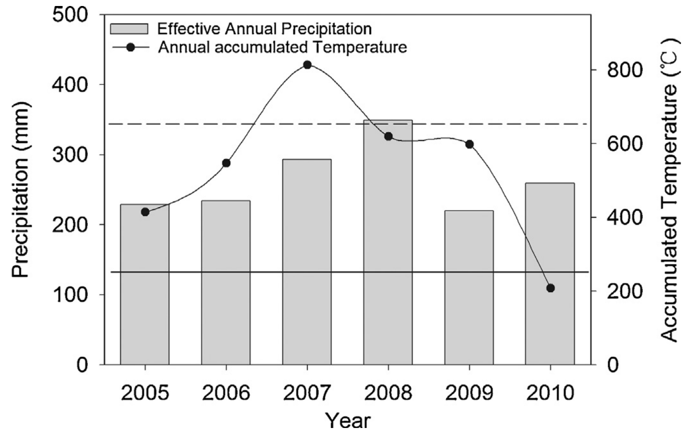

Fig. 1. Effective annual precipitation rates (previous-year October to current-year September) (left *y*-axis) and annual mean temperature (right *y*-axis) from 2005 to 2010. Dashed line indicates mean effective annual precipitation over 20 years (1983–2004) of 343 mm; bold line indicates mean annual temperature over 20 years (1983–2004) of 0.7 °C.

2. Materials and methods

2.1. Experimental site

The grazing experiment was established in 2005 in semi-arid steppe ecosystem of Inner Mongolia, P.R. China, close to the Inner Mongolia Grassland Research Station of the Chinese Academy of Sciences (IMGERS, 43° 38′ N, 116° 42′ E) at an elevation of approximately 1200 m a.s.l. As the precipitation during the winter of the previous year could affect the growth of vegetation in the subsequent year (Yuan and Zhou, 2005), effective annual precipitation (previous-year October to current-year September) rather than calendar annual sums (January to December) was applied in this study. This was considered to be a more appropriate period for relating precipitation to grassland vegetation (Fig. 1). During the six experimental years (2005–2010), effective annual precipitation ranged from 219 to 345 mm and annual mean temperature ranged from 0.5 to 2.2 °C (Fig. 1). The effective annual precipitation during the experiment period (2005–2010) was lower than long-term mean annual precipitation of 343 mm (from 1982 to 2004), but annual mean temperature during the six years was above the 20-years annual mean temperature of 0.7 °C (Fig. 1). Typically, about 80% of annual precipitation occurs during the growing season (May–August) and supports productivity of the steppe vegetation.

Stipa grandis P. Smirn. (perennial bunchgrass) and *Leymus chinensis* Trin. Tzvel. (perennial rhizomatous grass) are the two dominant species in the experimental site and are widely distributed in the Eurasian steppe. Together these two grasses account for approximately 60–80% of the total community aboveground biomass (AB) (Wan et al., 2011). The major soil types of this region are dark chestnut soils (Calcic Chernozem according to ISSS Working Group RB, 1998), with a fine-sand loess texture.

2.2. Experimental design

The grazing experiment was conducted over six years (from 2005 to 2010) as a continuous stocking system (terminology from Allen et al., 2011). A randomized complete block design with two replicates on two blocks differing by topographic position (one level block and one sloping block) was applied to analyze the effects of grazing intensity on productivity, forage nutritional value and nutritional yields. The grazed area covers 150 ha of natural grassland in total and was divided into 2-ha paddocks, which were randomly allocated among seven grazing intensities that cover all

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