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Review

Effects of grazing and climate variability on grassland ecosystem functions in Inner Mongolia: Synthesis of a 6-year grazing experiment

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ABSTRACT

From 2004 to 2010, the Sino-German research group MAGIM (Matter fluxes of Grasslands in Inner Mongolia as affected by grazing) ran a grazing experiment in a typical steppe ecosystem in Inner Mongolia, North China. Multiple ecological effects of grazing, climate variability and topography on plant and animal productivity, plant species composition change, decomposition and mineralization, soil nitrogen and organic matter distributions and dynamics, soil physics and chemistry, and soil-atmosphere gas exchange were measured in fenced plots with defined stocking rates and under different grazing management systems. This paper reviews and synthesizes the most important outcomes, conclusions, and open questions from the different project groups, as published in 125 ISI articles.

While greenhouse gas fluxes, plant properties, and livestock performance were particularly responsive to (inter-) annual climate variability, soil properties were more affected by grazing intensity. Various management options based on the project results for semi-arid grasslands under changing climatic conditions are discussed.

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1. Introduction

Grasslands in semi-arid temperate climates account for approximately 8% of the global terrestrial land surface (Loveland et al., 2000). The land use of semi-arid grasslands is dominated by extensive livestock husbandry (FAO, 2006), but low water availability often constraints ecosystem productivity (Kochy and Wilson, 2004) and, consequentially, land use practices. For this reason extensive, drought adapted nomadic or semi-nomadic pastoralism is the traditional land use (Wiesmeier et al., 2015).

In temperate grasslands of North China, since the 1950s, nomadic sheepherders were forced to settle down and the numbers of livestock were severely increased by stationary farming systems (Reiche et al., 2015; Wan et al., 2015). As a response to growing food markets and specifically livestock product demands, land use in this so called agro-pastoral ecotone was further intensified in the 1980s by grassland conversion to irrigated or rainfed cropland and by increasing stocking rates (Ren et al., 2015). As one consequence soil desertification in Northern China had reached a total area of approximately 376,000 km^2 in 2010 (Wang et al., 2011). Ongoing land use intensification and climate change are the most recent ecological challenges for the temperate grasslands of North China.

Effects of intensive grazing and climate change on several grassland ecosystem functions as plant diversity (Olff and Ritchie, 1998; Zhao et al., 2008), greenhouse gas budget (Allard et al., 2007; Del Prado et al., 2013), and soil physical properties (Greenwood and McKenzie, 2001; Wang et al., 2007b) are well analyzed. However, in most cases, only selected processes have been studied and important side-effects and feedback mechanisms have been largely ignored. Descriptions of the effects of grazing on grassland ecosystem functions are often controversial due to the heterogeneity of grassland ecosystem types and their use history. Moreover, contrasting findings are often the result of differences in the location of study sites (i.e. different resource availabilities, climate gradients, topography, soil properties, and land management) and the methodological approaches used (e.g. sampling time and design), which reduce the comparability of results from different studies. Therefore, in-depth analyses, which simultaneously monitor multiple ecological processes in grassland ecosystems under different grazing management systems and over a period of several years, are highly desirable for a comprehensive understanding of changes in ecosystem functions in response to grazing and climate change.

In 2004, the Sino-German research group “MAGIM” (MAtter fluxes in Grasslands of Inner Mongolia as affected by stocking rate) set up a grazing experiment in a typical steppe ecosystem of North China. The project included teams for the research fields soil physics, and -chemistry, wind erosion, plant biodiversity, -productivity, and -turnover, livestock performance, trace gas fluxes, and micrometeorology.

This paper review and summarize the most important findings of the research teams with focus on the effects of stocking rate and climate variability on soil properties e.g. aggregate formation, bulk density, soil organic carbon- (SOC) and nitrogen (N) stocks and dynamics, infiltration, nutrient availability, microbial turnover, and water content; greenhouse gas (GHG) fluxes; plants e.g. vegetation dynamics with regard primary production, carbon partitioning, species diversity, composition change, and proportion of plant functional groups, and biomass decomposition; and livestock e.g. production, nutritional quality of herbage, feed intake, and digestibility of the ingested diets as well as behavior, and performance level of grazing sheep.

Subsequent, disciplinary and interdisciplinary key findings are synthesized to increase our process and system orientated knowledge about stocking rate and climate variability effects on the investigated ecological processes. The identification of ecological key processes sensitive to grazing and/or climate will help to estimate ecosystem's response to anthropogenic interventions resulting from land use activities and the expected climate change; and thus enable us to develop a concept for sustainable grazing management system of this eco-zonal grassland system.

2. Material and methods

The MAGIM project was conducted at the Inner Mongolia Grassland Ecosystem Research Station, which is located in the upper Xilin River basin of Inner Mongolia, China (43° 38′ N, 116° 42′ E, Fig. 1). The mean annual precipitation and air temperature of the experimental area is 343 mm and 0.9 °C, respectively with great variances among seasons and years (Table 1, Fig. 2). About 81% of the annual precipitation is falling in the growing period between May and September. The precipitation rate was highly variable within the experimental period. While in some years the precipitation rates in summer were low (2009) and very low (2005), in 2006 and 2008 precipitation was close and above to the annual average (Table 1, Fig. 2).

The topography is characterized by rolling hills with elevations ranging between 800 m and 2000 m a.s.l. The dominant soil types of this region are calcic Chernozems and Kastanozems (IUSS Working Group WRB, 2006) developed from quaternary aeolian sediments above volcanic rocks. The studied plant community of the steppe vegetation is dominated by annual and perennial grasses such as *Stipa grandis* and *Leymus chinensis* (Bai et al., 2004).

2.1. Grazing experiment

A large-scale grazing experiment was set up in June 2005, to investigate the effects of stocking rate, climate variability, grazing management system and topography on a total area of 128 ha. Until 2003, the experimental area had been used for moderate sheep grazing of in average 1.5–3 ewes ha^{-1} yr^{-1} by local herdsmen. In 2004, the grassland got a resting phase from grazing before soil, vegetation, and livestock parameters were assessed every year during the growing periods of 2004–2010. Seven stocking rates