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Effects of herbivore species and season and intensity of grazing on the steppe rangelands in an adaptive management system

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Abstract

Effects of three herbivore species, four grazing seasons and three grazing intensity levels on a semi-arid rangeland in an adaptive management system were investigated using a 7-year grazing experiment in the Xilingol region of Inner Mongolia, China. The region experiences a semi-arid climate, with a mean annual temperature of -0.5℃, and a mean annual precipitation of 315 mm, which mainly falls during the plant growing season from May to September. The rangeland is a typical steppe dominated by *Stipa grandis* and *Leymus chinensis*. A rotational grazing management with grazing duration controlled on the basis of grassland residual height was applied to adapt to the inter-annual variation in plant production. The results showed that cattle, sheep and goats had different preferences for plant species, and grazing by these herbivores at moderate grazing intensity drove divergent changes in species composition of vegetation. Grazing in different seasons at moderate intensity affects plant community structure and production mainly through altering the seasonal pattern of plant standing dead and litter, which impacts soil moisture capture and retention, and thus soil nutrient availability for plant growth; and by changing plant nutrient resorption and remobilisation, with autumn grazing having the least plant nutrient resorped in autumn thus negatively affecting plant growth in subsequent spring. Autumn grazing had the biggest adverse effect on plant community structure and production, while winter and early spring grazing promoted plant growth. Grazing intensity and precipitation jointly shape the compensatory growth and ANPP of the rangeland, with the highest ANPP occurring at relatively high grazing intensity and under high precipitation. Our results provide insights into the rangeland vegetation dynamics under different grazing regimes, and suggest that adjusting livestock composition can be used as a tool in rangeland management. Winter and early spring grazing was better than complete animal exclusion for grassland health, and an adaptive grazing management based on residual vegetation height is efficient for coping with the large inter-annual variation in climate and vegetation production in semi-arid rangeland regions. This paper collates and summarises findings from the study.

Introduction

Plant production in arid and semi-arid rangeland areas varies widely across years driven by large inter-annual fluctuation in precipitation. The vast steppes in Inner Mongolia region of Northern China have been used as rangeland for thousands of years to graze livestock (sheep, goats, cattle and horses) using a nomadic system at low grazing intensity. With the privatization of land use rights in the rangeland region and associated reduction in livestock mobility, one of the major challenges in livestock management is to cope with the uncertainties in climate, to provide sustainable livestock production and other ecosystem services. We have proposed a grazing management strategy to set on and off livestock on the rangeland paddocks in the use-right privatized rangeland farms based on vegetation (residual) height, so as to keep the livestock-forage relations balanced and prevent rangeland from degradation. This management adjusts the summer grazing rangeland areas and the animal numbers at the end of plant growing season. It is essential to understand the effects of livestock grazing strategies in this adaptive grazing management system on plant and soil systems, including grazing season, intensity and livestock species for developing and improving rangeland management.

Methods

We conducted three interrelated grazing experiments to examine the effect of three livestock species, four grazing intensity levels and four grazing seasons on plant community composition and production, and soil properties over a 7-year period in a semi-arid rangeland, located in the Maoden farm, 45 km northeast of Xilinhot city, in Inner Mongolia of China (44°10′N, 116°28′E, 1101m asl). The region experiences a semi-arid climate, with a mean annual temperature of -0.5℃, and a mean annual precipitation of 315 mm, which mainly falls during the plant growing season from May to September. The rangeland is a typical steppe on a sandy loam chestnut soil dominated by tall grasses *Stipa grandis* and *Leymus chinensis,* with other important species of *Cleistogenes squarrosa, Carex korshinskyi* and several forbs.

The experimental rangeland was set up in 2016, with 36 paddocks of 50m × 50m, to arrange 9 grazing treatments, replicated by 4 blocks. The nine treatments include no-grazing (NG), summer sheep grazing at three intensity levels of light (LG), moderate (MG) and heavy (HG) grazing; summer cattle (Cattle) and goat grazing (Goat) at moderate intensity, and sheep grazing in early spring (Spring), later autumn (Autumn) and winter (Winter). Summer sheep grazing at moderate intensity (MG) was also used when comparing the grazing season or grazing animal species effects (i.e., MG in grazing intensity experiment = 'Summer' grazing in grazing season experiment = 'Sheep' grazing in animal species experiments). The grazing treatment was conducted from 2017 to 2023 inclusive, two-year old Mongolian sheep with an average initial bodyweight of approximately 33 kg were used for grazing treatments. The number of sheep for NG, LG, MG and HG were 0, 3, 6 and 9 respectively. The sheep were set on the grassland in paddocks in summer period of June, July and August each year, and set off when residual vegetation height decreased to about 6 cm at MG. The same sheep grazing days (i.e., sheep unit × grazing days) in the MG treatment was applied for all grazing treatments in grazing season experiment and animal species experiment. Plant species composition and biomass, and animal bodyweight before and after each grazing rotation were determined, soil properties were monitored each year, and animal daily intake was estimated. Potential plant aboveground biomass (AGBp) at peak plant biomass time was determined by setting up three grazing-exclusion cages of 1.2 m length × 1.2 m width × 1.0 m height in each paddock before the start of summer grazing in all the grasslands subject to grazing at different intensities. Grassland aboveground net primary productivity (ANPP) was determined as the sum of herbage accumulation consumed by animals during grazing season and the residual biomass of grassland at the end of grazing season, including the small amount of detached litter produced in the current year. Please refer to Shi et al. (2022, 2023) and Li et al. (2018, 2021, 2022, 2024) and Yan et al. (2024) for the details in grazing management and monitoring. Here we summarize the major findings from these interrelated experiments, and discuss their management implications.

Results

Grazing intensity effects: grazing promoted grassland productivity, and the promotion varied with precipitation, grazing intensity and plant species.

The realised grazing intensity in the experiment was around 20%, 40% or 60% of the ANPP being consumed at LG, MG and HG, with actual stocking rate controlled at 138 ~ 240 sheep grazing days per year at MG over the 7 years. A comparison of the AGBp and ANPP revealed that grazing at LG and MG promoted plant production, that is, generated compensatory growth (ANPP>AGBp), and the promotion was the highest for dominant grass *L. chinensis*; while the promotion at HG occurred only in wet years, and highest promotion was for *C. squarrosa* and annual species. The grazing enhanced nutrient cycling by defoliation and excreta deposition, accelerated decomposition of plant litter with animal dung (Wang et al 2023), and increased nutrient resorption, can be a major mechanism for grazing promotion of ANPP (Zhang et al. 2020).

Grazing season effects: grazing in winter or in early spring improved, while autumn grazing reduced grassland growth, compared to complete exclusion of animals from grassland.

With moderate grazing intensity applied, under which around 40% of ANPP was consumed by animals during the plant growing season, plant community height and aboveground biomass were higher under spring and winter grazing than that under autumn, summer or no- grazing. The divergence in plant community structure was mainly mediated by grazing-induced variation in the seasonal patterns of plant standing dead and litter mass across the grazing season treatments. A high plant standing dead and litter mass benefited soil moisture by enhancing accumulation of snow in winter and reducing soil evaporation during the plant growing season, benefiting plant growth; also, the removal of plant litter before the plant growing season increased the reception of solar radiation, thus improving soil temperature and plant production. Seasonal grazing, especially autumn grazing reduced plant nutrient resorption in autumn, thus negatively affecting plant growth in the coming year (Zhang et al. 2020).

Animal species effects: Forage preference differed among sheep, cattle and goats. Sheep preferred *L. chinensis* and forbs, cattle preferred *S. grandis* and forbs, and goats preferred *C. squarrosa* and *C. korshinskyi* (Li et al. 2018). Consequently, sheep grazing reduced *L. chinensis* and forbs, but increased *S. grandis*; cattle grazing decreased *S.grandis,* but increased *C. korshinskyi* and forbs; goat grazing reduced *C. squarroa* and *C. korshinskyi*, but increased forbs. However, dominant plant species of *L. chinensis* and *S. grandis* were still dominant over the 7-year period though their dominance changed. These results imply that animal species or population structure can be used as a tool to manipulate grassland communities, and the adaptive grazing of all three livestock species at MG to consume 40% of ANPP can sustain the grassland.

Discussion and conclusion

Our results show that adaptive grazing management by removing grazing animals based on grassland residual height can prevent grassland degradation. Grazing intensity and precipitation jointly determine the ANPP or compensatory growth of grazing grassland, and grazing can promote ANPP by accelerating nutrient cycling. Grazing season affects ANPP by changing the seasonal patterns of plant litter mass that modulate soil physical conditions, and by altering the nutrient resorption efficiency differently. Winter or spring grazing is better than no grazing for grassland restoration and improvement. Grazing by different animal species drives divergent changes in plant community, with cattle grazing preferring dominant tall bunch-grasses and leading to better plant diversity then sheep/goat grazing.

The results do not support the policy to have a grazing ban for preventing grassland degradation in the region. Instead, it suggests that light or moderate grazing (consuming up to 40% of ANPP) is beneficial to plant production. In addition, grazing in winter or early spring before plants starting to grow is better than complete animal exclusion for recovery of degraded grassland or prevention of grassland degradation. The reduction of grazing in autumn to allow more resorption of plant nutrient to belowground is important to keep the viability and production of

grassland plants in the coming year. These grazing management strategies should be incorporated in grassland management systems.

Our findings suggest encouraging the farmers to raise 'more cattle and less sheep' in the region, as cattle grazing in our adaptive management system can achieve a higher species diversity (Yan et al. 2024) and total ecosystem services (Shi et al. 2023), but with less damage than sheep production. The needle-like fruit of *S.grandis* is a nuisance in sheep grazing system, as it damages sheep skin and throat. Intensive cattle grazing in the early period of the reproductive stage of *S. grandis* is recommended before sheep grazing to prevent its negative effects on sheep production. Plant residual height-based adaptive grazing system with the rotation of different/mixed livestock species are expected to achieve the dual goal of pastoral production and ecosystem sustainability.

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