Plant communities responding to grazing pressure by sheep in an Alpine meadow

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ABSTRACT: The Chinese grassland ecosystem is an important national asset that not only impacts climate regulation, soil and water conservation, wind protection, and soil carbon and nitrogen fixation but is also an important contributor to maintaining grassland biodiversity while supporting livestock production. Grasslands are a key component contributing to the productivity of grazing animals but also provide basic food production via livestock grazing for herder survival. Grazing is the most basic means of grassland utilization but is considered one of the more important disturbance factors controllable by humans that has a universal and profound impact on the grassland ecosystem due to animal density and over grazing. For Alpine grasslands, it is not clear what grazing intensity (GI) can be achieved to improve plant biodiversity and vegetative nutritional value while improving sheep productivity. This field experiment was conducted for 7 yr comparing the impact of different GI on vegetation community characteristics, nutritional value, and sheep growth performance on the Alpine meadows of the Qinghai–Tibetan Plateau. The GI measured were: Control: 0 sheep/ha; Low: 3.7 sheep/ha; Medium: 5.3 sheep/ha; and Heavy: 7.6 sheep/ha. The grazing experiment started in 2008, but experimental data collection and analyses were collected for the final 4 yr of 2015 through 2018. All grazing intensities >0 sheep/ha reduced (P < 0.05) plant height (27%, 46%, and 48%, respectively, for 3.7, 5.3, and 7.6 sheep/ha), ground coverage (16%, 24%, and 48%), and above ground biomass (2%, 42% and 53%) of the various plant communities while increasing (P < 0.05) the grass community density (individuals/m²) compared to a nongrazed Control. With increasing GI, the community height, coverage, and above-ground biomass decreased (P < 0.05), and the plant community density increased then decreased (P < 0.05) compared to Control. As GI increased, the available community biomass nutritional quality increased (P < 0.05). Comprehensive analysis showed that the community density (quantity) and nutritional quality were the highest when the GI was 5.3 sheep/ha. The higher the GI, the greater the grass’s nutritive value with lower above-ground net primary production (ANPP). When GI was the highest, the average daily gain (ADG) per hectare was the highest in the short term, but the highest GI endangers the ANPP and profitability of the grassland grazing ecosystem in the long term. Targeting a moderate GI (5.3 sheep/ha) can provide 78% of the ADG per hectare of the highest GI, which meets the requirement of maintaining a sustainable grazing grassland.

Key words: Alpine meadow, animal performance, grazing intensity, nutritional quality, plant community

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INTRODUCTION

China is the second-largest grassland country in the world, with natural grasslands accounting for >40% of the country’s total area (Kemp et al., 2013; Gongbuzeren et al., 2015). These grasslands function for soil carbon and nitrogen fixation and water and soil conservation, along with providing ecological isolation. These grasslands were the origin and birthplace of nomadic peoples and their culture. The grasslands provide the raw materials, economic resources, and livestock production base, which nomadic people heavily depend on for their livelihood and survival. The grassland culture has an important role in maintaining the integrity of natural ecosystems and sustainable human development (Costanza et al., 1997; Nan, 2005; Mace et al., 2012).

Since the founding of the People’s Republic of China on October 1, 1949, the survival rate and average life expectancy of the nomadic people have greatly increased due to the continuous improvement in available food, resources, and raw materials, along with an improving quality of life. While maintaining their traditions, the nomadic people living on the grasslands have built settlements with increasing family size, which has resulted in subdividing the available grassland area into households (Gongbuzeren et al., 2015). The increase in livestock grazing numbers has increased grassland biomass consumption leading to grassland degradation via year-long overgrazing. Maintaining a balance between grassland biomass, diversity, and quantity is ultimately a question of balancing “human-grass-livestock” (Yang et al., 2011; Yao et al., 2019).

In recent years, the Qilian Mountain National Nature Reserve, located in the Chinese Gansu and Qinghai provinces, has experienced serious environmental problems and concerns (Zhang et al., 2012) via accumulating socioeconomic demand leading to environmental problems. The resulting ecological problem outbreak has resulted in the Chinese Central Government implementing the policies of banning grazing (rest, recovery, and abandonment) and/or rest grazing (spring grazing ban) to promote grassland ecological restoration (Gongbuzeren et al., 2015). However, the social problems inflicted by the policies are also obvious. For example, how can the herder and their family’s livelihood be supported? Direct economic subsidies that depend solely on government revenues are clearly not cost effective. In addition, can reducing grazing animal numbers meet the needs of feeding the people while maintaining grassland quantity, quality, and sustainability? Moreover, from the perspective of grassland science and livestock production, is the prohibition of grazing and/or partial rest grazing conducive to grassland restoration and sustainability?

Finding the optimal balance between human, grass, and livestock needs of these natural grasslands requires the use of an ecological-economic model (Kemp et al., 2013; Tan et al., 2014) to analyze the grassland biomass to meet the requirements for all parties involved (i.e., herders). Some policies and programs have been implemented to optimize allocation of domestic pasture resources through pasture replanting, confinement feeding, lambing time adjustment, precision management, ewe reduction, soil fertilization, multiple birth research, emergency feed preparation, and so forth while striving to improve the environmental effect on livestock genotype responses. Over the past 10 years, the typical livestock density dropped by 35%, but the adult ewe’s body weight (BW) increased by 34%, the lambing and survival rates have increased by 12% and 2%, respectively, thereby improving the economic benefits dramatically (Yang et al., 2011; Kemp et al., 2013; Yao et al., 2019). The study objective was to determine the optimal grazing intensity (GI, i.e., number of sheep per hectare) to maintain a sustainable grassland that is available for multiple economic, social, recreation, and agricultural uses and functions, including livestock production via grazing.

MATERIALS AND METHODS

Experimental Grassland Location

This study was carried out at the Sanding Village on the northeastern edge of the Tibetan Plateau, Kangle town, Sunan County, Zhangye, Gansu.
Province, in the P.R. of China (99°48’ E, 38°45’ N, and 3,200 m above sea level). This area belongs to the plateau's subcold zone subarid climate. The 30-year average annual precipitation was approximately 255 mm (1985–2014) with approximately 85% occurring during the summer growing season (May–September). The annual average temperature is approximately 3.8 °C with a range of −37 to 45 °C (1985–2014) with a cumulative seasonal growing temperature (i.e., growing degree days) of 2,324 °C. The annual average windspeed is approximately 4 km/h. The grassland's typical growing season is approximately 4 mo from June through September with 127 frost-free days. The grassland type is Alpine meadow with species diversification (richness) of 12–22 species/m² (Yao et al., 2019).

**Experimental Design**

The experimental study area and the research sites were highly degraded (i.e., overgrazed) due to heavy summer pasture grazing from June through September by Gansu Alpine fine-wool sheep prior to 2008. Starting on June 20, 2008, the experiment was initiated with four treatments: 1): Control: 0 sheep/ha (0) in a fenced-off area; 2): Low GI: 3.7 sheep/ha (3.7); 3): Medium GI: 5.3 sheep/ha (5.3); and 4): Heavy GI: 7.6 sheep/ha (7.6) conducted at three separate grazing locations utilizing four different herders. At each of the three locations, each treatment occupied 4 ha with an approximately 100-m separation barrier between treatments that was randomly selected within a homogeneous 48 ha area. Pasture grass sample collection for nutrient analyses commenced in 2015 through 2018. All locations were similar in slope, aspect, elevation, and soil type. At each site, following the line transect method (Buckland and Turnock (1992), three 100- × 100-m replication blocks (having an approximate 50 m separation barrier) were marked and selected for monitoring, which resulted in 36 total replicates for the four treatments per year. The 0 sheep/ha treatment was fenced to exclude livestock grazing for the entire 7-yr experiment. The fenced grazing treatments were freely grazed from June 20 to August 20 by the respective number of Gansu Alpine fine-wool sheep per hectare. The female sheep weighed approximately 35 kg.

**Above-ground Vegetation Community Survey and Plant Sampling**

In every experimental replicated location, five random quadrat (plots) samplings (1- × 1-m square) were collected with the distance between each quadrant being >1 m from edge to edge to eliminate marginal effects. A 1-m² sampling cage was placed over the selected area in the same location each year and the pasture samples were cut at an approximate height of 1.5 cm above the ground. Species composition, coverage, above ground biomass, and density were recorded for each quadrant. Plant species were clipped to a stubble height of approximately 1 cm. A total of 240 quadrats were sampled during the final 4-yr data collection of the 7-yr experiment. The average rainfall for the past 30 years is 255 mm, while the rainfall was 350, 206, 353, and 283 mm for 2015, 2016, 2017, and 2018, respectively.

**Grass Sample Nutrient Analysis**

The grassland samples from each quadrant were dried at 55 °C for 48 h in a forced air oven (model DHG-924385-III, Shangahi Yanhe Instrument Equipment, Shanghai, China) to a constant weight to determine biomass dry matter (DM) to calculate biomass yield. Samples were then crushed and ground through a 1-mm screen using a Foss Tecator Cyclotec 1093 mill (Foss North America, Eden Prairie, MN) for measuring nutrient concentrations. Samples were analyzed using the following Association of Official Analytical Chemists International (2019) Official Methods: DM (935.29), crude protein (CP; 990.03), neutral detergent fiber (NDF) with sulfite (2,002.04), acid detergent fiber (ADF; 973.18), DM digestibility (DMD; Tilley and Terry, 1963), and metabolizable energy (ME) was calculated according to the Yang (1993) equation: ME (MJ/kg) = −11.7492 + (0.5959 × DMD, %) − (0.0044 × DMD²). Sheep were weighed at the start of the grazing period and at the end of yearly grazing period using a digital platform scale (model XK3190-A12±3, Shanghai Yaohua Co., Ltd., Shanghai, China) and average daily gain (ADG) was calculated.

**Statistical Analyses**

Prior to statistical analysis, all data were checked for normality and outliers using the UNIVARIATE procedure of SAS (Version 9.4, SAS Institute Inc., Cary, NC) before any statistical analyses were conducted. The box and whisker plots and Shapiro–Wilk test were used to verify that data were normally distributed (P > 0.15). All data were then subjected to least squares analysis of variance (ANOVA) for a randomized complete
block design (Steele and Torrie, 1980) using SPSS version 19.0 (IBM Corp., Armonk, NY) using the mixed model option based on an autoregressive covariance structure. The statistical model used was:

\[
Y_{ijkl} = \mu + Rep_i + GI_j + Plots_k + Year_l + (GI_j \times Year_l) + (Plots_k \times Year_l) + (GI_j \times Plots_k \times Year_l) + e_{ijkl}
\]

where \(Y_{ijkl}\) = dependent variable, \(\mu\) = overall mean, \(Rep\) = replication or block, \(GI\) = grazing intensity (# of sheep/ha), \(Plots_k\) = sample plots, \(Year_l\) = Year of samples, \(GI_j \times Plots_k\) = interaction of \(GI\) with plots, \(GI_j \times Year_l\) = interaction of \(GI\) with year, \(Plots_k \times Year_l\) = interaction of plots by year, \(GI_j \times Plots_k \times Year_l\) = interaction of \(GI\) by plots by year, and \(e_{ijkl}\) = residual random error, which resulted in 240 observations. Grazing intensity, plots (quadrat), and year were considered fixed effects, while replication was considered a random effect, while plots were analyzed as a repeated measurement having an autoregressive covariance structure. The \(GI \times Plots\) and \(GI \times Plots \times Year\) interactions were found to be nonsignificant (\(P > 0.15\)) and dropped from the final statistical model. Least squares means were separated by the least significant difference (LSD) method when the ANOVA \(F\) test was significant. All results are reported as least squares means and differences among least squares means were considered significant at \(P < 0.05\).

**RESULTS**

**Grazing Pressure on Vegetation Responses**

The number of sheep per hectare grazing grasslands reduced \((P < 0.05)\) the grassland height, coverage, and above-ground biomass of the community grass species (Fig. 1) while increasing \((P < 0.05)\) the community density per square meter to reach a peak at 5.3 sheep/ha. The Control GI of 0 sheep/ha resulted in a community grass height of 8.8 cm with a community grass coverage of 79% and above-ground biomass of 175 g/m² with 136 individuals/m². Thus, the community grass height was reduced by 27%, 46%, and 48%, respectively, by grazing sheep at 3.7, 5.3, and 7.6 head/ha, while the community grassland coverage decreased by 16%, 24%, and 48%, respectively, with a 2%, 42%, and 53% reduction in biomass, respectively.

**Nutrient Quality Responses to Grazing Pressure**

The grassland CP concentration linearly increased \((P < 0.05)\) 1.9%, 8.6%, and 48% for 3.7, 5.3, and 7.6 sheep/ha, respectively, compared to Control 0 GI for the grassland having a mixed forage

![Figure 1. Vegetation community height (a), coverage (b), density (c), and above ground biomass (d) of alpine meadows being grazing by sheep at grazing intensity of 0, 3.7, 5.3, and 7.6 sheep/ha for 4 years (2015–2018; Means with same graph differ, \(P < 0.05\)).](image)
community (Table 1). The increasing GI quadratically reduced \( (P < 0.05) \) NDF concentrations by 1.1%, 2.4%, and 3.7% and ADF concentrations by 3.3%, 4.2%, and 10.4% compared to Control 0 GI (i.e., 0 sheep/ha). Ether extract (EE; fat) concentrations were linearly increased by 27%, 50%, and 36%, respectively compared with Control 0 GI. Dry matter digestibility increased quadratically with GI peaking at 7.6 sheep/ha. These nutrient changes influence by GI resulted in ME linearly increasing by 2.4%, 3.7%, and 8.5%, respectively, compared to the Control GI of 0 sheep/ha.

Sheep Growth Performance

The ADG was greatest \( (P < 0.05) \) for sheep at a GI of 5.3 sheep/ha, which was greater \( (P < 0.05) \) than a GI of 7.6 sheep/ha or 3.7 sheep/ha (Table 1). When ADG was expressed as g/ha/d sheep, a GI of 7.6 was greater \( (P < 0.05) \) compared to sheep grazing at 5.3 sheep/ha, which was greater \( (P < 0.05) \) than 3.7 sheep/ha. The economic growth model (Tan et al., 2014) predicted the optimal nutrient concentration to be 7% CP, 68.3% NDF, 52.6% DMD, with an ME of 7.0 MJ/kg, which resulted in an optimal GI of 5.3 sheep/ha.

DISCUSSION

Vegetative Community Influence by Grazing Intensity

The vegetation community grassland height, coverage, density, and above-ground biomass are typically measured to evaluate the functional status of grassland ecosystems (Li et al., 2015). These results demonstrate that long-term heavy GI results in the reduction of the number of individual plants, which leads to ecological biomass reduction (Ridley and Todd, 1966). These data are consistent with the results reported by Ridley and Todd (1966). The greater GI reduces the height, coverage, and biomass of the grassland plant communities. Decreased height, coverage, and biomass are associated with the reduction of photosynthetic area of plant leaves followed by a reduction in the efficiency of organic matter accumulation (Kleinebecker, 2011). Milchunas et al. (1995) reported that grazing livestock trampling the pasture resulted in altering soil compaction and water content resulting in the inhibition of soil enzyme activity and indirectly affecting forage biomass (Kleinebecker et al., 2011). Comparing the no grazing Control (i.e., GI 0 sheep/ha) to the remaining GI treatments, the grass nutrient concentrations changed dramatically resulting in a lower-quality forage that would have limited value for livestock feeding if it was harvested. However, no grazing would result in grassland changes to community structure, vegetation height, and density that would influence biomass yields (Hebblewhite et al., 2008). Mysterud et al. (2008) reported that a grassland GI of 0 sheep/ha resulted in greater withered litter (plant material). Garcia et al. (2003) reported that through grassland decomposition, this material returns to the soil, improving soil microbial activity, thereby promoting future plant growth and biomass accumulation as these results demonstrated over the years (i.e., significant year effect).

Vegetation Nutrient Concentrations Influenced by Grazing Pressure

This long-term experiment over 7 years demonstrates that fencing grasslands to eliminate grazing dramatically reduces Alpine meadow pasture nutrient quality, which is consistent with previous studies (Wang et al., 2009; Schönbach et al., 2016). The increasing GI quadratically reduced \( (P < 0.05) \) NDF concentrations by 1.1%, 2.4%, and 3.7% and ADF concentrations by 3.3%, 4.2%, and 10.4% compared to Control 0 GI (i.e., 0 sheep/ha). Ether extract (EE; fat) concentrations were linearly increased by 27%, 50%, and 36%, respectively compared with Control 0 GI. Dry matter digestibility increased quadratically with GI peaking at 7.6 sheep/ha. These nutrient changes influence by GI resulted in ME linearly increasing by 2.4%, 3.7%, and 8.5%, respectively, compared to the Control GI of 0 sheep/ha.

Table 1. Effects of GI and year on CP, NDF, ADF, EE, DMD, ME, and ADG

| Parameter          | Grazing intensity* | Main effects and interactions†, \( P < \) |
|--------------------|--------------------|------------------------------------------|
|                    | 0 3.7 5.3 7.6 SEM GI | Plots Year GI × Year Year × Plots |
| CP, % DM           | 10.4c 10.6d 11.3b 15.4a | 0.01 0.01 0.10 0.14 |
| NDF, % DM          | 70.5b 69.7c 68.8a 67.9b | 0.01 0.00 0.04 0.21 |
| ADF, % DM          | 34.9d 33.8c 33.5b 31.6a | 0.01 0.00 0.27 0.15 |
| EE, % DM           | 1.8c 2.3b 3.6a 2.8b | 0.02 0.01 0.11 0.24 |
| DMD, % DM          | 60.7a 60.8a 63.2b 64.7a | 0.00 0.01 0.13 0.33 |
| ME, MJ/kg DM       | 8.2a 8.4b 8.5b 8.9b | 0.01 0.00 0.19 0.26 |
| ADG, g/sheep/d     | — 66c 96a 77b | 0.02 0.00 0.02 0.31 |
| ADG, g/ha/d        | — 284a 468b 602a | 0.03 0.01 0.09 0.08 |

*0 Grazing intensity; 0 = fenced area with 0 sheep/ha; 3.5 = 3.5 sheep/ha; 5.3 = 5.3 sheep/ha; 7.6 = 7.6 sheep/ha.
†P values for main effects and interactions; GI; Year; Plots; and interactions of main effects.
*abMeans within the same row differ, \( P < 0.05 \).

Translate basic science to industry innovation
However, grazing is considered a basic grassland utilization method and eliminating grazing through long-term fencing will only waste grassland resources for livestock food production. The lack of long-term grazing, via fencing, can have serious negative consequences (Cuevas and Le Quesne, 2006). Schönbach et al. (2012) reported that grazing activities typically improves forage nutritional value.

These results demonstrated that GI had a dramatic influence on forage nutritional quality. Mild grazing could improve alkaline phosphatase, urease, invertase, and catalase activities to promote N mineralization, improve availability of soil nutrient concentrations, and increase forage CP concentrations (Karn et al., 2006). These data demonstrate that implementing moderate or heavy GI will result in plant tissues containing higher N with lower fiber concentrations, which agrees with Miao et al. (2015). However, long-term GI will permanently reduce plant leaf retention, resulting in fewer plant tissues reaching the next phenophase, which results in a reduction of organic matter being returned to the soil. Fanselow et al. (2011) reported that a high proportion of N reserves in plant stems and roots will mobilize new leaf sheaths and leaves. The forage biomass reduction caused by GI will increase N supply for the remaining leaves, which leads to relatively high N uptake in grazed grasslands (Legay et al., 2012). The decomposing organic matter process (Tan et al., 2014) provides many nutrients for plant growth while promoting plant nutrient accumulation. In the grazing process, the feeding, trampling, and livestock manure excretion can directly and/or indirectly promote soil respiration. At the same time, trampling can accelerate plant litter decomposition, while promoting the grass-livestock-soil balance. Grazing intensity impacts new tissue regeneration, delays plant lignification, thereby increasing the CP, EE, and DMD, while reducing NDF and ADF concentrations, which will help meet the nutrient requirements of grazing livestock (National Research Council, 2007; Čop et al., 2009).

**Grazing Sheep Performance**

Grazing intensity is an extremely important factor determining the productivity and profitability of livestock grazing systems. In theory, high grassland GI should produce maximum gain per hectare and short-term profits should be good. However, heavy GI (7.6 sheep/ha) in this study reduced grassland biomass by more than 80% at the end of the season. The large reduction of grassland biomass also changes plant species composition and density, along with reducing soil coverage by more than 60%. Reduction in soil coverage can lead to wind and water erosion resulting in greater grassland degradation (Christensen et al., 2003). Therefore, a GI of 7.6 sheep/ha may result in the highest short-term profit but, in the long term, will endanger the grassland ecosystem for livestock grazing productivity and profitability (Kemp and Michalk, 2007). These data demonstrate that implementing a moderate GI of 5.3 sheep/ha is recommended to maintain sustainability for the long-term Alpine meadow grasslands. Implementing a medium GI prevents a significant decrease in above-ground grassland productivity, while providing optimal ADG per hectare, which agrees with the work of Kemp and Michalk (2007). Therefore, ensuring optimal GI for sustainable grassland with sustainable livestock production management requires a reduction in livestock numbers per hectare, in which case, the grassland productivity per hectare can reach 75% of maximum in this study of 7.6 sheep/ha.

**CONCLUSIONS**

The grassland community height, coverage, above-ground biomass, and density were greatly reduced by increasing GI, while community density was increased. Increasing GI significantly increased the grass nutrient quality of the grassland community during the 4 yr of the 7-yr experiment. According to the comprehensive economic analysis, when the GI was 5.3 or 7.6 sheep/ha, the nutritional quality of the community was the greatest. However, a plant biomass shortage occurs when targeting a heavy GI (7.6 sheep/ha) leading to a decrease in ADG (g/d) per sheep but not in ADG g/ha. Therefore, when using the highest GI evaluated in this study, the ADG as g/ha is highest for the short term, which corresponds to current grazing practices by local herdsmen. However, achieving the goal of grassland sustainability to be available for future multiple functions needs to achieve sustainable livestock production as well. These research results recommend a policy change for implementing a management plan targeting a moderate GI of 5.3 sheep/ha based on study assumptions and with modification as more data becomes available. A GI of 5.3 sheep/ha provides 78% of the maximum ADG per hectare, which meets the requirement for sustainable livestock grassland.
grazing and ecological sustainability. But this GI recommendation is based on key assumptions of representative climate/weather of the study years going forward and that the vegetation starting in 2015 had re-equilibrated from the previous historical overuse. However, future work evaluating other potentially suitable grazing management systems, such as rotational grazing, could increase pasture yield and nutritional quality, thus contributing to the sustainable utilization and management of the Qilian Mountain Alpine grasslands for all uses.

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