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BIOMASS AND NITROGEN RESPONSES TO GRAZING INTENSITY IN AN ALPINE MEADOW ON THE EASTERN TIBETAN PLATEAU

ABSTRACT: This study was conducted to examine the seasonal dynamics of biomass and plant nitrogen (N) content under three grazing intensities (light grazing – LG: 1.2, moderate grazing – MG: 2.0, and heavy grazing – HG: 2.9 yaks ha⁻¹) in representative alpine meadow on the eastern Tibetan Plateau. Differentiation in grazing intensity in the study area started since 1997 and has continued to the present time. Plant samples were collected in the middle of June, August and September. The highest aboveground biomass occurred at the MG site for both August and September. Over the growing season, belowground biomass (0–30 cm) increased as grazing intensity increased. The total belowground biomass averaged over all sampling dates was 1226, 1908 and 2244 g m⁻² for LG site, MG site and HG site, which accounted for 75, 81 and 88% of total biomass, respectively. The results suggested that grazing intensity changed biomass allocation pattern between aboveground and belowground parts of plants. Higher grazing intensity resulted in higher N concentration in both live and dead aboveground biomass over the study period. Increased grazing intensity tended to increase plant N content averaged over all sampling dates, which were 17.9 g m⁻², 23.8 g m⁻² and 27.6 g m⁻² in LG site, MG site and HG site. The results indicated that higher grazing intensity had a potential to increase the ecosystem pool of plant N.

KEY WORDS: grassland, grazing, nitrogen, plant productivity, Tibetan Plateau

1. INTRODUCTION

Livestock grazing is one of the most prevalent land uses of the world's grasslands, and can considerably modify the productivity of the vegetation and the availability of N to plants in their grasslands (McNaughton et al. 1997, Frank et al. 2002). Grazing may modify plant productivity through effects on leaf area and light interception (Kooijman and Smit 2001, Baron et al. 2002). Generally, productivity is reduced as grazing intensity increases (Milchunas and Lauenroth 1993, Milchunas et al. 1998). However, grazing also can stimulate the productivity of the vegetation, especially at moderate levels of grazing (McNaughton 1985, Hik and Jeffries 1990, Frank and McNaughton 1993).

Similarly, livestock grazing also alters nitrogen status of plants. Livestock feces and urine provide large amounts of soluble N that is readily available to plants (Risser and Parton 1982, McNaughton 1990), and livestock excretions promote decomposition rates (Seagle et al. 1992, Pastor et
As a result, uptake rates of N by plants, plant tissue concentrations of N, N mineralization, and aboveground production of plant biomass may be increased on grazed sites (Coughenour 1991, Frank and Groffman 1998). Alternatively, livestock may reduce N mineralization and plant N pool (Risser and Parton 1982, Ritchie et al. 1998). Clearly, livestock may have different or even opposite effects on biomass and N in grassland systems and regionally-specific studies are thus critically important.

The Tibetan Plateau, the largest geomorphological unit on the Eurasian continent, is an important part of the global terrestrial ecosystem, and one of the major pastures in China. Alpine meadows, covering about 35% of the plateau area, are a representative vegetation type and the major grazing land of the region, especially in its eastern areas (Zheng 2000). Yet long-term overgrazing in the areas has resulted in considerable deterioration and even desertification (Wu and Liu 1999). However, there is little published evidence to grazing intensity impacts on N dynamics in these alpine meadows. Understanding biomass and N dynamics under different grazing intensity is essential to their proper management. The objective of this study was to examine the effects of grazing intensity on seasonal variety of biomass and plant N in an alpine meadow in the eastern Tibetan Plateau. The information obtained also provides insight into the potential benefits of plant to act as sinks of N in rangeland regions.

2. MATERIALS AND METHODS

2.1. Study sites

The study site is approximately 140 ha and located at Hongyuan County, Sichuan Province, China (33°03’N, 102°36’E) and has been previously used as traditional winter pasture (early November to mid-May) by local Tibetan nomads with light grazing intensities (Zhou 1998). It is 3462 m above sea level, with a continental harsh climate. Annual precipitation averages 752 mm, with about 86% received from May through September. Mean annual temperature is 1.1°C and there is not an absolute frost-free period. The highest monthly mean temperature is 10.9°C in July and the lowest is −10.3°C in January. The dominant species in the whole area was Clinelymus nutans (griseb) Nevski and Roegneria nutans (Keng) Keng, accompanied by Koeleria litwinowii Domin, Poa pratensis L., Agrostis schneideri (Pilger), Kobresia setchwanensis Hand.-Mazz. and Anemone rivularis Buch.-Ham. The vegetation covered over 90% (Zhou 1998).

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Fig. 1. Monthly mean air temperature (bars) and precipitation (line) for 2005 in the study area (source: The Meteorological Station of Hongyuan County).
Soils are Mat Cry-gelic Cambisols (Chinese soil taxonomy research group 1995). Soil organic matter and total N were 61.20 and 3.42 g kg\(^{-1}\), respectively (Gan et al. 1995).

In 1997, the study site was segregated into several pastures and contracted out to different farmers who established fences to enclose their own pastures. This caused a shift and redistribution of livestock across the study site with grazing intensities varying by farmer, but consistent among years for a given pasture. Three adjacent experimental sites, each with a different grazing intensity, were chosen for study. Light grazing intensity was 1.2 yaks ha\(^{-1}\) which resulted in 30% utilization of annual forage production for the 16 ha pasture area, and vegetation was dominated by *Roegneria nutans* (Keng) Keng, *Deschampsia caespitosa* (L.) Beauv., *Kobresia setchwanensis* Hand.-Mazz., and *Anemone rivularis* Buch.-Ham. The vegetation coverage ranged between 85–95%. Moderate grazing intensity was 2.0 yaks ha\(^{-1}\), resulting in 50% utilization over the 28 ha pasture, with vegetation dominated by *Kobresia setchwanensis* Hand.-Mazz., *Kobresia pygmaea* C.B. Clarke, *Roegneria nutans* (Keng) Keng, and *Aster alpinus* L. The vegetation covered over 90%. Heavy grazing intensity was 2.9 yaks ha\(^{-1}\), resulting in 70% utilization over the 20 ha pasture, with vegetation dominated by *Kobresia pygmaea* C.B. Clarke, *Kobresia setchwanensis* Hand.-Mazz., *Potentilla anserine* L., and *Leontopodium Franchetti* Beauv. The vegetation coverage was 65–75%.

The monthly mean air temperature and precipitation in the investigation area for 2005 are shown in Fig. 1. The soil characteristics of sites under different grazing intensities are shown in Table 1.

### Table 1. Soil characteristics to 10 cm depth under different treatments (mean ± S.D., n = 5).

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Light grazing</th>
<th>Moderate grazing</th>
<th>Heavy grazing</th>
</tr>
</thead>
<tbody>
<tr>
<td>pH</td>
<td>5.98±0.15a</td>
<td>5.85±0.09ab</td>
<td>5.71±0.19b</td>
</tr>
<tr>
<td>Organic C (g kg(^{-1}))</td>
<td>38.62±6.22b</td>
<td>49.58±11.70b</td>
<td>64.67±8.03a</td>
</tr>
<tr>
<td>Total N (g kg(^{-1}))</td>
<td>3.40±0.49c</td>
<td>4.33±0.68b</td>
<td>5.32±0.50a</td>
</tr>
<tr>
<td>C/N ratio</td>
<td>11.35±0.36</td>
<td>11.51±2.25</td>
<td>12.12±0.66</td>
</tr>
</tbody>
</table>

Within rows, means ± S.D. Different letters represent statistically significant at P <0.05. n = 5.
The least significant difference (LSD) were performed to determine the differences between treatment means at significance level $P < 0.05$.

3. RESULTS

3.1. Aboveground biomass and N concentration

Over the growing season, aboveground live biomass showed a single peak pattern with the highest biomass in August (Fig. 2A). In June, live aboveground biomass decreased as grazing intensity increased, but no significantly difference between treatments ($P > 0.05$). For August and September, however, live aboveground biomass was higher in the MG site than in the LG site and HG site. Over the study period, dead aboveground biomass showed an increasing tendency for each treatment and it was significantly lower in HG site compared to LG site and MG site, but no significant difference between LG site and MG site was detected ($P > 0.05$) (Fig. 2B).

The N concentration of the live aboveground biomass under each treatment tended to decrease from June to September, with

![Fig. 2. Aboveground live biomass (A) and dead biomass (B) under three different grazing intensities (light grazing, moderate grazing and heavy grazing) on three sampling dates (June, August and September). Within category, different letters within month represent statistically significant difference at $P < 0.05$. Vertical bars show S.D. (n = 5).]
the peak value appearing in HG site in June (20.6 g kg\(^{-1}\)) and the lowest at the LG site in September (12.6 g kg\(^{-1}\)) (Fig. 3A). N concentrations in the live aboveground biomass followed an increasing tendency with the increased of grazing intensity on each sampling date. The N concentration in aboveground dead biomass N was highest (11.9, 15.2 and 15.9 g kg\(^{-1}\) for LG, MG and HG, respectively) in June and decreased slightly throughout the study period, reaching minimum values in September of 10.9, 14.8 and 15.0 g kg\(^{-1}\), respectively (Fig. 3B). Over the study period, the dead aboveground biomass N concentration was significantly lower in the LG site than in the MG site and HG site, but no significantly difference between MG site and HG site is observed (\(P>0.05\)).

### 3.2. Belowground biomass and N concentration

Belowground biomass (0–30 cm) decreased with increasing soil depth and most of the belowground biomass was within 0–10 cm soil depth for all the treatments (i.e., in August, belowground biomass at the 0–10 cm made up 85, 87 and 92% of total belowground (0–30 cm) in the LG site, MG site and HG site, respectively) (Fig. 4). Over the study

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**Fig. 3.** N concentration of live (A) and dead (B) aboveground biomass under different grazing intensities (light grazing, moderate grazing and heavy grazing) on three sampling dates (June, August and September). Within category, different letters within month represent statistically significant difference at \(P<0.05\). Vertical bars show S.D. (\(n=5\)).
Fig. 4. Belowground biomass (A, B, C) and N concentration (D, E, F) for three soil layers (0–10 cm, 10–20 cm and 20–30 cm) under different grazing intensities (light grazing, moderate grazing and heavy grazing) on three sampling dates (June, August and September). Within each category, different letters within each soil layer and each month represent statistically significant difference at $P < 0.05$. Vertical bars show S.D. ($n = 5$).
period, the belowground biomass at the 0–10 cm soil depth was highest in August (Fig. 4B) and tended to increase with grazing intensity. The belowground biomass in the bottom two layers (10–20 cm and 20–30 cm) under different grazing intensity exhibited no obvious seasonal patterns.

The N concentration of belowground biomass also decreased with increasing soil depth, and the differences were narrowed between the bottom two layers (10–20 cm and 20–30 cm) (Fig. 4). In June, there was no significantly difference in belowground biomass N concentration between plots of different grazing intensities for each layer ($P > 0.05$) (Fig. 4). In August and September, the belowground biomass N concentration under different grazing intensity showed a similar pattern among three layers (0–10 cm, 10–20 cm and 20–30 cm), with the highest value in LG site and the lowest in HG site (Fig. 4).

3.3. Biomass and N partitioning

Biomass and N accumulations in above- and belowground components varied among grazing intensities (Fig. 5). Total aboveground biomass was highest in the MG site (462 g m$^{-2}$), followed by LG site (412 g m$^{-2}$) and HG site (324 g m$^{-2}$). The live aboveground biomass represented 34, 24 and 14% of total plant biomass at LG site, MG site and HG site, respectively. The total belowground biomass (0–30 cm) tended to increase with

![Fig. 5. Biomass (A) and nitrogen (B) partitioning averaged over all sampling dates in the three different grazing treatments (LG – light grazing; MG – moderate grazing; HG – heavy grazing).](image-url)
the grazing intensity, being respectively 1226, 1908 and 2244 g m$^{-2}$ in LG site, MG site and HG sites. Belowground biomass at 0–10 cm layer made up 85, 88 and 91% of total belowground (0–30 cm) biomass in LG site, MG site and HG site, respectively, suggesting that a greater amounts of biomass went into belowground plant components as grazing intensity increased (Fig. 5A).

Nitrogen content in plant components followed the similar patterns as their biomass among treatments (Fig. 5B). Total N storage of plant components was respectively 17.9, 23.8 and 27.6 g m$^{-2}$ at LG site, MG site and HG sites. The belowground biomass N content accounted for 71, 70 and 80% of total biomass N content in LG site, MG site and HG site, respectively. Most of the aboveground biomass N content distributed in live biomass and most of the belowground biomass N content was distributed within 0–10 cm soil depth (Fig. 5B).

4. DISCUSSION

In the present study, the live aboveground biomass tended to decrease as grazing intensity increasing in June when the growing season started, which was a common response and was a direct result of the consumption of biomass by the grazers (Hill et al. 1992). It was higher in the MG site than in the LG site and HG site for both August and September. This result suggested that the live aboveground biomass accumulated faster in the MG site than in the LG and HG sites during the growing season. In fact, the highest live aboveground biomass occurred at sites of moderate grazing pressure has been found in some studies in grasslands (McNaughton 1985, Van der Maarel and Titlyanova 1989, Hik and Jeffries 1990). The higher productivity under moderate grazing might be due to compensatory growth response to grazing (Hik and Jeffries 1990, Leriche et al. 2001). When grazing ended, the removal of grazers allowed a period of time for plants in grassland to recover, which was favorable for compensation to occur (Oesterheld and McNaughton 1991). Therefore, fast regrowth was expected to occur once grazers had left the area.

The dead aboveground biomass followed an increasing trend throughout the study period, which was consistent with the findings by Wang (2001) for kobresia meadow in Tibetan Plateau. Grazing with different intensities in the winter, one part of biomass in grassland was consumed by animals, at the same time, another part of biomass can be decomposed by animal trampling. As a result, higher grazing intensity led to lower aboveground dead biomass in June. However, in August and September, the highest dead biomass occurred at the MG site, probably because of higher live aboveground live biomass during this period. In terms of total aboveground biomass, a single peak pattern was observed with the highest biomass occurring in August over the growing season. This result corresponded well with a previous study in the same area reported by Wu et al. (2004).

Results reported in the literature regarding belowground biomass as a result of grazing were ambiguous. Milchunas and Lauenroth (1993), Wang and Wang (1999) and Frank et al. (2002) found mostly no changes, decreases, or increases, of belowground biomass as a function of grazing intensity. Our results suggested that the amount of belowground biomass tended to increase with grazing intensity. It was probably an expression of adaptation response of plant to grazing, since greater root investment could enhance plant resistance to grazing or other disturbances (Coughenour 1991). Jaramillo and Detling (1992) also found that plants growing in areas subject to prairie dog grazing invested more resources in roots than plants in less grazed areas. This change was reflected in the higher root to shoot biomass ratio (2.97, 4.13 and 6.93 in LG site, MG site and HG site, respectively) under the heavy grazing treatment compared to light grazing treatment. High proportion of root biomass in the total biomass can increase the capacity to tolerate environmental stresses and external disturbances, which is favorable for grassland restoration (Wang et al. 2003). However, aboveground biomass decreased under heavy grazing intensity, which indicated that the winter forage supply for this region reduced and accordingly the pressure on native grassland increased.
Nitrogen concentration in live aboveground biomass for all treatments showed a declining trend throughout the growing season, which was caused by dilution of N in plants as a result of plant growth (Woodmansee and Duncan 1980, Risser and Parton 1982). However, on monthly basis, it tended to increase with the increase of grazing intensity. This can be explained by the fact that plant N uptake may be enhanced by a higher root biomass (Chaneton et al. 1996). N concentration in the aboveground dead biomass followed a similar pattern to aboveground live biomass N concentration. This result suggested that N concentration of the dead aboveground biomass was subject to that of the live aboveground biomass. Changes in N concentration in the aboveground biomass may be the result of changes in plant allocation of N between aboveground and belowground tissues (Gorissen and Cotrufo 1999). In terms of belowground biomass N concentration, an obvious characteristic was that the lowest N concentration occurred at MG site in both August and September, which might be attributed to the fast accumulation of aboveground biomass that resulted in N transfer from belowground to aboveground tissues. In contrast, belowground biomass N concentration was higher in LG site than in HG site for August and September, probably because of N concentration dilution by higher biomass production in HG site (Owensby et al. 1993).

Nitrogen content in plant components showed similar patterns as their biomass under different grazing intensities. Belowground biomass N content accounted for most of the total biomass N content (71% in LG site, 70% in MG site and 79% in HG site, respectively). Although high N storage in belowground biomass is common in grasslands (Bobbink et al. 1989), the effects of grazing intensity on this pattern were different (i.e., HG amplified this pattern compared to MG and LG). Those results suggested that grazing intensity changed the above- and belowground allocation of N within vegetation. Belowground N allocation may allow compensatory responses to grazers (Turner et al. 1993), and might also facilitate the recovery of vegetation after natural disturbance (Hobbs et al. 1991). Increased grazing intensity may increase plant N content directly by changing the sink-strength of above and belowground organs (Chaneton et al. 1996), or indirectly by increasing soil nutrient availability through accelerated mineralization rates (Holland and Detling 1990, Olofsson et al. 2001) and excretion of readily available nutrients (McNaughton 1990, Pastor et al. 1993). Heavy grazing intensity resulted in higher N content in total biomass, demonstrating that heavy grazing intensity had a potential to increase the ecosystem pool of plant N.

Although heavy grazing intensity increased plant biomass and N content, greater amounts of matter and N storage went to the belowground biomass. What’s more, heavy grazing markedly decreased vegetation coverage. Those are undesirable for livestock production and sustainable grassland development. Grazing at light to moderate stocking rates seems to be beneficial to productivity and N sequestration in plants. The alpine meadow ecosystem in Tibetan Plateau is very fragile and evolved under grazing by large herbivores; therefore, without an appropriate level of grazing in a long term perspective on an ecological timescale, deterioration of the vegetable system and possible declines in N storage in the vegetable, are indicated.

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