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Influence of grazing intensity on performance of perennial grass mixtures in the alpine region of the Tibetan Plateau

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Abstract Effects of grazing intensity on leaf photosynthetic rate (Pn), specific leaf area (SLA), individual tiller density, sward leaf area index (LAI), harvested herbage DM, and species composition in grass mixtures (*Clinelymus nutans* + *Bromus inermis*, *Elymus nutans* + *Bromus inermis* + *Agropyron cristatum* and *Elymus nutans* + *Clinelymus nutans* + *Bromus inermis* + *Agropyron cristatum*) were studied in the alpine region of the Tibetan Plateau. Four grazing intensities (GI), expressed as feed utilisation rates (UR) by Tibetan lambs were imposed as follows: (1) no grazing; (2) 30% UR as light grazing; (3) 50% UR as medium grazing; and (4) 70% UR as high grazing. Leaf Pn rate and tiller density of grasses increased ($P < 0.05$), while sward LAI and harvested herbage DM declined ($P < 0.05$) with the increments of GI, although no effect of GI on SLA was observed. With increasing GI, *Elymus nutans* and *Clinelymus nutans* increased but *Bromus inermis* and *Agropyron cristatum* decreased in swards, LAI and DM contribution. Whether being grazed or not, *Elymus nutans* + *Clinelymus nutans* + *Bromus inermis* + *Agropyron cristatum* was the most productive sward among the grass mixtures. Thus, two well-performed grass species (*Elymus nutans* and *Clinelymus nutans*) and the most productive mixture of four species should be investigated further as the new feed resources in the alpine grazing system of the Tibetan Plateau. Light grazing intensity of 30% UR was recommended for these grass mixtures when swards, LAI, herbage DM harvested, and species compatibility were taken into account.

Keywords improved pastures; yields; leaf characteristics; herbage DM yield; species composition

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INTRODUCTION

On the Qinghai-Tibetan Plateau of China, conflicts between forage supply and animal requirements in traditional grazing systems result in two serious problems, rangeland degradation and low animal productivity. Natural forages of the alpine meadow accumulate annually about 2.5–4.0 t ha^{-1} dry matter (DM) within a 120–140-day growing period (Dong 2001). Livestock need around 6.0–7.0 t DM per year at 4–5 yaks ha^{-1} stocking rate on the meadow when yak farming is taken as an example. Alpine rangelands are extensively degrading due to overgrazing (Li & Huang 1995; Zhou et al. 2001). Even bare land, called “Black Soil Patches”, appears in alpine ecosystems (Ma et al. 1999; Shen et al. 2001). Because of inadequate feed from degraded rangeland, livestock productivity is low. Female yak, mainly regarded as dairy cattle on the plateau, can produce only 1.3 ± 0.3 kg milk per day, whether milking once or twice daily (Long 1994). Around

25% of body weight at the end of summer is normally lost over winter and spring (Long & Ma 1996).

To reduce grazing pressure on the alpine rangeland and, thus, to control rangeland degradation, several measures (e.g., subsidising Tibetan farmers the equivalent of their harvested animal products) have been taken by the Chinese Government to encourage reducing the numbers of grazing animals on rangeland. Tibetan farmers, however, are reluctant to accept this because they regard livestock as the symbol of their wealth and status. Thus, Tibetan farming systems for sustainable development are needed. A possible option is to develop new feed resources for livestock and to include them in grazing systems for the Tibetan Plateau.

Although oat (*Avena sativa*) has been successfully cultivated as winter supplementary feed for its high yield (around 7–8 t ha^{-1}) in this region for many years, wind erosion on reclaimed oat lands occurs extensively due to low coverage of vegetation during the 7- to 8-month non-growing period of this annual crop. Comparatively, perennial grasses such as *Elymus nutans*, *Bromus inermis*, *Clinelymus nutans*, and their mixtures can produce higher DM yield (around 8–14 t ha^{-1}) than oats and resist wind successfully (Dong 2001). Mixtures of perennial grasses are a sustainable and productive farming system in this legume-deficient alpine region. Perennial grass mixtures are recommended, but little information on grazing management is available. Thus, this research was conducted to clarify how grazing intensity (GI) influenced performance of 3-year-old perennial grass mixtures in the alpine region of the plateau based on leaf photosynthetic rate, specific leaf area, individual tiller density, swards leaf area index (LAI), herbage harvested DM, species composition in both LAI, and harvested DM in different grass mixtures. Thus, the optimum grazing intensity for the perennial grass mixtures is proposed to improve their productivity and maintain their persistence.

MATERIALS AND METHODS

Experimental site

In the first year (May 1998), three grass mixtures were sown with different compositions and seed rates as follows at the Alpine Grassland Station of Gansu Agricultural University in Jingqinghe Region (37°40′N, 103°32′E, 2960 m a.s.l.), the north-eastern end of Qinghai-Tibetan Plateau: (1) 56 kg ha^{-1} of *Clinelymus nutans* + 38 kg ha^{-1} of *Bromus inermis* (C + B); (2) 14 kg ha^{-1} of *Elymus nutans* + 38 kg ha^{-1} of *Bromus inermis* + 23 kg ha^{-1} of *Agropyron cristatum* (E + B + A); (3) 14 kg ha^{-1} of *Elymus nutans* + 28 kg ha^{-1} of *Clinelymus nutans* + 19 kg ha^{-1} of *Bromus inermis* + 23 kg ha^{-1} of *Agropyron cristatum* (E + C + B + A).

Each of the grass mixtures was randomly subdivided into 12 fenced plots (10 × 15 m). At the end of the growing season in the first year, all swards were cut for hay production.

The soil type of the experimental site was alpine steppe soil (40–60 cm deep) with an analysis of 100 g kg^{-1} organic matter, 6 g kg^{-1} (DM basis) total nitrogen (N), 67 mg kg^{-1} phosphorus (P), 170 mg kg^{-1} potassium (K) and pH of 7.0–8.0 (water based). At sowing time, a base fertiliser mixture of N, P, and K was applied to the soil at a recommended rate. During growth and regrowth of the swards, the experimental field was not irrigated or fertilised.

Weather data were collected from the nearest weather station, 10 km from the experimental site (Wushaoling Station, 1998–2000). The lowest temperature in January was about –20°C and the highest temperature in July was about 24°C. The average daily temperature was around –0.1°C. Annual temperature sum of the positive average daily temperature was 1380°C. Total annual rainfall averaged around 416 mm (plus about 200 mm snowfall in winter), which occurred primarily in July, August, and September. There was no frost-free period. Both native and cultivated plants can grow for about 120–140 days.

Treatments

In the second year (1999), the trial was subjected to four different defoliation regimes of cutting to 2 cm stubble height at either two (20 July and 15 September), three (28 June, 5 August, and 20 September), or four times (20 June, 25 July, 20 August, and 20 September) during the growing season, according to the methods recommended by Moore & Chapman (1986) and Ren (1998). In the light of those results (Dong 2001), the area was changed to a grazing trial in the following year.

In the third year (2000), a grazing experiment of three grass mixtures by four grazing intensities (GI) was conducted within a randomised block design with 12 plots (three spatial replications for each grazing treatment) for each mixture by using 5- to 6-month-old Tibetan sheep (body weight 24.4 ±

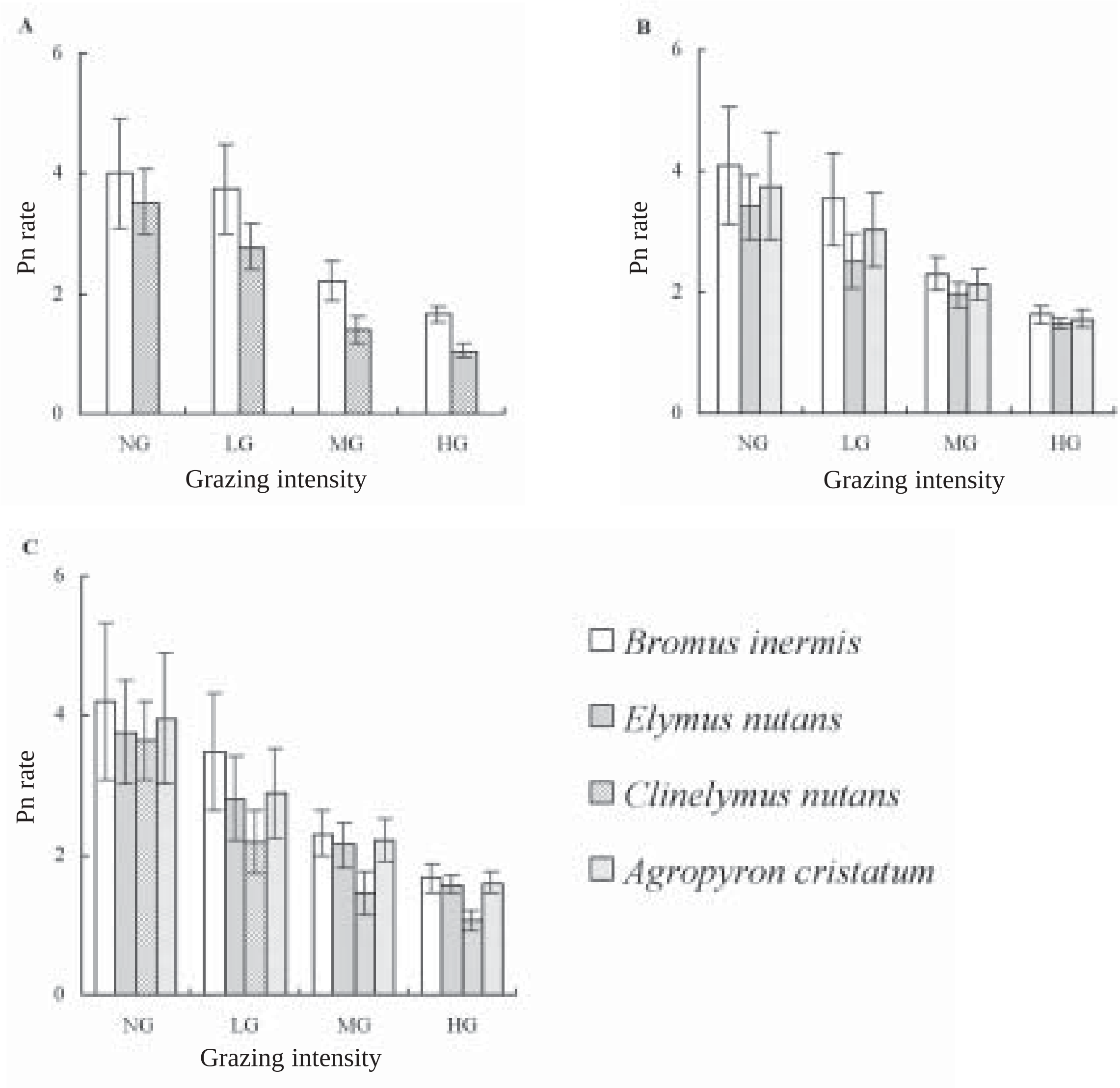

Fig. 1 Means (±SD) of photosynthesis rate (Pn) (μmol CO_2 m^{-2} s^{-1}) of leaves of component grasses in the mixtures of **A**, *Clinelymus nutans* + *Bromus inermis*; **B**, *Elymus nutans* + *Bromus inermis* + *Agropyron cristatum*; and **C**, *Elymus nutans* + *Clinelymus nutans* + *Bromus inermis* + *Agropyron cristatum* under the grazing intensities of no grazing (NG), light grazing (LG), medium grazing (MG), and high grazing (HG).

2.2 kg) from 1 July to 15 September 2000. The GI was defined as the utilisation rate (UR) of pasture according to feed taken by the animals and herbage yield of the swards. The herbage yield in each grazing plot was estimated by protecting the forage with three randomly located 1 × 1 × 1 m cages (McNaughton et al. 1996). The difference between herbage DM yield in cages and stubble DM yield was considered as feed taken. Four GIs, no grazing (NG), light grazing (LG) as 30% UR, medium grazing (MG) as 50% UR, and heavy grazing (HG) as 70% UR, were imposed by increasing or reducing animal numbers on the plots following a "put and take" method (Jiang 1991).

Each treatment was rotationally grazed around three plots with a 5-day grazing period (around 20-day rest period) and the first grazing on 1 July according to the results of the defoliation experiment in 1999. Grazing on the plots at each rotation started when the sward was 15–20 cm high and stopped around 7, 5, and 3 cm high for LG, MG, and HG, respectively. Rotations can be treated as replications at a time scale when the effect of grazing intensity is studied in a grazing experiment (Jiang & Li 1993).

Measurement

On the day before each grazing, three randomly allocated quadrats of 10×10 cm per plot were harvested to a 2-cm stubble height using hand-held shears. Living material of the samples was separated into component species for tiller density and leaf area measurement. Tillers of individual grass species were recorded directly following the method of Silvertown et al. (1994). Leaf areas of individual species were measured using a CI-203 Portable Laser Area Meter (CID Inc. USA) before drying at 65°C for 48 h and weighing. Leaf area index of swards and species compositions in LAI were thus estimated. Specific leaf area (SLA) was calculated as leaf area/leaf dry weight ($cm^2 g^{-1}$). The photosynthetic rate of the top leaves of new tillers in each plot were measured in three replicates by using a CI-301 PS Portable Photosynthesis System (CID Inc. USA). Harvests of component species and the swards within three quadrats of 1×1 m in each plot were dried at 65°C for 48 h and weighed to estimate herbage DM harvested and species composition in DM.

Statistical analysis

The data of leaf photosynthetic rate, tiller density of plants, species SLA, species compositions in LAI and DM, swards LAI, and herbage DM harvested in each plot under each GI treatment are presented in tables or in figures as the means of 27 repetitions (3 rotations × 3 plots × 3 quadrats). Effects of GI,

Table 1 Mean level of components of three grass mixtures in the third year over three grazing rotations at four grazing intensities. Species: E = *Elymus nutans*; C = *Clinelymus nutans*; B = *Bromus inermis*; A = *Agropyron cristatum*. Mixtures: C + B; E + B + A; E + C + B + A. Grazing intensity: NG = no grazing; LG = light grazing (30% feed taken); MG = medium grazing (50%); and HG = high grazing (70%). Within columns for the same parameter, the means followed by the same letter are not significantly different at 5% level.

Grazing intensity	Species mixtures								
	C + B		E + B + A			E + C + B + A			
	C	B	E	B	A	E	C	B	A
Total herbage (kg ha^{-1})									
NG	7642a		6404a			9479a			
LG	2489b		2088b			2842b			
MG	2220b		2177b			2719b			
HG	1330c		1170c			1616c			
SE	113		144			242			
Specific leaf area (cm^2 g^{-1})									
NG	168	182	175	173	174	162	180	163	172
LG	170	175	171	166	168	165	166	161	167
MG	170	168	171	178	165	166	168	173	166
HG	176	162	170	166	178	179	167	165	171
SE	4.4	7.6	2.4	4.8	5.4	6.8	6.1	4.7	3.2
Sward LAI contribution (%)									
NG	50a	50a	48a	51a	1a	31a	22a	46a	1a
LG	59b	41b	52a	47a	1a	44b	32b	23b	1a
MG	57b	43b	67c	33c	0b	42b	32b	26b	0b
HG	58b	42b	60b	40b	0b	43b	34b	23b	0b
SE	1.2	1.2	1.5	1.5	0.06	1.2	1.6	1.5	0.08
Sward DM contribution (%)									
NG	90a	10a	87b	7a	6a	72a	21a	5a	2a
LG	98b	2b	96a	3b	1b	63b	34b	2b	1b
MG	98c	2c	98a	2b	0c	58c	41c	1c	0c
HG	99d	1d	97a	3b	0c	46d	53d	1c	0c
SE	0.1	0.1	1.1	0.2	0.3	1.4	1.4	0.2	0.3

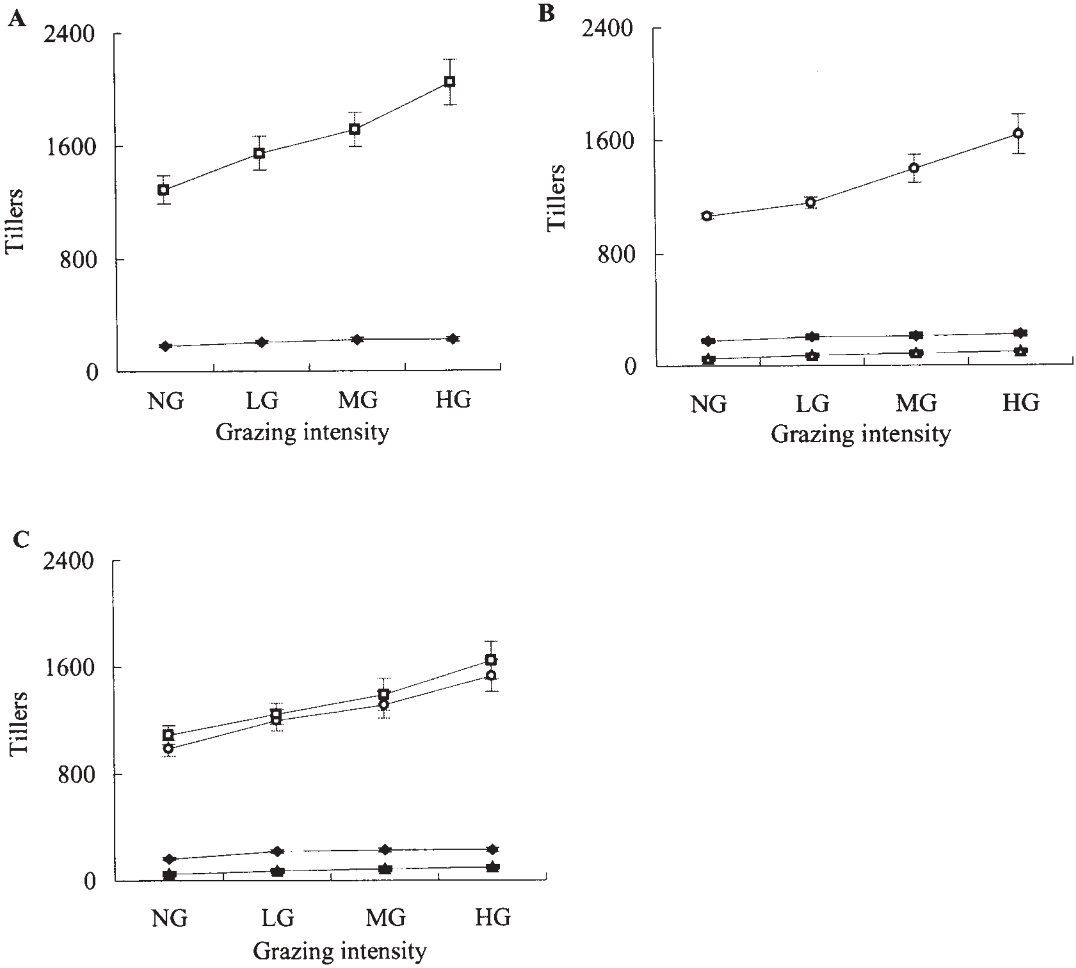

Fig. 2 Means (±SD) of tiller density (no. m^{-2}) of component grasses in the mixtures of **A**, *Clinelymus nutans* (□) + *Bromus inermis* (◆); **B**, *Elymus nutans* (○) + *Bromus inermis* + *Agropyron cristatum* (△); and **C**, *Elymus nutans* + *Clinelymus nutans* + *Bromus inermis* + *Agropyron cristatum* under the grazing intensities of no grazing (NG), light grazing (LG), medium grazing (MG), and high grazing (HG).

species combinations, and their interactions on leaf photosynthetic rate, species SLA, tiller density of plants, species compositions in LAI and DM, sward LAI, and herbage biomass were analysed via ANOVA by using a Generalised Liner Model (SPSS 10.0).

RESULTS

Leaf photosynthetic rates

Grass species differed in their leaf photosynthesis (Pn) rates. With the increment of GI from NG to HG, the leaf Pn rates of *Elymus nutans*, *Clinelymus nutans*, *Bromus inermis*, and *Agropyron cristatum* in their mixtures decreased ($P < 0.05$) from around 3.7 to 1.5, 3.6 to 1.1, 4.1 to 1.7, and 3.9 to 1.6 µmol CO_2 m^{-2} s^{-1} respectively (Fig. 1). Among the grass species, *Clinelymus nutans* showed the lowest ($P < 0.05$) Pn rate at MG and HG levels of GI. Effects of GI on Pn were constant across species mixtures and no interactions were observed.

Specific leaf area

Irrespective of species and combinations, the SLAs of component grasses were relatively constant under different GIs (Table 1), ranging from 160 to

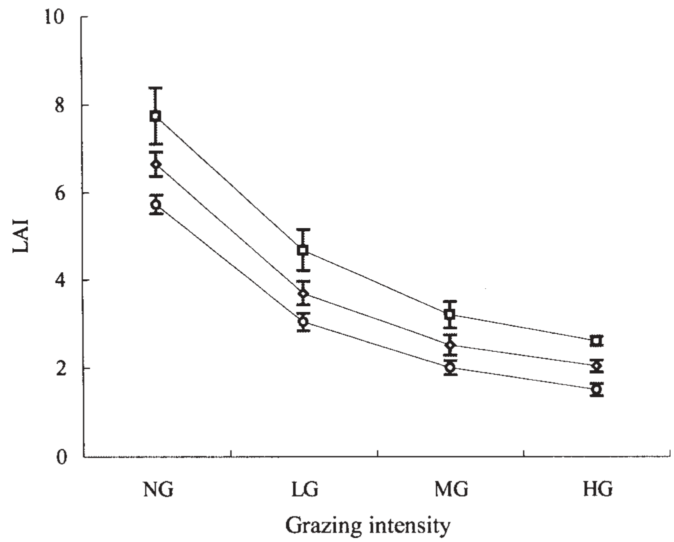

Fig. 3 Means (±SD) of leaf area index (LAI) of grass mixtures of *Clinelymus nutans* + *Bromus inermis* (◇), *Elymus nutans* + *Bromus inermis* + *Agropyron cristatum* (○) and *Elymus nutans* + *Clinelymus nutans* + *Bromus inermis* + *Agropyron cristatum* (□) under the grazing intensities of no grazing (NG), light grazing (LG), medium grazing (MG), and high grazing (HG).

180 $cm^2\ g^{-1}$. Likewise, there was no significant ($P > 0.05$) interaction between GI and combination on SLA of component grasses in the mixtures.

Tiller density

The tiller density of *Elymus nutans*, *Clinelymus nutans*, *Bromus inermis*, and *Agropyron cristatum* increased significantly from NG to HG (Fig. 2). Among the grasses, *Elymus nutans* and *Clinelymus nutans* had similar and highest tiller densities, *Bromus inermis* was intermediate, and *Agropyron cristatum* showed the lowest tiller density at any GI ($P < 0.05$). Tiller density of individual species decreased ($P < 0.05$) with increasing components of the mixtures, e.g., that of *Elymus nutans* decreased from 1350 tillers m^{-2} in the three-component mixture of *Elymus nutans* + *Bromus inermis* + *Agropyron cristatum* to 1261 tillers m^{-2} in the four-component mixture of *Elymus nutans* + *Clinelymus nutans* + *Bromus inermis* + *Agropyron cristatum*. No interactions ($P > 0.05$) between combination and GI on tiller density of individual grass species were observed.

Leaf area index

Sward LAIs of *Elymus nutans* + *Clinelymus nutans* + *Bromus inermis* + *Agropyron cristatum*, *Elymus nutans* + *Bromus inermis* + *Agropyron cristatum* and *Clinelymus nutans* + *Bromus inermis* declined from NG to HG (Fig. 3). Whether grazed or not, swards of *Bromus inermis* + *Elymus nutans* + *Clinelymus nutans* + *Agropyron cristatum* had the highest LAI ($P < 0.05$), and those of *Bromus inermis* + *Elymus nutans* + *Agropyron cristatum* the lowest LAI ($P < 0.05$).

Herbage DM harvested

In the absence of grazing (NG), all grass swards had the highest herbage DM harvested (Table 1). Among grazing treatments, HG intensity decreased ($P < 0.05$) herbage DM harvested, but no difference ($P > 0.05$) in harvested herbage DM harvested was observed between LG and MG. At all GIs, grass mixture of *Elymus nutans* + *Clinelymus nutans* + *Bromus inermis* + *Agropyron cristatum* had higher ($P < 0.05$) herbage DM harvested, and mixtures of *Elymus nutans* + *Bromus inermis* + *Agropyron cristatum* and *Clinelymus nutans* + *Bromus inermis* had similar ($P > 0.05$) but lower herbage DM harvested. There was significant ($P < 0.05$) interaction between GI and combination on herbage DM harvested.

Species compositions

LAI proportions of *Clinelymus nutans* in its mixtures increased and those of *Bromus inermis* declined ($P < 0.05$) with increased GI, although both showed no difference ($P > 0.05$) between grazing treatments (Table 1), i.e., LG, MG, and HG. LAI proportion of *Elymus nutans* in mixture of *Elymus nutans* + *Bromus inermis* + *Agropyron cristatum* was not different between NG and LG, but difference ($P < 0.05$) occurred among LG, MG, and HG, and in the mixture of *Elymus nutans* + *Clinelymus nutans* + *Bromus inermis* + *Agropyron cristatum* increased ($P < 0.05$) after grazing. Changes in the proportion of *Agropyron cristatum* in LAI were not obtained under MG and HG as few plants of this species survived in mixtures after grazing.

The DM proportions of *Clinelymus nutans* in its mixtures increased ($P < 0.05$) and those of *Bromus inermis* decreased ($P < 0.05$) with increased GI (Table 1). The DM proportions of *Elymus nutans* in the mixture of *Elymus nutans* + *Bromus inermis* + *Agropyron cristatum* increased ($P < 0.05$) and in the mixture of *Elymus nutans* + *Clinelymus nutans* + *Bromus inermis* + *Agropyron cristatum* declined ($P < 0.05$) after grazing. Again, changes in the proportion of *Agropyron cristatum* in DM were not obtained under MG and HG, as few plants of this species remained after grazing.

DISCUSSION

Previous grazing management studies on alpine meadow (Zhu et al. 1994) and alpine bushland (Han et al. 1993) of the Qinghai-Tibetan Plateau were consistent with the present study in the findings that leaf Pn, LAI, and herbage DM harvested declined with increased GI, but inconsistent with this study by reporting that SLA also dropped with the increment of GI. No significant variation of SLA under different GI treatments was observed in the present study. Similar to other studies on either native or cultivated grasses under alpine (Han et al. 1993; Zhu et al. 1994), temperate (Jewiss 1972; Hodgson 1990; Xia et al. 1994) and subtropical conditions (McKenzie 1996, 1997), intense grazing developed higher tiller densities of the grasses in the present study.

Rate of herbage growth may be influenced both by supply of energy from photosynthesis, reflecting size and photosynthetic efficiency of the leaf canopy, and by number and activity of growth sites of grass tillers (Hodgson 1990). In this study, decline in LAI and leaf Pn with the increase of grazing intensity may result in a sharp decline in herbage DM harvested at HG. However, higher tiller densities with the increased grazing intensities may partly compensate for the decrease of herbage DM harvested, leading to no significant difference of herbage DM harvested between LG and MG.

Hodgson (1990) suggested that, at LAI above 3, there is a closed sward canopy that ensures complete interception of incoming light and an effective balance between declining growth per tiller and increasing tiller numbers on both rotationally and continuously stocked swards. In our study, sward LAI declined below 3 when grazing intensity increased to MG and HG, except for *Elymus nutans* + *Clinelymus nutans* + *Bromus inermis* + *Agropyron cristatum* which maintained an LAI of 3.2 under MG. Interception of incoming light was incomplete for a sward canopy that was not closed, and the declining growth per tiller was not well balanced by the increasing tiller numbers on the grazed swards under MG and HG. As far as LAI is concerned, grazing intensities of 50 and 70% URs were too high for perennial grass mixtures in the alpine region of the Tibetan Plateau.

Herbivores affect plant production by removing material that might otherwise support further growth (Detling & Painter 1983) and by altering species composition (Coppock et al. 1983) and neighbourhood competitive interactions (Archer & Delting 1984). Decreased LAI with the increment of GI in the present study showed the leaves—the materials that can support further growth of grasses—were intensely removed by Tibetan sheep at higher GI. Although competitive intensities were not measured in this study, increased proportions of two component species *Elymus nutans* and *Clinelymus nutans*, and decreased proportions of the other two component species *Bromus inermis* and *Agropyron cristatum* in both LAI and DM indicated great variations of species compositions and intense neighbourhood competitive interactions with increased GI. This is why heavy grazing, namely 70% UR in this study, led to a lower plant production in a rotational grazing regime.

Dynamics of species composition can reflect species compatibility and sward persistence, although these indices are highly related to grass tolerance to grazing, species competitive ability, and even animal preference (Crawley 1983; Hodgson 1990; Hodgson & Illius 1996). The large fluctuation of species compositions both in LAI and DM in this study illustrated both poor species compatibility and sward persistence of these grass mixtures under grazing in the alpine region of the Tibetan Plateau. Comparatively, species compositions of all mixtures in both DM and LAI under LG were similar to those under NG, and so sward persistence may be better maintained under LG (30% UR) than higher GI. According to Nassiri & Elgersma (1998), SLA of species has an important role in sward composition and can be used as a measure of a cultivar's compatibility in perennial ryegrass-white clover mixtures. However, in the current study, SLA did not provide any information about variation of species compositions in grass mixtures under different GIs.

Whether being grazed or not, *Elymus nutans* + *Clinelymus nutans* + *Bromus inermis* + *Agropyron cristatum* was higher in LAI and DM production than the other two grass mixtures; *Elymus nutans* and *Clinelymus nutans* were higher in LAI, and sward LAI contribution and DM contribution than other two component species. Thus, they should be investigated further as the new feed resources in the alpine grazing system of the Tibetan Plateau.

Tibetan farmers normally maintain a high grazing intensity of above 70% UR on natural swards of alpine grassland and overgrazing has resulted in grassland degradation. Several authors (Feng 1989; Zhu et al. 1994; Song 1998) thus conducted researches on grazing management of native grassland and suggested a medium GI of 50% UR or even lighter GI for alpine grassland in the Tibetan Plateau. In this study, light GI of 30% UR was proposed for these three mixtures when taking swards LAI, herbage DM harvested, and species compatibility into account.

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REFERENCES

Archer, S.; Delting, J. K. 1984: The effects of defoliation and composition on regrowth of tillers of two North American mixed-grass graminoids. *Oikos 43*: 351–357.

Coppock, D. L.; Delting, J. K.; Ellis, J. E.; Dyer, M. I. 1983: Plant-herbivore interactions in a North American mixed-grass prairie. I. Effect of black-tailed prairie dogs on intraseasonal aboveground plant biomass and nutrient dynamics and plant species diversity. *Oecologia (Berlin) 56*: 1–9.

Crawley, M. L. 1983: Herbivory: the dynamics of animal-plant interactions. Oxford, Blackwell Scientific Publications.

Delting, J. K.; Painter, E. L. 1983: Defoliation responses of western wheatgrass population with diverse histories of prairie dog grazing. *Oecologia (Berlin) 57*: 65–71.

Dong, S. K. 2001: The stability of mixture grassland of cultivated perennial grass and its regulation in alpine region of Qinghai-Tibetan Plateau of China. Unpublished PhD thesis, Gansu Agricultural University, Lanzhou, China.

Feng, J. H. 1989: Effect of different grazing intensities on the alpine meadow. *Journal of Qinghai Animal and Veterinary Science Supplement (3)*: 15.

Han, F.; Ben, G. Y.; Shi, S. B. 1993: Study on some plant growth characteristics under different grazing intensities in alpine bushland. *Acta Phytoecologica et Geobotanica Sinica 17*: 331–338.

Hodgson, J. 1990: Grazing management science into practice. London, Longman Group UK Limited.

Hodgson, J.; Illius, A. W. 1996: The ecology and management of grazing systems. Wallingford, UK, CABI.

Jewiss, O. R. 1972: Tillering in grasses—its significance and control. *Journal of the British Grassland Society 27*: 65–82.

Jiang, W. L. 1991: Studies on the primary productivity and regulation on the stability of communities of mixture grassland in Weining, Guizhou. Unpublished PhD thesis, Gansu Agricultural University, Lanzhou, China.

Jiang, W. L.; Li, X. L. 1993: The effect of different utilization intensities on the yield and composition of the mixed sown pasture. *Acta Prataculturae Sinica 2(3)*: 1–10.

Li, X. L.; Huang, B. N. 1995: The cause of "Black Soil Patch" grassland in Qinghai Province and management countermeasures. *Grassland of China 85 (4)*: 51, 64–67.

Long, R. J. 1994: Milk performance of yak cows under traditional feeding and management on small Tibetan farms. *Acta Prataculturae Sinica 3(1)*: 71–76.

Long, R. J.; Ma, Y. S. 1996: Qinghai's yak production systems. *In*: Miller, D. *ed*. Proceedings of a workshop, 23–31 October, 1996, Kathmandu, Nepal. Pp. 105–114.

Ma, Y. S.; Lang, B. N.; Wang, Q. J. 1999: Review and prospect of the study on "Black Soil Type" deteriorated grassland. *Pratacultural Science 16(2)*: 5–9.

McKenzie, F. R. 1996: The influence of grazing frequency and intensity on the vigour of *Lolium perenne* L. under subtropical conditions. *Australian Journal of Agricultural Research 47*: 975–983.

McKenzie, F. R. 1997: Influence of grazing frequency and intensity on the density and persistence of *Lolium perenne* tillers under subtropical conditions. *Tropical Grasslands 31*: 219–226.

McNaughton, S. J.; Milchunas, D. G.; Frank, D. A. 1996: How can net primary productivity be measured in a grazing ecosystem? *Ecology 77*: 974–977.

Moore, P. D.; Chapman, S. B. 1986: Methods in plant ecology. Oxford, The Alden Press.

Nassiri, A.; Elgersma, A. 1998: Competition in perennial ryegrass-white clover mixtures under cutting. 2. Leaf characteristics, light interception and dry-matter production during regrowth. *Grass and Forage Science 53*: 367–379.

Ren, J. Z. 1998: Methods in grassland science. Beijing, China Agricultural Press.

Shen, Y. Y.; Ma, Y. S.; Li, Q. Y.; Hou, F. J. 2001: Grassland degradation and grassland management in Qinghai-Tibetan Plateau: a case study in Darlag county, Qinghai Province, P. R. China. *In*: Hong, F. C.; Ren, J. Z. *ed*. Prospects of grassland science and industry for the 21st century. Paper Collection of International Conference on Grassland Science and Industry, 14–16 July 2001, Hailaer, China. Pp. 84–91.

Silvertown, J.; Lines, C. E. M.; Dale, M. P. 1994: Spatial competition between grasses—rates of mutual invasion between four species and the interaction with grazing. *Journal of Ecology 82*: 31–38.

Song, H. S. 1998: Study on the seed performance of *Kobresia* under different grazing intensities. *Journal of Qinghai University 16(1)*: 25–27.

Xia, J. X.; Wang, P.; Fang, F. C. 1994: Research advances on effect of cutting and grazing on the regrowth and productivity of grass pastures. *Acta Agrestia Sinica 2(1)*: 45–55.

Zhou, X. M. 2001: *Kobresia* Meadow of China. Beijing, Scientific Press of China.

Zhu, Z. H.; Wang, G.; Zhao, S. L. 1994: Aboveground biomass dynamics of clonal ramet population of *Kobresia humilis* in alpine meadow under different stocking intensities. *Grassland of China (3)*: 10–14.