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Grazing Intensity Impacts on Carbon Sequestration in an Alpine Meadow on the Eastern Tibetan Plateau

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Abstract: Livestock grazing has the potential to substantially alter carbon (C) storage in grassland ecosystem. In this study, we evaluated the soil-plant system C (0-30cm) under three different grazing intensities by yaks (light: 1.2, moderate: 2.0, and heavy: 2.9 yaks/ha) in alpine meadow on the eastern Tibetan Plateau. Soil organic C at 0-30cm depth and total plant components C increased from light grazing (9795 and 806 g/m^2) to moderate grazing (10158 and 1087 g/m^2) and to heavy grazing (11729 and 1148 g/m^2). The results indicated that higher grazing intensity had a potential to increase soil-plant system C pool in the alpine meadow.

Keywords: Grassland, species composition, biomass, carbon storage

INTRODUCTION

Grasslands comprise about 40% of the earth's land surface, and are responsible for a comparable proportion of the carbon (C) flux associated with terrestrial net primary productivity[1]. In addition, grasslands store > 10% of terrestrial biomass C, 10-30% of global soil organic carbon (SOC), and they have been estimated to sequester C in soil at a rate of 0.5 Pg C/yr)[1,2]. This implies that modest changes in C storage in grassland ecosystems have the potential to modify the global C cycle and indirectly influence climate[3,4,5]. Despite this significance, our understanding of land use effects on the storage of C in rangelands remains limited[6,7].

Livestock grazing is one of the most prevalent land uses of the world's rangelands, and has the potential to substantially alter C storage in those ecosystems by: (1) Modifying the magnitude and relative allocation of C to above- and belowground biomass[8]; (2) Altering microclimate and the availability of light, water, and nutrients[9,10]; and (3) Influencing the quantity and quality of C inputs by modifying the species composition and functional diversity of plant communities[11]. Although these grazing-induced processes collectively appear to accelerate rates of C cycling processes in grazed ecosystems[12,13], their influence on ecosystem C storage often inconsistent and difficult to predict[7,14].

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 pasturelands 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[15]. The soil of these alpine meadows is rich in organic C (18.2 kg/m^2)[16]. The alpine ecosystem may be a major C sink because of its high productivity during the growing season and the low rate of decomposition resulting from low temperature[17]. However, it may also act as an important C source if grazing intensity increases[18]. In the alpine grassland ecosystem, long-term overgrazing has resulted in considerable deterioration and even desertification[19], which may release considerable quantities of C from the ecosystem to the atmosphere. Grazing intensity is therefore one of the critical factors controlling the C budget for these grassland ecosystems. However, there is little information about the effect of grazing intensity on the C budget of alpine grassland ecosystems on the Tibetan plateau.
The objective of this study was to quantify the impacts of grazing with different intensity on biomass, C sequestration in an alpine meadow ecosystem on the eastern Tibetan Plateau.

MATERIALS AND METHODS

Study Site: 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)

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by local Tibetan nomads with light grazing intensity[20]. 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* and *Roegneria nutans*, accompanied by *Koeleria litwinowii*, *Agrostis schneideri*, *Kobresia setchwanensis* and *Anemone rivularis*. The vegetation covered over 90%[20]. Soils are Mat Cry-gelic Cambisols[21]. Soil organic mater and total N were 61.20 and 3.42 g/kg, respectively [22].

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 (LG) intensity was 1.2 yaks/ha which resulted in 30% utilization of annual forage production for the 16 ha pasture area, and vegetation was dominated by *Roegneria nutans*, *Deschampsia caespitosa*, and *Elymus nutans*. Moderate grazing (MG) intensity was 2.0 yaks/ha, resulting in 50% utilization over the 28 ha pasture, with vegetation dominated by *Kobresia setchwanensis, Kobresia pygmaea, Roegneria nutans.* Heavy grazing (HG) intensity was 2.9 yaks/ha, resulting in 70% utilization over the 20 ha pasture, with vegetation dominated by *Kobresia pygmaea, Kobresia setchwanensis, Potentilla anserina.*

Field Investigation and Sampling: Five 10m×10m plots were selected randomly for sampling in each experimental site " behind "In August 2005,". In August 2005, Plant community characteristics were determined from two systematically located transects (50cm×500cm) of ten continuous quadrates (50cm×50cm) in each plot. Plant species were identified and recorded, the total ground cover, species canopy cover, and height determined from 0.25 m^2 quadrates. The frequency of each plant species was calculated for each plot. Importance data for individual species were calculated as averages of their relative abundance in terms of canopy cover, height, and frequency.

In each plot five 50cm×50cm quadrates were randomly selected for biomass sampling. The aboveground biomass was collected as living biomass and dead biomass (standing dead and litter). Root biomass was measured by collecting 5 soil cores (20cm in diameter) from depths of 0-30 cm in each plot, which were co-located with the above ground biomass measurement quadrates. The soil cores (20cm diameter) were cut into segments corresponding to sampling depths of 0-10, 10-20, and 20-30 cm. These cores were immediately washed over a 1-mm mesh screen to remove soil. Within each plot, composite soil samples consisting of 5 soil cores 7.5 cm in diameter of 30-cm depth were taken from the same five quadrats in which biomass was harvested and root cores were taken. All plant litter was removed from the soil surface before the sampling. Soil samples were segregated into 0-10, 10-20, 20-30 cm increments. Duplicate soil cores were also taken at each sampling quadrate for soil bulk density determination, which were used to convert soil C concentrations (in grams per kilogram) to C mass (in grams per square meter) in the soil.

Laboratory and Statistical Analyses: Soil samples intended for C analyses were passed through a 2-mm screen to remove plant crowns, visible roots and other debris. Samples were air-dried and analyzed for organic C by the potassium-dichromate oxidation procedure[23]. All plant samples were oven-dried for 48 h at 65°C and weighed. Dry samples were then milled and analyzed for C content with the same method as soil samples.

Data were statistically analyzed by one-way analysis of variance (ANOVA) and significant differences were tested by the least significant difference (LSD) at $P<0.05$.

RESULTS AND DISCUSSIONS

Results:

Plant Species Composition: Difference in plant species composition was observed between the treatments (Table 1). Dominant plant species in the LG site were *Roegneria nutans* (18.48% as importance value), *Deschampsia caespitosa* (11.43%), and *Elymus nutans* (8.54%), and *Kobresia setchwanensis* (7.68%). Major species in the MG site were *Kobresia setchwanensis* (17.43%), *Roegneria nutans* (8.72%), *Aster alpin*us (6.99%), and *Koeleria litwinowii* (5.68%). In the HG site, *Kobresia pygmaea* (12.54%), *Kobresia setchwanensis* (23.32%), *Potentilla anserine* (8.35%), and *Leontopodium franchetii* (6.09%) were most dominant species. Vegetation coverage was highest in the MG site, intermediate in the LG site, and lowest in the HG site.

Above- and Belowground Biomass: Live, dead and total aboveground biomass was significantly lower in the HG site compared to the other two sites, which did not significantly differ (Table 2).

Belowground biomass (0-30cm) decreased with increasing soil depth (Table 2). Belowground biomass at the 0-10cm increased with increasing grazing intensity ($P<0.05$), but that in the bottom two layers

Table 1: Species composition and their importance value at the three study sites

Species name	LG	MG	HG
Roegneria nutans	18.48	8.72	6.06
Elymus nutans	8.54	4.20	3.75
Deschampsia caespitosa	11.43	4.20	
Agrostis schneider	4.18		
Koeleria litwinowii	4.67	5.68	
Kobresia setchwanensis	7.68	17.43	23.32
Kobresia pygmaea	1.70	5.25	12.54
Gueldenstaedtia diversifolia	3.76	3.79	3.34
Oxytropis ochrocephala	2.09	2.78	4.25
Astragalus polycladus		2.09	
Aster alpinus	4.81	6.99	2.78
Saussurea hieracioides		4.60	2.28
Taraxacum maurocarpum	2.20	1.60	1.36
Ligularia virgaurea		1.85	
Leontopodium longifolium	2.60	2.82	6.09
Anemone rivularis	7.33	4.90	3.41
Consolida ajacis	2.32	1.86	
Anemone trullifolia		2.48	2.51
Thalictrum alpinum	1.80	2.26	1.80
Ranunculus brotherusii	1.53	1.74	3.24
Potentilla anserina	1.41	2.13	8.35
Potentilla discolor	1.66		
Geranium phlzowianum	4.19	2.04	1.86
Polygonum viviparum	2.55	5.42	4.11
Stellera chamaejasme	1.32	1.81	3.78
Plantago depressa	1.45	1.15	2.27
Gentiana algida	2.30	1.88	2.88
Total species number	23	25	20
Total cover (%)	89.7	92.6	73.6

(10-20cm and 20-30cm) under different grazing intensity exhibited no obvious variational patterns. For all grazing intensity, most of the belowground biomass was within 0-10cm soil depth, which made up 84.7, 86.5 and 91.9% of total belowground (0-30cm) in the LG, MG and HG, respectively.

Plant and Soil C Storage: Carbon storage per area in plant components showed the same trend as their biomass among treatments (Table 3). Total C storage of plant components in heavy grazing were 30% and 5% increases compared with those in light grazing and in moderate grazing, respectively.

Soil organic C in the top 10cm of the soil profile was significantly higher in the HG site than in the LG site, with no differences between the MG and the other sites (Table 3). Soil organic C both in 10-20cm soil depth and in 20-30cm soil depth was not significant between treatments. There was significantly higher total soil organic C in the HG site than in the LG and MG sites, but no statistically significant difference was found between the other two sites.

Total C in the plant-soil system was significantly higher in HG site that in MG or LG sites, but it was not significantly different between the MG site and the HG site (Table 3). In terms of the distribution of C in the soil-plant system, more that 90% of plant-soil C was in the soil at the 0-30 cm depth in all the treatment.

Discussions: The magnitude of impact that livestock grazing may have on a plant community is dependent upon intensity of grazing. In contrast to grazing at a light or moderate grazing intensity, grazing at heavy intensity has tended to decrease the numbers of grasses such as *Roegneria nutans* and *Deschampsia caespitosa* and increased the numbers of sedges such as *Kobresia setchwanensis* and *K. pygmaea*, which is good tolerant to be grazed, specially for yaks[24]. Heavy grazing also markedly reduced vegetation cover compared to light grazing and moderate grazing. This has an important implication for grassland management because vegetation cover is often used to assess spatial extent and degree of desertification[25].

Plant biomass is an important measure of ecosystem functioning for alpine meadows. After nine years grazing with different intensity, the aboveground biomass was lower with heavy grazing compared to light or moderate grazing intensities. The main reason for this result is that the dominator of HG community shifted from grasses- *Roegneria nutans* and *Deschampsia caespitosa* into sedges- *Kobresia pygmaea* and *K. setchwanensis*, which are small and good tolerant to grazing by yaks [24]. Also, as our results demonstrated, a larger proportion of total production was allocated to the belowground biomass with heavy grazing[26]. Aboveground biomass decreased under heavy grazing intensity indicated that the winter forage supply for this region reduced, which is undesirable for livestock production.

Root biomass responses to grazing are ambiguous. Milchunas and Lauenroth [14], Turner *et al.*[27], and Frank *et al.*[28] found mostly no changes, or increases, of root biomass as a function of grazing intensity. Our results suggested belowground biomass was lowest in the LG site and higher in both the MG and HG sites. This can be explained that heavy grazing induced more *Kobresia pygmaea* and *K. setchwanensis*, which have dense root system than that of *Roegneria nutans* and *Deschampsia caespitosa*[29]. This change was reflected in the higher root to shoot biomass ratio under the heavy grazing treatment compared to light grazing treatment. Biomass allocation ratio to root increasing is an adaptive response of plant to grazing, which is favorable for grassland restoration[30].

In this study, higher grazing intensity resulted higher C storage in both plant and soil, consistent with results for the short-grass steppe reported by Reeder and Schuman[7]. These increases within the plant and soil components of ecosystems may be due to grazing-induced increase in root biomass because roots are important C and N sinks in grassland[31]. Root input represents the primary sources of organic matter input into the soil environment[32]. Schuman *et al.*[33] and Hibbard *et al.*[34] reported larger root biomass can

Table 2: Plant biomass (g/m^2) as affected by grazing intensity.

System components	Grazing intensity		
	Light grazing	Moderate grazing	Heavy grazing
Above ground			
Live biomass	359±53a	412±65a	281±39b
Dead biomass	162±16a	177±30a	111±20b
Total above ground biomass	521±60a	589±91a	392±53b
Roots			
0-10cm	1523±184c	2147±335b	2686±449a
10-20cm	196±52	228±82	152±41
20-30cm	78±14	107±24	84±16
Total roots	1798±179b	2482±356a	2923±481a
Roots/shoot ratio	3.46±0.23b	4.27±0.77b	7.51±1.33a
Total plant biomass	2319±232b	3072±397a	3315±504a

Within rows, means±S.D. Different letters represent statistically significant at $P<0.05$, $n=5$

Table 3: Total amounts of carbon (g/m^2) stored in soil and plant pools as affected by grazing intensity.

System components	Grazing intensity		
	Light grazing	Moderate grazing	Heavy grazing
Above ground			
Live biomass	141±21a	162±31a	103±17b
Dead biomass	56±7a	62±8a	37±8b
Total above ground C	197±21a	225±39a	140±21b
Roots			
0-10cm	521±99c	741±131b	924±145a
10-20cm	63±14	82±28	56±13
20-30cm	24±5	38±11	28±7
Total roots C	609±98b	861±135ab	1008±155a
Total plant C	806±85b	1087±133ab	1148±159a
Soil profile			
0-10cm	4497±574b	5277±806ab	5863±736a
10-20cm	3103±488	2976±423	3520±654
20-30cm	2194±404	1906±294	2346±290
Total soil C (0-30cm)	9795±869b	10158±903b	11729±1096a
Total ecosystem C (to 30cm)	10601±862b	11245±866b	12877±1114a

Within rows, means±S.D. Different letters represent statistically significant at $P<0.05$, $n=5$.

contribute more C and N to soil in northern mixed-grass and semi-arid grassland, respectively. The results indicated that higher grazing intensity had a potential to increase C storage in the alpine meadow ecosystem.

Conclusion: Heavy grazing intensity led to higher levels of soil-plant C through changes in species composition. Nonetheless, heavy grazing markedly decreased vegetation cover and aboveground biomass, which are undesirable for livestock production and sustainable grassland development. Grazing at light to moderate grazing intensity resulted in stable, diverse plant communities dominated by forage grasses with high above ground biomass. The alpine meadows ecosystem in Tibetan Plateau are 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 plant-soil system, and possible declines in C sequestered in the soil, are indicated.

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REFERENCES

1. Scurlock, J.M. and D.O. Hall, 1998. The global carbon sink: A grassland perspective. Global Change Biology, 4: 229-233.
2. Schlesinger, W.H., 1997. Biogeochemistry: An Analysis of Global Change. Academic Press, New York.
3. Schimel, D.S., W.J. Parton, T.G. Kittel, D.S. Ojima and C.V. Cole, 1990. Grassland biogeochemistry: Links to atmospheric processes. Climatic Change, 17: 13-25.
4. Ojima, D.S., B.O. Dirks, E.P. Glenn, C.E. Owensby and J.O. Scurlock, 1993. Assessment of C budget for grasslands and drylands of the world. Water, Air, & Soil Pollution, 70: 95-109.
5. Conant, R.T., K. Paustian and E.T. Elliott, 2001. Grassland management and conversion into grassland: effects on soil carbon. Ecological Applications, 11: 343-355.
6. Schuman, G.E., H.H. Janzen and J.E. Herrick, 2002. Soil carbon dynamics and potential carbon sequestration by rangelands. Environmental Pollution, 116: 391-396.
7. Reeder, J.D. and G.E. Schuman, 2002. Influence of livestock grazing on C sequestration in semi-arid mixed-grass and short-grass rangelands. Environmental Pollution, 116: 457-463.
8. Briske, D.D., T.W. Boutton and Z. Wang, 1996. Contribution of flexible allocation priorities to herbivory tolerance in C4 perennial grasses: An evaluation with ^{13}C labeling. Oecologia, 105: 151-159.
9. Shariff, A.R., M.E. Biondini and C.E. Grygiel, 1994. Grazing intensity effects on litter decomposition and soil nitrogen mineralization. Journal of Range Management, 47: 444-449.
10. Kielland, K. and J.P. Bryant, 1998. Moose herbivory in taiga: effects on biogeochemistry and vegetation dynamics in primary succession. Oikos, 82: 377-383.
11. Ritchie, M.E., D. Tilman and J.M. Knops, 1998. Herbivore effects on plant and nitrogen dynamics in oak savanna. Ecology, 79: 165-177.
12. Ruess, R.W. and S.W. Seagle, 1994. Landscape patterns in soil microbial processes in the Serengeti National Park, Tanzania. Ecology, 75: 892-904.
13. Bardgett, R.D., D.A. Wardle and G.W. Yeates, 1998. Linking above-ground and below-ground interactions: How plant responses to foliar herbivory influence soil organisms. Soil Biology & Biochemistry, 30: 1867-1878.
14. Milchunas, D.G. and W.K. Lauenroth, 1993. Quantitative effects of grazing and soils over a global range of environments. Ecology Monographs, 63: 327-366.
15. Zheng, D., 2000. Mountain Geoecology and Sustainable Development of the Tibetan Plateau. Kluwer Academic Publishers, Dordrecht, The Netherlands.
16. Ni, J., 2002. Carbon storage in grasslands of China. Journal of Arid Environment, 50: 205-218.
17. Kato, T., Y.H. Tang, S. Gu, M. Hirota, M.Y. Du, Y.N. Li and X.Q. Zhao, 2006. Temperature and biomass influences on interannual changes in CO_2 exchange in an alpine meadow on the Qinghai-Tibetan Plateau. Global Change Biology, 12: 1285-1298.
18. Cao, G.M., Y.N. Li and J.X. Zhang, 2001. Values of carbon dioxide emission from different land-use patterns of alpine meadow. Environmental Sciences, 6: 14-19.
19. Wu, N. and Q. Liu, 1999. Ecological environment and strategies for sustainable development on the upper reaches of the Yangtze River. World Sci-Tech Research & Development, 21: 70-73.
20. Zhou, S.R., 1998. Grassland Resource of Sichuan. Sichuan People Press, Chengdu, pp: 141-153.
21. Chinese soil taxonomy research group, 1995. Chinese Soil Taxonomy. Science Press, Beijing, pp: 58-147.
22. Gan, Y.M., Z.D. Li, B. Ze, D.P. Fei, G.R. Luo, Q. Wang and X.L Wang, 1995. The Changes of grassland soil nutrition at different degradation alpine meadow of north-west in Sichuan. Acta Prataculturae Sinica, 14: 38-42.
23. Lu, R.K., 2000. Analytic Handbook of Soil Agriculture Chemistry. Chinese Agricultural Science and Technology Press, Beijing, pp: 146-165.
24. Wu, N., J. Liu and Z.L. Yan, 2004. Grazing intensity on the plant diversity of alpine meadow in the eastern Tibetan plateau. Rangifer, 15: 9-15.
25. De Soyza, A.G., W.G. Whitford, J.E. Herrick, J.W. Van Zee and K.M. Havastad, 1998. Early warning indicators of desertification: examples of tests in

the Chihuahuan Desert. Journal of Arid Environment, 39: 101-112.

26. Pierson, E.A., R.N. Mack and R.A. Black, 1990. The effect of shading on photosynthesis, growth, and regrowth following defoliation for *Bromus tectorurn.* Oecologia, 84: 534-543.
27. Turner, C.L., T.R. Seastedt and M.I. Dyer, 1993. Maximization of aboveground grassland production: the role of defoliation frequency, intensity, and history. Ecological Applications, 3: 175-186.
28. Frank, A.B., 2002. Carbon dioxide fluxes over a grazed prairie and seeded pasture in the Northern Great Plains. Environmental Pollution, 116: 397-403.
29. Yang, F.T., J. Shao and S.L. Zhang, 1982. The primary production of alpine shrub and meadow on the Qinghai Plateau. In: Xiao W.P. (Eds.), Alpine Meadow Ecosystem. Gansu People Press, Lanzhou, pp: 44-51.
30. Wang, R.Z., Q. Gao and Q.S. Chen, 2003. Effects of climate change on biomass and biomass allocation in Leymus chinensis (Poaceae) along the Northeast China Transect (NECT). Journal of Arid Environment, 54: 653-665.
31. Impithuksa V.W., G. Blue and D.A. Graetz, 1984. Distribution of applied nitrogen in soil-Pensacola bahiagrass components as indicated by Nitrogen-15. Soil Science Society of American Journal, 48: 1280-1284.
32. Cao, G.M. and J.X. Zhang, 2001. Soil nutrition and substance cycle of Kobersia meadow. In: Zhou X.M., (Eds.), Chinese Kobersia Meadow. China Science Press, Beijing, pp: 188-216.
33. Schuman, G.E., J.D. Reeder, J.T. Manley, R.H. Hart and W.A. Manley, 1999. Impact of grazing management on the carbon and nitrogen balance of a mixedgrass rangeland. Ecological Applications, l9: 65-71.
34. Hibbard, K.A., S. Archer, D.S. Schimel and D.W. Valentine, 2001. Biogeochemical changes accompanying woody plant encroachment in a subtropical savanna. Ecology, 82: 1999-2011.