N deposition can accelerate the degradation succession from grasses- and sedges-dominated plant communities into forbs-dominated ones in overgrazed alpine grassland systems on Qinghai-Tibetan Plateau

Hao Shen[a, d], Shikui Dong[a, b, c*], Antonio DiTommaso[d], Jiannan Xiao[b], Yangliu Zhi[b]

[a] School of Environment, State Key Joint Laboratory of Environmental Simulation and Pollution Control, Beijing Normal University, Beijing, 100875, China

[b] College of Grassland Sciences, Beijing Forestry University, Beijing, 100083, China

[c] Department of Natural Resources, Cornell University, Ithaca, NY,14853, United States

[d] Soil and Crop Sciences, School of Integrative Plant Science, Cornell University, Ithaca, NY,14853, United States (ORCID: 0000-0001-8215-2777).

[*] Corresponding author: dongshikui@sina.com

Running head: N deposition accelerate overgrazing-induced degradation succession

Abstract

Alpine grasslands are sensitive to grazing and atmospheric deposition of nitrogen (N). With the increase of N deposition, experimental investigations of the effects of grazing on alpine grassland vegetation with the background of N deposition are scarce.

In this study, we examined the effects of overgrazing and overgrazing with N deposition on eco-physiologies of alpine grassland plants at the functional group level. We found that both overgrazing and overgrazing with N deposition obviously changed species composition and the dominance of three plant functional groups (PFGs) in alpine meadow and alpine steppe.

Under overgrazing and overgrazing with N deposition treatment, forb tended to be predominant in the whole plant community, while grass and sedge dominance was obviously decreased. In addition, we found that the underlying eco-physiological processes that lead to forb-dominant were different under overgrazing and overgrazing with N deposition. Overgrazing with N deposition obviously tended to increase forb dominance both directly by selective herbivory and indirectly by enhancing forb photosynthetic capacity.

Our results suggested that long-term overgrazing with N deposition will lead to a more favorable living environment for forbs, making the grassland community of alpine grasslands on the Qinghai-Tibetan Plateau likely shift to forb-dominant in the future.

Key words: N deposition; overgrazing; plant functional groups; photosynthesis; respiration

Introduction

Livestock grazing is the primary land use of grasslands in the developing world where local livelihoods depend heavily on pastoralism (Sigcha *et al*., 2018; Yu *et al*., 2019; Dong *et al*., 2020). Generally, sustainable grazing plays an important role in keeping the balance between livestock intakes and grassland productivity, especially in alpine regions (Fen *et al*., 2010). In most previous studies, grazing usually leads to an obvious effect on grassland productivity, species composition and structure of plant community (Zhang *et al*., 2018). In recent decades, effect of overgrazing on grassland ecosystems has become a hot research topic in the Qinghai-Tibetan Plateau where the ecosystem is fairly sensitive to global change and human disturbance (Niu *et al*., 2019; Dong *et al*., 2020; Ji *et al*., 2020). Though fencing has usually been regarded as one of the most effective ways to prevent grassland degradation (Wang *et al*., 2011), light or moderate grazing is still considered beneficial to the health of grasslands (Quan *et al*., 2015). However, little is known about the effects of overgrazing on plant compositions and eco-physiological processes of the alpine grasslands in the scenario of increasing N deposition.

As we know, N deposition is one of the key driver of global change (Bobbink *et al*., 1998), and N deposition rate has been significantly increased for decades and predicted to continue in the future (Galloway *et al*., 2004; Galloway *et al*., 2008). In alpine grasslands, N deposition rate has increased to about 10 kg N $ha^{-1}yr^{-1}$ in recent years (Zhu *et al*., 2016). So far, many studies of N deposition effects on plants have been carried out worldwide. Both positive and negative effects of N deposition on grasslands are commonly reported (Van Der Wal *et al*., 2003; Li *et al*., 2018; Liu *et al*., 2018). Nevertheless, the studies of joint effects of overgrazing and N deposition on plants are scarce. To date, we still know little about how would overgrazing with N deposition affect plants in alpine regions, especially in the perspective of plant functional traits to functional group composition.

Therefore, we believe that it warrant much attention to study the joint effects of overgrazing and N deposition, which could possibly give us a better understanding of plant response mechanism under joint effects of human disturbance and global change rather the sole effect of single driver. We hypothesized that: 1) Responses of different functional groups to overgrazing and overgrazing with N deposition would be different. 2) Forbs would be dominant as all grass and sedge species in our study site are edible for herbivores, while most forbs are not edible or even poisonous to herbivores. 3) Overgrazing with N deposition would also promote the dominance of the forbs indirectly by increasing their photosynthetic capacity.

Material and Methods

Study area

The field experiment was conducted in alpine meadow locating at Xihai Town of Haiyan County (100°57′E,36°56′N, 3100 m ASL) and alpine steppe locating at Tiebujia Town of Gonghe County (99°35′N,37°02′E, 3270 m ASL) in Qinghai province, China. The alpine meadow is with clay soil and alpine steppe is with loam-clay soil. The mean annual temperature in alpine meadow is about 1.4 °C, the mean annual precipitation is about 330–370 mm and the annual evaporation is around 1400 mm. The mean annual temperature in alpine steppe is about 0 °C, the mean annual precipitation is about 377 mm, and the annual evaporation is about 1484 mm.

Fig.2

Experimental design

In 2012, the grassland with an area of 20m×20m in both two study sites (Fig.1) were fenced with iron fence (1.2m high), large herbivores such as yak and sheep were excluded from the fenced area. In 2018, three plots in the ungrazed area (2m by 5m) were chosen as the replication of control, In the area near the ungrazed area, three plots (2m by 5m) were randomly chosen for the replication of overgrazing, and other three plots (2m by 5m) were randomly chosen as the replication of overgrazing with N deposition. The grazed plots was overstocked by the free-ranging sheep from June to October over long term. In overgrazing with N deposition treatment, the plots were fertilized with ammonium nitrate (NH_4NO_3) in early May and July since 2018.

Vegetation and soil sampling

In early August (growing season) of 2018 and 2019, vegetation survey, plant and soil sampling were carried out. Vegetation in each plot were surveyed by using a randomly placed quadrat in the size of 1 m×1 m. The aboveground plant parts were harvested in a 0.5m ×0.5m sub-quadrat in each plot. After harvest, plant samples were oven dried at 65 °C for 24 hours to constant weight for the calculation of total AGB of community. We calculated the species dominance by using the equation of Dominance = (Relative abundance + Relative cover)/2. Soil cores (3.5 cm in dimeter) collected from 0–20 cm depth were air dried at 70°C and sieved through a 0.15-mm mesh. Element analyzer (EA 3000, Italy) was used to measure soil total nitrogen (STN) and soil total carbon (STC) content. Soil available potassium (SAK) and available phosphorus (SAP) were measured using inductively coupled plasma spectrometers (ICP) (SPECTRO ARCOS EOP, Germany). Soil total phosphorus (STP) was measured using an ultraviolet spectrophotometer (Lambda 25) based on the Mo–Sb colorimetric method. Soil Ca, Mg, K, and S content were determined by atomic absorption spectrometry (AA-610S; Shimadzu, Kyoto, Japan). Soil ammonium nitrogen (NH_4^+) and nitrate nitrogen (NO_3^-) concentrations were measured using a continuous flow auto-analyzer (AACE, Germany).

Photosynthesis and respiration measurement

We measured the photosynthetic parameters of all plant species appeared in the study plots using a LI-6800 portable photosynthesis system (Li-Cor, Lincoln, NE, USA), between 9:30 am and 11:00 am in early August 2018 and early August 2019. Net photosynthesis rate (*P*n) of all plant species in the study plots were quickly surveyed and recorded. For each plot, three of each species with similar growth status were chosen as a replication. The CO_2 concentration in the leaf chamber was regulated by the LI-COR CO_2 injection system, which was set to 400 μmol mol^{-1}. An irradiance of 1500 μmol (photons) m^{-2} s^{-1} was achieved using a built-in LED lamp (red/blue). Temperature in the leaf chamber was maintained at approximately 25°C. The respiration rate was measured after the measurement of net photosynthetic rate with the irradiance of 0 μmol (photons) m^{-2} s^{-1}. The net photosynthetic rate and respiration rate of three PFGs was calculated by averaging the values of the key plants in each functional group (only species whose abundance≥3 in each 1m by 1m quadrat were chosen for the final calculation of net photosynthetic rate and respiration rate of each functional groups).

Statistical analysis

One-way analysis of variance (ANOVA) was applied to test the difference of plant traits and soil properties of all plots. Dun-can's Multiple Range Test (Duncan) in analysis of variance (ANOVA) was used to test the effects of grazing and grazing with N deposition on plant photosynthesis and respiration. Principle component analysis (PCA) analysis was performed to determine the relationship between plant traits and soil properties. ANOVA analysis was carried out in SPSS22.0 and PCA analysis was carried out in R. In addition, structural equation model (SEM) was developed in AMOS 22.0 (Amos Development, Spring House, PA, USA) to identify the direct and indirect pathways that determine forb dominance under overgrazing and overgrazing with N deposition treatment.

Results

Effects of overgrazing and overgrazing with N deposition on species composition

Overgrazing and overgrazing with N deposition obviously affected species composition in both alpine meadow and alpine steppe, and both decreased the relative abundance of grass and sedge in the whole plant community in 2018 and 2019 (Fig.2). Grass species such as *Leymus secalinus* was most heavily affected. However, overgrazing and overgrazing with N deposition showed no obviously uniform effects on the relative abundance of the only two sedge species: *Carex capillifolia* and *Carex melanantha*. The relative abundance of forbs such as *Stellera chamaejasme*, *Pedicularis kansuensis* and *Aconitum carmichaeli* etc., mostly the poisonous plants were obviously increased under overgrazing and overgrazing with N deposition. The PFG dominance of forbs over that of grasses and sedges tended to dominate the plant communities in the alpine meadow and the alpine steppe of 2018 and 2019 (Fig.3).

Effects of overgrazing and overgrazing with N deposition on net photosynthetic rate of three PFGs

The *P*n of three functional groups (grass, sedge and forb) varied greatly under overgrazing and overgrazing with N deposition (Fig.4). In 2018, *P*n of grass and forb in the alpine meadow and the alpine steppe were significantly increased under overgrazing and overgrazing with N deposition (P<0.05), while *P*n of sedge was only significantly increased in the alpine steppe (P<0.05) (Fig.4a, 4b). In 2019, *P*n of grass and forb in the alpine meadow showed similar variation with that in 2018 (Fig.4c), yet *P*n of grass in the alpine steppe under the treatment of overgrazing with N deposition didn't show much significantly change compared with that under the treatment of ungrazing (Fig.4d, $P > 0.05$).

Effects of overgrazing and overgrazing with N deposition on respiration rate of three PFGs

Overgrazing and overgrazing with N deposition had similar effect on the *R*s of grass and forb (Fig.5). *R*s of grass and forb in alpine meadow and alpine steppe were significantly increased under overgrazing and overgrazing with N deposition treatment (Fig.5a, 5b, P<0.05), while *R*s of sedge showed no regular variation in the consecutive two years (Fig.5).

Relationship between plant eco-physiological characters and soil properties

PCA analysis of plant traits and soil properties showed that PC1 and PC2 explained 59.7% of the variance (Fig. 6). Different treatments in the PCA analysis made clear separation. Overgrazing and overgrazing with N deposition obviously affected soil nutrients. Overall, forb dominance was positively related with soil nutrients such as STN, SAK, STK, STS, SAP, soil NH_4^+-N and soil NO_3^--N. Among all soil properties, soil NH_4^+ and NO_3^-variation had a higher weight in all variables. Other soil nutrients were positively correlated with these two variables. Forb dominance was positively related to plant *P*n, while negatively related to grass and sedge dominance.

Path analysis under overgrazing and overgrazing with N deposition

Two SEM models were successfully developed with the data collected under overgrazing and overgrazing with N deposition (Fig.7).Different pathways leading to the variance of forb dominance were observed. Overgrazing showed a direct positive effect on forb dominance, while overgrazing with N deposition induced significant effects on forb dominance through more complex indirect paths, except for direct positive effect. Overgrazing with N deposition had an indirectly positive influence on forb dominance through increasing soil nitrate nitrogen, which directly increased plant N uptake and enhanced photosynthetic capacity of forb, leading to increased forb dominance in the end. Additionally, overgrazing with N deposition directly enhanced respiration of forb, which in turn directly promoted photosynthetic capacity and finally elevated forb dominance. However, negative effects of enhanced soil nitrate nitrogen (NO_3^--N) on forb dominance under overgrazing with N deposition were also observed.

Discussion

In general, overgrazing obviously causes some negative effects on plant community, such as decreasing vegetation cover, or breaking soil nutrient balance (Pasari *et al*., 2014; Sun *et al*., 2016;

Wang & Wesche 2016), which finally might cause land degradation (Yu *et al*., 2019). However, positive effects such as compensatory growth and stimulating photosynthesis were also found (Mipam *et al*., 2019; Zhang *et al*., 2019b). Certainly, these phenomena were only appeared in light and moderate grazing condition (Pykälä *et al*., 2005). As grazing has been a long-term human disturbance which is closely associated with local people's livelihood, many studies have focused on the grazing alone. In the era of global change, the effect of livestock overgrazing is simultaneously interacted with that of increasing N deposition on the alpine grasslands (mainly the alpine meadow and alpine steppe), the dominate ecosystems of the Qinghai-Tibetan Plateau (Dong and Sherman, 2015). Therefore, it is imperative to uncover the mechanisms that control the dynamics of plant communities of the alpine grasslands, if the livestock overgrazing and climate changes continue in the future.

Overgrazing and overgrazing with N deposition change species composition

Generally, grazing effects on plant species composition was usually more direct and principal (Pasari *et al*., 2014), as herbivores were sensitive and selective to plants. In our study, plant compositions of both the alpine meadow and meadow steppe were significantly altered by overgrazing and overgrazing with N deposition, i.e., forb tended to be dominant in the plant communities. Relative abundance of poisonous forbs such as *Stellera chamaejasme*, *Pedicularis kansuensis* and *Aconitum carmichaeli* were much higher under overgrazing and overgrazing with N deposition treatments than that under ungrazing treatment, indicating that overgrazing and overgrazing with N deposition could lead to a favorable living environment for poisonous forbs (Wang *et al*., 2019). Selective browsing by the overstocked herbivores might be a key factor that finally lead to the changes of species composition of alpine grassland plant community into forb-dominated. Moreover, the forbs could be much competitive with the decrease of plant species of other functional groups, as the decrease of plant density will certainly lead to increase of light penetration for forbs, which will definitely in turn improve their photosynthesis.

In contrast to sole overgrazing, overgrazing with N deposition could directly promote the positive effect of photosynthesis and the negative effects of nitrate nitrogen (NO_3^--N) on forb dominance. Positive effects of selective browsing and increasing photosynthesis associated with soil total nitrogen and nitrate nitrogen (NO_3^--N) may suppress the negative effects of nitrate nitrogen (NO_3^--N) on forb dominance, leading to a higher forb dominance under overgrazing with N deposition treatment than that under overgrazing treatment alone. This may be explained by that low N deposition (8kgNha^{-1}yr^{-1}) could supply N resource and bring beneficial effects on forbs in this N-limited ecosystem, even more pronounced in the overgrazed alpine grasslands.

Overgrazing and overgrazing with N deposition influence carbon gain and loss of three PFGs

It is well known that photosynthesis and respiration are the two most important physiological processes that determine carbon gain and loss in plants (Zhong *et al*., 2019). Generally, photosynthesis can affect carbon gain by absorbing atmospheric CO_2 and changing it into organic matter which is the ultimate source of energy for almost all organisms, while respiration is the energy center, which can provides adenosine triphosphate (ATP) and carbon skeletons (Sperlich *et al*., 2016). The trade-off between photosynthesis and respiration can actually determine plant fitness. Grass and forbs showed much higher net photosynthetic rate and respiration rate under overgrazing and overgrazing with N deposition treatments in contrast to the control, indicating that both drivers will promote carbon gain and loss process of grass and forb. However, the variation of net photosynthetic rate and respiration rate in sedges was not obviously consistent with other two functional groups, suggesting that uncertainty existed for the plant functional group of sedges. It might be attributed to a much lower sampling for the sedges, because only two sedge species were recorded in our study site. In general, grazing can remove plant aboveground parts, and introduce more light, which could definitely increase plant light use efficiency in photosynthesis. However, grazing-induced disturbance such as the behavior of trampling and eating could also cause mechanical injury which in turn accelerate plants respiration process, making plants consume more energy for their self-healing (Kurtz *et al*., 2016).

N deposition deepens grazing effect on plants by more N resource supply

Grazing-induced plant residue is the main resource of organic matter input into soil (Zhang *et al*., 2019a). In addition, livestock urine and faeces are an important path that returns most chemical elements to the soil, which accelerates nutrients cycling of grassland ecosystems (Naeth *et al*., 1991; Stark *et al*., 2000). Typically, soil nutrients balance is definitely an important factor affecting plants (Fransen *et al*., 2001; Zhang *et al*., 2019a). In our study, we found that soil available N played an important role in changing the plant eco-physiological traits in the overgrazing habitats. This is the evidence to support the fact that plant N uptake is usually an important physiological indicator to reflect plant fitness (Ariz *et al*., 2015). It seemed that N deposition brought more N resource for overgrazed plots, showing “gain effect” on plant photosynthesis. As we know, N is usually a limiting element in alpine regions (Simpson *et al*., 2019), thus N deposition could provide more N resource for plant. In our study, overgrazing with N deposition could significantly change soil properties, both directly and indirectly leading to the variations of plant composition. Additionally, overgrazing with N deposition can also indirectly enhance the photosynthesis of alpine grasslands plants whose habitat is usually N-limited (Zong *et* *al*., 2016), as the plant photosynthesis can be promoted by plant N uptake when soil N is adequate (Graaf *et al*. 2005). Our synthesized paper shows that livestock grazing and nitrogen deposition can change the plant productivity, diversity, soil physics and soil biochemistry of the alpine grasslands, though the findings about the effects of these two drivers remained controversial due to various data sources, different research methodologies, diverse study sites and times (Dong et al., 2020). Confidently, we drawn conclusion from reviewing hundreds of literatures that overgrazing can lead to declined productivity, biodiversity loss and soil deterioration of the alpine grasslands, and nitrogen deposition can result in soil acidification and eutrophication, which is harmful for alpine grassland health and stability (Dong et al., 2020). With increased yearly atmospheric N deposition in alpine regions in the future (Zhang *et al*., 2020), our results suggest that future N deposition will worsen overgrazing effects on the alpine grassland health and stability.

Conclusions

Two types of the alpine grasslands (alpine meadow and alpine steppe) showed similar responses of plant traits and vegetation community to both overgrazing and overgrazing with N deposition according to our consecutive two-year observation. Overgrazing and overgrazing with N deposition both tended to shift the grass- or sedge-dominated alpine grasslands into forb-dominated ones. The underlying mechanism associated with overgrazing with N deposition was more complex than that associated with sole grazing. Apart from direct effects of selective browsing, overgrazing with N deposition could also enhance forb-dominance through increasing forb photosynthesis due to increased available N resource for forb growth. Overgrazing-induced disturbance enhanced forb carbon loss, which in turn promoted forb photosynthesis for more carbon gain, thus to enhance its competence among the three PFGs. Indirect pathways of increasing forb dominance in the alpine grassland plant communities under overgrazing with N deposition was much more obvious than the sole overgrazing. Urgent actions are called for mitigating the accelerated shifts of alpine grasslands primarily dominated by grasses and sedges into degraded ones dominated by poisonous forbs with the couplings of continuous overgrazing and increasing N deposition on the Qinghai-Tibetan Plateau in the future.

Acknowledgements

This work was supported by grants from the Second Tibetan Plateau Scientific Expedition and Research Program (2019QZKK0307), National Key R & D Program of China (2016YFC0501906), Qinghai Provincial Key R & D program in Qinghai Province (2019-SF-145 & 2018-NK-A2), which are greatly appreciated.

Data Availability Statement

The datasets generated for this study are available on request to the corresponding author.

Conflict of Interest Statement

No conflict of interest exists in the submission of this manuscript, and the manuscript is approved by all authors for publication.

Reference

Ariz, I., Cruz, C., Neves, T., Irigoyen, J. J., García, C., Nogués, S., ... & Aranjuelo, I. (2015). Leaf $\delta^{15}N$ as a physiological indicator of the responsiveness of N_2-fixing alfalfa plants to elevated [CO_2], temperature and low water availability. Front. Plant Sci. 6, 574. DOI: https://doi.org/10.3389/fpls.2015.00574

Bobbink, R., Hornung, M., & Roelofs, J. G. (1998). The effects of air−borne nitrogen pollutants on species diversity in natural and semi−natural European vegetation. J. Ecol. 86(5), 717-738.

DOI: https://doi.org/10.1046/j.1365-2745.1998.8650717.x

Dong, S., Zhang, J., Li, Y., Liu, S., Dong, Q., Zhou, H., ... & Gao, X. (2020). Effect of grassland degradation on aggregate−associated soil organic carbon of alpine grassland ecosystems in the Qinghai−Tibetan Plateau. Eur. J. Soil Sci. 71(1), 69-79.
DOI: https://doi.org/10.1111/ejss.12835

Feng, R., Long, R., Shang, Z., Ma, Y., Dong, S., & Wang, Y. (2010). Establishment of Elymus natans improves soil quality of a heavily degraded alpine meadow in Qinghai-Tibetan Plateau, China. Plant Soil 327(1-2), 403-411.
DOI: https://doi.org/10.1007/s11104-009-0065-3

Fransen, B., de Kroon, H., & Berendse, F. (2001). Soil nutrient heterogeneity alters competition between two perennial grass species. Ecology 82(9), 2534-2546.
DOI:https://doi.org/10.1890/0012-9658(2001)082[2534:SNHACB]2.0.CO;2

Galloway, J. N., Dentener, F. J., Capone, D. G., Boyer, E. W., Howarth, R. W., Seitzinger, S. P., ... & Karl, D. M. (2004). Nitrogen cycles: past, present, and future. Biogeochemistry 70(2), 153-226.
DOI: https://doi.org/10.1007/s10533-004-0370-0

Galloway, J. N., Townsend, A. R., Erisman, J. W., Bekunda, M., Cai, Z., Freney, J. R., ... & Sutton, M. A. (2008). Transformation of the nitrogen cycle: recent trends, questions, and potential solutions. Science 320(5878), 889-892.
DOI: https://doi.org/10.1126/science.1136674

Gao−Lin, W., Dong, W., Yu, L., Lu−Ming, D., & Zhen−Heng, L. (2017). Warm−season grazing benefits species diversity conservation and topsoil nutrient sequestration in alpine meadow. Land Degrad. Dev. 28(4), 1311-1319.
DOI: https://doi.org/10.1002/ldr.2536

Ji, L., Qin, Y., Jimoh, S. O., Hou, X., Zhang, N., Gan, Y., & Luo, Y. (2020). Impacts of livestock grazing on vegetation characteristics and soil chemical properties of alpine meadows in the eastern Qinghai-Tibetan Plateau. Écoscience 1-12.
DOI: https://doi.org/10.1080/11956860.2019.1710908

Kurtz, D. B., Asch, F., Giese, M., Hülsebusch, C., Goldfarb, M. C., & Casco, J. F. (2016). High impact grazing as a management tool to optimize biomass growth in northern Argentinean grassland. Ecol. Indic. 63, 100-109.
DOI: https://doi.org/10.1016/j.ecolind.2015.10.065

Li, X., He, H., Yuan, W., Li, L., Xu, W., Liu, W., ... & Wang, Z. (2018). Response of soil methane uptake to simulated nitrogen deposition and grazing management across three types of steppe in Inner Mongolia, China. Sci. Total Environ. 612, 799-808.
DOI: https://doi.org/10.1016/j.scitotenv.2017.08.236

Liu, S., Zamanian, K., Schleuss, P. M., Zarebanadkouki, M., & Kuzyakov, Y. (2018). Degradation of Tibetan grasslands: Consequences for carbon and nutrient cycles. Agr. Ecosyst. Environ. 252, 93-104.
DOI: https://doi.org/10.1016/j.agee.2017.10.011

Lu, X., Kelsey, K. C., Yan, Y., Sun, J., Wang, X., Cheng, G., & Neff, J. C. (2017). Effects of grazing on ecosystem structure and function of alpine grasslands in Qinghai–Tibetan Plateau: a synthesis. Ecosphere 8(1), e01656.
DOI: https://doi.org/10.1002/ecs2.1656

Mipam, T. D., Chen, S., Liu, J., Miehe, G., & Tian, L. (2019). Short-term yak-grazing alters plant-soil stoichiometric relations in an alpine meadow on the eastern Tibetan Plateau. Plant Soil, 1-13.
DOI: https://doi.org/10.1007/s11104-019-04401-6

Naeth, M. A., Bailey, A. W., Pluth, D. J., Chanasyk, D., & Hardin, R. T. (1991). Grazing impacts on litter and soil organic matter in mixed prairie and fescue grassland ecosystems of Alberta. Rangeland Ecol. Manag. 44(1), 7-12.

Niu, Y., Zhu, H., Yang, S., Ma, S., Zhou, J., Chu, B., ... & Hua, L. (2019). Overgrazing leads to soil cracking that later triggers the severe degradation of alpine meadows on the Tibetan Plateau. Land Degrad. Dev. 30(10), 1243-1257.
DOI: https://doi.org/10.1002/ldr.3312

Pasari, J. R., Hernández, D. L., & Zavaleta, E. S. (2014). Interactive effects of nitrogen deposition and grazing on plant species composition in a serpentine grassland. Rangeland Ecol. Manag. 67(6), 693-700.
DOI: https://doi.org/10.2111/REM-D-13-00116.1

Plassmann, K., Edwards-Jones, G., & Jones, M. L. M. (2009). The effects of low levels of nitrogen deposition and grazing on dune grassland. Sci. Total Environ. 407(4), 1391-1404.
DOI: https://doi.org/10.1016/j.scitotenv.2008.10.012

Pykälä, J. (2005). Plant species responses to cattle grazing in mesic semi-natural grassland. Agr. Ecosyst. Environ. 108(2), 109-117.
DOI: https://doi.org/10.1016/j.agee.2005.01.012Get rights and content

Quan, Q., Nianpeng, H., Zhen, Z., Yunhai, Z., & Yang, G. (2015). Nitrogen enrichment and grazing accelerate vegetation restoration in degraded grassland patches. Ecol. Eng. 75, 172-177.
DOI: https://doi.org/10.1016/j.ecoleng.2014.11.053

Schieltz, J. M., & Rubenstein, D. I. (2016). Evidence based review: positive versus negative effects of livestock grazing on wildlife. What do we really know?. Environ. Res. Let.11(11), 113003.

DOI: https://doi.org/10.1088/1748-9326/11/11/113003

Simpson, A. C., Zabowski, D., Rochefort, R. M., & Edmonds, R. L. (2019). Increased microbial uptake and plant nitrogen availability in response to simulated nitrogen deposition in alpine meadows. Geoderma 336, 68-80.
DOI: https://doi.org/10.1016/j.geoderma.2018.08.029

Sigcha, F., Pallavicini, Y., Camino, M. J., & Martínez-Ruiz, C. (2018). Effects of short-term grazing exclusion on vegetation and soil in early succession of a Subhumid Mediterranean reclaimed coal mine. Plant Soil 426(1-2), 197-209.
DOI: https://doi.org/10.1007/s11104-018-3629-2

Sperlich, D., Barbeta, A., Ogaya, R., Sabaté, S., & Peñuelas, J. (2016). Balance between carbon gain and loss under long-term drought: impacts on foliar respiration and photosynthesis in *Quercus ilex* L. J. Exp. Bot. 67(3), 821-833.
DOI: https://doi.org/10.1093/jxb/erv492

Stark, S., Wardle, D. A., Ohtonen, R., Helle, T., & Yeates, G. W. (2000). The effect of reindeer grazing on decomposition, mineralization and soil biota in a dry oligotrophic Scots pine forest. Oikos 90(2), 301-310.
DOI: https://doi.org/10.1034/j.1600-0706.2000.900210.x

Sun, D. S., Wesche, K., Chen, D. D., Zhang, S. H., Wu, G. L., Du, G. Z., & Comerford, N. B. (2011). Grazing depresses soil carbon storage through changing plant biomass and composition in a Tibetan alpine meadow. Plant Soil Environ. 57(6), 271-278.
DOI: https://doi.org/10.17221/7/2011-PSE

Van Der Wal, R., Pearce, I., Brooker, R., Scott, D., Welch, D., & Woodin, S. (2003). Interplay between nitrogen deposition and grazing causes habitat degradation. Ecol. Lett. 6(2), 141-146.
DOI: https://doi.org/10.1046/j.1461-0248.2003.00407.x

Van der Graaf, A. J., Stahl, J., & Bakker, J. P. (2005). Compensatory growth of Festuca rubra after grazing: can migratory herbivores increase their own harvest during staging?. Funct. Ecol. 961-969.
DOI: https://www.jstor.org/stable/3599049

Wang, S., Fan, J., Li, Y., & Huang, L. (2019). Effects of grazing exclusion on biomass growth and species diversity among various grassland types of the Tibetan Plateau. Sustainability 11(6), 1705.
DOI: https://doi.org/10.3390/su11061705

Wang, S., Wilkes, A., Zhang, Z., Chang, X., Lang, R., Wang, Y., & Niu, H. (2011). Management and land use change effects on soil carbon in northern China's grasslands: a synthesis. Agr. Ecosyst. Environ. 142(3-4), 329-340.
DOI: https://doi.org/10.1016/j.agee.2011.06.002

Wang, Y., & Wesche, K. (2016). Vegetation and soil responses to livestock grazing in Central Asian grasslands: a review of Chinese literature. Biodivers. Conserv. 25 (12), 2401-2420.
DOI: https://doi.org/10.1016/j.agee.2011.06.002

Wan, H., Bai, Y., Schönbach, P., Gierus, M., & Taube, F. (2011). Effects of grazing management system on plant community structure and functioning in a semiarid steppe: scaling from species to community. Plant Soil 340(1-2), 215-226.
DOI: https://doi.org/10.1007/s11104-010-0661-2

Yu, L., Chen, Y., Sun, W., & Huang, Y. (2019). Effects of grazing exclusion on soil carbon dynamics in alpine grasslands of the Tibetan Plateau. Geoderma 353, 133-143.
DOI: https://doi.org/10.1016/j.geoderma.2019.06.036

Zhang, B., Beck, R., Pan, Q., Zhao, M., & Hao, X. (2019a). Soil physical and chemical properties in response to long-term cattle grazing on sloped rough fescue grassland in the foothills of the

Rocky Mountains, Alberta. Geoderma 346, 75-83. DOI: https://doi.org/10.1016/j.geoderma.2019.03.029

Zhang, T., Xu, M., Zhang, Y., Zhao, T., An, T., Li, Y., ... & Yu, G. (2019b). Grazing-induced increases in soil moisture maintain higher productivity during droughts in alpine meadows on the Tibetan Plateau. Agr. Forest Meteorol. 269, 249-256. DOI: https://doi.org/10.1016/j.agrformet.2019.02.022

Zhang, R., Wang, Z., Han, G., Schellenberg, M. P., Wu, Q., & Gu, C. (2018). Grazing induced changes in plant diversity is a critical factor controlling grassland productivity in the Desert Steppe, Northern China. Agr. Ecosyst. Environ. 265, 73-83. DOI: https://doi.org/10.1016/j.agee.2018.05.014

Zhang, Y., Zhang, N., Yin, J., Yang, F., Zhao, Y., Jiang, Z., ... & Hu, S. (2020). Combination of warming and N inputs increases the temperature sensitivity of soil N2O emission in a Tibetan alpine meadow. Sci. Total Environ. 704, 135450. DOI: https://doi.org/10.1016/j.scitotenv.2019.135450

Zhu, J., Wang, Q., He, N., Smith, M. D., Elser, J. J., Du, J., ... & Yu, Q. (2016). Imbalanced atmospheric nitrogen and phosphorus depositions in China: Implications for nutrient limitation. Journal of Geophysical Research: Biogeosciences 121(6), 1605-1616. DOI: https://doi.org/10.1002/2016JG003393

Zhong, X., Li, Y., Che, X., Zhang, Z., Li, Y., Liu, B., ... & Gao, H. (2019). Significant inhibition of photosynthesis and respiration in leaves of Cucumis sativus L. by oxybenzone, an active ingredient in sunscreen. Chemosphere 219, 456-462. DOI: https://doi.org/10.1016/j.chemosphere.2018.12.019

Zong, N., Shi, P., Song, M., Zhang, X., Jiang, J., & Chai, X. (2016). Nitrogen critical loads for an alpine meadow ecosystem on the Tibetan Plateau. Environ. Manage. 57(3), 531-542. DOI: https://doi.org/10.1007/s00267-015-0626-6