Pak. J. Bot., 55(5): 1819-1825, 2023. DOI: http://dx.doi.org/10.30848/PJB2023-5(16)

EFFECTS OF REST GRAZING IN DIFFERENT SEASONS ON GRASSLAND SOIL NUTRIENTS IN THE BOG MEADOW OF SANJIANG PLAIN, CHINA

MINGJUN WANG*, LINGBO ZHENG, ZHENYIN BAI, FENGCHENG ZHANG, DONGWEI LIU, YINTAO SHI AND GUOWEN CUI*

College of Animal Science and Technology, Northeast Agricultural University, China
Corresponding author's email: wangmingjun@neau.edu.cn

Abstract

Grazing heavily influences the soil organic carbon pool of grassland ecosystems and therefore plays an important role in the global carbon balance. In China, various efforts aimed at alleviating grazing pressure have been promoted in the past two decades to conserve and restore degraded grassland, and improved management has shown profound effects on grassland resilience. Although many studies have explored the role of rest-grazing in arid grasslands, little is known about the effects of seasonal rest-grazing strategies on carbon storage in mesic grasslands. This study analysed the effects of rest grazing in spring, summer, and autumn on the soil nutrients and plant growth content of plots under light, medium, and heavy grazing intensities, respectively, for 3 continuous years (2010-2012) on the *Deyeuxia angustifolia* meadow grassland in Sanjiang Plain in Northeast China. The study contributes to the understanding of the relative effectiveness of different seasonal rest-grazing strategies on grassland sustainability in the Sanjiang Plain. The results highlight the importance of timing in the use of seasonal rest-grazing in the short term for the soil carbon balance of mesic grassland: (1) under moderate and severe grazing pressure, the aboveground net primary productivity of grassland plants was significantly increased in spring and summer but not in autumn. (2) The organic matter content in the 0-30 cm soil layer significantly increased in spring and autumn, and the organic matter content in the 0-20 cm soil layer significantly increased in summer. (3) Seasonal rest-grazing significantly decreased the content of available nitrogen in the 0-30 cm soil layer, especially in the 10-20 cm soil layer. In addition to the driving power of growing season precipitation, our results suggest that seasonal rest-grazing has a great potential for the recovery of soil carbon storage in mesic grassland despite differential grazing intensity levels.

Key words: Grazing intensity; Rest-grazing; Net primary production; Organic carbon storage; Grassland management.

Introduction

Grassland has multiple important ecosystem service values (Costanza *et al*., 1997) and provides approximately 70% of the herbage for ruminants worldwide (Holechek *et al*., 2004). Grassland sustainability requires appropriate grassland management practices. The sustainable development of grasslands should highlight both the ecosystem and economic sustainability of grasslands. In China, almost 90% of natural grassland is degraded to varying extents, which is mainly due to overgrazing (Liu *et al*., 2004). Traditionally, livestock production in most areas in China depends on the availability of natural grass. The increasing livestock number, and thus the increasing consumption of plant biomass from the grassland, led to the drastically increased grazing intensity in the originally non or slightly degraded grassland in the ecologically fragile regions. Grasslands suffering from different degrees of grazing pressure require different measures for resilience. For slightly and moderately degraded steppes, grazing rotation and seasonal enclosures should be considered. For heavily degraded grassland, grazing should be banned to allow the resilience of native vegetation.

An improved understanding of the integrative effects of grazing intensity and plant species on soil carbon dynamics is important for improving the sustainability of forage systems (Wang *et al.,* 2014). It has been reported that grassland management affects soil organic carbon (SOC) content (Zinn *et al*., 2005; Garcia-Oliva *et al*., 2006), whereas grazing intensity exerts a major impact on plant growth and soil carbon balance (Franzluebbers & Stuedemann, 2009). In rangeland under human disturbance, grazing intensity is one of the critical factors controlling SOC and nutrient cycling by influencing both litter accumulation and soil structure (Piñeiro *et al*., 2009). For example, the SOC storage in the alpine meadow of China declined notably in the grazing plots compared to the undisturbed plots (Ma *et al.,* 2016).

Long-term rest grazing has been reported to be beneficial to soil water status and carbon storage (Wang *et al*., 2015) and vegetation storage (Li *et al*., 2014) in arid grasslands. The results showed that the content of soil organic carbon in grassland in the grazing area was significantly higher than that in the nongrazed area (p<0.05) (Reederetal *et al*., 2002). Milehunas & LaueRoth (1993) compared the data of grazing and forbidden grazing at 236 sites in the world. The results showed that the changes in underground biomass, organic carbon and nitrogen were not consistent with grazing and sometimes showed a positive correlation and sometimes a negative correlation. In summary, there are many studies on the effects of different grazing intensities, no grazing and no grazing on grassland vegetation and soil at home and abroad, but there are few discussions on the combination of different grazing intensities and seasonal grazing.

The Sanjiang Plain in Heilongjiang Province, China, is famous for its concentrated distribution of natural low-lying grassland, including large areas of intrazonal meadows, bog meadows and marshes (Zhou *et al*., 1992). The Sanjiang Plain has large plant productivity, which plays an important role in regulating and buffering the soil carbon balance. However, a large area of degradation occurred in this grassland, whereas overgrazing plays an important role (Li *et al*., 2008).

This study aimed to explore the potential contribution of different seasonal rest grazing strategies in the mesic Sanjiang Plain, China, by analysing the aboveground net primary production, soil organic carbon, and soil nitrogen of plots under different grazing intensities and seasonal rest grazing strategies.

Materials and Methods

Experimental fields: This study was conducted in experimental plots located in Heilongjiang Province in northeastern China. This region is under a temperate continental monsoon climate. The average annual temperature is 2.3-2.4 °C, and the average annual precipitation is 551.5 mm. During the experimental period (2010-2012), the total annual rainfall and growing season rainfall were outstandingly lower in 2011 and 2012 than in 2010 (Table 1). The growing season temperature was also lower in 2011 than in 2010 and 2012 (Table 1). The grassland type is low-lying meadow and marsh meadow. The main soil type is white pulp of meadow soil and marsh soil. The experimental plots were located in 46°41'16.9" N-46°41'38.3" N, 132°39'47.6" E-132°40'23.7" E. The main species is *Deyeuxia angustifolia (Kom.) Chang comb. Nov.*, and the main associated species is *Carex* spp. The experimental plots had been free from grazing for 10 years before this experiment.

Table **1. Precipitation and monthly mean temperature.**

Year	Precipitation (mm)			Air temperature (^{o}C)		
	2010	2011	2012	2010	2011	2012
Annual	566.4	381.9	488.6	4.3	4.7	4.2
Growing season (May to September)	452	320.8	357.9	19.92	18.56	19.58

Experimental design: In early 2010, grazing plots with three stocking rate levels–light grazing (LG, 0.6 AU/hm^2/month), moderate grazing (MG, 1.0 AU/hm^2/month) and heavy grazing (HG, 1.4 AU/hm^2/month) were established using a randomized block design. One cattle with a body weight of 454 kg was considered one animal unit (AU) based on the 1997 American Grassland Management Association. The local hybrid cattle were used to impose grazing pressure. Traditionally, the grazing season was from June to October, while in this study, three different rest grazing strategies were imposed. In particular, spring rest-grazing (Spr.-RG) is nongrazing in June, summer rest-grazing (Sum.-RG) is nongrazing in July and August, and autumn rest-grazing (Fal.-RG) is nongrazing in September. The grazing sample plots (G) began to graze in June 2010, and the sample plots had not been grazed or mowed for 5 years and were in an unused state. Simmental beef cattle commonly raised in the area were used as research animals. The grazing pressure (GI) treatment was set to three levels, namely, light (LG), moderate (MG) and heavy (HG). Additionally, a control area without grazing (CK) was established. Each treatment level was repeated three times, and a random distribution design was adopted in the sample plots. The sample plots of light, moderate and heavy grazing areas and the control area were 3.43 hm^2, 2.10 hm^2, 1.53 hm^2 and 0.25 hm^2, respectively, and the corresponding grazing stocking rates were 0.63 cattle/hm^2/month (LG), 1.05 cattle/hm2/month (MG) and 1.34 cattle/hm^2/month (HG). Among them, livestock unit AU is a cow with an adult weight of 454 kg or the average forage consumption is the equivalent of daily 12 kg dry matter (DM). The grazing season was from June to October, and the daily grazing time was from 5:00 am to 7:00 pm. After the end of grazing, the grazing area was driven out of the grazing area and into a unified livestock enclosure. The remaining grazing plot was set up in the centre of each grazing area, and the remaining grazing was designed as three treatments: summer rest grazing (July August, 60 days) and autumn rest grazing (September-October, 30 days). The area of each nongrazed plot was 15 × 20 m^2. In summer, each grazing area was set up with a rest-grazing plot, and in autumn, each grazing plot was set up with a rest-grazing area in autumn; additionally, the summer-off-grazing plot was removed.

Sampling and measurements: From 2010 to 2012, soil samples were collected for chemical analysis, and their physical properties were measured within each experimental plot. Eighteen soil cores (4.0 cm in diameter) were extracted and segmented into 0-20 cm depth increments in each grazing area. Subsamples of the air-dried soils were ground to pass a 0.15 mm sieve prior to the following chemical analysis for aboveground net primary production (ANPP), soil organic carbon (SOC) and alkaline hydrolysis nitrogen content. In late August, soil samples were collected and measured in each grazing plot, nongrazing plot and control area. The soil drilling five-point sampling method was used to determine the content of soil organic carbon (0-30 cm). Soil organic carbon was determined by the potassium dichromate volumetric method-external heat method.

Statistical analysis

All data analyses were performed in SAS (Anon., 2005). Multivariate analysis of variance was used to assess the effect of year, seasonal rest, grazing intensity and their interactions on ANPP. The effects of year, seasonal rest, grazing intensity, soil depth and their interactions on SOC and AHN. One-way ANOVA was used to compare means between treatments. Normality and homogeneity were evaluated before all analyses. A significant difference was considered when $p<0.05$.

Table 2. Variance analysis of year (Y), seasonal rest (SR), grazing intensity (GI) and their interaction effects on plant aboveground net primary production (ANPP).

Effects		df	F	*P*
ANPP	Y	1	21.067	<0.001***
	SR	3	11.331	<0.001***
	GI	2	2.465	0.092
	Y× SR × GI	6	1.144	0.3458

Table 3. Variance analysis of year (Y), seasonal rest (SR), grazing intensity (GI), soil depth (D) and their interaction effects on soil organic carbon (SOC) and alkaline hydrolysis nitrogen (AHN).

Effects		df	F	*P*
SOC	Y	1	13.517	<0.001***
	SR	4	3.968	0.006**
	GI	2	0.137	0.872
	D	1	558.067	<0.001***
	Y× SR × GI × D	6	0.249	0.958
AHN	Y	1	23.763	<0.001***
	SR	3	158.900	<0.001***
	GI	2	0.271	0.7633
	D	1	53.740	<0.001***
	Y× SR × GI × D	6	0.087	0.997

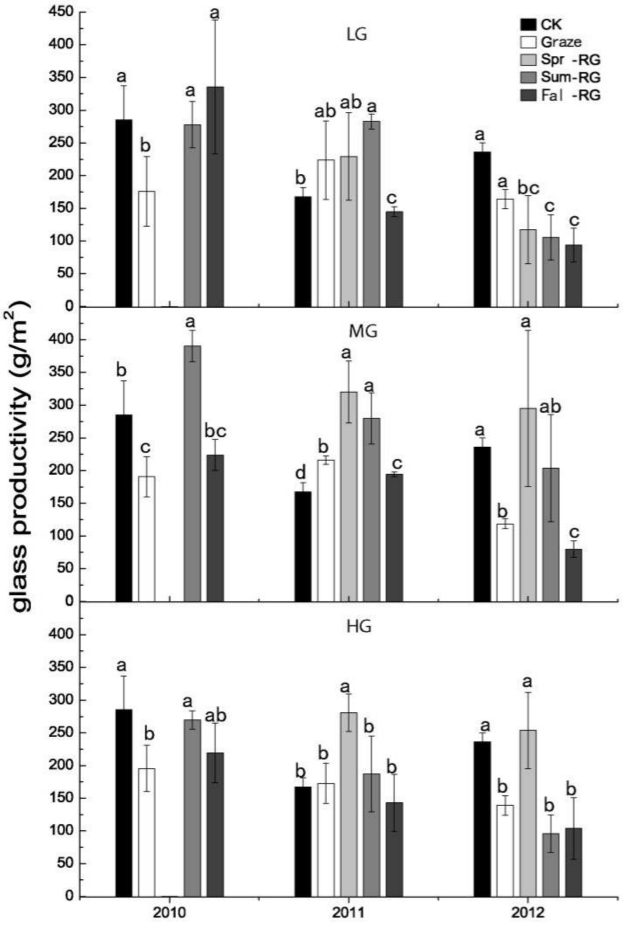

Fig. 1. Effects of rest grazing on the aboveground net primary production of different grazing intensity from 2010 to 2012 (mean ± SE; n=6).

*CK-not grazing area; G- grazing sample plots; Spr.-RG - spring rest grazing; Sum.-RG - summer rest grazing; Fal.-RG - autumn rest grazing. Different lowercase indicated significant differences in soil physicochemical properties in soil among different treatments ($p<0.05$). The following figures indicated the same.

Results

Aboveground net primary production: Year and seasonal rest grazing had significant effects on grassland ANPP ($p<0.001$) (Table 2). There were great differences in ANPP among the different years. The ANPP of all experimental groups showed a trend of annual decline, except for the grazing land. Since the grazing experiment began in July 2010, ANPP data for spring 2010 are not available. Figure 1 shows that in 2010, with more precipitation (Table 1), the ANPP of Sum.-RG under different grazing intensities was significantly higher than that of grazing land and even significantly higher than that of natural grassland and Fal.-RG under moderate grazing pressure ($p>0.05$, Fig. 1). Under moderate and heavy grazing intensities, the effect of rest grazing in summer was significantly higher than that in autumn. In 2011 and 2012, except for the mildly grazed areas, ANPP in the remaining areas in different seasons showed a decreasing trend in spring, summer and autumn. For moderate and severe grazing pressure, the effect of Spr.-RG was better, especially under heavy grazing pressure, and the ANPP of Spr.-RG was significantly higher than that in summer, autumn or the grazing land ($p<0.05$, Fig. 1).

ANPP is an important indicator reflecting the quantitative characteristics of grassland communities, and its size can be used to judge grassland status and productivity potential, which is of great significance for the regeneration or persistent growth of grassland plants. Overall, short-term seasonal grazing can improve the quantity index of the grassland community, which is related to grazing intensity and grazing season. Spring rest-grazing has the most obvious effect on grassland vegetation restoration, and autumn rest-grazing is poor. In addition, interannual climate fluctuations have a significant impact on the effect of seasonal rest grazing.

Soil organic carbon: Year, seasonal rest grazing and soil depth had significant effects on SOC (p<0.05) (Table 3). Large variation was found in the SOC content among years, which was closely correlated with the precipitation amount in the growing season of each year (Table 1). The year 2010, with the highest precipitation amount, showed a higher SOC content (0-20 cm) in all treatments than the years 2011 and 2012. In addition to the impact of precipitation, the timing of rest-grazing also played an important role in soothing the effect of grazing intensity on SOC. In 2010, the plots under different grazing intensities but with Spr.-RG showed no difference in SOC, while the plots with Sum.-RG showed significantly decreased SOC under moderate grazing ($p<0.05$, Fig. 2), and the plots with Fal.-RG showed significantly decreased SOC under heavy grazing ($p<0.05$, Fig. 2). In 2011, a significant decrease in SOC was found in all plots under heavy grazing ($p<0.05$, Fig. 2), indicating the compound impact between grazing intensity and precipitation. In 2012, no SOC decrease was found among the three grazing intensity levels in any plot (Fig. 2), which suggested that the free grazing in the three seasons in 2012 all soothed the grazing pressure; although the SOC content was lower than that in 2011 due to limited precipitation in the growing season.

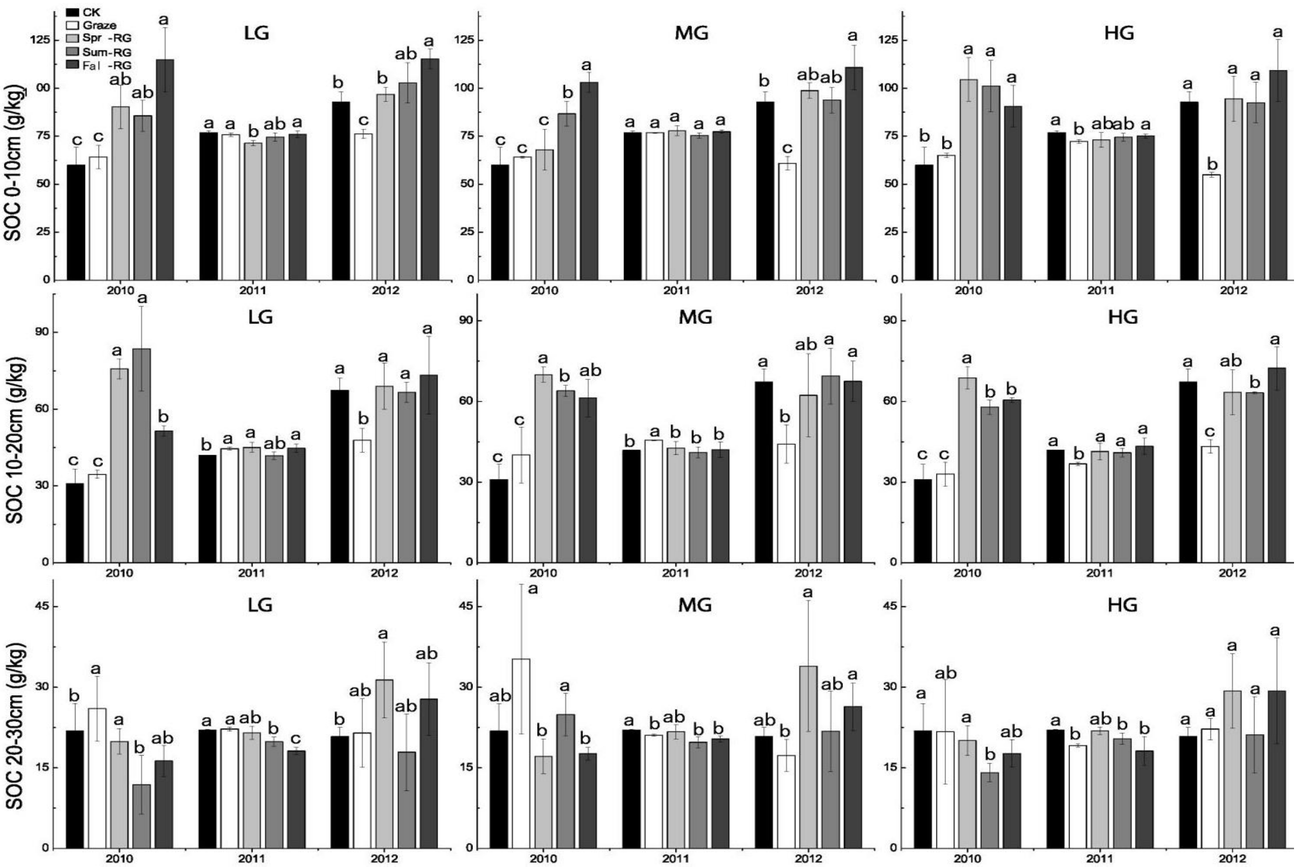

Fig. 2. Effects of rest grazing on the organic carbon storage in soil (0-30 cm) in plots of different grazing intensity from 2010 to 2012 (mean ± SE; n=6).

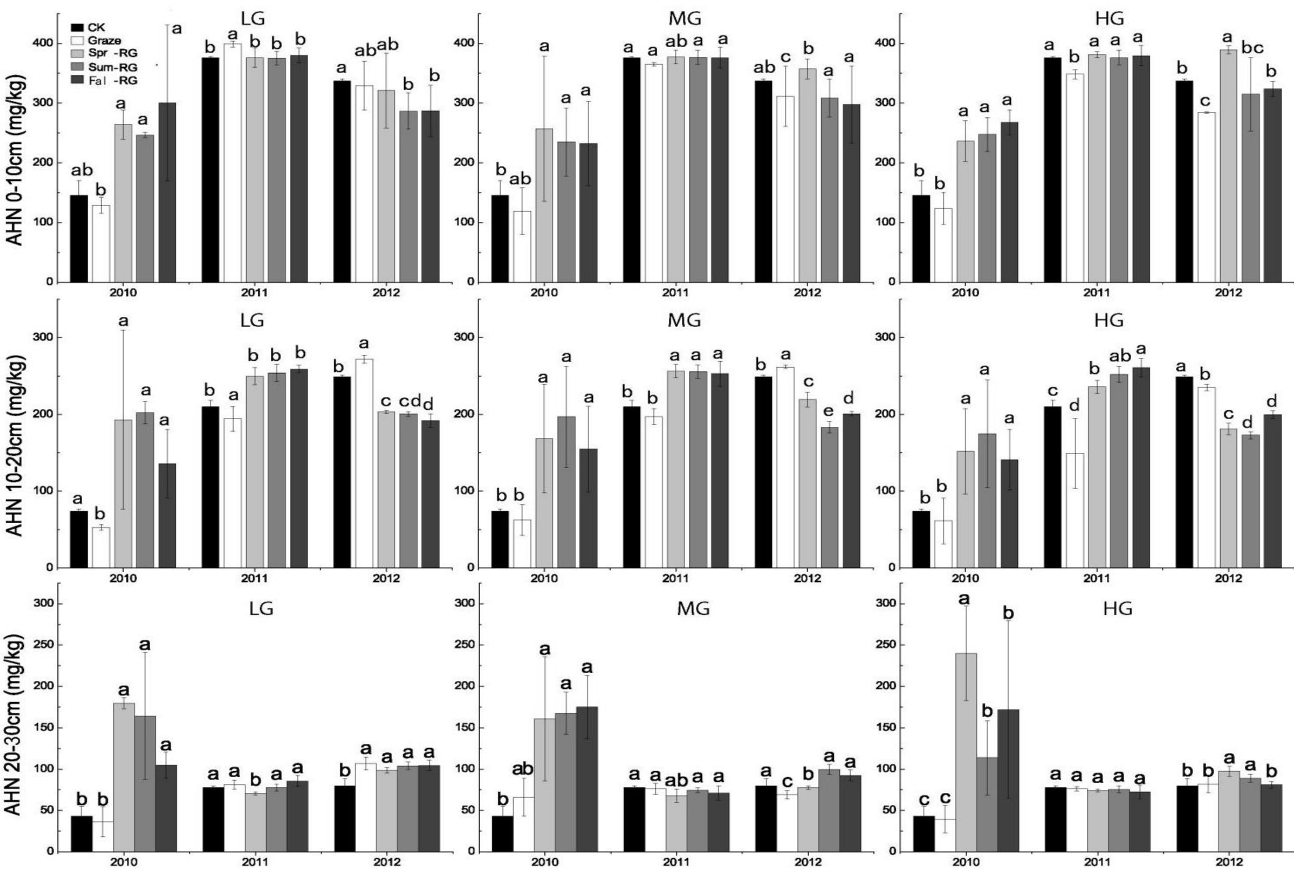

Fig. 3. Effects of rest grazing on the alkaline hydrolysis nitrogen in soil (0-30 cm) in plots of different grazing intensity from 2010 to 2012 (mean ± SE; n=6).

Alkaline hydrolysis nitrogen: Year, seasonal rest grazing and soil depth had significant effects on AHN ($p<0.001$) (Table 3). As shown in Fig. 3, in 2010, the AHN content of each experimental group was generally low, which may be due to climate reasons. More rainfall in the growing season is due to the vigorous growth of plants and the high demand for nitrogen, resulting in a decrease in AHN in the soil. Under different grazing intensities, the AHN content of each soil layer in the rest of the grazing area was significantly higher than that in the grazing area ($p<0.05$, Fig. 3). Sum.-RG significantly increased the AHN content of the 10-20 cm soil layer but had no significant effect on the 0-10 cm soil layer ($p<0.05$, Fig. 3). Compared with moderate grazing, Fal.-RG promoted the AHN of the 0-10 cm soil layer under light grazing and moderate grazing pressure. However, there was no significant difference in AHN between the different seasons. In 2011, compared with the control, the AHN content in the 10-20 cm soil layer increased significantly in the grazing area in different seasons but had no significant effect on the AHN content in the 0-10 cm and 20-30 cm soil layers. Under the light grazing intensity, the soil AHN content was promoted in the 0-10 cm soil layer grazing area compared with the nongrazing area. However, there was no significant difference in AHN between the different seasons ($p<0.05$, Fig. 3). In 2012, the AHN of the 10-20 cm soil layer content in the rest-grazing area was significantly lower than that in the control and grazing areas ($p<0.05$, Fig. 3), but in the 0-10 cm and 20-30 cm soil layers, the rest-grazing area was generally higher, and there was no significant difference from the control and grazing areas ($p>0.05$, Fig. 3). Generally, for light grazing pressure, the effect of no grazing in summer and autumn is more significant, while that of heavy grazing pressure is better in spring.

Discussion

Globally, the biological decomposition of soil organic matter due to human activities releases ten times more carbon into the atmosphere each year than the annual carbon emissions from fossil fuel combustion. For grassland ecosystems, grazing affects the contents and chemical composition of soil organic matter and the distribution of carbon in soil (Sun *et al*., 2010), which further affects the storage and cycling of soil carbon in grassland ecosystems and their productivity. Grassland ecosystem recovery, associated with rest grazing or reducing grazing intensity, has been designed and implemented by China's central government over the past three decades to control grassland degradation (Zhou *et al*., 2011). In China, various management efforts aimed at alleviating grazing pressure have been promoted to conserve and restore degraded grassland, which have shown profound effects on grassland resilience (Mu *et al*., 2013; Sun *et al*., 2020). However, there has been an outstanding controversy regarding the pattern of the dynamics of soil organic carbon in meadow grassland and steppe grassland under grazing pressure (Zinn *et al*., 2005; Wang *et al*., 2007; Zhou *et al*., 2011). There are also studies showing that the grazing treatment led to lower soil organic carbon compared to plots under rest-grazing treatment (Ding *et al*., 2012; Yan *et al*., 2020).

With increased grazing intensity, the present study found unaffected organic carbon storage in surface soil (0-20 cm) in plots under the spring rest-grazing but not the summer and autumn rest-grazing (Fig. 1). Spring rest-grazing could be the more important timing, other than the summer and autumn rest-grazing, as it is the key period for grass establishment and growth. Gao and Liu (2010) reported that grazing should be banned temporarily from April to June each year when the grass just turns green or to partition the grassland into different zones and each zone is grazed in turn. Rest-grazing, if taken in time, has been proven to be a very efficient grassland management strategy that could effectively restore vegetation and contribute to the sustainability of arid grassland (Li *et al*., 2014; Yan *et al*., 2020).

In the longer term, continuous free grazing in three different seasons in 2012 showed no response of organic carbon storage to increased grazing intensity, which implicates the importance of the time scale when determining the impact of improved grassland management on grassland carbon sequestration in the long term (Wang *et al*., 2011; Dong *et al*., 2020; Du *et al*., 2020). Many multiyear observations have found that improved grassland management, such as banned grazing and rotational grazing, is mainly responsible for the increase in vegetation coverage (Mu *et al*., 2013; Liu *et al*., 2020). Under these long-term improved management practices, the soil carbon losses under heavy grazing intensity in the first year could be reduced, and the soil carbon sequestration could be enhanced, probably in combination with higher net primary production and lower organic matter decomposition in the second and third years. For instance, Gao and Liu (2010) reported that the alleviated human intervention on previously degraded land could increase the biomass returned to the soil and improve its physical and chemical properties, which could potentially lead to increased soil carbon sequestration and decreased soil respiration and further reverse the spiral effect of continuous degradation (Su, 2007).

Soil available nutrients are mainly related to soil mineralization, plant absorption and livestock excretion (Li *et al*., 1998). The content of available nutrients reflects the actual fertilizer supply capacity of soil and is affected by soil temperature and humidity, especially microbial activities (Kotze *et al*., 2013). In grassland ecosystems, available nitrogen is the primary limited resource of primary productivity, which is closely related to plant growth and is also the main factor determining the species composition of the system (Gao *et al*., 2009). The content of available nitrogen can be used to evaluate the level of soil nitrogen supply in the short term. This study showed that after 3 years of grazing management, the gap in available nitrogen content in the 0~20 cm soil layer between continuous grazing plots and seasonal grazing plots decreased rapidly. In 2012, some grazing plots had lower available nitrogen contents than did the grazing plots. This was due to the large aboveground biomass of seasonal grazing plots, strong absorption of available nutrients by vegetation and small aboveground biomass of continuous grazing plots (Zhang *et al*., 2020). The absorption of available nutrients by vegetation decreased, while the excretion of livestock increased, and the content of organic matter in the surface layer of the soil increased. With the decrease in vegetation, the content of available nitrogen increased but was not absorbed, thus accumulating the content of available nitrogen.

With regard to the selection of the rest grazing season, the three rest times set in this experiment were spring grazing, that is, fencing in June, summer grazing in July and August, and autumn grazing in September. This experiment shows that the spring grazing measure is the most suitable for the experimental area to be popularized and implemented. Although the plant growth of the community with no grazing measure was relatively slow at the beginning of the growing season, it had enough time to grow and accumulate its biomass so that livestock had abundant biomass to feed. This period is also the period with the most abundant water and heat conditions in the steppe area, and the accumulation effect on the aboveground biomass of the community is obvious and reaches the highest in the whole growing season. After grazing and utilization, the accumulation of aboveground biomass began to enter the last stage, especially at the end of August, when plants began to senesce. Although the accumulation of biomass was small, there were enough communities to maintain their community structure and community stability. Compared with the rest of the grazing in spring, the rest of the grazing in autumn does not give the community enough time to accumulate biomass and use it for grazing, which does some damage to the plants of the community. The grazing utilization of summer fallow grazing at the end of the growing season makes the community without complete community structure and biomass overwintering, therefore affecting the accumulation and production of the grassland community in the second year. Long-term grazing and utilization at the end of the plant growing season is not conducive to the stability of grassland ecosystems and plant community composition structures, and community succession may occur.

Conclusion

The present study highlighted the importance of timing in the use of seasonal rest-grazing in the short term and the importance of duration of rest-grazing in the long term for the soil nutrient balance of mesic grassland. In addition to the driving power of growing season precipitation, after three years of grazing management, the final results showed that (1) under moderate and severe grazing pressure, the aboveground net primary productivity of grassland plants was significantly increased in spring and summer but not in autumn. (2) The organic matter content in the 0-30 cm soil layer significantly increased in spring and autumn, and the organic matter content in the 0-20 cm soil layer significantly increased in summer. (3) No grazing in summer and autumn significantly decreased the content of available nitrogen in the 0-30 cm soil layer, while no grazing in spring decreased the available nitrogen in the 10-20 cm soil layer but increased the available nitrogen in the 0-10 cm and 20-30 cm soil layers. The study contributes to the understanding of the impact of differential grazing intensities on the stability of the soil organic carbon pool and the relative effectiveness of different seasonal rest-grazing strategies on grassland sustainability on the Sanjiang Plain.

Acknowledgement

This study was supported by the Special Fund for Agro-scientific Research in the Public Interest (Project No. 200903060)

References

Anonymous. 2005. SAS OnlineDoc® 9.1.3. SAS Institute, Cary, NC.

Costanza, R., R. d’Arge, R. de Groot, S. Farber, M. Grasso, B. Hannon, K. Limburg, S. Naeem, R.V. O’Neill, J. Paruelo, R.G. Raskin, P. Sutton and M. van den Belt. 1997. The value of the world’s ecosystem services and natural capital. *Nature*, 387: 253-260.

Ding, X.H., L. Gong, D.B. Wang, X. Wu and G.H. Liu. 2012. Grazing effects on eco-stoichiometry of plant and soil in Hulunbeir, Inner Mogolia. *Acta Ecol. Sin.*, 32(15): 4722-4730.

Dong, S.K., Z.H. Shang, J.X. Gao and R.B. Boone. 2020. Enhancing sustainability of grassland ecosystems through ecological restoration and grazing management in an era of climate change on Qinghai-Tibetan Plateau. *Agric. Ecosyst. Environ.*, 287: 106684.

Du, C.J., J. Jing, Y. Shen, H.X. Liu and Y.H. Gao. 2020. Short-term grazing exclusion improved topsoil conditions and plant characteristics in degraded alpine grasslands. *Ecol. Indic.*, 108: 105680.

Franzluebbers, A.J. and J.A. Stuedemann. 2009. Soil-profile organic carbon and total nitrogen during 12 years of pasture management in the Southern Piedmont USA. *Agri. Ecosyst. Environ.*, 129: 28-36.

Gao, J. and Y.S. Liu. 2010. Determination of land degradation causes in Tongyu County, Northeast China via land cover change detection. *Int. J. Appl. Earth Obs. Geoinf.*, 12: 9-16.

Gao, X.F. 2009. Effects of different grazing systems on the contents of total nitrogen and available nitrogen in desert steppe soil. *Grass Ind. Inner Mongolia*, 21(3): 56-58.

Garcia-Oliva, F., J.F.G. Lancho, N.M. Montano and P. Islas. 2006. Soil carbon and nitrogen dynamics followed by a forest-to-pasture conversion in western Mexico. *Agrofor. Syst.*, 66: 93-100.

Holechek, J., R.D. Piepe and C.H. Herbel. 2004. Range Management: Principles and Practices. *N Jersey: Prentice-Hall*.

Kotzé, E, A. Sandhage-Hofmann, C.C. du Preez, J.A. Meinel and W. Amelung. 2013. Rang-eland management impacts on the properties of clayey soils along grazing gradients in the semi-arid grassland biome of South Africa. *J. Arid Environ.*, 97: 220-229.

Li, X.L., Q.H. Yuan, L.Q. Wan and F. He. 2008. Perspectives on livestock production systems in China. *Rangeland J.*, 30: 211-220.

Li, X.Z. and Z.Z. Chen. 1998. Effects of different stocking rates on grassland plants and soil C, N, P. *J. Grassl.*, 6(2): 90-98.

Li, Y.J., W.C. Yu, Hui, H. Wang, X. Lai, G. Li, J.N. Zhao and D.L. Yang. 2014. Effects of rest grazing on organic carbon storage in Stipa Baicalensis steppe in Inner Mongolia. *Acta Ecol. Sin.*, 34(3): 170-177.

Liu, M.Z., G.M. Jiang, L.H. Li, Y.G. Li, L.M. Gao and S.L. Niu. 2004. Control of sandstorms in Inner Mongolia, China. *Environ. Conserv.*, 31: 269-273.

Liu, X., Z.W. Ma, X.T. Huang and L.H. Li. 2020. How does grazing exclusion influence plant productivity and community structure in alpine grasslands of the Qinghai-Tibetan Plateau? *Glob. Ecol. Conserv.*, 23: e01066.

Ma, W.M., K.Y. Ding and Z.W. Li. 2016. Comparison of soil carbon and nitrogen stocks at grazing-excludedand yak grazed alpine meadow sites in Qinghai–Tibetan Plateau, China. *Ecol. Eng.*, 87: 203-211.

Milehunas, D.G. and W.K. Lauenroth. 1993. Quantitative effects of grazing on vegetation and soils over a global range of environments. *Ecol. Monogr.*, 63(4): 327-366.

Mu, S., S. Zhou, Y. Chen, J. Li, W. Ju and I.O.A. Odeh. 2013. Assessing the impact of restoration-induced land conversion and management alternatives on net primary productivity in Inner Mongolian grassland, China. *Global Planet. Change*, 108: 29-41.

Piñeiro, G., J.M. Paruelo, E.G. Jobbágy, R.B. Jackson and M. Oesterheld. 2009. Grazing effects on belowground C and N stocks along a network of cattle exclosuresin temperate and subtropical grasslands of South America. *Global Biogeochem.* 23: GB3002.

Reeder, J.D. and G.E. Schuman. 2002. Influence of livestock grazing on C sequestration in semi-arid mixed-grass and short-grass rangelands. *Environ. Poll.*, 116: 457-463.

Su, Y.Z. 2007. Soil carbon and nitrogen sequestration following the conversion of cropland to alfalfa forage land in northwest China. *Soil Tillage Res.*, 92: 181-189.

Sun, J., M. Liu, B.J. Fu, D. Kemp, W.W. Zhao, G.H. Liu, G.D. Han, A. Wilkes, Y.Y. Lu, Y.C. Chen, G.W. Cheng, T.C. Zhou, G. Hou, T.Y. Zhan, F. Peng, H. Shang, M. Xu, P.L. Shi, Y.T. He, M. Li, J.N. Wang, A. Tsunekawa, H.K. Zhou, Y. Liu, Y.R. Li and S.L. Liu. 2020. Reconsidering the efficiency of grazing exclusion using fences on the Tibetan Plateau. *Sci. Bull.*, 65(16): 1405-1414.

Sun, X.L., M.J. Wang, H.J. Chen, L.L. Chen and L. Na. 2010. Response of underground biomass to different grazing intensity in the Stipa breviflora desert steppe. *J. Inner Mongolia Agric. Univ.*, 31(4): 101-104.

Wang, D., Y. Liu, G.L. Wu., L.M. Ding, Z. Yang and H.M. Hao. 2015. Effect of rest-grazing management on soil water and carbon storage in an arid grassland (China). *Hydrol.*, 527: 754-760.

Wang, M.J., G.D. Han, M.L. Zhao, H.J. Chen, Z. Wang, X.L. Hao and T. Bo. 2007. The effects of different grazing intensity on soil organic carbon content in meadow steppe. *Pratac. Sci.*, 24(10): 6-10.

Wang, S.P., A. Wilkes, Z.C. Zhang, X.F. Chang, R. Lang, Y.F. Wang and H.S Niu. 2011. Management and land use change effects on soil carbon in northern China's grasslands: a synthesis. *Agric. Ecosyst. Environ.*, 142: 329-340.

Wang, Y., W.X. Duan, C. Tu, S. Washburn, L. Cheng and S. Hu. 2014. Soil Carbon, Nitrogen and Microbial Dynamics of Pasturelands: Impacts of Grazing Intensity and Planting Systems. *Pedosphere*, 24(3): 408-416.

Yan, L., Y. Li, L. Wang, X.D. Zhang, J.Z. Wang, H.D. Wu, Z.Q. Yan, K.R. Zhang and X.M. Kang. 2020. Grazing significantly increases root shoot ratio but decreases soil organic carbon in Qinghai-Tibetan Plateau grasslands: A hierarchical meta-analysis. *Land Degrad. Dev.*, 31(16): 2369-2378.

Zhang, T.R., F.Y. Li, C.J. Shi, Y.L. Li, S.M. Tang and T.G.T. Baoyin. 2020. Enhancement of nutrient resorption efficiency increases plant production and helps maintain soil nutrients under summer grazing in a semi-arid steppe. *Agric. Ecosyst. Environ.*, 292: 106840.

Zhou, R.C., H.T. Wang, H.W. Ni, K.P. Ma, Z.Q. Zhou and G.T. Yang. 1992. The research of wet grassland in the Sanjiang Plain of China. *Terr. Nat. Res. Study*, 1: 43-47.

Zhou, Z.Y., F.R. Li, S.K. Chen, H.R. Zhang and G.D. Li. 2011. Dynamics of vegetation and soil carbon and nitrogen accumulation over 26 years under controlled grazing in a desert shrubland. *Plant Soil*, 341: 257-268.

Zinn, Y.L., R. Lal and D.V.S. Resck. 2005. Changes in soil organic carbon stocks under agriculture in Brazil. *Soil Tillage Res.*, 84: 28-40.

(Received for publication 26 December 2021)