Carbon storage and sequestration under different stocking rates in a Eurasian Desert Steppe in China

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Abstract. The research on carbon source/sink of terrestrial ecosystem is an important part of global climate change. Under the sustainable grazing management, the carbon storage in grassland ecosystem will increase, which promotes the carbon sequestration in the grassland area. In order to understand the carbon sequestration in grazing system of desert steppe, a sheep grazing experiment for completely random block design was conducted in desert steppe. There were 4 stocking rates and 3 replications in this experiment. The effects of annual precipitation and stocking rate on the carbon sequestration of desert steppe were compared. The stocking rate treatments were as follows: no grazing, light grazing, moderate grazing, and heavy grazing. Plant composition, biomass, individual plant carbon, soil carbon, emission of soil and livestock, and carbon flux of ecosystem were measured. We discussed carbon storage and carbon sequestration based on the above indicators. The results showed that stocking rate has different effects on the aboveground net primary production, belowground net primary production, carbon storage of grassland ecosystem, net ecosystem exchange and soil respiration. We further analyzed the impact factors of different variables, understood the carbon sequestration and transition process from plant to soil in this steppe. Finally, we concluded that the optimal stocking rate in desert steppe according to the vegetation, balance of soil nutrients and livestock performance, provides the theoretical reference for the sustainable grassland management based on grassland carbon sequestration.

Introduction

Grassland resources are unique, and the development of grassland carbon sinks has become an important carrier for fulfilling international commitments, creating a new carbon sink economy, and building a beautiful China. The total carbon storage of grassland vegetation in China accounts for about 16.7 % of terrestrial ecosystems. Many studies have shown that different livestock grazing intensities change the composition of plant species and affect the biomass of grassland vegetation and soil carbon storage. Degraded grassland can increase soil carbon through appropriate grazing management measures, alleviate CH_4 emissions from grassland grazing systems, and optimize forage intake and livestock production performance in grazing systems. Overgrazing, and other human activities not only reduce the carbon sequestration capacity of grassland plants, resulting in a large release of organic carbon in the soil, reducing the input of grassland vegetation to the soil carbon pool, but also aggravate soil respiration and accelerate the decomposition of soil organic matter, thus accelerating the release of carbon from the soil to the atmosphere, resulting in a serious decline in grassland carbon sink function.

Especially in arid and semi-arid regions, overgrazing threatens the biodiversity and stability of grassland communities, changes the structure and function of ecosystems, and leads to increase soil carbon loss. Therefore, there are two scientific problems to be solved in carbon sequestration, storage and transformation of rangeland grazing system: (1) What is the carbon transformation mechanism of rangeland plants, soil and soil microorganisms? (2) The stocking rate threshold of carbon sink / source conversion in grassland grazing system and its relationship with environmental factors.

Grassland resources are not only the material basis for the development of animal husbandry in Inner Mongolia, but also an important economic component in ethnic minority areas. It is also the largest ecological barrier in northern China and is crucial to maintaining the ecological security of Inner Mongolia and even the north of the country. The greenhouse gas emissions caused by the development of grassland animal husbandry and related industrial production will have a profound impact on grassland carbon sequestration. Based on the long-term stocking rate manipulative experiment in the Inner Mongolia Plateau, this study conducted an in-depth study on the carbon storage, carbon sink process transformation and accumulation of grassland grazing systems. The mechanism of grassland carbon conversion and accumulation in grazing systems was deeply analyzed from multiple levels of vegetation, soil, livestock and microorganisms. The combination of carbon sequestration and greenhouse gases emission reduction with low stocking rate is very important in grassland. The application of low stocking rate in grassland and livestock system in pastoral areas will lead new era for dryland management in China.

Methods

Site

Plant and soil samples were collected in long-term stocking rate experimental plots of *Stipa breviflora* dominated plant community on light chestnut soil located in Siziwang Banner (41 ° 47'17 "N, 111 ° 53'46" E, elevation 1 450 m), Inner Mongolia, China. The annual average precipitation in the desert steppe is 280 mm, more than 80% of which is concentrated from June to November. Annual average air temperature is about 3.2℃.

Experimental design

The experiment was a randomized block experiment. The experimental plots covered about 50 ha of natural grassland, and had been enclosed for 17 years (2004-2020). The plots were divided into three blocks. Each block had four treatment plots (no grazing, NG; light grazing, LG; moderate grazing, MG; and heavy grazing, HG). Each treatment was repeated three times, and the area of each experimental plot was 4.4 ha. The stocking rates in each treatment are 0 (NG), 0.15 (LG), 0.30 (MG) and 0.45 (HG) sheep unit $\cdot ha^{-1}$ $mo^{-1,}$ respectively$\cdot$. In this experiment, 2-year-old adult wethers were selected and allowed to graze from June to November every year. During the experiment, the management measures in each grazing area are the same. The sheep were driven into the grazing plots at 6 am where they were free to feed, and returned back to the shed at 6 pm every day. Water was provided twice a day in the morning and evening, and supplementary salt was regularly available in the form of salt bricks.

Measurements and data analysis

In the annual plant growth peak season, we measured the vegetation composition, aboveground and belowground biomass, individual plant carbon, soil carbon, carbon flux of the ecosystem

and soil physical and chemical properties (Jin et al. 2023). In 2020, we measured soil microbial biomass carbon and nitrogen in different grazing plots, and measured soil microbial diversity and function using high-throughput sequencing method (Zhu, *et al*., 2022). We performed multivariate analysis of variance and Spearman correlation analysis on the data.

Results and discussion

Stocking rate had a significant effect on the aboveground and belowground carbon storage of plants (Wang, et al., 2017). The results showed that with the increase of stocking rate, the proportion of perennial grasses in plant communities increased, while the proportion of shrubs, semi-shrubs and forbs decreased, resulting in a significant decrease in aboveground carbon storage (ABC) and underground biomass (BGB) (Fig.1). Compared with the high stocking rate commonly used by local herdsmen, the low stocking rate increased the aboveground and underground carbon storage of plants by 7 %. Reducing the stocking rate can increase the carbon sequestration of aboveground and underground plants, and a reasonable stocking rate level is more conducive to the balance of desert steppe ecosystem. This long-term stocking rate manipulative experiment is a pioneering study of plant and soil carbon in grazing systems in the Eurasian desert steppe.

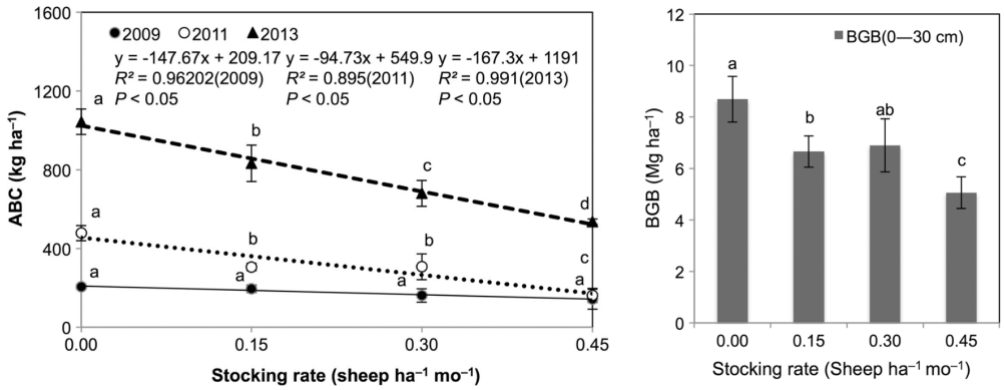

Figure 1. Changes of aboveground carbon storage (ABC) and belowground biomass (BGB) of plants under different stocking rates in *Stipa breviflora* desert steppe

The study analyzed the effect of stocking rate on grassland ecosystem carbon storage, which was reflected in aboveground and belowground biomass, but less than in soil carbon storage. The response of spatial variability of soil carbon to stocking rate showed that the spatial variability of soil carbon in no-grazing, moderate-grazing and heavy-grazing was mainly caused by regional factors. The spatial variation of soil carbon in light grazing is the result of the interaction of regional factors and random factors such as grazing. The overall variation of soil carbon was: no grazing > light grazing > moderate grazing > heavy grazing. Soil organic carbon was the highest in non-grazing area, followed by light and moderate grazing plots, and the lowest in heavy grazing plot. With the increase of stocking rate, the maximum spatial variability of organic carbon decreased. The spatial heterogeneity of organic carbon showed no grazing > light grazing > moderate grazing > heavy grazing.

Multivariate analysis of variance showed that grazing with different stocking rates significantly changed the net carbon exchange of ecosystem, especially heavy grazing, but had no significant

impact on ecosystem respiration (Table 1). It also showed that soil net carbon exchange and ecosystem respiration in different grazing plots are affected by interannual effects, which may be related to changes in precipitation and soil microbial community structure in different years.

Table 1 Net carbon exchange (NEE) and ecosystem respiration (ER) of ecosystems under different stocking rates in *Stipa breviflora* desert steppe in growing season

Grazing treatment	Net carbon exchange (NEE umol CO_2 /m^2/ s)				Ecosystem respiration (ER umol CO_2 /m^2/ s)			
	2011	2012	2013	total	2011	2012	2013	total
No grazing	-0.53Aa	-3.98Ab	-1.93Aa	-2.15A	2.31Aa	4.31Ab	2.78Aa	3.13A
Light grazing	-0.19Aa	-2.76ABb	-1.63Aab	-1.52AB	1.86Aa	3.38Ab	2.04Aab	2.43A
Moderate grazing	0.14Bb	-1.92Bb	-1.34Aab	-1.04AB	1.55Aa	2.62Aa	1.82Aa	1.97A
Heavy grazing	0.18Bb	-1.61Bb	-1.20Aab	-0.86B	1.27Aa	2.45Aa	1.74Aa	1.85A
	Variance results				P value			
Year	< 0.0001				< 0.0001			
Treatment	0.0355				0.0512			
Year* Treatment	0.1015				0.5288			

Note: Different upper case letters (A,B) represent the differences of different treatments in the same year, and different lower case letters (a,b) represent the differences of the same treatment in different years.

Conclusion

The study revealed the differences of grassland plant species and carbon sequestration capacity under different stocking rates. The deposition and transformation process of grassland soil carbon was clarified, and the optimum stocking rate of grazing utilization in desert steppe was proposed from the aspects of grassland vegetation status, soil nutrients and grazing livestock performance based on carbon sequestration of this ecosystem.

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