

## Effects of Grazing on Soil Aggregate Composition and Stability in Desert Shrub Grasslands (Post-print)

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### Abstract

This study examined desert grasslands in Alxa League, Inner Mongolia, to analyze the effects of different grazing intensities on soil physicochemical properties, aggregate composition, nutrient content, and stability. The results showed that, compared with light grazing, heavy grazing significantly decreased soil organic C and total N contents while significantly increasing soil bulk density in the 0-5 cm, 5-10 cm, and 10-20 cm soil layers. Soil aggregates in each layer were predominantly in the 0.053-0.25 mm size fraction. Increased grazing intensity reduced mean weight diameter (MWD) and geometric mean diameter (GMD) values of soil aggregates and increased fractal dimension (D) value, indicating damaged soil aggregate structure and decreased stability. This led to a shift from large-sized aggregates (0.25-2 mm) to small-sized aggregates (0.053-0.25 mm, <0.053 mm). Heavy grazing also increased the C/N ratio of soil aggregates, hindering the release of available nutrients and causing nutrient deficiency for plants. These findings demonstrate that heavy grazing is an important factor driving the degradation of desert grasslands in Alxa League.

### Full Text

## Effects of Grazing on the Composition and Stability of Soil Aggregates in Desert Shrub Grassland

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## Abstract

This study investigated the effects of different grazing intensities on soil physicochemical properties, aggregate composition, nutrient content, and stability in desert grasslands of Alxa League, Inner Mongolia. The results showed that compared to light grazing, heavy grazing significantly decreased soil organic carbon content and increased soil bulk density in the 0–5 cm, 5–10 cm, and 10–20 cm layers. Soil aggregates in all layers were predominantly composed of the 0.053–0.25 mm fraction. Increased grazing intensity caused a shift from large-diameter aggregates (0.25–2 mm) to small-diameter aggregates (0.053–0.25 mm and <0.053 mm). Heavy grazing reduced the mean weight diameter (MWD) and geometric mean diameter (GMD) of soil aggregates while increasing the fractal dimension (D) value, indicating structural damage and reduced stability. The elevated C/N ratio of soil aggregates hindered the release of available nutrients, leading to nutrient deficiency for plants. These findings demonstrate that heavy grazing is a critical factor driving the degradation of desert grasslands in Alxa League.

**Keywords:** grazing intensity; soil aggregate; stability; soil nutrients

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## Introduction

Grazing is one of the primary land use practices in grassland ecosystems, profoundly influencing soil physicochemical properties through various mechanisms. Different grazing intensities exert distinct effects on grassland vegetation, soil organic carbon, and soil aggregate structure. Numerous studies have demonstrated that changes in grassland plant communities are closely correlated with grazing intensity, with overgrazing representing the most significant cause of grassland degradation. Grazing intensity also constitutes a major factor affecting soil nitrogen content, as livestock consumption reduces plant carbon allocation to soils, while overgrazing alters soil physicochemical properties, ultimately leading to reductions in soil organic carbon.

Soil aggregates, as fundamental structural and functional units of soil, are porous formations of varying scales created through the synergistic action of mineral particles, organic matter, soil microorganisms, and natural physical

processes such as freeze-thaw and wet-dry cycles. Soil aggregates provide physical protection for organic carbon by isolating it from microbial decomposition, thereby facilitating its stable preservation and accumulation in soil. Consequently, soil aggregates constitute an essential foundation of soil fertility and serve as important indicators for evaluating soil quality.

Previous research has extensively examined soil aggregates, though most studies have focused on impacts from land use changes and tillage practices. While some investigations have addressed grazing effects on soil aggregates in the Loess Plateau's forest-grassland ecosystems, few have specifically examined desert grasslands. The Alxa League region in Inner Mongolia, located in northwestern China's inland area, represents an important forage resource for livestock production. Due to combined natural and anthropogenic factors, over 90% of grasslands in this region have experienced degradation, characterized by loss of vegetation diversity, reduced vegetation cover, and altered soil physicochemical properties. This study analyzes soil organic carbon characteristics, aggregate distribution patterns, and stability under different grazing intensities in the Alxa desert grassland, aiming to provide scientific references for soil quality assessment, carbon sequestration research, and ecological restoration of grazed grasslands.

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## 1. Study Area and Methods

**1.1 Study Area Description** The study site is located in Bayinchaogetu Gacha, Barunbieli Town, Alxa Left Banner, at geographic coordinates 38°9'28.14" N, 105°29'38.05" E, with an elevation of 1543 m. The region experiences a typical arid desert climate, with mean annual temperature of 8.1°C and mean annual precipitation of 60–150 mm, concentrated in the period with  $\geq 10^\circ\text{C}$  accumulated temperature of 3200–3400°C. The soil type is gray-brown desert soil. Dominant shrub species include *Reaumuria songorica* and *Salsola passerina*, while major herbaceous plants include *Cleistogenes songorica*, *Carex stenophylloides*, and *Eragrostis poaeoides*.

### 1.2 Research Methods 1.2.1 Plot Selection

A degradation gradient was established by radiating outward in a straight line from livestock pens adjacent to herder residences. Sample plots were established at distances of 0 m (heavy grazing, HG), 500 m (moderate grazing, MG), and 1000 m (light grazing, LG) from the pen, with three replicate plots (50 m  $\times$  50 m) for each grazing intensity.

### 1.2.2 Vegetation Community Characteristics

In August 2018, one 10 m  $\times$  10 m shrub quadrat and five 1 m  $\times$  1 m herbaceous quadrats were established in each replicate plot. Species composition and plant counts were recorded for both shrubs and herbs. Height and crown width were

measured for each plant. Herbaceous cover was determined using the pin-point method, while shrub cover was calculated from total crown area.

### 1.2.3 Soil Sample Collection and Analysis

In August 2018, five sampling points were randomly established within each shrub quadrat. Soil cores were collected from 0–5 cm, 5–10 cm, and 10–20 cm layers and composited by layer. Samples were sieved to remove roots and stones, thoroughly mixed, and approximately 1 kg was obtained using the quartering method for laboratory analysis. Concurrently, soil bulk density was measured using the ring knife method (100 cm<sup>3</sup> volume).

Air-dried soil samples were processed for analysis. A portion was ground to pass through a 0.149 mm sieve for soil organic carbon and total nitrogen determination. The remaining sample was sieved to determine aggregate composition and stability. Soil aggregate composition was analyzed using the wet sieving method with a soil aggregate analyzer (DM200-III, Shanghai). The sieve sizes were 2 mm, 0.25 mm, and 0.053 mm, corresponding to macro-aggregates (0.25–2 mm), micro-aggregates (0.053–0.25 mm), and fine fractions (<0.053 mm). Soil organic carbon was determined by the potassium dichromate oxidation method, and total nitrogen by the semi-micro Kjeldahl method. Soil particle size distribution was measured using a Mastersizer 2000 laser particle size analyzer.

### 1.3 Data Analysis

Statistical analysis was performed using IBM Statistics SPSS 25.0. Significance testing employed one-way ANOVA, with differences among means tested using Duncan's multiple range test at  $P < 0.05$  significance level. Figures were prepared using SigmaPlot 14.0.

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## 2. Results

### 2.1 Effects of Grazing Intensity on Vegetation Characteristics

Both shrub height and cover decreased significantly with increasing grazing intensity ( $P < 0.05$ ). Herbaceous plants showed similar trends [Figure 1: see original paper]. Compared to light grazing, shrub height under heavy grazing decreased by 41.1% and cover by 86.7%; herbaceous height decreased by 22.5% and cover by 89.0%. These results indicate that heavy grazing intensifies grassland vegetation degradation.

### 2.2 Effects of Grazing Intensity on Soil Physicochemical Properties

Soil organic carbon content in the 0–5 cm layer was highest in LG, followed by MG, and lowest in HG, with significant differences among all plots ( $P < 0.05$ ). In the 5–10 cm and 10–20 cm layers, LG and MG showed no significant difference but were both significantly higher than HG ( $P < 0.05$ ). Compared to light grazing, heavy grazing reduced soil organic carbon by 22.5% in the 0–5 cm layer, 17.8% in the 5–10 cm layer, and 15.5% in the 10–20 cm layer. Soil

total nitrogen showed similar trends. Soil bulk density increased gradually with grazing intensity, with HG significantly higher than LG and MG in all layers except 0–5 cm ( $P < 0.05$ ). Soil bulk density under heavy grazing increased by 14.3% in the 0–5 cm layer, 6.4% in the 5–10 cm layer, and 10.5% in the 10–20 cm layer compared to light grazing.

Soil particle composition was dominated by sand (73.0%–90.33%), with clay content of only 1.39%–3.20%. Sand content increased with grazing intensity, while silt and clay showed the opposite trend, indicating that heavy grazing exacerbates soil erosion, leading to loss of silt and clay fractions .

**2.3 Soil Aggregate Composition and Stability Under Different Grazing Intensities** The 0.053–0.25 mm fraction accounted for the largest proportion (73.5%–82.2%) of soil aggregates across all layers, while the 0.25–2 mm fraction was smallest (3.4%–8.3%). The percentage of 0.053–0.25 mm aggregates increased significantly with grazing intensity ( $P < 0.05$ ), while the 0.25–2 mm fraction decreased significantly ( $P < 0.05$ ) [Figure 2: see original paper]. The  $<0.053$  mm fraction showed no significant differences among treatments in most layers.

Mean weight diameter (MWD) and geometric mean diameter (GMD) of soil aggregates decreased gradually with increasing grazing intensity, while fractal dimension (D) increased. In the 0–5 cm layer, LG had significantly higher MWD and GMD than HG ( $P < 0.05$ ). The D value ranged from 2.61 to 2.94, with HG significantly higher than LG in all layers ( $P < 0.05$ ) . These results demonstrate that increased grazing intensity damages soil aggregate structure, reduces stability, and causes a shift from large to small aggregates.

**2.4 Soil Organic Carbon and Total Nitrogen Content in Aggregates** Soil organic carbon content in the 0.25–2 mm and  $<0.053$  mm fractions showed opposite trends with increasing grazing intensity. In the 0–5 cm and 5–10 cm layers, organic carbon in the 0.25–2 mm fraction was significantly higher in LG than in HG ( $P < 0.05$ ), while the  $<0.053$  mm fraction showed the reverse pattern. The 0.053–0.25 mm fraction showed no significant differences among treatments in most layers. Total nitrogen content in different aggregate fractions followed similar patterns to organic carbon [Figure 3: see original paper].

The C/N ratio of soil aggregates increased with grazing intensity. In the 0–5 cm and 5–10 cm layers, the C/N ratio of 0.25–2 mm and 0.053–0.25 mm aggregates under heavy grazing was significantly higher than under light grazing ( $P < 0.05$ ), increasing by 47.8%–125.3% and 102.4%–125.3%, respectively. The  $<0.053$  mm fraction showed no significant differences among grazing intensities .

### 3. Discussion

Grazing reduces soil organic carbon content, particularly in ecologically fragile arid and semi-arid regions. The decline in vegetation cover under heavy grazing reduces carbon input to soils and decreases microbial activity, limiting the production of binding agents necessary for aggregate formation. This results in fewer stable aggregates, looser soil structure, and reduced erosion resistance, consistent with findings from degraded grassland studies.

In the 0–5 cm and 5–10 cm layers, organic carbon in macro-aggregates (0.25–2 mm) decreased by 16.9% and 21.9% under heavy grazing compared to light grazing, while micro-aggregates (<0.053 mm) showed the opposite trend. This occurs because organic matter in macro-aggregates is less protected and more susceptible to decomposition as aggregate stability declines with increased grazing intensity. In contrast, organic carbon in <0.053 mm aggregates is tightly bound to clay minerals, providing effective physical protection against microbial decomposition and resisting physical disturbance from livestock trampling.

The C/N ratio reflects microbial mineralization and immobilization characteristics during organic matter decomposition. Ratios of 5.6–6.9 indicate favorable conditions for organic matter decomposition and net nitrogen mineralization. In this study, soil C/N ratios in the 5–10 cm layer were highest under heavy grazing and lowest under light grazing, suggesting that increased grazing intensity elevates C/N ratios. The 0.053–0.25 mm fraction accounted for 73.5%–82.3% of total aggregates, making it the primary determinant of overall soil C/N ratio. Changes in grazing intensity may alter soil microbial communities, ultimately affecting C/N ratios in soil aggregates.

Increased grazing intensity leads to reduced aboveground biomass. In this study, shrub cover under moderate and heavy grazing decreased by 22.5% and 41.1%, respectively, compared to light grazing, while shrub height decreased by 19.5% and 15.9%. Reduced vegetation cover intensifies soil erosion, causing loss of clay particles. Clay content in the 10–20 cm layer under heavy grazing decreased by 27.8% compared to light grazing, weakening the protective effect of clay on organic carbon and contributing to soil organic carbon loss.

The effects of grazing on soil total nitrogen vary among studies, with some reporting no effect, others showing increases, and still others demonstrating decreases with grazing intensity. In this study, soil total nitrogen decreased gradually with grazing intensity, primarily due to reduced soil organic carbon. As grazing intensity increased, reduced litter input limited microbial activity, decreasing the formation of large aggregates and causing them to disintegrate into smaller fractions. Livestock trampling compacted soils, increased bulk density, and reduced porosity, creating anaerobic conditions that inhibited aerobic microbial activity and slowed organic carbon decomposition. The elevated C/N ratio of aggregates under heavy grazing reflects reduced quality of soil organic matter and limited nutrient release, potentially causing plant nutrient deficiency.

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#### 4. Conclusion

- 1) Increased grazing intensity in desert shrub grasslands elevates soil bulk density and reduces soil organic carbon and total nitrogen contents.
  - 2) Grazing intensity increase damages soil aggregate structure and reduces stability, causing a shift from large-diameter to small-diameter aggregates. Heavy grazing elevates the C/N ratio of soil aggregates, hindering mineralization and nutrient release processes, which can lead to plant nutrient deficiency.
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