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# MORPHOLOGICAL CHARACTERISTICS AND BIOMASS ALLOCATION OF *LEYMUS CHINENSIS* (*POACEAE*) (TRIN.) RESPONSES TO LONG-TERM OVERGRAZING IN AGRO-PASTORAL ECOTONE OF NORTHERN CHINA

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## ABSTRCT

Overgrazing is the determinant factor to cause degradation and desertification of grazed grasslands in China. *Leymus chinensis* (*Poaceae*) (Trin.), the dominant grass in grassland of northern China, may exhibit distinctively strategies to survive under long-term overgrazing condition. In this study, we quantified its changes of morphological plasticity, biomass and biomass allocations when the long-term overgrazing activity was removed. A grazing-free plot and an overgrazed plot (without overgrazing stress during the experimental year) were established in the study area. Six quadrats were randomly selected in each plot for measurements. Results showed that when long-term overgrazing stress was removed, the number of vegetative shoot restored to normal level, while the plant height, leaf number, leaf length and breadth, reproductive shoot number, and biomass were still at a lower level. And the biomass allocation patterns differed significantly ($P<0.05$) between tested treatments. After long-term overgrazing activity, *L. chinensis* allocated more biomass of total biomass to below-ground, less biomass of above-ground to reproductive shoots compared to *L. chinensis* under grazing-free condition. These modified morphological characteristics and biomass allocations were adaptive strategies of *L. chinensis* induced by overgrazing, and rapid recovery of vegetative shoot number was an occupational strategy of *L. chinensis* to restore.

**Key words:** *Leymus chinensis,* overgrazing, morphological characteristics, biomass, biomass allocations, restore.

## INTRODUCTION

The degradation and desertification in grasslands have increased considerably in recent decade years (Zhu, 2004). Overgrazing by herbivores is generally recognized as a major ecological factor to cause these results (Cui *et al*., 2005; Katoh *et al*., 1998). Exposed to such unstable ecosystems, plants may exhibit distinctive strategies to cope with the environmental heterogeneity as reflected in individual phenotypic plasticity (Kobayashi *et al*., 2001), especially in morphological plasticity (Garman and Briske, 1985) and biomass allocation (Li *et al*., 2005). These changes included less biomass, lower plant height, smaller leaves and shorter internode length (Wang *et al*., 2000; Makhabu *et al*., 2006). All these changes help plant to survive under adverse environment (Kobayashi *et al*., 1999). Therefore, we hypothesized that the morphological plasticity and changes of biomass allocation of *Leymus chinensis* may reveal its responding mechanisms induced by long-term overgrazing activity.

However, little study has been conducted to quantify these changes on morphological characteristics and biomass allocation after long-term overgrazing activity. Since a concept of biomass allocation has been introduced (Harper and Ogden, 1970), biomass allocation of plants has become a popular means to study relationships among different organs, and to clarify the adaptation strategies of plants under varied and unstable environments. For example, the deficiencies of essential macronutrients (nitrogen, phosphorus, potassium and magnesium) result in an accumulation of carbohydrates in leaves and roots, and modify the shoot-to-root biomass ratio (Hermans *et al*., 2006). Similarly, plants grown in overgrazing condition have to utilize the limited resources efficiently to maintain its population. The question remains as how plants strike a balance or maximize fitness between growth and reproduction, above-and belowground biomass allocation patterns.

*Leymus chinensis*, a perennial species of the family Poaceae, is a dominated species in steppe grassland of Northern China, Mongolia and Siberia (Wang *et al*., 2004). This species is typically clone planted, relying on tilling and seed for regeneration (Yang and Li, 1994), and has an ability to tolerate drought, cold and alkali stresses (Shi and Wang, 2005). Due to its superior quantity and quality, especially the high palatability, *L. chinensis* becomes one of the most popular grasses for livestock. Understanding its responses of morphological characteristics and biomass allocation to overgrazing activity is important for its grassland management and restoration. Therefore, our objectives were to determine three questions: 1. Are there variation of morphological characteristics and growth between overgrazing (when the overgrazing activity was removed) and grazing-free *L. chinensis*? 2. Does biomass allocation of above-and belowground change? 3. How does plant trade-off between growth and reproduction?

## MATERIALS AND METHODS

**Site Description:** The study was conducted at the National Field Station for Grassland Ecosystem of China Agricultural University, Guyuan County, Hebei Province, China (41°44'N, 140°16'E). This area is an agro-pastoral ecotone of Northern China located in the southeast corner of Inner Mongolia steppe, where the elevation is 1,300-1,400m. Mean annual air temperature is about 1℃, varying from -18.6℃ in January to 17.6℃ in July. Annual precipitation ranges from 160 to 530mm, falling mainly during the summer monsoon. Average precipitation is 380 mm, of which 79% fell in June, July, and August. The soil type is chestnut (Chinese Soil Taxonomy) or calciustepts (US Soil Taxonomy). The typical vegetation is temperate semiarid grassland composed of *Leymus chinensis* (Poaceae) (Trin), which is the dominant species; *short subulated barley* (Hordeum brevisubulatum) and *Thermopsis lanceolata* (Thermopsis lanceolata R. Br.) which are main auxiliary species, along with miscellaneous class grass: *silverweed clinquefoil* (Potentilla anserine L.), *longleaf halerpestes* (Halerpestes ruthenica). In the farmlands, farmers grow crops of *naked oat* (Avena nuda), *benne* (Sesamum indicum), *corn* (Zea mays) and some other vegetables.

**Experiment Design:** A grazing-free pasture and overgrazing pasture were selected for this study. The grazing-free plot from grazing-free pasture was located in the fenced pasture, which has been established without grazing since 1997, and was mowed annually in late-August. The overgrazing plot was selected from the pasture which has been continuously grazed more than 30 years and showed severe degradation. We referred this pasture to overgrazing pasture. It was not grazed during experimental periods. Both plots never experienced agronomic measures, such as fertilization, ploughing and irrigation. Six 1×1m quadrats were randomly selected within corresponding plot. The plant with in quadrats was harvested in mid-august when the seeds were set.

**Sampling Procedure and Measurements:** In each quadrat, vegetative shoot density and reproductive shoot density were measured respectively. Twenty plants were randomly selected and tagged for following measurements: vegetative shoot height (vertical height), reproductive shoot height (vertical height), leaf number, leaf length (not including leaf sheath) and leaf breadth (measured at the widest of leaf). The top third leaf was selected for measuring leaf length and breadth. The plant materials of a 0.25×0.25×0.30m clod in each quadrat were obtained to measure biomass. Above-ground plant materials cut from soil surface were separated into vegetative shoot and reproductive shoot separately, and placed in perforated paper bag. Below-ground plant biomass (soil-free roots) was obtained by rinsing off attached soil though a 0.5-mm sieve using a fine water spray with gentle shaking sieve. All the biomass samples were oven-dried at 65℃to constant weight, and weighed accurately to 0.1g. Then growth indices and biomass allocation parameters were derived.

**Statistical Analysis:** Effects of overgrazing pressure on morphological plasticity, biomass production and biomass allocation were analyzed out using T Test. All analyses were conducted with statistical software SPSS ver.11.5 (SPSS Inc., Chicago, IL, USA) using T Test and differences were considered significant at $p<0.05$. Data was presented as mean ± SE. The plant height, leaf traits, biomass and the pattern of biomass allocation were diagrammed with Sigma Plot 10.0.

## RESULTS AND DISCUSSION

**Morphological Characteristics:** Analysis showed that there were significant differences in morphological characteristics between of *L. chinensis* between grazing-free and overgrazing treatment, indicating that a response of morphological characteristics induced by overgrazing.

Morphological characteristics studies of clonal plants have indicated responses to the habitat quality by changing spacer length and intensity (Wang *et al*., 2008). In our experiment, overgrazing activity dwarfed *L. chinensis* compared with *L. chinensis* under grazing-free condition. The plant height of *L. chinensis* sharply decreased after experiencing long-term overgrazing activity (fig.1). The vegetative shoot and reproductive shoot height of *L. chinensis* after long-term overgrazing activity decreased about 42.70% and 29.59% respectively, which differed significantly compared to that of *L. chinensis* under grazing-free condition ($p<0.05$). These results illustrated that the plant height could not return to normal level immediately after removing long-term overgrazing stress. At the same time, a decrease in plant height including the height of vegetative shoot and reproductive shoot under long-term overgrazing after removing overgrazing activity represented an adaptive strategy induced and selected by long-term overgrazing activity. Reducing plant height could relieve the grazing risk from herbivores (Sternberg *et al*., 2000). Moreover, small formed individuals reduced grazing damage by exhibiting significantly higher survival and a lower grazing rate than large formed individuals (Suzuki, 2008).

The densities of vegetative and reproductive shoot changed differently after experiencing long-term overgrazing activity (tab.1). Reproductive shoot number of *L. chinensis* after long-term overgrazing activity was significantly lower than that of *L. chinensis* under grazing-free condition ($p<0.05$). However, vegetative shoot number did not show significant difference between tested treatments ($p>0.05$), which indicated that the number of vegetative shoot returned to a normal level after removing grazing pressure, reflecting that the reduction of vertical elongation would make up for the horizontal growth to some extent (Tanner and Bellingham, 2006). This finding was not consistent with results reported by Wang, who observed that grazing activity declined the densities of vegetative shoot. This difference was likely because our research was conducted after removing grazing activity (Wang, 2004). These results indicated that rapid recovery of vegetative shoot number was an occupational strategy of *L. chinensis* to restore.

The leaf traits were significant differences between tested treatments ($p<0.05$), as shown in both table 1 and figure 2. Long-term overgrazing activity resulted in leaf number decreased. Leaf number of *L. chinensis* under grazing-free condition was significantly higher than that of ones after long-term overgrazing activity, 5.31 vs. 4.23 ($p<0.05$). Moreover, the *L. chinensis* leaf length after long-term overgrazing activity was about only one-third of the length of ones under grazing-free condition. Specifically, the leaf length and breadth of *L. chinensis* after long-term overgrazing activity became shorter and smaller, and were significant differences compared with that of *L. chinensis* under grazing-free condition ($p<0.05$). Less and smaller leaves may mean a protection measure of plant shown in our study, because herbivores prefer to eat palatable leaves rather than the other organs. However, leaves were the most important photosynthetic organs of plants, all of these data indicated that after long-term overgrazing activity, *L. chinensis* had a less photosynthetic organ, which would lead to less photosynthetic products inevitably, and finally affected the growth of plant.

**Biomass and Biomass Allocation:** Biomass and biomass allocation patterns are the critical indices of individual plant phenotypic plasticity in repeated defoliated environment (Li et al., 2005). Less and smaller leaves cause the decrease of carbon accumulation and the delivery of carbon compounds from shoots to roots, as well as the transport of biomass from above- to below-ground (Wang, 2004). As shown in figure 3, biomass decline was a remarkable feature of *L. chinensis* after long-term overgrazing activity. Generally, after removal of long-term overgrazing, there was still a significant ($p<0.05$) negative effect on *L. chinensis* biomass, of both whole quadrat and individual plant. The total biomass of *L. chinensis* after long-term overgrazing activity was about one third lower than that of ones under grazing-free condition, and the difference was significant ($p<0.05$). To this trend, above-ground biomass contributed more than below-ground biomass. Above-ground biomass of *L. chinensis* under grazing-free condition was two-fold greater than that of ones after long-term overgrazing activity ($p<0.05$). Below-ground biomass was also significantly different between tested treatments ($p<0.05$), though the difference was not as great as that of above-ground biomass. Vegetative and reproductive biomass were two important aspects of above-ground biomass, and differences of vegetative biomass and reproductive biomass between tested treatments were consistent with total above-ground biomass. Our data indicated that there was a reduction not only in the total biomass, but also in the biomass of each part associated with less and smaller leaves after long-term overgrazing. Long-term overgrazing activity induced a reduced plant biomass, most of which was photosynthetic organ, accompanied with carbon accumulation decreasing. After within such long-term defoliated environment, it is very important for plants to distribute the limited resources efficiently to different functional organs, in order to guarantee maintenance of normal growth (Li *et al*., 2010). Above- and belowground biomass allocation is a central issue in plant ecology (Yang *et al*., 2009), while vegetative and reproductive growth are the main process of plant life history (Vilela *et al*., 2008; Worley and Harder, 1996). Plants were supposed to trade-off in ways for maximizing fitness under environmental stress. In this study, there were differences on biomass allocations of *L. chinensis* between overgrazing and grazing-free treatments (fig.4), indicating that overgrazing affected biomass allocations. The ratio of below-ground biomass to total biomass in *L. chinensis* after long-term overgrazing activity was 0.81, which was significantly greater than that in grazing-free treatment ($p<0.05$). These results indicated that *L. chinensis* after long-term overgrazing activity distributed the most of limited resources to roots. It caused less biomass to be allocated to the above-ground part compared to *L. chinensis* grown in grazing-free condition, 18.73% vs. 31.49%. These parameters of biomass allocation showed that *L. chinensis* after long-term overgrazing activity had a greater allocation to below-ground biomass than *L. chinensis* under grazing-free condition. Previous reports demonstrated that clipping, a behavior similar to grazing, caused an increased root weight fraction (Li *et al*., 2004), higher biomass allocation to rhizomes indicating a strategy which may help plants uptake water and nutrients (Li *et al*., 2010), and furthermore store more material for growth and reproduction during the next growing season (Wang *et al*., 2001), which would do help to restoration. With the increasing probability of a frequent or large loss, plants would store more resources to support future growth (Dafni *et al*., 1981). Therefore, an adjustment ratio of below-ground will benefit for *L.*

*chinensis* after long-term overgrazing activity restoring to normal level.

**Table 1 The vegetative shoot, reproductive shoot and leaf number of *L. chinense* grown in grazing-free and long-term overgrazing (when the overgrazing activity was removed) condition. Different letters in the same item mean significant difference (P<0.05).**

| Treatment | Item | | |
|---|---|---|---|
| | Vegetative shoot number | Reproductive shoot number | Leaf number |
| Grazing-free | 411.33±17.25a | 51.67±1.52a | 5.31±0.079a |
| Long-term overgrazing | 409.67±11.04a | 25±0.58b | 4.23±0.071b |

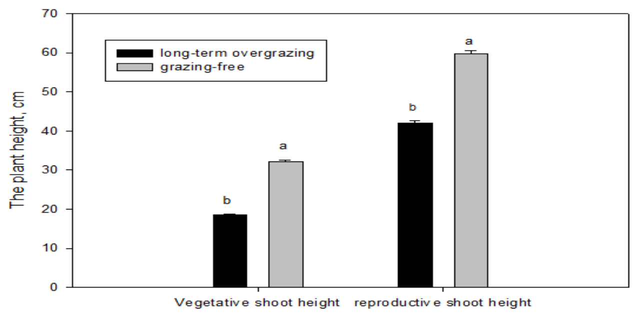


**Figure 1 The plant height of *L. chinense* grown in grazing-free and long-term overgrazing (when the overgrazing activity was removed) condition. Different letters in the same item mean significant difference (P<0.05).**

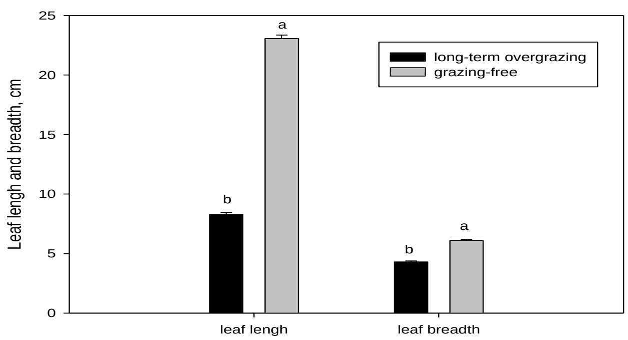


**Figure 2 The leaf traits of *L. chinense* grown in grazing-free and long-term overgrazing (when the overgrazing activity was removed) condition. Leaf breadth presented in the figure is 10 times of its actual value. Different letters in the same item mean significant difference (P<0.05).**

How plants distribute biomass to vegetative and reproductive parts can reflect vegetative and reproductive growth in a sense, as it denotes a strategy of plants to adversely environmental conditions. Contrast to *L. chinensis* under grazing-free condition, *L. chinensis* after long-term overgrazing activity allocated less biomass to above-ground organs, accordingly, it is critical for *L. chinensis* after long-term overgrazing activity to trade-off between vegetative and reproductive growth with the limited above-ground biomass. Vegetative and reproductive biomass of *L. chinensis* after long-term overgrazing activity changed significantly (P<0.05) compared to that of *L. chinensis* under grazing-free condition, so did the ratio of vegetative biomass to reproductive biomass (P<0.05). The proportion of vegetative biomass to above-ground biomass was 90.03% in the *L. chinensis* after long-term overgrazing activity, which was higher than that in *L. chinensis* under grazing-free condition, whereas, the proportion of reproductive biomass in *L. chinensis* under grazing-free condition was higher than that in *L. chinensis* after long-term overgrazing activity. These data suggested that after long-term overgrazing stress, less biomass was allocated to reproductive shoots in *L. chinensis*. Such biomass allocation patterns were also observed in other species under adversely environmental conditions (e.g. water shortage, denudation and clipping) (Wang *et al*., 2001; Li *et al*., 2010; Li *et al*., 2004). Reducing a biomass allocation to reproductive shoots was likely a strategy for plants to survive in an adverse environment. On the other hand, increased ratio of vegetative biomass maintained the growth of increased vegetative shoot.

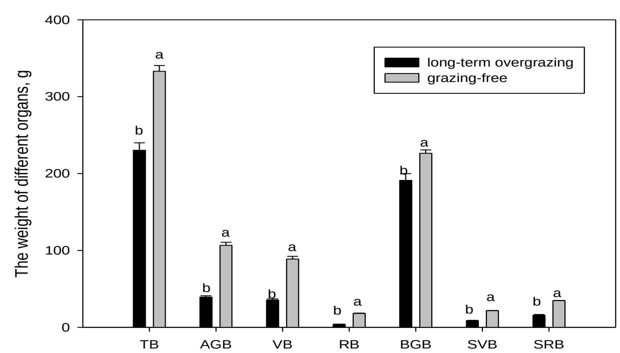


**Figure 3 The biomass of *L. chinense* grown in grazing-free and long-term overgrazing (when the overgrazing activity was removed) condition. SVB and SRB presented in the figure are 10 times of their actual value. Different letters in the same item mean significant difference (P<0.05). TB: total biomass; AGB: above-ground biomass; VB: vegetative shoot biomass; RB: reproductive shoot biomass; BGB: below-ground biomass; SVB: single vegetative shoot biomass; SRB: single reproductive shoot biomass.**

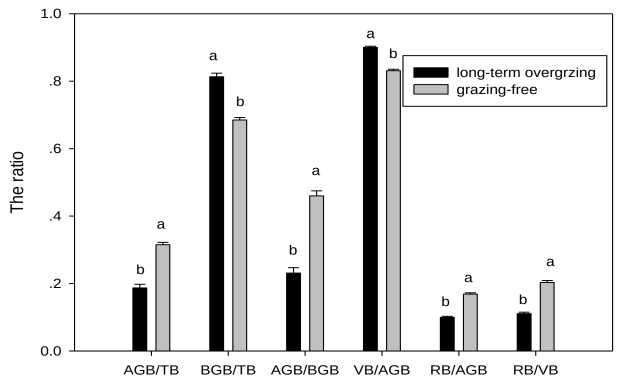


**Figure 4 The biomass allocations of *L. chinense* grown in grazing-free and long-term overgrazing (when the overgrazing activity was removed) condition. chinense. Different letters in the same item mean significant difference (P<0.05). TB: total biomass; AGB: above-ground biomass; VB: vegetative shoot biomass; RB: reproductive shoot biomass; BGB: below-ground biomass; SVB: single vegetative shoot biomass; SRB: single reproductive shoot biomass.**

**Conclusions:** This study demonstrated how *L. chinensis* changed after removal of long-term overgrazing activity, in which illustrated that the *L. chinensis* after long-term overgrazing activity, exhibited particular biomass allocation patterns and morphological characteristics. Although the negative effects of overgrazing on plants are inevitable, they may invoke plants adaptive plasticity to help escape or reduce such adversity of these unfavorable environmental conditions so that they can survive and restore to normal when the stress was removed. After removal of long-term overgrazing activity, rapid recovery of vegetative shoot number was an occupational strategy of *Leymus chinensis* to restore. However, plant height, reproductive shoots number, leaves number and area, can not restore to normal immediately, a dwarf performance existed.

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