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Response of Plant Diversity and Biomass on Different Defoliation in Songnen Grassland, China

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Abstract: A defoliation experiment was conducted on a *Leymus chinensis*-dominated steppe to provide guidelines of grazing management and restoration of degraded grasslands. There were five defoliation treatments: CK (non-defoliation as control); LD (Light Defoliation, cut 12 cm aboveground level); MD (Medium Defoliation, 8 cm); HD (Hard Defoliation, 4 cm) and SD (Severe Defoliation, 2 cm). Results showed that HD and SD defoliation significantly decreased the belowground biomass. Defoliation increased plant species diversity but decreased biomass of *L. chinensis* significantly. The biomass of *L. chinensis* under LD was lower than that in control indicating *L. chinensis* was highly sensitive to defoliation. It is necessary in this area that grazing should be restricted to a level of light defoliation to prevent loss of plant productivity.

Key words: *Leymus chinensis*, degraded grasslands, defoliation, Northeast, biomass

INTRODUCTION

Grasslands dominated by *L. chinensis* are widely distributed at the Eastern end of the Eurasian steppe from North Korea Westward to Mongolia and Northern China and North-Westward to Siberia (Yin *et al*., 1993; Xiao *et al*., 1995). However, during the past 50 years, Songnen grassland in these areas were widely converted to cropland while livestock numbers increased significantly and caused severe over-grazing problems (Han *et al*., 2008). As a result, these areas are subject to bad environmental problems such as soil erosion, grassland deterioration, desertification and dust storms (Ta *et al*., 2006; Li *et al*., 2008). Consequently, it is of consequence to comprehend the responses of grasslands to over-grazing (defoliation) in order to improve their management.

In defoliation management, the theory of moderate disturbance revealed that intermediate grazing intensity maintains high levels of diversity in grassland communities (Dickson and Foster, 2008). It also revealed the adaptive disturbance inflects the competitive relationship between plants and maintains the heterogeneity and botanical diversity of pastures (Hobbs and Huenneke, 1992; Tilman *et al*., 1996). Their studies also indicated that ecosystem productivity increased significantly with plant diversity and plant diversity significantly influenced nutrient use and retention in more-diverse ecosystems compared to less-diverse ecosystems. By contraries, other studies have shown that the species richness of grasslands was negatively correlated with the nutrient richness and plant productivity in some habitats (Bakker *et al*., 2002).

With regard to heavy defoliation, it could influence botanic composition and reduces species richness and diversity indices (Hobbs and Huenneke, 1992; Tilman *et al*., 1996). The study by Zhao *et al*. (2009) showed that the morphological and functional traits of *Leymus chinensis* changed significantly under heavy defoliation over several years. Noy-Meir (1993) reviewed that the net effect of single or repeated grazing events on the cumulative growth of plants might be zero, negative or positive, depending on availability of leaf area, stored nutrients and soil resources and on the intensity of the defoliation. The study by Guitian and Bardgett revealed that defoliation leads to a reduction in root mass and an increase in the allocation of resources to shoots while defoliation of grasses with low tolerance to defoliation had little effect on root mass but increased the relative allocation of resources belowground.

Defoliation changes photosynthetic shoot tissue and modifies the partitioning of assimilates between above and belowground plant organs (Snyder and Williams, 2003) and alters carbon flow through soil microbial communities (Macdonald *et al*., 2006). This might influence the allocation of nutrients among roots and soil chemical properties which inversely influences

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nutrient uptake and plant growth. A study by McInenly *et al*. (2010) showed that defoliation slowed elongation and decreased production of new roots thus reduced root biomass of *Leymus chinensis*. However, the effects of defoliation on belowground parts of Songnen grassland in Northeast China have been less explored in field studies.

In this study, researchers investigated the responses of earlier and belowground plant parts to defoliation intensities over 3 years of consecutive defoliation on a *L. chinensis* steppe in Northeast China. Researchers hypothesized that the reduction in aboveground biomass of *L. chinensis* induced by defoliation would be associated with a reduction in rhizome biomass.

MATERIALS AND METHODS

Study site: The field experiment was carried out at the Frigid Forage Research Station located at Lanxi county, run by Heilongjiang Academy of Agricultural Sciences (HASS). The station has an altitude of 160 m, longitude of 125°58', 46°32'N in Northeast China. The climate is classifed as a typical chillness semiwetness monsoon environment. Based on data from 1988 through 2008, the total yearly sunshine duration is 2713 h and the no frost period is 130 days. The annual mean air temperature is 5.3°C with a maximum temperature of 31.2°C (July) and a minimum temperature of -25.2°C (January). The annual mean accumulated heat units (above 10°C) is 2.760°C. The annual mean precipitation is 469.7 mm of which about 75% falls from June to August and the average annual free water evaporation is about 950 mm (Fig. 1). The soil is dark loam (mostly Chernozem, FAO Taxonomy) with high melanic humus. The site was a semi-arid steppe dominated by *L. chinensis* Tzvel with other minor species including *Lathyrus sativus* L., parapholis, *Phragmites australis* (Cav.) Trin. ex Steud, *Potentilla aiscolor* Bunge, Herba Senecionis Scandentis, *Potentilla bifurca* Linnaeus, *Hemerocallis citrina* Baroni, *Serratula coronata* L., *Plantago asiatica* L. The growing season was usually from late April to early October. Vegetation cover ranged from 60-96%. Prior to the experiment, the site was fenced-off from livestock from 2002 but hay was cut once a year in September until 2007. No further grassland improving measures were taken during 2002 to 2007. Treatments were imposed during the growing season (June to September) in 2008 to 2011.

Experimental design: There were five defoliation treatments with four replicates in a randomized block design: CK (non-defoliation as control); LD (Light Defoliation, cut 12 cm aboveground level); MD (Medium Defoliation, 8 cm); HD (Hard Defoliation, 4 cm) and SD (Severe Defoliation, 2 cm). Each treatment was cut whenever the average plant height was 5 cm earlier the designated height during growing season except for the control treatment which was cut once only when growing season was finished. Over the 3 years, on average the pastures were defoliated 10, 8, 6, 4 and 1 times for severe, hard, medium, light and control treatments, respectively. The plot size was 10×5 m with a 1.5 m buffer between the plots.

Measurements: The measurements started from the second year after treatments were imposed. In 2009 and 2010 and once in July 2011, the Aboveground Biomass (AGB) increment was measured using exclusion cages. At the start of each month, six quadrats (0.25 m^2) were randomly selected in each plot in which three quadrats were cut as the initial biomass and the other three

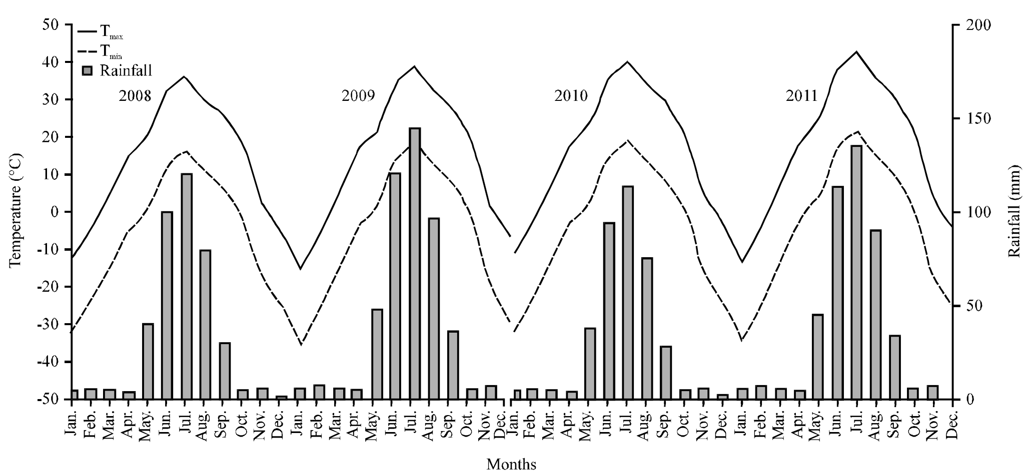

Fig. 1: Monthly maximum and minimum temperatures and total rainfall for 2008 and 2011 at Suihua, China

quadrats which were put under cages were excluded from defoliation for 1 month. At the end of the month, the biomass from those three quadrats under cages was measured as the final biomass. The difference between two measurements was the aboveground biomass increment during that month. The exclusion cages were relocated each month. All quadrats were cut at the ground level and the pasture samples were dried at 75°C for 48 h. Sub-samples were taken and hand sorted into species. In 2011, the aboveground biomass was measured once in July with no defoliation prior to the aboveground measurements for all treatments. The Belowground Biomass (BGB) was measured in July 2011 when the above ground biomass was measured. Three sods (20×20 cm) were dug out at two soil depths (0-15 and 15-30 cm) in each plot and were bulked into one composite sample. Roots were washed free from soil using tap water.

The plant species diversity indices were measured in July 2010 and 2011. The number of plant species and plant density of each species in each plot was counted to calculate the richness index (Margalef, Ma) a biodiversity index (Simpson, D and Shannon, H') and an evenness index (Pielou, J') using the following equations:

$$Ma = \frac{S-1}{InN}$$

$$D_i = 1-\Sigma P_i 2$$

$$H' = -\Sigma P_i lnP_i$$

$$J' = \frac{H'}{lnS}$$

Where:

S = The number of species
N = The sum of the number of all plant species
D_i = Plant density of certain species
ΣD_i = The sum of the plant density of all species
P_i = The relative plant density of the i species ($P_i = D_i/\Sigma D_i$)

Data analysis: All results are reported as means±standard deviations. The Least Significant Difference (LSD) test was used to compare the means of AGB, plant species diversity indices and soil chemical properties of different defoliation intensities at p≤0.05. All statistical analyses were conducted by using SPSS 17.0.

RESULTS

Aboveground biomass dynamics: There were significant interactions between defoliation intensity and year on total biomass increments of the plant community and *L. chinensis* (p<0.001, Table 1). The difference between defoliation intensities (CK, LD, MD, HD and SD) was always significant (p<0.001, Table 1). However, there was a consistent and generally strong, interaction between year on total biomass increments of *L. chinensis* (p<0.001, Table 1) and a weak significant in total biomass increments of the plant community (p<0.05, Table 1). In all cases, the difference in biomass increments of the plant community and *L. chinensis* between defoliation intensities increased as the season progressed: this was most pronounced in the Aug. 2009 (Biomass increments of the plant community and *L. chinensis* was 815.5 and 522.1 g/m^2, respectively) and in the Sep. 2010 (Biomass increments of the plant community and *L. chinensis* was 772.2 and 363.5 g/m^2, respectively) when all defoliation intensities were included in the analysis. In 2009, the monthly aboveground biomass increment for both plant community and *L. chinensis* decreased with increasing defoliation intensities. In 2010, a similar trend was found for *L. chinensis* with the exception that plant community biomass varied between treatments. Overall, the biomass of community of the SD treatment was the highest and the MD the lowest (Fig. 2) in 2010. *L. chinensis* accounted for the greatest proportion of the community biomass, especially in the LD treatments (Fig. 3). The proportion of *L. chinensis* decreased from 91.2-63.8% for the Ck treatment to 33.5 and 26.5% for the SD treatment in 2009 and 2010, respectively. Therefor, the total aboveground biomass increment was higher in 2009 than 2010 for treatments with CK and LD but lower for treatments with HD and S (Fig. 2 and 3).

Plant species diversity: There were significant between defoliation intensity on plant community diversity indices (p<0.05, Fig. 4). In general, the plant diversity indices

Table 1: Analysis of variance in repeated measures for total aboveground biomass and plant diversity indices

	Sum of aboveground biomass		Species diversity indices			
Model terms	Community	*L. chinensis*	D	H'	J'	Ma
Defoliation (D)	***	***	***	***	***	***
Year (Y)	*	***	***	***	***	**
Defoliation (D) x Year (Y)	***	***	NS	*	NS	*

***p<0.001; **p<0.01; *p<0.05; NS: Not Significant; D and H': Biodiversity indices (Simpson and Shannon); J': Evenness index (Pielou); Ma: Richness index (Margalef)

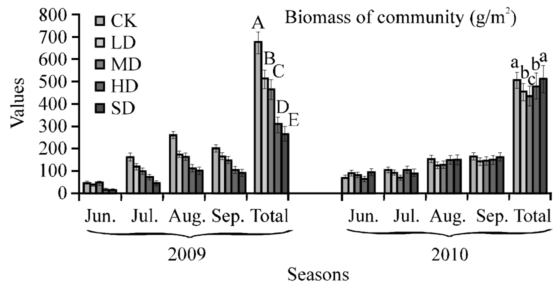

Fig. 2: Average values for total community biomass increment under different defoliation intensities in each month during the growing season in 2009 and 2010. CK (non-defoliation as control); LD (Light Defoliation, cut 12 cm above ground level); MD (Medium Defoliation, 8 cm); HD (Hard Defoliation, 4 cm) and SD (Severe Defoliation, 2 cm). T bars represent SEM for 5 treatment combinations

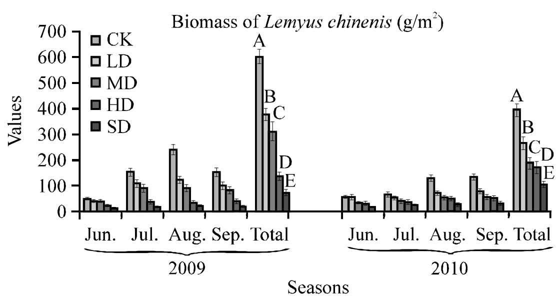

Fig. 3: Average values for total *L. chinensis* biomass increment under different defoliation intensities in each month during the growing season in 2009 and 2010. CK (non-defoliation as control); LD (Light Defoliation, cut 12 cm above ground level); MD (Medium Defoliation, 8 cm); HD (Hard Defoliation, 4 cm) and SD (Severe Defoliation, 2 cm). T bars represent SEM for 5 treatment combinations

increased with increasing defoliation intensities for 2010 and a weak significant for 2011 except for Shannon (H') indices. Overall, the lowest indices were observed in the CK and LD treatments and the highest observed in the SD treatment (p<0.05, Fig. 4).

Plant biomass: The below and aboveground biomass of the CK and LD treatments was significantly higher compared to the HD and SD treatments (p<0.05). The total root biomass decreased with decreasing defoliation intensities and the lowest indices were observed in the SD treatments (Fig. 5) but the ratio of below and aboveground biomass decreased with increasing defoliation intensities, ranging from 0.9 (SD) to 1.6 (CK).

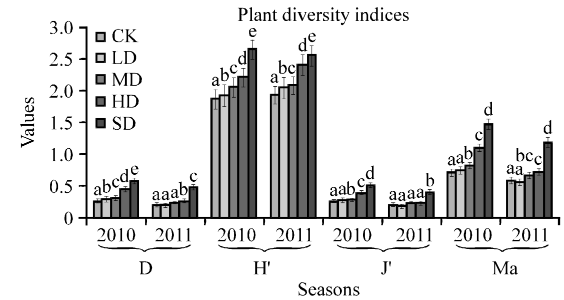

Fig. 4: Average values for plant community diversity indices under different defoliation intensities during the growing season in 2010 and 2011. CK (non-defoliation as control); LD (Light Defoliation, cut 12 cm aboveground level); MD (Medium Defoliation, 8 cm); HD (Hard Defoliation, 4 cm) and SD (Severe Defoliation, 2 cm). T bars represent SEM for 5 treatment combinations

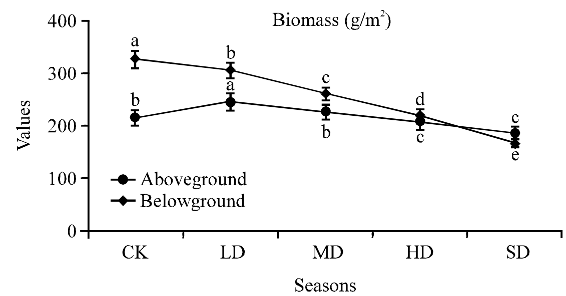

Fig. 5: Average values for above and belowground biomass under different defoliation intensities during the growing season in 2010 and 2011. CK (non-defoliation as control); LD (Light Defoliation, cut 12 cm aboveground level); MD (Medium Defoliation, 8 cm); HD (Hard Defoliation, 4 cm) and SD (Severe Defoliation, 2 cm). T bars represent SEM for 5 treatment combinations

DISCUSSION

L. chinensis was one of the most important plant species in typical steppe in northeast China, playing important roles in maintaining high productivity and stability (Renzhong and Ripley, 1997; Han *et al.*, 2010). However, the AGB of *L. chinensis* reduced significantly with increasing defoliation intensities in both 2009 and 2010. The changes of *L. chinensis* biomass with increasing plant diversity indices in this study which were consistent with short-stature plants in the steppe community may have increased the tolerance of plants to defoliation as reported by Schiborra *et al.* (2009). This might explain the insignificant changes of AGB in HD and

SD treatments compared to the CK in 2010. Whereas these changes reduced the proportion of palatable species such as *L. chinensis* which is subject to severe grassland degradation.

The number of plant species was no positive correlation with community biomass as reported by Tilman *et al*. (2006). In this study, the relationship between plant diversity and monthly biomass increment of plant community was unimodal, the relationship between diversity and monthly *L. chinensis* biomass increment was curve (Han *et al*., 2010). The differences observed in the current study might be related to the different environment conditions and spatial scale. Waide *et al*. (1999) reviewed that the relationships between species richness and productivity might be unimodal, positive linear, negative linear or not significant, suggesting that the relationship was scale-dependence. Huston (1997) reported that productivity was determined by the productivity of the most productive species which was well adapted to the environment. Therefore, the most productive species in this study may have influenced the productivity more than other plant species in the plant community.

The BGB significantly decreased with increasing defoliation intensities. Rhizome biomass was significantly lower compared to the non-defoliation treatment at both soil depths. This was consistent with the decrease of AGB of *L. chinensis*. Defoliation reduces the plant leaf area, affecting the energy that is available to develop buds (Chapin III and Slack, 1979) which may explain the growth reduction of rhizome plants such as *L. chinensis*. The changes in AGB and BGB with increasing defoliation intensities indicates that *L. chinensis* was sensitive to heavy defoliation as reported by Li *et al*. (2008).

CONCLUSION

The *L. chinensis* steppe in agro-pastoral transitional zone in Northeast China was sensitive to defoliation and was not adaptive for intensive defoliation. The reduction of AGB of *L. chinensis* after defoliation goes with the reduction of the concentrations of soluble carbohydrates in rhizomes and fibrous roots. It is necessary in this area that grazing should be restricted to a level of light defoliation to prevent loss of plant productivity.

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