African Journal of Biotechnology Vol. 10(12), pp. 2216-2222, 21 March, 2011
Available online at http://www.academicjournals.org/AJB
DOI: 10.5897/AJB10.971

Full Length Research Paper

Effect of mowing and grazing on ramet emergence of *Leymus racemosus* in the inner Mongolia steppe during the spring regreening period

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Accepted 23 February, 2011

The invasive *Leymus racemosus* species is mainly established by ramets (or clonal seedling). A field experiment was conducted in the spring of 2004 to investigate the effects on the surface soil temperature caused by mowing, grazing and grazing exclusion, and the influence of these factors on the ramets emergence characteristics. The primary effect of the treatments was significant changes in soil temperature in the grazing plots due to the mulch cover which was removed by sheep, keeping the daily mean soil temperature above 0°C during the period of the experiment. Grazing had positive impacts on the emergence of ramets, and their final cumulative emergence in the grazing plot significantly increased by 77 and 59% when compared to that in the grazing-exclusion and mowing plots. A linear function model was used to describe the correlation between the cumulative ramets emergence percentage and soil thermal time (θ_T). Variation in θ_T explained 98% of the observed variation in cumulative emergence; there were no significant differences in the soil thermal requirements for final ramets emergence completion for the other treatments. Both mowing and grazing exclusion had a significant effect on the invasive *L. racemosus* species ramets recruitment control.

Key words: Grassland management practices, soil temperature, ramets emergence, *Leymus racemosus.*

INTRODUCTION

Leymus racemosus (Tzvel) is one of the main invasive weed species in the steppe grassland ecosystem disturbed by heavy grazing in northern China. Ramets emergence is the primary cause of their establishment (Huang and Gutterman, 2004; Wang et al., 2004; Yang and Zhang, 2004). This invasive plant displaces valuable species, resulting in degradation of the steppe grassland (Yang et al., 2001; Wang et al., 2009). Extensive research on the *L. racemosus* invasion process has been conducted. Early studies focused on vegetation production, competition strategy for the nutrient and grazing management (Winkler and Schmid, 1995; Zhang et al., 1996; Shiyomi et al., 2005) and ecosystem management (Bai and Li, 2004), most of these studies being conducted in summer. The emergence of the ramets in spring is the first stage of *L. racemosus* survival, and determines the vegetation community establishment (Yang et al., 1999; Ali, 2001). To date, few researchers have investigated the effects of grassland management strategies (mowing, grazing and grazing exclusion) on the ramets dynamics during the steppe spring regreening period.

Soil temperature is the dominant factor influencing both the ramets and seedling emergence (Harper, 1977; Hegarty, 1977); soil temperature is governed by mulches on the soil surface or by other management practices (Awal and Ikeda, 2002; Romo, 2004; Gao et al., 2004). Currently, mowing and grazing are the primary utilization methods in the Inner Mongolia steppe, while grazing exclusion is the crucial measure for grassland conservation and restoration in northern China (Shiyomi et al., 2005; Zhan and Cheng, 2007; Han et al., 2008). There is evidence that mulches covering the steppe grassland are altered by those measures during the spring regreening

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period, leading to significant soil temperature fluctuation (Hou and Romo, 1997; Roman et al., 1999; Romo, 2004). Many investigations have indicated that there is a positive linear relationship between soil temperature and seedling emergence (Roberts and Summerfield, 1987; Wang et al., 2003). Soil temperature dynamics influence such physiological characteristics of seedlings as soluble sugar content and hormonal level, and ultimately determine seedling emergence percentages and emergence times (Qing and Li, 2001). However, information linking ramets emergence and soil temperature under field conditions on the steppe grassland is fairly limited. Thus, functional relationships between ramets emergence and soil temperature were studied in detail to determine what practical methods are needed to improve the steppe grassland by eliminating *L. racemosus* under field conditions. The objectives of this study are to investigate the application of various steppe grassland management practices (mowing, grazing and grazing exclusion, which contribute to change in the soil surface mulches) and associated effects on soil temperature dynamics as well as determine the effects of soil temperature variation on the ramets emergence. We hypothesize that decreasing the temperature of the soil is the critical factor controlling ramets emergence and establishment of the *L. racemosus* plant community.

MATERIALS AND METHODS

Site

The study was conducted in the Grassland Vegetation Restoration and Reconstruction Key Laboratory of China Ministry of Agriculture Experiment Station (41°46′N, 115 40′E, 1,460 m a). The landscape has the physical appearance of typical Inner Mongolian steppes and the natural dominant vegetation species are *Leymus chinensis* and *Stipa krylovii*. The research site is characterized by a continental, semi-arid, monsoonal climate in the temperate zone, with windy and dry winter and spring, and a warm, comparatively rain-rich summer followed by a short, cool autumn. The soil belongs to the chestnut soil group (Chinese classification system) or the calcicorthic aridisol (US soil taxonomy classification system). Annual precipitation ranges from 350 to 450 mm, about 80% of which falls between June and September. According to earlier research, the spring regreening period was defined as that occurring from mid-March to mid-May in the study area (Li and Li, 2001). In the present paper, the study was conducted in the period of 15 March to 25 May, 2004, at the steppe grassland spring regreening stage.

Experiment and treatment design

In the study area, the grassland was slightly degraded under heavy sheep grazing, and the experimental site was enclosed in 2001 to prevent grazing disturbance. In 2003, the *L. racemosus* coverage was 18%, and the main grass species important value (important value = relative coverage + density + biomass) for *L. chinensis*, *S. krylovii*, *Artemisia frigida*, *L. racemosus* and *Elymus dahuricus* were 0.4782, 0.2862, 0.1967, 0.1493, 0.0971, respectively. Within the study site, there were three treatments:

1. T1 grazing exclusion: The experimental plots were enclosed to prevent grazing (where the vegetation canopy coverage was 92.4% and 50 mm thick dead grass litter covered the soil surface).
2. T2 mowing: Grass on the experimental plots were harvested as hay on 12 March, 2004, at 8 cm height (where the vegetation canopy coverage was 82.1% and 20 mm thick dead grass litter covered the soil surface).
3. T3 grazing: Heavy grazing by Mongolian sheep at a rate of 6.7 sheep (50 kg ewe + lamb) per ha, grazing from 9:00 to 15:00 during early spring (15 February to 10 March) (where the vegetation canopy coverage was 31.6%, and nearly no dead grass litter covered the soil surface).

There were three replicates for each treatment. Plot area was 300 × 300 m; distance between plots was 50 m, to minimize the influence of microclimate (e.g. precipitation, air temperature and radiation) and soil conditions.

Measurements

Soil temperature was measured hourly at 15 cm depth (80% of the *L. racemosus* rhizome system is located in the 10 to 20 cm soil layer) by automatic data loggers (model NTC, Seng Eng Scientific Inc., People's Republic of China). Soil temperature data were averaged daily throughout the experimental period. For each experimental plot, one soil temperature probe was randomly placed. Soil thermal time (θ_T degree-days) was calculated according to Garcia- Huidobro et al. (1982):

$$\theta_{T_g} = (T - T_B)t_g$$

Where, T is the mean daily temperature; T_B is the base temperature below which ramets emergence does not occur {for *L. racemosus*, T_B = 0 C (Ma et al., 2008; Liu et al., 2009)}; and t_g is the actual time (days) to ramets emergence of g%.

Ramets emergence (or clonal seedling emergence) were investigated as follows: Taking the center of each experimental plot as the starting point, four lines were drawn, respectively, to the east, south, west and north. Sample quadrats were randomly distributed along each direction. Sampling quadrat size was 1 × 1 m; 10 sampling quadrats were established in each experimental plot. Ramets emergence was monitored at 2-day intervals during the peak periods and 4-day intervals during the non-peak periods. Any ramets that had emerged beyond the soil surface were numbered and identified with colored markers. The ramets emergence percentage was calculated by dividing the number of emerged ramets in each quadrat by the maximum number of ramets that had emerged by the end of the spring regreening period. The studies were terminated when no new ramets were observed for each treatment for seven consecutive days.

Statistical analysis

Plots were randomly assigned to the experimental fields. All data were statistically analyzed by SAS 8.0 software and the different treatments were analyzed by Tukey's least significant difference test at 0.05 probability levels.

RESULTS

Daily precipitation and air temperature

Most of the precipitation occurred in the late spring (Figure 1). The total precipitation in the regreening period

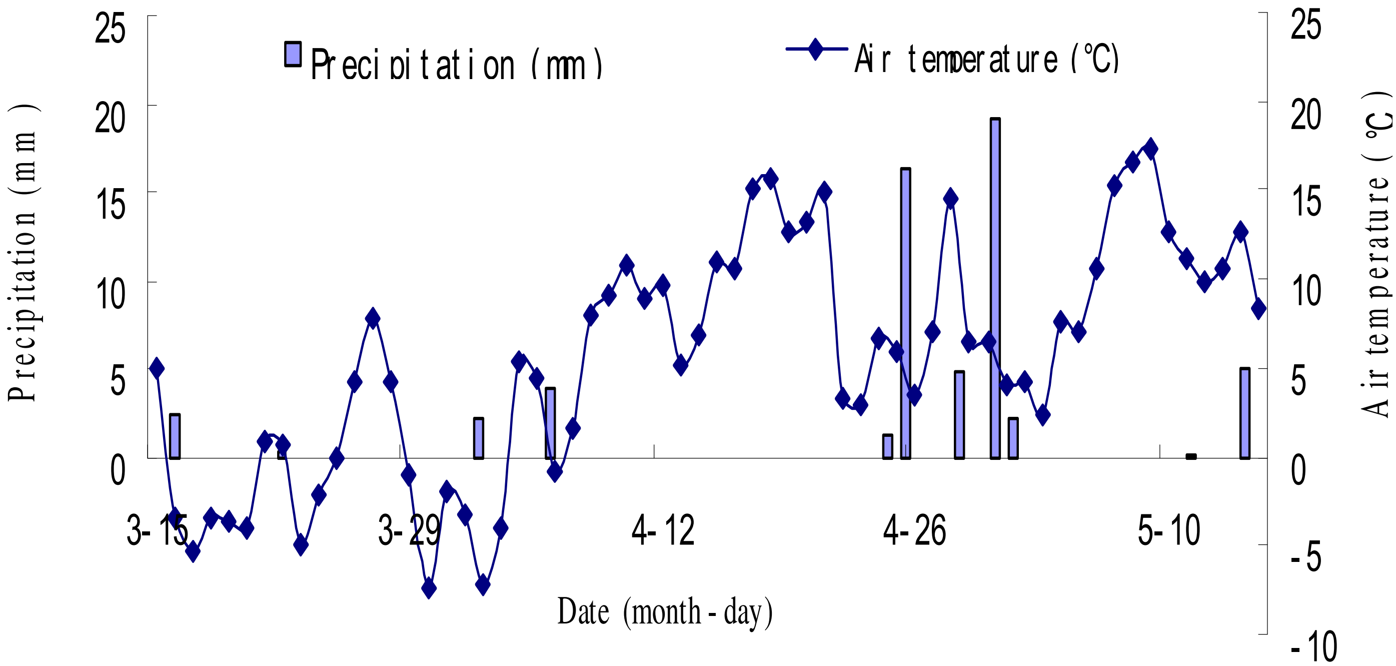

Figure 1. Daily precipitation and air temperature during the Inner Mongolia steppe spring regreening period.

was 57.8 mm. The annual precipitation was 420.6 mm; the precipitation in the steppe spring regreening accounted for 13.7% of this total. Results for the average daily air temperature dynamics showed extraordinary temporally variable characteristics. The minimum air temperature was –7.3℃ in early spring, rising to a maximum of 17.4℃ in late spring. Until early April, the air temperature was consistently above 0℃. Precipitation and temperature fluctuations are the most notable features of the steppe grassland area climate in northern China, particularly in the spring regreening period, which could influence the steppe grassland ecosystem. The unstable environmental factors affect the grass ramets recruitment.

Effect of treatments on soil temperature

Each treatment influenced the vegetation materials covering the grassland, which in turn affected the levels of incident solar radiation on the soil surface, leading to the soil temperature variation shown in Figure 2. For the grazing plot, the above-ground vegetation was removed by sheep and the grassland soil surfaces absorbed the solar radiation directly, contributing to a significant elevation of soil temperature. Throughout the experimental period, the soil temperature in the grazing plot always remained above 0℃. The soil temperature in the grazing exclusion plot did not differ significantly from that in the mowing plot, both of them being clearly lower than in the grazing plot. During the spring regreening period, the soil temperature dynamic in the grazing exclusion and mowing plot increased in a stable manner, following a similar trend to the air temperature.

Ramets emergence dynamics under natural field conditions

The results showed that grazing had positive impacts on the final cumulative ramets emergence of *L. racemosus* during the spring regreening period under field conditions. The maximum cumulative ramets emergence was 329 n.m^{-1} which occurred in the grazing plots; the minimum, occurring in the grazing exclusion plots, was 186 n.m^{-1}. In comparison with the grazing exclusion and mowing plots, the final cumulative ramets emergence in the grazing plot significantly increased by 77 and 59%, while the differences between the grazing exclusion and mowing plots were not significant.

As for the soil temperature effects on ramets emergence of *L. racemosus*, higher soil temperature in the grazing plots promoted the *L. racemosus* ramets emergence, which contributed to the invasive plant community recruitments (Table 1). Moreover, higher soil temperature also accelerated the ramets emergence rate and led to a shortened ramets emergence period in the grazing plots, where the ramets emergence was completed by mid-April, nearly 20 days before the other two treatments.

Significant differences in θ_T were observed for the 50%

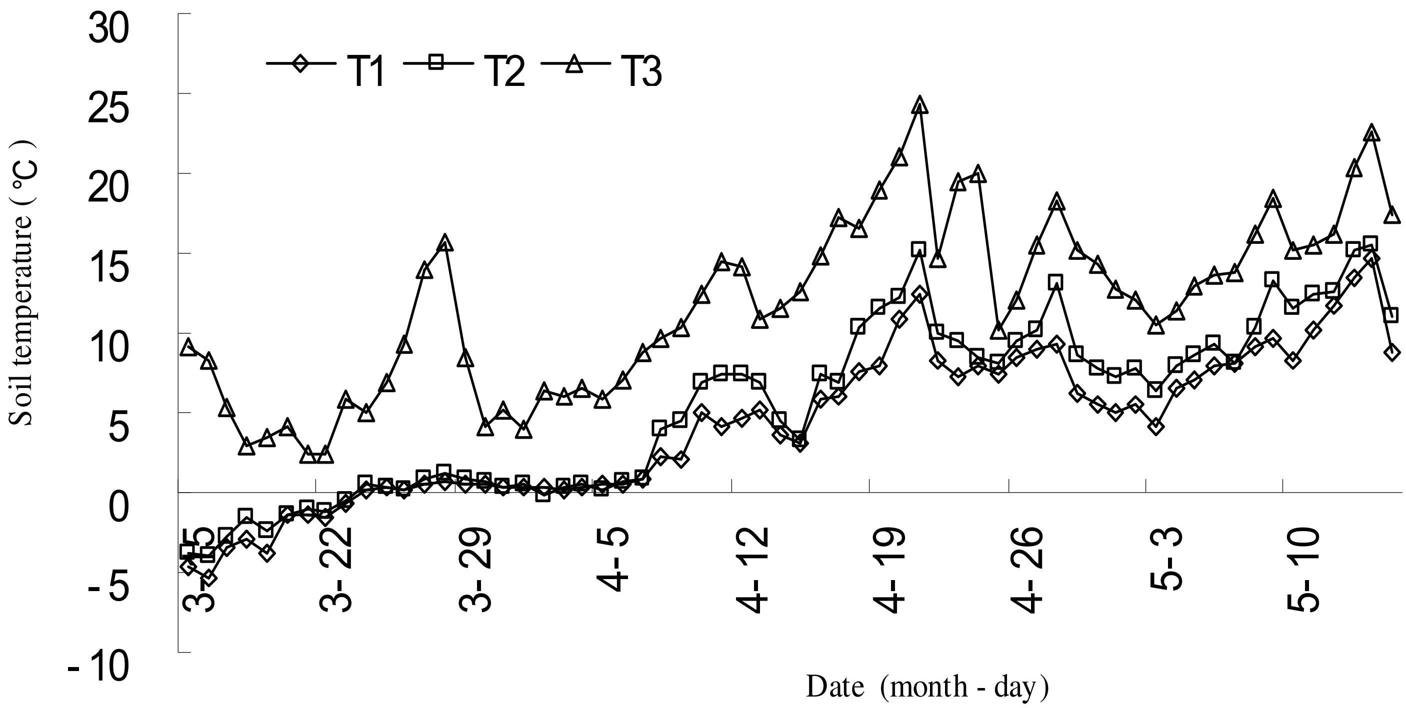

Figure 2. Means daily soil temperature (15 cm depth) during the experiment (T1, grazing exclusion; T2, mowing; T3, grazing).

Table 1. Average soil temperature (15 cm depth), maximum ramets emergence number (n) and ramets emergence days during the experiment period.

Treatment	Average soil temperature (℃)	Maximum ramets emergence number (n)	Ramets emergence days (Initial to competition)
Grazing exclusion (T1)	4.2[b]	186[b]	54[a]
Mowing (T2)	5.5[b]	207[b]	49[a]
Grazing (T3)	11.8[a]	329[a]	33[b]

Values within a column and marked with the same letter are not significantly different (p ≤ 0.05).

cumulative ramets emergence percentage (Figure 3). In comparison, the lowest θ_T occurred in the grazing plots (Figure 3) at 107.3 C.d, and decreased by 50.2 and 71.7% when compared to grazing exclusion and mowing plots (P ≤ 0.05). However, at completion of the final ramets emergence, the θ_T in all of the treatments was about 300 C.d with no significant difference between the treatments. The cumulative ramets emergence percentage E_c was closely correlated to θ_T, and a simple linear formula was derived linking the two terms (Figure 4):

$$E_c = 0.373\ \theta_T - 0.875\ (R^2 = 0.98,\ n = 86)$$

This suggests that, although cumulative ramets emergence values differed between treatments, there was no significant difference in θ_T for the ramets emergence completion, confirming the validity of 0℃ as the best value for T_B.

DISCUSSION

Solar radiation is the main influence on soil temperature and thermal conditions. The soil temperature is therefore strongly periodic in time due to diurnal and annual variations in solar irradiance (Tyson et al., 2001). At the same time, the soil temperature regime influences vegetative growth and the geographical distribution of plants. This paper shows that although the mean air temperature fluctuated greatly throughout the spring regreening period (Figure 2), the soil temperature beneath the surface in the grazing plots remained stable above the zero point. The main reason is thought to be the heavy grazing disturbance which contributed to grass vegetation removal. For the mowing and grazing exclusion plots, the grass vegetation cover shielded the soil from incoming solar radiation. The dead grass mulch on the soil surface may be the primary reason for difference in the soil

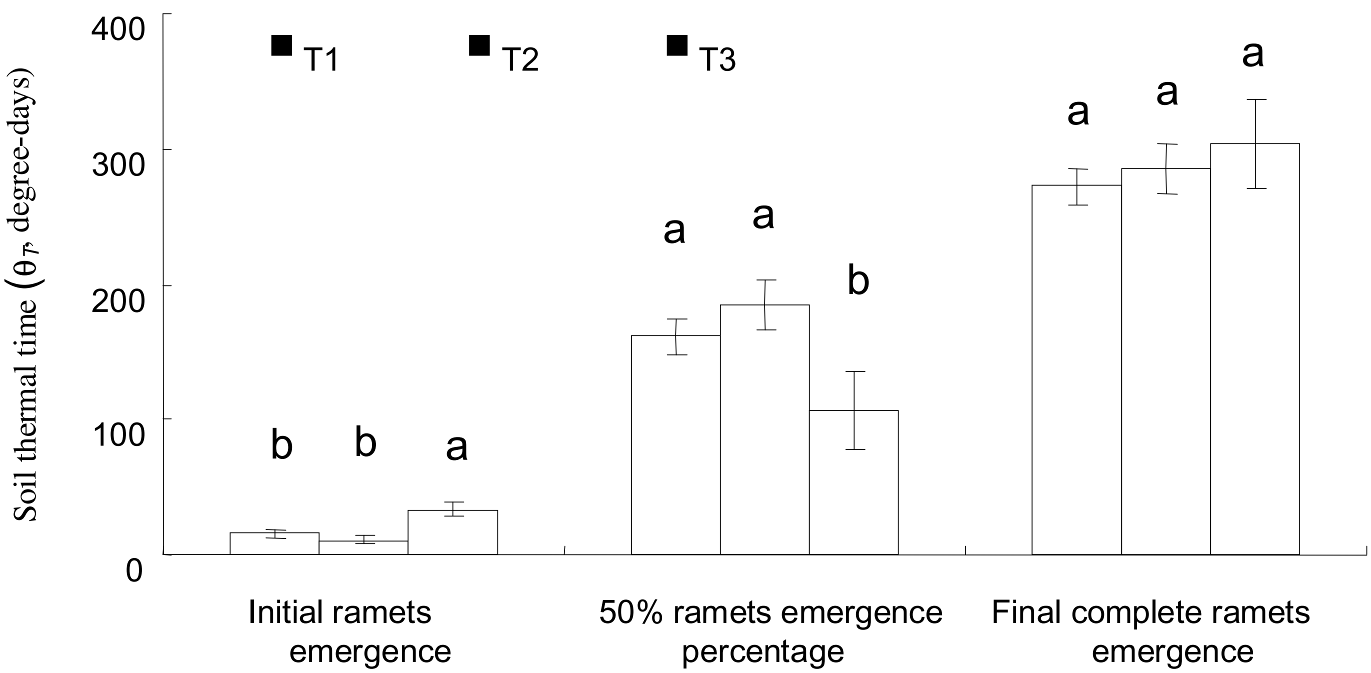

Figure 3. Soil thermal time (θ_T) required for ramets emergence in *L. racemosus* under different treatments (T1, grazing exclusion; T2, mowing; T3, grazing). Values within a column and marked with the same letter are not significantly different ($P \leq 0.05$)

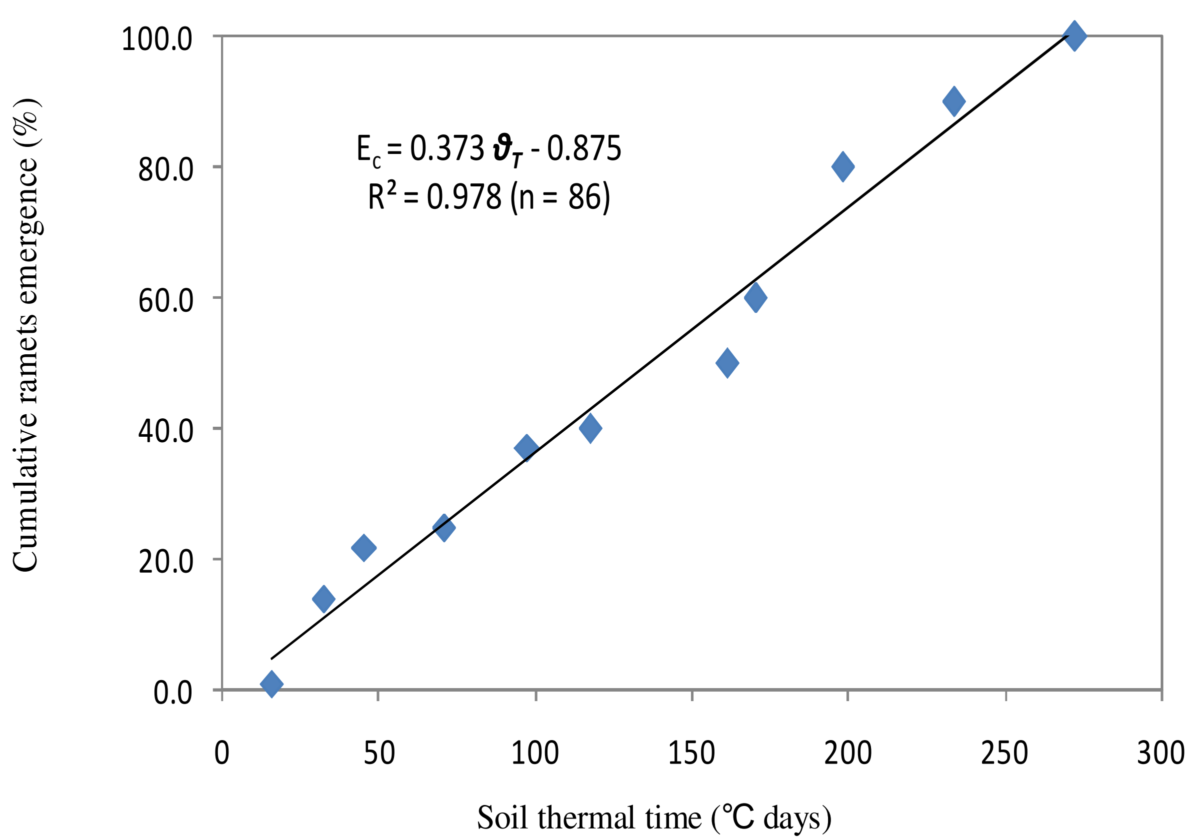

Figure 4. Correlation between cumulative ramets emergence (E_c, %) and soil thermal time ($\boldsymbol{\theta_T}$, ℃ days) for all treatments.

temperature.

The *L. racemosus* ramets came from dominant bud germination, while the root system and rhizome supplied most of their nutrition needs and the soil temperature was the predominating environmental factor determining their emergence (Huang and Gutterman, 2004). The soil surface environment greatly affected seedling emergence (Boyd and Acker, 2003). There were positive correlations between the topsoil temperature (15 cm soil layer) and cumulative ramets emergence percentage. It is also concluded that soil temperature greatly affected both emergence time and percentage of *L. racemosus* ramets. Soil temperature is commonly used in soil thermal-time models for forecasting seedling emergence in the field (Grundy et al., 2000; Forcella et al., 2000). Most soil thermal-time models explain some of the variance in over- and under-estimating seedling emergence percentage (Garacia-Huidobro et al., 1982). Our findings allowed us to derive a linear function describing the relation between ramets emergence and soil thermal time, which allows the breadth of the thermal range for ramets emergence to be estimated.

The grass species composition and plant numbers had changed greatly in the Inner Mongolia steppe enclosures due to grazing disturbance (Shiyomi, 1998). Under natural field conditions, ramets recruitment is the main way in which Inner Mongolia steppe vegetation establishes itself; seedlings from seed germination account for only a small proportion of the plant community composition. Former researchers have emphasized species interaction, competition and adaptability to the environment and to grazing disturbance, and have investigated the vegetation succession process (Wang et al., 2002). However, the ramets emergence was the predominant factor determining plant community establishment (Ting and Richard, 1996). In the present study, the ramets dynamics showed that, with decreased mulch cover, the final cumulative ramets emergence of *L. racemosus* in the grassland showed significant increase in the grazing plots. Earlier researches also indicated that the *L. racemosus* species competed aggressively and grew rapidly, using up nutritional and other resources, resulting in grassland degradation (He et al., 2005; Li et al., 2008). Conservation of the Inner Mongolia steppe in northern China is hampered by the impact of invasive herbaceous species (Liu et al., 2007).

Previous research has also shown that some management practices such as prescribed fire, herbicide and mowing can evoke different responses in invasive species (Li et al., 2005; Liu et al., 2007). The most earlier work focused on the invasive plant ecological scales and ecosystem levels. The spring regreening period is the curial stage for Inner Mongolia steppe regeneration, and accordingly, our studies concentrated on steppe management of ramets emergence together with future vegetation establishment. Our findings indicate that both mowing and grazing exclusion have a significant effect on species control of the invasive *L. racemosus*.

Acknowledgements

Funding was provided in part by National Forage Industrial Technology System, China Special Public Sector Research Project (Agriculture: 200903060 and 201003019), Doctoral Foundation of Ministry of Education of P.R.China (200800190001), and China Agriculture University Foundation for New Researcher Scholars.

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