Rangeland Ecology & Management xxx (2015) xxx–xxx

Contents lists available at ScienceDirect

Rangeland Ecology & Management

journal homepage: http://www.elsevier.com/locate/rama

Management Regimen and Seeding Rate Modify Seedling Establishment of *Leymus chinensis*☆

G.X. Liu [a,b], F. He [a], L.Q. Wan [a], X.L. Li [a,*]

[a] *Institute of Animal Sciences, Chinese Academy of Agricultural Sciences, Beijing, China*
[b] *College of Life Science, Hebei University, Baoding, Hebei Province, China*

ARTICLE INFO

Available online xxxx

Keywords:
Leymus chinensis
Regeneration niche
Reseeding
Restoration
Seedling establishment

ABSTRACT

Broadcasting of Chinese wild rye, *Leymus chinensis* seeds (without plowing) is the long-standing recommendation for reseeding degraded grasslands in Northern China. However, no experimental assessments have been made to determine which management options, including presow harrowing, postsow cutting, nitrogen fertilizer, and seeding rate, may influence the establishment of *L. chinensis* seedlings after broadcasting. We conducted a 2-year field study that quantified the relative impacts of these factors on seedling emergence, survival, and growth on a degraded short-grass steppe site at SaiBei, Hebei Province, China. Broadcast seeding of *L. chinensis* after harrowing resulted in the highest seedling emergence (16.4%), seedling survival (62.5%), and plant height (8.5 cm) compared with the other management regimens assessed. By Year 2, survival was 10 times greater in plots where harrowing had been implemented. This finding was especially important because of the drought conditions that occurred during the study period. The lowest seeding rate (400 seeds · m^{-2}) was linked with 15% seedling emergence and average heights of 7.3 cm at the end of the 2 years. It is our recommendation that seedling establishment is optimized when harrowing is used for initial soil preparation and seed dispersal. Harrowing improved seed–soil contact, increased the number of seed safe sites on the soil surface, and reduced competition from the already existing sward.

Introduction

Leymus chinensis (Trin.) Tzvel. is a native perennial rhizomatous grass with economic and ecological importance as fodder because of its good palatability and high forage value (Wang et al., 2004b). Grasslands dominated by this species are widely distributed from the southern Chinese loess plateau (approximately 107°00′E, 34°00′N) to the northern Russian Baikal (107°40′E, 53°00′N), and from the Sanjiang plain in eastern China (135°05′E, 49°27′N) to Ulan Bator (106°53′E, 47°55′N) of Mongolia (Wang et al., 2004a). *L. chinensis* grasslands are among the most important grazing and mowing pastures in China (Wang et al., 2004b). This distribution covers a range of climates from semiarid to subhumid (Wang et al., 1999). However, heavy grazing in recent decades has degraded these grasslands, leading to their conversion for arable cropping. Productivity and profitability have declined, and environmental hazards such as dust storms have carried away the newly exposed dry topsoil by strong northeasterly winds.

Previous experiments have shown that reseeding is the most economical and effective way to reestablish *L. chinensis* populations on degraded sites. Researchers have also recommended that *L. chinensis* be resown along with other desirable, competitive native species, such as *Agropyron cristatum* (L.) Gaertn., *Bromus inermis* Leyss, *Elymus dahuricus* Turcz., and the legume *Melissitus ruthenica* (L.) Peschkova (Gao, 2004; Zhao and Sun, 2004).

The seedling stage is a vulnerable time of development within the plant life cycle. Thus seedling establishment is a critical period for successful species recruitment and restoration (Hofmann and Isselstein, 2004; Kitajima and Fenner, 2000). Consequently, the environment immediately surrounding a seed or seedling is an important determinant of establishment, vigor, and development of a plant community structure. Seedlings can fail to establish because of unfavorable grassland conditions such as competition from dense existing vegetation and/or nutrient limitations (Elmarsdottir et al., 2003; Muller et al., 1998). Furthermore, agronomic variables must be optimized to ensure high establishment rates. Such variables include how the soil surface is disturbed (e.g., harrowing, raking, or plowing; the type of nitrogenous fertilizer applied; cutting regimens [frequent use or performed just before resowing]); and seeding rate. Harrowing or presow raking may positively affect microsite availability (Hofmann and Isselstein, 2004; Schmiede et al., 2012), providing the optimal environmental cues to trigger germination (Fleischer et al., 2013; Hofmann and Isselstein, 2004), and improve seedling establishment (Juenger and Bergelson, 2000; Pugnaire and Lozano, 1997). The quantity of nitrogenous fertilizer applied may also strongly influence plant succession (Tilman, 1986, 1987). Some field studies have shown that nitrogen enrichment

☆ Research was funded by the National Natural Science Foundation of China (Grant 31072069) and Special Fund for Agro-scientific Research in the Public Interest (201103005).

* Correspondence: XiangLin Li, Institute of Animal Sciences, Chinese Academy of Agricultural Sciences, Beijing, 100193 China. Tel./fax: +86 10 62815997.
E-mail address: lixl@iascaas.net.cn (X.L. Li).

http://dx.doi.org/10.1016/j.rama.2015.01.007
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increases the likelihood of establishment (Chambers, 1989; Sultan et al., 1998; Young et al., 1997). Frequent cutting after seedlings begin to grow can also significantly improve establishment and sward density (Hofmann and Isselstein, 2004, 2005). For several grass species, certain seeding rates have made important contributions toward successful seedling establishment (Black et al., 2006; Bouzid and Papanastasis, 1996; Young et al., 1994), and a high rate is often recommended (Eriksson and Eriksson, 1997; Hopkins et al., 1999).

Historically, improvements to management strategies with *L. chinensis* have focused on increasing the density and aboveground biomass in reestablished swards within 1 or 2 years after reseeding (Gao, 2004; Zhao and Sun, 2004). Methods to optimize seedling recruitment for this species, however, have not been evaluated, although such insight could potentially inform restorative grassland management or "rehabilitation practices" (Ueckert, 1979). Broadcast seeding (without plowing) is the recommended method for reseeding *L. chinensis* in Northern China (Li, 1996; Wang et al., 2004a). However, no experimental assessment has been conducted to compare the *L. chinensis* seedling emergence, growth, and survival associated with broadcasting versus alternative approaches such as harrowing, postsow cutting, nitrogen applications, and adjustments to seeding rates. Therefore our investigation involved a comparative analysis of establishment for this species in response to presow harrowing, postsow cutting, nitrogenous fertilizer, and seeding rates. The following hypotheses were addressed: seedling establishment of *L. chinensis* by broadcasting the seeds into degraded grassland 1) would be hard to succeed without additional management regimen and 2) would benefit from presow harrowing, postsow cutting, nitrogen fertilizer and increasing seeding rate, and/or the interactive effects of these factors.

Materials and Methods

Site Description

This study was conducted at the National Field Station of Grassland Ecosystems (NFSGE) (41°45′~41°57′N, 115°39′~115°48′E; 1400 m above sea level) located at SaiBei, Hebei Province, China, south of the Xilingol steppe grassland. The climate of NFSGE is semiarid, with a mean annual precipitation of 398.8 mm that mainly falls in July, August, and September. Mean annual temperature is 1.9°C, and mean minimum temperature in coldest months (January) is –17.4°C. Annual average wind speed is 4.3 $\mathrm{m \cdot s^{-1}}$. The growing season lasts approximately 100 d (Meteorology Station, Gu Yuan ranch). The main soil type, chestnut, is sandy clay loam texture and slightly alkaline (pH 7.6). During our experimental period, from June 2005 to September 2006, total rainfall was lower than average (Fig. 1). Differences in mean monthly rainfall and temperature data between our experimental years and the 20-year average values are shown in Figure 1, and soil nutrient values for the study site are presented in Table 1. Historically, the most common vegetation on this site had been a mixture of Poaceae (Gramineae) and Compositae members, such as *L. chinensis, B. inermis,* and species of *Artemisia* (Liu, 1985). However, the recently degraded site is now dominated by the forbs *Artemisia eriopoda* Bunge, *A. Tanacetifolia* Linn., *Saussurea amara* (L.) DC, and *Potentilla tanacetifolia* Willd. ex Schlecht., plus the grasses *Cleistogenes squarrosa* (Trin.) Keng and *Poa annua* Linn. (Zhang, 2007).

Plant Material

Seeds of *Leymus chinensis* were harvested in autumn 2004 from natural populations growing wild in the SaiBei Administrative. Seeds were air-dried at room temperature, cleaned, and stored in paper bags. Seed quality was examined visually by assessing the extent to which grains were "filled" by gently squeezing individual seeds to test the ease with which the embryo was exposed. In total, 2500 seeds per harvested batch were randomly selected for this assessment. Their viability was determined via germination tests of 400 filled seeds, as recommended by the Association of Official Seed Analysts (1998). Q6

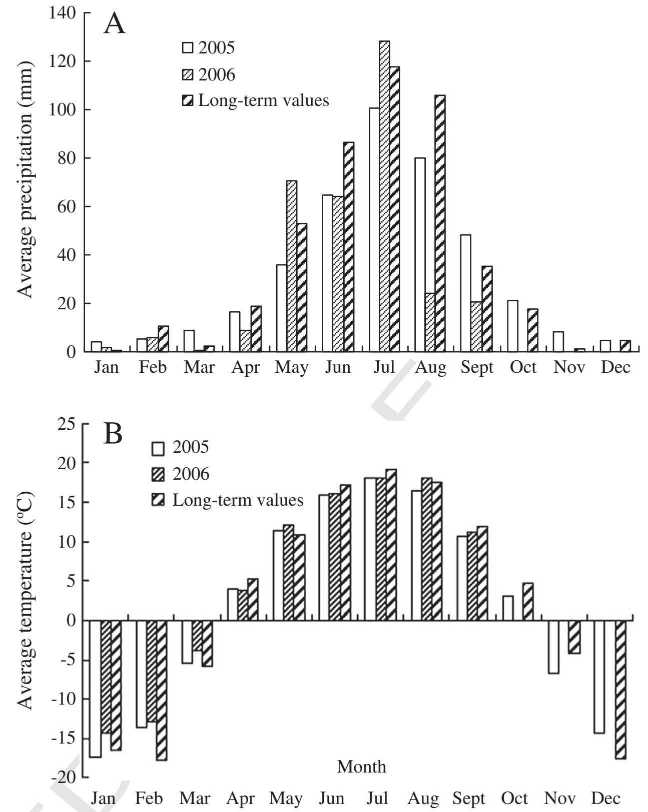

Figure 1. Annual precipitation **A** and temperature **B** based on averages of 20-year and experimental year monthly (data gathered at SaiBei weather station).

Experimental Design

We used two terms to distinguish plant status: 1) "seedling establishment," which refers to seedlings that survive for a second year of growth (c.f., Cook, 1980; O'Connor, 1996) and 2) "seedling recruitment," which described only survival through the early developmental stages of germination, emergence, and initial seedling growth.

The experiment was conducted in a split-split-split plot design with five replications. In each replication, the main plots were randomly assigned to two cultivation harrowing treatments: 1) control (i.e., no additional mechanical disturbance to the soil before seed was sown); and 2) harrowing, which was done 3 d before sowing by pulling a metal rake through the grassland until the soil surface layer was disturbed to a depth of 5 to 10 cm and 50% of the tiller density was diminished. In the main plot, two postsow cutting treatments were randomly allocated and there was no cutting (control) or cutting at 35 d postsowing to achieve a vegetation height of 5 cm. At the subplot level, treatments comprised either the control (none) or fertilizer applied at 100 $\mathrm{kg \cdot hm^{-2}}$ KNO_3 randomly allocated to them. At the sub-sub plot level, three seeding rates of 400, 800, or 1200 seeds $\cdot$ $\mathrm{m^{-2}}$ were randomly nested within the nitrogen application treatments. Thus a total of 120 experimental units were assessed. The distance between blocks and main plots was 2 m, with 1 m buffer between the subsidiary plots. All treatments were applied to the 2×2 $\mathrm{m^2}$ experimental units.

Cutting was done 35 d postsowing in plots that received postsow cutting treatment. The existing vegetation in postsow cutting treatment plots was cut to a height of less than 5 cm, and care was taken to ensure that the seedlings were not cut. Harrowing was carried out 3 d before the seeds were hand sown on 11 June 2005. Afterward, the soil for all treatments was compressed with a roller. Livestock were excluded