Acta Ecologica Sinica 37 (2017) 38–47

Contents lists available at ScienceDirect

Acta Ecologica Sinica

journal homepage: www.elsevier.com/locate/chnaes

The effects of gap disturbance on the seedling emergence, survival and growth of two different native species in Inner Mongolia

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ARTICLE INFO

Article history:
Received 30 June 2016
Received in revised form 7 September 2016
Accepted 14 September 2016

Keywords:
Reseeding management
Restoration ecology
Gap disturbance
Gap size

ABSTRACT

A field study was conducted to investigate the effects of gap disturbance on the seedling establishment process of two native species. Seeds of *Agropyron cristatum* and *Stipa krylovii* were reseeded to artificially created gaps in a degraded steppe in North China. There were seven treatments: shoot gaps and root gaps (10 cm, 20 cm and 40 cm in diameters), no gaps (control). Shoot gaps were formed by removing above ground vegetation and below ground biomass without restricting the re-growth of neighbor roots back into the gap. The root gaps were accomplished by using polyvinyl chloride pipes sunk in the soil of shoot gaps to exclude neighboring roots. Seedling emergence, survival and growth performance after 90 days of growing were recorded for both species. Gap significantly increased soil moisture, especially for root gaps. Emergence increased significantly for both species as gap size increased. Seedling emergence and survivorship of both species were greater in gaps than in controls. However, the gap size showed a significantly negative effect on *Agropyron cristatum*'s survivorship. Growth performance of *Agropyron cristatum* and *Stipa krylovii* differ in their response to gap disturbance. Gap had positive effects on seedling growth (including seedling height, dry weight, and numbers of tillers and leaves) of *Stipa krylovii*, but had negative effects on seedling growth of *Agropyron cristatum*. The two species have significantly different responses to gap disturbance. All results suggest that *Stipa krylovii* is a gap-enhanced species, and *Agropyron cristatum* is not. Predation by insects may be one of the key reasons to explain the stand dominance in this grassland.

1. Introduction

Restoration of semi-natural grassland communities involves a combination of sward disturbance to create a temporal window for establishment and target species introduction, the latter usually accomplished by seed sowing [1]. Disturbance is an important factor in maintaining species richness in plant communities [2]. It operates on adult plants by providing regeneration niches for recruitment if it has greater relative impact on dominant species [1,3,4]. Gap creation has been shown by many authors to be a key requirement for diversity maintenance in grassland communities [5] and necessary for successful seedling establishment of many species [6], as many species are limited by microsite [7], seed [8]. Gaps provide an opportunity for regeneration from seed already present in the seed bank, existing vegetation, or by introduction from outside the site. This is true not only for guilds of annuals and biennials [7], but also for the replacement of perennials [9].

Both *Agropyron cristatum* and *Stipa krylovii* have the same photosynthetic pathway and are resistant to drought. They are native perennial grasses with good palatability and high forage value in northern China, especially in the Inner-Mongolia steppe [10]. In the eastern parts of typical steppes of Inner Mongolia, *Stipa krylovii* is often a subdominant species with *Leymus chinensis* dominant, and *Agropyron cristatum* is mostly a companion species in a semi-arid grassland community [10,11]. However, nearly 86% of these grasslands are facing degradation or have been degraded in recent decades due to excess reclamation and overgrazing [12]. Climate change and human activities have amplified the magnitude of these disturbance events [13]. To understand the implications of these disturbance conditions for community structure and stability, the conceptualization of “gap disturbance” seems necessary. Studies on the effects of gaps in *Stipa kryovii* and *Agropyron cristatum* seedling establishment can give a better understanding of restoration mechanisms for degraded steppe of Inner Mongolia and will also provide knowledge for the gap disturbance theory.

Reintroduction of native species has been proven to be a highly effective way for restoration of degraded grassland [14]. It not only improves grassland community productivity, but also maintains diversity and stability of grassland system [15,16]. Previous studies have shown that reseeding native species including *Leymus chinesis*, *Elymus dahuricus* and *Bromus inermis* would promote grassland productivity

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http://dx.doi.org/10.1016/j.chnaes.2016.09.002

and speed up the process of grassland restoration [4,17,18]. However, all these species are dominant and rhizomatous, and there are few studies about non-dominant or non-rhizomatous species (i.e. *Stipa krylovii* and *Agropyron cristatum*). Therefore, an insight into the effects of gap disturbance on seedling establishment of non-dominant species could be a step towards a better understanding of grassland community structure and composition, and used for future management in order to give more effective strategies in grassland restoration.

Availability of seed may not be sufficient [19] and gap disturbance is also needed for seedling establishment [20,21]. These factors limit not only the establishment of species dependent on seed in soil banks but also those species that have wind-dispersed seed and germinate immediately [5]. The early phase of seedling establishment is a vulnerable stage in plant life circle [22]and a critical period for successful species recruitment [23]. Limitations to seedling emergence and establishment are competition by neighbor plants, physical hazards like desiccation, and seed predation and herbivory [22]. The relative importance of these different constraints on seedling recruitment depend on the abiotic and biotic conditions of a site [24]. Gaps provide conditions in which competition is reduced or absent [6], and they could provide regeneration niches for species recruitment [24]. Light, temperature and moisture regimes in gaps are very different from those in closed vegetation or bare soil [25,26].

Creating gaps is favorable for re-vegetation of seedling establishment and survival is crucial for re-vegetation of degraded grassland [17]. Gaps provide an opportunity for regeneration from seed already present in the seed bank or existing vegetation or by invasion from outside the site [27]. Previous studies had indicated that seedling establishment percentages of reseeded species in gaps were significantly higher than that in intact vegetation [1]. Most of the early research focused on the species coexistence within the vegetation community, biodiversity maintenance and gap dynamics [6,28]. More recently, they began to emphasis on the regeneration in gaps and seed dispersal in grassland [20], but there have been few analysis of the gap disturbance on different species' seedling establishment. Seedling establishment requirements differ among individual species, and could determine establishment of individual species [29], meaning that there still need to be more studies in detail to clarify the mechanism of gap disturbance on seedling establishment in grassland.

Previous research showed that existing vegetation had significant negative effects on *Stipa krylovii* [30,31] and *Agropyron cristatum* [14]. Seedling mortality is the main filter in recruitment [32]. Seed predation may have important effects on plant population dynamics [30,33]. Gap characteristics are also important in the reconstruction of semi-natural plant communities from seed, ramets, and planted seedlings [34]. Most of the early studies on *Stipa krylovii* and *Agropyron cristatum* focused on their inherited characters, physiological properties and their competition with other dominant species in forest or grassland systems, there were few investigations on their seedling establishment under the gap disturbance in semi-arid grassland conditions. Results from this study may contribute to improved techniques for grassland restoration and reconstruction in northern China.

Our hypothesis is that *Stipa krylovii* and *Agropyron cristatum* responses to gap disturbance are different. This could explain why *Stipa krylovii* is a sub-dominant species and *Agropyron cristatum* is a companion species. The objectives of this study are to evaluate: 1) the impact of gap disturbance on microclimate (soil moisture and soil temperature), 2) whether different species differ in their ability to germinate and survive in the same gap disturbance, and whether they suffer different predation pressures, 3) gap type and gap size effects on seedling establishment of these two species.

2. Materials and methods

2.1. Study site

The experiment was carried out in the Grassland Vegetation Restoration and Reconstruction Key Laboratory of China, Ministry of Agriculture Experiment Station (41°52′N, 115°50′E, altitude 1370 m), Saibei administrative region, Hebei province, China. The site is located in the southern portion of the Xilingol steppe grassland, which is the most representative steppe in northern China. The climate here is semi-arid, with a windy and dry winter and spring, a warm and comparatively rain-rich summer, followed by a short and cool autumn. Annual average rainfall range is 350-450 mm, and is summer dominant, with an average of 70% falling during the growing season (late spring, summer and autumn). Mean annual temperate of the site is 1.41 °C·The accumulated temperature ≥ 10 °C is 1513.1 °C. The growing season lasts about 100 days. Soils on the study site were chestnut and a little alkaline, and the topography is flat (<1% slope). The natural dominant vegetation species are *Leymus chinensis*, *Stipa krylovii*, *Artemisia eriopoda*, *Artemisia tanacetifolia* and *Cleistogensesquarrosa*. The main companion species were *Bromus inermis*, *Agropyron cristatum* and *Poaannua*. The vegetation cover was 60–80%, with a mean vegetation height of 25 ± 0.36 cm. All the weather data was monitored with an automatic meteorological station which is located in the center of the site. Mean monthly temperature and rainfall data between the experimental periods are shown in Fig. 1.

2.2. Materials

The experiment was conducted in a split-plot design, and in each plot a randomized block design was used. The main plots consist of two different species separately (*Agropyron cristatum*, *Stipa krylovii*). In herbaceous communities, gaps <50 cm diameter are most common [35], and gaps appear as a result of the death of established individuals or animal activity. We refer to a gap with the presence of neighboring roots and loss of photosynthetic biomass as a "canopy gap," or we can call it "shoot gap," and a shoot gap with neighboring roots excluded as a "root gap" [6]. There were seven treatments randomized in each of eight replicate blocks in one plot. The treatments were no gap (control), and shoot and root gaps each with diameters of 10, 20 and 40 cm. Before the experiment started, shoot gaps were created by the removal of both above- and below-ground biomass without any restriction to the neighbor roots re-growth into the gap, and root gaps were created by using a cylindrical PVC pipe to restrict neighbor roots re-growth into the gaps. All this was done in May 2011, and a total of 112 small plots were distributed in the field. The distance between blocks was 1 m.

The gap treatment was created by cutting out circles of vegetation of different diameters (10,20,40 cm) approximately 1.5 cm deep. Then a 25-cm-deep layer of soil underlying the removed circles was removed and passed through a 2-mm soil sieve, removing plant roots, seeds, and other plant materials. For the treatment of shoot gaps, holes were backfilled with the sieved soil and firmed until the new soil was flush with the existing ground surface. The root gap treatments were created by using PVC pipes to exclude neighboring root systems [36]. PVC tubes were installed with their tops flush with the soil surface. The holes were refilled with the removed soil until the new soil was flush with the PVC and firmed. Soil was not mixed within or between plots. For the control treatments (no shoot gap and neighboring roots present), all vegetation and soil was left intact original conditions.

Both seeds (*Agropyron cristatum*, *Stipa krylovii*) were collected from the natural habitat in experimental area in the autumn of 2012. Then they were air dried at room temperature, cleaned and stored in paper bags. Before the sowing, the germination rate and thousand-grain weight of each species was determined. The germination rate of *Agropyron cristatum* and *Stipa krylovii* was 75% and 55% respectively. The thousand-grain weight of *Agropyron cristatum* and *Stipa krylovii* was 4.23 g and 2.30 g respectively.

On the 28th of June 2012, 10 seeds of each species were sown into the center (8 cm in diameter) of each gap or under the intact canopy for the control at a depth of 2 cm. To ensure seedling emergence, 10 mm of water was added weekly for the first 4 weeks, until no new seedlings appeared. After seeding, the number of emerging seedlings