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Micro-environmental conditions affect grass and shrub seedling emergence in denuded areas of the arid Patagonian Monte, Argentina

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ABSTRACT

Harsh micro-environments in bare soil patches generated by disturbance may affect the emergence of plant species in desert ecosystems. We evaluated the effects of litter addition on the emergence of perennial grass and evergreen shrub species under different conditions of UV radiation and soil water content in disturbed patches of bare soil. We sowed seeds of perennial grasses (*Nassella tenuis* and *Poa ligularis*), and shrubs (*Atriplex lampa*, *Larrea divaricata* and *Schinus johnstonii*) in microcosms containing blocks of upper soil (28 cm depth) subjected to different levels of three factors: litter (bare soil without litter cover, high quality litter cover from undisturbed plant patches, and low quality litter cover from disturbed plant patches), UV radiation (near ambient and attenuated UV radiation), and soil water (5–15% and 15–25% of volumetric soil water content). The patterns of seedling emergence in relation to litter, UV radiation, and soil water content varied among species independently of life form. Seedling emergence of all species increased under exposure to UV radiation at all combinations of litter and soil water factors. High soil water content had an important positive effect on the emergence of *N. tenuis* and *L. divaricata* in combination with UV radiation and litter. In contrast, soil water content did not affect or affected negatively the emergence *P. ligularis* and *A. lampa* in combination with litter and UV radiation. The emergence of *S. johnstonii* occurred only under exposure to UV radiation mostly at high soil water content, independently of litter levels. These results highlight the importance of the combined effects of the presence and type of litter, soil water content, and UV radiation on seedling emergence of perennial grass and shrub species and consequently on the vegetation reestablishment processes at disturbed areas.

Introduction

In arid and semiarid ecosystems, vegetation consists of patches with high plant cover dominated by evergreen shrubs and perennial grasses distributed on a matrix of bare soil or scattered vegetation (Aguiar and Sala, 1999; Ares et al., 2003; Bisigato and Bertiller, 1997). The micro-environmental conditions strongly differ between the two phases of the mosaic. The areas in the vicinity or beneath patches with high plant cover have higher input and retention of organic matter and nutrients, lower exposure to UV radiation, and lower temperature and evaporative demand than open patches (bare soil patches or patches with scattered vegetation) (Bertiller et al., 2002; Callaway, 2007). Accordingly, enhanced micro-environmental conditions due to the creation of fertility islands and sheltered areas associated with dense plant patches (Bertiller et al., 2009; Burke et al., 1989) may increase seed germination, emergence and establishment of perennial grasses and evergreen shrubs in these microsites (Belsky et al., 1989; Bertiller et al., 2002; Bisigato and Bertiller, 1999).

Disturbances such as grazing, fire or mechanical removal of vegetation may lead to the reduction of the size, number, and cover of plant patches and to a significant increase in the size of open patches (Ares et al., 1990; Bisigato and Bertiller, 1997; Boyd and Svejcar, 2011; Carrera et al., 2009; Milchunas and Lauenroth, 1993; Rostagno et al., 2006). These open patches with low or null plant cover have harsh microclimatic conditions and little microsite differentiation within them (Carrera and Bertiller, 2010). However, the litter transported by wind-blown or runoff from plant patches may be eventually accumulated in these open patches in irregularities on the soil surface such those created by animal treading and trampling or biological crusts (Farrel et al., 2012). Furthermore, artificial addition of litter could be a managerial alternative to improve microenvironmental conditions in large bare soil areas resulting from anthropogenic disturbance (Simons and Allsopp, 2007). Thus

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natural accumulation or the artificial addition of litter on open areas could induce small heterogeneities in the level of soil resources (water and nutrients) available to plants and could also be important for seed retention thus benefiting plant regeneration processes in these microsites (Arriaga and Maya, 2007; Luzuriaga and Escudero, 2008). Litter quality, given by concentrations of nutrients and secondary compounds (Aerts, 1997; Carrera and Bertiller, 2013; Xu et al., 2010), and the amount of litter accumulated on the soil surface may have an important effect on the chemical and physical soil attributes (Meier and Bowman, 2008; Suding et al., 2008; Wardle and Bardgett, 2004). Thus, high nutrient release and input to soil, lowered soil temperatures, and seed protection from desiccation induced by litter accumulation may promote the emergence and establishment of seedlings (Bansal et al., 2014; Farrel et al., 2012; Loydi et al., 2013). However, litter may also act as a mechanical barrier to seedling emergence or may release toxic compounds thus reducing emergence as well as other biological processes (Aerts and Chapin, 2000; Carrera and Bertiller, 2013; Loydi et al., 2013; Ruprecht et al., 2010; Xiong and Nilsson, 1999).

Moreover, the exposure of seeds and seedlings to UV radiation in open patches without litter protection could affect emergence processes and seedling growth depending on the intrinsic protection mechanisms of seeds and plants (Musil et al., 1998; Tosserams et al., 1997). There is evidence that long-lived perennial plants with low growth rates, such as evergreen shrubs, have high concentration of secondary compounds in tissues protecting them from herbivore damage, water shortage or exposure to high UV radiation. In contrast, herbaceous plants with high growth rates, such as perennial grasses, have tissues with low concentration of secondary compounds (Aerts and Chapin, 2000; Bertiller et al., 2006; Campanella and Bertiller, 2008; Carrera et al., 2009). Accordingly, shrubs are more adapted than perennial grasses to colonize severely disturbed areas with low fertility and harsh microclimatic conditions (Bertiller and Bisigato, 1998).

There is little knowledge about how the micro-environmental conditions induced by litter accumulation may affect the processes of emergence of plant species of different life forms in open patches resulting from disturbance processes in desert environments. The aim of this study was to evaluate the effects of litter addition on the emergence of perennial grasses and evergreen shrubs under different conditions of UV radiation and soil water content in open patches resulting from disturbance in the arid Patagonian Monte. We hypothesized that the emergence of perennial grass and evergreen shrub species is differentially affected by the combined effects of the presence and type of litter, soil water content, and exposure to UV radiation. We predicted that the emergence of perennial grasses would be positively affected by the combined effect of the presence of easily decomposable litter (high quality litter), high soil water content and attenuation of UV radiation while the emergence of evergreen shrubs would be less dependent than that of perennial grasses on these micro-environmental conditions of seedbeds.

Materials and methods

Study area and species

The study area is located in the southern portion of the Monte Phytogeographical Province (Patagonian Monte) dominated by the community of *Larrea divaricata* Cav. and *Stipa* spp., (León et al., 1998). The average annual temperature is 13.4 °C, the annual mean precipitation is 235.9 mm and the average speed of wind (prevailing from west-southwest) is 4.6 m s^{-1} (Centro Nacional Patagónico, 2009). Soils are a complex of Typic Haplocalcids and Typic Petrocalcids (del Valle, 1998; Soil Survey Staff, 1998). Within this area, we selected two dominant species of perennial grasses (*Nassella tenuis* (Phil.) Barkworth and *Poa ligularis* Nees ex Steud) and three dominant species of evergreen shrubs (*Atriplex lampa* Gill. ex Moq., *L. divaricata* and *Schinus johnstonii* FA Barkley) (Bertiller et al., 1991; Bisigato and Bertiller, 1997).

Sampling and manipulative experiment

Within the study area, we selected six representative sites disturbed by grazing and fire. Two sites (43°06′13.4″S, 65°43′51.3″W; 150 m a.s.l.; and 43°08′52.0″S, 65°42′49.6″W; 151 m a.s.l.) were subjected to sheep grazing with a stocking rate of 0.11–0.14 sheep ha^{-1} since the beginning of the last century (Bär Lamas et al., 2013). Three sites (42°11′38.7″S, 64°59′37.3″W; 75 m a.s.l.; 42°12′27.8″S, 64°59′34.5″W; 94 m a.s.l.; and 42°12′13.7″S, 64°58′55.6″W; 92 m a.s.l.) were subjected to the same stocking rate until 2003 when a wildlife refuge was created and the stocking rate was gradually reduced (0.01 sheep ha^{-1} per year) until 2008 when all domestic herbivores were removed (Bär Lamas et al., 2013; Larreguy et al., 2014). The sixth site (42°49′15.6″S, 65°00′24.5″W; 63 m a.s.l.) was subjected to sheep grazing with the same stocking rate as the former until 2001 when a fire reduced the plant cover and domestic herbivores were removed (del Valle et al., 2004).

We randomly selected 12 bare soil open patches (>2 m in diameter) per site. At each bare soil open patch (hereafter bare soil patch), we collected one block of the upper soil (30 cm × 40 cm × 14 cm deep) without altering its structure and then, we collected the sub-superficial soil (30 cm × 40 cm × 14–28 cm deep) with a shovel. Blocks of the surface soil and the sampled sub-superficial soil from each bare soil patch were placed in individual waterproof wooden boxes (30 cm × 40 cm × 28 cm deep) reconstructing the soil stratigraphy (microcosm). After this, the surface litter was carefully removed from each microcosm. The surface of each microcosm was divided into 48 cells of 5 cm × 5 cm each.

Besides, we collected the litter beneath 12 undisturbed (dominated by shrub and perennial grasses) and 12 disturbed (dominated by shrubs) plant patches from each site. We pooled each litter type (disturbed and undisturbed patches) collected from all study sites in two composed samples and dried them at 45 °C for 48 h. Litter chemistry of each litter mixture was assessed using the protocols followed by Bertiller et al. (2006). The litter mixture from disturbed plant patches had higher concentrations of N, soluble phenols and lignin (18.55 ± 0.20, 12.69 ± 0.12, and 128.02 ± 1.88 mg g^{-1}, respectively) than litter mixtures from undisturbed plant patches (8.49 ± 0.02, 6.04 ± 0.08, and 80.14 ± 2.69 mg g^{-1}, respectively). Previous studies in the area reported that changes in the canopy structure (i.e. reduction of perennial grass cover and replacement of perennial grasses by shrubs) induced by disturbance lead to increased leaf litter recalcitrance (high concentration of secondary compounds), and reduced litter decay, soil N mineralization rate, and nutrient release (Carrera and Bertiller, 2013). Thus, based on the concentration of secondary compounds (soluble phenols and lignin) we defined two litter types: high quality litter (undisturbed plant patches) and low quality litter (disturbed plant patches). Moreover, high quality litter consisted of a mixture of perennial grass and shrub litter and low quality litter was a mixture of shrub litter, predominantly *L. divaricata* litter. Seeds from all species were collected during the period of seed dispersal of each species within the study area and were then pooled in a composed sample per species.

The manipulative experiment was conducted in the experimental area of the Centro Nacional Patagónico (CENPAT) (42°47′10.4″S, 65°00′28.2″W; 5 m a.s.l.) with disturbed natural vegetation characteristic of the Patagonian Monte with large open patches generated by anthropogenic disturbance. In this experimental area, we selected six large (>2 m diameter) bare soil patches. At each bare soil patch (n = 6), we placed the 12 microcosms from each site (n = 6)