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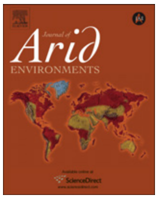

Clubmoss, precipitation, and microsite effects on emergence of graminoid and forb seedlings in the semiarid Northern Mixed Prairie of North America

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ABSTRACT

Clubmoss (*Selaginella densa* Rydb.) provides extensive ground cover throughout the Northern Mixed Prairie of North America, but little is known about how this cryptogam affects seedling emergence relative to precipitation. Seedbed treatments including a control, Glyphosate applied to kill clubmoss, and clubmoss removal were factorially combined with ambient precipitation, precipitation reduced, and irrigation. Graminoid and forb emergence in the seedbeds and the microsites of live clubmoss, dead clubmoss, bare soil, litter, and caespitose grasses was determined. Forb emergence was greatest with clubmoss removal and irrigation. About 2.6–3.6-fold more forbs emerged from bare soil microsites, but clubmoss reduced forb emergence by 32–76%. Litter reduced forb emergence in 2 of 3 years. Graminoid emergence did not vary among seedbeds ($P \geq 0.780$), but irrigating increased seedling emergence. Graminoid emergence was unaffected or improved in live clubmoss, dead clubmoss, bare soil, and litter microsites. In the semiarid Northern Mixed Prairie, above-average precipitation combined with bare soil will favor emergence of forbs. By contrast, clubmoss does not limit graminoids because seedlings emerge from a range of seedbeds and microsites provided diaspores are present and precipitation is above average. Emergence of graminoids and forbs is constrained primarily by precipitation in the semiarid Northern Mixed Prairie.

1. Introduction

Clubmoss (*Selaginella densa* Rydb.) is an important component of many native plant communities in the Northern Mixed Prairie of North America, yet little is known about the role of this cryptogam in seedbed ecology. This low growing (≤10 mm), non-flowering, spore-reproducing, vascular plant covers up to 80% of the soil surface in many grassland communities on the Northern Great Plains (Coupland, 1950; Dolan and Taylor, 1972; Heady, 1952; Van Dyne and Vogel, 1967). The dense mats of clubmoss purportedly limit seedling establishment (Heady, 1952), and gaps in clubmoss cover are needed for seedling emergence (Clarke and Tisdale, 1936). Under controlled environmental conditions, more fringed sagebrush (*Artemisia frigida* Willd.) seedlings emerge from bare soil than from dead clubmoss and live clubmoss (Bai and Romo, 1995). Live clubmoss and dead clubmoss also reduce emergence of crested wheatgrass (*Agropyron desertorum* Fisch.) (Romo, 2005). Romo and Bai (2004) suggested seedling recruitment for many plants is limited by seed reserves in the soil seed bank and not by clubmoss.

True mosses reduce, increase, or have no effect on seedling emergence of many plant species (Keizer et al., 1985; Ryser, 1993; van Tooren, 1988, 1990) depending on the thickness and the species of moss (Serpe et al., 2006), as well as macro- and micro-environmental conditions (Rabotnov, 1969). Bryophyte limitations to seedling emergence vary with moisture conditions; when moisture is abundant, bryophytes have no effect on seedling emergence, but they reduce seedling emergence under dry conditions (Zamfir, 2000). Similarly, the distribution and amount of precipitation are more important than clubmoss in controlling seedling emergence of fringed sagebrush in the Northern Mixed Prairie (Bai and Romo, 1995). Precipitation has an overriding influence on seedling dynamics in semiarid grasslands (Defosse et al., 1997a; Potvin, 1993) with more seedlings emerging with above-average precipitation (Aguilera and Lauenroth, 1995; Ambrose and Wilson, 2003; Bai and Romo, 1995, 1996; Karl et al., 1999).

Clubmoss likely plays roles in the structuring and composition of plant communities because of its extensive cover and its potential effects on the soil seed bank and seedling emergence. The influence of clubmoss on seedling emergence of different functional groups of plants may also be modulated by amounts of precipitation. We hypothesized that the effects of seedbeds and clubmoss on seedling emergence vary with functional groups of

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plants and precipitation amount. We tested this hypothesis in the field by observing emergence of forb and graminoid seedlings in all possible combinations of: 1) a control seedbed in which no treatment was imposed; 2) clubmoss removed from the seedbed; 3) clubmoss in the seedbed was killed with Glyphosate; 4) ambient precipitation; 5) precipitation supplemented by irrigating, and; 6) precipitation reduced using rainout shelters. The objectives of this study were to determine 1) the effects of clubmoss, precipitation amounts, and seedbed microsites on the densities of graminoid and forb seedlings emerging from the soil seed bank, and 2) the densities of seedling emerging from the seed banks beneath clubmoss and bare soil in the semiarid Northern Mixed Prairie of central Saskatchewan, Canada.

2. Materials and methods

2.1. Study sites

Research was conducted about 60 km south of Saskatoon, Saskatchewan in the Moose Woods Sand Hills Landscape Area (lat 51°31′N, long 106°48′W, 525 m elevation) of the Moist Mixed Grassland Ecoregion in the Prairie Ecozone (Acton et al., 1998). These sand hills formed along the south shore of Glacial Lake Saskatchewan 11 000 to 14 000 years ago (Christiansen, 1979). The area of study is classified as a Sandy range site (Abouguendia, 1990) with Dark Brown Chernozemic soils belonging to the Asquith association (Ellis et al., 1970). This soil developed on sandy, glacio-fluvial and lacustrine deposits, and is moderately coarse-textured.

The Northern Mixed Prairie of Canada was described by Coupland (1950). The study sites, hereafter referred to as Dundurn and Rudy, were grazed with cattle in late summer to early autumn for many years before conducting these studies with annual utilization of graminoids estimated at 70–80%. Ecological range condition, based on species composition (Abouguendia, 1990), was poor and fair at the Dundurn and Rudy sites, respectively (Colberg and Romo, 2003). Junegrass (*Koeleria macrantha* [Ledeb.] J.A. Schultes), blue grama (*Bouteloua gracilis* [HBK.] Lag.), and needle-and-thread (*Hesperostipa comata* [Trin. & Rupr.] Barkworth) dominated the study sites; common forbs included fringed sagebrush (*Artemisia frigida* Willd.), late yellow locoweed (*Oxytropis campestris* L.), hairy golden aster (*Heterotheca villosa* [Pursh] Shinners.), low goldenrod (*Solidago missouriensis* Nutt.) and Hood's phlox (*Phlox hoodii* Richardson) (Colberg, 2000). Canopy cover of plants excluding clubmoss averaged 39% at the Dundurn study site in 1997, 35% at the same site in 1998, and 34% at the Rudy study site in 1998 (Colberg, 2000).

Annual precipitation in this area averages 338 mm with about 49% of the annual precipitation being received in May, June, and July (Environment Canada and Atmospheric Environmental Service, 2009). Temperatures average 3.4 °C annually and they range from a mean of −17 °C in January to 19 °C in July.

2.2. Seedbed and precipitation treatments

The effects of three seedbed treatments and three precipitation treatments on seedling emergence were tested in 36-3 m by 3 m plots with a 2 m buffer on all sides at each of the two study sites. Seedbeds were manipulated with treatments including: 1) a control in which no treatment was imposed; 2) clubmoss removed, and; 3) live clubmoss killed with Glyphosate (N-[phosphonomethyl] glycine). In the clubmoss removal treatment, the cryptogam was removed from plots by carefully uprooting and removing it with a garden rake with minimal disturbance to the soil and other plants. Live clubmoss was killed in the Glyphosate treatment by applying a 33% solution of the herbicide in water with hand-held spray bottles. Glyphosate was restricted from contacting other plants in the sward by holding spray bottles at ground level and carefully applying the herbicide only on live clubmoss in the 3 m by 3 m plots. Seedbed treatments were applied once to a set of plots at Dundurn in April 1997, and the experiment was repeated on a new set of plots about 2 km away at Rudy beginning in April 1998.

The three seedbed treatments were factorially combined with three precipitation treatments including: 1) ambient precipitation; 2) precipitation supplemented by irrigating, and; 3) precipitation reduced using rainout shelters. Irrigating plots simulated above-average growing season precipitation, reducing precipitation was intended to simulate drought and reduce soil water content, and ambient precipitation was planned to provide an intermediate amount of precipitation and soil water.

On irrigated plots, ambient precipitation was supplemented with one-40 mm application of water in the middle of May, June, July, and August of 1997 and 1998 for a total of 160 mm more water than ambient precipitation each year. The 3 m by 3 m plots were irrigated with fresh, well water applied at a rate of about 45 L min^{-1} using a gas-powered pump and a hose with an adjustable nozzle. Irrigation was intended to increase precipitation to about 75% greater than long-term mean precipitation received from May through August in this area (Environment Canada and Atmospheric Environmental Service, 2009). Irrigating increased the actual May through August precipitation by 73% and 69% in 1997 and 1998, respectively.

Rainout shelters were constructed by building a square frame using boards that were 3 m long, 5 cm wide and 10 cm high; two additional boards of the same size were placed through the center of each shelter for support. Heavy-duty greenhouse plastic was stretched over the frame and secured. The design of rainout shelters is described in detail by Colberg (2000). Rainout shelters were placed about 1.0–1.2 m above the plots by fastening them to posts in each corner of the 3 m by 3 m plots. Rainwater was allowed to run off the rainout shelters into the buffer areas between plots. Rainout shelters were put up on 22 April 1997 and 10 April 1998 and left up until late September each year.

Seedling counts were restricted to a 2 m by 2 m observation area centered in the 3 m by 3 m plots. In early May 1997 and 1998, a permanent, 50 cm by 50 cm quadrat was randomly located within the 2 m by 2 m observation area. The number of forb and graminoid seedlings emerging in the quadrats was determined on seven dates at about two-week intervals from May through August at Dundurn in 1997 and on eight dates at Rudy in 1998. Seedling censuses were done once in May, June, July, and August at Dundurn in 1998.

Seedbed microsites were classified as live clubmoss, dead clubmoss, bare soil, litter, and caespitose grasses. Live clubmoss and dead clubmoss were considered separate microsites because it was expected that living clubmoss would have a greater influence on seedlings by competing for resources. It is also possible that clubmoss exerts physical influences on seedling emergence, and thus dead clubmoss was treated as a separate microsite. A litter microsite is one in which the surface of the seedbed was covered by dead, detached, and procumbent plant material. Litter therefore covered an underlying surface of live clubmoss, dead clubmoss, or bare soil. On each sampling date, individual forbs and graminoids emerging in the permanent quadrat in each plot were marked with color-coded toothpicks and the microsite was recorded. Seedlings were not identified to species.

From May through August, soil water in the 0–5 cm depth was determined by collecting two soil samples from random locations in each 2 m by 2 m observation area using a 2.5-cm diameter soil probe. The two soil samples were combined into one sample, weighed, dried 48 h at 80 °C, and re-weighed. Soil water content was calculated on a dry weight basis. A pressure plate was used to