Association of Soil Conditions and Grass Species with Variable Cover of Leafy Spurge

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ABSTRACT Variation in soil conditions and grass cover was assessed across a range of leafy spurge (*Euphorbia esula* L.) cover values on a sandy rangeland in Manitoba, Canada. Soil conditions varied by site but not in relation to cover of leafy spurge. We observed a significant negative relationship between total grass cover and increasing cover of leafy spurge. Only porcupine grass (*Hesperostipa spartea* [Trin.] Barkworth) had a negative relationship with leafy spurge, falling from high cover at low weed occurrence to only trace levels at the highest leafy spurge abundance. Neither prairie Junegrass (*Koeleria macrantha* [Ledeb.] Schult.), rough bentgrass (*Agrostis scabra* Willd.), nor Kentucky bluegrass (*Poa pratensis* L.) had any relationship to cover of leafy spurge. The negative correlation between porcupine grass and increasing leafy spurge cover is consistent with the interpretation that leafy spurge suppresses growth of this grass. Experimental manipulations are needed to identify causal relationships among these plants.

KEY WORDS *Agrostis scabra*, competition, *Euphorbia esula*, *Hesperostipa spartea*, *Koeleria macrantha*, pin frame, *Poa pratensis*, prairie, soil

Leafy spurge (*Euphorbia esula* L.) is a noxious weed in Manitoba and the surrounding region (Wilson and Belcher 1989) that was introduced to North America over a century ago from Eurasia (Dunn 1985). In western rangelands, this species typically forms extensive patches that can be mapped by remote sensing (Mitchell and Glenn 2009*a*, 2009*b*). Patches of leafy spurge gradually expand radially by seeding (Selleck et al. 1962) and have the capacity to respond to mowing by regrowth (Coupland et al. 1955, Foley et al. 2009) from an extensive root system (Coupland and Alex 1955). A degree of success to suppress leafy spurge has been achieved in the Northern Great Plains by combinations of chemical treatments, cultivation, and biological control (Lym 1998, Joshi 2008). However, attempts to control leafy spurge by chemical means are not always possible, because of policy or cost. Also, attempts at biological control of leafy spurge populations (Mico and Shay 2002, Larson and Grace 2004) by flea beetles (*Aphthona spp*. Chevrolat) are a challenge in sandy soils, because these flea beetle populations have poor establishment on coarse textured soils (Samuel et al. 2008).

Leafy spurge has been shown to modify soil conditions as revealed by reduced growth of native forb seedlings following spurge (Jordan et al. 2008). Leafy spurge occurs on a wide range of soil textures (Samuel et al. 2008) and across disparate environmental conditions at the continental scale (Dunn 1979). However, local leafy spurge abundance varies greatly within a site (Ferrel et al. 1998) or region (Mitchell and Glenn 2009*b*). Information is scarce on potential relationships between leafy spurge abundance and local soil conditions.

Suppression and displacement of native plant species by leafy spurge patches has been reported previously in the ecological literature (Selleck et al. 1962, Belcher and Wilson 1989, Butler and Cogan 2004). After monitoring plots on leafy spurge infested rangeland for eight years, Selleck et al. (1962) reported that annual forbs mostly disappeared, whereas biennial and perennial forbs were somewhat reduced over time in terms of species richness and stem counts. Grass cover, however, was sustained within leafy spurge infestations (Selleck et al. 1962). Comparing rangeland plants on and off leafy spurge patches at multiple locations, Belcher and Wilson (1989) reported that cover was reduced significantly on leafy spurge patches for all four grass species studied. Butler and Cogan (2004) investigated plots within leafy spurge infested and non-infested areas on rangelands. In that study, frequency was reduced by up to 30% for five grass species in infested plots, but it was either not changed or increased within leafy spurge infestations for another three grass species. Given the variability for the impact of leafy spurge on prairie grasses as described above, further data are needed to document these interactions so that strategies for grassland management can be developed for areas where local leafy spurge eradication seems beyond reach in the immediate future.

Thus, the primary objectives of our study were as follows. First, we investigated if variation in leafy spurge cover across a predominantly sandy mixed-grass prairie was related to local soil conditions in terms of plant-available P, total N, organic C, pH, and soil particle size. To our knowledge, local variation in leafy spurge abundance in relation to local soil conditions had not previously been investigated. Our second aim was to evaluate grass species abundance in association with varying cover of leafy spurge. If leafy spurge is detrimental to the growth of the grasses, then reduced grass cover would be expected in areas of greater cover of leafy spurge.

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STUDY AREA

We conducted fieldwork at Canadian Forces Base Shilo (CFBS), Manitoba, Canada. The most abundant plant community on the 40,000-ha rangeland at CFBS was mixed-grass prairie (Shay 1984) with species composition variable among locations but with prominent populations of the following native forbs: cutleaf anemone (*Pulsatilla patens* [L.] Mill. ssp. *multifida*), field sagewort (*Artemisia campestris* L.), prairie sagewort (*A. frigida* Willd.), white sagebrush (*A. ludoviciana* Nutt.), northern bedstraw (*Galium boreale* L.), old man's whiskers (*Geum triflorum* Pursh), stiff sunflower (*Helianthus pauciflorus* Nutt. ssp. *subrhomboideus*), sandcherry (*Prunus pumila* L.), and prairie rose (*Rosa arkansana* Porter). Botanical nomenclature throughout followed United States Department of Agriculture (2013). Mean annual precipitation from 1971 to 2000 was 47.2 cm at the nearest Environment Canada monitoring station located 25 km to the northwest of CFBS at Brandon Airport (Environment Canada 2013). Leafy spurge was first recorded at CFBS in 1920 and was treated with herbicide until 1996 (S. Punak, CFBS, unpublished data). Biocontrol flea beetles were introduced to CFBS and are still present at CFBS, but flea beetle abundance is low (S. Punak, CFBS, unpublished data).

METHODS

Sites and Plots

Soil Conditions and Leafy Spurge Cover.—In 2008, we established four replicate sites with three, 5-m × 5-m (25-m^2) plots marked permanently for each site, for a total of 12 plots. We designated sites as Sites 1 through 4. At each site, we subjectively placed one of the three plots on an area where density of leafy spurge was considered low on the basis of visual inspection. We subjectively placed a second plot on an area where the leafy spurge density was in a similar way considered medium, and a third plot on an area where leafy spurge density was in a similar way considered high. These visual ratings of low, medium, and high had approximate correspondence to respective flower head densities per m^2 of 0–10, 11–25, and > 25, although a flower head census was not undertaken. Within a site, the nearest edges of each of the three 25-m^2 plots were within 5 m of each other. We arranged sites 1 to 4 in a straight line in ascending numerical sequence with respective site-to-site separation of 2 km, 2 km, and 0.5 km. In 2008, we evaluated a separate set of leafy spurge patches to compare soil conditions on and off leafy spurge patches. We used eight patches of leafy spurge that had previously been sketch mapped with the patch center coordinates noted. In each case, we designated an area immediately adjacent to the patch on the west side as the location for the collection of soil off-patch in a zone completely devoid of leafy spurge. We located the eight patches during random hikes across the CFBS prairie in previous years, with neighboring patches separated by distances of 0.1–1.0 km.

Cover of Grass Species in Relation to Leafy Spurge.—In 2009, we re-used the six plots at Sites 2 and 3, along with an additional replicate designated as Site 5, to study grass species cover. We configured Site 5 plots in the identical manner to Sites 2 and 3, as a set of 3 plots at the same 3 levels of leafy spurge abundance (i.e., low, medium and high). Thus, we studied 9 plots of 5 m × 5 m in 2009 across three replicates, Sites 2, 3, and 5. These three sites had similar representation of the more common grass species. Because they had an overwhelming abundance of only a single grass species, we omitted Sites 1 (porcupine grass accounting for 78% of total cover of grass) and 4 (prairie Junegrass accounting for 73% of total cover of grass) from the study of grass cover by species in relation to leafy spurge cover. We separated sites 4 and 5 by 60 m, the distance to a nearby area of infestation convenient for study.

Soil Collection and Analysis

Following soil science protocol (Pennock et al. 2008), we collected a soil sample composed of bulked 2-cm diameter probe samples taken to 15-cm depth at ten random positions within each of the 12 plots in June 2008 across Sites 1–4. We followed similar methodology for sample collection for soils on and off patches of leafy spurge. We allowed soils to air dry immediately following collection to prepare them for storage prior to analysis. We determined soil particle size using the hydrometer method (Gee and Bauder 1986). We determined total N using furnace combustion (Rutherford et al. 2008) at 950°C in a Leco TruSpec analyzer (Leco Corporation, St. Joseph, MI, USA). We determined soil organic C by loss on ignition in a muffle furnace at 400°C (Nelson and Sommers 1996). We applied each of the above analyses to all samples. Limited resources dictated that soil pH and soil P was determined only for soils in the study of soil conditions across a range of leafy spurge abundances, and not for the study of soils on and off patch. We determined soil pH using a pH meter for a 2:1 mass ratio of deionized water to soil after shirring for 60 min. We determined plant-available soil P using the Olsen method, followed by acidification and inductively coupled plasma emission spectrometry (Kuo 1996).

Determination of Plant Cover

Except for patch boundary demarcation by presence and absence, we did not score vegetation in the study of soil conditions on and off patch. For Sites 1–5, we used an 8-pin-frame apparatus to determine percentage cover of leafy spurge and grass species for each plot in 2008 and 2009. A pin-frame scoring system (Goldsmith and Harrison 1976) is not constrained to a maximum of 100%, because multiple plant contacts can be scored for any given pin. We lowered the pin frame into the vegetation and enumerated data every time a plant part touched a pin. We divided the 5-m × 5-m plots into 25, 1-m × 1-m quadrats. We recorded four pin-frame counts in each quadrat. We recorded three counts in succession in one plane in a quadrat, whereas a fourth count was recorded centrally and perpendicular to overlap the first three. We determined percent cover from these counts by recording the total number of counts in a plot for a particular plant species, and dividing by the total number of pins. Given that several leaves usually touched each pin, cover normally exceeded 100%. In the case of each 1-m × 1-m quadrat, the total number of pins was 32. For each 25-m^2 plot in a single year, the total was 800 pins. For the entire study, 16,800 pins were scored. The pins were small (1 mm) in diameter to limit exaggeration (i.e., the likelihood of leaves intercepting pins by virtue of having a larger circumference; Barbour et al. 1987). We identified representative grass specimens using Scoggan (1957) and Barkworth et al. (2007). We deposited voucher specimens at the Brandon University Herbarium with accession numbers in sequence from BU20080722001 to BU20080722004 and from BU20080722007 to BU20080722009.

Data Analysis

We compared soil properties among Sites 1–4 for data collected in 2008 with two-way analysis of variance without interaction (Zar 2011), with site as the first factor at four levels, and with leafy spurge abundance as the second factor at three levels: low, medium, and high. We compared soil properties on and off patch by two-way analysis of variance without interaction, with patch location as one treatment factor at eight levels, and with position as the other treatment factor at two levels: on-patch or off-patch. In all cases, we used a significance level of 5% and separated treatment means where appropriate using the Tukey method. We investigated relationships between cover of leafy spurge and total cover of grass for data collected in 2008, and between cover of leafy spurge and cover of both total grass and individual grass species for data collected in 2009, using linear regression (Zar 2011). We used Statistix 8 (Analytical Software, Tallassee, FL, USA) to conduct all statistical analyses.

RESULTS

Soil Conditions and Leafy Spurge Cover.—Plot configuration successfully generated a range of leafy spurge cover, with no difference ($F_{3, 6}$ = 2.40, P = 0.17) among sites but with the expected difference of leafy spurge cover among plots designated as low, medium, and high: ($F_{2, 6}$ = 52762, P < 0.001; mean cover values were: low = 7%, medium = 130%, and high = 236%). Overall means for soils data are given (Table 1), because there was no effect ($F_{2, 6} \leq 1.27$, $P \geq 0.35$) of leafy spurge abundance on soil conditions: for plant-available P, total N, organic pH, percentage sand, percentage silt, and percentage clay. Total soil N and available soil P were similar (P = 0.32 and 0.36, respectively) among sites, whereas organic enrichment was lower (P = 0.003) at Site 2 relative to Site 4 (Table 1). Soils were of low Olsen-P availability, with overall mean 4.71 mg P kg^{-1}, but total N was moderate, with an overall mean of 3.1 g N kg^{-1} (Table 1). Sites were close to neutrality, although Site 3 had slightly reduced pH (Table 1). Using the texture triangle (Brady and Weil 2010), soils at Sites 1 and 2 were interpreted as sands, whereas those at Sites 3 and 4 were interpreted as loamy sands. Soil conditions were similar on the leafy spurge patches compared to adjacent land without leafy spurge. To-

Table 1. Mean values for soil properties for sites (n = 3) and overall means (n = 12; SD). For the analysis of variance, probability values are given and values of $F_{3, 6}$ for effect of Site. Means within a column followed by different letters are significantly different (P < 0.05).

	Olsen P (mg kg^{-1})	Total N (g kg^{-1})	Organic C (g kg^{-1})	pH	Sand (%)	Silt (%)	Clay (%)
Site							
1	3.5	2.5	31.2 ^{b}	7.00 ^{ab}	93 ^{b}	2 ^{a}	5 ^{a}
2	4.2	4.4	17.4 ^{a}	7.14 ^{b}	93 ^{b}	2 ^{a}	5 ^{a}
3	5.2	2.7	28.8 ^{ab}	6.78 ^{a}	83 ^{a}	10 ^{b}	7 ^{b}
4	5.9	2.9	35.7 ^{b}	7.07 ^{ab}	85 ^{a}	8 ^{b}	7 ^{b}
Value of F	1.5	1.3	10.3	6.7	22.6	15.3	3401.0
Probability	0.32	0.36	0.009	0.024	0.001	0.003	<0.001
Mean	4.7	3.1	28.3	7.0	89	5	6
SD	1.6	1.4	7.8	0.2	5	4	1

tal N ($\bar{x}$ = 2.7 g kg^{-1}), organic C ($\bar{x}$ = 27.2 g kg^{-1}), sand ($\bar{x}$ = 89%), silt ($\bar{x}$ = 8%), and clay ($\bar{x}$ = 3%) were similar ($F_{1,7} \leq$ 4.88, $P \geq 0.06$) on leafy spurge patches compared to adjacent land without leafy spurge.

Cover of Grass Species in Relation to Leafy Spurge.—We found a negative relationship between total grass cover and leafy spurge cover for all sites in 2008 ($F_{1,11}$ = 7.43, P = 0.02; y = 384.3 – 0.84 x; r^2 = 0.43; Fig. 1a). We did not investigate relationships between cover of leafy spurge and cover of individual grass species in 2008 because sites varied widely in grass dominance (Table 2). Site 1 was dominated by porcupine grass (*Hesperostipa spartea* [Trin.] Barkworth) whereas Site 4 was dominated by prairie Junegrass (*Koeleria macrantha* [Ledeb.] Schult.), with approximate co-dominance by these two species at Sites 2 and 3 (Table 2).

In 2009, Sites 2, 3, and 5 all had approximate co-dominance of porcupine grass and prairie Junegrass (Table 2). Other grasses recorded at lesser abundance were rough bentgrass (*Agrostis scabra* Willd.), Kentucky bluegrass (*Poa pratensis* L.), smooth brome (*Bromus inermis* Leyss.), little bluestem (*Schizachyrium scoparium* [Michx.] Nash), and Rocky Mountain fescue (*Festuca saximontana* Rydb.; Table 2). We found a negative relationship between total grass cover and leafy spurge cover for Sites 2, 3, and Site 5 in 2009 ($F_{1,8}$ = 21.46, P = 0.002; y = 473.0 – 0.86 x; r^2= 0.75; Fig. 1b). During 2009, for a single grass species the only significant negative relationship we documented was between porcupine grass and leafy spurge cover ($F_{1,8}$ = 8.38, P = 0.02; y = 241.6 – 0.85 x; r^2= 0.55; Fig. 2a). There was no significant ($F_{1,8} \leq$ 1.18, $P \geq 0.31$) relationship between cover for grass and leafy spurge for prairie Junegrass (Fig. 2b), rough bentgrass (Fig. 2c), or Kentucky bluegrass (Fig. 2d). Insufficient abundance of smooth brome, little bluestem, and Rocky Mountain fescue precluded investigation of relationships in 2009 between these species and leafy spurge.

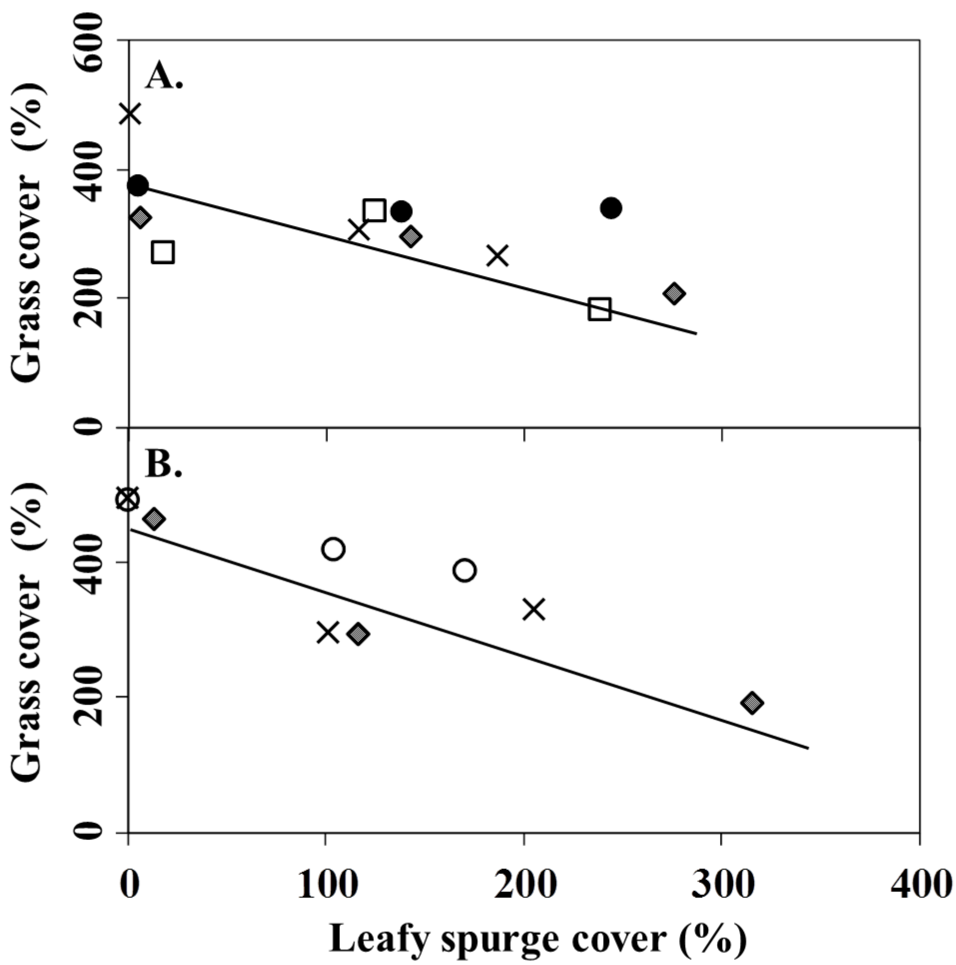

Figure 1. Percentage cover in (a) 2008 for n = 12 plots, and (b) 2009 for n = 9 plots, of all grasses on the y-axis against percentage leafy spurge cover on the x-axis. Each point on the graph is a mean percentage cover based on 800 pins. Sites are indicated as follows: Site 1 (hollow square), Site 2 (shaded diamond), Site 3 (X), Site 4 (filled circle), and Site 5 (hollow circle). The fitted regression lines are given.

Table 2. Percentage cover of leafy spurge, and of all recorded grass species, averaged across three 5-m × 5-m plots at each site. For a given site-year combination, each cover is a percentage for three plots × 800 pins per plot = 2,400 pins, as scored with a pin-frame apparatus.

Location	Site 1	Site 2		Site 3		Site 4	Site 5
Year	2008	2008	2009	2008	2009	2008	2009
Species	Cover (%)						
leafy spurge	127	141	149	101	102	129	91
prairie Junegrass	34	150	176	133	184	256	211
porcupine grass	207	123	138	143	163	14	133
rough bentgrass	4	2	0	3	24	46	76
Kentucky bluegrass	2	0	2	37	1	26	13
smooth brome	17	0	0	0	0	6	1
little bluestem	0	0	0	4	3	0	0
Rocky Mountain fescue	1	0	0	0	0	1	0

DISCUSSION

Soil analyses found differences among sites, yet all sites remained within the broad category of neutral sandy soils with low plant-available soil P and moderate surface enrichment of both organic C and total N. The organic enrichment at the surface of the plot areas was consistent with the black color of the surface soil and the continuous vegetation cover at the sites studied. In contrast, limited sections of the CFBS separate to the sites studied have discontinuous plant cover, intermittently exposing fox-colored sand without organic enrichment at the soil surface. The sites studied therefore have soil conditions that are broadly representative of much of CFBS.

He and Guo (2006) showed that mixed-grass prairie has a leaf area index with mean 1.25 and a range from 0.44 to 3.85 (n = 60), which was consistent with our finding of cover exceeding 100%. Leafy spurge variation in cover up to 300% was not related to local soil conditions. Instead, leafy spurge appears to grow at cover values that vary independently of soil conditions. In addition, soil conditions were similar on leafy spurge patch when compared to adjacent land free of leafy spurge. It is possible that the range of leafy spurge abundance in the field is related to the patchy growth of this species and the gradual radial expansion of those patches over decades (Selleck 1962). Grasses were found to persist in patches of leafy spurge, with a grass cover of approximately 200%, even when leafy spurge was at a cover of about 300% (Fig. 1, Fig. 2). However, individual grass species had different patterns of association with leafy spurge. Only porcupine grass had a negative relationship with increasing cover of leafy spurge. At the highest levels of leafy spurge cover, porcupine grass was reduced to trace levels. This negative association is consistent with the interpretation that higher density of leafy spurge causes a reduction in porcupine grass cover, such as by competition for resources. However, the data indicate correlation only, with no insight for causal relationships. A plausible alternative interpretation may be that the leafy spurge grew better where the porcupine grass was already at low abundance. In contrast to our findings, Butler and Cogan (2004) reported that porcupine grass was persistent in leafy spurge infestation, although cover data were not given.

Among the grasses studied, the most striking case of a grass species not influenced by leafy spurge was prairie Junegrass, which maintained cover of close to 200% at all levels of leafy spurge cover (Fig. 2b). Sustained abundance of prairie June grass found across a range of leafy spurge cover was surprising, given previous research by Belcher and Wilson (1989), who noted that porcupine grass and prairie Junegrass had reduced cover on-patch compared to off-patch. Our results suggested that variation in association between porcupine grass, prairie Junegrass, and leafy spurge was not related to season of growth given that both grasses are C_3 plants (Waller and Lewis 1979), whereas leafy spurge is a C_4 plant (Ziska and Dukes 2010). Kentucky bluegrass and rough bentgrass were at lower abundance compared to the more dominant porcupine grass and prairie Junegrass, but they had no relationship to leafy spurge cover. Thus, potential effects of higher or lower relative abundance did not facilitate a negative relationship between grass cover and leafy spurge. The lack of significant relationships between cover for leafy spurge and grass species (other than porcupine grass) indicated there was no apparent suppression of growth by leafy spurge for prairie Junegrass, rough bentgrass, and Kentucky bluegrass. The Kentucky bluegrass at CFBS is *Poa pratensis* L. subsp. *angustifolia* (L.) Lej., which is itself introduced from Eurasia (Barkworth et al. 2007). Kentucky bluegrass

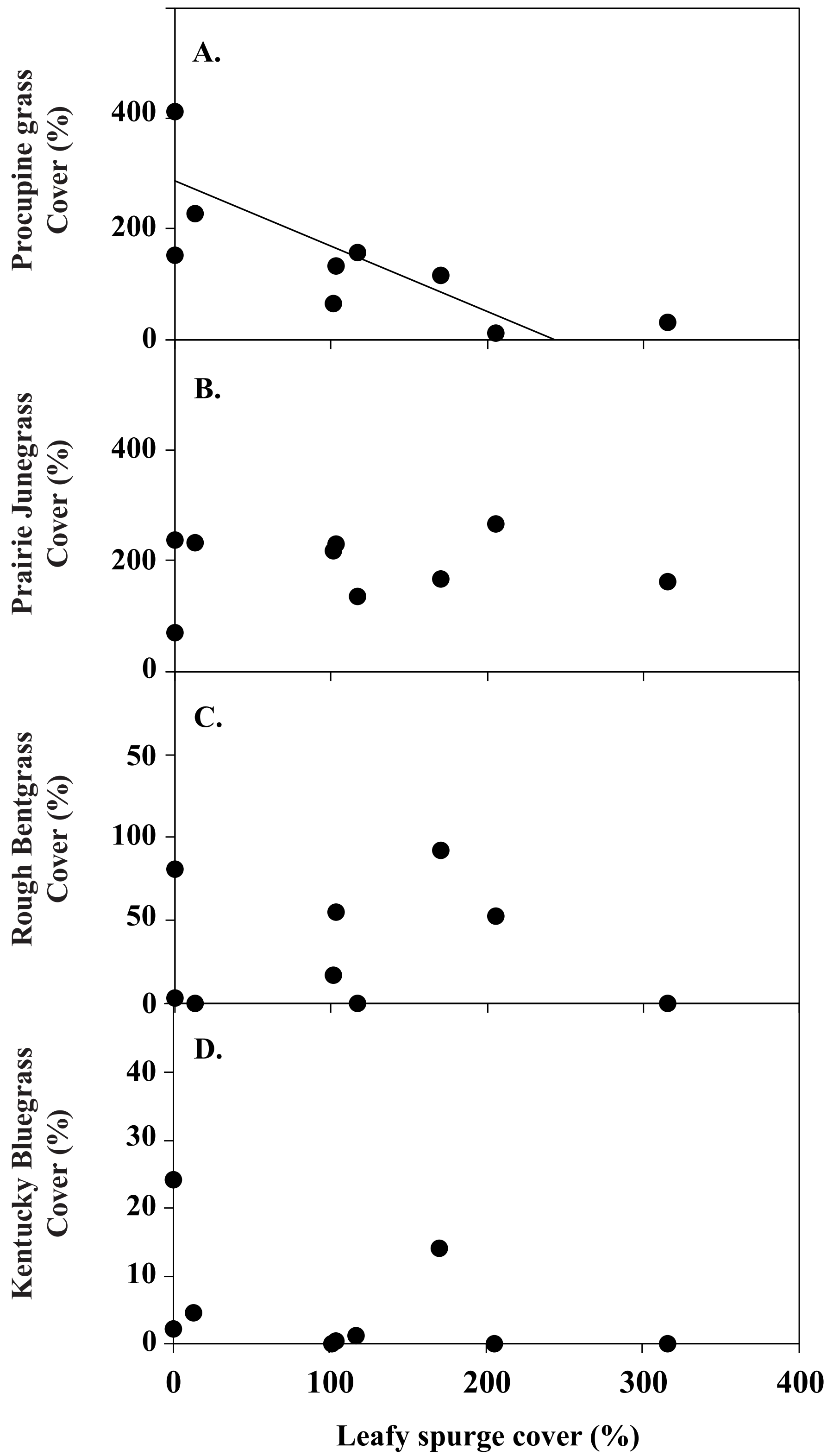

Figure 2. Percentage cover in 2009 of (a) porcupine grass, (b) prairie Junegrass, (c) rough bentgrass, and (d) Kentucky bluegrass on the y-axis against percentage leafy spurge cover on the x-axis. For each grass, $n = 9$ plots. Each point on the graph is a mean percentage cover based on 800 pins. The fitted regression line is given for porcupine grass, but no lines are fitted for the other grasses, because there were no other significant relationships.

germination is influenced by microsite topography (Bookman 1983), which may limit the spread of this grass at CFBS (Table 2). Butler and Wacker (2010) reported that Kentucky bluegrass replaced leafy spurge as the dominant species following successful biological control of leafy spurge by flea beetles.

MANAGEMENT IMPLICATIONS

Rangeland management for areas with infestations of leafy spurge should consider the possible threat of this invasive weed to porcupine grass. Possibly, suppression of porcupine grass may already be in progress. However, management implications for leafy spurge impact on porcupine grass are tentative pending manipulative experiments designed to investigate cause-and-effect relationships. The patchiness of leafy spurge on the landscape may limit any negative impacts to local populations of porcupine grass. Refuges may persist in nearby off patch areas, from which grass populations can subsequently expand and recolonize any areas for which leafy spurge starts to decline. Prairie Junegrass and rough bentgrass had no change in cover across a range of leafy spurge abundance, yet monitoring of these grasses should continue given the persistent high levels of leafy spurge in the environment. Kentucky bluegrass, having been introduced to the Northern Great Plains, may constitute a threat of its own for possible modification of the native species composition of the prairie.

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