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POTENTIAL FOR CONTROLLING THE SPREAD OF *CENTAUREA MACULOSA* WITH GRASS COMPETITION

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ABSTRACT.—Spotted knapweed (*Centaurea maculosa* Lam.) is a major rangeland and roadside weed of the northern Rocky Mountains. It is often found in plant communities dominated by *Pseudoroegneria spicatum* or *Festuca idahoensis*, but it rarely invades roadsides dominated by *Bromus inermis* Leyss. Aboveground biomass of the 3 grass species grown in mixture with *Centaurea* was compared to growth in monoculture at a range of nitrogen input levels. The results suggest that *Bromus* is capable of suppressing the growth of *Centaurea* with the degree of suppression increasing with increasing nitrogen levels. The 2 native grasses had no impact on *Centaurea* under the controlled environment conditions of this study.

Key words: competition, weed control, Centaurea maculosa, Bromus inermis, Agropyron spicatum, Festuca idahoensis, *exotic plants.*

Centaurea maculosa Lam. (spotted knapweed) is a major weed associated with spring wet–summer dry areas of the northern Rocky Mountains (Forcella and Harvey 1981, Tyser and Key 1988, Weaver et al. 1989). *Centaurea* dominates waste places, invades disturbed rangeland, and sometimes invades undisturbed range (Tyser and Key 1988). In contrast, it rarely invades roadsides dominated by *Bromus inermis* Leyss. (Weaver et al. 1989). This suggests that it may be excluded from waste places that are planted to *Bromus* before *Centaurea* invades. Alternatively, because planting exotics violates the charge of national park managers, one may ask whether *Centaurea* might also be excluded from disturbed areas by planting native grasses that naturally dominate either relatively dry (*Pseudoroegneria spicatum* [Pursh] Scribner and Smith = *Agropyron spicatum*) or more moist (*Festuca idahoensis* Elmer.) foothill habitats.

Weed suppression may be accomplished by (1) preempting resources with more competitive plant species or (2) using biocontrols or herbicides that selectively increase weed mortality, decrease vigor, or prevent reproduction (Lindquist et al. 1995). This study considers management of *Centaurea maculosa* by competition rather than by common herbicide and biocontrol methods. This approach deserves attention because it may be less expensive and more effective than herbicides in the long term.

Our objective was to measure the competitive ability of 3 grass species against *Centaurea* in 2-way interaction experiments in sand culture. Mixture and monoculture treatments were tested for 12 wk at 5 positions on a nitrogen gradient to determine whether competitive relations were influenced by differences in nitrogen availability. A plant's ability to compete is related to its growth rate or ability to gain biomass relative to associated species (Harper 1977). We compared aboveground biomass of each species grown in mixture with *Centaurea* to its growth in monoculture.

MATERIALS AND METHODS

The rhizomatous exotic pasture grass *Bromus inermis* Leyss. and 2 native bunchgrasses normally dominating relatively dry foothills (*Pseudoroegneria spicatum*) or moister grasslands immediately above and below the conifer zone (*Festuca idahoensis*) were grown in 2-species mixtures (replacement series) with *C. maculosa*.

Experiments consisted of 3 competition treatments (monocultures of both grass and *Centaurea*, and 50:50 mixture) combined with 5 nitrogen addition treatments. Each treatment combination had 10 replicates. Within each experiment, pots were arranged in a completely randomized design on a greenhouse bench and rotated weekly to minimize position effects. Each experiment was subject to different light

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conditions because of its position in the greenhouse. A square planting pattern was used with 4 plants spaced 5 cm apart. In each pot in the mixture treatments, plants of the same species were located on the diagonal.

Seeds were planted at a depth of 1.0 cm in 1000-cm^3 pots filled with coarse washed sand. Pots were watered daily for 1 wk to allow seedling establishment. Excess seedlings were thinned and remaining seedlings allowed to grow for an additional week prior to the addition of nutrients. The basic nutrient solution was balanced with respect to all essential nutrients but could be varied to allow the establishment of nitrogen levels from 0%, 1%, 10%, 30%, and 100% of a standard level (Machlis and Torrey 1956). Sufficient nutrient solution (200 ml) was applied to saturate the pot twice weekly and water (200 ml) was added once each week. Regular watering with nutrient solution and alternate washing with tap water held the soil solution near the applied level and prevented any concentration of the soil solution due to evapotranspiration. Experiments were conducted during March, April, and May 1988, when greenhouse temperatures ranged from 14° to 32° C (25° C mean).

Twelve weeks after emergence, plants in each pot were clipped at the soil surface, separated by species, dried at 45° C for 5 d, and weighed.

Nonlinear regression procedures (SAS 1988, Gauss-Newton least squares estimation method) were used to fit a rectangular hyperbola equation [1] (Cousens 1985) to mixture and monoculture data for each species:

$$B = \frac{I_i \cdot N}{\left(1 + \frac{I_i \cdot N}{A_i}\right)} \qquad [1]$$

where B = aboveground dry biomass (g $plant^{-1}$), A_i = maximum aboveground biomass of species i (g $plant^{-1}$), N = relative nitrogen addition level, and I_i = biomass of species i as relative nitrogen addition level approaches zero.

To determine the relative success of *Centaurea* in competition with each grass species, estimates of A_i and I_i were compared between mixtures and monocultures using the extra sum of squares procedure (Ratkowsky 1983, Lindquist et al. 1996). In addition, relative competition intensity (RCI; Grace 1995) was calculated to determine whether competitive relationships varied across relative nitrogen levels. RCI is calculated as

$$\mathrm{RCI} = (\mathrm{B_{mono}} - \mathrm{B_{mix}})/\mathrm{B_{mono}} \qquad [2]$$

where B_{mono} and B_{mix} are the aboveground dry biomass (g $plant^{-1}$) for a species grown in monoculture and mixture, respectively. A negative RCI value indicates that the species performs better in mixture than in monoculture. RCI may be the best measure for determining species displacement under competitive conditions across a resource gradient (Grace 1995). Analysis of variance was used to test for differences in RCI within a species across nitrogen treatments. Student's t was used to compare RCI between species at each nitrogen addition level.

RESULTS

A hyperbolic relationship between individual plant biomass and relative nitrogen level was found in all mixtures and monocultures (Figs. 1a–f). Estimates of I_i (biomass at intercept) differed between mixtures and monocultures only for *Centaurea* grown in mixture with *Bromus* (Table 1). Estimates of A_i (maximum biomass) differed for *Bromus* and *Centaurea* (Table 1).

Relative competition intensity was significantly negative for *Bromus* at all nitrogen addition levels; it varied from negative values at low nitrogen to positive values at higher nitrogen levels for *Centaurea* in competition with *Bromus* (Fig. 2). However, RCI did not differ from zero in the experiments where *P. spicatum* and *F. idahoensis* were in competition with *Centaurea* (data not shown).

DISCUSSION

Growth response of *Bromus* to nitrogen was greater in mixture with *Centaurea* than in monoculture, as indicated by the regression lines (Fig. 1a) and the negative RCI values across all nitrogen addition levels (Fig. 2). In contrast, growth response of *Centaurea* was lower in mixture with *Bromus* than in monoculture (Fig. 1). The increase in *Centaurea* RCI at high relative nitrogen level indicates that *Bromus* is a better competitor in the high nitrogen treatments (Fig. 2). Results suggest that *Bromus* is capable of suppressing the

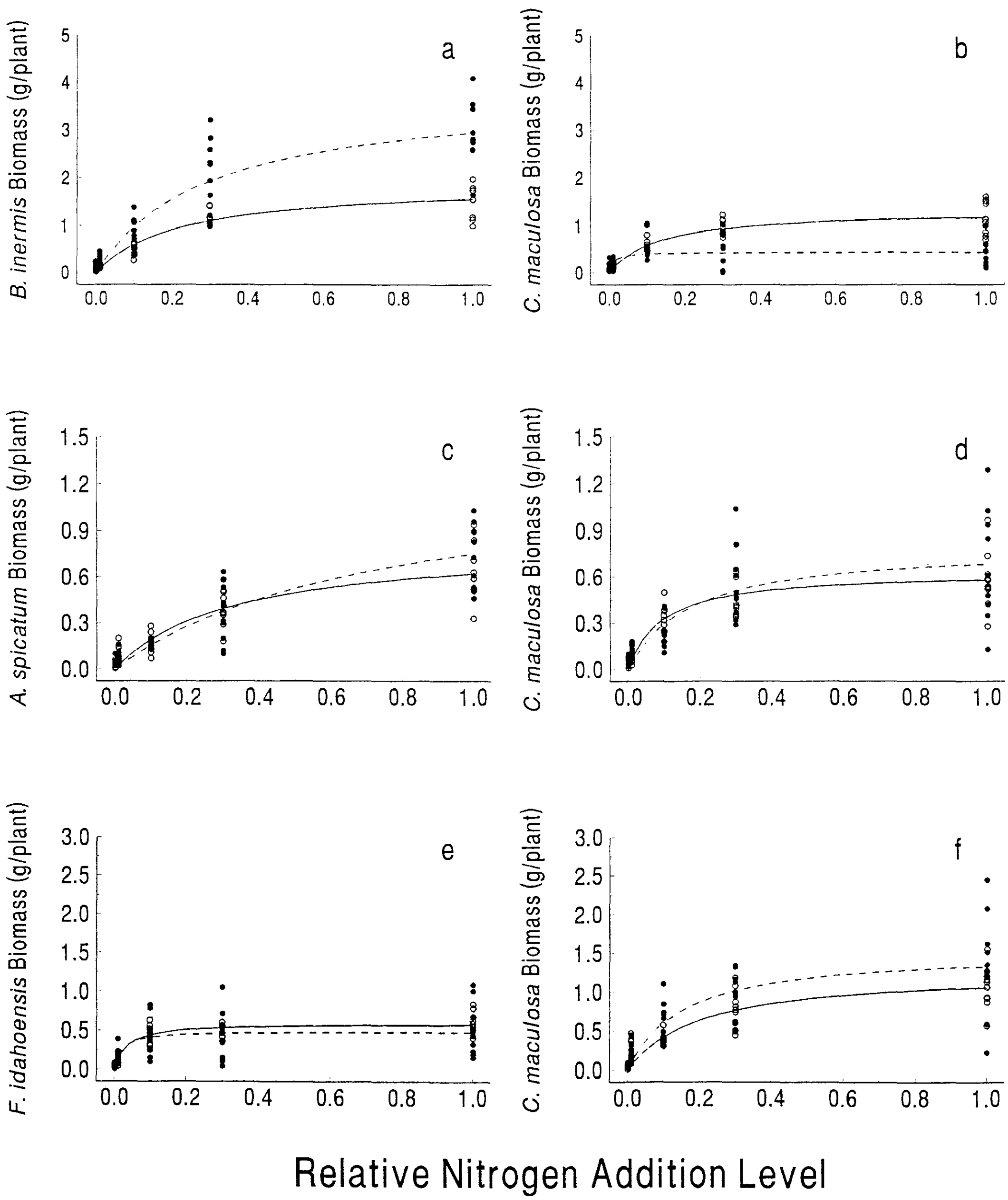

Fig. 1. Plot of observed (○) and predicted (•) aboveground dry biomass plant^{-1} on relative nitrogen addition level when grown in monoculture (____) and mixture (----): a, *Bromus* grown in monoculture and in mixture with *Centaurea*; b, *Centaurea* grown in monoculture and in mixture with *Bromus*; c, *Pseudoroegneria* grown in monoculture and in mixture with *Centaurea*; d, *Centaurea* grown in monoculture and in mixture with *Pseudoroegneria*; e, *Centaurea* grown in monoculture and in mixture with *Festuca*; f, *Festuca* grown in monoculture and in mixture with *Centaurea*.

TABLE 1. Estimates of parameter values followed by asymptotic standard errors for maximum aboveground biomass (g plant^{-1}) (A), biomass as relative nitrogen level approaches zero (I), and the coefficient of determination (r^2) obtained from fitting equation [1] to monoculture and mixture data of each species. Variation in I and A between competition treatments was tested using the extra sum of squares principle, with P value indicating the significance level for the comparison of parameter (Coeff) values from the monoculture and mixture regressions.

Species	Coeff	Competition treatment		P value
		Monoculture	Mixture	
Bromus	A	1.884(0.115)	3.819(0.361)	<0.000
	I	8.769(1.141)	12.893(2.197)	0.283
	r^2	0.90	0.84	
Centaurea with *Bromus*	A	1.306(0.082)	0.438(0.056)	<0.000
	I	10.621(1.861)	45.717(35.47)	0.023
	r^2	0.85	0.14	
Pseudoroegneria	A	1.289(0.237)	0.827(0.087)	0.081
	I	1.758(0.323)	2.490(0.442)	0.410
	r^2	0.80	0.82	
Centaurea with *Pseudoroegneria*	A	0.636(0.048)	0.805(0.107)	0.307
	I	6.770(1.639)	4.617(1.454)	0.665
	r^2	0.77	0.60	
Festuca	A	0.595(0.029)	0.491(0.056)	0.303
	I	16.747(3.892)	23.921(14.925)	0.857
	r^2	0.83	0.39	
Centaurea with *Festuca*	A	1.262(0.114)	1.522(0.172)	0.514
	I	6.418(1.295)	10.061(2.870)	0.535
	r^2	0.77	0.66	

growth of *Centaurea*, the degree of suppression increasing with increasing nitrogen levels.

Growth response of *Pseudoroegneria* and *Festuca* to nitrogen when growing in mixture with *Centaurea* did not differ from their response in monoculture. Likewise, growth response of *Centaurea* did not differ between monoculture and mixtures with *Pseudoroegneria* or *Festuca*. Therefore, these results suggest that these native grasses are not likely to increase or suppress growth of *Centaurea*, regardless of nitrogen addition level. This result is contrary to the observed invasion of *Centaurea* into communities dominated by these grasses. One explanation may be that disturbance (especially grazing) in the field creates gaps in the grass community where *Centaurea* can establish itself even though it is not a superior competitor for resources.

Competitive interactions were greater between each grass species and *Centaurea* at the high end of the nitrogen gradient. This may be a function of rapid growth. Thus, in nitrogen-rich environments fast-growing plants may rapidly occupy space and usurp resources to the exclusion of slow-growing species (Grime 1979, Radosevich and Holt 1984). Similar competitive effects may be expected to occur on other soil resource gradients, assuming adaptations for acquisition of nitrogen and other mobile nutrients, as well as water, are similar (Grime 1979, Fitter and Hay 1987). In addition, one may hypothesize, based on the resource ratio theory (Tilman 1982), that *Bromus* is a superior competitor for nutrients other than nitrogen relative to *Centaurea.* By increasing nitrogen, both species should be limited by essential nutrients other than nitrogen, and the species with the lowest R* (the superior competitior) for the other nutrients should displace the species with the higher R* for the same nutrients (Tilman 1990).

The ability of *Bromus* to out-compete *Centaurea* in nutrient culture provides one explanation for the observed population dynamics of *Centaurea* in the field. Roadsides seeded with *Bromus* are rarely invaded by *Centaurea* (Weaver et al. 1989). Both field and laboratory observations suggest that disturbed sites seeded simultaneously with *Centaurea* and the exotic, *Bromus*, will be dominated by *Bromus*. The effectiveness of *Bromus* in suppressing *Centaurea* may be increased with fertilization. Furthermore, it may be expected that established *Bromus* plants will suppress the growth of *Centaurea* seedlings. The results of this study suggest that at the seedling stage *Bromus* may be used to competitively exclude *Centaurea*. This method of weed management merits trial in the field. On the other hand, the regional dominants,

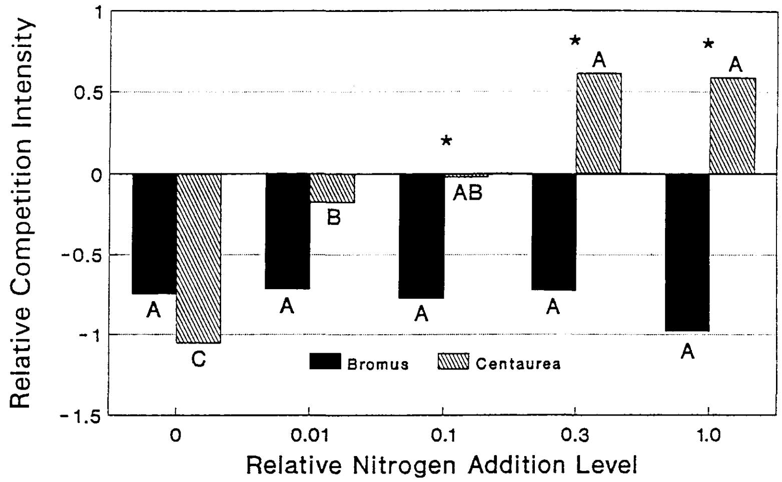

Fig. 2. Relative competition intensity (RCI) of *Bromus* and *Centaurea* across 5 relative nitrogen addition levels. Letters above bars indicate whether RCI varies (Duncan's multiple range test, $P < 0.05$) within species across nitrogen level. An asterisk indicates that RCI differs ($P < 0.05$) among species at that nitrogen level.

Pseudoroegneria and *Festuca*, probably would not sufficiently suppress *Centaurea* to decrease the potential for invasion.

Advantages of the competitive method over herbicides and biocontrol treatments used to manage *Centaurea* are its long duration and low environmental impact. Given these advantages, exclusion of *Centaurea* with *Bromus* merits trial in environments where the danger of invasion exists.

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