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Grass defoliation intensity, frequency, and season effects on spotted knapweed invasion

JAMES S. JACOBS AND ROGER L. SHELEY

Authors are post-doctoral research associate and associate professor, Department of Land Resources and Environmental Sciences, Montana State University, Bozeman, Mont. 59717.

Abstract

Preventing the invasion of uninfested rangeland is central to managing spotted knapweed (*Centaurea maculosa* Lam.). Intensity, frequency, and season of grass defoliation determine the ability of grasses to tolerate grazing and resist weed invasion. We hypothesized that as grass defoliation intensity increases, spotted knapweed cover, density, and biomass would increase, that increasing defoliation frequency would increase the intensity effect, and that spring defoliation would cause a greater increase in spotted knapweed than summer defoliation. We hand clipped grasses in 1 m^2 plots at 2 spotted knapweed infested Idaho fescue (*Festuca idahoensis* Elmer) sites in western Montana. Clipping treatments were 4 intensities (0, 30, 60, and 90% of the foliage), 3 frequencies (1, 2, and 3 at 14-day intervals), and 2 seasons (spring beginning in mid-May and summer beginning in mid-July), factorially arranged in a randomized-complete-block design with 4 replications for a total of 24 treatments per replication. Treatments were applied in 1995 and 1996. By 1997 grass cover and density were reduced by defoliation intensity of 90%. Defoliation frequency greater than once caused a reduction in grass cover and density at the 60% intensity. Spring defoliation caused a greater reduction in grass cover and density than summer defoliation. Grass biomass was reduced by the 30% defoliation treatment. Grass defoliation intensity greater than 60% caused an increase in spotted knapweed cover and density. Defoliation more than once increased spotted knapweed cover. Spring defoliations increased spotted knapweed cover compared to summer defoliations. Spotted knapweed biomass was not affected by defoliation treatments. Our study suggests that an annual single grass defoliation of 60% or less, regardless of the season, will not increase spotted knapweed invasion on rangeland.

Key Words: *Centaurea maculosa*, weed invasion, grazing management, Idaho fescue

Resumen

Un punto importante en el manejo del "Spotted knapweed" (*Centaurea maculosa* Lam.) es el prevenir la invasión de pastizales no infestados con esta especie. La intensidad, frecuencia y época de defoliación de los zacates determina su capacidad para tolerar el apacentamiento y resistir la invasión de maleza. Hipotetizamos que: 1) conforme aumenta la intensidad de defoliación del zacate, la cobertura, densidad y biomasa de "Spotted Knapweed" se incrementaría, 2) incrementando la frecuencia de defoliación, el efecto de la intensidad de defoliación sería mayor y 3) la defoliación en primavera causaría un mayor incremento de "Spotted knapweed" que la defoliación en verano. Cortamos manualmente los zacates en parcelas de 1 m^2 en 2 sitios de "Idaho fescue" (*Festuca Idahoensis* Elmer), localizados en el oeste de Montana e infestados con "Spotted knapweed". Los tratamientos de corte consistieron de 4 intensidades (0, 30, 60 y 90 % del follaje), 3 frecuencias (1, 2 y 3 a intervalos de 14 días) y 2 épocas (inicio de primavera a mediados de Mayo e inicios de verano a mediados de Julio). El diseño experimental fue el de bloques completos al azar en arreglo factorial con 4 repeticiones, con un total de 24 tratamientos por repetición. Los tratamientos se aplicaron en 1995 y 1996. La intensidad de defoliación de 90% redujó la cobertura y densidad de los zacates. Con la intensidad de defoliación de 60%, la frecuencia de defoliación mayor de una vez disminuyó la cobertura y densidad de los zacates. La defoliación en primavera produjó una mayor reducción en la cobertura y densidad de los zacates que la defoliación en verano. La biomasa de los zacates se redujo con el tratamiento de defoliación de 30%. La intensidad de defoliación mayor de 60% provocó un incremento en la cobertura e intensidad de "Spotted knapweed". La defoliación en primavera incrementó más la cobertura de "Spotted knapweed" que la defoliación en verano. Los tratamientos de defoliación no afectaron la biomasa de "Spotted knapweed". Nuestro estudio sugiere que una sola defoliación anual del zacate al 60% o menos, sin importar la época, no incrementará la invasión de "Spotted knapweed" en el pastizal.

Spotted knapweed (*Centaurea maculosa* Lam.) is a perennial noxious weed native to the steppic grasslands of southeastern Europe and Asia Minor. This invasive weed was introduced to North America around 1883 (Groh 1944) and has been spreading rapidly during this century. In Montana, where spotted knapweed is the most wide-spread noxious rangeland weed, it has been spreading at an average rate of 27% per year over the last 80 years (Chicoine et al. 1985). This weed has been reported in 326 counties throughout 15 western states

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and 2 Canadian provinces. It has been estimated that spotted knapweed currently infests about 2.5 million ha in the western U.S. and Canada (Sheley et al. 1998). In perennial bunchgrass communities, spotted knapweed is associated with loss of biodiversity (Tyser and Key 1989), reductions of wildlife habitat and livestock forage (Watson and Renney 1974, Spoon et al. 1983), and increased soil erosion (Lacey et al. 1989).

Preventing the invasion of uninfested rangelands is central to managing spotted knapweed (Sheley et al. 1998). Integrated management of spotted knapweed infested rangeland has been summarized by Sheley et al. (1998), and identifies establishing and/or maintaining competitive desirable plants as an important part of any successful prevention program. Historically, grazing has been used to maintain grass on western rangeland, and the effects of grazing on grasses are well studied. However, managing grazing to maintain competitive plant communities to prevent weed invasion is poorly understood. It is generally believed that grazing accelerates weed invasion (Maxwell et al. 1992).

Intensity, frequency and timing of grass defoliation determine the ability of grasses to tolerate grazing and resist weed invasion (Maschinski and Whitham 1989, Briske 1990). Recent studies have investigated the relationship between grass defoliation and weed invasion. A single severe (> 60% of the grass foliage) defoliation of a bluebunch wheatgrass [*Pseudoroegneria spicata* (Prush.) Löve], needle-and-thread (*Stipa comata* Trin. & Rupr.) or crested wheatgrass (*Agropyron cristatum* (L.) Gaertn.) community enhanced diffuse knapweed (*Centaurea diffusa* L.) establishment (Sheley et al. 1997). Increasing both defoliation level and frequency of Idaho fescue (*Festuca idahoensis* Elmer) plants grown in pots in a controlled environment caused an increase in soil water content and an increase in spotted knapweed seedling emergence and growth (Jacobs and Sheley 1997). These results suggest that moderate intensity and infrequent grazing will not encourage weed invasion.

Timing of defoliation also impacts grass vigor and could affect its ability to compete with weeds. A single severe defoliation of bluebunch wheatgrass during the period between 26 May and 28 June reduced herbage production the following year more than early spring or fall defoliation (Blaisdell and Pechanec 1949). The impact of defoliation on Idaho fescue was greatest when clipped in late-July and August, during flowering and seed ripening, compared to defoliation during early growth or after the foliage began to dry (Mueggler 1967). More recent studies show that grasses are able to recover from early season defoliation with less use of root carbohydrate reserves, that late-season defoliations reduce reserves because more has been invested by the grass, and after seed set, carbohydrates are transported to the roots from the leaves (Engle et al. 1998).

The objective of this study was to determine the effect of intensity, frequency and season of grass defoliation on spotted knapweed and grass density, cover, and biomass over a 3-year period. We expected that as defoliation intensity increases, spotted knapweed cover, density and biomass would increase, increasing defoliation frequency would enhance the defoliation intensity effect, and that spring defoliation would have a greater impact on spotted knapweed than summer defoliation.

Materials and Methods

Study sites

Field studies were conducted during 1995, 1996, and 1997 on 2 sites in western Montana. Both sites were within a *Festuca idahoensis/Agropyron spicatum* habitat type (Mueggler and Stewart 1980). Site 1 was on Cayuse Trail, 10 km west of Bozeman, Mont., level, and at an elevation of 1,340 m. The soil was a complex consisting of 70% Beaverton cobbly loam (Loamy-skeletal over sandy-skeletal, mixed, Typic Argiustolls) and 30% Hylite loam (Fine-loamy, mixed, Typic Argiborolls). Idaho fescue was the dominant species with mean cover of 44% (N=20, SD=3.9). Subdominant grasses included bluebunch wheatgrass, timothy (*Phleum pretense* L.), and Kentucky bluegrass (*Poa pratensis* L.). Spotted knapweed density at the beginning of the study was 46 (N=20, SD=40) plants m^{-2}. Average annual (60 year) precipitation is 350 mm with a bimodal distribution with peaks in autumn and spring. Temperatures range from 36 to –35°C with a frost free season of 90 days.

Site 2 was located in Hodgeman Canyon, 15 km northwest of Bozeman, Mont. The soil was a Bavdark loam (Fine-loamy, mixed Argic Pachic Cryoborolls) with a 10 to 20% northwesterly slope and 1,400 m elevation. Spotted knapweed was the dominant species on this site with a mean density of 824 (N=20, SD=187) plants m^{-2}. Grasses were predominantly Idaho fescue with low densities of bluebunch wheatgrass, onespike oatgrass (*Danthonia unispicata* (Thurb.) Munro ex Macoun) and timothy. Mean grass cover at Hodgeman Canyon was 25% (N=20, SD=4.3). Average annual (60 year) precipitation is 510 mm with a bimodal distribution with peaks in autumn and spring. Temperatures range from 35 to –31°C with a frost free season of 60 days.

Experimental Design

Twenty-four treatments (4 defoliation levels, 3 defoliation frequencies, 2 seasons) were applied to 1 m^2 plots factorially arranged in a randomized-complete-block design. The experiment was replicated 4 times at each site. The defoliation levels were 0, 30, 60, or 90% of the upper portion of the grass foliage and tillers. Grass was hand clipped, simulating ungrazed, light, moderate and severe grazing (McKinney 1997). Clipped foliage was removed from the plots. Defoliation frequencies were 1, 2, or 3 clippings at 14-day intervals. Defoliation seasons were spring, beginning in mid-May, and summer, beginning in mid-July. There were 3 clippings at each season. Defoliation treatments began in spring 1995 and were repeated in 1996.

Sampling

Density of spotted knapweed and cover of spotted knapweed and grass were sampled in September 1995 at both sites and in 1996 at Cayuse Trail. Early snowfall prevented density and cover sampling at Hodgeman Canyon in 1996. During the last week of July and the first week of August 1997, density, cover and biomass were sampled. Spotted knapweed density was measured by counting the number of rosettes and flowering stems within a 10 by 50 cm frame (Daubenmire 1970) placed randomly in each plot. Cover was estimated for spotted knapweed and grass within the frame using 6 cover classes: 0–5%

(1), 6-25% (2), 26-50% (3), 51-75% (4), 76-95% (5), and 96–100% (6) of the ground covered. Biomass of spotted knapweed and grass was harvested in the last week of July and the first week of August 1997 by clipping all species within a randomly placed 0.5 m^2 hoop at the soil surface. Samples were dried at 60°C until weights were constant, separated by species, and weighed.

Data Analysis

Treatment effects on density, cover and biomass were analyzed using standard analysis of variance procedures. Each site was analyzed separately. Density of spotted knapweed and all cover variables were analyzed using a split-plot in time with defoliation treatments and their interactions as the wholeplots. Wholeplots were tested using the mean square error of block X defoliation intensity X defoliation frequency X defoliation season. Year and all year X defoliation interactions were included in the subplot analysis. Subplots were tested using the residual mean square as the error term. Biomass was analyzed using analysis of variance testing main effects and all interactions. When a significant (P≤0.05) F-test was calculated, differences among means were tested using protected least significant differences procedures (Peterson 1985).

Results

Cover

The effect of defoliation intensity on grass cover was dependent on year at Cayuse Trail (Table 1). In 1995, the first year of treatment, clipping 90% of the grass foliage reduced grass cover compared to all other defoliation intensities (Fig. 1a). By 1996, clipping grass foliage by 60% reduced grass cover compared to the unclipped grass, and 90% defoliation reduced grass cover compared to all other intensities. In 1997, 2 years after treatment (1 year recovery), there was no detectable difference in grass cover regardless of the defoliation treatment.

The interaction between frequency of defoliation and season of defoliation also depended on year at Cayuse Trail (Table 1). In 1995, the general trend was that clipping grass more than once (regardless of intensity) decreased grass cover when defoliated in the spring, but not in the summer (Fig. 1b). In 1996, the trend was similar, however only plots where grasses were 3-times clipped in the spring was different than those clipped 3-times in the summer. By 1997, the effect of season of defoliation was undetected and defoliation more than once tended to cause a greater reduction in grass cover compared to a single defoliation.

Defoliation intensity interacted with defoliation frequency to affect grass cover at Cayuse Trail (Table 1). Grass defoliation of 60% or less had little effect on grass cover, with the exception of 60% defoliation repeated 3-times (Fig. 2a). Defoliation at 90%, regardless of frequency reduced grass cover compared to no defoliation or 30% defoliation. Defoliation at 90% 3-times caused the greatest reduction in grass cover.

Defoliation intensity interacted with season of defoliation to affect grass cover at Cayuse Trail (P=.057, Table 1). Spring defoliation at 30%, but not sum-

Table 1. Mean squares generated from analysis of variance of grass and spotted knapweed cover data.

Component	Cayuse df	Cayuse Grass	Cayuse Knapweed	Hodgeman df	Hodgeman Grass	Hodgeman Knapweed
Block	3	0.14	1.47*	3	1.14	0.48
Intensity	3	14.23*	3.40*	3	5.22*	1.28
Frequency	2	0.26	0.38	2	0.07	0.14
I X F	6	1.37*	0.18	6	0.75	0.68
Season	1	4.50*	0.78	1	0.26	0.52
I X S	3	1.88*	0.13	3	0.21	0.03
F X S	2	1.50*	1.97*	2	0.01	0.69
I X F X S	6	0.24	0.11	6	0.36	0.10
Wholeplot error	69	0.37	0.56	69	0.45	0.49
Year	2	9.96*	1.90*	1	0.26	2.52*
Y X I	6	2.65*	0.87	3	0.63	0.03
Y X F	4	0.42	0.86	2	0.07	0.88
Y X S	2	0.28	0.14	1	0.63	1.69*
Y X I X F	12	0.24	0.37	6	0.63	0.12
Y X I X S	6	0.31	0.81	3	0.34	0.28
Y X F X S	4	1.20*	0.57	2	0.51	0.20
Y X I X F X S	12	0.47	0.14	6	0.11	0.40
Residual error	213	0.46	0.42	141	0.41	0.43

* Significant at P≤0.05.

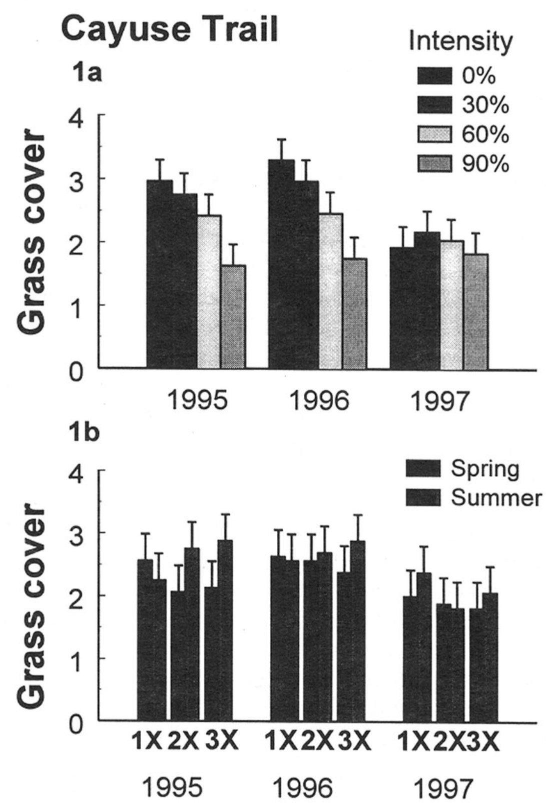

Fig. 1. The effect intensity of grass defoliation by year of defoliation (a), and season by frequency of grass defoliation (b) on grass cover (by cover class) at Cayuse trail. Error bars represent least significant differences (α=0.05).

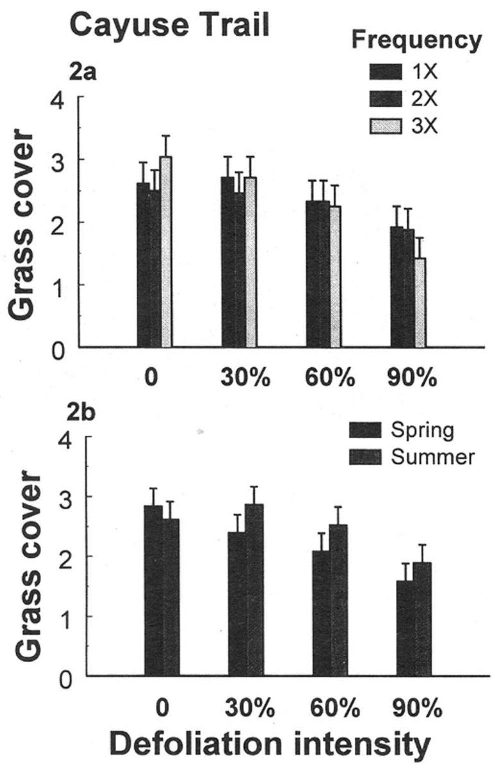

Fig. 2. The effect of intensity by frequency of grass defoliation (a) and intensity by season of grass defoliation on grass cover (by cover class) at Cayuse trail. Error bars represent least significant differences (α=0.05).

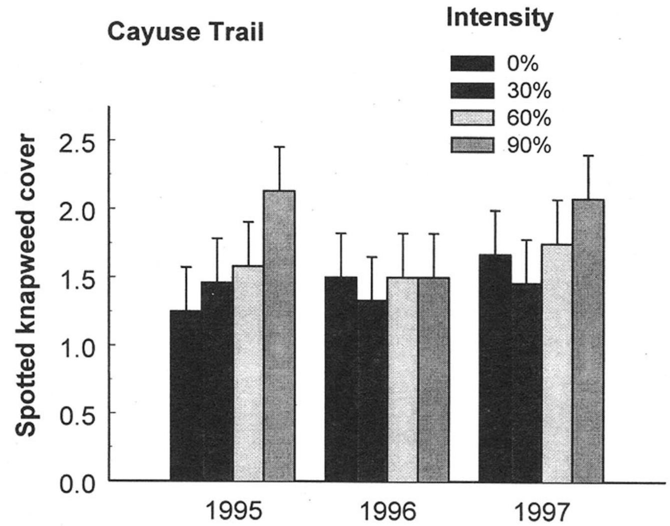

Fig. 3. The effect of intensity of grass defoliation by year on spotted knapweed cover (by cover class) at Cayuse trail. Error bars represent least significant differences (α=0.05).

mer defoliation, reduced grass cover compared to no defoliation (Fig. 2b). Spring defoliation at 60% further reduced grass cover. Defoliation at 90% reduced grass cover regardless of season, however, the effect was greater when clipped in the spring compared to summer defoliation.

The effect of grass defoliation intensity on spotted knapweed cover depended on year at Cayuse Trail (Table 1). In 1995 and 1997, spotted knapweed cover was greater when 90% of the grass was defoliated compared to all other defoliation levels (Fig. 3). In 1996, there was no difference in spotted knapweed cover between defoliation treatments, and the amount of spotted knapweed cover was similar to defoliation intensities less than 90% in 1995 and 1997.

Grass defoliation frequency and season interacted to affect spotted knapweed cover at Cayuse Trail (Table 1). Defoliating grass more than once in the spring, but not in the summer, increased spotted knapweed cover (Fig. 4). Spotted knapweed cover was similar between timings except when grass was defoliated 3-times. In this case, spotted knapweed cover was greater when grass was defoliated in the spring compared to summer defoliation.

At Hodgeman Canyon only defoliation intensity affected grass cover (Table 2). No defoliation (cover class 2.00) and 30% defoliation (cover class 2.02) had similar cover ($LSD_{\alpha=0.05}$ =0.41). Grass cover was reduced when defoliated at 60% (cover class 1.56) and 90% (cover class 1.35).

Year and season of defoliation interacted to affect spotted knapweed cover at Hodgeman Canyon (Table 1). Spotted knapweed cover in 1997 was greater when grass was defoliated in the summer compared to spotted knapweed cover in 1995 (Fig. 5).

Density

At Cayuse Trail, defoliation intensity and season interacted to affect grass density in 1997, the only year it was measured on this site (Table 2.). Spring defoliation at 60% of the foliage reduced grass density from 1,231 tillers m^{-2} (undefoliated) to 782 tillers m^{-2}, and 90% defoliation reduced density to 569 tillers m^{-2} (Fig. 6). At 30% defoliation, there were 883 tillers m^{-2} when clipped in the spring and 1,359 tillers m^{-2} when clipped in the summer. At 60% defoliation there were 782 tillers m^{-2} when clipped in the spring compared to 1,363 tillers m^{-2} when clipped in the summer. Season of defoliation had no effect when grass was defoliated at 90%.

Table 2. Mean squares generated from analysis of variance of grass density data.

Component	df	Cayuse	Hodgeman
Block	3	1285938*	350475*
Intensity	3	711224*	384269*
Frequency	2	933759*	142079
I X F	6	137750	27328
Season	1	1820504*	70417
I X S	3	973896*	136519
F X S	2	38314	2329
I X F X S	6	47768	103636
Residual	69	232261	76004

* Significant at P≤0.05.

Table 3. Mean squares generated from analysis of variance of grass and spotted knapweed density data.

	Cayuse		Hodgeman	
Component	df	Mean square	df	Mean square
Block	3	44252*	3	114588
Intensity	3	43148*	3	44449
Frequency	2	26676	2	25882
I X F	6	12254	6	64816
Season	1	7100	1	87552
I X S	3	6186	3	75198
F X S	2	12318	2	92726
I X F X S	6	671	6	70369
Wholeplot error	69	8917	69	96238
Year	2	74218*	1	45633
Y X I	6	14990*	3	25518
Y X F	4	14745	2	10285
Y X S	2	15672	1	19
Y X I X F	12	8377	6	52684
Y X I X S	6	16917*	3	15279
Y X F X S	4	10537	2	98720
Y X I X F X S	12	2277	6	25674
Residual error	213	6778	141	72555

* Significant at $P \leq 0.05$.

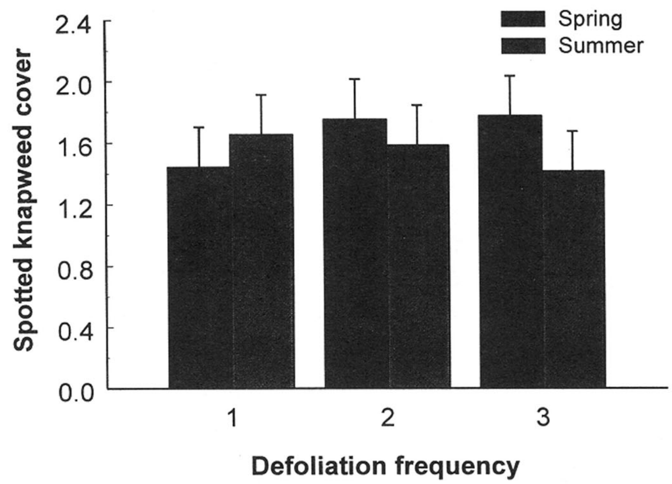

Fig. 4. The effect of season by frequency of grass defoliation on spotted knapweed cover (by cover class) at Cayuse trail. Error bars represent least significant differences (α=0.05).

There was a main effect of defoliation frequency on grass density (Table 2). Defoliation once per year resulted in 1,016 tillers m^{-2}. Two defoliations decreased grass density to 745 tillers m^{-2}, while 3 defoliations resulted in 719 tillers m^{-2} ($LSD_{\alpha=0.05}$ =205).

The effect of intensity and season of grass defoliation on spotted knapweed density was dependent on year at Cayuse Trial (Table 3). In 1995, only 90% defoliation of the grass in spring increased spotted knapweed density (Fig. 7). No defoliation effects on spotted knapweed density were detected in 1996. By 1997, defoliation of 90% in the spring (compared to 30% defoliation) and 90% in the summer increased spotted knapweed density. Grass defoliation of 90% in the summer had the highest spotted knapweed density.

At Hodgeman Canyon, only defoliation intensity affected grass density (Table 2). No defoliation (512 tillers m^{-2}), 30% defoliation (504 tillers m^{-2}) and 60% defoliation (392 tillers m^{-2}) had similar grass density ($LSD_{\alpha=0.05}$=128). Defoliation at 90% reduced grass density to 241 tillers m^{-2}. Defoliation treatments did not affect spotted knapweed density at Hodgeman Canyon (Table 3).

Biomass

After 2 years of defoliation and 1 year of rest, there were only treatment main effects on grass biomass at Cayuse Trail. Grass biomass was affected by defoliation intensity and season, but not frequency (Table 4). Clipping 30% of the grass foliage for 2 years reduced grass biomass in the third year from 108 g m^{-2} when the grass was not defoliated to 90 g m^{-2} ($LSD_{\alpha=0.05}$ =17). Defoliation of 60% and 90% further reduced grass biomass to 47 and 53 g m^{-2}, respectively. Grass clipped in the spring produced 66 g m^{-2} compared to 83 g m^{-2} when clipped in the summer ($LSD_{\alpha=0.05}$ = 13). Defoliation treatments did not affect spotted knapweed biomass at Cayuse Trail (Table 4).

At Hodgeman, defoliation treatments did not affect grass biomass, and only season of defoliation affected spotted knapweed biomass (Table 4). Defoliating grass in the spring and summer resulted in 108 and 136 g m^{-2} of spotted knapweed, respectively ($LSD_{\alpha=0.05}$ = 17).

Discussion

Grass defoliation intensity, frequency, and season affected spotted knapweed cover and density. Clipping greater than 60% of the grass foliage caused an increase in spotted knapweed density and cover. Similar results were found for diffuse knapweed establishment in bluebunch wheatgrass and crested

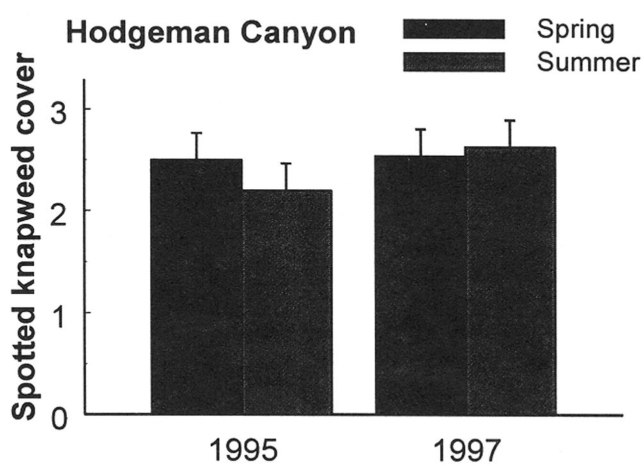

Fig. 5. The effect of season of grass defoliation by year on spotted knapweed cover at Hodgeman Canyon. Error bars represent least significant differences (α=0.05).

Table 4. Mean squares generated from analysis of variance of grass and spotted knapweed biomass data.

Component	df	Cayuse Grass	Cayuse Knapweed	Hodgeman Grass	Hodgeman Knapweed
Block	3	645	1957	187	8007
Intensity	3	20793*	7035	59	5114
Frequency	2	1882	1547	29	6034
I X F	6	1122	3876	20	618
Season	1	7305*	1675	10	13211*
I X S	3	959	5744	205	5505
F X S	2	809	6749	116	515
I X F X S	6	894	3429	50	2059
Residual	50	1152	4819	85	2404

* Significant at P≤0.05.

wheatgrass (Sheley et al. 1997), and spotted knapweed establishment in Idaho fescue in a controlled environmental chamber (Jacobs and Sheley 1997). This suggests that the recommended grazing level on western rangeland (60% or less) should not accelerate spotted knapweed invasion.

Clipping grass more than once reduced grass cover and density and increased spotted knapweed cover at Cayuse Trail. Jacobs and Sheley (1997) found that increasing the clipping frequency of pot-grown Idaho fescue increased soil water content and spotted knapweed seedling density and weight. For sand bluestem (*Andropogon hallii* Hack.), multiple grass defoliations reduced grass root weight, root area, root length, and weight of total nonstructural carbohydrates in roots more than did single defoliations (Engle et al. 1998). This suggests that lower root growth and carbohydrate reserves caused by multiple defoliations may reduce grass competitiveness with spotted knapweed.

The intensity and frequency of defoliation influence how season of defoliation affected spotted knapweed. When clipped 3-times (averaged over intensities), spring defoliation resulted in a greater increase in spotted knapweed cover than summer defoliations. Grass defoliation during early growth or late in the season after the foliage has started to dry, has less impact on grass than do mid-season defoliations (Blaisdell and Pechanec 1949, Mueggler 1967). Engle et al. (1998) determined that grazing during the dormant season or once early in the growing season was least detrimental to sand bluestem. Our 3-time spring defoliation treatment reduced the grass when it was most susceptible to defoliation damage (Blaisdell and Pechanec 1949) and increased spotted knapweed cover. However, 90% grass defoliation (when averaged over frequencies) in the summer increased spotted knapweed density more than did the spring 90% defoliation treatment. These results are inconsistent with the results discussed above and our expectations. We believe that the first summer defoliations were applied early enough in the season, before the grass was dormant, and most susceptible to defoliation (Mueggler 1967).

Defoliation treatments had very little effect at Hodgeman Canyon, where spotted knapweed was the dominant species. Only defoliation level affected grass cover and density without causing an increase in spotted knapweed. However, summer grass defoliation resulted in more spotted knapweed than did spring defoliation. Since season of defoliation did not affect grass, but did affect spotted knapweed, the effect was possibly due to something other than grass defoliation.

Grazing managers of rangeland under the threat of weed invasion must consider the effects of intensity, frequency, and season of grazing on weed invasion. Our defoliation study, and those of Sheley et al. (1997) and Jacobs and Sheley (1997), suggest that defoliation of 60% or less maintains a competitive grass community and should not increase weed invasion. Increasing graz-

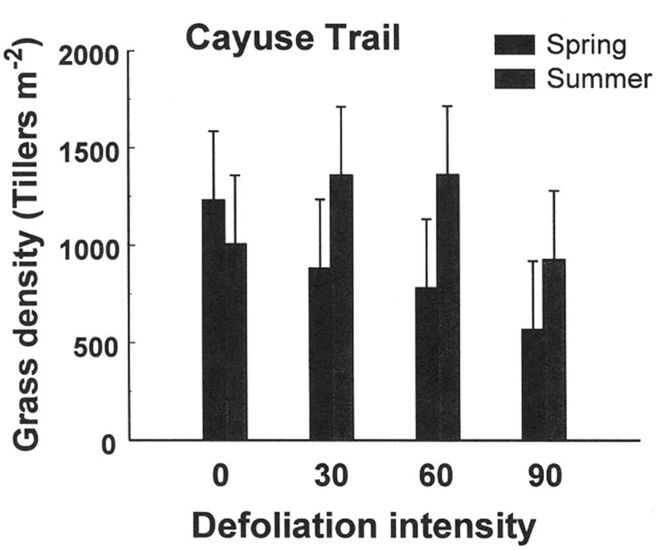

Fig. 6. The effect of intensity by season of grass defoliation on grass density at Cayuse Trail. Error bars represent least significant differences (α=0.05).

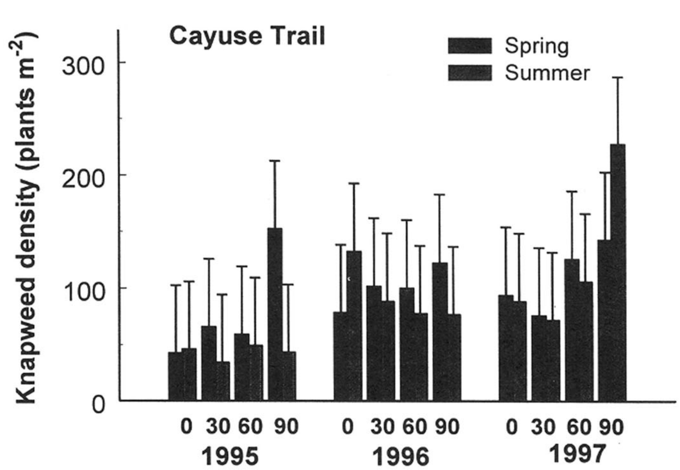

Fig. 7. The effect of intensity by season of defoliation by year on spotted knapweed density at Cayuse Trail. Error bars represent least significant differences (α=0.05).

ing frequency causes stress to grasses that are similar to increases in intensity. Early season infrequent defoliation allows grasses time to recover, and defoliation after the grasses have matured minimizes impacts (Mueggler 1967). Other factors not addressed in this study, including trampling and abiotic factors, may also be important in weed/grass interactions on grazed lands.

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