Response of tap- and creeping-rooted alfalfas to defoliation patterns

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Abstract

Under grazing, creeping-rooted alfalfa (*Medicago sativa* L.) cultivars have been reported to be more productive and have higher survival than tap-rooted cultivars. To determine if differences in persistence could be related to response to defoliation patterns, we clipped 3 tap- and 3 creeping-rooted alfalfa cultivars. Different fractions of the total number of stems were clipped to different stubble heights every 21 days. Both tap- and creeping-rooted cultivars responded similarly to defoliation. Maximum forage production was obtained when one-third of the stems on a plant were cut back to 5 cm above the ground at each harvest. The lowest forage production was obtained when all stems on a plant were cut back to 5 cm. The most lenient defoliation (one-third of the height of one-third of the stems removed at each harvest) maximized total herbage production (forage plus stubble) but only 32% of the herbage was harvested as forage, leaving 68% as unharvested stubble. Severe defoliation every 21 days decreased the concentration of total nonstructural carbohydrate in the roots and reduced total root biomass. Thirteen alfalfa cultivars responded similarly to grazing when seeded in dense stands. The greater persistence of creeping-rooted alfalfa cultivars under grazing does not appear to be a result of greater intrinsic productivity or more rapid recovery from defoliation. The lateral spread of individual creeping-rooted plants in open stands may increase the probability that some stems will escape defoliation at each grazing; these stems then contribute to rapid recovery from grazing and to plant survival.

Key Words: ***Medicago sativa* L., grazing, clipping, root reserves, survival, forage production**

Alfalfa (*Medicago sativa* L.) has been grazed for many years in different areas of the world with varying degrees of success. However, stand deterioration is common when alfalfa is grazed. Alfalfa cultivars differ in type of root or crown, stem number, stem height, extent of axillary branching, and site and activity of regrowth; all these characteristics may influence their response to grazing.

Newly developed cultivars of rhizomatous or creeping-rooted alfalfas have been reported to survive longer and produce more forage under grazing than tap-rooted alfalfas (Clark 1960, Kilcher and Heinrichs 1966, Ashford and Heinrichs 1967, Daday 1968, Rumbaugh and Pedersen 1979, Counce et al. 1984, Heinrichs and Bolton 1985, Berdahl et al. 1989, Smith et al. 1989). In contrast, Leach (1969) reported that creeping-rooted alfalfa cultivars had no advantage in either production or survival when grazed in Australia. He also pointed out that the effect of grazing on alfalfa depended on the time, intensity, and frequency of defoliation.

Our objectives were to evaluate the forage production of creeping-rooted and tap-rooted alfalfas under lenient to severe clipping, and to relate the survival of cultivars under actual grazing to their responses to grazing simulated by clipping.

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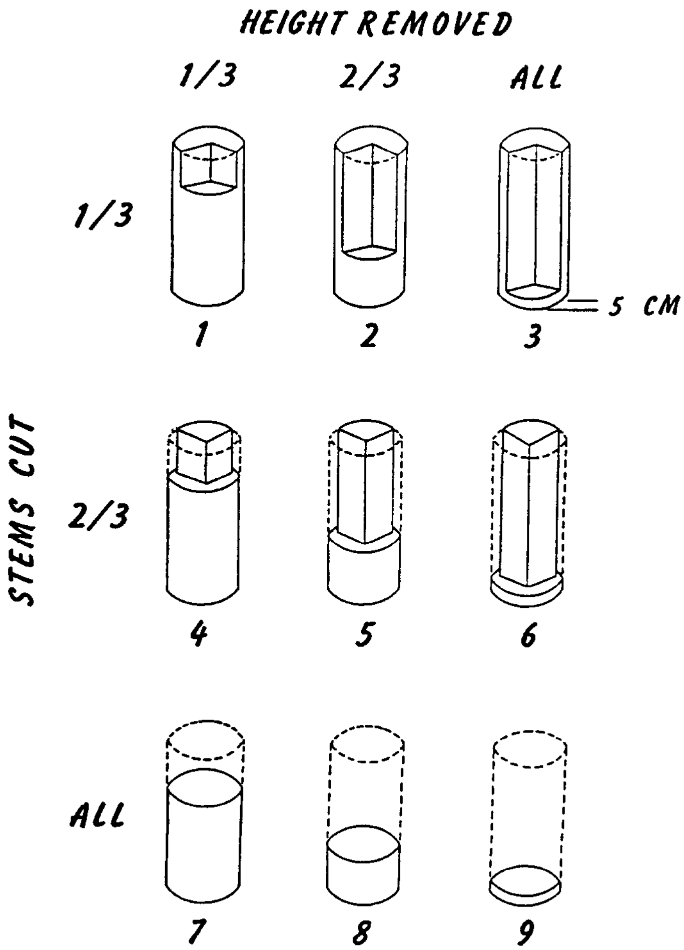

Fig. 1. Clipping treatments: dotted lines indicate portions removed.

Materials and Methods

Two studies were conducted at the USDA-ARS High Plains Grasslands Research Station near Cheyenne, Wyoming (latitude 41° 11′ N, longitude 104° 54′ W) during 1978–1980. Elevation of the study area is 1,885 m. Mean annual temperature is 9° C, with January having the lowest mean monthly temperature (-3° C) and July the highest (20° C). Length of frost-free growing season is approximately 127 days per year, but considerable alfalfa growth may occur before the last frost of spring and after the first frost of fall. April–September precipitation averages 272 mm; April–September precipitation was 276 mm in 1978, 339 mm in 1979, and 200 mm in 1980.

The experiments were established on irrigated Archerson sandy clay loam (Aridic Argiustoll). Analysis of the soil from the 0–15 cm depth showed 230 kg N ha^{-1}; 60 kg P ha^{-1}; 140 kg K ha^{-1}; 1,070 kg Ca ha^{-1}; 80 kg Mg ha^{-1}; and a pH of 7.5

The 13 alfalfa cultivars tested were: 'Drylander', 'NC-Crl', 'Roamer', 'Travois', and 'Victoria' with creeping roots and the

Table 1. Total dry matter harvested from 3 creeping-rooted and 3 tap-rooted alfalfa cultivars under 9 cutting treatments during 1979 (3 cuts).

	Treatment number									
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	
	1/3 of stems cut			2/3 of stems cut			All stems cut			
	Fraction of height (above 5 cm) removed									
Cultivar	1/3	2/3	All	1/3	2/3	All	1/3	2/3	All	Mean
	g/plant									
Creeping-rooted										
Drylander	34a	82ab	149ab	52a	77a	69a	41a	37a	28a	63A
Roamer	50a	123a	169a	71a	69a	61a	52a	32a	34a	73A
Travois	40a	61b	102b	79a	71a	71a	52a	40a	45a	60A
Tap-rooted										
Agate	43a	63b	107b	45a	61a	72a	43a	43a	34a	60A
Vernal	36a	90ab	119ab	40a	63a	88a	51a	38a	42a	64A
WL 307	21a	45b	129a	48a	74a	71a	47a	41a	32a	56A
Mean	36D	77B	127A	56BCD	69BC	72B	48CD	39D	36D	

a,A Cultivar × treatment means in the same column followed by the same lower-case letter and cutting treatment or cultivar means followed by the same upper-case letter are not significantly different (0.05 level, Tukey's Test).

ability to produce stems on these creeping or laterally spreading roots: 'Teton' with rhizomes; and 'Agate', 'Baker', 'Kanza', 'Ramsey', 'Riley', 'Vernal', and 'WL307' with taproot systems.

The Clipping Experiment

Six alfalfa cultivars (Drylander, Roamer, Travois, Agate, Vernal, and WL307) were seeded in the greenhouse on 10 June 1978 in sandy loam soil in clay pots 15 cm across and 15 cm deep. The seeds were scarified and inoculated with *Rhizobium* immediately before planting 1 seed per pot. Forty-five days after seeding, the plants were transplanted to the field. Each plot of 1 m^2 consisted of 2 plants spaced 30 cm apart. A randomized complete block design with 4 replications was used. Each replication contained 54 plots (6 cultivars × 9 treatments).

Clipping treatments were classified according to the fraction of the total number of stems that were clipped (1/3, 2/3, or all) and the fraction of the height above 5 cm that was removed from the clipped stems (1/3, 2/3, or all). Combinations of number of stems clipped and height of clipping produced 9 cutting treatments (Fig. 1).

Plants were clipped 4 June, 28 June, and 19 July in 1979; a severe hailstorm 31 July removed all top growth to ground level and precluded further clipping. In 1980, plants were clipped 28 May, 18 June, 9 and 30 July, and 19 August, and the aftermath remaining after the last clipping was harvested to ground level on 3 September. Clipped forage was dried 48 hr at 70° C, and the dry weight was recorded.

In both years, the alfalfa plants were first clipped at 10% bloom; Smith (1972) concluded grazing should be delayed until this stage to maintain productive stands. The optimum interval between defoliations is 35–45 days (Smith 1972, Irvine and McElgunn 1982), but the 21-day interval was chosen to increase defoliation stress and accelerate the response to clipping.

Crowns on each plant under treatments 1 through 6 were divided into 3 equal sectors. Under treatments 1, 2, and 3, we clipped all stems from sector 1 at the first clipping, sector 2 at the second clipping, sector 3 at the third, sector 1 at the fourth, and sector 2 at the fifth. Under treatments 4, 5, and 6, we clipped all stems from sectors 1 and 2 at the first clipping, sectors 3 and 1 at the second clipping, sectors 2 and 3 at the third, etc. Under treatments, 7, 8, and 9 all stems were clipped at each clipping.

At the end of the experiment, on 10 September 1980, main crowns and tap roots to a depth of 30 cm were collected from all tap-rooted plants. Samples of creeping roots were randomly selected on creeping-rooted plants. The samples were dried and analysed for total nonstructural carbohydrate (TNC) by a modification of the method of Smith (1969). Amylglucodiase enzyme was used to hydrolyse starch and a colormetric procedure was used to determine reducing power.

Table 2. Total dry matter harvested from 3 creeping-rooted and 3 tap-rooted alfalfa cultivars under 9 cutting treatments during 1980 (5 cuts).

	Treatment number									
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	
	1/3 of stems cut			2/3 of stems cut			All stems cut			
	Fraction of height (above 5 cm) removed									
Cultivar	1/3	2/3	All	1/3	2/3	All	1/3	2/3	All	Mean
	g/plant									
Creeping-rooted										
Drylander	220	306	382	256	272	231	256	85	66	230
Roamer	171	354	494	306	244	208	269	86	76	245
Travois	156	362	341	319	268	251	180	79	92	228
Tap-rooted										
Agate	209	242	423	203	278	285	166	120	83	232
Vernal	158	381	349	244	226	206	279	134	85	229
WL 307	152	205	377	233	256	342	236	72	58	215
Mean	178C	308B	394A	260B	257B	254BC	231BC	96D	77D	

A,B Cutting treatment means followed by the same upper-case letter are not significantly different (0.05 level, Tukey's Test). Cultivar and cultivar × treatment means are not significantly different.

Table 3. Aftermath dry matter harvested from 3 creeping-rooted and 3 tap-rooted alfalfa cultivars following 5 cuts under 9 cutting treatments in 1980.

	Treatment number									
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	
	1/3 of stems cut			2/3 of stems cut			All stems cut			
	Fraction of height (above 5 cm) removed									
Cultivar	1/3	2/3	All	1/3	2/3	All	1/3	2/3	All	Mean
	g/plant									
Creeping-rooted										
Drylander	473	179	124	206	103	64	173	36	18	153
Roamer	333	199	123	272	67	48	150	35	19	139
Travois	265	181	72	229	84	65	76	39	18	114
Tap-rooted										
Agate	453	111	80	196	83	60	118	28	15	129
Vernal	169	212	77	169	63	35	206	32	17	142
WL 307	314	96	75	187	56	58	157	14	15	108
Mean	368A	163B	92BC	210B	76C	55C	147B	31C	17C	

A,B Cutting treatment means followed by the same upper-case letter are not significantly different (0.05 level, Tukey's Test). Cultivar and cultivar × treatment means are not significantly different.

The Grazing Study

All 13 alfalfa cultivars were used in this study. They were drill-seeded in June 1978 in the field at 7 kg/ha of pure live seed. Plots consisted of 5 rows 8 m long and 25 cm apart, in a randomized complete block design with 5 replications. Ranger alfalfa was seeded around the outside of the plot area to create a total area of alfalfa of 0.3 ha.

This area was grazed by 3 ewes on 25–29 June, and 2–7 and 9–14 July 1979; all remaining forage was clipped with a rotary mower 16 July and the area was grazed again 8–29 August. In 1980, the area was grazed by 5 ewes 27 May–14 June, 7–25 July, and 18–31 August. Stocking rates were equivalent to 11 animal-months/ha during the 1979 growing season and 26 animal-months/ha during the 1980 growing season. Ewes weighed 55 to 70 kg each. The percentage of row covered by plant crowns (basal cover) was estimated visually on 4 permanent 1-m plots in each of the 3 center rows of each plot on 18 September 1978, 16 June and 22 September 1979, and 22 May and 20 September 1980.

Data Analysis

Analyses of variance and F-tests were performed on the forage dry matter yields of 1979, 1980, and both years together; on aftermath yields of 1980; on row cover; and on the TNC data. Tukey's test at the 0.05 level was used to separate means.

Row cover at the end of the 1980 grazing season was analyzed by covariance, using 1978 row cover as the covariate. Adjusted means were separated by Tukey's test at the 0.05 level.

Results

Yield, Survival, and Root TNC Concentration under Clipping

In 1979 treatment 3, in which one-third of the stems of each plant were cut at 5 cm above ground level while the other two-thirds were left uncut at each of the 3 clipping dates, produced the greatest forage dry matter (DM) yield (Table 1). Production was significantly reduced below treatment 3 when only two-thirds of the height was removed from one-third of the stems at each harvest (treatment 2). Cutting two-thirds of the stems at each harvest (treatments 4, 5, and 6) produced the same amount of forage DM as treatment 2, regardless of the fraction of height removed. Cutting all stems at each harvest (treatments 7, 8, and 9) produced no more forage DM, again regardless of height, than removing only one-third of the height of one-third of the stems at each harvest (treatment 1).

No significant differences were found among cultivar means. The only significant interaction found was among cultivars and treatments 2 and 3. Under both treatments, Roamer produced more forage than Agate or Travois, but under treatment 2 Roamer also produced more than WL 307.

In 1980, clipping effects on yield (Table 2) were similar to those in 1979. Treatment 3 again produced the highest forage yield, followed by treatments 2, 4, 5, and 6, which were not significantly different. But in 1980, removing one-third of the height of all stems on each plant (treatment 7) produced as much forage as any treatment except treatment 3 and more forage than removing two-thirds or all of the height from all the stems (treatments 8 and 9). Differences among cultivars and the cultivar × treatment interaction were not significant.

All 6 cultivars under all treatments produced higher forage DM yields from the first 3 cuttings in 1980 than in 1979 when only 3 cuttings were taken. Mean yields from 3 cuts were 142 and 62 g/plant, respectively. Plants were a year older in 1980 and capable of much higher yields. All plants established in 1978 survived through 1980, regardless of clipping treatment.

The most lenient cutting treatment, treatment 1, was also the least productive treatment in 1979, and in 1980 produced more forage than only treatments 8 and 9. Most of the production under treatment 1 remained in the uncut stubble, which contained more DM than that of any other treatment at the end of the season (Table 3). Less DM remained in stubble when two-thirds or all of the height of cut stems was removed than when only one third was removed, and when two-thirds or all of the stems were harvested rather than only one-third. No significant differences were found among stubble yields of the 6 cultivars.

Cultivars and the cultivar × treatment interaction had no effect on total nonstructural carbohydrate (TNC) concentrations in roots. Roots from treatment 1 had the highest TNC concentration of 42.5%, followed by treatment 7 with 42.2%; 2, 41.8%; 4, 41.4%; 3, 40.8%; 5, 39.9%; 6, 38.9%; 8, 35.1%; and 9, 33.6%. Concentrations of TNC under treatments 8 and 9, the most severe cutting treatments, were significantly less than concentrations under other treatments.

Although roots of adjacent plants were so intermingled that an accurate root weight could not be obtainable, field observations indicated that root systems of all alfalfa cultivars tested became much smaller under more intensive clipping. Cutting alfalfa every 3 weeks not only reduced the rate of regrowth and decreased the yield, but also decreased the TNC concentration and reduced root growth which together reduced the total amount of TNC in the roots.

Cover under Grazing

Data collected in 1978 on stand establishment indicated significant differences among alfalfa cultivars. Crowns of WL 307 produced the highest percentage of basal cover in the row, Riley the least, and Ramsey, Vernal, NC-Crl, Roamer, Agate, Victoria, Travois, Kanza, Drylander, Baker, and Teton intermediate, with no differences among them (Table 4).

Table 4. Proportion of row covered by crowns of 6 creeping-rooted and 7 tap-rooted alfalfa cultivars, 1978–1980.

Cultivar	1978	1979 Pre-grazing	1979 Post-grazing	1980 Pre-grazing	1980 Post-grazing Actual	1980 Post-grazing Adjusted[1]
	% Row cover					
Creeping-rooted						
Drylander	62bc	47	47	50	48	48b
NC-Crl	69b	47	51	59	50	51ab
Roamer	68b	47	51	61	48	50ab
Teton	61bc	56	56	66	53	50ab
Travois	63bc	64	59	72	55	48b
Victoria	64bc	53	47	54	43	48b
Tap-rooted						
Agate	63bc	50	48	59	53	50ab
Baker	61bc	36	37	44	38	48b
Kanza	63bc	38	44	50	46	52ab
Ramsey	70b	51	63	62	55	52ab
Riley	57c	34	37	41	36	48b
Vernal	69b	52	54	64	56	51ab
WL 307	83a	70	69	75	67	56a

[1]Adjusted for initial differences in row cover.
a,b Means or adjusted means in the same column followed by the same letter are not significantly different (0.05 level, Tukey's Test). Unadjusted means in 1979 and 1980 were not analysed.

During the 1979 growing season, when the study area was grazed at a stocking rate of 11 animal-months/ha, sheep grazed primarily on leaves and branches; thick stems were left ungrazed and were removed by clipping. Sheep were observed to prefer Drylander and Travois first; Agate, Kanza and WL 307 last; and other cultivars in between. This result seems to be related to the thinner stems of Drylander and Travois, which are creeping-rooted cultivars, compared to the thick stems of Agate, Kanza and WL 307, which are tap-rooted cultivars.

During the 1980 growing season, when the study area was grazed at 26 animal-months/ha, sheep grazed the alfalfa plants more heavily than in 1979. Although they grazed on leaves and branches first, stems also were grazed. No appreciable amount of stubble was left at the end of each grazing period in 1980, although some stubble had been left after grazing and before clipping in 1979.

After 2 years of grazing, WL-307 (tap-rooted) had maintained more basal cover in the row (adjusted for 1978 levels) than Drylander, Travois, Victoria (all creeping-rooted), Baker, or Riley (both tap-rooted). All other cultivars were intermediate, with no differences among them.

Discussion and Conclusions

Folkins et al. (1961) reported that the yield of creeping-rooted Rhizoma was not significantly different from that of tap-rooted 'Grimm' over 5 years. Irvine and McElgunn (1982) reported that yields of tap-rooted 'Beaver' alfalfa were not significantly different from yields of creeping-rooted Roamer. On the other hand, Langille et al. (1965) found that Rhizoma yielded more than tap-rooted 'DuPuits' when the first cut was taken at a pre-bud stage followed by 2 cuts at the 50% flowering stage. Among tap-rooted cultivars, Kehr et al. (1963) found that adapted narrow-crowned alfalfa cultivars generally produced higher yields than did broad-crowned or creeping-rooted cultivars. Broad-crowned alfalfa cultivars were found to persist better than narrow-crowned cultivars under shorter intervals between harvests (Jung et al. 1969; Jones 1971). Yields of alfalfa cultivars may show a strong cultivar × defoliation frequency interaction, particularly if cultivars vary in their adaptation to the area where they are tested.

As expected, forage production declined as intensity of defoliation increased (Graber et al. 1927, Smith 1972, Irvine and McElgunn 1982). But all cultivars, tap- or creeping-rooted, responded the same.

Again as expected, TNC concentrations in roots decreased as the intensity of defoliation increased (Graber et al. 1927, Smith 1972, Chatterton et al. 1974). TNC reserves in the roots of alfalfa plants are used to produce new top growth, and the decrease in TNC concentration continues until the plant has produced about 15 to 20 cm of new top growth (Smith 1972). Frequent or prolonged grazing does not permit enough top growth to persist for long enough to restore root carbohydrates, slowing recovery from defoliation and reducing forage production and plant survival. These effects can persist into the following year (Allen et al. 1986a and 1986b). But we found no differences among individual cultivars or between tap- and creeping-rooted cultivars.

Our study revealed no significant differences in forage production, survival, or root TNC concentrations between creeping- and tap-rooted alfalfas. Yet survival of the creeping-rooted cultivars 'Nomad' and 'Rhizoma,' after 7 years of grazing at Grouse Creek, Utah, was much better than that of 'Ladak', the only tap-rooted *M. sativa* cultivar to survive (Rumbaugh and Pedersen 1979). Twice as many plants of Rhizoma and 5 times as many plants of Nomad survived as plants of Ladak. Survival of the creeping-rooted Travois was as great as that of any tap-rooted cultivar, and better than that of 7 of the 21 tap-rooted cultivars, after 2 years of grazing (Counce et al. 1984). Berdahl et al. (1989) included several of the cultivars in our study in their study of 17-year-old alfalfa stands near Mandan, North Dakota. Mean survival of creeping-rooted Drylander, Roamer, and Travois was 6.0 plants/m^2, vs a mean of 2.0 plants/m^2 for Baker, Kanza, Ramsey, and Riley. Smith et al. (1989) reported that, after 3 years of grazing in Georgia, 6–9 plants/m^2 of tap-rooted hay-type alfalfas (Apollo and Florida 77) survived, vs 40–48 plants/m^2 of creeping-rooted grazing type alfalfas (Travois, Spredor II, and GA-GC).

Greater survival of creeping-rooted alfalfas may be related less to an intrinsic capacity to recover from grazing than to the probability of escaping complete defoliation. In the clipping study, creeping-rooted cultivars produced stems as far as 2 m from the original plant. Under range conditions, plants may be widely spaced; Rumbaugh and Pedersen (1979) and Rosenstock and Stevens (1989) reported stands of 1.6 to 3.8 and 0.5 to 2.5 plants/m^2 respectively, comparable to our spacing of 2 plants/m^2. In such an open stand, the probability that some stems on each plant would remain ungrazed at each grazing event would be increased, although other stems might be completely removed. This is the defoliation pattern imposed in treatments 1 through 6, which produced higher yields and TNC concentrations than treatments 7 through 9 in which all stems were defoliated simultaneously. Treatments 7, 8, and 9 resemble the way in which narrow-crowned, tap-rooted alfalfas are defoliated under grazing.

Pitelka and Ashmun (1985) concluded that formation of spreading clones via rhizomes or stolons favored higher rates of survival and more rapid recovery after defoliation in many species of perennial plants, including grasses, legumes, and other forbs. Cook (1985) stated "Sources of mortality that are intense but local in space would favor clonal reproduction. The effects of herbivores . .. might operate in this way." Jeffries (1984) concluded that the probability of damage to a plant from grazing decreases as the number of stems or tillers increase. Gosse et al. (1988) suggested that competition among alfalfa stems for light may limit growth when stem densities are high; this is more likely to happen with tap-rooted than with creeping-rooted cultivars.

Thus the reported superiority of creeping-rooted cultivars, in view of the similar response of all cultivars to the treatments, may be caused by their ability to evade complete grazing and inter-tiller competition, rather than from any special ability to resist or recover rapidly from grazing. Rosenstock and Stevens (1989) also concluded that the survival of creeping-rooted alfalfas was related to their ability to evade complete defoliation, and cited the earlier work of Gdara (1985) in support. They and Berdahl et al. (1986) questioned whether rapid regrowth after defoliation was conducive to alfalfa survival in semiarid conditions. However, the proliferation of roots of creeping-rooted alfalfas under moderate defoliation (Carlson et al. 1964) may increase chances of survival.

This conclusion is not contradicted by the fact that all cultivars reacted similarly to grazing. In the grazing study, the alfalfa was planted at a heavy seeding rate; there was little opportunity for plants to spread (Kilcher and Heinrichs 1969, Daday et al. 1974) and creeping-rooted cultivars had little opportunity to evade complete grazing as they might have in a more open stand on rangeland. Hartnett (1989) found defoliation was equally damaging to switchgrass (*Panicum virgatum* L.) and big bluestem (*Andropogon gerardii* Vitman) in dense stands, but was much less damaging to the rhizomatous switchgrass than to bluestem in open stands.

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