Dinitrogen fixation and transfer in legume-crested wheatgrass mixtures

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Abstract

Crested wheatgrasses [*Agropyron cristatum* L. Gaertn. and *A. desertorum* Fisch. ex (Link) Schult.] have been extensively seeded on semiarid western rangelands, but without supplemental N many of these seedlings decline in vigor, ground cover, and productivity as the stand ages. Biological N₂ fixation by legumes may represent a viable alternative to fertilizer N for increasing stand productivity. Two growth-room studies were designed to investigate N₂ fixation and N transfer in mixtures of alfalfa (*Medicago sativa* L.) or annual sweetclover (*Melilotus alba* Medik. var. *annua* Coe) and crested wheatgrass. Growth media were enriched with ¹⁵N-labeled KNO₃ at a rate of 24.2 kg N ha⁻¹ and used to grow mixtures and monocultures of alfalfa or sweetclover and crested wheatgrass. Fixed and transferred N were determined at 3 harvest dates from differences in isotopic composition between the legume species in mixture with crested wheatgrass and crested wheatgrass in monoculture. The percentage of legume N derived from fixation was >80% for the final 2 harvests and increased as the proportion of crested wheatgrass in the mixtures increased. Nitrogen transfer from alfalfa to crested wheatgrass accounted for <5% of the grass total N. Conversely, nitrogen transfer from sweetclover to crested wheatgrass accounted for about 20% of the grass total N. Nitrogen transfer from alfalfa or sweetclover to crested wheatgrass may be important in maintaining stand productivity on N-limited western rangelands.

Key Words: hycress, isotope dilution, *Medicago sativa* L., *Melilotus alba* Medik. var. *annua* Coe, Nitrogen-15, nitrogen cycling

Crested wheatgrass [*Agropyron cristatum* (L.) Gaertn. and *A. desertorum* Fisch. ex (Link) Schult.] productivity is frequently limited by lack of N on western rangelands, especially as established stands age. Nitrogen fertilization can increase the forage quality and quantity of crested wheatgrass stands, but these increases are erratic; the magnitude of the response is site specific and integrated over the capacity of the plants to assimilate N, the capacity of the soil to immobilize N, and the amount of available soil water (Mayland 1986).

Because legumes are known to fix and transfer significant amounts of N within subhumid grass-legume pastures (Silver and Hardy 1976, Ta and Faris 1987b, Brophy et al. 1987), interseeding native or introduced legumes on crested wheatgrass-dominated western rangelands has been suggested (Johnson and Rumbaugh 1981). The benefits of growing crested wheatgrass with legumes are well documented and imply transfer of fixed N from legumes to crested wheatgrass. This transfer, however, has not been directly

demonstrated. Johnson and Rumbaugh (1981) showed that alfalfa (*Medicago sativa* L.) and yellow sweetclover [*Melilotus officinalis* (L.) Pall.] were well nodulated and capable of fixing significant amounts of N₂ (measured qualitatively by acetylene reduction) on semiarid rangelands during the most stressed portion of the growing season. Alfalfa also has been shown to survive for up to 23 years in semiarid environments (Rumbaugh and Pedersen 1979) and is capable of self reseeding on sites receiving 280 mm of average annual precipitation (Rumbaugh 1982).

Annual legumes, such as black medic (*Medicago lupulina* L.) and white sweetclover (*Melilotus alba* Desr.), also fix N₂, produce seed on sites receiving 160 mm of average annual precipitation, and are adapted to semiarid environments (Turkington et al. 1976, Duke 1981). When compared to perennial legumes such as alfalfa, lower percentages of lignin and other fibrous materials in annual sweetclovers result in faster decomposition rates (Schwendiman and Kaiser 1960), which may provide more immediate N transfer to crested wheatgrass.

Although alfalfa and annual sweetclover are capable of fixing N₂ on semiarid sites and differ markedly in short-term decomposition release of fixed N, the potential N contribution from these legumes to crested wheatgrass remains unknown and should be quantitatively investigated under both laboratory and field conditions. The objectives of this research were to: (1) quantify N₂ fixation and transfer of fixed N in alfalfa-crested wheatgrass and annual sweetclover-crested wheatgrass mixtures of varying ratios under controlled laboratory conditions using isotope dilution methodology (Chalk 1985) and (2) provide baseline data relative to the methodology, design, and development of complementary field studies (Gebhart et al. 1993).

Materials and Methods

Experiment 1

Plants of 'Spredor 2' alfalfa and 'Hycress' crested wheatgrass (*Agropyron cristatum* × *A. desertorum*) (Asay et al. 1985) were grown from seed in 20-liter plastic pots filled with a mixture of washed sand and vermiculite (4:1, v:v respectively). Each pot had ¹⁵N-labeled KNO₃ (12.13 atom % ¹⁵N excess) applied at 24.2 kg N ha⁻¹ in a water carrier.

Five treatments were used: pure alfalfa, pure crested wheatgrass, and grass:legume ratios of 75:25, 50:50, and 25:75. Eight equally spaced planting locations per pot were sown with either 4 crested wheatgrass seeds or 3 inoculated alfalfa seeds (*Rhizobium meliloti* Dang, Lot ACT18, Urbana Labs) to meet the required ratios. After emergence, seedlings were thinned to 1 per location. The pots were routinely watered to field capacity with an N-free, half-strength Hoagland's nutrient solution (Hoagland and Arnon 1950) when the weight of the pots was about 85% of the field capacity weight.

Plants were grown for 149 days in a relatively homogeneous

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growth room environment under a 13-hour day/11-hour night with a temperature regime of 29/21°C. Pot locations within the growth room were re-randomized every 7 days. Light intensity was 500 $\mu\text{mol m}^{-2} \text{s}^{-1}$ during the day. Plants were clipped to a height of 5 cm 74, 114, and 149 days after planting, which corresponded to about 10% legume bloom. Aboveground biomass was separated by species. At the final clipping, roots were washed and separated by species using a differential staining technique (Ward et al. 1978). Plant tissues were dried at 60°C for 48 hours, weighed, and ground to pass through a 0.5-mm screen. Total N was determined by the Kjeldahl method (Nelson and Sommers 1973) and percent ^{15}N was determined by mass spectrometry (Porter and O'Dean 1977). The proportion of N derived from N_2 fixation in alfalfa and of N transferred from alfalfa to crested wheatgrass in mixture were estimated from differences in isotopic composition between the 2 species in mixture and crested wheatgrass in monoculture (Fried and Middelboe 1977, Hardarson et al. 1988).

For each clipping, treatments were compared by analysis of variance procedures for a completely randomized design with 4 replications. Means were compared with Fisher's Protected LSD test ($P < 0.05$) (Steel and Torrie 1980).

Experiment 2

This experiment was conducted in the same manner as Experiment 1 except that (1) 'Hubam' annual sweetclover (*Melilotus alba* Medik. var. *annua* Coe) was substituted for alfalfa in order to focus on differences in N_2 fixation and transfer between perennial and annual legumes having markedly different lignin and fiber contents, (2) washed sand was used instead of a washed sand-vermiculite growth medium, (3) 1.21 atom % ^{15}N excess KNO_3 was applied instead of 12.13 atom % ^{15}N excess KNO_3 , and (4) plants were grown for 148 days instead of 149 days and clipped at 74, 113, and 148 days after planting.

Results and Discussion

Dry Matter Yield

Shoot (leaves and stems) and root dry matter yields of alfalfa and crested wheatgrass decreased as the proportion of each species in the mixtures decreased (Table 1). Significant reductions ($P < 0.05$),

Table 1. Dry weights of shoots and roots of crested wheatgrass (CWG) and alfalfa (ALF) grown in mixtures of varying ratios and clipped 3 times.

Clip ¹	Species	Grass:Legume Ratio					LSD ²
		0:100	25:75	50:50	75:25	100:0	
Shoot	dry wt.	(g pot ⁻¹)					
1	CWG	—	1.27	1.84	2.89	2.74	0.56
	ALF	6.41	4.12	3.57	1.28	—	2.15
2	CWG	—	0.50	0.61	0.56	0.97	0.21
	ALF	8.03	9.65	8.96	4.46	—	3.03
3	CWG	—	0.90	1.32	1.88	2.39	0.59
	ALF	7.80	7.14	5.23	4.00	—	2.92
Total	CWG	—	2.68	3.77	5.33	6.11	0.52
	ALF	22.24	20.90	17.76	9.74	—	5.15
Root	dry wt.	(g pot ⁻¹)					
3	CWG	—	4.15	6.99	7.42	6.41	2.19
	ALF	12.66	11.86	11.19	5.92	—	2.72

¹Clippings 1, 2, and 3 occurred 74, 114, and 149 days after planting, respectively.

²The Fisher's Protected LSD values were computed at the 0.05 level of significance and are applicable for comparisons across grass:legume ratios within species.

however, were not observed between crested wheatgrass in monoculture and crested wheatgrass in a grass:legume ratio of 75:25 except at the second clipping. Significant reductions ($P < 0.05$) in shoot dry matter yield were not observed between alfalfa in monoculture and alfalfa in grass:legume ratios of 25:75 and 50:50, except

Table 2. Dry weights of shoots and roots of crested wheatgrass (CWG) and sweetclover (SC) grown in mixtures of varying ratios and clipped 3 times.

Clip ¹	Species	Grass:Legume Ratio					LSD ²
		0:100	25:75	50:50	75:25	100:0	
Shoot	dry wt.	(g pot ⁻¹)					
1	CWG	—	0.20	0.24	0.37	0.85	0.02
	SC	10.79	9.90	7.87	5.33	—	2.02
2	CWG	—	0.21	0.43	0.45	1.54	0.11
	SC	13.72	11.73	9.88	8.43	—	2.33
3	CWG	—	0.32	0.65	0.77	1.91	0.14
	SC	18.52	16.09	15.48	11.48	—	2.79
Total	CWG	—	0.74	1.33	1.59	4.32	0.71
	SC	43.03	37.72	33.21	25.22	—	7.82
Root	dry wt.	(g pot ⁻¹)					
3	CWG	—	4.89	7.11	9.12	7.91	0.72
	SC	17.77	15.66	13.24	11.25	—	1.40

¹Clippings 1, 2, and 3 occurred 74, 113, and 148 days after planting, respectively.

²The Fisher's Protected LSD values were computed at the 0.05 level of significance and are applicable for comparisons across grass:legume ratios within species.

at the first clipping.

Shoot and root dry matter yields of sweetclover and crested wheatgrass also were reduced when grown in mixtures (Table 2). Dry matter production of sweetclover shoots was much greater than that of crested wheatgrass shoots for all 3 clippings. The difference in root dry matter production between crested wheatgrass and sweetclover, however, was less pronounced than the difference in shoot dry matter production and indicated that crested wheatgrass invested proportionally more carbon in root production than sweetclover. Smith and Gorz (1965) reported that annual sweetclovers exhibit lower root:shoot production ratios when compared to biennial varieties.

Nitrogen Concentration

Increasing the proportion of alfalfa or sweetclover in the mixtures generally increased N concentration of crested wheatgrass (Tables 3 and 4). The N concentration of crested wheatgrass shoots

Table 3. Nitrogen concentration of shoots and roots of crested wheatgrass (CWG) and alfalfa (ALF) grown in mixtures of varying ratios and clipped 3 times.

Clip ¹	Species	Grass:Legume Ratio					LSD ²
		0:100	25:75	50:50	75:25	100:0	
Shoot		(mg N g ⁻¹ dry wt.)					
1	CWG	—	17.9	17.2	14.9	12.7	0.4
	ALF	24.3	25.2	24.0	25.2	—	1.5
2	CWG	—	19.2	16.9	15.8	13.3	3.4
	ALF	28.1	26.7	26.7	28.6	—	2.6
3	CWG	—	14.3	9.4	7.1	10.4	3.3
	ALF	29.6	27.6	25.4	28.3	—	3.3
Mean	CWG	—	17.1	14.6	12.6	12.2	1.3
	ALF	27.3	26.5	25.4	27.3	—	2.1
Root		(mg N g ⁻¹ dry wt.)					
3	CWG	—	5.3	4.9	4.7	5.7	0.8
	ALF	22.6	17.7	17.2	16.6	—	1.7

¹Clippings 1, 2, and 3 occurred 74, 114, and 149 days after planting, respectively.

²The Fisher's Protected LSD values were computed at the 0.05 level of significance and are applicable for comparisons across grass:legume ratios within species.

grown in a grass:legume ratio of 25:75 with alfalfa (Table 3) or sweetclover (Table 4) was significantly greater ($P < 0.05$) than that for crested wheatgrass in monoculture at all 3 clippings. Crested wheatgrass N uptake, expressed as the product of biomass and N concentration on an individual plant basis, also was greater in grass:legume ratios of 25:75 with alfalfa or sweetclover than in

Table 4. Nitrogen concentration of shoots and roots of crested wheatgrass (CWG) and sweetclover (SC) grown in mixtures of varying ratios and clipped 3 times.

Grass:Legume Ratio							
Clip ¹	Species	0:100	25:75	50:50	75:25	100:0	LSD ²
Shoot		----- (mg N g ⁻¹ dry wt.) -----					
1	CWG	—	45.5	42.4	37.0	32.9	1.8
	SC	29.4	28.9	30.5	29.3	—	1.7
2	CWG	—	20.2	19.2	18.8	18.4	1.1
	SC	36.7	36.3	37.5	36.3	—	1.7
3	CWG	—	19.4	14.2	13.9	11.3	0.9
	SC	37.8	39.0	38.9	39.6	—	2.0
Mean	CWG	—	28.4	25.3	23.2	20.8	1.1
	SC	34.6	34.6	35.6	35.0	—	1.3
Root		----- (mg N g ⁻¹ dry wt.) -----					
3	CWG	—	9.6	8.3	6.7	6.1	0.3
	SC	17.7	17.7	18.1	17.1	—	1.6

¹Clippings 1, 2, and 3 occurred 74, 113, and 148 days after planting, respectively.

²The Fisher's Protected LSD values were computed at the 0.05 level of significance and are applicable for comparisons across grass:legume ratios within species.

monoculture at all 3 clippings (data not shown). Nitrogen compounds excreted directly from legume roots, such as ammonium N, amino acids, and proteins (Brophy and Heichel 1989), or from senescence of legume root and nodule tissues are all possible mechanisms explaining the increased N concentration and uptake of crested wheatgrass plants when grown with alfalfa or sweetclover in N-free or N-limited growth media. Similar N concentration increases in reed canarygrass (*Phalaris arundinacea* L.), timothy (*Phleum pratense* L.) and crested wheatgrass grown in mixture with alfalfa also have been reported by Brophy et al. (1987), Ta and Faris (1987a), and Lutwick and Smith (1977), respectively.

Alfalfa (Table 3) or sweetclover (Table 4) shoot N concentrations were not significantly affected by the presence of crested wheatgrass in the mixtures. Alfalfa or sweetclover root N concentration tended to decline as the proportion of crested wheatgrass increased. Many legumes compete poorly for soil N when growing in association with grasses (Broadbent et al. 1982).

Dinitrogen Fixation

Compared to legume monocultures, the atom % ¹⁵N excess in legume shoots and alfalfa roots from grass:legume ratios of 75:25 were lower for all clippings (Tables 5 and 6). Similar trends were not observed for sweetclover roots and were probably the result of grass root cross-contamination due to incomplete differential

Table 5. Atom percent ¹⁵N excess in shoots and roots of crested wheatgrass (CWG) and alfalfa (ALF) grown in mixtures of varying ratios and clipped 3 times.

Clip ¹	Species	Grass:Legume Ratio					LSD ²
		0:100	25:75	50:50	75:25	100:0	
Shoot		----- (%) -----					
1	CWG	—	11.635	12.250	12.062	11.985	0.389
	ALF	2.084	1.524	1.221	0.630	—	0.388
2	CWG	—	10.915	12.055	11.830	11.095	0.364
	ALF	0.430	0.228	0.132	0.128	—	0.098
3	CWG	—	8.535	9.878	9.860	8.510	1.501
	ALF	0.398	0.263	0.166	0.086	—	0.084
Root		----- (%) -----					
3	CWG	—	7.981	8.477	8.772	8.780	0.802
	ALF	1.253	0.779	0.609	0.357	—	0.227

¹Clippings 1, 2, and 3 occurred 74, 114, and 149 days after planting, respectively.

²The Fisher's Protected LSD values were computed at the 0.05 level of significance and are applicable for comparisons across grass:legume ratios within species.

Table 6. Atom percent ¹⁵N excess in shoots and roots of crested wheatgrass (CWG) and sweetclover grown in mixtures of varying ratios and clipped 3 times.

		Grass:Legume Ratio					
Clip ¹	Species	0:100	25:75	50:50	75:25	100:0	LSD ²
Shoot		----- (%) -----					
1	CWG	—	0.821	1.094	1.092	1.011	0.054
	SC	0.220	0.298	0.325	0.524	—	0.066
2	CWG	—	1.020	0.964	0.996	0.975	0.063
	SC	0.060	0.062	0.048	0.043	—	0.017
3	CWG	—	0.589	0.818	0.809	0.855	0.085
	SC	0.010	0.013	0.004	0.003	—	0.002
Root		----- (%) -----					
3	CWG	—	0.582	0.687	0.658	0.716	0.075
	SC	0.133	0.151	0.102	0.144	—	N.S.

¹Clippings 1, 2, and 3 occurred 74, 113, and 148 days after planting, respectively.

²The Fisher's Protected LSD values were computed at the 0.05 level of significance and are applicable for comparisons across grass:legume ratios within species. N.S. = nonsignificant.

staining that caused difficulties in accurately separating grass and sweetclover roots in mixtures. The largest declines in ¹⁵N occurred in mixtures having the highest proportion of crested wheatgrass, underscoring the relatively greater N₂ fixation by alfalfa or sweetclover in mixture. This is also shown in Tables 7 and 8 where the

Table 7. Proportion of nitrogen derived from fixation (%Ndfa) in shoots and roots of alfalfa grown in mixtures of varying ratios with crested wheatgrass (CWG) and clipped 3 times.

Clip ¹	Grass:Legume Ratio					LSD ²
	0:100	25:75	50:50	75:25	100:0	
Shoot	----- (%Ndfa) -----					
1	82.6	87.3	89.8	94.7	—	3.2
	96.1	97.9	98.8	98.8	—	0.8
2	95.3	96.9	98.1	98.9	—	0.9
	95.3	96.9	98.1	98.9	—	0.9
Shoot	----- (%Ndfa) -----					
3	85.7	91.1	93.1	95.9	—	2.5
	85.7	91.1	93.1	95.9	—	2.5

¹Clippings 1, 2, and 3 occurred 74, 114, and 149 days after planting, respectively.

²The Fisher's Protected LSD values were computed at the 0.05 level of significance and are applicable for comparisons across grass:legume ratios within species.

percentage of N derived from fixation, calculated using pure-stand crested wheatgrass as the reference crop, was significantly greater ($P < 0.05$) for alfalfa or sweetclover in mixture compared to alfalfa or sweetclover in monoculture. An exception to this occurred at the first clipping where the atom % ¹⁵N excess (Table 6) of sweetclover shoots increased and the percentage of N derived from fixation (Table 8) decreased as the proportion of crested wheat-

Table 8. Proportion of nitrogen derived from fixation (%Ndfa) in shoots and roots of sweetclover grown in mixtures of varying ratios with crested wheatgrass and clipped 3 times.

Clip ¹	Grass:Legume Ratio					LSD ²
	0:100	25:75	50:50	75:25	100:0	
Shoot	----- (%Ndfa) -----					
1	78.1	70.5	67.8	48.2	—	6.7
	93.7	93.7	95.1	95.5	—	1.9
2	98.7	98.5	99.4	99.6	—	0.2
	98.7	98.5	99.4	99.6	—	0.2
Root	----- (%Ndfa) -----					
3	81.4	78.9	85.8	79.9	—	2.0
	81.4	78.9	85.8	79.9	—	2.0

¹Clippings 1, 2, and 3 occurred 74, 113, and 148 days after planting, respectively.

²The Fisher's Protected LSD values were computed at the 0.05 level of significance and are applicable for comparisons across grass:legume ratios within species.

grass in the mixture increased. This anomaly suggests that during early stages of growth, sweetclover may be more competitive for soil N when grown in association with crested wheatgrass.

The relatively greater percentage of N₂ fixed by alfalfa or sweetclover in mixture with crested wheatgrass may be due to the depletion of limited soil N and fertilizer N by the more competitive crested wheatgrass, thereby increasing the reliance of alfalfa or sweetclover on N₂ fixation. The declining ¹⁵N enrichment of crested wheatgrass shoots with each successive clipping (Tables 5 and 6) support this explanation.

The ¹⁵N label was not uniformly distributed in plant tissues at the third clipping (Tables 5 and 6), as has been observed for other species (Chalk 1985). Crested wheatgrass shoots were slightly more enriched in ¹⁵N than roots and, conversely, alfalfa or sweetclover shoots were at least 3 times less enriched than roots. This pattern may inflate the estimation of the percentage of N derived from fixation by as much as 15% when only shoots are harvested (Ruschel et al. 1982). Despite non-uniform labeling, the percentage of N derived from fixation for shoots and roots were high enough and similar enough to overcome problems associated with isotopic fractionation (Bergersen and Turner 1983).

Nitrogen Transfer

Nitrogen transfer was calculated as the difference between the isotopic composition of crested wheatgrass in mixture and monoculture. Indirect evidence for N transfer is supported when the ¹⁵N enrichment of grass in mixture with legumes is lower than that of grass in monoculture (Danson et al. 1988).

With few exceptions, the atom % ¹⁵N excess in shoots and roots of crested wheatgrass in monoculture was higher than crested wheatgrass shoots and roots from grass:legume ratios of 25:75 (Tables 5 and 6). Based on isotopic composition differences between monocultures and mixtures of crested wheatgrass, less than 5% of the shoot N and 10% of the root N of crested wheatgrass in a grass:legume ratio of 25:75 at the third clipping was derived by transfer from alfalfa (Table 9). Conversely, about 20%

Table 9. Proportion of nitrogen in shoots and roots of crested wheatgrass transferred from alfalfa when grown in mixtures of varying ratios and clipped 3 times.

Clip ¹	Grass:Legume Ratio			LSD ²
	25:75	50:50	75:25	
Shoot	----- (%) -----			
1	4.1	0.0	0.6	1.9
2	2.5	0.0	0.0	1.6
3	4.9	0.0	1.7	6.9
Root	----- (%) -----			
3	10.1	3.6	2.7	7.8

¹Clippings 1, 2, and 3 occurred 74, 114, and 149 days after planting, respectively.

²The Fisher's Protected LSD values were computed at the 0.05 level of significance and are applicable for comparisons across grass:legume ratios.

of the shoot and root N of crested wheatgrass in a grass:legume ratio of 25:75 at the third clipping was derived by transfer from sweetclover (Table 10). Nitrogen transfer from sweetclover to crested wheatgrass generally increased in later clippings and as the proportion of sweetclover in the mixture increased. These results support hypotheses that the N transfer pathway from legume to grass in mixtures may be by direct root excretion of N compounds, such as ammonium N, amino acids, and proteins, and by decomposition of dead legume root and nodule tissue at later growth stages. Intermingling of crested wheatgrass and sweetclover roots was extensive at the final clipping. When compared to alfalfa roots collected in the companion experiment, a higher proportion of sweetclover roots and nodules were soft, discolored, and failed to differentially stain (Ward et al. 1978), indicating that cell lysis and root and nodule senescence may have been greater for sweetclover

Table 10. Proportion of nitrogen in shoots and roots of crested wheatgrass transferred from sweetclover when grown in mixtures of varying ratios and clipped 3 times.

Clip ¹	Grass:Legume Ratio			LSD ²
	25:75	50:50	75:25	
Shoot	----- (%) -----			
1	18.8	0.0	0.0	1.3
2	0.0	4.3	0.0	2.9
3	22.3	4.4	7.9	6.4
Root	----- (%) -----			
3	18.8	4.2	10.2	6.6

¹Clippings 1, 2, and 3 occurred 74, 113, and 148 days after planting, respectively.

²The Fisher's Protected LSD values were computed at the 0.05 level of significance and are applicable for comparisons across grass:legume ratios.

than alfalfa. This may be responsible for the higher N transfer estimates for sweetclover to crested wheatgrass when compared to alfalfa.

Under the conditions of this study, N transfer from sweetclover to crested wheatgrass was estimated to range from 0 to 22% of the grass total N depending on tissue type (root or shoot), grass:legume ratio, and clipping date. Generally, increasing the proportion of legume in the mixture increased N transfer from sweetclover to crested wheatgrass. Nitrogen transfer from alfalfa to crested wheatgrass was estimated to account for less than 10% of the grass total N. However, this was a short-term experiment using juvenile plants, and the limited N transfer observed was probably due to active excretion of N compounds from alfalfa roots (Brophy and Heichel 1989). The young age of the plants and the favorable growing conditions probably limited alfalfa root and nodule turnover, which can significantly contribute to long-term N transfer. These results suggest that significant N transfer may not occur during early stages of stand development but will likely increase with time as alfalfa root and nodule tissue turnover becomes more pronounced. Regardless of differences between legumes, N transfer from alfalfa or sweetclover to crested wheatgrass may be important in maintaining stand productivity on N-limited western rangelands.

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internode elongation in forage grasses. It can be used to categorize germplasm for potential problems with crown node elevation. We are using it in a recurrent selection protocol to develop grasses with reduced tendency for crown node elevation.

The value of this procedure in improving the establishment of *Panicoid* grasses, that can exhibit the elevated crown syndrome, remains to be tested. That species such as sideoats grama and kleingrass can develop elevated crowns is known. Our populations, selected for greater sensitivity to light, will be tested in variable greenhouse and field environments to validate the selection procedure and to determine if a reduction in crown node elevation can impact seedling establishment.

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