Sod-seeding alfalfa in spring into established crested wheatgrass in southwest Saskatchewan

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Schellenberg, M. P., Waddington, J. and King, J. R. 1994. **Sod-seeding alfalfa in spring into established crested wheatgrass in southwest Saskatchewan.** Can. J. Plant Sci. **74**: 293–301. Five experiments were started over a 3-yr period to examine the width of a strip of established crested wheatgrass (*Agropyron desertorum* (Fisch.) Schult.) that should be killed for reliable establishment of alfalfa (*Medicago sativa* L.) by sod-seeding in semiarid southwestern Saskatchewan. The value of pruning the grass roots along the edges of the killed area for alfalfa establishment was also examined. When alfalfa seeds were sown in a single row in strips of dead crested wheatgrass, alfalfa establishment improved as the width of the dead strip increased up to 75 cm, the maximum used, because of less competition for moisture and light. Pruning grass roots did not improve alfalfa establishment. Killing the crested wheatgrass in a strip wider than 50 cm favoured weed growth. Annual and biennial weeds were present only in the establishment year, but perennials persisted for the duration of the experiments. Yields of Rangelander, a creeping-rooted alfalfa of mixed ssp. *sativa* (L.) Lesins & Lesins and ssp. *falcata* (L.) Arcangeli parentage, and SCMf3713, a tap-rooted ssp. *falcata* were similar in the seedling and the following year. Etiolated growth of established plants revealed that SCMf3713 had a more persistent recovery characteristic which probably confers survival ability in severe environments. Killing the resident crested wheatgrass benefitted alfalfa establishment, as measured by seedling numbers, growth, seedling and first harvest year yields, and root reserves.

Key words: Crested wheatgrass, sod-seeding, alfalfa, *Agropyron desertorum*, *Medicago sativa*

Schellenberg, M. P., Waddington, J. et King, J. R. 1994. **Sursemis de luzerne au printemps dans une prairie d'agropyre à crête dans le sud-ouest de la Saskatchewan.** Can. J. Plant Sci. **74**: 293–301. Cinq expériences ont été mises en place sur une période de trois ans pour examiner la largeur de la bande d'une prairie établie d'agropyre à crête (*Agropyron desertorum* (Fisch.) Schult.) qu'il faudrait traiter au dessiccants pour obtenir une bonne installation de la luzerne (*Medicago sativa* L.) en sursemis dans la zone semi-aride du sud-ouest de la Saskatchewan. On examinait aussi l'utilité de trancher les racines de la graminée le long des bords de la bande desséchée. Lorsque la luzerne était semée en une seule ligne dans la bande d'agropyre desséchée, son installation s'améliorait avec la largeur de la bande traitée jusqu'à concurrence de 75 cm (largeur maximum comparée). Ce comportement s'explique par la moindre concurrence pour l'eau et pour la lumière. Le fait de tailler les racines d'agropyre n'améliorait pas l'installation de la luzerne. Une largeur de bande desséchée de plus de 50 cm favorisait la croissance des mauvaises herbes. Les mauvaises herbes annuelles et bisannuelles ne s'observaient que dans l'année d'installation de la luzerne, mais les vivaces persistaient tout au long des expériences. Le rendement de Rangelander, variété de luzerne à racines traçantes, d'ascendance mixte: spp. *sativa* (L.) Lesins et Lesins et spp. *falcata* (L.) Arcangeli et celui de 'SCMf3713' spp. *falcata* à racine pivotante était semblable dans l'année du semis et dans l'année suivante. La croissance étiolée des plantes installées révélait que 'SMCf3713' possédait une persistance de reprise plus durable, ce qui lui conférait probablement une meilleure survie dans les milieux difficiles. La destruction de l'agropyre en place facilitait l'installation de la luzerne: nombre de plantules, croissance, rendement dans l'année de semis et dans la première année d'exploitation, réserves racinaires.

Mots clés: Agropyre à crête, sursemis, luzerne, *Agropyron desertorum*, *medicago sativa*

Southwest Saskatchewan has a semi-arid climate supporting mid-shortgrass prairie and seeded pasture that is generally deficient in nitrogen and has only a minor legume component. The inclusion of alfalfa (*Medicago sativa* L.) in grazing lands can, because of its nitrogen-fixing ability, increase production of forage by 100% or more (Leyshon 1978; Kreuger and Vigil 1979), with concomitant increases in beef and lamb production (Hervey 1960; Kreuger and Vigil 1979). However, in Saskatchewan pastures, the legume declines for several reasons including drought, overgrazing, and episodic winterkill. In the past, re-establishment of the alfalfa was usually achieved by reseeding after cultivation. More recently, seeding into established swards (sod-seeding) has been practiced (Vogel et al. 1983; Malik and Waddington 1990). Sod-seeding has an advantage over cultivation when the potential for erosion is high, cultivation to prepare a seedbed is impractical, or the purpose is to modify rather than replace the existing vegetation (Vallentine 1980).

Vallentine (1980) stated that sod-seeding should occur on the same date as seeding into cultivated land. Herbel (1983) suggested that the most desirable time to seed is directly prior to the season of the most reliable rainfall. In Saskatchewan, both these suggestions coincide with the recommended early spring seeding (Kilcher 1961). However, temperature and light requirements for alfalfa germination and growth (Bula and Massengale 1972) indicate that seedlings will likely emerge after grasses are growing, which puts the alfalfa seedlings at a competitive disadvantage.

Competition from neighbouring plants is the greatest single hazard faced by colonizing seedlings (Fenner 1985), particularly when the neighbouring plants are well-established. In arid and semiarid regions, a significant reduction in competition for water by the established vegetation is required if sod-seeding is to be successful (Waddington 1989). In natural plant communities, Goldberg (1987) found that the probability of establishing new perennials from seed was low to rare without the presence of "gaps" of 10 cm diameter or larger in the resident vegetation. Bigger gaps were positively related to survival, growth and production of *Solidago* spp. (Goldberg and Werner 1983).

In pastures, herbicides may be used to create gaps by suppressing or killing the existing vegetation while leaving the soil surface undisturbed. The amount of suppression or kill of the resident vegetation has not been defined clearly for all situations. Bowes and Friesen (1967) found that suppression of a bluegrass (*Poa pratensis* L.) sward was unnecessary when seeding alfalfa. Waddington (1989) suggested that there was no advantage to controlling a strip of vegetation wider than 40 cm for establishing sod-seeded alfalfa in a variety of pastures located within Saskatchewan. Smoliak and Feldman (1979) found that the wider the tilled strip the better the establishment of Russian wildrye (*Psathyrostachys juncea* (Fisch.) Nevski) in native prairie in southeastern Alberta. As Vallentine (1980) suggested, the width required is dependent on the vigour of the existing stand, soil moisture content and forage species being interseeded: wider strips are needed for more competitive sods, for less competitive seedlings, and for drier sites where competition for moisture is high.

Research in the parkland region of Saskatchewan (Bittman et al. 1991) and in central North Dakota (Berdahl et al. 1989) has shown that alfalfa cultivars and experimental strains with a high proportion of ssp. *falcata* parentage survive longer in association with grass than varieties composed mainly of ssp. *sativa*.

The experiments reported in this study investigated the requirements for sod-seeding alfalfa in spring in semi-arid southwestern Saskatchewan.

MATERIALS AND METHODS

Two experiments were established in each year 1989 and 1990, and one in 1991 at the Agriculture Canada Research Station, Swift Current, Saskatchewan (50°17′N, 107°41′W) on a Swinton loam soil (Orthic Brown Chernozem (Ayres et al. 1985)), on solid stands of 30+ year old crested wheatgrass (*Agropyron desertorum* (Fisch.) Schult.). Experiment 1 was established in 1989 on a level site in crested wheatgrass which had been harvested for hay for many years, and exp. 1 in 1990 was adjacent to it. Experiment 2 in 1989 was established nearby on a low-productivity site which had been harvested for hay occasionally, and exp. 2 in 1990 was adjacent to it but in a pasture which had been grazed intermittently in the past. The sites had a slight slope to the north. The experiment in 1991 was established 1 km north of the other sites on an area with a mixed grazing and haying history and with a moderate west-facing aspect. None of the sites had received fertilizer for at least 5 yr prior to the start of the experiments.

A three-factor factorial design with four replicates was used. The factors were: (1) two locally adapted alfalfa types: Rangelander, a creeping-rooted variety of mixed ssp. *sativa* and ssp. *falcata* parentage, and SCMf3713, a tap-rooted ssp. *falcata*. (2) The width of the strip (0, 25, 50, or 75 cm) of resident vegetation killed prior to seeding the alfalfa. (3) Whether or not roots of live grass adjacent to the killed strips were pruned to a depth of 15 cm along both sides of the killed areas.

Plots were 9 m long and 3 m wide. Glyphosate (*N*-(phosphonomethyl) glycine) was applied at 2.2 kg a.i. ha^{-1} in a single band centred along the length of a plot in early spring when the grass was actively growing. Strips not completely killed were resprayed 2 wk later. Alfalfa seed was inoculated with *Rhizobium meliloti*, and sown at 100 seeds m^{-1}, centred along the length of each plot, utilizing a self-propelled press drill plot seeder (Dyck et al. 1993). In 1989, glyphosate was applied on 10 May, roots were pruned using a flat-face spade on 1 June, and alfalfa was seeded on 2 June. In 1990, the glyphosate application, root pruning, and seeding operations were conducted on 17 May, 1 June, and 3 June respectively, and in 1991, on 16 May, 6 June, and 10 June, respectively. The control plots (no glyphosate application) were pruned at a width of 50 cm.

Three 1-m strips within each plot were randomly selected, staked, and alfalfa seedlings were counted 14 d after seeding and again in late August to early September. In 1989 and 1990, the number of days from seeding to the development of three true leaves on the majority of seedlings was recorded. In 1991, the numbers of leaves present 35 d after seeding were recorded. Late in the growing season in the seedling year and in mid-July of the following year, alfalfa, grass, and weeds were cut separately at ground level from a strip 1.0 m wide centred on the alfalfa row. The strip length was 0.5 m in 1989, 2.0 m in 1990, and 1.0 m in 1991.

A Campbell Pacific Nuclear Model 503 Hydroprobe with a surface adaptor (Chanasyk and Naeth 1988) was used to monitor surface (0–15 cm) soil moisture from exp. 1 approximately biweekly in the seedling years in 1989 and monthly in 1990 and 1991. The same probe was used in 1989 and 1990 to measure moisture in each plot to a depth of 45 cm via access tubes placed in the alfalfa row. A measurement of the incident global radiation received by the seedlings was taken in mid-June near midday, using a Licor Li-188 quantum meter placed in each seedling row.

In October, 1990 and 1991, three 16-mo-old alfalfa plant crowns and roots were excavated to a depth of 15 cm from each plot of exp. 1. Within 24 h, plants were washed to remove soil, planted in 10-cm-diameter by 25-cm-deep plastic pots filled with medium-textured vermiculite, and placed in growth rooms with a constant temperature of 20°C, a relative humidity of 80% and no light. The etiolated growth was harvested every second week until no further growth occurred (McKenzie et al. 1988), oven-dried at 100°C for a minimum of 24 h and weighed.

Meteorological records were obtained from an Environment Canada weather station near the experimental areas. Precipitation and potential evaporation (U.S. Weather Bureau Class A pan) were totalled on a weekly basis over the growing season (1 May to 30 September). Data were analysed using SAS GLM (SAS Institute Inc. 1990). Orthogonal polynomial contrasts were used to identify relationships among the widths of grass control strips.

RESULTS

In 1989, precipitation occurred regularly from May to September with major events in the second week of May, the second and fourth weeks of June and the third and fourth weeks of August (Fig. 1). The major precipitation events in 1990 occurred in the third week of May and from the first to the fourth week of July: almost no precipitation fell in September. Overall, less precipitation was received during the growing season of 1990 than in 1989. In 1991, major precipitation events occurred in the second week of May, and the first, third and fourth weeks of June. Potential evaporation peaked in the fourth week of July in all years. Overall, potential evaporation was greater in 1990 than in 1989 or 1991. Water balances (precipitation minus potential evaporation) for the growing seasons of 1989, 1990, and 1991 were −30.54 mm, −33.84 mm, and −39.9 mm per week respectively. The 30-yr average is −25.6 mm.

Seedling population density 2 wk after seeding, averaged across all treatments, was 39, 11, and 18% of the seeding rate in 1989, 1990, and 1991, respectively (Table 1). By fall, plant population density was 31, 7, and 11% of the seeding rate. Only in 1990 was emergence in spring improved significantly ($P < 0.05$) by killing the crested wheatgrass. However, in all experiments, population density in fall was significantly greater where the grass was killed, and in four of five experiments was significantly greater the wider the killed strip. Where the crested wheatgrass was not killed, alfalfa seedlings failed to survive in 1990, and in 1991 seedlings present in spring were almost eliminated by fall. Differences in establishment between the two alfalfa types were also significant in exp. 1 of each year. In 1989, SCMf3713 had 22% more seedlings than Rangelander in spring, and 26% more in the fall. In 1990, SCMf3713 produced only 67% as many seedlings in spring as Rangelander, and this had fallen to only 46% by fall. In 1991, SCMf3713 produced only 42% as many seedlings as Rangelander in spring, though this improved to 57% by fall. The second experiment showed a similar trend in seedling population density to the first experiment of the same year, but the differences did not reach significance. In 1989 and 1991, pruning crested wheatgrass roots had no effect on alfalfa seedling density. In fall 1990, alfalfa population densities in exps. 1 and 2 were 11 and 6 respectively per metre of row where grass roots had been pruned, significantly greater when compared to 7 and 3 respectively where they were not pruned.

Controlling the resident vegetation shortened the time required for the alfalfa seedlings to reach the three-true-leaf stage (Table 2): plots without grass control had development times from 4 to over 20 d longer. For three of five experiments, a negative linear relationship existed between alfalfa

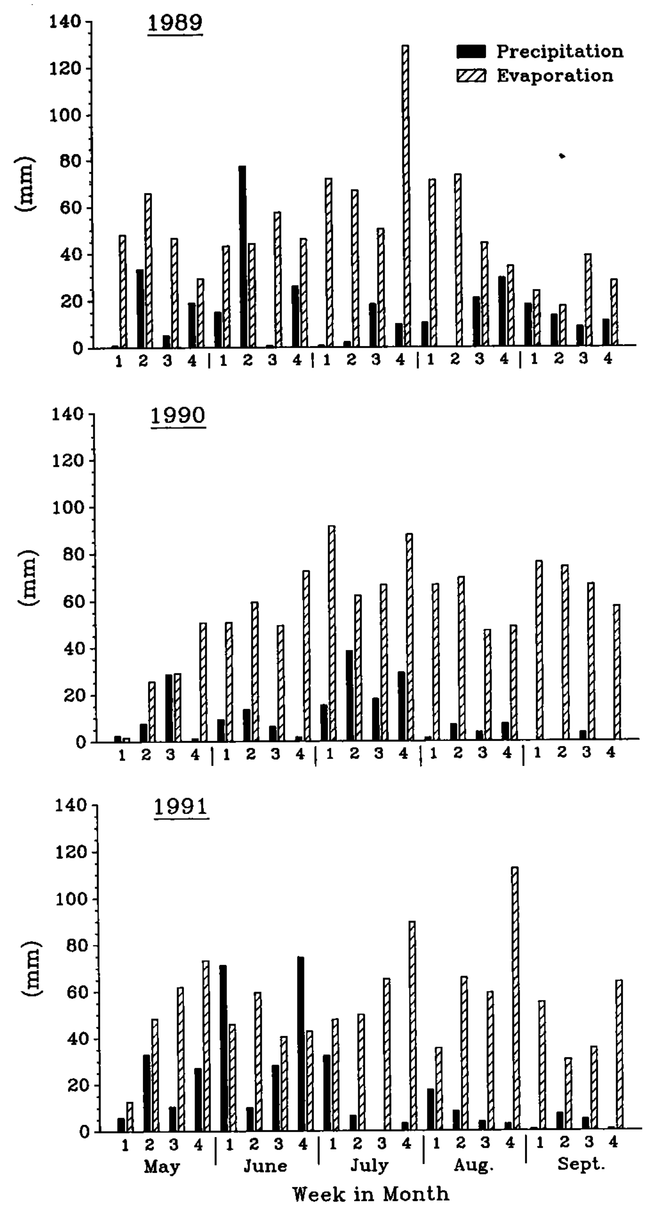

Fig. 1. Weekly precipitation and potential evaporation at Swift Current during the growing seasons 1989–1991.

development and the width of the crested wheatgrass area killed. In the first 2 yr, there were no significant differences between alfalfa types in the time taken to develop three true leaves. In 1991, alfalfa seedlings had significantly more leaves in the grass-control strips than where grass was not controlled, and Rangelander developed at a significantly faster rate than SCMf3713. Pruning grass roots had no effect on alfalfa development time.

In all experiments there was a significant positive linear relationship between the width of the crested wheatgrass area killed and alfalfa dry matter yields in the year of seeding (Table 3). There was little or no alfalfa where the grass was not killed. Although statistical comparisons were not made between years, there appeared to be more grass growth and less alfalfa and weeds in the 1990 experiments than in those started in 1989. The 1991 experiment had the most grass. As expected, the amount of grass harvested was significantly less where some of it was killed, and was negatively correlated with width of the killed strip in two of the five experiments. In four of five experiments weeds increased linearly as the width of the killed strip increased, although they were a large component only where a 75 cm strip of grass had been killed.

Alfalfa production in the year following the seedling year was always significantly greater where the grass had been killed, and was positively related to strip width, significantly so in four of five experiments (Table 4). Treatments affected grass significantly only in exp. 2 in 1991 where yields were greater in plots where grass strips had been killed the previous year. Weeds were a minor component in all except exp. 2 started in 1989 where *Antennaria* spp. were abundant. Differences in dry matter production between the two experiments seeded in the same year were evident in both 1989 and 1990 experiments. Experiment 2 seeded in 1989 had grass dry matter yields approximately 60% less in 1990 than exp. 1, and much more weed growth. Experiment 2 seeded in 1990 had alfalfa yields about 70% less in 1991 than exp. 1. There were no differences between alfalfa types, and no effect of grass root pruning on dry matter yields the year following the seedling year.

Alfalfa from areas subjected to grass control in 1989 had significantly more etiolated growth than that from areas without grass control (Table 5). Also, there was a significant positive linear relationship between the width of grass strip killed and alfalfa etiolated growth for many of the

Table 1. Alfalfa seedlings present in spring and fall of the seedling year after seeding into killed strips of several widths in established crested wheatgrass

Year of seeding	Exp. no.	Width of killed crested wheatgrass strip (cm)	Time of count: Spring, Rangelander (No. of seedlings m^{-1})	Spring, SCMf3713	Fall, Rangelander	Fall, SCMf3713
1989	1	0	36	39	7	14
		25	38	45	37	42
		50	37	47	38	49
		75	37	49	42	52
Grass killed vs. not:			NS[z]		1%	
Linear effect, strip width:			NS		NS	
Rangelander vs. SCMf3713:			1%		5%	
Standard error:			2.9		4.0	
	2	0	36	31	9	6
		25	34	43	28	29
		50	38	40	33	34
		75	33	46	33	42
Grass killed vs. not:			NS		1%	
Linear effect, strip width:			NS		5%	
Rangelander vs. SCMf3713:			NS		NS	
Standard error:			2.8		2.7	
1990	1	0	5	7	0	0
		25	17	8	13	2
		50	16	13	18	9
		75	21	15	20	12
Grass killed vs. not:			1%		1%	
Linear effect, strip width:			5%		1%	
Rangelander vs. SCMf3713:			1%		1%	
Standard error:			1.6		1.4	
	2	0	3	5	0	0
		25	8	9	3	3
		50	7	7	6	5
		75	18	8	12	5
Grass killed vs. not:			5%		1%	
Linear effect, strip width:			5%		1%	
Rangelander vs. SCMf3713:			NS		NS	
Standard error:			1.6		1.0	
1991	1	0	23	9	1	0
		25	27	13	14	5
		50	23	14	19	12
		75	26	13	20	13
Grass killed vs. not:			NS		1%	
Linear effect, strip width:			NS		1%	
Rangelander vs. SCMf3713:			1%		1%	
Standard error:			2.1		1.2	

[z]NS, 5%, 1%: Comparisons not significantly different, different for $P < 0.05$ and $P < 0.01$, respectively.

Table 2. Development of alfalfa seedlings after seeding into killed strips of several widths in established crested wheatgrass

Width of killed crested wheatgrass strip (cm)	Alfalfa type	Number of days to develop three true leaves: 1989 Exp. 1 (d)	1989 Exp. 2 (d)	1990 Exp. 1 (d)	1990 Exp. 2 (d)	Number of leaves 35 d after seeding 1991
0	Rangelander	34	37	44	>40	2.4
	SCMf3713	32	37	44	>40	1.9
25	Rangelander	28	33	34	20	4.0
	SCMf3713	27	32	37	25	3.5
50	Rangelander	28	32	31	19	5.4
	SCMf3713	28	30	31	27	3.9
75	Rangelander	27	30	33	30	5.2
	SCMf3713	27	30	31	19	4.4
Grass killed vs. not;		1%[z]	1%	1%	1%	1%
Linear effect, strip width:		NS	5%	1%	NS	1%
Rangelander vs. SCMf3713:		NS	NS	NS	NS	1%
Standard error:		0.7	1.1	0.9	3.1	0.21

[z]NS, 5%, 1%: Comparisons not significantly different, different for $P < 0.05$ and $P < 0.01$, respectively.

Table 3. Dry matter yields of alfalfa, grass, and weeds in seedling year after seeding alfalfa into killed strips of several widths in established crested wheatgrass (CWG)

Year of seeding	Exp. no.	Forage	Width of killed crested wheatgrass strip (cm): 0 ($g\ m^{-2}$)	25	50	75	Standard error	Contrasts: Killed vs. not	Linear width killed
1989	1	Alfalfa	0.6	5.2	13.6	14.7	1.42	1%[z]	1%
		CWG	78.2	56.1	37.2	27.6	4.65	1%	1%
		Weeds	1.2	7.4	24.9	55.8	8.61	5%	1%
	2	Alfalfa	0.1	2.5	5.2	7.8	0.99	1%	1%
		CWG	29.0	25.9	26.0	29.6	2.88	NS	NS
		Weeds	3.1	9.0	5.0	14.6	2.77	5%	NS
1990	1	Alfalfa	0.1	1.6	6.2	10.8	1.12	1%	1%
		CWG	121.4	105.3	105.8	95.8	6.76	5%	NS
		Weeds	0.0	0.4	1.0	7.0	1.43	NS	1%
	2	Alfalfa	0.0	0.3	3.8	3.4	0.87	5%	5%
		CWG	198.9	158.2	156.5	171.4	9.75	1%	NS
		Weeds	0.0	0.0	3.4	20.5	3.25	NS	1%
1991	1	Alfalfa	0.0	2.3	9.3	10.4	1.11	1%	1%
		CWG	297.4	278.2	216.4	227.4	15.07	1%	5%
		Weeds	0.1	0.5	2.1	8.8	1.99	NS	1%

[z]NS, 5%, 1%: Comparisons not significantly different, different for $P < 0.05$ and $P < 0.01$, respectively.

individual harvests and for total yield. Rangelander alfalfa produced twice the etiolated growth of SCMf3713 at the first harvest after transplanting but with successive harvests Rangelander regrowth steadily decreased. Growth of SCMf3713 equalled that of Rangelander at the second harvest and produced significantly more dry matter than Rangelander thereafter. Alfalfa etiolated growth from the experiment started in 1990 showed a similar pattern to the one started the previous year, but with fewer significant differences. Also, a beneficial effect of grass root pruning was apparent during the first two growth periods and in the overall production (data not shown).

In most cases, killing strips of grass resulted in increased surface soil moisture, and in general, surface soil moisture tended to increase with increasing width of the killed strip (Table 6). In 1989, the lowest readings were obtained on 8 August with an average value of 12.9%, just above the volumetric wilting point of 11% for 1-yr-old alfalfa seedlings in this soil (Cutforth et al. 1991). The lowest value in 1990, 13.4%, occurred on 7 September, and was also above the permanent wilting point. The lowest value measured in 1991 occurred on 11 August, and was well below the permanent wilting point.

Significant though small differences between alfalfa types occurred only in surface soil moisture measurements taken

Table 4. Dry matter yields of alfalfa, grass, and weeds in the first harvest year after seeding alfalfa into killed strips of several widths in established crested wheatgrass (CWG)

Harvest year (year of seeding)	Exp. no.	Forage	Width of killed crested wheatgrass strip (cm) 0	25	50	75	Standard error	Contrasts: Killed vs. not	Contrasts: Linear width killed
			($g\ m^{-2}$)						
1990 (1989)	1	Alfalfa	4.9	20.7	37.1	46.9	2.86	1%[z]	1%
		CWG	154.0	144.1	143.0	139.1	5.44	NS	NS
		Weeds	0.0	0.0	0.0	0.4	0.13	NS	NS
	2	Alfalfa	13.5	37.1	35.4	48.4	6.32	1%	NS
		CWG	53.4	44.5	54.6	41.9	6.24	NS	NS
		Weeds	18.3	16.5	16.0	16.9	2.63	NS	NS
1991 (1990)	1	Alfalfa	0.9	37.2	141.7	185.0	16.04	1%	1%
		CWG	92.6	102.7	103.9	120.5	9.00	NS	NS
		Weeds	0.3	0.8	0.1	1.1	0.36	NS	NS
	2	Alfalfa	0.3	12.3	61.6	74.0	12.63	1%	1%
		CWG	139.3	180.2	189.3	179.2	11.78	1%	NS
		Weeds	0.0	0.6	1.7	1.9	0.65	NS	NS
1992 (1991)	1	Alfalfa	0.0	1.4	5.6	4.7	0.69	1%	1%
		CWG	131.9	125.0	135.3	142.7	8.42	NS	NS
		Weeds	0.0	0.0	0.0	0.0	—	—	—

[z]NS, 5%, 1%: Comparisons not significantly different, different for $P < 0.05$ and $P < 0.01$, respectively.

Table 5. Etiolated growth from alfalfa plant crowns in late summer of the year following seeding into killed strips of several widths in established crested wheatgrass

Harvest sequence	Alfalfa type	Width of killed crested wheatgrass strip (cm) 0	25	50	75	Standard error	Contrasts: Killed vs. not	Contrasts: Linear width killed	Contrasts: Rglndr vs. SCMf3713
		($g\ plant^{-1}$)							
1989 Experiment 1									
1	Rangelander	0.044	0.099	0.178	0.167	0.02	1%[z]	NS	1%
	SCMf3713	0.040	0.049	0.094	0.061				
2	Rangelander	0.010	0.034	0.083	0.083	0.01	1%	5%	NS
	SCMf3713	0.010	0.049	0.061	0.072				
3	Rangelander	0.002	0.011	0.027	0.037	0.02	1%	5%	5%
	SCMf3713	0.010	0.037	0.037	0.050				
4	Rangelander	0.000	0.008	0.039	0.029	0.01	1%	1%	1%
	SCMf3713	0.019	0.042	0.053	0.084				
5	Rangelander	0.000	0.003	0.043	0.017	0.01	1%	5%	1%
	SCMf3713	0.003	0.030	0.038	0.069				
Total	Rangelander	0.055	0.154	0.335	0.331	0.04	1%	1%	NS
	SCMf3713	0.081	0.206	0.281	0.335				
1990 Experiment 1									
1	Rangelander	0.021	0.373	0.594	0.428	0.06	1%	NS	1%
	SCMf3713	0.013	0.071	0.271	0.312				
2	Rangelander	0.012	0.145	0.133	0.252	0.03	1%	NS	1%
	SCMf3713	0.003	0.016	0.098	0.081				
3	Rangelander	0.006	0.037	0.046	0.080	0.02	5%	5%	NS
	SCMf3713	0.002	0.005	0.049	0.054				
4	Rangelander	0.002	0.019	0.018	0.030	0.007	1%	5%	NS
	SCMf3713	0.005	0.007	0.034	0.044				
5	Rangelander	0.000	0.006	0.008	0.010	0.008	NS	5%	5%
	SCMf3713	0.005	0.007	0.042	0.052				
6	Rangelander	0.000	0.000	0.002	0.000	0.004	NS	NS	5%
	SCMf3713	0.001	0.003	0.014	0.024				
Total	Rangelander	0.041	0.579	0.799	0.769	0.109	1%	5%	5%
	SCMf3713	0.028	0.105	0.507	0.564				

[z]NS, 5%, 1%: Comparisons not significantly different, different for $P < 0.05$ and $P < 0.01$, respectively.

on 20 and 27 June 1989. Plots seeded with SCMf3713 alfalfa had moisture readings of 31.6 and 24.4% compared with 31.1 and 23.7% where Rangelander was seeded. Plots where roots had been pruned differed significantly only on 23 July 1990 with an average water content of 19.1% compared with 18.5% where roots had not been pruned.

For the 15- to 45-cm soil layer, soil moisture tended to increase as strip width increased (Table 6), but not always by a significant amount, and the trend disappeared in measurements taken in late September 1989. In 1989, the lowest readings were obtained on 29 July; in 1990 on 6 September. Plots where grass was not killed were at or below the permanent wilting point in the 15- to 45-cm depth at least once in each year, whereas plots where grass was killed had significantly more available water at those times. Snowmelt failed to recharge the lower soil depths in spring 1990 (data not shown).

In all three establishment years, light intensity readings at ground level were significantly higher in plots where the grass was killed (Table 7). Light intensity increased linearly with strip width, although the trend was significant in only one experiment in each year. Pruning crested wheatgrass roots had no significant effect on light intensities, and there were no significant differences between SCMf3713 and Rangelander.

DISCUSSION

All measurements of the degree of alfalfa establishment: seedling numbers and growth, establishment and first harvest year yields, etiolated growth from root reserves show the same trends. Killing the resident crested wheatgrass benefitted alfalfa establishment, and the wider the strip killed the better the alfalfa established. These trends are similar to those reported by Hagood (1988) when establishing alfalfa in tall fescue (*Festuca arundinacea* Schreb.), by McConnaughay and Bazzaz (1990) for annuals colonizing a Kentucky bluegrass field, and by Smoliak and Feldman (1979) when establishing Russian wildrye in native pasture. Differences between experiments due to specific site factors such as amount of thatch, associated weeds, and fertility, occurred, but there were two clear trends throughout. Better alfalfa establishment was associated with greater soil moisture and light. The wider the strip killed, the more of these resources became available and the longer the time interval in which

Table 6. Seedling year soil moisture after seeding alfalfa into killed strips of several widths in established crested wheatgrass

Measurement date	Width of crested wheatgrass strip killed (cm): 0	25	50	75	Standard error	Significance level: Killed vs. not	Linear width killed
	(% water by volume)						
			1989 (Experiment 1)				
0–15 cm soil layer							
13 June	32.6	32.3	32.9	33.3	5.01	NS[z]	NS
20 June	29.8	31.4	31.4	32.8	0.81	5%	5%
27 June	23.2	23.8	24.4	24.9	0.34	5%	5%
4 July	19.2	19.9	20.9	21.4	2.19	5%	5%
29 July	19.0	18.7	19.2	19.9	1.10	NS	5%
8 Aug.	12.4	12.7	13.1	13.3	0.43	5%	5%
23 Aug.	16.7	17.2	16.9	17.5	0.27	NS	NS
27 Sept.	28.2	27.3	27.5	27.8	0.79	5%	NS
15–45 cm soil layer							
13 June	30.5	32.8	31.0	32.9	0.65	5%	NS
29 July	10.9	15.1	15.3	16.3	0.85	1%	NS
27 Sept.	13.5	13.5	13.0	13.3	0.71	NS	NS
			1990 (Experiment 1)				
0–15 cm soil layer							
25 June	17.3	19.8	20.8	21.2	1.13	1%	1%
23 July	16.5	18.4	20.0	20.2	3.03	5%	5%
14 Aug.	17.4	16.8	19.0	18.5	0.84	5%	1%
7 Sept.	16.3	16.5	16.9	17.0	0.52	5%	5%
15–45 cm soil layer							
25 June	14.0	19.0	23.8	24.7	0.75	1%	1%
14 Aug.	11.2	13.6	17.0	18.4	0.77	1%	1%
6 Sept.	10.2	11.4	12.3	12.0	0.57	5%	NS
			1991				
0–15 cm soil layer							
11 June	22.1	23.6	24.6	26.3	0.44	1%	1%
19 July	11.9	13.2	15.0	15.4	0.41	1%	1%
11 Aug.	8.0	6.7	4.9	5.5	3.10	NS	NS
9 Sept.	11.1	11.8	13.3	13.0	0.28	1%	1%

[z]NS, 5%, 1%: Comparisons not significantly different, different for $P < 0.05$ and $P < 0.01$, respectively.

Table 7. Light levels at ground level in mid-June where alfalfa was seeded directly into killed strips of several widths in established crested wheatgrass

Year seeded	Exp. no.	Width of killed crested wheatgrass strip (cm) 0	25	50	75	Standard error	Contrasts: Killed vs. not	Contrasts: Linear width killed
		(μmol m^{-2} s^{-1})						
1989	1	308	437	449	489	16.9	1%[z]	5%
	2	638	726	690	786	36.2	5%	NS
1990	1	869	1030	1188	1338	72.8	1%	1%
	2	1167	1558	1609	1612	45.8	1%	NS
1991	1	160	664	710	777	29.6	1%	5%

[z]NS, 5%, 1%: Comparisons not significantly different, different for $P < 0.05$ and $P < 0.01$, respectively.

moisture in the soil was available to seedlings. Also superimposed on this pattern were year-to-year variations in response to weather. Until alfalfa plants have developed a mature root system, they must extract all their moisture from soil nearer the surface. As well, root growth of young seedlings is slowed by soil moisture stress (Waddington and Shoop 1994). The major precipitation events in June in 1989 and 1991 (Fig. 1) provided good-excellent moisture conditions for a much longer period than the low-precipitation conditions in June 1990, and the early seedling counts reflect this. There was also significant rainfall late in 1989, but not in the other 2 years, and the numbers of surviving seedlings reflect this also. However, it was not possible to demonstrate a linear relationship between seedling establishment and rainfall in the first 1-2 wk following seeding as reported by Barker et al. (1988). Although the soil moisture measurements demonstrated the benefit to alfalfa seedlings of killing the resident vegetation, the technology used was not able to measure from a small enough volume within the zone of influence of the seed and seedling to be able to say when and to what degree the seedlings were stressed.

Because of observations that vigorous established alfalfa plants can have a crown diameter of 10 cm or more, Waddington (1989) suggested that a 10% establishment from a seeding rate of 100 seeds m^{-1} of row was satisfactory for alfalfa in Saskatchewan. Based on this assumption, all Rangelander treatments in strip widths of 75 cm were satisfactory by the end of the seedling year. However, in one experiment seeded in 1990, SCMf3713 had established less than the suggested 10% of sown seeds, as had Rangelander in the same experiment when a strip of grass 50 cm wide or less was killed. Because this experiment was seeded in an area with a thick layer of litter, seed placement was poorer than in the other experiments. Nevertheless, alfalfa growth was good in this and other experiments the following year. It was not satisfactory only in the experiment established in 1991. It is likely that the site used in 1991 is deficient in phosphorus; there is no record of any ever having been applied.

Suppressing crested wheatgrass in a strip wider than 50 cm resulted in a much greater increase in weed biomass than alfalfa. In most of the experiments, the majority of weeds were annuals or biennials, and were no longer present in the second year. The exception was exp. 2 in 1989 in which *Antennaria* spp. spread rapidly into the strips where the grass was killed. Competition from the alfalfa was inadequate, and reinvasion of the strips by the crested wheatgrass did not occur to the same extent as in the other experiments.

Pruning grass roots at the edge of the area killed by glyphosate had only minor benefits to alfalfa in the seedling year, and none in the following year. These benefits occasionally reached significance, mainly in 1990, the driest of the 3 years. This suggests that in a solid stand, grass roots extend only short distances laterally, presumably because of competition from neighbouring plants. However, in the year of seeding, crested wheatgrass at the edges of the killed areas was observed to grow better and remain green later in the summer than grass surrounded by other grass plants, an effect similar to the findings of McGinnies (1984) in blue grama (*Bouteloua gracilis* (H.B.K.) Lag.). This "edge effect" which appeared whether roots were pruned or not, shows that these plants were benefitting from the control of the adjacent vegetation, obtaining one or more of additional water, nutrients from decay of dead vegetation, or light.

The seed of Rangelander is about twice the size of SCMf3713 seed, which should confer an advantage during the early stages of establishment due to faster growth from larger seedlings. In the experiment established in 1991, and in one of the 1990 experiments, Rangelander established more seedlings, but in the 1989 experiments, there were more seedlings of SCMf3713. Rangelander exhibited significantly faster growth only in the 1991 experiment. These differences may be present because SCMf3713 has a large number of hard seeds (personal observation), which in the absence of scarification, require longer periods of contact with moisture to initialize germination. The alfalfa seeds were not scarified for any of the experiments, so that some may have remained dormant to germinate at some later time if the initial germination failed because of drought. None of these differences translated into more dry matter.

Etiolated growth provided a clear contrast between the two alfalfa types. Rangelander appeared to exhaust most of its root reserves with its initial growth. SCMf3713 produced smaller amounts of etiolated growth but continued to produce them over repeated harvests, demonstrating a possible adaptation for greater persistence as found by Bittman et al. (1991). Slow, decumbant regrowth and the ability to go dormant during midsummer drought were characteristics considered to give alfalfa with ssp. *falcata* parentage an advantage for rangeland interseeding in semiarid regions

(Berdahl et al. 1989). Harper (1978) noted that agronomic value rarely confers survival value. Shorter development time and large energy expenditure of resources for rapid regrowth may limit the survivabilty of Rangelander in situations when repeated harvests may occur.

The results demonstrate that sod-seeding alfalfa to increase legume content of forage fields is an option in semi-arid areas provided sufficient resident vegetation is killed to prevent its competing with the legume seedlings during the establishment year. Additional research to quantify the relationship between water stress, soil type, soil fertility, and early seedling growth would improve our ability to predict the likelihood of success in establishing alfalfa in specific circumstances.

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