Seedbed preparation, timing of seeding, fertility and root pathogens affect establishment and yield of alfalfa

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Hwang, S. F., Gossen, B. D., Turnbull, G. D., Chang, K. F. and Howard, R. J. 2002. **Seedbed preparation, timing of seeding, fertility and root pathogens affect establishment and yield of alfalfa**. Can. J. Plant Sci. **82**: 371–381. Invasion by grasses and weedy species occurs when plant density in alfalfa fields falls below critical levels. Several soil-borne fungal pathogens can reduce stand density in alfalfa by impeding seedling establishment and by killing older plants weakened by other stresses. Surveys of alfalfa fields were conducted in 1997, and pathogenic fungi from rotted roots were isolated and identified. Isolates of selected pathogens were applied with the seed in field trials to assess the impact of fertilizer and seeding system (conventional vs. sod-seeding, spring vs. dormant-fall seeding) on seedling emergence and subsequent productivity when disease pressure was high. The impact of various fungicide seed treatments was also assessed. Seed treatment improved seedling emergence and initial forage productivity in one of three trials; however, it had little effect on long-term forage yield. Addition of sulphur fertilizer had little effect on seedling emergence or survival, but improved forage productivity at all three trial sites. Sod-seeded plots suffered more winterkill and were less vigorous than plots seeded into a tilled seedbed. Seedling emergence was lower when seedlings were planted in the fall than in the spring. However, fall-seeded treatments showed a less adverse response to inoculum treatments and, in some cases, these seedlings were able to take advantage of early-season moisture to produce higher yields than their spring-seeded counterparts.

Key words: *Medicago*, *Fusarium*, *Pythium*, *Phoma*, fungicide, seed treatment, fertilizer, tillage

Hwang, S. F., Gossen, B. D., Turnbull, G. D., Chang, K. F. et Howard, R. J. 2002. **La préparation de la planche de semis, la date du semis, la fertilité et les pathogènes racinaires affectent l'établissement et le rendement de la luzerne**. Can. J. Plant Sci. **82**: 371–381. Quand la densité de peuplement de la luzerne tombe sous un seuil critique, les champs sont envahis par les graminées et les adventices. Or, plusieurs cryptogames telluriques réduisent la densité du peuplement en nuisant à l'établissement des plantules et en tuant les plants plus âgés affaiblis par divers facteurs de stress. Un examen des champs de luzerne, en 1997, a permis d'isoler les cryptogames pathogènes dans les racines pourries. Les isolats ont ensuite été identifiés puis on a appliqué certains d'entre eux aux semences en prévision d'un essai au champ devant servir à évaluer l'impact des engrais et de la méthode d'ensemencement (semis classique contre sursemis; ensemencement au printemps contre ensemencement des graines dormantes à l'automne) sur la levée de la luzerne et sa productivité subséquente quand le stress de la maladie est élevé. Les auteurs ont aussi examiné l'incidence de plusieurs fongicides pour semences. Le traitement des semences améliore la levée et a accru la production initiale de fourrage lors d'un essai sur trois, mais n'a pas eu grand effet sur la productivité à long terme. L'addition d'engrais soufré n'a guère d'incidence sur la levée ni sur la survie des plantules, mais a amélioré la production de fourrage aux trois sites expérimentaux. Les parcelles sursemées ont souffert de l'hiver davantage et étaient moins vigoureuses que celles ensemencées après travail de la planche de semis. Les plantules lèvent moins bien quand on ensemence à l'automne plutôt qu'au printemps. Néanmoins, les semences mises en terre à l'automne réagissent moins à l'inoculum, de sorte que les plantules tirent à l'occasion parti de la plus grande quantité d'eau disponible au printemps pour donner un rendement supérieur à celui des plants résultant des semis printaniers.

Mots clés: *Medicago*, *Fusarium*, *Pythium*, *Phoma*, fongicide, traitement des semences, engrais, travail du sol

Alfalfa (*Medicago sativa* L.) is the most important species for the production of high-quality forage on the Canadian prairies. Extending the productive life of an alfalfa stand allows producers to amortize the cost of stand establishment over a longer period and to maintain the productivity of the stand for more years. To be profitable, the alfalfa stand must be dense enough to out-compete a wide range of weedy species. As a result, low seed germination, poor seedling establishment, and factors that reduce winter survival can be serious constraints to alfalfa production.

Soil-borne pathogens can reduce seedling establishment and shorten stand longevity by causing seedling blights and crown and root rot. *Cylindrocladium gracile* Bugn., *Phoma sclerotioides* Preuss ex Sacc. (syn. *Plenodomus meliloti* Mark.-Let.), *Rhizoctonia solani* Kühn, as well as several *Fusarium*, *Pythium* and *Sclerotinia* species, all reduce stand establishment and the longevity of alfalfa on the northern prairies (Reeleder 1982; Stelfox and Bertsch 1983; Hwang and Flores 1987; Hwang et al. 1989; Gossen 1994a, 1998; Wang et al. 1999). These fungi affect the stand in a number of ways: they attack feeder rootlets on healthy plants, reducing foliar productivity (Hancock 1985); attack vulnerable seedlings and reduce establishment; or invade and kill plants weakened by other stresses and reduce plant density and forage production.

Alfalfa stands are subject to a variety of stresses that can combine to reduce stand establishment and longevity. The winter period is an annual source of stress on alfalfa on the Canadian prairies. Nutrient deficiency can compound this stress because plants must not only have sufficient nutrient reserves to maintain themselves through the winter months, but must also retain enough nutrients to produce new growth in spring. Alfalfa has a high requirement for sulphur and potassium (Jung and Smith 1959; Fox et al. 1964; Reid et al. 1965; Rehm 1987). Plants that are deficient in these nutrients become chlorotic, stunted, more susceptible to winterkill (Bailey 1983), and may also have less tolerance to soil-borne pathogens, resulting in poor stand establishment and reduced stand longevity.

Direct seeding into undisturbed crop residue is becoming the preferred planting option for forage crops on the prairies because it reduces labour, fuel inputs and soil erosion, conserves soil moisture and provides a firm, consistent seedbed that is essential for seedling establishment and subsequent productivity of small-seeded forage crops. However, direct seeding requires effective weed control, generally via a broad-spectrum herbicide, to reduce the need for seedlings to compete for resources (Bowes and Zentner 1992).

Dormant seeding (just before freeze-up in late fall) is also becoming a popular management option for canola in the prairie region (Kirkland and Johnson 2000), due to improved availability of broad-spectrum herbicides for weed control and improved seed-coating techniques that delay germination until early spring. Germination in early spring enables the crop to take advantage of early spring moisture and to avoid late summer drought and heat by maturing earlier than spring-seeded crops (Kirkland and Johnson 2000). This management option would allow producers to distribute their workload away from traditional peak periods of spring seeding and fall harvest (Byer and Topinka 2000). Similar advantages may be realized with dormant seeding of alfalfa and other cool-season forages.

The objective of this project was to assess several crop management techniques that could affect the severity of soil-borne diseases of alfalfa, and thereby affect seedling establishment and stand longevity. These factors were: 1) sulphur and potassium fertilization, 2) direct and conventional tillage systems, 3) dormant seeding, and 4) fungicide seed treatments. All of these factors were evaluated with and without high populations of soil-borne pathogens. We are not aware of any previous research that examines the effect of the time of seeding or seedbed preparation on establishment of alfalfa in the presence of pathogens.

MATERIALS AND METHODS

Pathogenicity Trials

Diseased plant root samples were collected from five, 1-m^2 sites (surveyed in a W-shaped pattern with 50 m between consecutive sites) from each of nine fields in central Alberta on May 23, 1997. The samples were surface-sterilized and plated onto potato dextrose agar (PDA) media amended with streptomycin at 300 ppm. From these samples, 53 morphologically distinct fungal isolates were purified. Each isolate was grown on five, 10-cm dishes of PDA and incubated at 20°C, until the cultures covered the dishes. The colonized agar of each isolate was blended and then mixed with 0.5 L of sterilized soil. The inoculated soil was used to fill five, 7-cm-dia. plastic pots, and 10 alfalfa seeds were seeded 1-cm deep in each pot. Seedling emergence was counted 12 days after planting. Root rot symptoms were evaluated 17 days after seeding using a 0-4 scale, where: 0 = no disease, 1 = small lesions on root, 2 = large lesions, 3 = lesions covering > ½ of the root circumference, and 4 = lesions occupying > ½ of the root cross-section. The experiment was conducted twice using the alfalfa cvs. Algonquin and Peace. The most pathogenic of these isolates were identified by morphology of the reproductive structures.

Inoculum Production

Inoculum for the first-year fertilizer and fungicide experiments was produced from three known virulent isolates of the pathogen *Pythium paroecandrum* Drechsler (Hwang 1988) and two of *Fusarium avenaceum* (Fr.) Sacc. (Hwang et al. 1989). For the second-year fertilizer and fungicide trials, and the direct-seeding and dormant-seeding trials, 10 virulent isolates of *F. avenaceum* and three virulent isolates of *Phoma sclerotioides*, identified in the pathogenicity trial (above), were used. All pathogenic isolates were grown in pure cultures on a sterile mixture of autoclaved oat and rye grain (1:1 vol:vol) until the grain was completely colonized. The colonized grain was air-dried, then stored at –20°C until required for use in the various experiments. Inoculum was produced by bulking together equal volumes of dried, colonized grain from each pathogenic isolate within a species. Aliquots of the sterile grain were also dried and stored for use as noninoculated control treatments for all experiments.

Effect of Inoculation

Seed of alfalfa cv. Algonquin was sown at Vegreville, AB, and at a site near Lac La Biche, AB, to assess the effect of inoculation with *F. avenaceum* (combined inoculum of 10 isolates) or *P. sclerotioides* (three isolates combined), compared with a noninoculated control. A randomized complete block design with four replicates was used in each experiment. Each subplot consisted of four, 6-m rows, with 20-cm between rows at a 1.5-cm depth. Adjacent subplots were separated by 0.6 m and adjacent replicates by 10 m. The inoculum treatments were incorporated with the seed at the time of seeding. The experiments were seeded at a rate of 4 kg seed ha^{-1} with a granular *Rhizobium* inoculant applied at 65 kg ha^{-1}. The experiment near Lac La Biche was seeded on 10 June 1998 into sod treated with Roundup® (glyphosate S, 356 g L^{-1}, Monsanto) at 2.0 L ha^{-1} on 25 August 1997 and 11 June 1998. The experiment at Vegreville was sown into land tilled with a John Deere® 400 garden rototiller on 5 June 1998 using a Fabro® small plot seeder (Fabro Ltd., Swift Current, SK). Adjacent plots were separated by 0.6 m and adjacent replicates by 2 m. Pursuit® (imazethapyr S, 240 g L^{-1}, Cyanamid) was applied at 210 mL ha^{-1} to both sites approximately 1 mo following planting to reduce weed infestation. Poast Ultra® (sethoxydim EC, 450 g L^{-1}, BASF) was also applied to the plots at Lac La Biche at 470 mL ha^{-1} at the same time. Emergence was counted for the middle two rows of each plot at Lac La Biche on 28 July 1998. Overwinter survival was visually assessed on 7 June 1999 and 7 June 2000 by estimating the percentage of total row length filled with alfalfa plants. Plots were harvested on 9 July and 22 September 1999, and 12 July and 17 August 2000. Emergence was counted at

Vegreville on 13 July 1998 and survival was assessed on 18 June 1999 and 6 June 2000. Plots were harvested on 2 July and 8 September 1999 and on 20 July and 18 August 2000. To calculate dry matter yield for all forage experiments, the total fresh weight of the forage harvested from each plot was taken, a sample of about 1 kg was removed, weighed, dried and reweighed to determine moisture content, then the fresh weight of the forage harvested from the sub-plot was adjusted for moisture content.

Fertilizer Treatments

Field plots of alfalfa cv. Algonquin were established near Evansburg, AB, on 12 July 1995 and near Camrose, AB, on 10 June 1997 and 27 May 1998 to assess the effect of fertilizer on overwinter survival and productivity of alfalfa stands seeded into pathogen-infested soil. The plot areas were prepared by cultivation and compaction using a John Deere® 400 garden rototiller. Edge DC® (ethalfluralin DC, 60%, Dow Agrosciences) was applied at 1900 g ha^{-1} to all plots at Camrose before seeding and Pursuit® was applied at 210 mL ha^{-1} to both experiments approximately 1 mo following planting to reduce weed infestation. Plots in both experiments were seeded in a split-plot design with four replicates using a V-belt push seeder (Almaco®, Nevada, IA) adjusted to a 1.5-cm depth. Plots were seeded at a rate of 4 kg seed ha^{-1} with a granular *Rhizobium* inoculant applied at 65 kg ha^{-1}. Each subplot consisted of four, 6-m rows, with 20 cm between rows. Adjacent subplots were separated by 0.6 m and adjacent replicates by 2 m. Inoculation with *Pythium paroecandrum* (three isolates combined), *Fusarium avenaceum* (two isolates) and sterilized ground grain as a non-inoculated control were the main plots. The inocula were incorporated with the seed at the time of seeding. For the trial seeded in 1998, the inoculated treatments were replaced by the 10-isolate preparation of *F. avenaceum* and the 3-isolate preparation of *Phoma sclerotioides* (see Inoculum Production). Subplots were allocated to fertilizer treatments: (1) no fertilizer = control, (2) 15 kg K ha^{-1} (potash) + 11-51-0 fertilizer (11 kg P and 51 kg N ha^{-1}) = Base, (3) Base + 10 kg S ha^{-1} (elemental sulphur) = S10, 4) Base + 20 kg S ha^{-1} = S20, and 5) Base + 40 kg S ha^{-1} = S40. In the two trials at Camrose, a high-potassium treatment (Base + 45 kg K ha^{-1} as potash = K45) was included instead of the Base + S10 treatment. The fertilizer treatments were applied as a top-dressing to established plots on 11 October 1995 at Evansburg, and on 19 June 1997 for the plot at Camrose seeded in 1997 and, as a pre-treatment, on 7 November 1997 for the plots seeded at Camrose in 1998. Soil samples for unfertilized treatments showed available N, P, K, and S at 101, 69, 583 and 90 kg ha^{-1}, respectively.

Seedling emergence was assessed at Evansburg on 18 August 1995 by counting 2-m sections of the middle two rows of each plot. Emergence was assessed on 15 July 1997 and 16 June 1998 at Camrose by counting the middle two rows of each plot. Overwinter stand survival was visually assessed at Evansburg on 19 June 1996 and at Camrose on 16 June 1998 and 8 June 1999 by estimating the percentage of total row length filled with alfalfa plants. Plots were harvested on 2 July and 21 August 1996 and on 17 June and 31 July 1997 at Evansburg. The study seeded at Camrose in 1997 was harvested on 24 June and 27 August 1998; 29 June and 20 August 1999, and on 28 June 2000. The trial seeded at Camrose in 1998 was harvested 27 August 1998, 30 June and 19 August 1999 and 27 June 2000.

Fungicide Seed Treatment

Field plots of alfalfa cv. Algonquin were seeded near Morinville, AB, on 11 June 1997 and near Camrose on 10 June 1997 and 27 May 1998 to assess the effect of fungicidal seed treatments on overwinter survival and productivity of alfalfa stands seeded in pathogen-infested soil. The plot preparation, tillage and seeding equipment, seeding depth, seeding rate, plot layout and inoculation are described above. Edge DC® was applied at 1900 g ha^{-1} to all plots at Camrose before seeding and Pursuit® was applied at 210 mL ha^{-1} to all plots in both experiments approximately 1 mo following planting to reduce weed infestation. The main plots were inoculation treatments. In 1997, the inoculum treatments applied with the seed were: (1) *Pythium paroecandrum*, (2) *Fusarium avenaceum*, and (3) sterilized grain as a noninoculated control. These inocula were incorporated with the seed at the time of seeding. At Camrose in 1998, the inoculation treatments were replaced by a 10-isolate *Fusarium avenaceum* preparation and by a 3-isolate preparation of *Phoma sclerotioides* (see Inoculum Production). Sub-plots were allocated to fungicide seed treatments: (1) Apron FL (metalaxyl, 317 g L^{-1} SU) at 1.1 mL kg^{-1} seed + Thiram (thiram, 75% WP) at 3.6 g kg^{-1} seed, (2) Apron + Crown (carbathiin + thiabendazole, 92 + 58 g a.i. L^{-1} SU) at 4.0 mL kg^{-1} seed, and 3) untreated control. At Camrose in 1997, each seed treatment (Apron, Thiram, Crown) was also assessed separately at the rates described above.

Seedling emergence was counted on 15 July 1997 at Camrose, and on 17 July 1997 at Morinville, for the middle two rows in each plot. Emergence for plots seeded at Camrose in 1998 was counted on 22 July 1998. Overwinter survival was evaluated visually by estimating the percentage of total row length filled with alfalfa plants on 16 June 1998 and 8 June 1999 at Camrose and on 15 May 1998 at Morinville. Plots seeded in 1997 at Camrose were harvested on 24 June and 26 August 1998, 29 June and 18 August 1999, and 27 June 2000. Plots seeded in 1998 were harvested on 27 August 1998, 30 June and 19 August 1999 and 28 June 2000. Plots at Morinville were harvested on 9–10 July 1998. Plots at Morinville were flooded in the spring of 1999, so the experiment was abandoned.

Spring vs. Fall-dormant Seeding

Seed of alfalfa cv. Algonquin was sown at Vegreville to compare overwinter survival and stand productivity in spring- and dormant-seeded alfalfa. At Vegreville, plots were seeded in a randomized complete block design using four, 6-m rows, with 20 cm between rows at a 1.5-cm depth. Adjacent subplots were separated by 0.6 m and adjacent replicates by 2 m. Plots were seeded at a rate of 4 kg seed ha^{-1} with a granular *Rhizobium* inoculant applied at 65 kg ha^{-1}, using a V-belt push seeder. Spring and fall-dormant seeding served as treatments. The dormant-seeded portion was seeded on 21 October 1997; the spring-seeded portion on 19 May 1998. Emergence was counted on 16 June 1998 for all four rows in each plot and survival was assessed on 18 June 1999 and 6 June 2000 by visually estimating the percentage of total row length filled with alfalfa plants. Harvest dates were 28 June and 8 September 1999 and 21 July and 18 August 2000.

A similar field trial was seeded near Lac La Biche to compare overwinter survival and stand productivity in spring- and dormant-seeded alfalfa in pathogen-infested soil. Plots were seeded in a randomized split-plot design with inoculation treatments (a 10-isolate *Fusarium avenaceum* preparation, a 3-isolate preparation of *Phoma sclerotioides* and a noninoculated control) serving as main plots and spring (25 June 1999) and fall-dormant (22 October 1998) seeding serving as sub-plots. The inocula were incorporated with the seed at the time of seeding. Adjacent subplots were separated by 0.6 m and adjacent replicates by 10 m. The test was seeded using a Fabro® small plot seeder, at the depth and rate described above, using the same inoculant, directly into a mixed bluegrass-smooth bromegrass-alfalfa sod that had been killed with an application of Roundup® at 2.0 L ha^{-1} on 25 August 1997, then mowed. Roundup® was re-applied at the same rate on 28 September 1998 and at 1.8 L ha^{-1} to the area that was spring-seeded on the same day that spring seeding occurred. Emergence was counted for all four rows in each plot on 28 July 1998. Overwinter survival was visually assessed on 7 June 1999 and 7 June 2000 by estimating the percentage of total row length filled with alfalfa plants. Plots were harvested on 9 July and 22 September 1999, and 12 July and 17 August 2000.

Direct vs. Conventional Seeding

A test to compare alfalfa emergence, persistence and productivity under direct seeding and in tilled land, when sown into pathogen-infested soil, was established near Lac La Biche on a forage field composed of a mixture of smooth bromegrass, Kentucky bluegrass and alfalfa. Roundup® was applied to the plot area at 2.0 L ha^{-1} to the stand on 25 August 1997. Alfalfa cv. Algonquin was seeded on 10 June 1998. The plot area received a second application of Roundup® at 1.8 L ha^{-1} on 11 June 1998. Plots were seeded in a randomized split-plot design with the 10-isolate *F. avenaceum* preparation or sterilized grain as a noninoculated control serving as the main plots. The inoculum was incorporated with the seed at the time of seeding. Sub-plots were seeded either into sod or into rototilled land. Sub-plots were seeded in four, 6-m rows, with 20 cm between rows at a 1.5-cm depth. Adjacent subplots were separated by 0.6 m and adjacent replicates by 10 m. Plots were seeded at a rate of 4 kg seed ha^{-1} with a granular *Rhizobium* inoculant applied at 65 kg ha^{-1}, using a Fabro® small plot seeder. The inoculum treatments were incorporated at the time of seeding. Emergence was counted for all four rows in each plot on 28 July 1998 and overwinter survival was assessed visually on 7 June 1999 and 7 June 2000 by estimating the percentage of total row length filled with alfalfa plants. Plots were harvested on 9 July and 20 September 1999, and on 13 July and 21 August 2000.

At a second test site located at Vegreville, a predominantly Kentucky bluegrass sod was sprayed with Roundup® at 2.0 mL ha^{-1} on 14 May and seeded with alfalfa cv. Algonquin on 9 June 1998. Plot layout, design, seeding equipment, seed placement, seeding rate, cultivar, inoculant, and treatments were the same as at Lac La Biche. Plots at both sites were treated with a combination of Pursuit® at 210 mL ha^{-1} and Poast Ultra® at 470 mL ha^{-1} approximately 1mo following planting to reduce weed infestation. Emergence was counted for all four rows in each plot at Vegreville on 13 July 1998 and survival was assessed on 18 June 1999 and 6 June 2000 by estimating the percentage of total row length filled with alfalfa plants. Plots were harvested on 2 July and 8 September 1999 and on 20 July and 18 August 2000.

Data Analysis

Data were assessed using the General Linear Model procedure for the analysis of variance (SAS Institute, Inc. 1985) and, where appropriate, LSD or Duncan's New Multiple Range Tests was used for means separation. The significance level for means comparison was $P < 0.05$ unless otherwise stated. An arcsine transformation was applied to percentage germination data prior to analysis to minimize differences in the variance, but only the nontransformed data are presented.

RESULTS

Pathogenicity Trials

Significant differences ($P \leq 0.05$) in seedling survival and disease severity were noted between some of the isolates (Table 1). Ten isolates of *F. avenaceum* and three of *P. sclerotioides* were highly virulent on both alfalfa cultivars.

Effect of Inoculation

In the sod-seeded trial at Lac La Biche, inoculation with *F. avenaceum* significantly reduced ($P \leq 0.05$) seedling emergence compared to the noninoculated control (Table 2). Stand density was significantly lower in both 1999 and 2000 in plots inoculated with *P. sclerotioides* compared to the noninoculated plots. Stand density in plots inoculated with *F. avenaceum* was intermediate. Forage yield was not significantly affected by pathogen treatment in either year. At Vegreville, where seed was sown into tilled land, inoculation with *F. avenaceum* and *P. sclerotioides* reduced seedling emergence. Stand density was similar among all treatments in 1999, but was lower in the inoculated treatments in 2000. Forage yield was lower for *Fusarium*-inoculated plots in 1999, but neither *F. avenaceum* nor *P. sclerotioides* had an impact on yield in 2000.

Fertilizer Treatments

In the trial seeded at Evansburg in 1995, seedling emergence was counted before the fertilizer treatments were applied, so these results were not tabulated. Stand survival was not affected by fertilizer treatment, but treatments with added sulphur (Base + S20, Base + S40) produced significantly more ($P < 0.05$) forage than the unfertilized control in the first year

Table 1. Pathogenicity test of fungal isolates from diseased alfalfa roots collected in a 1997 disease survey on seedlings of two alfalfa cultivars under controlled conditions

	Algonquin		Peace	
Isolate	Seedling survival[z]	Severity[y]	Seedling survival (%)	Severity
Phoma sclerotioides				
AF-20	26	3.5	24	3.0
AF-18	46	2.9	50	3.4
AF-19	62	2.8	48	2.7
Fusarium avenaceum				
AF-10	0	4.0	6	3.9
AF-26	0	4.0	32	3.7
AF-40	20	4.0	22	4.0
AF-16	28	3.8	36	3.8
AF-30	12	3.7	14	3.9
AF-25	12	3.6	30	3.9
AF-12	54	3.3	50	3.4
AF-35	68	3.1	56	3.2
AF-15	58	3.1	68	3.1
AF-36	50	2.4	38	3.5
Mean virulent	34	3.4	36	3.5
Mean non-virulent[x]	79	1.2	79	1.2
Check	94	0.16	96	0.0
LSD ($P < 0.05$)	17.1	0.62	19.4	0.65

[z]Percentage of surviving plants 12 d after planting.
[y]Disease severity based on a 0 to 4 scale, where: 0 = no disease, 1 = small lesions on root, 2 = large lesions, 3 = lesions covering > half of the root circumference, and 4 = lesions occupying > half of the root cross-section.
[x]Mean of the 38 isolates that did not cause substantial injury on alfalfa seedlings and did not substantially reduce seedling survival.

Table 2. Effect of inoculation with *Fusarium avenaceum* or *Phoma sclerotioides* on seedling emergence and growth of alfalfa cv. Algonquin seeded directly into sod at Lac La Biche and into tilled land at Vegreville in 1998

Treatment[2]	Emergence (seedlings/6 m)	Survival (%)		Forage yield (t ha^{-1})[z]	
		1999	2000	1999	2000
		Lac La Biche			
Noninoculated	106.5*a*	54*a*	49*a*	2.24*a*	3.80*a*
F. avenaceum	76.6*b*	48*ab*	46*ab*	2.14*a*	3.69*a*
P. sclerotioides	96.0*a*	45*b*	43*b*	2.0*a*	3.48*a*
		Vegreville			
Noninoculated	120.7*a*	87*a*	76*a*	4.00*a*	6.73*a*
F. avenaceum	90.7*b*	89*a*	60*b*	3.18*b*	6.50*a*
P. sclerotioides	94.6*b*	89*a*	64*b*	3.85*a*	6.71*a*

[z]Represents a total of two cuts for each growing season.
a,b Means within a column and treatment group followed by the same letter do not differ based on Duncan's Multiple Range Test ($P \le 0.05$).

of harvest (Table 3). In 1997, no differences in forage production were observed among the fertilizer treatments. At the trial seeded at Camrose in 1997, fertilizer treatments did not affect seedling emergence, but overwinter survival was significantly higher ($P < 0.05$) in the base and sulphur treatments than in the nonfertilized control in the spring of 1998 (Table 4). Treatments with added fertilizer had significantly higher ($P < 0.05$) forage production than the nonfertilized control in 1998. Base + potassium and base + S40 produced higher forage yields than the base treatment alone. There were no differences in forage yield among treatments in 1999. In 2000, forage yield was higher in the treatments with the highest level of sulphur or potassium compared to the control. Total dry matter production from 1998 to 2000 showed a similar pattern to that observed in 2000 (Table 4).

In the trial seeded at Camrose in 1998, seedling emergence was greatest where the highest rate of sulphur fertilizer was applied, but fertilizer treatment had no impact on plant survival (Table 4). Forage productivity in 1998 (the establishment year) and 1999, and total forage productivity over all 3 yr, was significantly higher ($P < 0.05$) in treatments with added sulphur or high levels of potassium than in the control. Only the treatments with the highest levels of sulphur and potassium continued to enhance forage productivity into 2000.

In the trial seeded at Evansburg, inoculation with *P. paroecandrum* significantly reduced ($P < 0.05$) seedling emergence, stand survival and subsequent forage yield compared to the noninoculated control; inoculation with *F. avenaceum* reduced seedling emergence to minimal lev-

Table 3. Effect of fertilizers and inoculation with *Pythium paroecandrum* and *Fusarium avenaceum* on overwinter plant survival and forage yield of alfalfa cv. Algonquin seeded at Evansburg, AB, in 1995

Treatment	Emergence[z] (plants/2 m)	Survival 1996 (%)	Forage yield (t ha^{-1})[y] 1996	1997
Inoculation (main plot)				
Noninoculated	29*a*	76*a*	5.4*a*	3.9*a*
P. paroecandrum	18*b*	50*b*	4.2*b*	3.1*b*
F. avenaceum	2*c*	0*c*	0*c*	0*c*
Fertility Treatment[w] *(sub plot)*				
Control		62*a*	4.5*b*	3.2*a*
Base		63*a*	4.8*ab*	3.4*a*
Base + S10		61*a*	4.7*ab*	3.5*a*
Base + S20		65*a*	5.1*a*	3.7*a*
Base + S40		64*a*	5.1*a*	3.7*a*

[z]Emergence was counted before application of fertility treatments, so data on effect of fertility on emergence were not included.
[y]Represents a total of two cuts in each growing season.
[x]There were no significant inoculation × fertility treatment interactions.
[w]Base = 51 kg N ha^{-1} + 11 kg P + 15 kg K, S10 = 10 kg S ha^{-1}, S20 = 20 kg S ha^{-1}, S40 = 40 kg S ha^{-1}.
a – c Means within a column and treatment group followed by the same letter do not differ based on Duncan's Multiple Range Test ($P \leq 0.05$).

Table 4. Effect of fertilizers and inoculation with *Pythium paroecandrum*, *Phoma sclerotioides* or *Fusarium avenaceum* on seedling emergence, plant survival overwinter and forage yield of alfalfa cv. Algonquin at Camrose, AB, seeded in 1997 and 1998

	Emergence (seedlings/6 m)	Survival (%)	Forage yield (t ha^{-1})[z] 1998	1999	2000	Total
			Seeded in 1997			
Inoculation[y]						
Noninoculated	105*a*	69*a*	9.8*a*	10.4*a*	5.6*a*	25.8*a*
P. paroecandrum	82*b*	65*b*	8.6*b*	9.2*b*	4.7*b*	22.5*b*
F. avenaceum	78*b*	61*b*	9.3*ab*	9.5*b*	5.0*b*	23.8*b*
Fertilizer[x]						
Control	91*a*	62*b*	7.5*c*	9.0*a*	4.5*b*	21.0*b*
Base	83*a*	68*a*	8.8*b*	10.0*a*	5.0*ab*	23.8*ab*
Base + K45	93*a*	66*ab*	9.9*a*	10.0*a*	5.4*a*	25.3*a*
Base + S20	89*a*	69*a*	9.7*ab*	9.7*a*	4.9*ab*	24.3*ab*
Base + S40	86*a*	69*a*	10.3*a*	9.9*a*	5.6*a*	25.8*a*
			Seeded in 1998			
Inoculation						
Noninoc	93*a*	87*a*	3.7*a*	11.2*a*	6.6*a*	21.5*a*
P. sclerotioides	93*a*	88*a*	3.3*b*	10.6*b*	6.5*a*	20.4*b*
F. avenaceum	90*b*	82*b*	3.2*b*	10.3*b*	5.8*b*	19.3*c*
Fertilizer						
Control	91*b*	85*a*	3.1*c*	9.8*b*	5.7*b*	18.6*c*
Base	91*b*	86*a*	3.1*bc*	10.5*ab*	5.9*b*	19.5*bc*
Base + K45	91*b*	86*a*	3.5*ab*	11.3*a*	6.9*a*	21.7*a*
Base + S20	91*b*	85*a*	3.5*ab*	10.8*a*	5.9*b*	20.2*b*
Base + S40	94*a*	87*a*	3.6*a*	11.1*a*	7.0*a*	21.7*a*

[z]For both trials, forage yield was based on two cuts for 1999 and a single cut for 2000. For the trial seeded in 1997, two cuts were taken in 1998; for the trial seeded in 1998, only one cut was taken in 1998.
[y]There were no significant inoculation × fertilizer treatment interactions in either experiment.
[x]Base = 51 kg N ha^{-1} + 11 kg P + 15 kg K, S20 = 20 kg S ha^{-1}, S40 = 40 kg S ha^{-1}, K45 = 45 kg K ha^{-1}.
a–c Means within a column and treatment group followed by the same letter do not differ based on Duncan's Multiple Range Test ($P \leq 0.05$).

els and both stand survival and forage yield to zero (Table 3). In the trial seeded at Camrose in 1997, inoculation with *P. paroecandrum* or *F. avenaceum* reduced ($P < 0.05$) seedling emergence and subsequent winter survival (Table 4). Throughout the trial, overall forage productivity was higher in the noninoculated controls than in the plots inoculated with *P. paroecandrum* or *F. avenaceum.* In the trial seeded at Camrose in 1998, seedling emergence and plant survival overwinter were slightly lower ($P < 0.05$) in plots inoculated with *F. avenaceum* than in plots inoculated with *P. sclerotioides* or in the control (Table 4). Forage yield was lower in plots inoculated with *F. avenaceum* or *P. sclerotioides* compared to the noninoculated treatment in 1998 and 1999. In 2000, inoculation with *F. avenaceum* reduced yield rela-

Table 5. Effect of fungicide seed treatments and inoculation with *Pythium paroecandrum* or *Fusarium avenaceum* on emergence, survival and forage yield of alfalfa cv. Algonquin seeded at Camrose in 1997

Treatment	Rate (kg^{-1} seed)	Emergence (seedlings/6 m)	Survival (%)	Forage yield ($t\ ha^{-1}$)[z] 1998	1999	2000
Inoculation[y]						
Noninoculated	–	80*a*	76*a*	8.4*a*	9.8*a*	5.2*a*
P. paroecandrum	–	79*a*	76*a*	9.2*a*	8.9*b*	5.1*a*
F. avenaceum	–	79*a*	74*a*	8.1*a*	8.3*b*	4.6*b*
Fungicide						
Apron + Crown	1.1 mL + 4.0 mL	81*ab*	77*a*	10.5*a*	9.4*a*	4.1*a*
Apron + Thiram	1.1 mL + 3.6 g	81*ab*	74*a*	10.1*ab*	9.2*a*	4.7*a*
Crown	4.0 mL	79*abc*	76*a*	8.6*bc*	9.1*a*	4.9*a*
Apron	1.1 mL	82*a*	76*a*	8.4*bc*	9.1*a*	5.3*a*
Thiram	3.6 g	76*c*	74*a*	8.0*c*	8.7*a*	5.2*a*
Nontreated	–	77*bc*	73*a*	7.2*c*	8.6*a*	4.7*a*

[z]Represents a total of two cuts per season in 1998 and 1999 and one cut in 2000.
[y]There were no significant inoculation × fungicide treatment interactions.
a–c Means within a column and treatment group followed by the same letter do not differ based on Duncan's Multiple Range Test ($P \leq 0.05$).

tive to the control and inoculation with *P. sclerotioides*. Total forage production over all 3 yr was higher in the noninoculated control than in those inoculated with *P. sclerotioides*, which, in turn, were higher than in plots inoculated with *F. avenaceum.* There were no interactions between fertilizer and inoculation treatments in these trials.

Fungicide Seed Treatments

In the trial seeded at Camrose in 1997, no differences were observed in seedling emergence, survival, or forage yield in 1998 among the inoculated treatments and the noninoculated control (Table 5). However, yield was significantly lower ($P < 0.05$) for both inoculation treatments in 1999, and was lower in the *F. avenaceum* treatment than in the other two treatments in 2000. Apron improved seedling emergence, but none of the fungicides had an impact on overwinter survival. The Apron + Crown and Apron + Thiram treatments increased forage productivity over the nontreated control in 1998, but no differences in yield were noted in 1999 or 2000.

For the test at Morinville seeded in 1997, inoculation with *P. paroecandrum* or *F. avenaceum* very substantially reduced ($P < 0.05$) seedling emergence (Table 6). Overwinter plant survival was also reduced, and overall survival was lower than at Camrose. Forage yield was lower in the *F. avenaceum* treatment compared to *P. paroecandrum* or the control. Both Apron + Crown and Apron + Thiram treatments improved survival, but did not affect forage yield.

In the trial seeded at Camrose in 1998, seedling emergence was lower for treatments inoculated with *F. avenaceum*, but overwinter survival was similar among all of the inoculation treatments. Inoculation with *F. avenaceum* or *P. sclerotioides* reduced forage yield in 1998 and 1999, but not in 2000 (Table 6). Application of the Apron treatments improved seedling emergence and application of Apron + Crown improved overwinter survival. However, neither of the treatments had an effect on forage yield. There were no significant interactions between inoculation and fungicide seed treatment in either of the trials.

Spring vs. Fall-dormant Seeding

In the trial seeded in the fall of 1998 and the spring of 1999 at Lac La Biche**,** both pathogens significantly reduced ($P < 0.05$) seedling emergence, overwinter survival and forage yield compared to the noninoculated control, but inoculation with *F. avenaceum* had a significantly larger impact than inoculation with *P. sclerotioides* (Table 7). Fall-dormant seeded plots had lower seedling emergence than with spring seeding, but stand density was comparable by the second year. Forage yield was consistently higher in the fall-dormant seeded plots, even though initial seedling emergence was lower than for spring seeding. Interaction of inoculum treatment and timing of seeding was significant at $P \leq 0.01$ for emergence, 2000 forage yield and total forage yield; significant at $P \leq 0.05$ for stand survival, and not significant for 1999 forage yield.

In the trial seeded in the fall of 1997 and the spring of 1998 at Vegreville under conventional tillage management**,** seedling emergence and plant survival were higher ($P < 0.05$) in plots seeded in spring than with fall-dormant seeding (Table 7). Forage yields were similar for the first harvest year (1999), but were greater for the fall-dormant seeded plots in 2000.

Direct vs. Conventional Seeding

In the test seeded at Lac La Biche in 1998, inoculation with *F. avenaceum* reduced ($P < 0.05$) seedling emergence (Table 8). This trend was reflected in reduced stand density in 1999, but not in 2000. There were no differences in forage yield between inoculated and control treatments in 1999 or 2000. Seedling emergence was much higher in direct-seeded plots than in those seeded into conventionally tilled plots. Stand density in 1999 and 2000 reflected this difference, but yield in the direct-seeded treatments was only higher in 2000.

In the test seeded at Vegreville in 1998, inoculation had no impact on seedling emergence or forage yield, but reduced plant survival overwinter in 1999 and 2000 (Table 8). Seeding method did not affect seedling emergence, but

Table 6. Effect of inoculation with *Fusarium avenaceum*, *Phoma sclerotioides*, or *Pythium paroecandrum* on seedling emergence, survival and forage yield of alfalfa cv. Algonquin seeded at Morinville in 1997 and Camrose in 1998

Treatment	Rate (kg^{-1} seed)	Emergence (seedlings/6 m)	Survival (%)	Forage yield ($t\ ha^{-1}$)[z] 1998	1999	2000
			Morinville			
Inoculation[y]						
Noninoculated	–	80*a*	76*a*	8.4*a*	9.8*a*	5.2*a*
F. avenaceum						
P. paroecandrum	–	79*a*	76*a*	9.2*a*	8.9*b*	5.1*a*
	–	79*a*	74*a*	8.1*a*	8.3*b*	4.6*b*
Fungicide						
Apron + Thiram	1.1 mL + 3.6 g	145*a*	51*a*	0.56*a*	–	–
Apron + Crown	1.1 mL + 4.0 mL	125*a*	48*a*	0.53*a*	–	–
Control	–	41*b*	28*b*	0.55*a*	–	–
			Camrose			
Inoculation						
Noninoculated	–	200*a*	90*a*	3.3*a*	11.1*a*	6.4*a*
F. avenaceum	–	162*b*	89*a*	2.8*b*	9.6*b*	5.9*a*
P. sclerotioides	–	209*a*	89*a*	2.6*b*	10.0*b*	6.6*a*
Treatment	–					
Apron + Thiram	1.1 mL + 3.6 g	199*a*	89*ab*	2.9*a*	10.5*a*	6.3*a*
Apron + Crown	1.1 mL + 4.0 mL	206*a*	92*a*	3.0*a*	10.4*a*	6.2*a*
Control	–	167*b*	88*b*	2.7*a*	9.7*a*	6.0*a*

[z]Numbers represent a single cut for Morinville and the totals for two cuts for Camrose in 1998 and 1999 and one cut in 2000.
[y]There were no significant inoculation × fungicide treatment interactions at either site.
a–c Means within a column and treatment group followed by the same letter do not differ based on Duncan's Multiple Range Test ($P \leq 0.05$).

Table 7. Comparison of fall-dormant vs. spring seeding of alfalfa cv. Algonquin at Lac La Biche and Vegreville and effect of *Fusarium avenaceum* and *Phoma sclerotioides* on fall-dormant vs. spring seeding at Lac La Biche

Treatment	Rate (kg^{-1} seed)	Emergence (seedlings/6 m)	Survival (%)	Forage yield ($t\ ha^{-1}$)[z] 1998	1999	2000
Lac La Biche (sod seeded)						
Noninoculated[y]	Fall 1998	42.1*b*	37*a*	1.70*a*	4.67*a*	6.19*a*
	Spring 1999	98.5*a*	41*a*	0.88*b*	4.38*a*	5.00*a*
F. avenaceum	Fall 1998	14.4*a*	18*a*	1.20*a*	5.77*a*	7.48*a*
	Spring 1999	6.7*b*	9*b*	0.33*b*	5.48*a*	6.36*a*
P. sclerotioides	Fall 1998	31.6*a*	25*a*	1.52*a*	4.76*a*	5.96*a*
	Spring 1999	38.2a	22*a*	0.63*b*	2.13*b*	2.46*b*
Vegreville (tilled land)						
Noninoculated	Fall 1997	50.8*b*	71*b*	6.39*a*	9.84*a*	16.23*a*
	Spring 1998	107.3*a*	84*a*	7.38*a*	7.74*b*	15.12*a*

[z]Represents the total of two cuts for each growing season at Vegreville, of one cut in 1999 and of two cuts in 2000 at Lac La Biche.
[y]Interaction of inoculum treatment and timing of seeding was significant at $P \leq 0.01$ for emergence, 2000 forage yield and total forage yield; significant at $P \leq 0.05$ for stand survival, and not significant for 1999 forage yield.
a–c Means within a column and inoculum treatment group followed by the same letter do not differ based on Duncan's Multiple Test ($P \leq 0.05$).

overwinter survival was lower in direct-seeded plots in 1999. Stand density declined over the second winter, but the decline was more severe in the conventionally tilled plots, so that stand density was similar in both direct seeded and conventionally tilled plots in 2000. Forage yield was higher in the conventionally tilled plots in both 1999 and 2000. There were no significant interactions between tillage treatment and inoculation in either of the trials.

DISCUSSION

This study showed that several fungal pathogens that are present in commercial alfalfa fields in Alberta, such as *F. avenaceum*, *P. sclerotioides* and *P. paroecandrum*, can reduce seedling emergence and overwinter plant survival under field conditions. Under conducive conditions, *F. avenaceum* caused 100% reduction in the stand density and yield of alfalfa, but the impact of these three pathogens varied substantially from year to year and from site to site. These pathogens have previously been implicated as affecting forage yield by increasing chronic plant stress that indirectly contributes to stand decline (Reeleder 1982; Stelfox and Bertsch 1983; Hwang and Flores 1987; Hwang 1988; Hwang et al. 1989).

Fertilizer treatments had little impact on seedling emergence or plant survival. They had the greatest effect on forage production when high rates of sulphur or potassium

Table 8. Impact of direct vs. conventional seeding of alfalfa cv. Algonquin and inoculation with *Fusarium avenaceum* on seedling emergence, stand density and forage yield at Lac La Biche and Vegreville, AB, seeded in spring 1998

Treatment	Emergence (seedlings/6 m)	Survival(%)		Forage yield (t ha^{-1})[z]		
		1999	2000	1999	2000	Total
Lac La Biche						
Inoculation[y]						
Noninoculated	100*a*	45*a*	44*a*	2.93*a*	3.39*a*	6.32*a*
F. avenaceum	55*b*	28*b*	37*a*	2.58*a*	3.39*a*	5.97*a*
Seeding method						
Tilled	31*b*	27*b*	30*b*	2.97*a*	3.00b	5.97*a*
Direct	123*a*	47*a*	51*a*	2.53*a*	3.75*a*	6.28*a*
Vegreville						
Inoculum						
Noninoculated	174*a*	82*a*	60*a*	2.39*a*	5.72*a*	8.11*a*
F. avenaceum	159*a*	77*b*	47*b*	2.19*a*	5.32*a*	7.51*a*
Seeding Method						
Tilled	168*a*	87*a*	54*a*	2.80*a*	5.95*a*	8.75*a*
Direct	165*a*	71*b*	53*a*	1.77*b*	5.04*b*	6.81*b*

[z]Represents the total of two cuts for each growing season.
[y]There were no significant inoculation × tillage treatment interactions.
a–c Means within a column and treatment group followed by the same letter do not differ based on Duncan's Multiple Range Test ($P \leq 0.05$).

were applied. The fertilizer treatments showed the most significant deviation from the control in the year following their application; in the subsequent year, fewer of the treatments showed a significant difference from the control. However, in the trial seeded in 1997, greater differences were observed between the heavy fertilizer treatments and the control in the third year following stand establishment than in the second. Previous studies in this region have shown little or no impact of fertilizer application to mature stands on crown rot severity or forage yield (Malik and Waddington 1990; Gossen 1994a; Gossen et al. 1993, 1994) in the absence of severe deficiency symptoms. Soil tests showed that neither K nor S was deficient. Absence of significant interaction between fertilizer and inoculation treatment indicated that level of fertility had little effect on vulnerability of alfalfa to the soil-borne pathogens used in these trials.

The fungicide seed treatments containing Apron increased alfalfa emergence in both trials. This occasionally resulted in higher forage yields from the treated plots in the first harvest. Absence of interactions between fungicide and inoculation treatments indicated the probable presence of indigenous soil-borne pathogens that resulted in treatment effects for both noninoculated and inoculated treatments. Hancock (1991, 1993) reported that systemic treatments protect the seedlings after emergence, when they are especially vulnerable to attack by soil-borne pathogens. However, following establishment, growth of adjacent plants may have compensated for the gaps in the stand and no subsequent differences in forage yield were observed. In an earlier study, seed treatment had no impact on alfalfa germination in noninoculated plots (Gossen 1994b). However, recent studies indicate that the importance of seedling blight pathogens is increasing on many crops in the northern prairies (Gossen and Derksen 2000; Hwang et al. 2000a, b; Chongo et al. 2001). This may be associated with the dramatic increase in the acreage of canola, pulses and other highly susceptible crop species in the past 25 yr. Based on the results of the present study, seed treatment may be warranted where populations of soil-borne pathogens are high, or where stand uniformity is especially important, such as for certified seed production.

Seedling emergence and stand density after the first winter under direct seeding were equal to or higher than where conventional tillage operations were carried out prior to seeding. However, our results indicate that the yield potential of individual alfalfa plants was higher when seeded on tilled land than when sod-seeded. Plants at both sites were visibly more robust in the tilled treatment than in the sod-seeded treatment. At Lac La Biche, four times as many seedlings emerged under direct seeding as with conventional seeding; after the first winter, stand density was still 2:1. However, tilled and sod-seeded plots produced similar amounts of forage in the first harvest year; sod-seeding produced a 25% higher yield in the second year. At Vegreville, where seedling emergence counts were similar in tilled and sod-seeded plots, the tilled treatment consistently out-yielded sod-seeding. The absence of interaction between tillage treatment and inoculation indicated that tillage treatment did not affect vulnerability of the alfalfa plants to the inocula used in this study. The results at the Lac La Biche site indicate that sod seeding can result in improved seedling establishment of alfalfa. Studies on other crops (Allen and Entz 1994; Hart et al. 1985; Hoveland et al. 1996) have shown that direct seeding conserves soil moisture and reduces soil erosion while lowering energy input costs. However, the results at Vegreville show that while sod seeding can offer gains in seedling emergence, it requires further study to improve long-term productivity.

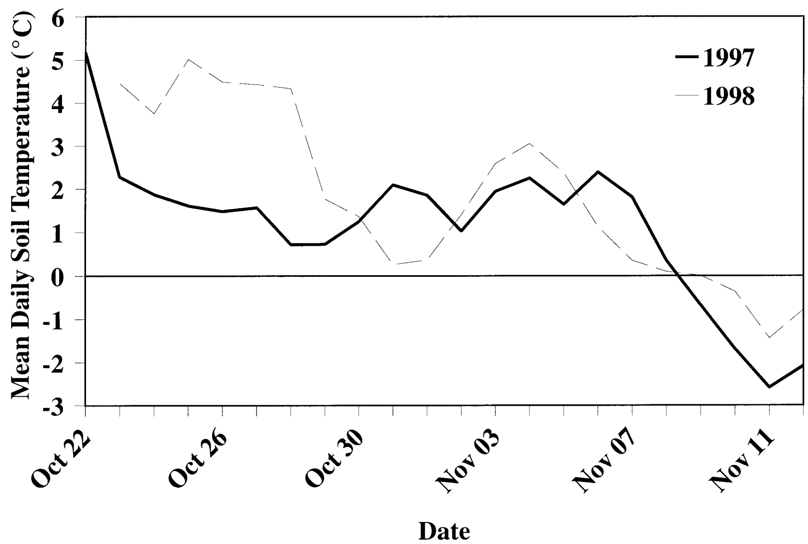

Fig. 1. Mean daily soil temperatures between date of planting and fall freezeup at Vegreville in 1997 and at Lac La Biche in 1998.

Timing of seeding had a very marked affect on stand establishment. Interactions in emergence between inoculation and timing of seeding indicated that alfalfa was substantially more vulnerable to the soil-borne pathogens, especially to *Fusarium avenaceum*, after spring planting than after fall-dormant seeding. Interactions in yield probably reflected the differences in stand establishment between inoculated and noninoculated plots. Absence of interaction between inoculation and timing of seeding with regard to the 1999 forage yield was probably due to the later stage of development in spring-seeded plots in the year of establishment. Plots seeded in late spring would have had at least 1 mo less of growth than their fall-seeded counterparts, so would have produced substantially less biomass, regardless of larger or smaller plant populations. Success in fall-dormant seeding of non-coated seed depends on timing; planting should be done before the ground is frozen, but after the latest opportunity for the seed to germinate. Soil temperatures and moisture conditions can fluctuate dramatically over the course of a few days in the late fall. This can promote seed germination very late in the season, freeze the soil, or cover it with snow at an earlier date than is normally judged safe for fall-dormant seeding. The mean soil temperature on the day following seeding of alfalfa at Vegreville in the fall of 1997 (22 October) was 5.2°C, but temperatures dropped substantially the following day so that soil temperatures for the days between 23 October and 9 November (freezeup) averaged 1.6°C. In the fall of 1998, soil temperatures averaged 4.4°C between seeding on 22 October and 28 October (6 d), dropped to an average of 1.5°C for the next 10 d, and dropped below freezing 2 d later (Fig. 1). The single warm day in 1997, immediately after seeding, and the week of borderline conditions in 1998 may have allowed some germination to occur. Any seedlings that germinated in the fall would be expected to die when soil temperatures dropped below –2.2°C (McKenzie and McLean 1982). The risk of untimely germination can be somewhat offset with seed treatments to inhibit seed germination in the fall.

Fall-dormant seeding has the potential for higher yields when adequate levels of seedling emergence are achieved, because the dormant-seeded alfalfa can take advantage of early season moisture and may allow alfalfa to escape seedling diseases that reduce plant populations later in the spring. In the present study, yields were usually higher with fall-dormant seeding than in spring plantings. In a preliminary trial at Lac La Biche (not presented), seedling emergence was much lower for the dormant-seeded plots, but the impact on forage yield was minimal. We feel that this approach has merit, but that more work is required before widespread implementation of fall-dormant seeding of alfalfa and other forages can be recommended.

In summary, high populations of soil-borne pathogens substantially and consistently reduced seedling emergence and the overwinter survival of plants, and generally reduced forage yield under a wide range of crop management systems. Fungicide seed treatments effectively reduced losses in seedling emergence, but had little impact on ultimate forage yield. Direct seeding of alfalfa often resulted in excellent seedling establishment in these trials, but more work is required to enhance long-term productivity. Dormant seeding in late fall showed potential to improve stand productivity, but more research is required to improve seedling establishment.

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Allen, C. L and Entz, M. H. 1994. Zero-tillage establishment of alfalfa and meadow bromegrass as influenced by previous annual grain crop. Can. J. Plant Sci. **74**: 521–529.
Bailey, L. D. 1983. Effect of potassium fertilizer and fall harvests on alfalfa grown in the eastern Canadian Prairies. Can. J. Soil Sci. **54**: 255–263.
Bowes, G. G. and Zentner, R. P. 1992. Effect of vegetation suppression on the establishment of sod-seeded alfalfa in the Aspen Parkland. Can. J. Pant Sci.**72**: 1349–1358.
Byer, J. and Topinka, K. 2000. Alternative date seeding of spring canola. Alberta Agriculture Agdex 149/22-1.
Chongo, G., Gossen, B. D., Kutcher, H. R., Gilbert, J., Turkington, T. K., Fernandez, M. R. and McLaren, D. 2001. Reaction of seedling roots of 14 crop species to *Fusarium graminearum* from wheat heads. Can. J. Plant Pathol. **23**: 132–137.
Fox, R. L., Flowerday, A. D., Hosterman, F. W., Rhoades, H. F. and Olson, R. A. 1964. Sulfur fertilizers for alfalfa production in Nebraska. Res. Bull. **214**: 1–37.
Gossen, B. D. 1994a. Field response of alfalfa to harvest frequency, cultivar, crown pathogens and soil fertility. II. Crown rot. Agron. J. **86**: 88–93.
Gossen, B. D. 1994b. Effect of fungicide seed treatments on establishment of alfalfa 1994. Pages178–181 *in* 1994 Pestic. Manage. Rep., Agriculture and Agri-Food Canada, Ottawa, ON.
Gossen, B. D. 1998. Development of secondary crowns reduces crown rot severity in alfalfa cultivars. Agron. J. **90**: 587–590.
Gossen, B. D. and Derksen, D. 2000. Impact of tillage and crop rotation on ascochyta blight of lentil. Final report, ADF Project #94000010, SK Agric. and Food, Regina, SK. 17 pp.
Gossen, B. D., Goplen, B. P., Soroka, J. J., Wright, S. M. B. and Ukrainetz, H. 1993. Management of alfalfa for seed production under irrigation. Final report for IBED Project #SP-89CA-27, Saskatchewan Water Corp, Outlook, SK.
Gossen, B. D., Horton, P. R., Wright, S. B. M. and Duncan, C. H. 1994. Field response of alfalfa to harvest frequency, cultivar, crown pathogens and soil fertility. I. Survival and yield. Agron. J. **86**: 82–88.
Hancock, J. G. 1985. Fungal infection of feeder rootlets of alfalfa. Phytopathology **75**: 1112–1120.
Hancock, J. G. 1991. Seedling and rootlet diseases of forage alfalfa caused by *Pythium irregulare*. Plant Dis. **75**: 691–694.
Hancock, J. G. 1993. Fungal rootlet colonization and forage yields of alfalfa in fungicide-treated field plots. Plant Dis. **77**: 601–608.
Hart, M., Waller, S. S., Lowrey, S. R. and Gates, R. N. 1985. Discing and seeding effects on sod bound mixed prairie. J. Range Manage. **38**: 121–125.
Hoveland, C. S., Durham, R. G. and Boulton, J. H. 1996. No-till seeding of grazing-tolerant alfalfa as influenced by grass suppression, fungicide and insecticide. J. Prod. Agric. **9**: 410–414.
Hwang, S. F. 1988. Effects of VA mycorrhizae and metalaxyl on growth of alfalfa seedlings in soils from fields with “alfalfa sickness” in Alberta. Plant Disease **72**: 448–452.
Hwang, S. F. and Flores, G. 1987. Effects of *Cylindrocladium gracile*, *Fusarium roseum* and *Plenodomus meliloti* on crown and root rot, forage yield, and winterkill of alfalfa in northeastern Alberta. Can. Plant Dis. Surv. **67**: 31–33.
Hwang, S. F., Gossen, B. D., Turnbull, G. D., Chang, K. F., Howard, R. J. and Thomas, A. G. 2000a. Effect of temperature, seeding date, fungicide seed treatment and inoculation with *Fusarium avenaceum* on seedling survival, root rot severity and yield of lentil. Can. J. Plant Sci. **80**: 899–907.
Hwang, S. F., Gossen, B. D., Turnbull, G. D., Chang, K. F., Howard, R. J. and Thomas, A. G. 2000b. Seeding date, temperature, and seed treatment affect pythium seedling blight of field pea. Can. J. Plant Pathol. **22**: 392–399.
Hwang, S. F., Howard, R. J. and Moskaluk, E. 1989. Crown and root rot of alfalfa in southern Alberta. Can. Plant Dis. Surv. **69**: 9–11.
Jung, G. A. and Smith, D. 1959. Influence of soil potassium and phosphorus content on the cold resistance of alfalfa. Agron. J. **51**: 585–587.
Kirkland, K. J. and Johnson, E. N. 2000. Alternative seeding dates (fall and April) affect *Brassica napus* canola yield and quality. Can. J. Plant Sci. **80**: 713–719.
Malik, N. and Waddington, J. 1990. No-till pasture renovation after sward suppression by herbicides. Can. J. Plant Sci. **70**: 261–267.
McKenzie, J. S and McLean, G. E. 1982. The importance of leaf frost resistance to the winter survival of seedling stands of alfalfa. Can. J. Plant Sci. **62**: 399–405.
Reeleder, R. D. 1982. Fungi recovered from diseased roots and crowns of alfalfa in north central Alberta and the relationship between disease severity and soil nutrient levels. Can. Plant. Dis. Surv. **62**: 21–27.
Rehm, G. W. 1987. Application of phosphorus and sulphur on irrigated alfalfa. Agron. J. **79**: 973–979.
Reid, D. J., Lathwell, D. J. and Wright, M. J. 1965. Yield and carbohydrate responses of alfalfa seedlings grown at several levels of potassium fertilization. Agron. J. **57**: 434–437.
SAS Institute, Inc. 1985. SAS user’s guide. SAS Institute Inc., Cary, NC.
Stelfox, D. and Bertsch, M. 1983. Low-temperature fungi associated with alfalfa root and crown rot in central Alberta. Can. Plant Dis. Surv. **63**: 7–11.
Wang, H., Turnbull, G. D., Hwang, S. F., Chang, K. F. and Howard, R. J. 1999. Disease survey of forage alfalfa fields in Alberta in 1998. Can. Plant Dis. Surv. **79**: 96–98.