Seeding date and polymer seed coating effects on plant establishment and yield of fall-seeded canola in the Northern Great Plains

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Johnson, E. N., Miller, P. R., Blackshaw, R. E., Gan, Y., Harker, K. N., Clayton, G. W., Kephart, K. D., Wichman, D. M., Topinka, K. and Kirkland, K. J. 2004. **Seeding date and polymer seed coating effects on plant establishment and yield of fall-seeded canola in the Northern Great Plains.** Can. J. Plant Sci. **84**: 955–963. The time interval for planting fall-seeded *Brassica napus* L. canola in the Northern Great Plains is narrow, since seeding must occur as close to soil freeze-up as possible to minimize the risk of winter kill. The Prairie ecoregion tends to have more stable fall and winter temperatures than the Rocky Mountain foothill region, where fall and winter chinooks may initiate germination and increase the risk of winter mortality. Our objectives were to determine an optimum seeding date interval for fall-seeded canola and whether a water-impervious polymer seed coating could advance the seeding date and reduce the risk of stand loss and corresponding yield reduction in two distinct agroecoregions. A range of fall seeding dates and a water-impervious polymer seed coating vs. a control treatment (water-soluble film) were assessed at 14 sites (five locations) from 1998 to 2001 in Alberta and Saskatchewan (Prairie sites) and at six sites (four locations 1999–2001) in Montana, USA (Foothill sites). Highest seedling densities and canola yield responses for the control treatment were attained in the first 2 wk of November in the Prairie sites, while responses to seed date were much more variable in the Foothill region. In the Prairie sites, the water-impervious polymer seed coating improved seedling density and seed yield as seeding date was progressively moved forward from the first week of November to the first week of October. The benefit of the water-impervious polymer seed coating became notable when soil temperatures were above 5°C. The water-impervious polymer coating provided only marginal improvement in plant stand and canola yield in the Foothill region. In the Foothill region and at Lethbridge, fall-seeded canola densities were on average 60% lower than spring-seeded canola densities and fall seeding increased canola yield in only one site-year when compared with spring-seeded canola. In the Prairie region, a water-impervious polymer coating can broaden the time interval for fall seeding; however, it does not ensure that recommended densities of spring seedlings will be attained. The optimum seeding date for fall seeding in the Foothill region could not be adequately defined for either the control or the water-impervious polymer coated seed due to the variable nature of the late fall and winter weather.

Key words: Canola (*Brassica napus* L.), alternative seeding date, germination

Johnson, E. N., Miller, P. R., Blackshaw, R. E., Gan, Y., Harker, K. N., Clayton, G. W., Kephart, K. D., Wichman, D. M., Topinka, K. et Kirkland, K. J. 2004. **Conséquences de la date des semis et de l'enrobage des semences avec un polymère sur l'implantation et le rendement du canola semé à l'automne dans le nord des grandes plaines**. Can. J. Plant Sci. **84**: 955–963. Le laps de temps dont on dispose pour semer le canola (*Brassica napus* L.) à l'automne dans le nord des grandes plaines est relativement court, car l'opération doit survenir aussi plus près que possible de la date où le sol gèle si l'on veut réduire les risques de destruction par l'hiver. L'écorégion des Prairies a tendance à connaître des températures automnales et hivernales plus stables que celle des contreforts des Rocheuses où le chinook amorce parfois la germination, donc accroît les risques de mortalité hivernale. Les auteurs voulaient établir l'intervalle optimal pour les semis automnaux et déterminer si l'enrobage des semences avec un polymère imperméable permettrait d'avancer la date des semis tout en atténuant les risques de destruction du peuplement et de baisse concomitante du rendement dans deux écorégions précises. Les auteurs ont évalué plusieurs dates de semis automnales et comparé l'enrobage avec un polymère imperméable à un traitement témoin (pellicule hydrosoluble) à 14 sites (cinq endroits) dans les Prairies, en Alberta et en Saskatchewan (de 1998 à 2001), et à six sites (quatre endroits) dans la région des contreforts du Montana, aux États-Unis (de 1999 à 2001). Avec le traitement témoin, on a obtenu la plus forte densité de peuplement et le meilleur rendement lors des deux premières semaines de novembre dans les Prairies, la réaction à la date des semis s'avérant beaucoup plus variable dans la région des contreforts. Dans les Prairies, l'enrobage avec le polymère imperméable améliore la densité du peuplement et le rendement grainier, car il permet d'avancer progressivement la date des semis de la première semaine de

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novembre à la première d'octobre. L'utilité de l'enrobage devient manifeste dès que la température du sol dépasse 5 °C. Dans la région des contreforts, le polymère n'entraîne cependant qu'une amélioration marginale des peuplements et du rendement. Quand on sème le canola à l'automne dans cette région et à Lethbridge, les peuplements ont une densité 60 % plus faible que celle des peuplements du canola semé au printemps; l'ensemencement à l'automne n'a accru le rendement qu'une année-site, comparativement aux semis printaniers. Dans les Prairies, l'utilisation d'un polymère imperméable élargit le laps de temps dont on dispose pour les semis automnaux; toutefois, le traitement ne garantit pas l'obtention de la densité de peuplement recommandée au printemps. La date idéale pour les semis automnaux dans la région des contreforts n'a pu être établie de manière adéquate pour le traitement témoin ni pour l'enrobage avec le polymère imperméable à cause de la variabilité des conditions climatiques à la fin de l'automne et en hiver.

Mots clés: Canola (*Brassica napus* L.), autres dates de semis, germination

Late fall seeding of canola (*Brassica napus* L.) offers several potential benefits to producers, including early maturity and increased yields. Kirkland and Johnson (2000), and Johnston et al. (2002) reported that seeding canola in the fall rather than in mid-May, on average, increased yield by about 40% and oil concentration by 5%. In addition to producing higher yields, canola seed produced from fall planting has been shown to be larger and of higher vigour than seed produced from May planting (Gusta et al. 2004). In contrast, Karamonas et al. (2002) found that fall-seeded canola produced 4 to 31% lower yields than spring-seeded canola, particularly in the sub-humid Black soil zone. More recently, studies in Alberta found that fall-seeded canola produced inferior yields to early spring-seeded canola, primarily due to 46% lower plant densities from fall seeding (Clayton et al. 2004a). Therefore, the results from fall seeding have been inconsistent with some indication that improvements in canola yield and quality are more likely to occur in ecozones where drought and high air temperatures coincide with flowering and seed filling growth stages.

A key component of successful management of fall-seeded canola is the prevention of stand loss from premature germination. Fall seeding operations must be delayed until soils are cool (just prior to freeze-up) to avoid premature germination and stand loss. The most favourable seeding interval on the Canadian Prairies is often narrow (last few days of October and first few days of November) and is frequently associated with wet and freezing weather conditions that make seeding operations difficult. Polymer seed coatings that delay germination may advance fall seeding dates into early October, thus reducing the risks associated with inclement climatic conditions. Polymers have been used in a variety of agricultural applications, such as preserving seed germinability and chelating fertilizer release (Zhang et al. 1998; Chachalis and Smith 2001). A water impervious, freeze-sensitive, polymer seed coating that controls fall germination of canola was patented and marketed in western Canada under the trade name Extender® (Zaychuk and Enders 2001). The coating impedes the movement of water from the soil to the seed by absorbing water into its polymer structure. Upon freezing, water absorbed by the coating crystallizes and expands the polymer to create micro-fractures. Water can pass through the micro-fractures in the coating allowing germination to proceed as the soil temperature rises above freezing.

Fall-seeded canola has been evaluated in many parts of the prairies where low, stable winter temperatures restrict seed germination (Kirkland and Johnson 2000; Karamonas et al. 2002; Clayton et al. 2004a;b). The Foothill region east of the Rocky Mountains is a portion of the Northern Great Plains where fall-seeded canola may allow for the expansion of canola production, since the area typically experiences higher air temperatures than those encountered by Kirkland and Johnson (2000). The Foothill region is also characterized by a general lack of insulating snow cover and unstable winter temperatures that can melt snow quickly and/or warm soil rapidly. Choosing an optimum date for fall seeding in the Foothill region may be more challenging than picking an optimum date for the prairies. Delaying seeding into late November and early December, if field conditions permit, could reduce risk by shortening the time period in which unfavourable winter conditions could promote canola seed germination,

A study was conducted in the Prairie and Foothill regions of the Northern Great Plains to determine an optimum seeding date interval for fall-seeded canola in these ecoregions and whether a water-impervious polymer seed coating could advance the seeding date and reduce risk of stand loss and yield reduction. A secondary objective for the Foothill region was to determine the relative performance of fall-seeded canola compared to spring-seeded canola.

MATERIALS AND METHODS

Site Description and Experimental Design

An experiment investigating seeding dates and seed coatings was conducted at two locations (Scott and Swift Current) in Saskatchewan, Canada, three locations (Lethbridge, Lacombe and Ellerslie) in Alberta, Canada and at four locations (Willow Creek, Huntley, Moccasin and Bozeman) in Montana, USA, from 1998 to 2001. Soil characterizations for the sites are summarized in Table 1. The Canadian sites are located in Agroecoregions 10, 11 and 12 (Padbury et al. 2002) and are referred to as the Prairie ecoregion (Ecological Stratification Working Group 1995). The Montana sites are located in Agroecoregion 9 and the western part of Agroecoregion 1 (Padbury et al. 2002) and are referred to as the Foothill ecoregion.

For the experiment conducted within the Prairie ecoregion, treatments were arranged in a split-plot design with four replicates. The main plot included a range of seeding dates (Table 2). The sub-plot treatments included a check and two to three water-impervious polymer seed coatings. The check treatment

Table 1. Soil characterization for Prairie and Foothill region sites within the Northern Great Plains

Region/location	Soil classification	Soil texture	Soil texture (% sand, silt, and clay)	Organic matter conc. (g kg^{-1})	pH
Prairie					
Swift Current	Aridic Haploboroll	Clay loam	33, 39, 28	17	7.6
Scott	Typic Boroll	Loam	31, 42, 27	35	6
Lethbridge	Typic Boroll	Sandy loam	37, 30, 33	36	7.8
Lacombe	Typic Haplustoll	Clay loam	43, 21, 36	82	5.9
Ellerslie	Typic Argialboll	Clay	19, 42, 39	110	5.7
Foothill					
Willow Creek	Frigid Typic Calciustoll	Silt loam	15, 72, 13	10	8.1
Huntley	Ustollic Haplargids Aridisol	Loam		13	7.6–8.3
Moccasin	Frigid Typic Calciustoll	Clay loam	32, 33, 35	33	8
Bozeman	Frigid Typic Haploustoll	Silt loam	8, 64, 27	25	7.2–7.8

Table 2. Seeding dates at Prairie and Foothill region sites within the Northern Great Plains

Location	Year[z]	October				November				December		Spring
		1st week	2nd week	3rd week	4th week	1st week	2nd week	3rd week	4th week	1st week	2nd week	
Swift Current	1998			Oct. 22	Oct. 29	Nov. 05	Nov. 12					
	1999	Oct. 09		Oct. 19	Oct. 26	Nov. 06	Nov. 12					
	2000		Oct. 12	Oct. 19	Oct. 26	Nov. 03						
Scott	1998	Oct. 09	Oct. 14	Oct. 20	Oct. 27	Nov. 03						
	1999	Oct. 05		Oct. 19	Oct. 26	Nov. 06						
	2000	Oct. 07	Oct. 14	Oct. 21	Oct. 29							
	2001	Oct. 05	Oct. 12	Oct. 19	Oct. 27							
Lethbridge	1999	Oct. 06	Oct. 13	Oct. 19	Oct. 28	Nov. 03						May 22
	2000	Oct. 08		Oct. 22	Oct. 28	Nov. 03						April 27
Lacombe	1999	Oct. 06			Oct. 27	Nov. 05	Nov. 13					
	2000	Oct. 05	Oct. 12	Oct. 19	Oct. 26	Nov. 02	Nov. 09					
Ellerslie	1999			Oct. 20			Nov. 10					
	2000	Oct. 04	Oct. 11	Oct. 18	Oct. 25	Nov. 01						
	2001	Oct. 05	Oct. 12	Oct. 19	Oct. 25	Nov. 02						
Willow Creek	1999				Oct. 30		Nov. 13			Nov. 30		Apr. 19
	2000					Nov. 01	Nov. 12		Nov. 24		Dec. 06	Mar. 31
Huntley	1999						Nov. 16		Nov. 23	Nov. 30	Dec. 07	Apr. 12
	2000							Nov. 16	Nov. 23	Nov. 30	Dec. 08	Mar. 23
Moccasin	2000				Oct. 26	Nov. 02		Nov. 15		Dec. 03		Apr. 06
Bozeman	2001						Nov. 09	Nov. 15	Nov. 22	Nov. 29		May 09

[z]Year cropped was harvested, fall seeding dates took place the previous fall.

was coated with Guard Coat® (GC check), a highly water-soluble polymer film coating produced by Grow Tec Seed Coatings Inc. [3](Grow Tec Seed Coatings Inc., 10710 – 180 Street, Edmonton, Alberta, Canada T5S 2L6), which is commonly applied to spring-seeded canola to reduce producer exposure to seed applied pesticides. The polymer seed coating designated as the experimental coating FS1A at the start of the experiment has since been commercialized by Grow Tec Seed Coatings Inc. under the commercial name Extender®, and hereinafter is referred to by its commercial name. Extender® was the only polymer coating that was used consistently across locations and years; therefore, the analysis and discussion is limited to the performance of the Extender® polymer seed coat relative to the GC check.

The treatments for the Foothill experiments were arranged in a split-plot design with seeding dates as the main plot factor (Table 2) and seed coating the sub-plot factor. Seed coating treatments were Guard Coat® (GC check), Extender® polymer and two experimental compounds. As with the Prairie data, only the Guard Coat® and Extender® data are analyzed and presented. The first fall seeding dates were later than those used in western Canada due to the warmer, more open autumn weather (Table 2). The Foothill sites also included a spring-seeded check to assess the relative performance of fall- vs. spring-seeded canola. The Lethbridge site is technically in the Prairie ecoregion but shares some similar environmental conditions with the Foothill region in Montana; therefore, a spring-seeded treatment was also included at this location. The seeding dates for the spring checks are listed in Table 2.

Details regarding plot size and site management practices applications are summarized in Table 3. The canola plots were generally seeded directly into standing stubble or chem-fallow, with a few notable exceptions where plots were seeded into tilled fallow. The canola cultivars are listed in Table 3 and all seed was treated with a commercial fungicide/insecticide. Fertility requirements were based on soil test recommendations. Nitrogen requirements on stubble were met by broadcasting urea (Scott, Willow Creek) or ammonium nitrate (Swift Current, Ellerslie) in early spring (Scott, Swift Current, Willow

Table 3. Management practices at Prairie and Foothill region sites within the Northern Great Plains

		Management practices						
					Seeding equipment			
Location	Year	Previous crop	Plot size (m)	Cultivar	Type	Row spacing (cm)	Seed rate (seeds m^{-2})	Harvest method
Swift Current	1998	Tilled fallow	2 × 6	Quest	Disc	30	250	Swathed, plot combine
	1999	Durum wheat	2 × 6	LG3295	Hoe-drill	25	250	Swathed, plot combine
	2000	Durum wheat	2 × 6	LG3235	Hoe-drill	25	250	Swathed, plot combine
Scott	1998	Spring wheat	2 × 5	Quest	Hoe-drill	23	225	Plot combine entire plot
	1999	Chem-fallow	2 × 5	LG3295	Hoe-drill	23	225	Plot combine entire plot
	2000	Chem-fallow	2 × 5	LG3235	Hoe-drill	23	225	Plot combine entire plot
	2001	Barley silage	2 × 5	LG3455	Hoe-drill	25	225	Plot combine entire plot
Lethbridge	1999	Tilled fallow	2 × 6	LG3295	Double disc	20	200	Swathed, plot combine
	2000	Spring wheat	2.5 × 6	LG3235	Double disc	23	200	Swathed, plot combine
Lacombe	1999	Tilled fallow	1.4 × 5.5	LG3295	Double disc	23	75	Swathed, plot combine
	2000	Spring wheat	1.4 × 5.5	LG3235	Double disc	23	75	By hand 1-m^2 quadrat
Ellerslie	1999	Spring wheat[z]	1.8 × 6.7	LG3295	Double disc	20	250	Plot combine entire plot
	2000	Spring wheat[z]	1.8 × 6.7	LG3235	Double disc	20	225	Plot combine entire plot
	2001	Spring wheat[z]	1.8 × 6.7	LG3455	Double disc	23	225	Plot combine entire plot
Willow Creek	1999	Tilled fallow	1.2 × 6.1	Ebony	Hoe-drill	30	250	By hand 2.9-m^2 area
	2000	Chem-fallow	1.8 × 6.1	Hyola 357RR	Disc	26	200	By hand 2.6-m^2 area
Huntley	1999	Tilled fallow	1.2 × 9.1	Ebony	Disc	15	250	Plot combine entire plot
	2000	Tilled fallow	1.2 × 9.1	Hyola 357RR	Disc	15	200	Plot combine entire plot
Mocassin	2000	Spring wheat	1.4 × 6.1	Hyola 357RR	Hoe-drill	28	200	Plot combine entire plot
Bozeman	2001	Barley	1.8 × 6.1	Hyola 357RR	No-till disc	26	200	Plot combine 7.9-m^2 area

[z]Straw was baled prior to seeding.

Creek) or late fall (Ellerslie). Urea was side-banded at the time of seeding at Lacombe, Moccasin 2000, and Bozeman 2001. Phosphorus was applied with the seed at all locations with the exception of the Huntley sites. At Huntley, nutrient requirements on summerfallow were met by broadcasting 112 kg ha^{-1} of 18-46-0 in advance of fall seeding. Potassium and sulphur fertilizers were blended with phosphorus at Scott and applied in the seed-row (1998, 1999, 2001 studies) or 2.5 cm below the seed (2000 study). At Ellerslie, sulphur fertilization was accomplished by broadcasting a blend of 20-0-0-24 in early spring. A glyphosate tolerant cultivar was used at all the Prairie sites (Table 3) so in-crop weed control was accomplished with one or two glyphosate applications at rates of 450 g a.i. ha^{-1} at recommended growth stages for canola and weeds. At Ellerslie, the experimental area also received a pre-seed glyphosate application at rates of 356 or 800 g a.i. ha^{-1} prior to the first fall seed date. In-crop weed control at the Foothill sites was accomplished by glyphosate at rates of 400 to 840 g a.i. ha^{-1} when glyphosate tolerant cultivars were seeded. Quizalofop was applied at 48 g a.i. ha^{-1} for grassy weed control in the conventional canola cultivar used at Willow Creek in 1999. The Moccasin 2000 and Bozeman 2001 sites also received pre-seed glyphosate at 400 g a.i. ha^{-1} in mid-October. Other pesticides and desiccants (diquat) were applied as needed in accordance to label recommendations. Plots were harvested at physiological maturity using various methods summarized in Table 3.

Data Collection

Fall soil temperatures were recorded at nearby meteorological stations at a 5 cm depth. Canola plant density and seed yield were measured in each plot. Canola seedlings were counted in two or three 0.5-m sections of crop rows or in two 0.25-m^2 quadrats within each plot. At the Prairie sites, seedling density for the fall-seeded treatments was assessed 3–4 wk after seedling emergence in the spring. At the Foothill region sites, stand density was determined 4–8 wk after seedling emergence in the spring to assess the plant density contributing to yield formation. Seed samples harvested from each plot were dried to constant moisture, cleaned, and their weights were recorded.

Statistical Analysis

The data collected from the Prairie and the Foothill regions experiments were analyzed separately, since seeding date was later in the Foothill studies. Data were analyzed with the PROC MIXED procedure of SAS (Littel et al. 1996). Seeding dates, seed coatings, blocks, and sites (location-year combinations) were analyzed as fixed effects. Sites also were analyzed as a random effect to make more general conclusions (i.e., make inferences beyond the sites included in the study) regarding effect of canola seed coatings, as fall seeding date is varied in this region. Not all seeding dates were conducted at each location-year, resulting in unbalanced data for the combined analysis. However, PROC MIXED was able to estimate fixed effects and compute standard errors for the unbalanced data (Littel et al. 2002). For means separation, the PDIFF statement was used to obtain estimated standard errors and to calculate the least significant difference. Treatment effects were declared significant at $P < 0.05$ for all analyses.

RESULTS AND DISCUSSION

Prairie Ecoregion

Canola plant density with the GC check canola seed was improved as seeding date was delayed past the third week of

October when averaged across all sites (Fig. 1). Extender® seed coating improved spring seedling density at least twofold when seeding was conducted prior to the fourth week of October (Fig. 1). Seedling density did not differ between seed coating types when seeding occurred in the fourth week of October to the second week of November.

Extender® coating resulted in higher yields than the GC check when canola was seeded in the first 3 wk of October (Fig. 1). Seeding the first week of October resulted in nearly complete stand loss with the GC check and yields were less than half of that attained with the Extender® coating. Canola yield response to seeding date may be one of the reasons for the divergent findings of Karamonas et al. (2002) and Kirkland and Johnson (2000), who reported up to 31% lower and up to 40% higher yields from fall-seeded canola, respectively. Neither study used a water-impervious polymer seed coating like Extender®. Five of the six sites in the Karamonas et al. (2002) study were seeded prior to October 20, whereas the latter study was generally seeded close to the end of October or in early November.

The Extender® coating resulted in similar plant density and seed yield at all seeding dates (Fig. 1). Extender® coating benefited canola stands and yields compared to the GC check when mean daily soil temperatures were higher than 5°C (Fig. 1). It should be noted that soil temperatures were taken at nearby meteorological stations at a 5 cm depth. Therefore, the soil temperatures are not exactly indicative of the soil temperature at which the canola is seeded (1.5 to 2.5 cm), but provide a general indication of the soil temperatures where Extender® coating may or may not be beneficial.

Plant density and yield response to seeding date and polymer coating varied by site; however, there was some consistency in responses when locations were grouped by similar fall environmental conditions when seeding occurred. In general, the fall environmental conditions preceding the Scott 1998 site and all the 1999 sites were generally wetter than the fall environmental conditions preceding the 2000 sites (Fig. 2). The falls preceding the Swift Current 1998 site and the 2001 sites were also dry (Fig. 3), but these sites differed from the 2000 sites in that they also experienced extremely dry spring conditions.

Seedling densities tended to be higher in 2000 (dry fall) compared to the wetter fall locations (Scott 1998/All 1999) with both the Extender® treatment and GC check (Fig. 2). Under wetter conditions, adequate protection was not provided by Extender® for the earliest seeding dates. Seedling densities for the Extender® treatments seeded the first 2 wk of October were about 42–50% lower than treatments seeded past the third week of October. Under moist fall conditions, Extender® yields for the earliest seeding dates were about 20% lower than yields obtained at later seeding dates ($P = 0.001$) (Fig. 2). When averaged across all sites, the yield of Extender®-treated canola was similar across all seed dates, suggesting that yield could be maintained even with early October seeding (Fig. 1). However, the Scott 1998/All 1999 data suggest that seeding in early October with Extender® coating is risky when conditions are moist. This was particularly evident in Lacombe in 1999 when > 60 mm of precipitation was received in the first 2 wk of October. At Lacombe, seeding Extender® coated seed in the first week of October and the first week of November resulted in seedling densities of 2 and 43 plants m^{-2} and canola yields of 1189 and 3145 kg ha^{-1} for the respective seed dates (data not shown). Therefore, the Extender® treatment advanced the fall seeding interval by 2 to 3 wk at Prairie sites, but there were limitations to advancing the seeding date beyond that period. This also suggests that freezing of the Extender® coating is not required for water to be imbibed by the seed and the water-impervious polymer will break down under warm, moist conditions. Confirming this, unpublished studies (Johnson) have shown that Extender®-coated seed will germinate and emerge when seeded in the spring but the emergence is delayed compared to uncoated seed. The mean soil temperature at which Extender® improved seedling density was above 2.8 and 5.5°C under moist and dry conditions, respectively (Fig. 2).

Under dry fall conditions, Extender®coating resulted in higher seedling density than the GC check when seeded in the first 3 wk of October; however yield responses to Extender® were limited to the first week of October (Fig. 2). Under dry fall conditions, there was sufficient fall and winter survival of the GC check when seeded in the second and third weeks of October so yields were similar to the Extender® treatment. Although plant establishment was higher when the autumn was dry (2000), yields were higher for the Scott 98/All 1999 sites reflecting the better growing season conditions for these site-years.

Delaying seeding until the second week of November tended to reduce canola plant density in 2000 (Fig. 2). It is difficult to attain proper furrow closure with the seeding implement when the soil surface freezes (Miller, personal observation). Seeding into frozen soil results in a high percentage of uncovered seeds and responses are similar to broadcast seeding. Broadcasting canola seed on the soil surface in the fall has not been successful relative to drilling the seed at a shallow depth (Johnson et al. 2000).

Late fall seeding with Extender® coating was detrimental under conditions experienced at Swift Current, Scott, and Ellerslie in 1998, 2001, and 2001 respectively (Fig. 3). The Extender® treatment resulted in lower seedling densities and yields than the Guard Coat check at the late fall seeding dates (Fig. 3). These differences corresponded with delayed spring emergence (visual observation) for the Extender® treatments. Dry fall, winter and spring conditions may have enhanced the persistence of the polymer seed coating. For example, fall 2000 (September/October), winter 2000–2001 (November-March) and spring 2001 (April/May) precipitation at Scott was 65, 63 and 73% of the long-term average, respectively. Similar negative results from Extender® coating were reported in a study conducted in Beaverlodge, Alberta in 2000 (Clayton et al. 2004b). The dry fall conditions may have impeded moisture uptake into the polymer complex; therefore, there was limited fracturing of the coating over winter. The dry spring also did not provide conditions conducive to polymer breakdown. Controlled environment studies showed that germination characteristics of Extender®-coated seeds were influenced negatively by decreasing osmotic potential, particularly at low temperatures (Willenburg et al. 2003).

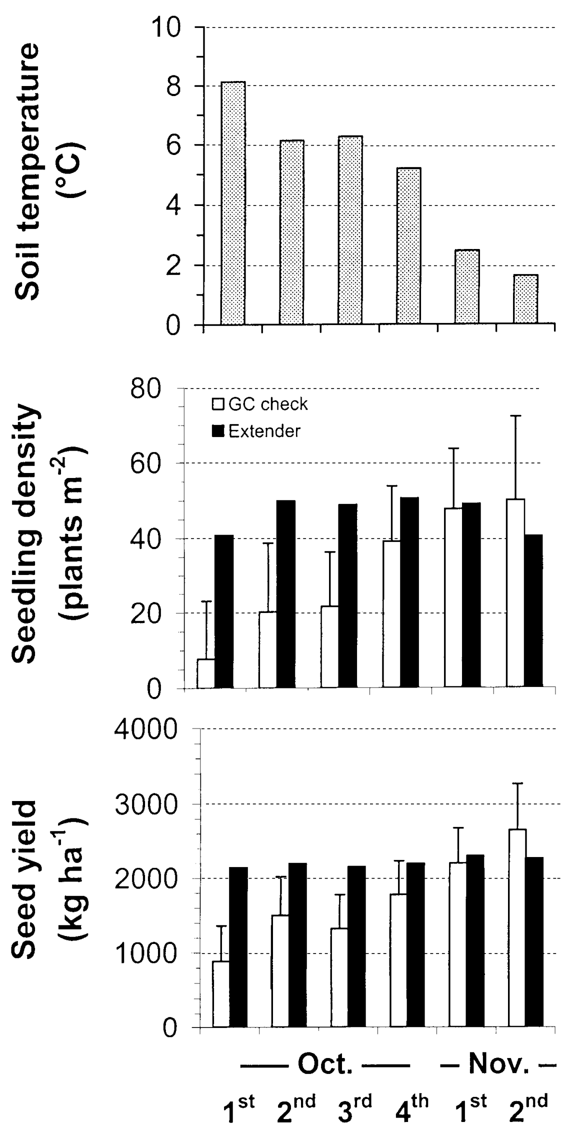

Fig. 1. Canola responses to seeding date (month/week) and seed coating when results were averaged across data collected at 14 site-years in the Prairie ecoregion. Site-years were considered a random effect. Bars represent the $LSD_{0.05}$.

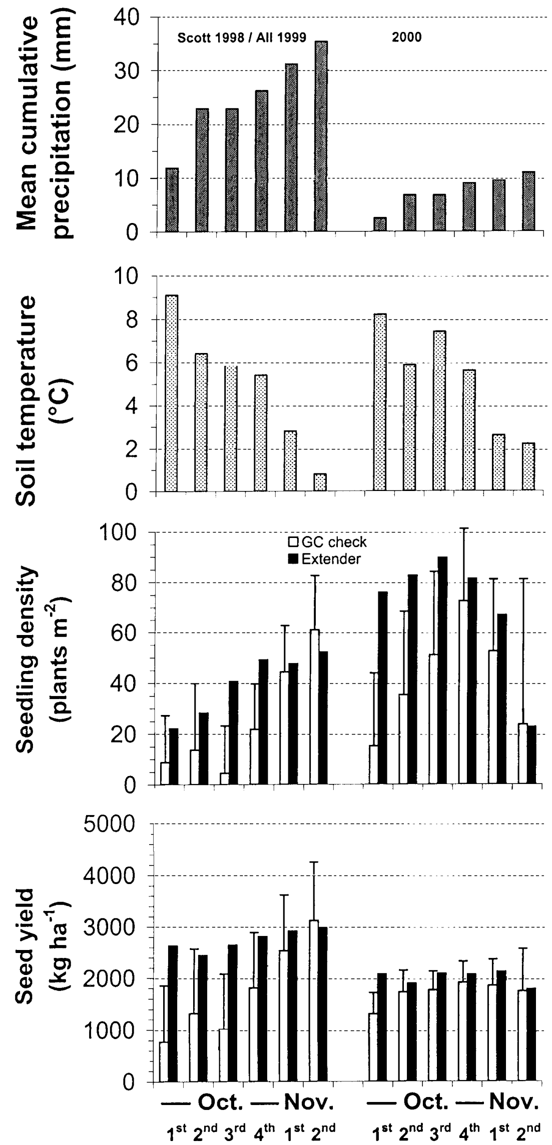

Fig. 2. Canola responses to seeding date (month/week) and seed coating when results were averaged across data collected under moist soil conditions (Scott 1998/All 1999) and dry soil conditions (2000) at Prairie ecoregion sites. Bars represent the $LSD_{0.05}$.

The Canola Growers Manual recommends seedling densities of greater than 80 plants m^{-2} to optimize canola yield (Thomas 2002). Angadi et al. (2003) reported that a reduction in plant population from 80 to 40 plants m^{-2} did not affect seed yield. However, a further reduction to 20 plants m^{-2} reduced yield by 20% in years of normal precipitation and 36% in years of below-normal precipitation. The highest plant densities achieved, with or without Extender® coating, exceeded 80 plants m^{-2} in only 4 out of 14 site-years (data not shown). Three of four of these sites occurred in 2000, likely due to the low October precipitation received in the fall of 1999. Stand densities of < 20 plants m^{-2}, between 20 and 40 plants m^{-2}, and 40 to 80 plants m^{-2} were achieved in 2, 2, and 6 of the 14 site-years, respectively (data not shown). Therefore, Extender® may advance the fall seeding date, but does not necessarily overcome the problem of low plant stands from fall seeding as reported by Clayton et al. (2004a).

Foothill Region

When averaged across the 6 site-years, the response of plant stand to fall seeding date and seed coating was more inconsistent than the Prairie sites (Fig. 4). Generally, canola plant density was lower with the early seed dates and highest with the latest seed dates; however, densities were variable at intermediate seeding dates. Extender® coating improved seedling density in 4 of the 6 site-years; however, biologically impor-

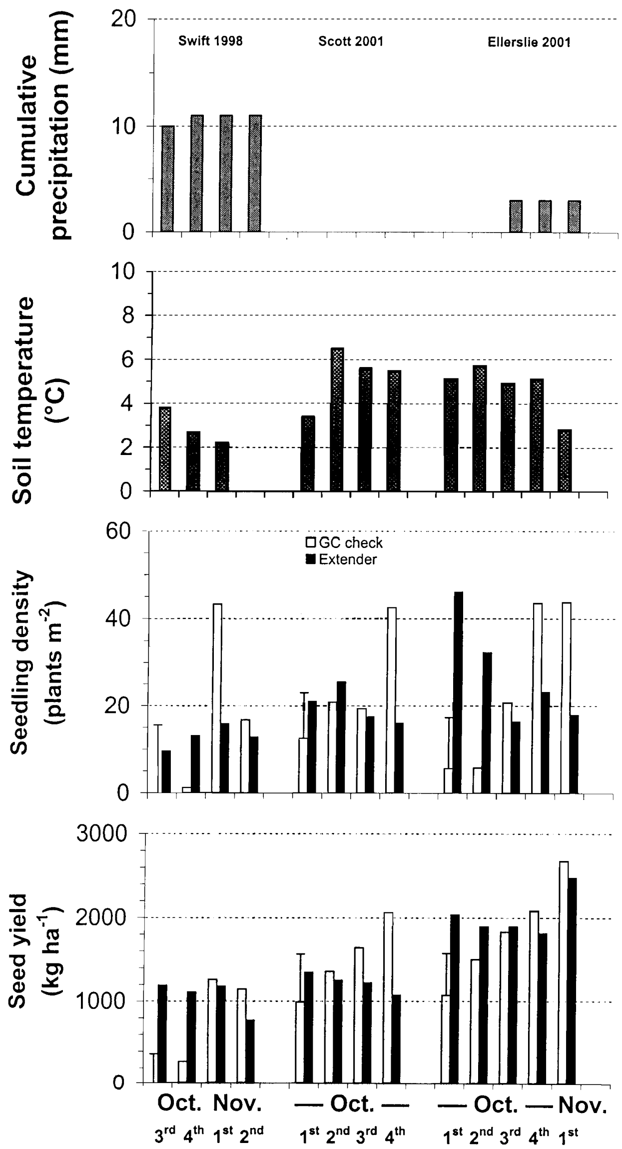

Fig. 3. Canola response to seeding date (week) and seed coating for data collected at Swift Current, SK, Scott, SK and Ellerslie, AB, in 1998, 2001, and 2001, respectively. Bars represent the $LSD_{0.05}$ for the seeding date × seed coating interaction.

tant differences were small, with the exception of Huntley and Moccasin 2000 (Table 4). When averaged across all site-years, yields of the Guard Coat® check and Extender® increased as seeding date was delayed until the second and fourth week of November, respectively (Fig. 4). Extender® treatment resulted in a marginal yield increase ($P < 0.10$) at the earliest seed date and a significant yield increase when seeding occurred in the fourth week of November. At individual sites, Extender® coating resulted in higher yields in 2 of the 6 site-years even though it had only a small effect on plant stand at Huntley 1999 (Table 4). Unlike the Prairie data, there was very little relationship between fall soil temperature and the benefit of Extender® seed coating for improving stand density and crop yield (Fig. 4), even though soil temperatures were similar to the Prairie ecoregion.

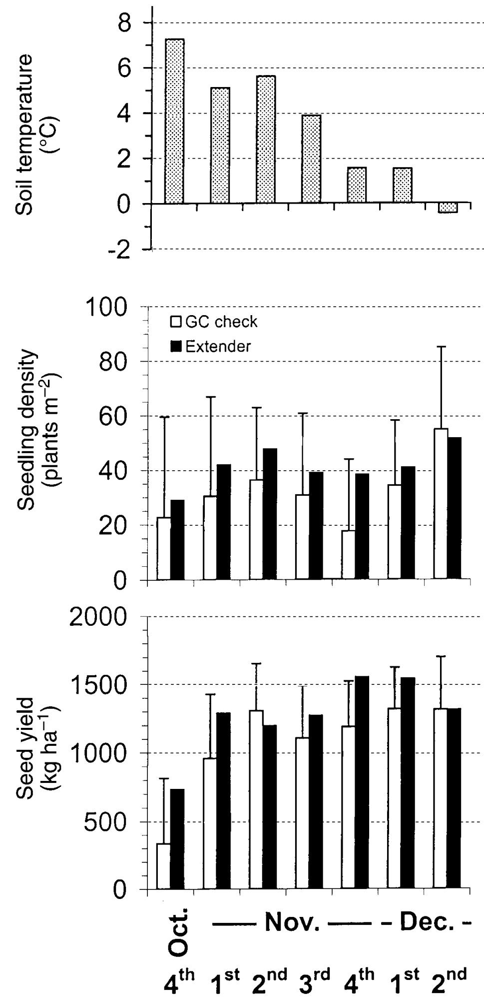

Fig. 4. Canola response to seeding date (month/week) and seed coating when results were averaged across data collected at 6 site-years at the Foothill region of the Northern Great Plains from 1999 to 2001. Site-year was considered a random effect in the analysis. Bars represent the $LSD_{0.05}$.

Performance of Fall- vs. Spring-seeded Canola in Lethbridge and the Foothill Region (Extended Foothill Region)

In general, fall seeding resulted in lower plant stands than spring seeding (Table 5). Only in one of the site-years did fall-seeded canola stand density exceed the recommended stand density of 80 plants m^{-2}. Fall seeding resulted in similar plant stands as the spring-seeded check for all fall seeding dates at Huntley 2000 and the earliest date at Bozeman 2001 (Table 5). At Bozeman 2001, the canola was seeded 4 d after a significant snowfall event (~15 cm), which created the ideal seedbed for effective seed placement and low stable temperatures to restrict seed germination. The three subsequent fall dates were also seeded under the same snow cover; however, the soil surface had begun to freeze, which prevented effec-

Table 4. *P* values and means of fall seeding dates and seed coating effects at six site-years in the Foothill region of the Northern Great Plains

Treatment	Huntley 1999	Willow Creek 1999	Huntley 2000	Moccasin 2000	Willow Creek 2000	Bozeman 2001
			Seedling density			
Date	<0.01	<0.01	<0.01	<0.01	0.05	<0.01
Coat	<0.01	0.06	<0.01	<0.01	0.05	0.88
D × C	0.02	0.57	0.06	0.38	0.14	<0.01
			Polymer seed coating treatment means (plants m^{-2})			
Uncoated	3	8	109	12	9	52
Extender	7	11	147	21	12	50
$LSD_{0.05}$	4	NS	20	6	3	NS
			Seed yield			
Date	<0.01	<0.01	0.09	0.20	0.08	0.50
Coat	<0.01	0.44	0.57	<0.01	0.23	0.65
D × C	<0.01	0.43	0.18	0.17	0.09	0.85
			Polymer seed coating treatment means (kg ha^{-1})			
Uncoated	375	1258	1034	831	960	2382
Extender	744	1549	1043	1202	1021	2465
$LSD_{0.05}$	116	NS	NS	147	NS	NS

Table 5. Plant density and seed yield of canola seeded at four fall dates and one spring date at 8 site-years in the extended Foothill region of the Northern Great Plains

Date	Huntley 1999	Lethbridge 1999	Willow Creek 1999	Huntley 2000	Lethbridge 2000	Moccasin 2000	Willow Creek 2000	Bozeman 2001
				Plant density (plants m^{-2})				
Fall 1[z]	3	36	3	152	6	14	14	89
Fall 2	5	43	11	127	24	23	7	31
Fall 3	16	40	21	139	20	25	17	45
Fall 4	5	32	–	171	30	24	8	35
Mean fall	7	38	12	147	20	22	12	50
Spring	110	79	153	186	82	34	26	75
$LSD_{0.05}$	7	20	13	NS	24	6	6	26
Contrast								
Fall vs. spring	<0.01	<0.01	<0.01	0.07	<0.01	0.03	<0.01	0.02
				Seed yield (kg ha^{-1})				
Fall 1	607	4410	775	844	1160	1062	917	2511
Fall 2	624	3560	1360	1228	1563	1426	616	2198
Fall 3	976	3912	2384	1168	1595	1411	1643	2331
Fall 4	773	3950	–	934	1510	1228	935	2266
Mean fall	745	3958	1506	1044	1457	1282	1028	2327
Spring	745	3560	2652	862	1948	1237	1479	1706
$LSD_{0.05}$	202	608	895	260	348	NS	535	422
Contrast								
Fall vs. spring	0.99	0.11	<0.01	0.08	<0.01	0.81	<0.01	<0.01

[z]Actual seed dates are presented in Table 2.

tive seed furrow closure. The latest seeding date at Willow Creek 2000 also occurred in semi-frozen soils, resulting in lower plant stands (Table 5). The response to frozen soils is consistent with the Prairie experience discussed earlier, and highlights the requirement for accurate seed placement to optimize seed-to-soil contact. New developments in seeding equipment technology such as angled disc openers may improve the success of seeding into frozen soils.

Reasons for stand failure at other locations were varied. At Huntley 1999 and Willow Creek 1999, a mild snow-free winter with intermittent moisture caused sporadic germination throughout the winter. At Willow Creek, soil moisture was completely depleted in the upper 15 cm of the soil profile in tilled fallow due to evaporation (Miller, personal observation) and intermittent light rainfall events (< 5 mm) in the early spring, which caused the seed to germinate but the seedlings desiccated from severe drought stress. Kirkland and Johnson (2000) reported crop emergence problems with fall-seeded canola on tilled fallow, primarily due to soil crusting. Low plant densities at two of the sites in 2000 (Moccasin and Willow Creek) were due to repeated severe frost events where spring temperatures dropped as low as –10°C. The variable pattern of frost mortality could not be clearly related to seedling age or any other obvious factor (Miller, personal observation). Fall-seeded canola at Lethbridge 2000 also experienced significant frost injury. Kirkland and Johnson (2000) reported that fall-seeded canola tolerated spring frosts of –8°C; however, Clayton et al. (2004a) reported that multiple spring frosts were responsible for low plant stands in some of the Alberta studies.

The plant stand results from fall seeding in the extended Foothill region are consistent with the findings of Clayton et al. (2004a), where fall seeding resulted in 46% lower plant density than an early spring seeding date, and both these studies were unable to achieve the plant stands reported by Kirkland and Johnson (2000).

The mean yield of all the fall seeding dates was lower than the spring yields in three of eight site years (Table 5). Mean fall-seeded yields were equal to or higher than spring yields at 4 and 1 site-years, respectively. The best yields for fall-seeded canola were achieved at Bozeman 2001 and at Lethbridge 1999. Highest yields at the Bozeman site were achieved when soils conditions were conducive to good plant establishment and maintenance of quiescence (i.e., shortly after a snowfall but prior to soil freezing). With the exception of Lethbridge in 2000, there was at least one fall seed date at each location where yields were equal to or higher than the spring-seeded check (Table 5). However, unlike the Prairie data, the highest yielding date was not necessarily the later seed dates. In order for fall seeding to be adapted in the Foothill region, technologies will need to be developed than can improve the producer's ability to predict an optimum seed date.

To summarize, the optimum seeding date interval for the GC check in the Prairie sites was the last week of October or the first week of November. Extender® coating advanced the fall seeding date at the Prairie sites by 2 to 3 wk, allowing seeding to occur in mid-October. The Extender® coating could be detrimental if seeded late into very dry soils. While Extender® allowed for earlier fall seeding, it did not eliminate the problem of low plant densities that have been reported in Alberta studies. The reasons for low plant densities varied, and there still remains a lack of understanding of the factors that cause overwinter or spring mortality of fall-seeded canola.

Choosing an optimum fall seed date in the Foothill region is more challenging. The highest densities and yields of fall-seeded canola did not always occur at the latest seed dates, and Extender® coating resulted in only marginal improvements. At both the Prairie and Foothill sites, delayed seeding into frozen soils was detrimental in terms of plant stand and crop yield. A more thorough understanding of the factors leading to winter and spring mortality of canola seeds in the Foothill region is required for fall seeding to be generally adopted by producers.

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Angadi, S. V., Cutforth, H. W., McConkey, B. G. and Gan, Y. 2003. Yield adjustment by canola grown at different plant populations under semiarid conditions. Crop Sci. **43**: 1358–1366.

Chachalis, D. and Smith, M. L. 2001. Hydrophobic-polymer application reduces imbibition rate and partially improves germination or emergence of soybean seedlings. Seed Sci. Technol. **29**: 91–98.

Clayton, G. W., Harker, K. N., O'Donovan J. T., Blackshaw, R. E., Dosdall, L. M., Stevenson, F. C. and Ferguson, T. 2004a. Fall and spring seeding date effects on herbicide-tolerant canola (*Brassica napus* L.) cultivars. Can. J. Plant Sci. **84**: 419–430.

Clayton, G. W., Harker, K. N., O'Donovan J. T., Blackshaw, R. E., Dosdall, L., Stevenson, F. C., Johnson, E. N. and Ferguson, T. 2004b. Polymer coating of early- and late-fall seeded herbicide-tolerant canola (*Brassica napus*). Can. J. Plant Sci. **84***:* 971–979.

Ecological Stratification Working Group. 1995. A national ecological framework for Canada. Cent. For Land and Biol. Resour. Res. Agric. And Agri-Food Can., Ottawa, ON and Ecozone Analysis Branch, State of Environ. Directorate of Environ. Canada, Hull, QC.

Gusta, L. V., Johnson, E. N., Nesbitt, N. T. and Kirkland, K. J. 2004. Effect of seeding date on canola seed quality and seed vigour. Can. J. Plant Sci. **84**: 463–471.

Johnson, E. N., Johnston, A. M. and Kirkland, K. J. 2000. Fall seeded canola – agronomic studies and growth analysis. Pages 236–245 *in* Proc. 2000 Soils and Crops Workshop. Extension Division, University of Saskatchewan, Saskatoon, SK.

Johnston, A. M., Johnson, E. N., Kirkland, K. J. and Stevenson, F. C. 2002. Nitrogen fertilizer placement for fall and spring seeded *Brassica napus* canola. Can. J. Plant Sci. **82**: 15–20.

Karamonas, R. E., Harapiak, J. T. and Flore, N. A. 2002. Fall and early spring seeding of canola (*Brassica napus* L.) using different methods of seeding and phosphorus placement. Can. J. Plant Sci. **82**: 21–26.

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.

Littel, R. C., Milliken, G. A., Stroup, W. W. and Wolfinger, R. D. 1996. SAS System for mixed models. SAS Institute, Inc., Cary NC. 656 pp.

Littel, R. C. Stroup, W. W. and Freund, W. J. 2002. SAS for linear models. SAS Institute, Inc., Cary, NC. 466 pp.

Padbury, G., Waltman, S., Caprio, J., Coen, G., McGinn, S., Mortensen, D., Nielsen, G. and Sinclair, R. 2002. Agrogecosystems and land resources of the Northern Great Plains. Agron. J. **94**: 251–261.

Thomas, P. 2002. Canola growers manual [on-line] Available: http:www.canola-council.org/ [2003 Mar. 22].

Willenborg, C. J., Gulden, R. H., Johnson, E. N. and Shirtliffe, S.J. 2004. Germination characteristics of polymer coated canola (*Brassica napus* L.) seeds subjected to moisture stress at different temperatures. Agron. J. **96**: (in press).

Zaychuk, K. S. and Enders, N. 2001. Water insoluble, freeze sensitive seed coatings. United States Patent 6230438. US Patent and Trademark Office. 2001 May 15.

Zhang., M, Nyborg, M. and Solberg, E. D. 1998. Seed germination and seedling dry matter production of canola, barley and wheat as affected by seed-placed KCl and polymer-coated KCl. Can. J. Soil Sci. **78**: 611–614.