INFLUENCE OF SIMULATED SPRING FROST ON GROWTH AND YIELD OF THREE BARLEY CULTIVARS

J. S. McKENZIE, D. G. FARIS[1], and R. M. DE PAUW[2]

Research Station, Agriculture Canada, Beaverlodge, Alberta T0H 0C0. *Contribution no. NRG 81-2 of the Northern Research Group. Received 30 Mar. 1981, accepted 27 Oct. 1981.*

McKENZIE, J. S., FARIS, D. G. AND DE PAUW, R. M. 1982. Influence of simulated spring frost on growth and yield of three barley cultivars. Can. J. Plant Sci. **62**: 81–88.

Three spring barley (*Hordeum vulgare* L.) cultivars were planted at four seeding dates to evaluate the effect of a simulated frost at the two-leaf stage on growth and yield. A portable field freezing chamber was used to subject the plants to a −5.6°C stress. The frost caused 49, 64 and 68% injury to the leaves and delayed heading by 2.4, 1.4 and 2.4 days in Galt, Atlas and Olli, respectively. Frost also reduced the number of tillers per plant, ripe heads per plant and plants per plot in all cultivars. Although the late-maturing cultivar Galt had the most leaf frost resistance, the average 13.8% yield reduction within all three cultivars, owing to the freezing stress, was not significantly different between any of the cultivars. Complete defoliation by clipping resulted in no further reduction in yield than that which occurred from partial defoliation by freezing. Delayed seeding resulted in an 8.6% reduction in yield. Frost reduced the yield of early seeded cultivars by 9.8% and late-seeded cultivars by 17.1%.

On a semé trois cultivars d'orge de printemps (*Hordeum vulgare* L.) à quatre dates pour évaluer l'effet d'une gelée simulée au stade de 2 feuilles sur la croissance et le rendement. On a utilisé une chambre portative de congélation pour soumettre les plants à un stress de -5,6 °C au champ. La gelée a endommagé les feuilles à 49, 64 et 68 % et a retardé l'épiaison de 2,4, 1,4 et 2,4 jours, respectivement, chez Galt, Atlas et Olli. Le traitement a également réduit le nombre de talles/plant, d'épis mûrs/plant et de plants/parcelle chez tous les cultivars. Bien que le cultivar tardif Galt s'avère le plus résistant à la gelée des feuilles, les cultivars ne manifestent aucune différence significative dans la réduction moyenne de 13,8% du rendement due au stress. La défoliation complète par taille ne réduit pas davantage le rendement que la défoliation partielle due à la congélation. Le recul du semis entraîne une réduction de 8,6 % du rendement. La gelée abaisse le rendement des cultivars semés tôt et tard de 9,8 et 17,1 %, respectivement.

Late spring and early fall frosts are constraints which can severely decrease crop yields. In northwestern Canada, the short growing season makes early seeding essential with the result that frosts often occur after the seedlings emerge. These frosts may cause immediate visual damage to the leaves, but this damage becomes obscure in cereal crops as new growth replaces the affected tissue. Furthermore, if maturity is delayed in plants which have been subjected to frost in the spring, then during a short growing season, these plants are more likely to experience frost again

[1]Present address (D. G. F.): ICRISAT, Patancheru P. O., Andhra Pradesh 502–324, India.
[2]Present address (R. M. DE P.): Agriculture Canada, Research Station, Swift Current, Saskatchewan S9H 3X2.

Can. J. Plant Sci. 62: 81–88 (Jan. 1982)

0008-4220/82/6201-0081 $2.00

at the end of the growing season.

Barley cultivars have been reported to differ in their leaf frost resistance (Harrington 1936a; Johnston et al. 1949). According to Platt (1937b), early maturing cereal cultivars are more susceptible to freezing stress than late-maturing cultivars. Plot yields, however, do not always correlate with seedling frost injury ratings (Harrington 1936b; Ivanov 1935) and it is conceivable that some cultivars may have a greater capacity to recover from freezing stress than others.

In the past, the danger of spring frost was always considered to warrant some attention by plant breeders (Harrington 1936a, b; Johnston et al. 1949; Platt 1937b), but spring frost was never thought to be among the most important factors limiting cereal production in western Canada (Johnston et al. 1949). Due to the twofold increase in cereal acreage in the Peace River region of northwestern Canada from 1951 to 1980 (Statistics Canada 1951, 1980), the potential limiting effect of spring frost on cereal production may now be of considerable importance to producers and plant breeders. The objective of this study was to evaluate the effect of a spring frost on the development and yield of three barley cultivars.

MATERIALS AND METHODS

Three spring six-row barley cultivars, Galt, Atlas and Olli were used in this study. Galt and Olli were chosen because they are grown widely in the Peace River region of northwestern Canada. Galt is a late- and Olli an early maturing cultivar. Atlas is a coastal type of spring barley grown in California during the winter. It has been reported to have some seedling frost tolerance (Dantuma and Andrews 1960) and is early maturing.

All three cultivars were randomly planted in rows spaced at 46 cm and replicated four times in a Landry clay loam soil at Beaverlodge, Alberta (latitude 55° 12′ N) in 1976. The seeding rate was 110 seeds·m^{-2} with 60 kg·ha^{-1} of 11-48-0 fertilizer sidebanded. Cultivars were planted on 28 Apr., 7 May, 14 May and 21 May with a Planet Junior seeder. Prior to treatment, 50-cm wide plots were selected perpendicular to the three rows of barley to facilitate the portable freezing chamber or weather proof boxes. After plants had attained the two leaf stage, they were subjected to a control, frosted and clipped treatment. The treatments were replicated four times, each on a consecutive night.

Preliminary studies in 1974 and 1975 indicated that the barley leaves could supercool to temperatures below −5°C, particularly during dry weather conditions. This would result in no leaf injury at temperatures above −5°C. In the present study, moisture stress problems were overcome by saturating the soil surface with 5 L of water immediately before subjecting the plants to the freezing treatment. We also found this prevented the leaves from supercooling below −1°C.

The plots were frost stressed artificially with a 50 × 180 × 60-cm high portable field freezing chamber (Reid et al. 1976). The refrigeration system was controlled by an electronic programmer (Model 5300, Data Trak, R.I. Controls Inc., Minneapolis, Minn.) to maintain the required air temperature - time profile inside the cabinet. Two 25-cm fans were suspended inside the cabinet to improve air circulation. The plots were covered with the freezer at 1600 h and a chamber temperature of 5°C was maintained for 4 h. The temperature was then lowered to 0°C over a period of 2 h and plants were gradually cooled to −5.6±1.1°C during the 2300-0400 h period. The minimum temperature was maintained between 0400 h and 0500 h. Following this freezing period, the chamber was warmed to 1°C by 0800 h and to 5°C by 0900 h after which time the freezing chamber was removed. Leaf temperature was monitored by four copper constantan thermocouples. The control and clipped plots were covered with 50 × 180 × 70-cm high weatherproof boxes equipped with fans to circulate air from outside to maintain ambient air temperatures. In the clipped plots the plants were cut 1 mm below the soil surface immediately upon removing the box in the morning.

Leaf injury was evaluated 2-3 days following treatment by visually estimating the percentage of leaves damaged on each plant. Plot means were then calculated. The clipped plots were all scored as 100% injured and the control plots scored as not injured.

The following parameters were measured

during the growing season: days from emergence to heading and to maturity; plant height in centimetres at the second and fourth week after treatment; the number of tillers and mature heads per plot; and the number of plants per plot at harvest. After harvesting and threshing, the total seed yield per plot and 1000-kernel weight in grams were determined. The change in height between the second and fourth week following treatment and the number of tillers and ripe heads per plant were calculated from these measurements. The unripe heads were not counted and the number of kernels per head were not calculated because the fertile and infertile tillers were not separated.

RESULTS

There were significant differences among treatments, planting dates and cultivars for almost all variables studied (Table 1). There were also a number of significant second order interactions. Because there were no significant third order interactions the data are not shown.

Galt showed greater leaf frost resistance than either Atlas or Olli when frozen at the two-leaf stage (Table 2). The freezing treatment caused 49, 64 and 68% leaf injury in Galt, Atlas and Olli, respectively. The differences in leaf damage among planting dates appeared to follow closely the actual mean leaf temperature during the freezing treatment at each planting date (Table 2). However, the large unexplained variability in injury following freezing of the 7 May and 21 May planting dates precluded significant differences between cultivars.

The injury caused by freezing or clipping resulted in a significant reduction in the yield of all three cultivars (Fig. 1A; Table 1). The frost reduced the yield of Galt, Atlas and Olli by 12, 13 and 15%, respectively. The clipping treatment reduced yield by 14, 19 and 13% in Galt, Atlas and Olli, respectively. Although the yield potential of the cultivars differed significantly, the lack of a significant cultivar by treatment interaction indicated that there was no significant difference in yield re-

Table 1. *F*-values and mean squares for 11 characteristics of three barley cultivars planted at four dates and receiving freezing and clipping treatments

Source	d.f.	Percent leaf injury	Yield (g·0.23 m^{-2})	Height at 2 wk	Height at 4 wk	Height 4–2 wk	Days to head	Days to mature	Number plants·0.23 m^{-2}	Tillers per plant	Ripe heads per plant	g/1000 kernels
Reps. (R)	3	0.75†	0.524	1.20	1.23	0.56	1.67	1.12	0.53	2.59	6.14*	0.49
Dates (D)	3	0.93	9.79**	15.67**	6.00*	3.86*	70.40**	49.30**	3.82	17.85**	9.88**	22.87**
M.S. Error A	9	472.7	683.5	16.72	112.8	104.3	7.093	9.556	13.90	.9368	.13902	0.0703
Treats (T)	2	778.15**	20.93**	161.65**	76.10**	8.67**	88.54**	54.37**	6.69**	17.08**	30.88**	2.42
Cult (C)	2	3.41*	106.20**	7.86**	44.42**	42.39**	378.23**	75.76**	21.57**	33.26**	6.46**	92.05**
D × T	6	2.81*	2.11	4.13**	2.99*	3.31**	2.71*	0.71	0.93	1.57	1.19	1.41
D × C	6	0.46	3.30**	2.15	3.65**	3.99**	1.54	3.62**	1.79	1.56	1.16	0.73
T × C	4	3.41*	0.59	1.77	2.78*	2.08	2.66*	1.61	1.41	0.90	1.64	1.28
M.S. Error B	96	167.2	343.4	3.028	13.62	10.31	2.252	6.775	17.97	.6255	.09308	.0521

† Unless indicated in source as mean square (MS) all numbers are *F* values.
* Means significant at $P = 0.05\%$; ** means significant at $P = 0.01\%$.

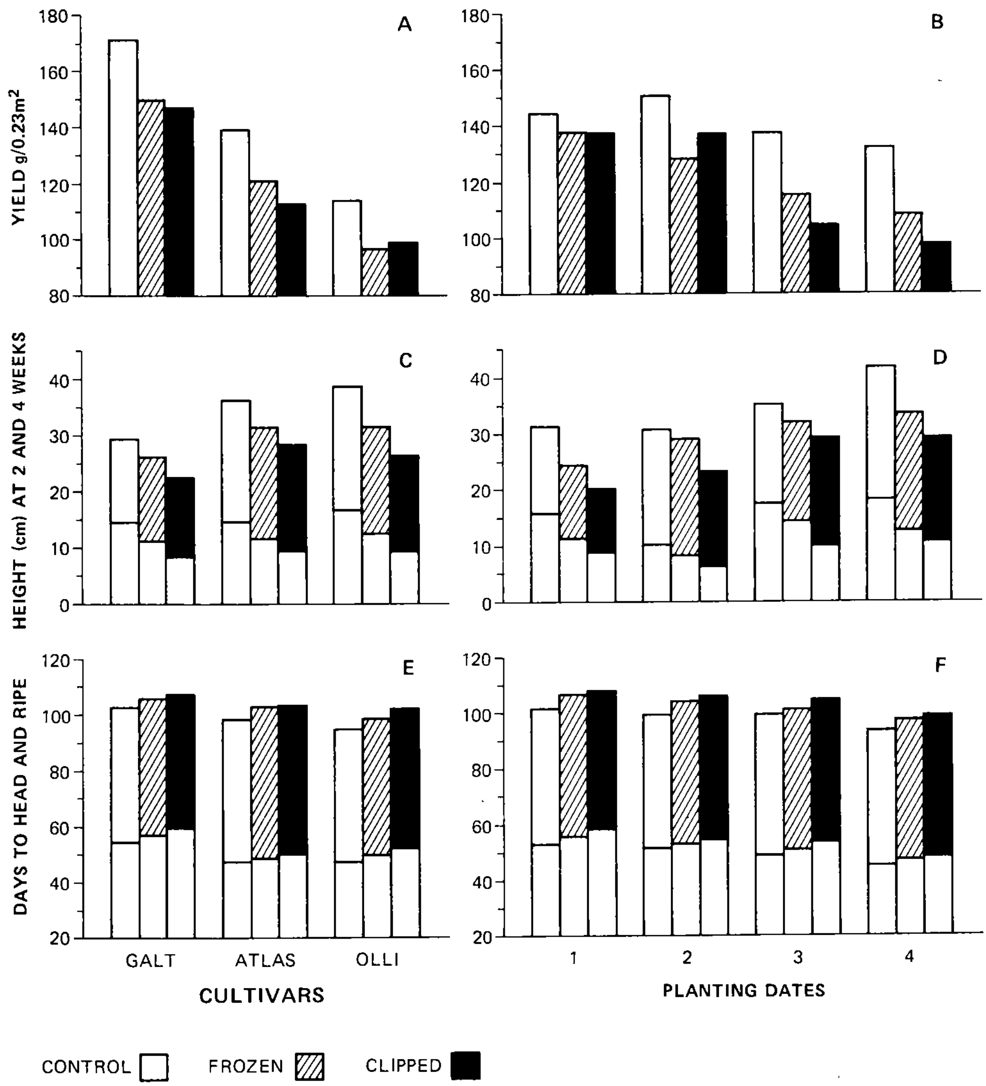

Fig. 1. The mean grain yield (A), plant height (C), days to head and ripe (E) of four planting dates, of three barley cultivars; and the mean grain yield (B), plant height (D), days to head and ripe (F) of four planting dates (1-28 April, 2-7 May, 3-14 May, and 4-21 May), of three barley cultivars subjected to three treatments: control, artificially frozen, and clipped at the two-leaf stage.

duction among the three cultivars owing to either the freezing or the clipping treatment (Fig. 1A; Table 1). However, there was a significant yield difference among seeding dates with the two early seeding dates averaging an 8.6% higher yield than the two later seeding dates (Fig. 1B). Frost reduced the yield of the two early seeding dates an average of 9.8%. This was further reduced to 17.1% in the two later seeding dates. Clipping reduced yield on the early seeding dates by 7.0%, but by 25.1% in

Table 2. Percent leaf injury following freezing treatments of three barley cultivars at four seeding dates and mean minimum leaf temperature during freezing treatment

Cultivar	Planting dates 28 Apr.	7 May	14 May	21 May	Mean
			% Freezing injury		
Galt	61 *b*	34 *a*	40 *b*	62 *a*	49 *B*
Atlas	79 *ab*	62 *a*	54 *ab*	62 *a*	64 *A*
Olli	86 *a*	64 *a*	62 *a*	62 *a*	68 *A*
Mean	75 *A*	54 *B*	52 *B*	62 *AB*	
			Mean leaf temperature (°C)		
	−6.4 *A*	−5.0 *B*	−5.0 *B*	−6.2 *AB*	−5.6

a,b Means within a column followed by the same letter are not significantly different at $P = 0.05$ according to Duncan's multiple range test.
A,B Grand means within rows or columns followed by the same letter are not significantly different at $P = 0.05$ according to Duncan's multiple range test.

the two late-seeding dates. Galt showed the greatest reduction in yield owing to delayed seeding (results not shown) and Galt was the only cultivar to show a significant correlation between percent leaf injury and reduction in yield owing to frosting ($r = 0.534$). The correlation coefficient for Atlas was $r = 0.336$ and for Olli $r = 0.223$.

Clipping reduced plant height more than freezing as shown 2 and 4 wk following treatment (Fig. 1C). Plant height was reduced by 32% in the early maturing cultivar Olli, 23% in the late-maturing Galt and 22% in Atlas 4 wk following the clipping treatment. On the other hand, frost reduced height by 11, 13 and 19% in Galt, Atlas and Olli, respectively.

The date of seeding also affected the plant height following treatment. The larger heights in late-planted seedlings compared to early planted seedlings (Fig. 1D) is probably directly related to the increasing number of heat units per day and the increasing photoperiod as seeding dates were delayed (data not shown). Atlas and Olli grew more rapidly than Galt during the 2- to 4-wk period following the treatments (Fig. 1C).

The clipping and freezing treatment significantly set back growth by increasing the number of days to head and mature in all cultivars (Fig. 1E). These treatments had the greatest effect on increasing the number of days for the plants to head. The frost treatment significantly increased the number of days to head in Galt, Atlas and Olli by 2.4, 1.4 and 2.4 days, respectively. Clipping also increased the number of days to heading by 5.2, 2.8 and 4.8 for Galt, Atlas and Olli, respectively. Both treatments were significantly different from one another. The frost and clipping treatment did not affect the number of days from heading to maturity in Galt and Olli, but both treatments significantly lengthened the time from heading to maturity in Atlas by an average of 2.9 days. However, there was no significant difference between the two stress treatments. Delayed seeding significantly reduced the number of days to heading and maturity within all treatments (Fig. 1F). There were significant treatment by cultivar interactions for days to heading, but not for days to mature (Table 1).

Many of the yield components (number of plants·0.23 m^{-2}, tillers·$plant^{-1}$, and g·1000 $kernels^{-1}$ were significantly affected by date of seeding, treatment and cultivar (Table 1). The number of plants·0.23 m^{-2} were not affected by planting dates and kernel weight was not affected by treatment. Galt had the highest number of plants·0.23 m^{-2} and Olli the lowest (Fig. 2A). The frozen plots had the

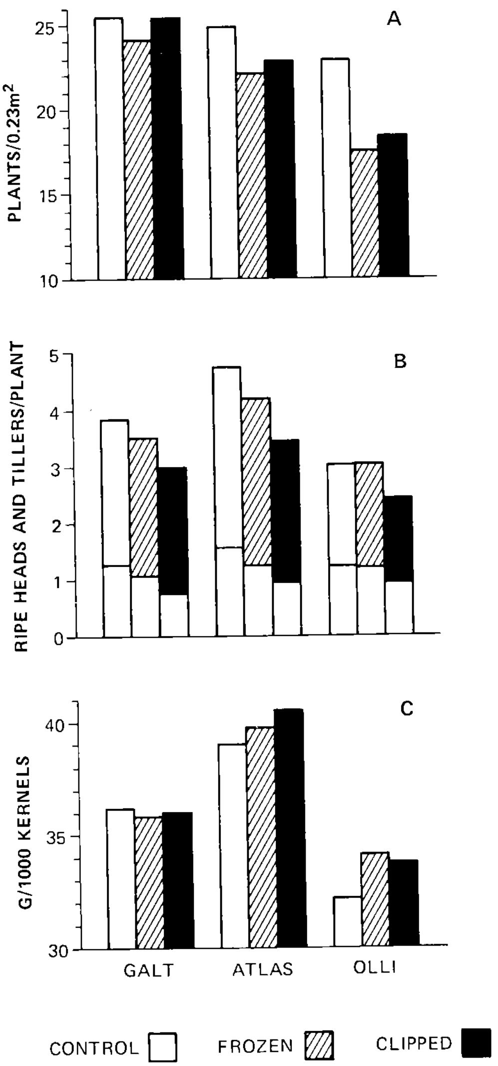

Fig. 2. The mean number of plants·0.23 m^{-2} (A), ripe heads and tillers per plant (B), and 1000-kernel weight (g) (C), of four planting dates, of three barley cultivars subjected to three treatments at the two-leaf stage: control, artificially frozen, and clipped.

fewest plants within all cultivars, but these numbers were not significantly different from the number of plants in the clipped plots. Olli had the largest reduction in plant stand by clipping and freezing, and Galt had the smallest (Fig. 2A).

Frost significantly reduced the number of ripe heads per plant in Galt and Atlas but not in Olli (Fig. 2B). Clipping further reduced the number of ripe heads per plant in all three cultivars. Atlas had the highest number of tillers per plant and Olli the fewest (Fig. 2B). Although frost had no significant affect on the number of tillers per plant, clipping significantly reduced the number of tillers per plant within all cultivars (Fig. 2B). Atlas had the highest seed weights and Olli the lowest (Fig. 2C). The freezing and clipping treatment had no significant effect on seed weight.

Date of seeding had no effect on the number of plants·0.23 m^{-2}, but there was a significant affect on the number of ripe heads per plants, tillers per plant and seed weight (Table 1). As seeding date was delayed, the number of ripe heads per plant decreased from 1.4 to 1.1 and the number of tillers per plant decreased from 4.4 to 2.9 (data not shown). In both cases there were no significant treatment by date interactions (Table 1). Seed weight, however, increased from 34.7 to 39.1 g·1000 $kernels^{-1}$ as seeding date was delayed (data not shown), but there were no significant treatment by date interactions (Table 1).

DISCUSSION

The late-maturing cultivar Galt had more leaf frost resistance than either Olli or Atlas. These results support Platt's (1937a, b) finding that seedlings of early maturing spring cereal cultivars are more susceptible to leaf frost injury than late-maturing cultivars.

The freezing treatment caused a significant reduction in yield in all cultivars. Although differences in leaf frost resistance between cultivars was as high as 19%, there was no significant difference in the percent reduction in yield among the three cultivars. However, there was a significant correlation between leaf frost injury and yield in the late-maturing cultivar Galt. These results confirm Harrington's (1936b) findings that plot yields do not always correlate with seedling frost damage notes.

The yield potential of barley was reduced as seeding dates were delayed. Delayed seeding reduced the number of days to heading, the number of ripe heads per plant and tillers per plant, but increased the 1000-kernel weight. Similar results have also been obtained by Anderson and Hennig (1964). However, in the present study, the yield potential of seedlings from early seeding dates subjected to stress had a greater chance to recover from that stress than those stressed at the same stage of development later in the spring season. Soil moisture appears to have an effect on seedling survival (Platt 1937a) and temperature and photoperiod are known to have a large effect on influencing the yield potential of barley cultivars (Faris and Guitard 1969; Briggs and Faris 1973). Undoubtedly all these factors played some role in the plant's ability to recover from the freezing or clipping stress.

There were no significant differences in the percent yield reduction between all three cultivars subjected to the frost, but the influence of frost on the number of plants surviving the stress differed for each cultivar. Although all cultivars were stressed at the two-leaf stage, the rate at which each cultivar develops may explain why Olli had the largest reduction in stand due to frost and Galt had the smallest. Olli is the earliest maturing cultivar and the most rapid growing and it was in a late two-leaf stage while Galt was in an early two leaf stage during the frost and/or clipping treatment. Peltier and Kiesselbach (1934) pointed out that cereal seedlings are most susceptible to frost injury at the two- or three-leaf stages because these stages coincide with the exhaustion of the seed endosperm and come before there is a buildup of plant dry matter. It is possible that the more rapid growth of early maturing cultivars, as shown by the height at 2 and 4 wk after treatment, may reduce the potential to recover from stress and result in reduced resistance to frost in the seedling stage.

It is interesting that clipping the total leaf area did not reduce yield significantly more than when 49–68% of the leaves were damaged by frost. In general, clipping had a greater effect on reducing the growth and development of the plants than freezing as indicated by the reduced height at 2 and 4 wk following treatment and with the increased time to heading and maturity. Furthermore, clipping consistently resulted in fewer tillers and heads per plant than freezing.

The frost also affected some yield components. In Olli, the frost tended to have less effect on the number of ripe heads and tillers per plant, but there was a larger increase in seed weight and reduction in stand in Olli than in the frosted Galt and Atlas cultivars. The reduced yield from the frost and clipping treatment in both Galt and Atlas appear to be more closely associated with the reduced number of heads per plant. However, the reduced stand may also have had some additional affect on the reduced yield in Atlas.

We conclude that the late-maturing cultivar Galt has more leaf frost resistance than the early maturing cultivars Olli or Atlas. When frosted to −5.6°C in the two-leaf stage, the yield potential of all three cultivars is reduced equally by an average of 13.8%. Delaying the seeding from 28 April to 21 May resulted in an 8.6% reduction in yield. Frost reduced the yield of early seeded cultivars by 9.8% and late-seeded cultivars by 17.1%. The limited data suggests that some components of yield within cultivars responded differently to the frost stress suggesting that considerable yield compensation seems to have occurred. However, additional work is clearly necessary to elucidate the effect of low temperature stress on the components of yield.

ACKNOWLEDGMENTS

The authors wish to express their appreciation to Gordon McLean, Larry Kerr and Lorne

Johnson for their valuable assistance during the course of this study.

ANDERSON, C. H. and HENNIG, A. M. F. 1964. The effect of date of seeding and fertility level on the yield of wheat, oats and barley in northwestern Alberta. Can. J. Plant Sci. **44**: 15-20.

BRIGGS, K. G. and FARIS, D. G. 1973. Performance of spring wheat and barley cultivars sown in the fall and spring in northern Alberta. Can. J. Plant Sci. **53**: 743-747.

DANTUMA, G. and ANDREWS, J. E. 1960. Differential response of certain barley and wheat varieties to hardening and freezing during sprouting. Can. J. Bot. **38**: 133-151.

FARIS, D. G. and GUITARD, A. A. 1969. Yield and primary culm yield components of two spring barley cultivars as influenced by temperature, daylength and growth stage. Can. J. Plant Sci. **49**: 701-713.

HARRINGTON, J. B. 1936a. Varietal resistance of small grains to spring frost injury. J. Am. Soc. Agron. **28**: 374-388.

HARRINGTON, J. B. 1936b. The effect of a spring frost on yields of spring sown grain. Sci. Agric. **16**: 538-548.

IVANOV, S. M. 1935. The response of spring crops to spring frosts. Bull. Appl. Bot. Gen. Plant Breed. Ser. **3**: 199-220. 1935. (Russian with English Summary.)

JOHNSTON, W. H., WELLS, S. A. and KUSCH, A. G. 1949. Reaction of barley varieties to spring frost. Sci. Agric. **29**: 60-68.

PELTIER, G. L. and KIESSELBACH, T. A. 1934. The comparative cold resistance of spring small grains. J. Am. Soc. Agron. **26**: 681-687.

PLATT, A. W. 1937a. The effect of freezing temperatures and of defoliation on the subsequent growth of wheat plants. Sci. Agric. **17**: 429-430.

PLATT, A. W. 1937b. The effect of soil moisture, hardening, endosperm condition and variety on the frost reaction of wheat, oat and barley seedlings. Sci. Agric. **17**: 616-626.

REID, W. S., HARRIS, R. E. and MCKENZIE, J. S. 1976. A portable freezing cabinet for cold-stressing plants growing in the field. Can. J. Plant Sci. **56**: 623-625.

STATISTICS CANADA 1951. Census of Agriculture. Ottawa, Ontario.

STATISTICS CANADA 1980. Handbook on agriculture statistics. Ottawa, Ontario.