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Frost Seeding Increases Spring Cereal Yield

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Abstract

Short growing season and mid-summer heat and drought are limiting factors for spring cereal production in Canada, suggesting that higher and more stable yields may be possible if seeding date occurred earlier in the spring. Field trials were conducted in southern Ontario, Canada, in 2003 and 2004 to compare development and yield potential of frost (early April) and conventional (late April – early May) seeded hard red spring wheat (*Triticum aestivum* L.), spring barley (*Hordeum vulgare* L.), and oat (*Avena sativa* L.) established using commercially available no-till planting equipment. Frost seeding had lower plant populations than conventional seeding with pre-tillering plant population reductions for frost seeding averaging 44 pl m⁻² (12%) for wheat and 27 pl m⁻² (10%) for oats. In spite of lower plant population, frost seeding yields were higher than conventional seeding with yield increases averaging 0.66 Mg ha⁻¹ (24%) for wheat, 0.72 Mg ha⁻¹ (20%) for oats, and 0.36 Mg ha⁻¹ (11%-2004 only) for barley. Frost seeded cereals had earlier occurrence of key phenological stages with average heading dates for frost seeded wheat and barley occurring 5d earlier. Frost seeded cereals also had a

longer vegetative period, which along with earlier heading dates, contributed to increased yields for frost seeded cereals.

Key words: Spring wheat, spring barley, oat, frost seeding, planting date

Introduction

Canada is one of the main producers of wheat, barley and oat in the world. In 2013, 29.3 million tonnes of wheat, 7.1 million tonnes of barley, and 2.9 million tonnes of oats were produced in Canada (Statistics Canada, 2014). In Canada, like many other spring cereal producing regions of the world, one of the most important agronomic factors that determines yield is planting date (McLeod et al., 1992; Chen et al., 2003). Reduced yields resulting from delayed planting are associated with reductions in tiller number, shorter grain filling periods (Lanning et al., 2012), and increased occurrence of heat stress and drought stress during key phenological stages (He et al., 2012). Crop management techniques that enable earlier planting could impact yield and other agronomic traits.

Early planting of spring cereals, in many parts of Canada, is constrained by soil moisture content during April and May (Bootsma and De Jong, 1988). Wet soil conditions due to snow accumulation, duration of winter thaw, and cool spring temperatures constraining soil drying rate can restrict the use of tillage and planting machinery in the field, thus delay seeding time. Spring planting is traditionally determined by the time required for the soil to freely drain to the plastic limit such that the soil is friable and resists compaction when undergoing tillage and planting operations. The time required for fine textured soils, in particular, to dry to this “friable soil” level can cause significant planting delays of spring cereals (Fallow et al., 2007).

Frost seeding is a crop management technique where spring cereals are planted early in the spring into a stale seedbed or no-till soil with a frost layer capable of supporting planting

equipment. Frost seeding is a technique that could overcome the seeding delays associated with excessive soil moisture. Yield advantages associated with early spring or frost seeding have been reported for canola (*Brassica napus* L.) (Kirkland and Johnson, 2000) and grass-legume mixtures (Gettle et al., 1996). Frost seeding wheat and barley has also been previously shown to increase yield (Stoskopf et al. 1968), however, yield increases were not consistent due to stand injury from subsequent frost damage to exposed seedlings resulting from seed being broadcast using a cyclone seeder onto a bare, frozen soil. Yield advantages of frost seeding could be more consistently realized if conducted using commercial no-till planter equipment currently available. Commercial no-till equipment, currently used for planting spring cereals on conventional spring seeding dates into friable soil, is capable of penetrating a 2-4 cm layer of frost and could improve stability of response to frost seeding.

The main objective of this study was to evaluate the effects of frost seeding using commercially available no-till planting equipment on establishment, development and yield of hard red spring wheat, spring barley and oat compared to conventional spring seeding. It was hypothesized that frost seeded spring cereals would have earlier emergence and heading dates which would result in increased yield potential when compared to conventionally seeded spring cereals. Wheat, barley and oat were included in the study as they are commonly grown spring cereals in temperate regions, where often spring planting date is delayed by excessive soil moisture.

Materials and Methods

Site Description and Experimental Design

The experiment was conducted over two production years (2003-2004) at five different trial locations in southern Ontario, Canada. The five trial locations were located within 15 km of the

University of Guelph Elora Research Station, (43°39' N, 80°25'W, 376 m above mean sea level). Daily maximum air temperature and daily precipitation during 2003 and 2004 growing seasons (Apr. – Aug.) were measured at the Elora Research Station. Soil and cropping history for each trial location are summarized in Table 1.

Seeding date (frost and conventional) response for multiple cultivars of 3 cereal species (hard red spring wheat, spring barley and oats) were evaluated at each of the five trial locations. Each trial location had 3 separate experiments located next to each other that evaluated cereal species seeding date and cultivar responses. Species were not randomized within the trial location as a whole but rather were in 3 side by side trial blocks.

The experimental design for each cereal species at each trial location was a randomized block split-plot with 3 replications. The split-plot dimensions were 3m by 30m. The whole-plot factor was cultivar which were Celtic (Thompsons LTD.), Quantum (C & M Seeds), AC Taho (C & M Seeds) and 606 (C & M Seeds) for the wheat trials; OAC Baxter (University of Guelph) and AC Parkhill (Secan Association) for the barley trials and OAC Paisley (Secan Association) and Manotick (Agriculture and Agri-Food Canada) for the oat trials.

The split-plot factor was seeding date, frost or conventional. Frost seeding dates for each site occurred when fields were free from snow and when freezing temperatures resulted in a 2-4 cm frozen soil surface layer. Conventional seeding occurred when soils were sufficiently dry to support typical seeding operations. Actual seeding dates and air temperature for the frost seeding date are summarized in Table 1.

Plant Establishment

Spring cereals were seeded using a John Deere 750 no-till drill (John Deere Ltd., Moline IL, USA) in 0.19 m wide rows. The target seeding rates were 4.25, 3.75 and 3.25 million seeds ha⁻¹ for wheat, barley, and oats respectively.

Urea was top-dressed applied at a rate of 70 kg N ha⁻¹. At each trial location, urea was applied on the same date for both seeding date treatments and all three cereal crops. Urea application occurred in mid-May to early June, which corresponds with recommended N application practices for conventional spring seeding in Ontario.

Weed control consisted of Post emergent application of bromoxynil-MCPA for wheat and barley and bromoxynil for oats. These herbicides were applied at the various locations on the same date for both seeding treatments in mid-May.

Data Collection

Plant population was calculated by counting the number of plants from 2 randomly selected 1 m length of rows per plot when cereals were at the pre-tillering stage. The date of 50% heading was determined for each plot by daily monitoring each plot until 50% of plants had headed. Final plant height was measured for each plot after stem elongation was completed.

Yield and grain moisture measurements for each plot were taken using a R42 Gleaner combine equipped with a high capacity grain gauge (Juniper systems Inc.). Frost and conventional seeded cereals were harvested on the same date. Final grain yield was adjusted to a moisture content of 145 g-H₂O kg-grain⁻¹.

Statistical Analysis

Plant population, final height, 50% heading date, yield, and harvest grain moisture data was initially analyzed for each crop species using an analysis of variance appropriate for a randomized complete block split-plot design combined over trial locations using the GLIMMIX

procedure of SAS ver. 9.3 (SAS Institute, Cary, NC). Fixed effects were cultivars, seeding date and their interaction. Random effects were trial location and location interactions with the various fixed effects and/or blocks (replicates). Significance of fixed effect by location interactions and heterogeneity of residual error variance across locations were determined using ratio likelihood tests. Residuals were evaluated for outliers and the need for data transformation. Harvest grain moisture was analyzed using log transformed data. Unless otherwise stated, any discussed fixed or random effects are significant at $P=0.05$. Similarly, unless otherwise stated any treatment mean differences are based on a protected t-test at $P=0.05$.

A combined analysis that included crop species was also conducted to determine if yield response to seeding date differed among species. The fixed effects for this combined analysis were species, cultivar nested in species, seeding date, seeding date by species and seeding date by cultivar nested in species. The random effects were trial, species nested in trial, seeding date nested in species and trial, cultivar nested in species and trial, cultivar by seeding date nested in species and trial, block nested in species and trial as well as block by cultivar nested in species and trial. All tests of fixed and random effects described earlier for the individual species analyses were also applied to this combined over species analysis.

Results

The combined analysis over species for grain yield had significant seeding date by species ($P=0.04$) and seeding date by cultivars within species ($P=0.05$) interactions; so wheat, oat and barley responses to seeding date are presented and discussed by species.

Effect of Frost Seeding on Wheat

Seeding date by cultivar interactions were not significant for wheat yield, population, heading date, final height and harvest moisture (Table 2). This suggests that wheat response to seeding date was similar across wheat cultivars; at least for the 4 cultivars included in this study.

Frost seeding wheat increased yield, averaged across cultivars and locations, by 0.66 Mg ha⁻¹ (24%) compared to where wheat was seeded conventionally (Table 3). These higher yields occurred even though plant population averaged 44 pl m⁻² (12%) lower when frost seeded. The wheat yield increase associated with frost seeding varied across locations (Table 2), ranging between 0.33 to 1.07 Mg ha⁻¹ (by location data not shown). Similarly, population reductions associated with frost seeding varied across locations ranging from essentially 0 to 76 pl m⁻² (by location data not shown). Frost seeding plant population were in the recommended target plant populations for spring wheat of 300-400 pl m⁻² (OMAFRA, 2016).

The four wheat cultivars evaluated produced similar yields when averaged across locations and seeding dates (Tables 2 & 3). Wheat cultivar Quantum had plant populations that averaged 55 pl m⁻² less than the other 3 cultivars (Table 3). The seeding date by cultivar interaction was not significant (Table 2), so lower population for Quantum was not due to larger population reductions when frost seeded compared to the other 3 cultivars.

Heading occurred 5 d earlier for frost seeded wheat (Table 3). The difference between frost and conventionally seeded heading dates for wheat varied across locations (Table 2), with frost seeding heading dates ranging from 3 to 7 d earlier than conventional seeding (by location data not shown).

Wheat cultivar also affected heading date (Table 2) with 606 heading 3 d later than the other 3 cultivars (Table 3). Significant variation in heading date for cultivars across locations

(Table 2) can partially be attributed to later heading for 606 at some locations (by location data not shown).

Final wheat height was similar for both seeding dates (Table 2 and 3). Slight variation in wheat height response to seeding date across locations did occur (Table 2); with frost seeded wheat heights ranging from 0 to 7 cm taller than when conventionally seeded (by location data not shown).

Final plant height did differ among wheat cultivars (Table 2) with an average 17 cm difference between the shortest and tallest cultivars (Table 3). Cultivar variation in plant height at the various locations (Table 2) is primarily one of magnitude where the difference between the tallest and shortest cultivars ranged from 11 to 24 cm (by location data not shown).

Harvest grain moisture averaged $24 \text{ g-H}_2\text{O kg-grain}^{-1}$ ($P=0.06$) lower when frost seeded (Table 3). Seeding date effects on harvest moisture varied across locations (Table 2) with frost seeding always having lower harvest moisture than conventional seeding with location specific differences ranging from 3 to $71 \text{ g-H}_2\text{O kg-grain}^{-1}$ (by location data not shown). Slightly lower frost seeded wheat harvest moisture can be attributed to earlier heading dates associated with frost seeding.

Effect of Frost Seeding on Oats

Seeding date by oat cultivar interactions for population, heading date, final height and harvest grain moisture were not significant (Table 2) indicating that the 2 oat cultivars evaluated had similar responses to seeding date for all measured parameters except yield.

The magnitude of yield response to frost seeding varied among oat cultivars (Table 2) with the yield increase associated with frost seeding for OAC Paisley that was 0.50 Mg ha^{-1}

¹ ($se=0.107$, $P=0.001$) greater than for Manotick (data not shown). Oat yield increases associated

with frost seeding varied across locations (Table 2), ranging from 0.26 to 1.39 Mg ha⁻¹ (by location data not shown).

Manotick yields were 1.15 Mg ha⁻¹ higher than OAC Paisley (Table 3). The yield difference between the 2 cultivars varied across locations (Table 2) with Manotick yields ranging from 0.53 to 1.97 Mg ha⁻¹ higher than OAC Paisley (by location data not shown).

The variation in seeding date and cultivar yield response across locations for oats was always of magnitude where Manotick always yielded higher than OAC Paisley and frost seeding always was associated with higher yields than conventional seeding.

Frost seeding resulted in oat plant populations that averaged 27 pl m⁻² (10%) less than conventional seeding (Table 2 and 3). Manotick had average populations that were 55 pl m⁻² lower than OAC Paisley (Table 3). Interactions between seeding date and cultivar with locations were not significant (Table 2) indicating that seeding date effects on population were similar over locations for the 2 cultivars evaluated. Frost seeding plant population were in the recommended target plant populations for oat of 200-300 pl m⁻² (OMAFRA, 2016).

Seeding date did not affect heading date (Table 2). However, seeding date effects varied across locations (Table 2) with frost seeding having heading dates that were 0 to 5 days earlier than conventional seeding (by location data not shown). Frost seeded oats was slightly taller, averaging 7 cm taller than when seeded conventionally (Table 3). Cultivar and location interactions with seeding date were not significant (Table 2).

Harvest moisture was not affected by cultivar or seeding date (Table 2).

Effect of Frost Seeding on Barley

Seeding date by barley cultivar interactions were not significant (Table 2) indicating that yield, population, heading date, final plant height and harvest grain moisture response to seeding date were similar for the 2 barley cultivars evaluated.

Averaged over locations barley yields were not increased by frost seeding (Tables 2 and 3). However, barley yield response to frost seeding was not consistent over locations (Table 2). Frost seeding reduced barley yield by 0.29 Mg ha^{-1} ($\text{se}=0.091$, $P=0.03$) (8%) at the 2003 locations and increased yield by 0.36 Mg ha^{-1} ($\text{se}=0.095$, $P=0.02$) (11%) at the 2004 locations (by location data not shown). The reasons for different yield response to seeding date at the 2003 and 2004 locations are not known.

Frost seeded barley headed 5 d earlier than conventionally seeded barley (Table 3). Earliness of heading for frost, compared to conventionally seeded barley varied across locations (Table 2); with frost seeded barley heading dates across locations ranging from 3 to 7 d earlier than conventionally seeded barley (by location data not shown).

Seeding date did not affect barley plant population, final height or harvest moisture at $P=0.05$ (Tables 2 and 3). Barley plant population reduction for frost seeding, relative to conventional seeding, averaged 36 pl m^{-2} (12%, $P=0.16$) (Table 3). This plant stand reduction associated with barley frost seeding was similar to frost seeded plant population reductions observed for both wheat and oats (Table 3). Frost seeding plant population were in the recommended target plant populations for barley of $250\text{--}350 \text{ pl m}^{-2}$ (OMAFRA, 2016).

OAC Baxter yields averaged 0.28 Mg ha^{-1} ($P=0.06$) higher and averaged 17 cm taller than AC Parkhill (Tables 2 and 3). Barley cultivar height differences varied across locations (Table 2). OAC Baxter was always taller than AC Parkhill with differences varying from 13 to 22 cm

across locations (by location data not shown). Barley cultivars evaluated had similar heading dates and harvest grain moisture (Table 2).

Discussion

Yield Benefit of Frost Seeding

Consistently, across all five locations, wheat and oat yield was increased by frost seeding compared to conventional spring seeding. For barley, frost seeding increased yield at the two 2004 locations.

One of the factors determining the yield benefit of the frost seeding is early heading, which enables avoidance of extreme growing conditions (heat and drought stress), especially during the reproductive stage. In spring cereals photoperiod (day length) is often considered a main mechanism controlling the transition phase from vegetative to reproductive in most cereals (Mahfoozi et al., 2000; Saisho et al., 2011), however, thermal accumulation requirements can also influence heading date (Miller et al., 2001). In the current study, frost seeding had heading dates that averaged 5 d earlier for wheat and barley (range 3 to 7 d) compared to spring conventional seeding (Table 3). This suggests that it is not simply a photoperiod effect but may also be due to thermal accumulation. Earlier heading associated with the frost seeding is probably due to earlier completion of thermal heat requirements when compared to the conventionally seeded cereals.

Heat and moisture stress during the heading stage directly affect flowering, seed set, final yield, and quality of grain in spring cereals (Ferris et al., 1998; Gibson and Paulsen, 1999; Altenbach et al., 2003; Barnabás et al., 2008; Hossain et al., 2012). Therefore, early flowering is one of the possible approaches to avoiding extreme growing conditions, increase water use efficiency, and improving yield in temperate cereals (Richards et al., 2002). Early planting

facilitates early flowering, which helps to avoid drought and high temperatures that prevail during July especially in Ontario. Heading date for the frost seeded cereals generally occurred in the last week of June, while the conventionally seeded cereals started to head in the first week of July. Maximum daily air temperature in the last week of June was 1.0 and 3.6 °C cooler than the first week of July in 2003 and 2004 respectively (Environment and Natural Resources, 2003/04). Therefore, frost seeding had an advantage of lower negative effect of high temperature during the reproductive stage compared to conventional seeding.

Frost seeding may also reduce moisture stress through alterations in root:shoot ratio. Exposure of plants to low temperatures increases the root: shoot ratio in spring cereals (Equiza et al., 2001). Earlier planting dates associated with frost seeding will increase cereal plant exposure to cooler temperatures which may increase root mass and thereby minimize risk of moisture stress.

In the current study, frost seeding was completed 2-4 weeks earlier than conventional spring seeding (Table 1). It was observed that at the time of conventional spring seeding, the frost seeding plants were typically at the 2–4 leaf stage. Frost seeding was associated with a longer vegetative period, which can influence yield parameters such as total number of leaves, , and leaf area, and spike bearing tiller number (Mid-more *et al.*, 1984; Acevedo et al., 2002) ,. Future studies on frost seeding should explore these yield parameters to determine if they explain variable response to frost seeding across wheat, oats and barley.

Frost Seeding Reduces Plant Density

Photosynthetic active radiation (PAR) interception, aboveground biomass, and grain yield generally increase asymptotically with seeding rate and plant density (Gooding et al., 2002). Plant density at early vegetative growth was higher under the conventional spring seeding

compared to the frost seeding for all three species (Table 3). The number of days required for seed germination and seedling emergence is determined by thermal accumulation. Following frost seeding, soil is typically colder and wetter than soil following conventional spring seeding due to lower seasonal temperatures and reduced evaporative drying of soil. In the present study, seeding rate was the same for the frost seeding and conventional spring seeding treatments. Low plant count under the frost seeding treatment was probably due to higher seed mortality, germination and/or emergence failure, resulting from an extended germination and emergence period due to low temperatures.

Irrespective of lower plant density, frost seeding still achieved higher grain yield for the three spring cereals compared to conventional spring seeding (Table 3). One of the main yield parameters of wheat is the number of fertile tillers per plant (Duggan et al., 2000). Low plant densities facilitate higher tiller numbers (Sanderson and Reed, 2000), delay in senescence, and increase the assimilate supply for grain filling (Wang et al., 1997), which agree with our findings of high wheat yield under low plant counts when frost seeded.

Frost Seeding Enables Early Harvest

To avoid confounding yield estimates with harvest date, at each location both frost seeding and conventional seeding date treatments were harvested on the same day. In a commercial setting a farmer may choose to harvest the frost seeding treatments earlier. The possibility for early harvest is supported by observations of heading date and grain moisture content, which are both indicators of relative maturity. Heading dates of frost seeded wheat, oats and barley all occurred earlier than conventional seeding date. For wheat heading date was advanced by upto one week. Similarly frost seeding was observed to reduce grain moisture content of wheat and oats. The methodology used for harvesting tends to underestimate harvest moisture differences

and result in some occurrences of location interactions. Frost seeding and conventional seeding treatments were harvested on the same date, since it was not logistically possible to target a harvest date for each location that maximized grain moisture differences. The tendency for all species to have lower grain moisture content at harvest is consistent with the observation of early heading date with the frost seeding treatment.

Frost seeding enables an earlier harvest date than conventional seeding date. This has potential agronomic advantages such as a longer post-harvest niche for growing cover crops. Frost seeding could also enable a longer infield dry-down period prior to harvest; thereby enabling lower moisture content at harvest and/or reduced grain drying costs. Grain moisture at harvest is a key factor determining storage life and quality of the grain (Jayas and White, 2003; Magan and Aldred, 2007). Low grain moisture content at harvesting provides many advantages; reduce drying period, minimize cost involved in drying, low spoilage and minimize production of mycotoxins (Jayas and White, 2003; Magan and Aldred, 2007).

Conclusion

In the present study frost seeding enabled spring cereals to be planted 2-4 weeks earlier than a conventional spring seeding method that requires friable soil. Earlier planting dates using frost seeding has a significant yield advantage for wheat, barley, and oat compared to a conventional spring seeding date, with the yield advantage appearing to be more consistent and pronounced for wheat and oat. The yield advantage of frost seeding is, in part, derived from a longer vegetative period, as well as earlier heading dates which reduce the risk of yield reductions due to adverse weather conditions during the reproductive stage. Other potential agronomic benefits that frost seeding may provide to the system need to be evaluated. These include enhanced cover crop opportunities arising from earlier harvest date. Finally, in the

present study frost seeding was compared to conventional spring seeding using management practices typical for conventional spring seeded spring cereals. Larger frost seeded cereal yields may be possible if management practices such as seeding rate, nitrogen rate, weed control timing are specifically tailored for frost seeded spring cereal production systems.

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Table 1. Previous crop history, soil type, air temperature at frost seeding, and seeding dates for the five trial locations that evaluated spring cereal response to seeding date in southern Ontario, Canada (2003-2004).

Location	Year	Previous crop	Soil type	Air temperature at frost seeding (°C)	Frost seeding date	Conventional seeding date	Time gap between seeding treatments (d)
2003-1	2003	Soybean	Loam	-5 to -8 °C	1-Apr-03	30-Apr-03	29
2003-2	2003	Soybean	Loam	0 to -1 °C	11-Apr-03	30-Apr-03	19
2003-3	2003	Soybean	Sandy Loam	-3 to -4 °C	17-Apr-03	8-May-03	21
2004-1	2004	Alfalfa	Clay Loam	-1 to -2 °C	12-Apr-04	28-Apr-04	16
2004-5	2004	Alfalfa	Loam	-2 to -3 °C	08-Apr-04	28-Apr-04	16 (Wheat)
				0 °C	12-Apr-04	28-Apr-04	20 (Oat/Barley)

Table 2. Summary of fixed effect F-tests (seeding date, wheat cultivar), likelihood ratio chi-square tests of random effects (location, location by fixed effect interactions) for four hard red spring wheat cultivars, two oat cultivars, and two barley cultivars that were frost and conventionally seeded at five locations in southern Ontario, Canada (2003-2004).

Crop	Effect	Yield	Population	Heading Date	Final Height	Harvest ^a Moisture
Wheat	Fixed					
	Cultivar (C)	2.57*	8.67***	5.21**	20.75***	5.63**
	Seeding Date (SD)	18.93**	7.64**	26.67***	3.74	7.02*
	C*SD	2.65	0.11	1.42	0.39	0.81
	Random					
	Location (L)	4.49**	0.08	1.40	5.98***	5.50**
	C*L	2.32	0.25	4.88**	5.48***	1.86
	SD*L	11.45***	4.59**	8.47***	3.68**	14.20***
	C*SD*L	2.51	-	4.42**	2.63**	-
	L Residual	42.79***	3.20	29.62***	8.66*	29.41***
	Homogeneity					

30	Oats	Fixed					
31		Cultivar (C)	17.94**	11.08**	4.85*	2.78	0.70
32		Seeding Date (SD)	9.48**	5.86**	3.64	5.64**	0.54
33		C*SD	22.12***	0.11	0.23	0.11	0.19
34		Random					
35		Location (L)	0.89	0.03	0.08	-	0.66
36		C*L	6.27**	1.01	3.35*	1.13	0.47
37		SD*L	5.36**	-	6.92***	1.27	3.37*
38		C*SD*L	-	-	-	-	2.81*
39		L Residual	29.48***	5.17	n.a.	6.27	9.49**
40		Homogeneity					
41	Barley	Fixed					
42		Cultivar (C)	6.30*	2.11	0.93	45.09***	2.49
43		Seeding Date (SD)	0.02	2.90	21.60***	0.00	1.23
44		C*SD	0.27	0.27	0.75	0.13	0.47
45		Random					

46	Location (L)	5.35**	0.06	6.92***	2.64*	4.97**
47	C*L	1.28	0.08	2.27	3.85**	-
48	SD*L	4.19**	2.05	3.57*	-	1.31
49	C*SD*L	0.02	-	-	-	-
50	L Residual	3.88	2.30	n.a.	1.63	26.73***
51	Homogeneity					

^a Harvest grain moisture analysis was performed using log transformed data.

***, ***, ** indicate F tests and LRT chi-square tests significant at P=0.1, 0.05 and 0.01, respectively.

Table 3. Grain yield, plant population, heading date, final plant height and harvest grain moisture response of four hard red spring wheat cultivars, 2 oat cultivars, and 2 barley cultivars either frost or conventionally seeded at five locations in southern Ontario, Canada (2003-2004).

Treatment ^a	Yield (Mg ha ⁻¹ d)	Population (pl m ⁻²)	Heading Date (day of year)	Final Height (cm)	Harvest ^b Moisture (g-H ₂ O kg-grain ⁻¹)
Wheat Cultivar					
606	2.93	351 a	181 a	83 c	183 a
Celtic	3.05	352 a	177 b	87 c	166 bc
Quantum	3.28	294 b	178 b	93 b	179 ab
AC Taho	3.09	345 a	178 b	100 a	164 c
se	0.26	16.1	1.1	3.7	1.7
Wheat Seeding Date					
Frost	3.42 a	313 b	176 b	92	161
Conventional	2.76 b	357 a	181 a	89	185
se	0.26	16	1	3.6	1.7
Oat Cultivar					

71	Manotick	4.57 a	231 b	181	107	96
72	OAC Paisley	3.42 b	286 a	182	102	91
73	se	0.294	15	0.8	2.2	1.4
74	Oat Seeding Date					
75	Frost	4.35 a	245 b	181	108 a	90
76	Conventional	3.64 b	272 a	183	101 b	96
77	se	0.285	13.8	0.9	2.2	1.5
78	Barley Cultivar					
79	OAC Baxter	3.58	274	180	95 a	113
80	Parkhill	3.3	296	181	78 b	119
81	se	0.356	15.8	2.2	3.5	1.4
82	Barley Seeding Date					
83	Frost	3.42	267	178 b	86	114
84	Conventional	3.45	303	183 a	86	118
85	se	0.364	17.4	2.2	3.3	1.4

86 ^a Within column cultivar and seeding date means followed by the same letter, or no letters, are not different based on a protected T-
87 test at $P=0.05$.

88 ^b Harvest grain moisture analysis was performed using log transformed data. Harvest grain moisture values are back log transformed
89 harvest grain moisture means.

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