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Effect of nitrogen fertilization on seed-borne *Fusarium* species in oat

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Abstract: Fusarium head blight (FHB) is a common disease of oat and resistant cultivars are not available in Canada. The effect of nitrogen (N) fertilization on incidence of seed-borne *Fusarium* spp. was evaluated under natural field conditions in three locations (Ottawa, Ontario; Melfort, Saskatchewan; Normandin, Québec) in Canada in 2013 and 2014. At each site, oat cultivars, CDC Morrison, AAC Nicolas, and AAC Noranda, were used under four levels of N fertilization (0, 50, 100 and 150 kg N ha⁻¹). Of the seven *Fusarium* spp. recovered, *F. poae*, *F. equiseti*, *F. graminearum*, *F. sporotrichioides*, and *F. avenaceum* were the most common species, and isolated from 9.6, 1.3, 1.1, 1.0, and 0.3% of the harvested grain representing 72, 10, 8, 7, and 3% of the pathogen population, respectively. The remaining species including, *F. acuminatum* and *F. oxysporum*, were each recovered from a single seed only. A significant N treatment effect ($P<0.05$) was observed in four of the six location-years, in which the highest N treatment of 150 kg N ha⁻¹ resulted in greater incidence of the predominant species *F. poae* and total *Fusarium* spp. than the untreated control (0 kg N ha⁻¹). Among the commonly recovered species, only seed-borne infection by *F. graminearum* increased significantly with the levels of N treatments applied. A highly significant effect of location, year and location x year interaction ($P<0.01$) was observed, suggesting that the field and weather conditions have a stronger influence on incidence of seed-borne *Fusarium* spp. than the N treatments.

Key words: Fusarium head blight, oat, *Avena sativa* L., *Fusarium* spp., N fertilization

Résumé: La fusariose de l'épi (FHB) est une maladie fréquente chez l'avoine mais les cultivars résistants ne sont pas disponibles au Canada. L'effet de la fertilisation azotée (N)

sur les incidences de *Fusarium* spp. a été évaluée sous des conditions naturelles à trois sites (Ottawa, Ontario; Melfort, Saskatchewan; Normandin, Québec) au Canada en 2013 et 2014. A chaque site, les cultivars d'avoine, CDC Morrison, AAC Nicolas et AAC Noranda ont été traités avec quatre niveaux de fertilisation azotée (0, 50, 100 et 150 kg N ha⁻¹). Parmi les sept *Fusarium* spp. récupérés, les espèces de *F. poae*, de *F. equiseti*, de *F. graminearum*, de *F. sporotrichioides* et de *F. avenaceum* ont été isolées sur 9.6, 1.3, 1.1, 1.0 et 0.3% du grain récolté représentant 72, 10, 8, 7 et 3% de la population pathogène, respectivement. Les autres espèces, *F. acuminatum* et *F. oxysporum*, ont été recueillies chacune à partir d'un seul grain. Un effet significatif du traitement N ($P < 0.05$) a été observé à quatre des six sites-années, où les traitements N de 150 kg N ha⁻¹ ont entraîné une plus grande incidence des espèces *F. poae* et *Fusarium* spp. total que le contrôle non traité à trois années- site. Parmi les espèces couramment récupérées, seule l'infection transmise par les graines par *F. graminearum* a augmenté de façon significative avec les niveaux de N. Un effet très significatif de site, de l'année et l'interaction de site x année ($P < 0.01$) a été observé, ce qui suggère que le champ et les conditions météorologiques ont une influence plus forte sur l'incidence de *Fusarium* spp. sur les semences que celle des traitements N.

Mots clés: fusariose de l'épi, avoine, *Avena sativa* L., *Fusarium* spp., fertilisation N

Abbreviations: FHB, Fusarium head blight; N, Nitrogen

Oat (*Avena sativa* L.) is a low input cereal crop widely grown around the world and used as food, feed or as a source of high value compounds with industrial applications (Tsopmo et al. 2010; Sobotka et al. 2012; Marshall et al. 2013). Oat, as a cultivated crop, was

introduced into North America in the 16th century (Coffman, 1977). In recent years, oat has been recognized as a health food, mainly due to its unique composition consisting of high levels of β -glucan, oil and antioxidants (Behall et al. 1997; Marshall et al. 2013). Diseases present a constraint to oat production in Canada, one of which is Fusarium head blight (FHB) (Tekauz et al. 2008; Xue and Chen, 2016).

Over the past 20 years, there has been an increase in the incidence of FHB on oat grown in the two main production regions of Canada: the Canadian prairies and the eastern provinces of Ontario and Québec (Couture et al. 1996; Tamburic-Ilincic, 2010; Tekauz et al. 2004; Xue et al. 2016). Seed harvested from these regions may contain *Fusarium*-infected kernels and seed-borne *Fusarium* spp. (Clear et al. 2000; Bourdages et al. 2006; Xue et al. 2016). In addition, the various *Fusarium* spp. that cause FHB produce mycotoxins in kernels, including deoxynivalenol, zearalenone, and HT-2, which are harmful to humans and livestock (Placinta et al. 1999; Bottalico and Perrone, 2002; Stenglein, 2009).

Host resistance has been considered the most practical and effective way to control FHB, even though there are no completely resistant oat cultivars available (Tekauz et al. 2008; Yan et al. 2010b; Mitchell Fetch et al. 2016). Various researchers have reported differences between susceptible and moderately resistant cultivars, the highest level of resistance being commercially available (Yan et al. 2010b; Mitchell Fetch et al. 2016). Knowing that highly resistant oat cultivars are not available, cultural practices such as crop rotation, tillage and the application of chemical fungicides have been employed by producers to control FHB (Tekauz et al. 2004; Dill-Macky and Van Sanford, 2016). However, there is no simple and effective control procedure to consistently and

economically manage FHB in cereal (Gilbert and Haber, 2013; Dill-Macky and Van Sanford, 2016), the effects of nitrogen fertilization on FHB have been examined (Lemmens et al. 2004; Ma et al. 2013). While it is believed that the appropriate use of N fertilization enhances plant growth and tolerance to diseases, recent studies on the effects of N fertilization on FHB produced conflicting results (Hofer et al. 2016). Martin et al. (1991) indicated that increasing N availability from 70 to 170 kg N ha⁻¹ significantly increased the incidence of *Fusarium*-infected grain in wheat, barley and triticale. Similarly, Lemmens et al. (2004) suggested that increasing N fertilizer, whether organic or mineral, significantly increased FHB disease intensity in wheat. However, Yang et al. (2010) and Hofer et al. (2016) reported that N fertilization reduced FHB severity and incidence of seed-borne infection by *Fusarium* spp. in barley. Meanwhile, Heier et al. (2005) and Krnjaja et al. (2015) could not detect any effect of N fertilization on FHB in winter wheat, suggesting that the effect of N on FHB remains unclear and more work is needed to better understand this issue. There have been no studies thus far to investigate the effects of N fertilization on FHB and seed-borne infection by *Fusarium* spp. in oat.

The objective of this study was to examine the effect of nitrogen level on incidence of seed-borne infection by various *Fusarium* spp. in oat under natural field conditions in the Canadian prairies and the eastern provinces of Ontario and Québec.

MATERIALS AND METHODS

Experimental Design and Field Management

Field experiments were carried out at three sites in Canada in 2013 and 2014: the Central Experimental Farm (lat. 45°22'N, long. 75°43'W) in Ottawa, Ontario, the Melfort Research

Farm (lat. 52°49'N, long. 104°36'W) in Melfort, Saskatchewan; and the Normandin Research Farm (lat. 48°51'N, long. 72°33'W) in Normandin, Québec. The soil types were sandy clay loam and sandy loam at Ottawa, silty clay and clay loam at Melfort, silty clay loam and clay loam at Normandin, for 2013 and 2014, respectively. These test sites are classified as belonging to a northern temperate climate at Ottawa, a prairie semi-arid climate at Melfort, and a boreal climate at Normandin. According to Yan et al. (2010a, 2011), the sites selected for this study belong to three different mega-environments of oat production in Canada. Residual N levels, including both $\text{NO}_3\text{-N}$ and $\text{NH}_4\text{-N}$, at the Ottawa site were 3.12 and 4.69 $\mu\text{g g}^{-1}$ for 2013 and 2014, respectively, based on soil testing prior to the experiment establishment each year. At Melfort site, residual $\text{NH}_4\text{-N}$ was not measured; the $\text{NO}_3\text{-N}$ levels in soil were 12 $\mu\text{g g}^{-1}$ in 2013 and 4 $\mu\text{g g}^{-1}$ in 2014. Soil residual N levels at Normandin were not measured.

Three oat cultivars, including two FHB susceptible varieties, CDC Morrison and AAC Noranda, and a moderately resistant variety, AAC Nicolas, were used in this study. Four levels of N fertilizer treatments, consisting of 0, 50, 100 and 150 kg N ha^{-1} as urea, were broadcasted and incorporated to 15 cm soils with a field cultivator one day prior to, or the same day of seeding. At each site, the experiment was arranged in a split-plot design with four N levels as the main plots and three oat cultivars as subplots, with three replicates for both 2013 and 2014.

Plot dimensions varied among sites. At Melfort and Normandin, plots consisted of 10 rows, 6 m long, with 0.18 m row spacing and 0.5 m between plots. At Ottawa, plots consisted of 12 rows, 5 m long, with 0.20 m row spacing and 0.5 m between plots. Plots were seeded at a rate of 300 seeds m^{-2} on May 9, May 21 and May 27, 2013, and on May

10, May 22 and May 24, 2014 at the Ottawa, Normandin, and Melfort sites respectively. Herbicide Bromoxynil/MCPA ester (280 g a.i. ha⁻¹/280 g a.i. ha⁻¹) was sprayed post emergence in June at Ottawa and Melfort for weed control, while at Normandin, Refine SG, i.e. thifensulfuron methyl/tribenuron methyl (10 g a.i. ha⁻¹/5 g a.i. ha⁻¹) was used. All other cropping practices were in accordance with the recommended management procedures in each province. All plots received adequate phosphorus (P) and potassium (K) fertilizers during soil preparation, according to soil test recommendations.

Plots were harvested using a small plot combine when the plants were physiologically mature during the first week of August at Ottawa and the third week of August at Melfort and Normandin. Grain was air dried at 13-17°C and a sample of approximately 500 g of seed was taken from each plot for the isolation of *Fusarium* spp. Seed samples were stored at 5°C for 3-6 weeks prior to isolation of *Fusarium* spp.

Isolation and Identification of Seed-borne *Fusarium* spp.

Approximately 3-6 weeks after harvest, a subsample of 100 seeds per plot was taken at random to determine the level of infection by *Fusarium* spp. The seeds were surface-disinfected for 1.5 min with 0.5% NaOCl, rinsed three times with sterile distilled water, and drained on sterile filter paper. Five seeds were placed in each of 20 Petri dishes containing modified potato dextrose agar (mPDA; 10 g dextrose per liter, which is 50% of the recommended rate of 20 g dextrose per liter) amended with 20 ppm streptomycin sulfate. Dishes were placed under a fluorescent light set of mixed UV light and artificial daylight, on a 12-h light/dark cycle for 7-14 days at 22-25°C. The mPDA medium was used to reduce mycelium growth and to increase spore production by *Fusarium* spp. (Xue et al.,

2015). *Fusarium* spp. were then identified directly from mPDA or, if necessary, sub-cultured on carnation leaf agar (CLA) for identification (Fisher et al. 1982). The fungi were identified by microscopic examination using taxonomic keys for *Fusarium* spp. described by Nelson et al. (1983) and illustrated morphological manuals by Samson et al. (2000).

Statistical Analysis

A square root transformation of the incidence of each *Fusarium* spp. was used in the analysis of variance to stabilize variance and to respect the assumption of homogeneity of model residuals (Snedecor and Cochran, 1980). Data were back-transformed to the original scale for presentation. An individual analysis of variance for each location-year and a combined analysis over the three locations and two years was conducted using the PROC MIXED models procedure in SAS version 9.3 (SAS Institute Inc., Cary, NC, USA) with locations, years and replications as random factors, and cultivars and N treatments as fixed effects. Treatment means were separated using Fisher's Least Significant Difference (LSD) test at a probability level of $P \leq 0.05$. To establish the relationship between seed-borne infection by *Fusarium* pathogens and N treatments, the means of replicates were plotted against the N treatment levels applied. A straight line was fitted through the points using simple linear regression. Linear regression analyses were performed using PROC REG in SAS.

RESULTS

A total of seven *Fusarium* spp. were recovered from 2,877 of the 21,600 seeds tested in 2013 and 2014 (Table 1). *Fusarium poae* (Peck) Wollenw. was the most common species,

recovered from 9.6% of the seeds tested, and represented 72% of the seed-borne *Fusarium* pathogen population. *Fusarium equiseti* (Corda) Sacc., *F. graminearum* Schwabe, *F. sporotrichioides* Sherb., and *F. avenaceum* (Corda: Fr.) Sacc., were less common, recovered from 1.3, 1.1, 1.0, and 0.3 % of seeds and represented 10, 8, 7 and 3% of the pathogen population, respectively. Other species, including *F. acuminatum* Ellis & Everhart and *Fusarium oxysporum* Schlecht., were each isolated from only a single seed at Melfort in 2013.

The analysis of variance indicated that year, location, and the year x location interaction had highly significant effects ($P < 0.01$) on incidence of the five common species and total *Fusarium* spp., with the exception that incidence of *F. avenaceum* and *F. equiseti* was not affected by year (Table 2). A significant nitrogen treatment effect was observed for *F. graminearum*, *F. poae*, and the total *Fusarium* spp. A significant oat cultivar effect was observed for *F. equiseti*, *F. graminearum*, *F. poae*, and total *Fusarium* spp. There was also a significant year x nitrogen interaction effect on incidences of *F. graminearum* and *F. poae*, a significant year x location x nitrogen interaction effect on incidence of *F. poae* and total *Fusarium* spp., and a significant year x nitrogen x cultivar interaction effect on *F. poae*. The interactions of nitrogen x cultivar, nitrogen x location, nitrogen x cultivar x location, and nitrogen x cultivar x location x year were not significant.

A significant N treatment effect ($P < 0.05$) was observed in four of the six location-years, in which the N treatments of 150 kg N ha⁻¹ resulted in greater incidence of the predominant species *F. poae* and total *Fusarium* spp. than the untreated control in three location-years (Table 3). There were no significant differences among the 50, 100, and 150 Kg N ha⁻¹ treatments for the five common species and the total *Fusarium* spp. except for *F.*

poae and the total *Fusarium* spp. at Melfort in 2013 and *F. graminearum* at Melfort and Normandin in 2014, in which the highest level of N treatment (150 Kg N ha⁻¹) resulted in significantly higher incidence than that of the treatment with 50 Kg N ha⁻¹.

Of the three cultivars, AAC Nicolas exhibited significantly lower incidence of *F. equiseti* and total *Fusarium* spp. in 2013 and lower incidence of *F. graminearum* and *F. sporotrichioides* in 2014 than CDC Morrison or AAC Noranda (Table 3). However, there were no significant differences among these cultivars for incidence of other species including *F. poae*, the predominant species recovered from the harvested grain in this study.

The five common species and total *Fusarium* spp. varied greatly ($P < 0.05$) in their frequency of recovery among the three locations each year and between the two years (Table 3). Significantly higher incidence of *F. avenaceum*, *F. equiseti*, *F. poae* and total *Fusarium* spp. were observed at Normandin than those at Melfort and Ottawa in 2013. A similar situation was observed at Melfort in 2014, except for *F. equiseti*. A significantly lower incidence of *F. graminearum* was found at Ottawa than at Melfort or Normandin in either 2013 or 2014.

A significantly positive linear relationship occurred between the percentage of seed infection by *F. graminearum* and N treatment levels applied in both 2013 and 2014 (Fig. 1). The relationships accounted for 39% of the variance in 2013 and 44% of the variance in 2014, which were significant at the $P \leq 0.05$ and $P \leq 0.01$ levels in 2013 and 2014, respectively. The linear relationship between percentages of seed infection by the other four common species, the total *Fusarium* spp. and N treatment levels applied in both years was not significant at $P \leq 0.05$.

DISCUSSION

Of the five common *Fusarium* spp. recovered from the naturally infected oat kernels, the predominant species, *F. poae*, and total *Fusarium* spp. had a higher frequency of recovery with the treatment of 150 kg N ha⁻¹ than with the untreated control in four of the six location-years (Table 3). The linear regression analysis further revealed that the percentage of seed-borne infection by *F. graminearum* increased significantly with the levels of N treatments applied (Fig. 1). These results were likely due to the fact that the N fertilizer increased plant growth and might have changed the microenvironment and delayed harvest, which in turn provided the pathogens with better growth conditions and more time to infect, spread and colonize kernels. These results are generally consistent with findings by Lemmens et al. (2004), Martin et al. (1991), and Subedi et al. (2007) in which N fertilizers were found to significantly affect FHB development and increase the occurrence of *Fusarium*-infected grains in small-grain cereals. Among the three oat cultivars used, AAC Nicolas exhibited a lower incidence of total *Fusarium* spp. compared to CDC Morrison and AAC Noranda (Tables 3). The varietal differences observed were similar to field reactions of these cultivars to FHB. AAC Nicolas is considered moderately resistant; while CDC Morrison and AAC Noranda are susceptible (Xue et al., unpublished).

Fusarium spp. infect cereal crops during flowering and grain fill periods (Gilbert and Tekauz, 2000). The higher recovery frequency for the total *Fusarium* spp. at each of the three locations in 2014 than in 2013 (Table 3) was likely due to differences between the two years in weather conditions in July and August, when plants were at the flowering and maturity stages of growth (Fig. 2). The higher canopy humidity, as a result of particular

rain events a few days before and after flowering have led higher canopy humidity, and in addition to relatively high temperatures in 2014, were more favourable for FHB development and seed infection with *Fusarium* spp. than in 2013. The differences in seed infection by *Fusarium* spp. among the three locations could also be related to the differences in soil and crop rotation systems employed at among sites. Few differences were observed among the N rates of 50 to 150 kg/ha (Table 3). This might be due to the possible existence of relatively high levels of residual N in the soil. For instance, the residual N levels, including both $\text{NO}_3\text{-N}$ and $\text{NH}_4\text{-N}$, at the Ottawa site were 3.12 and 4.69 $\mu\text{g g}^{-1}$ for 2013 and 2014, respectively, based on soil testing prior to the experiment establishment in each year. These residual N levels in the soil are relatively low but the rapid warm up of the soil after planting may have stimulated N mineralization and release from soil organic matter decomposition and helped the establishment and early growth. Melfort had $\text{NO}_3\text{-N}$ of 12 $\mu\text{g g}^{-1}$ in 2013 and 4 $\mu\text{g g}^{-1}$ in 2014. The residual $\text{NH}_4\text{-N}$ in soil at Melfort was not measured but the $\text{NO}_3\text{-N}$ of 12 $\mu\text{g g}^{-1}$ in 2013 was relatively high and adequate for oat production without additional N fertilization. Soil residual N levels at Normandin are not available. Different weather conditions could have also explained some of the variability between locations. Location and year seemed to affect the incidence of *Fusarium* spp. to a greater extent than the effect of N fertilization, based on the results of the analysis of variance (Table 2). These results suggest that environmental (weather, site, soil, preceding crops, etc.) conditions have a great impact on the incidence of seed infection, and proper N fertilization should only be used as part of a larger integrated management strategy for reducing seed infection by *Fusarium* spp. in Canadian oat production.

This study demonstrated that *F. poae* was the most common seed-borne *Fusarium* spp. affecting oat grown at the three test locations representing the three mega-environments of oat production in Canada (Table 1). *Fusarium poae* was isolated from 9.6% of the harvested grain and represented 72% of the pathogen population causing FHB. Meanwhile *F. graminearum*, the principal cause of FHB in wheat and barley in Canada (Gilbert and Tekauz, 2000; Xue et al. 2016), was isolated from only 1.1% of oat kernels and represented 8% of the pathogen population. Xue et al. (2016) and Mitchell Fetch et al. (2016) reported that *F. poae* was the most frequently isolated species from FHB infected oat grains in Ontario from 2008 to 2015 and in oat grains from western Canada in recent years. It has also been documented as a major *Fusarium* component causing FHB in Argentina, France, Hungary, Ireland, Poland, Slovakia, and the United Kingdom (Lukanowski and Sadowski, 2002; Ioos et al., 2004; Roháček & Hudec, 2005; Xu et al., 2005; González et al., 2008). Despite frequent encounters, little information is available concerning when and how *F. poae* infects oats and other small-grain cereals. Previous studies by Xue et al. (2004a, 2006) indicated that *F. poae* was moderately pathogenic on wheat and weakly pathogenic on barley in causing FHB, compared to the highly pathogenic species *F. graminearum*, *F. culmorum* (W.G. Smith) Sacc., and *F. crookwellense* Burgess, Nelson & Toussoun. However, *F. poae* is increasingly recognized as the most toxic species in the FHB complex (Stenglein, 2009; Stenglein et al., 2014; Vogelgsang, 2016). It produces an extensive range of mycotoxins including aurofusarin, beauvericin, butenolide, culmorin, cyclonerodiol, enniatins, fusarin, moniliformin, and certain trichothecenes associated with human and animal toxicoses (Stenglein, 2009; Dinolfo and Stenglein, 2014; Stenglein et al., 2014). Further studies investigating the pathological mechanisms of *F.*

poae and its impact on oat would facilitate future research and provide valuable information to predict and reduce the mycotoxins in harvested oat in Canada.

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Table 1. Frequency of *Fusarium* spp. isolated from harvested kernels of oat grown in Melfort, SK; Normandin, QC; and Ottawa, ON in 2013 and 2014.

<i>Fusarium</i> spp.	No. infected seeds ^a						Total infected seeds	Incidence (%)
	Melfort		Normandin		Ottawa			
	2013	2014	2013	2014	2013	2014		
<i>F. poae</i>	174	879	254	362	14	394	2077	9.6
<i>F. equiseti</i>	3	6	158	10	38	75	290	1.3
<i>F. graminearum</i>	10	77	10	95	0	31	223	1.1
<i>F. sporotrichioides</i>	8	13	16	60	13	101	211	1.0
<i>F. avenaceum</i>	1	58	7	4	0	2	72	0.3
<i>F. acuminatum</i>	1	0	0	0	0	0	1	0.0
<i>F. oxysporum</i>	1	0	0	0	0	0	1	0.0
Total	200	1033	445	531	65	603	2877	13.3

^aNumber of infected seeds of 3600 seeds tested per site each year.

Table 2. Mean squares from the analysis of variance for effects of N treatment, oat cultivar, location, year and their interactions on the incidence of five common seed-borne *Fusarium* spp. in 2013 and 2014.

Source	DF	<i>Fusarium</i> spp. ^a					Total
		Fa	Fe	Fg	Fp	Fs	
Replicate	2	0.4	4.2	0.3	8.8	0.1	17.8
Year (Y)	1	14.5	54.0	155.0 **	6589.1 **	86.9 **	9882.0 **
Error A	2	0.9	3.6	0.4	10.5	0.5	21.1
Site (S)	2	13.0 **	90.6 **	20.7 **	1505.2 **	30.4 **	1096.3 **
Y × S	2	15.4 **	134.7 **	10.5 **	1240.8 **	23.9 **	1985.4 **
Error B	8	0.5	2.7	0.8	20.9	2.2	43.2
Nitrogen (N)	3	0.4	0.6	8.8 **	60.9 *	2.4	88.7 *
Y × N	3	0.4	0.0	5.2 *	81.5 *	0.5	60.6
S × N	6	0.3	0.2	3.3	38.9	1.7	52.3
Y × S × N	6	0.4	0.7	2.0	66.1 **	0.5	88.3 **
Error C	36	0.9	2.3	1.0	31.1	1.2	28.5
Cultivar (C)	2	0.2	11.8 **	7.7 **	45.2 *	1.8	74.9 *
Y × C	2	0.4	5.0	4.2	4.4	1.7	0.8
S × C	4	1.0	2.8	0.3	18.7	1.4	41.5
N × C	6	0.3	1.0	1.1	33.2	2.2	27.2
Y × S × C	4	0.5	4.6	0.8	41.7	0.0	57.9
Y × N × C	6	0.5	2.1	0.7	50.7 *	2.7	57.0
S × N × C	12	0.3	1.8	0.4	15.4	1.0	20.9
Y × S × N × C	12	0.3	2.9	0.6	21.6	1.2	29.7
Error D	96	0.6	2.3	1.4	21.3	2.0	26.1

^aFa = *F. avenaceum*; Fe = *F. equiseti*; Fg = *F. graminearum*; Fp = *F. poae*; Fs = *F.*

sporotrichioides.

*, ** significant at $P \leq 0.05$ and 0.01 levels, respectively.

1 **Table 3. Effect of N treatment and cultivar, location and year on the incidence of common seed-borne *Fusarium* spp. in oat grains.**

N treatment (kg/ha)	Incidence (%)											
	2013						2014					
	Fa ^a	Fe	Fg	Fp	Fs	Total	Fa	Fe	Fg	Fp	Fs	Total
Melfort												
0	0.0 <i>a</i>	0.2 <i>a</i>	0.1 <i>a</i>	4.9 <i>b</i>	0.0 <i>a</i>	5.2 <i>b</i>	1.3 <i>a</i>	0.0 <i>a</i>	1.3 <i>b</i>	18.6 <i>c</i>	0.3 <i>a</i>	21.9 <i>c</i>
50	0.0 <i>a</i>	0.0 <i>a</i>	0.2 <i>a</i>	4.1 <i>b</i>	0.4 <i>a</i>	4.8 <i>b</i>	2.2 <i>a</i>	0.1 <i>a</i>	1.0 <i>b</i>	26.2 <i>ab</i>	0.4 <i>a</i>	30.9 <i>ab</i>
100	0.1 <i>a</i>	0.0 <i>a</i>	0.4 <i>a</i>	3.3 <i>b</i>	0.4 <i>a</i>	4.3 <i>b</i>	1.7 <i>a</i>	0.4 <i>a</i>	3.1 <i>a</i>	30.3 <i>a</i>	0.6 <i>a</i>	36.4 <i>a</i>
150	0.0 <i>a</i>	0.1 <i>a</i>	0.3 <i>a</i>	7.0 <i>a</i>	0.0 <i>a</i>	7.4 <i>a</i>	1.2 <i>a</i>	0.1 <i>a</i>	3.1 <i>a</i>	26.6 <i>ab</i>	0.1 <i>a</i>	31.2 <i>ab</i>
Normandin												
0	0.2 <i>a</i>	4.6 <i>a</i>	0.1 <i>a</i>	6.3 <i>a</i>	0.3 <i>a</i>	11.6 <i>a</i>	0.1 <i>a</i>	0.2 <i>a</i>	2.1 <i>b</i>	10.4 <i>a</i>	1.2 <i>a</i>	14.1 <i>a</i>
50	0.1 <i>a</i>	4.4 <i>a</i>	0.1 <i>a</i>	7.7 <i>a</i>	0.6 <i>a</i>	12.9 <i>a</i>	0.2 <i>a</i>	0.3 <i>a</i>	2.1 <i>b</i>	11.9 <i>a</i>	1.2 <i>a</i>	15.8 <i>a</i>
100	0.4 <i>a</i>	4.4 <i>a</i>	0.3 <i>a</i>	6.9 <i>a</i>	0.2 <i>a</i>	12.3 <i>a</i>	0.0 <i>a</i>	0.3 <i>a</i>	2.0 <i>b</i>	10.3 <i>a</i>	1.8 <i>a</i>	14.4 <i>a</i>
150	0.0 <i>a</i>	4.1 <i>a</i>	0.6 <i>a</i>	7.3 <i>a</i>	0.7 <i>a</i>	12.7 <i>a</i>	0.1 <i>a</i>	0.2 <i>a</i>	4.3 <i>a</i>	10.6 <i>a</i>	2.4 <i>a</i>	17.7 <i>a</i>
Ottawa												
0	0.0 <i>a</i>	0.7 <i>b</i>	0.0 <i>a</i>	0.1 <i>b</i>	0.0 <i>b</i>	0.9 <i>b</i>	0.1 <i>a</i>	2.2 <i>a</i>	1.1 <i>a</i>	9.0 <i>a</i>	2.7 <i>a</i>	15.2 <i>a</i>
50	0.0 <i>a</i>	1.0 <i>ab</i>	0.0 <i>a</i>	0.4 <i>ab</i>	0.2 <i>ab</i>	1.7 <i>ab</i>	0.0 <i>a</i>	2.2 <i>a</i>	0.6 <i>a</i>	14.3 <i>a</i>	2.6 <i>a</i>	19.7 <i>a</i>
100	0.0 <i>a</i>	1.6 <i>a</i>	0.0 <i>a</i>	0.4 <i>ab</i>	0.3 <i>ab</i>	2.4 <i>ab</i>	0.0 <i>a</i>	2.1 <i>a</i>	0.7 <i>a</i>	8.4 <i>a</i>	2.6 <i>a</i>	13.8 <i>a</i>
150	0.0 <i>a</i>	1.0 <i>ab</i>	0.0 <i>a</i>	0.9 <i>a</i>	0.9 <i>a</i>	2.8 <i>a</i>	0.1 <i>a</i>	1.8 <i>a</i>	1.1 <i>a</i>	12.0 <i>a</i>	3.4 <i>a</i>	18.4 <i>a</i>
Cultivar												
CDC Morrison	0.0 <i>b</i>	2.1 <i>a</i>	0.1 <i>b</i>	4.4 <i>a</i>	0.3 <i>a</i>	6.8 <i>a</i>	0.6 <i>a</i>	1.1 <i>a</i>	2.2 <i>a</i>	14.6 <i>a</i>	1.9 <i>a</i>	20.2 <i>a</i>
AAC Nicolas	0.0 <i>b</i>	1.1 <i>b</i>	0.1 <i>b</i>	3.9 <i>a</i>	0.3 <i>a</i>	5.6 <i>b</i>	0.7 <i>a</i>	0.6 <i>a</i>	1.3 <i>b</i>	15.4 <i>a</i>	1.3 <i>b</i>	19.4 <i>a</i>
AAC Noranda	0.2 <i>a</i>	2.4 <i>a</i>	0.4 <i>a</i>	4.5 <i>a</i>	0.4 <i>a</i>	7.8 <i>a</i>	0.6 <i>a</i>	0.8 <i>a</i>	2.4 <i>a</i>	15.6 <i>a</i>	1.7 <i>a</i>	21.3 <i>a</i>
Location												
Melfort	0.0 <i>b</i>	0.1 <i>c</i>	0.3 <i>a</i>	4.8 <i>b</i>	0.2 <i>a</i>	5.4 <i>b</i>	1.6 <i>a</i>	0.2 <i>b</i>	2.1 <i>a</i>	24.4 <i>a</i>	0.4 <i>c</i>	29.1 <i>a</i>
Normandin	0.2 <i>a</i>	4.4 <i>a</i>	0.3 <i>a</i>	7.1 <i>a</i>	0.4 <i>a</i>	12.4 <i>a</i>	0.1 <i>b</i>	0.3 <i>b</i>	2.6 <i>a</i>	10.1 <i>b</i>	1.7 <i>b</i>	14.8 <i>b</i>
Ottawa	0.0 <i>b</i>	1.1 <i>b</i>	0.0 <i>b</i>	0.4 <i>c</i>	0.4 <i>a</i>	1.9 <i>c</i>	0.1 <i>b</i>	2.1 <i>a</i>	0.9 <i>b</i>	10.9 <i>b</i>	2.8 <i>a</i>	16.8 <i>b</i>

2 **Note:** means within a column not sharing a lowercased italic letter differ significantly at the $P < 0.05$ level (LSD).

3 ^aFa = *F. avenaceum*; Fe = *F. equiseti*; Fg = *F. graminearum*; Fp = *F. poae*; Fs = *F. sporotrichioides*.

4 **Figure Captions**

5

6 **Fig. 1.** The linear relationship between the incidence of common and total seed-borne
7 *Fusarium* spp. and the applied levels of nitrogen treatments in 2013 and 2014.

8 Fa = *F. avenaceum*; Fe = *F. equiseti*; Fg = *F. graminearum*; Fp = *F. poae*; Fs = *F.*
9 *sporotrichioides*.

10 **Fig. 2.** Daily temperatures and precipitation from May 1st to August 31st at Melfort,
11 Normandin, and Ottawa in 2013 and 2014. Data were collected by Environment Canada
12 weather stations within 1 km from field trials at each location.

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Percentage of recovery

Fig. 1.

Fig. 2.