Tillage System and Cropping Sequence Effects on Fusarium Head Blight in Barley in Eastern Saskatchewan

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Key words: Fusarium head blight, *F. avenaceum, F. graminearum, F. poa, F. sporotrichioides, Fusarium*-damaged kernels, crop rotation, reduced tillage, herbicides

Abstract

Fusarium head blight (FHB) in barley is well established in the eastern Canadian Prairies and appears to be moving westward. A survey of 192 barley crops in eastern Saskatchewan was conducted to determine the impact of agronomic practices on FHB (1999-2002) and *Fusarium*-damaged kernels (FDK) (2000-2001). The most common species isolated from spikes/kernels were *F. sporotrichioides*, *F. avenaceum*, and *F. graminearum*, followed by *F. poae* and *F. culmorum*. Disease tended to be higher under minimum- than conventional- and/or zero-till. *F. sporotrichioides* was favored by a previous cereal crop, whereas *F. avenaceum* was higher after a pulse crop, and *F. graminearum* decreased after a pulse but not an oilseed crop. The latter two pathogens were also more prevalent after diversified cropping sequences than after two cereal crops. Summerfallow, or summerfallow alternated with cereals, decreased FDK. Previous glyphosate (Group 9 herbicides) use was associated with increased infection by all *Fusarium* spp., whereas Group 1 herbicides were associated with increased infection by *F. poae* and *F. sporotrichioides*. Number of previous glyphosate applications was also correlated with FHB caused by *F. avenaceum* and *F. graminearum*. We concluded that in eastern Saskatchewan, barley grown under minimum-till where glyphosate had been sprayed and following diversified cropping sequences would sustain the greatest damage due to FHB/FDK caused by *F. avenaceum* and *F. graminearum*.

Introduction

Fusarium head blight (FHB) became an important barley disease in the eastern Canadian Prairies around 1997 (Tekauz et al., 2000), and has since spread westward. FHB surveys conducted throughout the Canadian Prairies detected this disease in barley grown in eastern Saskatchewan (Clear et al., 2000; Fernandez et al., 2002) and Alberta (Turkington et al., 2002), although at lower levels than in Manitoba (Tekauz et al., 2000). In the last few years, due to unfavourable weather for disease development at flowering, FHB has occurred at low levels in Saskatchewan (Pearse et al., 2006); however, there is still the potential for this disease to continue spreading westward.

There are several *Fusarium* species that can cause FHB in barley. The most important FHB pathogen in Manitoba is *F. graminearum*, followed by other species, the most common of which are *F. avenaceum*, *F. poae*, and *F. sporotrichioides* (Tekauz et al., 2000; 2006). In Saskatchewan and Alberta, *F. graminearum* has been less commonly isolated from barley than in regions where this disease is more prevalent. *Fusarium avenaceum* was reported as the most, or one of the most, common species found in infected spikes and kernels of barley (Clear et al., 2000; Pearse et al., 2006; Turkington et al., 2002).

Although the most effective way of controlling FHB is by developing barley cultivars with improved levels of resistance, knowing which agronomic practices contribute to reduced disease and inoculum levels should form part of a comprehensive strategy for disease control.

The objective of this study was to determine how FHB development, and relative prevalence of *Fusarium* pathogens, in barley crops grown in eastern Saskatchewan is affected by crop production systems, in particular tillage method and cropping sequence. This information would help to identify agronomic practices that might reduce the further spread of damage to barley from FHB on the Canadian Prairies.

Materials and Methods

A total of 192 barley crops were sampled from 1999 to 2002 in Crop Districts 1B and 5A of eastern Saskatchewan (30 in 1999, 63 in 2000, 50 in 2001, and 49 in 2002). At the mid-milk to early-dough stage, 100 spikes were taken at random from each field. Disease incidence (percentage of spikes with FHB-like symptoms) and severity (percentage of spikelets discolored on each spike) were estimated. To confirm infection by *Fusarium* spp. and for species identification, lemma showing discoloration were carefully removed, surface-sterilized, and plated on modified PDA (Fernandez and Chen, 2005). A FHB index [(% of spikes infected X mean severity of infection)/100] was calculated for each of the barley crops sampled based on the presence of *Fusarium* isolates in the discolored lemma tissue plated. From 2000 to 2002, FHB indices were also calculated for each crop based on the percent isolation of the most common *Fusarium* spp., *F. avenaceum* (FHB-*Fav*), *F. graminearum* (FHB-*Fg*), *F. poae* (FHB-*Fp*), and *F. sporotrichioides* (FHB-*Fspo*).

In 2001 and 2002, grain samples from most of the barley crops sampled were also obtained from cooperating producers. Kernels with FDK-like symptoms were visually identified in a 50 g subsample, removed, and weighed. The percentage of FDK-like symptoms was determined based on total weight of the sample. A subsample of kernels with FDK symptoms was then plated and incubated as above, and fungi growing out of the kernels were identified. A percent “total FDK” was then calculated based on the percent isolation of *Fusarium* spp. In addition, percent FDKs were also calculated based on the percent isolation of the most common species (FDK-*Fav*, FDK-*Fg*, FDK-*Fp*, and FDK-*Fspo*).

Producers provided information regarding the agronomic practices used on the crop(s) sampled, which was used to categorize the crops/fields according to crop production factor. For cultivar susceptibility to FHB, crops were categorized into “susceptible” and “intermediate” cultivars. Susceptible cultivars were those rated as “Poor”, and intermediate cultivars were those rated as “Fair” or “Fair+” in the Saskatchewan Varieties of Grain Crops publication (Saskatchewan Agriculture, Food and Rural Revitalization, 2005). For tillage system, fields were categorized according to the total number of tillage operations they received in the previous three years (conventional-till, CT, had a total of 7 or more operations, minimum-till, MT, had a total of 1 to 6 operations, and zero-till, ZT, had none). Herbicide applications within each tillage system were categorized according to whether the fields had received any of the herbicide Groups 1, 2, 4 and 9 (Saskatchewan Agriculture and Food, 2006) in the previous 18 months. For previously-grown crop(s), fields were categorized according to the crop, if any, grown the previous year: cereal, oilseed, pulse, or summerfallow. Fields were also categorized according to the crops, if any, grown the previous two years, regardless of the order in the sequence: two cereal (C) crops (C-C) or two noncereal (NC) crops (NC-NC), or a combination of a cereal and a noncereal crop (C-NC), or summerfallow (F) and a crop (C-F or NC-F).

Disease- and fungal-related responses were compared with the SURVEYREG procedure of SAS and means were estimated with the SURVEYMEANS procedure of SAS (SAS Institute, Inc. 1999). Data collected for each year were assumed to be stratum for the analysis. Contrasts were performed among cropping sequences and tillage systems for total FHB index or percent FDK, and for those attributed to the most commonly isolated fungi. Pearson correlations were performed between the total number of Group 9 herbicide applications in the previous 18 months and the FHB indices. Effects were again declared significant at $P \leq 0.10$.

Results

FHB and Crop Production Factors

When FHB data were analyzed based on cropping sequence, total FHB index, FHB-*Fa,* and FHB-*Fg* were significantly higher for susceptible cultivars than for those with intermediate resistance (Table 1). However, there were no significant effects of cropping sequence on the total FHB index but only on FHB-*Fa* and FHB-*Fg*. Levels of FHB-*Fav* were also lower after C-C than after the other cropping sequences with two consecutive crops. In contrast, FHB-*Fg* was present at the lowest mean levels in barley grown after a pulse crop, but tended to be higher after an oilseed than a cereal crop. Similar to FHB-*Fav*, FHB-*Fg* was also lower after C-C than after continuously cropping sequences with at least one noncereal crop in the previous two years. Barley grown after a cereal had a higher FHB-*Fspo* than when grown after an oilseed crop.

Overall, there were no significant tillage effects (Table 1). For most of the fungi, differences between FHB indices in barley grown under CT and reduced tillage varied with cultivar susceptibility. For total FHB index, FHB-*Fg* and FHB-*Fspo*, susceptible cultivars had the lowest disease levels under CT, whereas cultivars with intermediate resistance had the lowest levels under ZT; this resulted in barley grown under MT having similar or higher disease levels than that grown under the other tillage systems.

FDK and Crop Production Factors

Percent FDK-total and FDK-*Fav* in 2000/2001 tended to be higher in barley grown after a pulse than after the other crops, but not significantly so at $P < 0.10$ (Table 2). In contrast, FDK-*Fg* and FDK-*Fp* were lower after a pulse than other crops; although, significantly so only for the former, whereas FDK-*Fspo* was significantly lower in barley grown after an oilseed.

A previous year of summerfallow had consistent effects on most of the fungi colonizing barley kernels and on the total percent FDK (Table 2). Barley grown immediately after summerfallow had significantly lower FDK-total, FDK-*Fav*, FDK-*Fp,* and FDK-*Fspo* levels than for the other previous crops combined. Furthermore, percent FDK-total and FDK-*Fspo* were significantly lower after sequences that included a year of summerfallow (C-F, NC-F) than after continuously cropped sequences. In addition, percent FDK-*Fav* was also significantly lower after C-F than after C-NC. Percent FDK-*Fg* also tended to be lower when barley was grown immediately after summerfallow, or after two-year sequences that included summerfallow, than when grown after a crop or continuously-cropped sequences. Lower levels of FDK-total and FDK-*Fg* after C-F and NC-F than after the other cropping sequences is mostly attributed to their high levels after sequences that included at least one noncereal crop (C-NC, NC-NC).

Barley grown under MT had significantly higher percent total FDK, FDK-*Fg*, and FDK-*Fp* than barley in the other tillage systems combined (Table 2). Lowest levels of FDK-*Fg* and FDK-*Fp* were observed under ZT, whereas lowest levels of FDK-*Fspo* were observed under CT.

Herbicide Effects on FHB

The analysis of the effect of previous herbicide use (yes/no) on FHB levels was done for each of the tillage systems; although, sample size for treated and/or untreated fields was lower for CT- and ZT- than for MT-managed fields. In most cases, there were no significant effects of previous herbicide use on total FHB index and the FHB indices attributed to the individual fungi (Table 3). For barley crops under MT, previous Group 1 use in barley fields was associated with a significantly higher level of FHB-*Fp*, whereas Group 9 use was associated with a significantly higher FHB-*Fav* than in barley grown in untreated fields. Similarly, for barley crops under ZT, a significant increase in the total FHB index and FHB-*Fspo* was associated with previous Group 1 use, whereas significant increases in total FHB index, FHB-*Fg*, and FHB-*Fspo* were associated with previous use of Group 9 herbicides. For barley grown under CT, there were also significantly higher FHB-total, FHB-*Fp*, and FHB-*Fspo* levels in fields that had received Group 9 herbicide applications than in those that had not; in contrast, significant reductions in FHB-*Fav* were associated with Group 2, and significant reductions in total FHB index, FHB-*Fp*, and FHB-*Fspo* were associated with previous use of Group 4 herbicides.

Correlation between the number of previous Group 9 herbicide applications and FHB-*Fg* or FHB-*Fav* was significant for cultivars with intermediate resistance (r=0.439 and 0.347, $P < 0.01$, for FHB-*Fav* and FHB-*Fg*, respectively) but not for susceptible cultivars (data not presented). Similar correlations for the other FHB indices and for other herbicide groups were not significant ($P > 0.10$).

Discussion

F. avenaceum was among the most commonly isolated fungi from FHB-affected barley spikes. In Manitoba, *F. avenaceum* was the second most commonly isolated species from FHB-affected barley crops sampled in that province in 2005 (Tekauz et al., 2006). In our study, the *Fusarium* species associated with FDK in the barley crops sampled have also been reported elsewhere as the most commonly isolated species from infected barley grain in the Canadian Prairies (Clear et al., 2000; Turkington et al., 2002).

Analysis of the data by tillage system suggested that MT management favored disease development, especially percent FDK. Rioux et al. (2005) reported that barley grown under MT had higher DON content than when grown under CT. The observation that overall barley grown under MT had higher disease levels than barley grown under the other tillage systems agrees with the report by Fernandez et al. (2005) for common and durum wheat crops.

A previous year of summerfallow affected FDK in 2000/2001 more than the overall mean FHB levels, reducing kernel infection by most fungi. Observations by Sturz and Johnston (1985) that *Fusarium* isolations from barley spikes were higher in barley grown on stubble than on summerfallow agree with results from our FDK analysis, but not with the FHB data. On average, barley crops preceded by summerfallow, or by a year of summerfallow and a cereal crop, had received lower N input than barley grown after the other sequences. Lemmens et al. (2004) found significant increases in FHB and DON in wheat as a result of N fertilization.

Percent FDK-*Fa* and FDK-*Fg* were lower in continuous cereal systems mostly under MT (C-C) than in continuous diversified systems (C-NC, NC-NC) under MT or ZT, or with a noncereal alternated with summerfallow (NC-F), mostly under CT or MT. However, FHB-*Fav* and FHB-*Fg* after C-C were similar to those in barley grown after C-F, which was also mostly under CT or MT. These results suggest that cropping sequence had a greater impact on infection of barley by *F. avenaceum* and *F. graminearum* than tillage system, and that noncereal crops played a more important role in disease development attributed to these fungi in succeeding barley crops than the presence of host cereal crops grown continuously in the previous two years (i.e. C-C).

There was also a differential effect of the previous noncereal crop on *F. avenaceum* and *F. graminearum* on spikes and kernels. Compared to other crops, a previous pulse crop favored an increase in FHB/FDK caused by *F. avenaceum*, but it resulted in a decrease in that associated with *F. graminearum*. Dill-Macky and Jones (2000) also reported lower FHB and DON levels, attributed mostly to *F. graminearum,* in spring wheat grown after soybean than after a wheat crop. Changes in the prevalence of FHB pathogens associated with the preceding crop have been reported before. Cromey et al. (2002) found that while *F. graminearum* was the predominant grain pathogen in spring wheat planted after corn, the percentage of grain infected by this pathogen decreased, and that of *F. avenaceum* and *F. poae* increased, in wheat planted after other crops.

The increase in disease levels caused by *F. avenaceum* after pulse crops could be attributed to the susceptibility of pulses to this pathogen. In the same area that this study was conducted, *F. avenaceum* was found at higher levels in pulse than in cereal or canola roots and residues (Fernandez, 2004; Fernandez et al., 2003a).

Fusarium avenaceum and *F. graminearum* tended to be present at similar or higher levels on barley spikes when grown after an oilseed than a cereal crop. Canola and flax stem residues from the cereal fields sampled in this area were also shown to have a higher percent isolation of *F. avenaceum* than cereal residues (Fernandez et al., 2003a), suggesting that oilseed residues could be an important source of inoculum for this pathogen. The similar or higher *F. graminearum* levels in barley grown after an oilseed (mostly canola) or after diversified sequences involving mostly canola crops partly agrees with Obst et al. (1997) who did not find any differences in DON levels between winter wheat grown after canola than after another cereal crop. The lack of an effect of a previous oilseed crop on FHB-*Fg* levels in barley could be partly explained by the colonization by *F. graminearum* of stem residues (Fernandez et al., 2003a) and roots (Fernandez, 2004) of these crops; however, isolation of this pathogen from oilseed tissue was low. Most previous oilseed crops were preceded by a cereal two years previous to the barley crop sampled, and these older residues might have also been an inoculum source. However, it is not known why *F. graminearum* levels in barley were lowest when preceded by two cereal crops given that inoculum levels would have been expected to be higher than when a noncereal crop was included in the sequence. The significantly higher grain yields of the same barley crops when they followed an oilseed versus a cereal crop (Fernandez et al., 2007) suggests that a previous oilseed crop might have resulted in a higher N status in the subsequent barley crop. In addition, barley fields preceded by two cereal crops had also received on average less N input (55 kg ha^{-1}) than when a noncereal crop was included in the sequence (65 kg ha^{-1}), and also had significantly lower grain yield than when there was at least one noncereal crop in the previous two years, as reported by Fernandez et al. (2007). The higher N availability when a noncereal crop was included in the sequence might have affected FHB development (Lemmens et al. 2004).

It appeared that use of Group 9 (glyphosate) herbicides, done in fields preceded mostly by an oilseed crop, were also associated with increased levels of all *Fusarium* pathogens, although these effects varied with tillage system. Some of these Group 9 herbicide applications had been done in-crop indicating that they were done on glyphosate-tolerant canola. However, due to the nature of this study, and the small sample size for unsprayed barley fields preceded by an oilseed crop, it was not possible to separate the impact of previously-grown oilseed crops from that of previous Group 9 herbicide applications on disease levels. The other herbicides associated with significant increases in FHB levels attributed to *F. poae* and *F. sporotrichioides* belonged to Group 1, although this again depended on tillage system. As for Group 9, it was not possible to separate the effect of previous crop from that of Group 1 herbicide use on *Fusarium* infections.

The association of previous Group 9 herbicide applications with FHB levels is similar to the observations made on spring wheat in regards to total FHB index, FHB-*Fg* and FHB-*Fav* (Fernandez et al., 2003b; Fernandez et al., 2005). As indicated for wheat, the mechanism(s) responsible for the increase in disease levels in barley associated with previous Group 9 herbicide use is not known. However, based on the correlations between the total number of Group 9 herbicide applications in the previous 18 months and FHB-*Fg* and FHB-*Fav* levels in barley crops, it was apparent that the impact of this herbicide on disease levels was greater for cultivars with intermediate resistance than for susceptible cultivars, suggesting that cultivar susceptibility might override the apparent impact of Group 9 herbicides on disease levels. Barley crops with intermediate resistance grown under MT management in fields that had received two glyphosate applications in the previous 18 months had similar or slightly lower mean percent FHB-*Fa* (0.4%) and FHB-*Fg* (0.5%) than the mean for all susceptible barley crops grown under MT (0.4 and 0.7%, respectively). In a parallel study of common root rot of the same barley crops sampled in this study (Fernandez et al., 2006), glyphosate was found to be the only herbicide associated with significant increases in *Fusarium* levels in subcrown internodes in fields under MT management.

The other crop production factors that affected *Fusarium* infections on spikes in this study were also similar to those that affected the percent isolation of *Fusarium* spp. from subcrown internodes of the same barley crops sampled from 1999 to 2001 (Fernandez et al., 2007). The similar impact of production factors on FHB and common root rot points to the importance of agronomic practices *vis-a-vis* the environment in the development of these barley diseases in eastern Saskatchewan.

Based on our observations, we conclude that growing barley under MT management where glyphosate had been applied, and in continuous diversified rotations, would result in the most damage due to FHB caused by two of the most important pathogens in this and other affected regions, *F. graminearum* and *F. avenaceum*. It is not known if barley grown in areas with traditionally higher FHB levels or where *F. graminearum* is the predominant pathogen, would be more or less impacted by the same crop production factors. In any case, determining the relative contribution of cropping sequence, tillage method and herbicide applications to FHB development in barley would assist in devising the most appropriate agronomic recommendations for its control.

Considering that currently popular production practices appeared to be associated with FHB development in this region, and based on the importance of *F. avenaceum*, a wide-host range pathogen, relative to the other *Fusarium* pathogens, breeding for resistance to FHB would seem to be the most practical way of controlling this important cereal disease. Furthermore, incorporating resistance to *Fusarium* infections in roots/crowns might also be important for controlling the development and spread of FHB in barley on the western Canadian Prairies. However, determining the mechanism responsible for the association of previous glyphosate applications with spike infections caused by *F. graminearum* and *F. avenaceum* would help in disease control and to possibly maintain the resistance of barley to this important disease.

Acknowledgements

This work was conducted with financial support from the Saskatchewan Agriculture Development Fund. We thank S. Stolhandske-Dale, Y. Chen, M. Boire, and D. Kern for technical assistance.

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Table 1. Effect of crop susceptibility, tillage system and previous crop(s), and their interactions, on total Fusarium head blight (FHB) index, and on that attributed to *F. avenaceum* (FHB-*Fav*), *F. graminearum* (FHB-*Fg*), *F. poae* (FHB-*Fp*), and *F. sporotrichioides* (FHB-*Fspo*) in barley crops sampled in Crop Districts 1B and 5A in eastern Saskatchewan, 1999-2002.

Effect / Contrast	No.	FHB-total	FHB-*Fav*	FHB-*Fg*	FHB-*Fp*	FHB-*Fspo*
		P value				
Cultivar susceptibility (CS)[1]		0.038	<0.001	0.086	0.914	0.156
		Mean % (SE)				
Susceptible cultivars	85	1.9 (0.3)	0.4 (0.1)	0.6 (0.2)	0.1 (0.1)	0.9 (0.2)
Intermediate cultivars	102	1.3 (0.2)	0.2 (<0.1)	0.2 (<0.1)	0.2 (<0.1)	0.6 (0.1)
		P value				
Previous crop		0.978	0.039	0.002	0.543	0.198
cereal vs. oilseed		0.753	0.091	0.149	0.205	0.059
cereal vs. pulse		0.820	0.008	0.014	0.707	0.846
oilseed vs. pulse		0.948	0.114	0.029	0.649	0.209
oilseed vs. cereal, pulse		0.835	0.670	0.068	0.303	0.043
pulse vs. cereal,oilseed		0.933	0.027	0.006	0.989	0.617
		Mean % (SE)				
cereal	74	1.8 (0.3)	0.2 (0.1)	0.3 (0.1)	0.2 (0.1)	1.0 (0.2)
oilseed	86	1.4 (0.3)	0.3 (0.1)	0.5 (0.2)	0.1 (<0.1)	0.5 (0.1)
pulse	13	1.5 (0.4)	0.6 (0.2)	<0.1 (<0.1)	0.2 (0.1)	0.9 (0.3)
summerfallow	19	1.6 (0.4)	0.2 (0.1)	0.2 (0.1)	0.2 (0.1)	0.7 (0.2)
		P value				
Previous two crops[2]		0.994	<0.001	0.119	0.075	0.929
C-C vs. C-NC, NC-NC		0.907	0.000	0.054	0.239	0.396
C-C vs. NC-F		0.724	0.000	0.080	0.539	0.502
		Mean % (SE)				
C-C	24	1.5 (0.5)	<0.1 (<0.1)	0.1 (<0.1)	0.2 (0.1)	1.1 (0.5)
C-NC	112	1.5 (0.2)	0.3 (0.1)	0.4 (0.2)	0.1 (<0.1)	0.6 (0.1)
NC-NC	13	1.6 (0.5)	0.5 (0.2)	0.7 (0.4)	<0.1 (<0.1)	0.6 (0.3)
C-F	18	2.3 (0.5)	0.3 (0.1)	0.2 (0.1)	0.2 (0.1)	1.0 (0.3)
NC-F	23	1.6 (0.4)	0.4 (0.1)	0.4 (0.2)	0.3 (0.1)	0.7 (0.2)
Tillage system[3]						
		P value				
CS x Tillage system		0.020	0.853	0.049	0.066	0.003
CS x CT vs. MT, ZT		0.006	0.630	0.014	0.311	0.001
		Mean % (SE)				
Susceptible cultivars						
CT	20	1.1 (0.3)	0.5 (0.2)	0.1 (0.1)	0.4 (0.3)	0.4 (0.1)
MT	47	2.1 (0.5)	0.4 (0.1)	0.7 (0.3)	0.1 (<0.1)	0.9 (0.2)
ZT	18	2.2 (0.6)	0.4 (0.1)	0.5 (0.3)	0.3 (0.2)	1.2 (0.5)
Intermediate cultivars						
CT	13	1.9 (0.4)	0.3 (0.1)	0.3 (0.1)	0.1 (<0.1)	1.3 (0.3)
MT	65	1.4 (0.3)	0.2 (<0.1)	0.2 (0.1)	0.2 (0.1)	0.7 (0.2)
ZT	24	0.5 (0.1)	0.2 (0.1)	<0.1 (<0.1)	0.1 (<0.1)	0.2 (0.1)

[1] Categorization of cultivars into "Susceptible" ("Poor") and "Intermediate" ("Fair" or Fair+") is based on data presented in Varieties of Grain Crops (Saskatchewan Agriculture, Food and Rural Revitalization, 2005) for each of the cultivars.
[2] C: cereal; NC: noncereal; F: summerfallow. Barley crops grouped according to previous two crops or summerfallow, regardless of the order in the sequence (C-C, C-NC, NC-NC, C-F, and NC-F)
[3] CT: conventional-till; MT: minimum-till; ZT: zero-till.

Table 2. Effect of previous crop(s) and tillage system on total percent *Fusarium*-damaged kernels (FDK), and on that attributed to *F. avenaceum* (FDK-*Fav*), *F. graminearum* (FDK-*Fg*), *F. poae* (FDK-*Fp*), and *F. sporotrichioides* (FDK-*Fspo*), in barley crops sampled in Crop Districts 1B and 5A in eastern Saskatchewan, 2000 and 2001.

Effect / Contrast	No.	FDK-total	FDK-*Fav*	FDK-*Fg*	FDK-*Fp*	FDK-*Fspo*
		---------- P value ----------				
Previous crop		0.002	0.065	0.276	0.172	< 0.001
oilseed vs. cereal, pulse		0.216	0.135	0.309	0.671	0.067
pulse vs. cereal, oilseed		0.189	0.172	0.053	0.135	0.191
summerfallow vs. others		0.001	0.020	0.110	0.067	0.004
		---------- Mean % (SE) ----------				
cereal	38	2.0 (0.4)	0.5 (0.2)	0.4 (0.2)	0.2 (0.1)	0.7 (0.1)
oilseed	47	1.7 (0.4)	0.4 (0.1)	0.6 (0.3)	0.2 (<0.1)	0.4 (0.1)
pulse	8	3.6 (1.3)	1.4 (0.7)	0.1 (0.1)	0.1 (<0.1)	1.5 (0.7)
summerfallow	14	0.7 (0.1)	0.2 (0.1)	0.1 (0.1)	0.1 (<0.1)	0.2 (<0.1)
		---------- P value ----------				
Previous two crops[1]		0.024	0.256	0.502	0.427	0.001
C-F vs. C-NC		0.005	0.053	0.176	0.124	0.000
C-F, NC-F vs. others		0.063	0.577	0.162	0.605	0.030
		---------- Mean % (SE) ----------				
C-C	10	1.3 (0.4)	0.4 (0.1)	0.2 (0.1)	0.1 (0.1)	0.6 (0.2)
C-NC	56	2.3 (0.5)	0.6 (0.2)	0.6 (0.3)	0.2 (<0.1)	0.7 (0.1)
NC-NC	9	2.0 (0.9)	0.4 (0.1)	0.6 (0.4)	0.1 (0.1)	0.8 (0.6)
C-F	16	1.1 (0.3)	0.3 (0.1)	0.2 (0.1)	0.1 (0.1)	0.3 (0.1)
NC-F	16	1.3 (0.4)	0.5 (0.2)	0.3 (0.1)	0.2 (0.1)	0.3 (0.1)
		---------- P value ----------				
Tillage system[2]		0.046	0.309	0.014	0.002	0.001
MT vs. CT, ZT		0.017	0.204	0.070	0.021	0.330
		---------- Mean % (SE) ----------				
CT	20	1.2 (0.2)	0.4 (0.1)	0.3 (0.1)	0.2 (0.1)	0.2 (0.1)
MT	68	2.2 (0.4)	0.6 (0.1)	0.6 (0.2)	0.2 (<0.1)	0.6 (0.1)
ZT	19	1.1 (0.4)	0.3 (0.1)	<0.1 (<0.1)	<0.1 (<0.1)	0.7 (0.3)

[1] C: cereal; NC: noncereal; F: summerfallow. Barley crops grouped according to previous two crops or summerfallow, regardless of the order in the sequence (C-C, C-NC, NC-NC, C-F, and NC-F)
[2] CT: conventional-till; MT: minimum-till; ZT: zero-till.

Table 3. Effect of herbicide use (previous 18 months) on total Fusarium head blight (FHB) index, and FHB index attributed to *F. avenaceum* (FHB-*Fav*), *F. graminearum* (FHB-*Fg*), *F. poae* (FHB-*Fp*), and *F. sporotrichioides* (FHB-*Fspo*), of barley crops within each tillage system, sampled in Crop Districts 1B and 5A in eastern Saskatchewan, 1999-2002.

Herbicide group	Tillage System[1]	Herbicide use	No.	FHB-total	FHB-*Fav*	FHB-*Fg*	FHB-*Fp*	FHB-*Fspo*
				---------- *P* value ----------				
Group 1	CT			0.105	0.194	0.177	0.238	0.270
	MT			0.454	0.146	0.158	0.034	0.837
	ZT			0.081	0.422	0.785	0.319	0.080
Group 2	CT			0.878	0.069	0.306	0.928	0.421
	MT			0.752	0.513	0.550	0.897	0.867
	ZT			0.642	0.333	0.236	0.883	0.448
Group 4	CT			0.099	0.000	0.069	0.000	0.065
	MT			0.292	0.338	0.349	0.107	0.968
	ZT			0.104	0.377	0.150	0.329	0.281
Group 9	CT			0.017	0.841	0.121	0.071	0.001
	MT			0.465	0.010	0.375	0.585	0.801
	ZT			0.015	0.604	0.100	0.378	0.025
				---------- Mean % (SE) ----------				
Group 1	CT	No[2]	10	1.0 (0.3)	0.3 (0.2)	0.1 (0.1)	0.1 (0.1)	0.6 (0.3)
	CT	Yes	11	1.9 (0.6)	0.5 (0.2)	0.3 (0.1)	0.4 (0.2)	1.1 (0.3)
	MT	No	25	1.4 (0.5)	0.2 (0.1)	0.1 (0.1)	0.1 (0.0)	0.9 (0.4)
	MT	Yes	99	1.6 (0.2)	0.3 (0.0)	0.4 (0.2)	0.2 (0.0)	0.7 (0.1)
	ZT	No	14	0.6 (0.2)	0.2 (0.1)	0.1 (0.1)	0.1 (0.0)	0.1 (0.1)
	ZT	Yes	29	1.5 (0.4)	0.3 (0.1)	0.2 (0.2)	0.2 (0.1)	0.8 (0.3)
Group 2	CT	No	15	1.5 (0.4)	0.5 (0.2)	0.1 (0.0)	0.2 (0.2)	0.6 (0.2)
	CT	Yes	6	1.4 (0.6)	0.1 (0.0)	0.4 (0.2)	0.2 (0.1)	1.4 (0.5)
	MT	No	66	1.6 (0.4)	0.2 (0.1)	0.4 (0.2)	0.2 (0.1)	0.7 (0.2)
	MT	Yes	58	1.5 (0.2)	0.2 (0.1)	0.3 (0.1)	0.2 (0.0)	0.7 (0.1)
	ZT	No	18	1.0 (0.3)	0.1 (0.1)	0.4 (0.3)	0.2 (0.1)	0.3 (0.2)
	ZT	Yes	25	1.3 (0.4)	0.3 (0.1)	0.1 (0.0)	0.2 (0.1)	0.7 (0.3)
Group 4	CT	No	4	2.6 (1.3)	1.4 (0.1)	0.4 (0.0)	1.1 (0.6)	1.3 (0.3)
	CT	Yes	17	1.2 (0.3)	0.3 (0.1)	0.1 (0.1)	0.1 (0.0)	0.8 (0.2)
	MT	No	36	2.0 (0.6)	0.2 (0.1)	0.6 (0.4)	0.3 (0.1)	0.6 (0.2)
	MT	Yes	88	1.4 (0.2)	0.3 (0.1)	0.2 (0.1)	0.1 (0.0)	0.7 (0.2)
	ZT	No	9	0.8 (0.2)	0.3 (0.2)	0.1 (0.0)	0.1 (0.0)	0.4 (0.2)
	ZT	Yes	34	1.3 (0.3)	0.3 (0.1)	0.2 (0.1)	0.2 (0.1)	0.6 (0.3)
Group 9	CT	No	14	0.8 (0.3)	0.4 (0.2)	0.1 (0.0)	0.0 (0.0)	0.4 (0.2)
	CT	Yes	7	2.8 (0.7)	0.4 (0.2)	0.4 (0.2)	0.6 (0.3)	1.5 (0.4)
	MT	No	47	1.4 (0.3)	0.1 (0.0)	0.2 (0.1)	0.2 (0.0)	0.7 (0.3)
	MT	Yes	76	1.7 (0.3)	0.3 (0.1)	0.4 (0.2)	0.2 (0.1)	0.7 (0.1)
	ZT	No	7	0.5 (0.3)	0.3 (0.3)	0.0 (0.0)	0.1 (0.0)	0.0 (0.0)
	ZT	Yes	36	1.3 (0.3)	0.3 (0.1)	0.2 (0.1)	0.2 (0.1)	0.7 (0.2)

[1] CT: conventional-till; MT: minimum-till; ZT: zero-till.
[2] No: no herbicide of this group applied; Yes: herbicide of this group applied at least once in the previous 18 months.