Agronomic Factors Associated with the Development of Fusarium Head Blight in Spring Wheat in Southeast Saskatchewan

M.R. Fernandez[1], F. Selles[1], D. Gehl[2], R.M. DePauw[1], and R.P. Zentner[1].

[1]Semiarid Prairie Agricultural Research Centre, Agriculture and Agri-Food Canada, P.O. Box 1030, Swift Current, SK S9H 3X2; [2] Indian Head Research Farm, Agriculture and Agri-Food Canada, P.O. Box 760, Indian Head, SK S0G 2K0.

Key Words: wheat, fusarium head blight, tillage, glyphosate.

Abstract

Because of the increasing importance of fusarium head blight (FHB) in western Canada, identification of crop production factors (CPF) associated with the development of this disease is important in devising an effective strategy for its control. A survey of 659 spring wheat crops over four years (1999 to 2002) indicated that environment was the most important factor determining disease development. The CPFs that affected FHB the most were the previous application of a glyphosate formulation (GF), tillage practice, previously-grown crop, and cultivar susceptibility. GF application in the previous 18 months (or 3 years) was significantly associated with higher FHB levels every year of the study; it was the only CPF in 1999, and one of only two CPFs in 2002, that affected FHB indicating that its effects were not influenced as much by environmental conditions as those of other CPFs. In 2000 and 2001, the average increase in the FHB index resulting from a previous GF application(s) was 75% for all crops, and 122% for those under minimum-till management. It is not known if similar effects of GF on FHB would occur in environments different from the ones encountered in this study. Further research is needed to elucidate the nature of the GF-FHB association and underlying mechanisms.

Introduction

Fusarium head blight (FHB) has the potential of becoming an important disease of cereal crops in Saskatchewan. Province-wide surveys have indicated that FHB in spring wheat and barley has been increasing in eastern Saskatchewan and is spreading westward (e.g. Fernandez et al., 2000; 2001; 2002; Pearse et al., 2003).

The most important FHB pathogen in North America is *F. graminearum*, which produces mycotoxins harmful to humans and livestock. Due to processing problems and potential food safety concerns, tolerance levels for Fusarium-damaged kernels are very low. Low tolerance levels could represent significant economic losses to Saskatchewan producers in affected areas.

Because of the increasing importance of FHB in western Canada and its slow spread further westward, it is essential to put in place a comprehensive strategy to stop or reduce the rate of spread of this disease, and to decrease the damage it has been causing in the eastern part of the province, where it is already well established.

The objective of this study was to identify agronomic practices, or crop production factors (CPF), associated with the development of FHB in southeast Saskatchewan, and to determine what factors would be necessary to change to prevent further damage caused by this disease.

Materials and Methods

Number of spring wheat fields sampled in southeast Saskatchewan was 89 in 1999, 128 in 2000, 189 in 2001, and 253 in 2002. At the mid-milk to early dough stage, heads were taken at random from each field. Percentage of heads with FHB symptoms (incidence) and percentage of discolored spikelets in each head (severity) were determined visually. A FHB index (% of heads infected X mean severity of infection)/100), was calculated for each wheat crop sampled.

Producers supplied information regarding the agronomic practices used in each of the fields sampled. The information included cultivar, seeding rate and date, crop history, N fertilizer use, herbicide use, and tillage management. This information was used to group the crops/fields into categories, based on CPFs. For cultivar susceptibility, wheat crops were categorized into susceptible (or 'poor') and intermediate (or 'fair') (Saskatchewan Varieties of Grain Crops, 2003). For tillage system, fields were categorized according to the number of tillage operations they received in the previous three years: seven or more for conventional-till, one to six for minimum-till, and no passes for zero-till. For previously-grown crop, fields were categorized according to the crop, if any, grown the previous year: cereal, oilseed, pulse or summerfallow. For herbicide application, fields were categorized into those that had received at least one application of herbicide Groups 1, 2, 4 or 9 (glyphosate) in the previous 18 months, or 3 years, and those that had not been treated during the same time period.

In order to assess the relative contribution of each CPF to the total variance of FHB, we compared the ratios of the sum of squares of each CPF to the total corrected sum of squares from an analysis of variance (ANOVA) model where we included cultivar susceptibility, tillage system, previously-grown crop, and previous use of glyphosate formulations (GF).

The FHB data from each year were tested for normality using the Shapiro-Wilk test (Shapiro and Wilk, 1965). Because the data consisted of percentages, values were transformed using arcsine (Gomez and Gomez, 1984) prior to testing for normality. In addition, for the variables categorized into CPFs, a test of homogeneity of variances (Gomez and Gomez, 1984) was conducted for the arcsine-transformed data, and for the log-transform of the arcsine-transform. If this test determined that the variances of the categorized variables, or their transformations, were homogeneous across the CPF categories, the data were subjected to ANOVA using the CPF categories as class variables. For those variables where the data had heterogeneous variances, but the transformed data had homogeneous variances, ANOVAs were conducted on the transformed variables. For those data whose variances were heterogeneous (1999 and 2002), the data were grouped into a 'high' and a 'low' FHB class based on the sample median as class separator. The effects of the CPFs on the distribution of observations into the high and low FHB classes were assessed with a chi-square test, under the assumption that if CPFs had no effect, the distribution of the observations into high and low classes would remain unchanged. For uniformity, chi-squares were also performed on the 2000 and 2001 data.

All statistical analyses were conducted with JMP 5.0.1.2 (SAS Institute, 2002).

Results and Discussion

Overall, the percentage of fields with FHB was highest in 2000 and 2001 (97-98%), intermediate in 1999 (71%), and lowest in 2002 (51%), whereas the mean FHB index was highest in 2001 (8.4%), intermediate in 2000 (2.7%) and lowest in 1999 (0.2%) and 2002 (0.4%).

In general, on a yearly basis from 1999 to 2001 the CPFs examined explained about 15% of the variance; in 2002 the model explained only 2% of the variance. Annually, tillage system and previous GF application accounted for a larger proportion of the variance than any other CPF, followed by previously-grown crop. Of all CPFs, previous GF application was the factor that accounted for a more consistent proportion of the variance every year, whereas the proportion explained by the other CPFs varied considerably from year to year, suggesting that weather conditions during the growing season determined to a large extent the relative importance of each CPF.

Table 1. Significance of the Effects of Crop Production Factors (CPF) on the Fusarium Head Blight Index of Spring Wheat Sampled in Southeast Saskatchewan, from 1999 to 2002.

	Year			
CPF	**1999**	**2000**	**2001**	**2002**
Cultivar susceptibility	ns[1]	***	(*)	ns
Glyphosate use	*	**	**	*
Previously-grown crop	ns	*	ns	**
Tillage system	ns	(*)	**	ns

[1] ns=not significant, *, ** and ***, significant at P<0.10, 0.05 and 0.01, respectively, according to chi-square and ANOVA tests. Symbols in parenthesis indicate that only the ANOVA test was significant. Note that ANOVA tests were only conducted on the 2000 and 2001 data.

When data were pooled across years, and we introduced a term to the model to represent the effect of growing season conditions (year factor), the model explained 38% of the variance, with the year term alone explaining 32% of the variance. Previous GF application, tillage system and previously-grown crop each accounted for about 2% of the variance, while cultivar susceptibility contributed less than 1% to the variance. The effects of herbicide Groups 1, 2 or 4, N fertilizer use, seeding rate and date had no significant effect on FHB in any year and therefore were not included in this analysis.

The observation that the environment was the most important factor determining FHB development is supported by previous studies (Cromey et al., 2002; Schaafsma et al., 2001).

The significance of the effects of the CPFs that affected FHB the most for each of the years is summarized in Table 1 for all fields sampled. Overall, the effects of the various CPFs on FHB were lower in years with high (2001) and low (1999 and 2002) disease pressure compared to a year with moderate (2000) disease pressure for this region of the Prairies.

GF application in the previous 18 months (or 3 years) significantly affected disease levels every year (Table 1). Even though disease levels were low, previous GF application was the only CPF in 1999, and one of only two CPFs in 2002, that significantly affected the FHB index. In addition, the fact that the GF effect was not confounded by that of other CPFs, such as tillage system, in 1999 and 2002, confirmed the observations made in the other years when disease levels were higher (2000 and 2001). These observations suggest that the effects of previous GF application on FHB was not affected by environmental conditions as much as those of the other CPFs.

Table 2. Significance of Effects of Crop Production Factors (CPF) on the Fusarium Head Blight Index of Spring Wheat Grown Under Minimum-till Management in Southeast Saskatchewan, from 2000 to 2002.

	Year		
CPF	**2000**	**2001**	**2002**
Cultivar susceptibility	**[1]	ns	ns
Glyphosate use	**	***	*
Previously-grown crop	ns	ns	ns

[1] ns=not significant, *, ** and ***, significant at P<0.10, 0.05 and 0.01, respectively, according to chi-square and ANOVA tests. Note that ANOVA tests were only conducted on the 2000 and 2001 data.

The proportion of fields that had received GF applications at any time in the previous 18 months or 3 years was highly dependent on the tillage system used by producers. When only fields under minimum-till were analyzed (Table 2), the effects of the previously-grown crop and cultivar susceptibility on the proportion of fields in the high FHB class were smaller than when all crops were analyzed together. However, the effect of previous GF application on FHB levels was greater in wheat crops under minimum-till than when all tillage systems were combined (Table 1).

In all four years, crops grown in fields previously treated with GF had a higher FHB index than crops grown in fields that had not been treated with GF in the same time period. For 2000 and 2001, the years with the highest disease levels, the mean FHB index for all wheat crops grown in GF-treated fields was about 75% higher than for wheat crops grown in GF-untreated fields, while for fields under minimum-till management previous GF application increased the mean FHB index by an average of 122%.

Even though this study has shown a positive association of previous GF application with FHB development, the nature of this association is not known. Although previous studies have reported a stimulatory effect of glyphosate on plant diseases, none examined FHB in cereals or *F. graminearum*, the most important FHB pathogen in North America.

A review by Levesque and Rahe (1992) showed that herbicides can have a direct effect on various components of the soil microflora, such as plant pathogens, antagonists, or mycorrhizae, which can potentially result in increased or decreased incidence of plant disease. Pathogens able to infect weeds can increase their inoculum potential after weeds have been sprayed with herbicides, which could subsequently affect host crops. Glyphosate application may indirectly stimulate pathogen invasion of weeds through root exudates after treatment.

Fusarium spp. are among several fungi that have been shown to act synergistically in causing the death of glyphosate-treated plants. Levesque et al. (1987) reported that glyphosate application increased root colonization of various treated weeds by *F. avenaceum* and *F. oxysporum*, and it also increased the propagule density of these *Fusarium* species in the soil. Levesque et al. (1992) reported that the efficacy of glyphosate on wheat seedlings depended on the synergistic action of these species and others in the soil.

Johal and Rahe (1984) and Rahe et al. (1990) suggested that poor emergence, establishment, and growth of crops planted soon after glyphosate treatment could be due to stimulation of pathogenic root fungal activity on treated plants. They concluded that the glyphosate-induced root colonization by *Fusarium* spp. and other pathogens was the cause, and not the result, of plant death following application of certain doses of glyphosate. Flax plants treated with glyphosate were also rapidly colonized by several species of fungi, including *F. culmorum* (Brown and Sharma, 1984).

Kawate et al. (1997) also suggested that weed control with glyphosate in the spring may provide *Fusarium* pathogens an energy source for survival and proliferation. *Fusarium* populations were greater in the rhizosphere soil from glyphosate-treated henbit than from untreated henbit. Pea planted in soil where henbit has been treated with glyphosate could be exposed to higher populations of *F. solani* f. sp. *pisi*. Similarly, glyphosate-treated quackgrass was rapidly colonized by *F. culmorum* which caused damage to the subsequent barley crop (Lynch and Penn, 1980).

Although more recent reports found that glyphosate-tolerant and -nontolerant cultivars responded similarly to infection by *F. solani* f. sp. *glycines* (sudden death syndrome), they also observed that after herbicide application a synergistic interaction with glyphosate occurred. Sanogo et al.

(2000, 2001) concluded that herbicide-induced stress could explain the significant increase in sudden death syndrome and pathogen isolation frequency following application of glyphosate, among other herbicides, to glyphosate-treated soybean. In a field study conducted in Missouri, Kremer (2003) also reported that glyphosate applications on glyphosate-tolerant soybeans at recommended rates resulted in increases in *Fusarium* populations on the roots and rhizosphere. These observations led them to conclude that glyphosate applications could cause increased disease levels in soybean, and potential yield losses.

In *in vitro* studies, growth of *F. graminearum* and *F. avenaceum* was stimulated when fungi were grown on media amended with GF (Hanson and Fernandez, 2003), whereas Krzysko-Lupicka and Orlik (1997) showed that *Fusarium* spp. grew out of soil suspensions only when these were plated on nutrient media in which glyphosate had been used as the sole source of C or P, but not on nutrient media alone.

In regards to tillage system, our study found that fields under minimum-till had the highest, or among the highest, disease levels, although this difference was significant only in 2000 and 2001 when disease pressure was medium to high. The FHB index of crops grown under zero-till was significantly lower than that of crops grown under minimum-till management in both years, and lower than that of crops grown under conventional systems in 2001. On average, the magnitude of the increase in FHB levels from crops grown under zero-till to those grown under minimum-till was about 70%. In a FHB survey, Schaafsma et al. (2001) also reported that deoxynivalenol levels in wheat under minimum-till were higher than in wheat under no-till or conventional-till. Dill-Macky and Jones (2000) reported that FHB was lower in wheat grown in rotation with corn using moldboard plow compared to either chisel plowed or no-till plots. They attributed the lack of a difference in FHB between chisel plow and no-till to the density and layering of residues in the latter which reduced residue to soil contact and might have affected the sporulation potential of the pathogen. The layering of the crop residues, poor fungal colonization of the upper fresh residues, leaching of antifungal compounds in the initial stages of residue decomposition, and/or other factors related to the microenvironment might explain the lower disease levels under zero-till than minimum-till observed in our study. The even greater effect of previous GF application on FHB levels when fields under minimum-till were analyzed separately suggest that the lower FHB index in wheat crops grown under zero-till than minimum-till management observed in our study was not related to previous GF application, but to factor(s) intrinsic to zero-till and the lack of residue disturbance which appears to have impacted inoculum levels and/or its availability for head infection.

In general, the previously-grown crop did not affect FHB consistently across years, and this effect was only significant in 2000 and 2002 when all crops were analysed (Table 1). The lack of a significant previously-grown crop effect could be due, at least partly, to noncereal roots and residues harbouring FHB inoculum (e.g. Fernandez, 2003; Fernandez et al., 1992; Fernandez et al., 2003).

For cultivar susceptibility, the intermediate level of resistance available in wheat cultivars currently registered in western Canada appeared to be more effective under moderate (2000) than under high (2001) disease pressure for this area of the Prairies (Tables 1 and 2). As expected, differences in susceptibility to FHB among wheat cultivars did not play an important role under the low disease pressure experienced in 1999 and 2002.

Conclusions

- FHB levels differed significantly from 1999 to 2002, indicating that the environment had the greatest effect on disease development.

- Based on the observations of 659 spring wheat crops made across four years, we conclude that in southeast Saskatchewan growing wheat in fields where GF has been applied in the previous 18 months or 3 years, and growing susceptible wheat cultivars under minimum-till management, resulted in the most damage due to FHB in years conducive to disease development. Factors other than previous GF application resulted in a lower FHB index in wheat crops grown under zero-till than minimum-till management.

- The effect of previous GF application on FHB levels did not appear to be as affected by environmental conditions as that of other CPFs whose effects on disease levels were not very consistent from year to year. However, it is not known if similar effects of GF on FHB development would occur in environments less or more conducive to FHB development.

- Based on the statistically significant and consistent effect of previous GF application on FHB development in spring wheat throughout the four years of this study conducted in producers= fields, further research is needed to elucidate the mechanisms determining these effects.

Acknowledgements

This research was conducted with financial support from the Saskatchewan Agriculture Development Fund. The technical assistance of Shanna Stolhandske-Dale, Melissa Boire, Dale Kern and Stephen Walter is gratefully acknowledged.

References

Brown, A.E. and H.S.S. Sharma, 1984. Production of polysaccharide-degrading enzymes by saprophytic fungi from glyphosate-treated flax and their involvement in retting. Ann. Appl. Biol. 105: 65-74.

Cromey, M.G., S.C. Shorter, D.R. Lauren, and K.I. Sinclair, 2002. Cultivar and crop management influences on fusarium head blight and mycotoxins in spring wheat (*Triticum aestivum*) in New Zealand. N. Z. J. Crop Hortic. Sci. 30: 235-247.

Dill-Macky, R. and R.K. Jones, 2000. The effect of previous crop residues and tillage on Fusarium head blight of wheat. Plant Dis. 84: 71-76.

Fernandez, M.R., 2003. *Fusarium* populations in underground tissue of pulse, oilseed and cereal crops grown in the Black soil zone of southeastern Saskatchewan. Page 147. In: Proceedings of 3rd Canadian Fusarium Head Blight Workshop, Winnipeg, MB.

Fernandez, M.R., J.M. Fernandes, and J.C. Sutton, 1992. Effects of fallow and of summer and winter crops on survival of wheat pathogens in crop residues in southern Brazil. Plant Dis. 77:698-703

Fernandez, M.R., P.G. Pearse and G. Holzgang, 2003. *Fusarium* spp. in residues of cereal and noncereal crops grown in rotation in eastern Saskatchewan. Can. J. Plant Pathol. 25: 423.

Fernandez, M.R., P.G. Pearse, G. Holzgang, and G. Hughes, 2000. Fusarium head blight in common and durum wheat in Saskatchewan in 1999. Can. Plant Dis. Surv. 80:57-59.

Fernandez, M.R., P. G. Pearse, G. Holzgang and G. Hughes, 2001. Fusarium head blight in common and durum wheat in Saskatchewan in 2000. Can. Plant Dis. Surv. 81: 83-85.

Fernandez, M.R., P.G. Pearse, G. Holzgang, and G.R. Hughes, 2002. Fusarium head blight in common and durum wheat in Saskatchewan in 2001. Can. Plant Dis. Surv. 82: 36-38.

Gomez, K.A. and A.A. Gomez, 1984. Statistical Procedures for Agricultural Research. Second Ed. John Wiley and Sons, New York, NY.

Hanson, K.G. and M.R. Fernandez, 2003. Glyphosate herbicides affect plant pathogenic fungi. Can. J. Plant Pathol. 25: 120.

Johal, G.S. and J.E. Rahe, 1984. Effect of soilborne plant-pathogenic fungi on the herbicidal action of glyphosate on bean seedlings. Phytopathology 74: 950-955.

Kawate, M.K., S. G. Colwell, A.G. Ogg, Jr., and J. M. Kraft, 1997. Effect of glyphosate-treated henbit (*Lamium amplexicaule*) and downy brome (*Bromus tectorum*) on *Fusarium solani* f. sp. *pisi* and *Pythium ultimum*. Weed Sci. 45: 739-743.

Kremer, R., 2003. Soil biological processes are influenced by Roundup Ready soybean production systems. Phytopathology 93: S104.

Krzysko-Lupicka, T. And A. Orlik, 1997. The use of glyphosate as the sole source of phosphorus or carbon for the selection of soil-borne fungal strains capable to degrade this herbicide. Chemosphere 34: 2601-2605.

Levesque, C.A. and J.E. Rahe, 1992. Herbicide interactions with fungal root pathogens, with special reference to glyphosate. Ann. Rev. Phytopathol. 30: 579-602.

Levesque, C.A., J.E. Rahe, and D.M. Eaves, 1987. Effects of glyphosate on *Fusarium* spp.: its influence on root colonization of weeds, propagule density in the soil, and crop emergence. Can. J. Microbiol. 33: 354-360.

Levesque, C.A., J.E. Rahe, and D.M. Eaves, 1992. The effect of soil heat treatment and microflora on the efficacy of glyphosate in seedlings. Weed Res. 32: 363-373.

Lynch, J.M. and D.J. Penn, 1980. Damage to cereals caused by decaying weed residues. J. Sci. Food Agric. 31: 321-324.

Pearse, P.G., G. Holzgang, C.L. Harris, and M.R. Fernandez, 2003. Fusarium head blight in common and durum wheat in Saskatchewan in 2002. Can. Plant Dis. Surv. 83: 57-59.

Rahe, J.E., C.A. Levesque, and G.S. Johal, 1990. Synergistic role of soil fungi in the herbicidal efficacy of glyphosate. pp. 260-275. In: Biological weed control using microbes and microbial products as herbicides. Ed. R.E. Hoagland. American Chemical Society, Washington, D.C. 341 pp. Symposium, April 9-14, 1989.

Sanogo, S., X.B. Yang, and P. Lundeen, 2001. Field response of glyphosate-tolerant soybean to herbicides and sudden death syndrome. Plant Dis. 85: 773-779.

Sanogo, S., X.B. Yang, and H. Scherm, 2000. Effects of herbicides on *Fusarium solani* f. sp. *glycines* and development of sudden death syndrome in glyphosate-tolerant soybean. Phytopathology 90: 57-66.

SAS Institute, Inc. 2002. JMP Statistics and Graphics Guide. SAS Institute Inc, Cary, NC.

Saskatchean Varieties of Grain Crops 2003. Saskatchewan Agriculture and Food, Regina, Saskatchewan.

Schaafsma, A.W., L. Tamburic-Ilinic, J.D. Miller, and D.C. Hooker, 2001. Agronomic considerations for reducing deoxynivalenol in wheat grain. Can. J. Plant Pathol. 23: 279-285.

Shapiro, S.S. and M.B. Wilk, 1965. An analysis of variance for normality (complete samples). Biometrika 52: 591-611.