The Effect of Leaf Spots on Yield and Quality of Wheat in Southern Saskatchewan

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Abstract

Although leaf spots have been reported to have a negative effect on yield and quality, the magnitude of the effect of leaf spots on grain yield and quality of wheat cultivars grown on dryland in southern Saskatchewan is not known. Experiments were conducted at Swift Current (Brown soil) and Indian Head (Black soil) for three years to determine effects of leaf spots on grain yield, kernel weight, test weight and protein concentration of wheat. Two fungicides, Folicur 3.6F and Bravo 500 were applied at different growth stages in order to diversify the severity of leaf spots. Three common wheat (*T. aestivum* L.) cultivars - AC Domain, Laura and AC Elsa and three durum wheat (*T. turgidum* L. var *durum*) cultivars with different levels of leaf spot susceptibility were used in this study. The control of leaf spots by fungicides often did not cause an increase of yield, kernel weight, test weight or grain protein concentration in the drier Prairies where yield potential is relatively low. Fungicide treatments significantly increased yield in only two of six location-years (Folicur applied at head emergence in 1997 (0.07-0.13 t ha^{-1}) ($P < 0.05$) and Folicur applied at flag emergence and/or head emergence in 1998 (0.41-0.47 t ha^{-1}) ($P < 0.001$) at Indian Head. Fungicide applications significantly increased kernel weight in only three of six location-years (applications at flag leaf emergence at Swift Current (0.8-1.1 mg) ($P < 0.05$) and Indian Head (1.8-2.0 mg) ($P < 0.001$) in 1998 and at Indian Head in 1999 (10-1.1 mg) ($P < 0.01$). An increase of grain protein concentration was only found in treatments of Bravo applications at Indian Head in 1998 (0.3-0.7%) ($P < 0.001$). It seems that the control of leaf spots tended to have higher effect on yield and quality at Indian Head than Swift Current, it could be attributed to better controls of leaf spots at early milk stage ($P < 0.001$) and/or higher yield potential at Indian Head ($P < 0.001$). Although the cultivars used in this study have different leaf spot susceptibility ($P < 0.001$), there were no consistent cultivar differences in the effectiveness of the fungicides on control of leaf spots and on the yield, kernel weight and other quality characteristics.

Leaf spots are a common and potentially severe foliar disease of wheat. Many studies have reported that leaf spots have a negative effect on grain yield (Eyal and Ziv, 1974; King, et al., 1983; McKendry and Henke, 1994), test weight (Milus, 1994) and milling quality (Mckendry et al., 1995), especially under environments favorable for the development of leaf spots or under intensive management such as irrigation (Duczek and Jones-Flory, 1994) and high N fertilizer rates (Howard, et al., 1994). In the past decade there has been an increase in the incidence of leaf spotting diseases of wheat in southern Saskatchewan, Canada. These are attributed mainly to *Pyrenophora tritici-repentis* (tan spot), *Septoria nodorum* and *S. tritici* (septoria leaf blotch complex) and all current spring wheat cultivars are susceptible to this disease complex

(Fernandez, et al., 1996; Fernandez, et al., 1998). Consequently there is increased pressure on producers to chemically control diseases that might affect yield and quality. The magnitude of the impact of leaf spots on grain yield and quality of wheat cultivars grown on dryland in this area, however, is not known. Research on these issues is therefore necessary to provide informed guidelines for use by producers. The objective of this study was to determine the effect of leaf spots on grain yield, kernel weight, test weight and protein concentration of spring common (*T. aestivum* L.) and durum (*T. turgidum* L. var *durum*) wheat in southern Saskatchewan.

Materials and Methods

A three-year experiment (1997-1999) was conducted at two locations, Swift Current in the Brown soil zone and Indian Head in the Black soil zone of southern Saskatchewan. A factorial, randomized complete block design was used. The first factor was genotypes. There were three hard red spring cultivars (common wheat, *T. aestivum* L.) - AC Domain, Laura and AC Elsa and three durum wheat genotypes - Durex, Kyle and DT665. Preliminary observations had shown that these genotypes differed for level of leaf spot susceptibility. The second factor was fungicide application. In 1997, there were four fungicide treatments: a control - no fungicide, Folicur 3.6F (39% of tebuconazole, a systemic fungicide) applied at the stem elongation stage (Zadoks' growth stage, GS 31-32, Zadoks et al., 1974), head emergence (GS 58), and both stages (GS 31-32 and GS 58). There were seven fungicide treatments in 1998 and 1999: control, Folicur 3.6F sprayed at flag leaf just visible (GS 37), head emergence (GS 58) and both stages (GS 37 and GS 58), and Bravo 500 (500 g L^{-1} of chlorothalonil, a contact, protectant fungicide) sprayed at flag leaf ligule just visible (GS 39), head emergence (GS 58) and both stages (GS 39 and GS 58). Spray rates were 336 mL ha^{-1} of product for Folicur and 2500 mL ha^{-1} for Bravo for each application. Plants were grown on summerfallow with four replications. Each plot was 16-rows, 3 m long with rows 0.23 m apart, with 1 m wide buffer area between plots seeded to fababean. Seeding rate was 250 viable seeds m^{-2}. Seeding dates were 14 May (day of year (DOY) 134) and 23 May (DOY 143) in 1997, 12 May (DOY 132) and 26 May (DOY 146) in 1998 and 26 May (DOY 146) and 30 May (DOY 150) in 1999 at Swift Current and Indian Head, respectively. Growth stages were recorded from each plot according to Zadoks scale. respectively. Growth stages (GS) were recorded from each plot according to Zadoks scale. Twenty leaves from each leaf position sampled (the third, penultimate and/or flag leaf) were taken randomly from each plot and the percentage area affected by leaf spots on leaves was estimated visually. The prevalence of each of the leaf spotting fungi was determined by plating eleven leaf samples from each plot on water agar, and determining percent colonization by each of the fungi using the method described by Fernandez et al (1994). Grain yields were determined by harvesting plots with a plot combine. Kernel weight, test weight and grain protein concentration were determined from the harvested samples.

Statistical analysis

The Mixed model (SAS, 1996) with the REML option was conducted with fungicide treatments and genotypes fixed and replications random. Bartlett's test for homogeneity of errors (Steel et al. 1997) was performed over environments on each trait. The errors were heterogeneous, so separate analyses were performed for each trait in each location within each year. The

ESTIMATE statement was used to compare traits between a fungicide treatment and the control, and between Folicur and Bravo applications. Standard error of the difference between means (SED) was calculated for fungicide treatment.

Results and Discussion

For all cultivars in the three years, *Pyrenophora tritici-repentis* was the most prevalent leaf spotting pathogen at both Swift Current and Indian Head in the three years (71-96%), while the secondary pathogen was *Septoria nodorum* at Swift Current (2-17%) and *Cochliobolus sativus* (spot blotch) at Indian Head (2-8%). There were significant cultivar differences in leaf spot severity, grain yield, kernel weight, test weight and protein concentration (P < 0.001) and cultivar differences for untreated controls were very consistent over the three years and the two locations. For overall means, Durex had the highest leaf spot severity on flag leaf at early milk (20.0%), followed by AC Domain (7.0%), Laura (4.8%), Kyle (4.3%), DT665 (2.6%) and AC Elsa (2.1%). DT 665 had the highest yield (3.8 t ha^{-1}), followed by Kyle (3.4 t ha^{-1}), Durex (3.3 t ha^{-1}), AC Elsa (3.2 t ha^{-1}), Laura (3.1 t ha^{-1}) and AC Domain (3.1 t ha^{-1}). Cultivars with higher yield are associated with higher kernel weight and test weight compared with cultivars with lower yield (data not shown). AC Domain had the highest protein concentration (15.1%), followed by AC Elsa (15.0), Laura (14.7%), DT 665 (13.5%), Kyle (13.2%), and Durex (12.9%). The incidence of leaf spots for untreated controls at Swift Current at early milk was usually higher than Indian Head, such as flag leaf in 1997 (P < 0.01, Table 1), penultimate leaf in 1998 (P < 0.001, Table 3) and both flag and penultimate leaf in 1999 (P < 0.001, Table 4). Differences in leaf spot severity among different years were also significant at both locations (P < 0.001). It was the highest in 1999, followed by 1998 and 1997. Table 1, 2 and 4). Differences in grain yield were different among the three years and between two locations (P □ 0.001), except between 1997 and 1999 at Swift Current and between Swift Current and Indian Head in 1999. Average yields for untreated controls were 2.99 and 3.40 t ha^{-1} in 1997, 3.61 and 4.26 t ha^{-1} in 1998 and 3.00 and 2.72 t ha^{-1} in 1999 at Swift Current and Indian Head, respectively. 1998 was the year with highest yield for both locations. In general, Indian Head had higher yield potential than Swift Current (P □ 0.001) except that the yield was reduced by frost in 1999 at Indian Head.

At Swift Current in 1997, precipitation from seeding to stem elongation (26 June, DOY 177) was relatively high (110 mm), however, only 37 mm and 15 mm fell between stem elongation and head emergence (16 July, DOY 197) and between head emergence and early milk stage (30 July, DOY 211), respectively. Leaf samples taken at head emergence showed that over all genotypes, Folicur applied at stem elongation significantly (P < 0.05) lowered leaf spots (7%) on the third leaf from the control (10%) and no fungicide treatment □ genotype interaction was found (Table 1). The incidence of leaf spots on the flag leaf was low at early milk, which was attributed to the dry condition after flag leaf emergence. No treatment difference in leaf spot severity on flag leaf was found. Folicur treatments did not significantly affect grain yield, kernel weight, test weight and protein concentration, while Folicur treatment □ genotype interactions were significant for kernel weight and test weight (P □ 0.05, Table 2). The reason for those interactions is not known, but obviously it is not related to the control of leaf spots by Folicur treatments.

Indian Head was very dry in 1997. The total precipitation was only 61 mm between seeding and early milk stage (31 July, DOY 212), and most fell before stem elongation (July 5, DOY 187). No treatment difference in leaf spot severity was found at heading. Although all Folicur treatments reduced leaf spots of flag leaf significantly ($P < 0.001$) at early milk (Table 2), the incidence of leaf spots was very low and the magnitude of treatment difference was too small. Even the drought was very severe in 1997, the yield at Indian Head was still higher than Swift Current (Table 2) reflecting a higher yield potential at Indian Head. Fungicide treatments did not significantly affect kernel weight, test weight and protein concentration; however, Folicur applications at head emergence and at both stages slightly, but significantly (P □ 0.05) increased yield and the Folicur treatment □ genotype interaction was not significant (Table 3). Obviously, this effect can not be explained by the reduction of leaf spots by Folicur applications. It is possible that this Folicur effect on yield was not directly related to disease control. Similarly, Kettlewell and Davies (1982) found that the yield increase by the application of Tilt was not directly related to disease control, but was associated with the higher photosynthetic rate.

Precipitation between seeding and flag leaf emergence (5 July, DOY 186) was high at Swift Current (149 mm) in 1998, but only 26 mm fell within 30 days after flag leaf emergence. It was hot and dry during the period of grain filling. Fungicide applications significantly ($P < 0.001$) differed for leaf spot severity at early milk for both flag and penultimate leaves and fungicide treatment □ genotype interactions were not significant (Table 3). Early fungicide application followed by late fungicide applications reduced leaf spot severity significantly ($P < 0.001$), and Folicur was significantly more effective than Bravo ($P < 0.05$) for the flag leaf. For the penultimate leaf, only early applications reduced leaf spots significantly ($P < 0.01$) and the effectiveness did not differ between two fungicides. Fungicide treatments and genotype □ fungicide treatment interactions were not significant for yield and quality characteristics, except for kernel weight ($P < 0.05$). Early and double Folicur applications and early Bravo application increased kernel weight significantly ($P < 0.05$).

At Indian Head in 1998, precipitation between the period of seeding and flag leaf emergence (July 16, DOY 197) was 213 mm, but only 28 mm fell within 30 days after flag leaf emergence. Fungicide applications significantly ($P < 0.001$) affected leaf spot severity for both leaf positions (Table 3). Although the fungicide treatment □ genotype interactions were significant ($P < 0.001$), all fungicide applications significantly ($P < 0.05$) reduced leaf spots for each genotype. Both early and late applications reduced leaf spots significantly ($P < 0.001$). The average yield at Indian was significantly ($P < 0.001$) higher than Swift Current (Table 3). Fungicide treatment effects on the yield, kernel weight and protein concentration were significant ($P < 0.001$) and the fungicide treatment □ genotype interaction was only significant for kernel weight ($P < 0.01$). All Folicur treatments significantly increased yield, while treatments of Bravo did not differ from the control significantly (Table 3). Except for AC Domain and Laura, the genotypes has similar treatment differences in kernel weight. All Folicur treatments and early Bravo application increased kernel weight. For AC Domain, only early application of Bravo had significantly ($P < 0.05$) higher kernel weight than the control. For Laura, no fungicide treatment difference was found for kernel weight (data not shown). Bravo treatments, especially for applications at both stages, significantly increased protein concentration ($P < 0.01$). Although both fungicides were effective in reducing the severity of leaf spots in 1998 at Indian Head, Folicur applications tended to increase kernel weight and yield, while Bravo applications tended to increase protein concentration. This difference is probably due to the difference in the effect of fungicides on the physiology of the plant, not directly related to the decrease in disease severity.

The incidence of leaf spots for penultimate leaf at Swift Current was severer and the control of leaf spots by fungicide applications was less effective than Indian Head (Table 3). This could be the reason that the increase of grain yield by the fungicide applications was only found at Indian Head. Another possible reason is that the yield potential at Indian Head is higher. The control of leaf diseases is usually more important to grain production in the environment with higher yield potential (Duczek and Jones-Flory, 1994; Howard, et al., 1994). Kernel weight appeared to be the main parameter affected by leaf spots, but grain yield and protein concentration could also be affected. Gooding et al. (1994) found that fungicide applications increased grain yield and kernel weight significantly, but the grain protein concentration was reduced significantly at the same time. It did not occur in our study. It seems that the control of leaf spots could improve the uptake of both carbohydrates and nitrogen by the grain.

Precipitation was 120 mm between seeding and flag leaf emergence (July 19, DOY 200) and 46 mm within 30 days after flag emergence at Swift Current in 1999. Fungicide application significantly ($P < 0.001$) affected leaf spot severity, and the fungicide treatment × genotype interaction was not significant for both leaf positions (Table 4). Both early and late applications reduced leaf spots significantly for both leaf positions. Fungicide treatment effects on yield, kernel weight, test weight and protein content were not significant.

There were 149 mm of precipitation between seeding and flag leaf emergence (July 14, DOY 195) at Indian Head in 1999 and 72 mm within 30 days after flag emergence. The average mean, maximum and minimum air temperature over 80 years in August is 17.5 ^{0}C, 24.8 ^{0}C and 10.2 ^{0}C and in 1999 was 16.6 ^{0}C, 23.7 ^{0}C and 9.5 ^{0}C, respectively. The low temperature during grain filling delayed maturity and caused lodging and frost damage. Significant ($P < 0.001$) fungicide treatment effects were found for both leaf positions (Table 4). Although the fungicide treatment × genotype interaction was significant for flag leaf ($P < 0.001$), fungicide applications reduced leaf spot severity significantly for each genotype ($P < 0.05$). Both early and late applications reduced leaf spots significantly for both leaf positions. Similar to 1998 at both locations, a significant fungicide effect on kernel weight was found ($P < 0.01$) and fungicide treatment × genotype interaction was not significant. All treatments including an early fungicide application had higher kernel weight ($P < 0.05$) than the control.

Again, the incidence of leaf spots at Swift Current was severer and the control of leaf spots by fungicide applications was less effective than Indian Head (Table 4) and this could be the reason that the increase of kernel weight by the fungicide applications was found at Indian Head, but not at Swift Current.

Overall, the control of leaf spots by fungicides often did not cause an increase of yield or the improvement of grain quality in the drier Prairies where yield potential is relatively low. Although the cultivars used in this study have different leaf spot susceptibility, there were no consistent cultivar differences in the effectiveness of the fungicides on control of leaf spots and on the yield, kernel weight and other quality characteristics.

Table 1. Leaf spot severities of the third leaf at head emergence (LS3) and of flag leaf at early milk (LSF), yield, kernel weight (kwt, mg), test weight (twt, kg hL^{-1}) and protein concentration (%) at Swift Current and Indian Head in 1997.

Treatment	LS3	LSF	Yield	kwt	twt	protein
	------ % ------		t ha^{-1}	mg	kg hL^{-1}	%
Swift Current						
1 Untreated control	10.1	5.3	2.99	31.3	74.9	12.9
2 Stem elongation	7.4	3.4	2.86	30.2	73.7	13.5
3 Head emergence	--	4.1	2.96	30.3	74.1	13.1
4 Both stages	--	5.6	3.01	31.2	74.3	12.9
SED	1.1	1.7	0.08	0.6	0.6	0.3
Indian Head						
1 Untreated control	11.6	1.4	3.40	38.5	77.3	15.8
2 Stem elongation	11.4	1.0	3.41	39.0	77.3	16.0
3 Head emergence	--	0.9	3.53	39.3	77.4	15.9
4 Both stages	--	0.7	3.47	38.9	77.1	16.0
SED	1.2	0.1	0.05	0.4	0.2	0.1

Table 2. Treatment comparisons of kernel weight and test weight for each cultivar at Swift Current in 1997.

	Hard Red Spring Wheat			Durum		
Treatment	AC Domain	Laura	AC Elsa	Durex	Kyle	DT665
Kernel weight						
	---------------------------------- mg --------------------------------					
1 Untreated control	28.0	27.4	29.5	33.2	33.9	35.5
2 Stem elongation	29.6	25.4	27.3	34.9	30.0	34.2
3 Head emergence	26.0	27.1	28.5	35.6	29.8	34.8
4 Both stages	29.1	26.5	27.5	33.9	31.1	38.9
SED† (0.05) = 0.7						
Test weight						
	---------------------------------- kg hL^{-1} ----------------------------					
1 Untreated control	73.9	73.6	74.1	74.4	77.0	76.2
2 Stem elongation	74.2	70.6	72.5	73.6	73.5	78.0
3 Head emergence	71.6	73.4	73.7	75.3	74.0	76.4
4 Both stages	73.4	71.6	73.1	74.7	73.0	79.9
SED† (0.05) = 0.6						

† Standard error of difference between treatments.

Table 3. Leaf spot severities of flag leaf (LSF) and of penultimate leaf (LSP) at early milk, yield, kernel weight (kwt), test weight (twt) and protein concentration at Swift Current and Indian Head in 1998.

Treatment	LSF	LSP	Yield	kwt	twt	protein
	------- % -------		t ha^{-1}	mg	kg hL^{-1}	%
Swift Current						
1 Untreated control	13.0	73.6	3.61	33.1	79.3	13.7
2 Folicur at flag emergence	5.7	60.2	3.61	33.9	79.5	13.9
3 Folicur at head emergence	6.9	69.2	3.70	33.3	79.4	13.6
4 Folicur at both stages	4.2	53.8	3.76	34.4	80.2	13.5
5 Bravo at flag emergence	6.5	62.0	3.59	34.2	79.4	13.5
6 Bravo at head emergence	9.8	74.4	3.57	33.6	79.4	13.3
7 Bravo at both stages	5.1	53.0	3.65	33.8	79.8	14.0
SED	1.2	4.9	0.11	0.4	0.4	0.2
1 Untreated control	10.8	29.7	4.26	36.0	78.5	14.1
2 Folicur at flag emergence	3.2	7.0	4.72	38.0	79.6	14.3
3 Folicur at head emergence	3.2	14.5	4.67	37.9	79.1	13.9
4 Folicur at both stages	2.9	6.9	4.73	38.0	79.0	14.0
5 Bravo at flag emergence	2.9	9.8	4.49	37.8	79.2	14.4
6 Bravo at head emergence	5.5	16.8	4.29	35.6	79.1	14.4
7 Bravo at both stages	3.3	8.8	4.24	35.9	79.3	14.8
SED	0.7	2.0	0.13	0.5	0.4	0.2

Table 4. Leaf spot severities of flag leaf (LSF) and of penultimate leaf (LSP) at early milk, yield, kernel weight (kwt), test weight (twt) and protein concentration at Swift Current and Indian Head in 1999.

Treatment	LSF	LSP	Yield	kwt	twt	protein
	------- % -------		t ha^{-1}	mg	kg hL^{-1}	%
Swift Current						
1 Untreated control	17.3	79.6	3.00	31.0	75.7	14.7
2 Folicur at flag emergence	12.5	71.9	3.05	30.7	75.6	14.7
3 Folicur at head emergence	12.2	70.6	3.09	31.0	75.6	14.4
4 Folicur at both stages	11.3	72.5	2.95	31.2	75.6	14.8
5 Bravo at flag emergence	10.1	68.8	3.06	30.8	75.3	14.7
6 Bravo at head emergence	12.6	73.6	3.03	30.5	75.7	14.9
7 Bravo at both stages	8.9	63.7	2.97	31.4	75.9	14.8
SED	1.2	3.4	0.06§	0.3	0.2	0.2
1 Untreated control	12.5	49.8	2.72	30.0	72.3	13.2
2 Folicur at flag emergence	7.9	34.4	2.91	31.0	72.9	13.2
3 Folicur at head emergence	6.9	34.2	2.87	30.7	72.6	13.2
4 Folicur at both stages	6.2	27.1	2.83	31.6	73.0	13.0
5 Bravo at flag emergence	7.8	41.3	2.97	31.1	73.1	13.2
6 Bravo at head emergence	7.2	38.3	2.62	30.3	72.3	13.2
7 Bravo at both stages	6.0	32.2	2.93	30.9	72.7	13.2
SED	0.9	3.8	0.15	0.4	0.4	0.1

§ There were missing values, but the SEDs were very close among different treatment comparisons. Therefore, the mean of SEDs was used.

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