Effect of Foliar Fungicide Application on Seed Size of Winter Wheat[1]

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ABSTRACT

Seed wheat frequently includes only those grains with a diameter larger than 0.238 cm. Foliar diseases of winter wheat (*Triticum aestivum* L.) have the potential to affect the amount of large seed produced. During two years, three experiments were established to quantify the impact of foliar disease (mostly tan spot caused by *Pyrenophora tritici-repentis* (Diet.) Drechs.) and foliar fungicides on yields of large seed. Foliar fungicides were applied to cultivars resistant and susceptible to tan spot. A "healthy" control, treated once a week with Dithane M-45, was included to assess the total impact of tan spot on production of large seed. Increases of 32-44% in large seed from the susceptible cultivars in the "healthy" treatment indicated substantial negative impact from tan spot. Although the systemic fungicide Tilt applied at flag leaf emergence significantly reduced foliar disease ratings, it did not significantly increase the amount of large seed produced, even by susceptible cultivars. Conversely, a single application of Folicur resulted in significant increases (21-34%, 666-971 kg ha^{-1}) in the amount of large seed harvested, but only from susceptible cultivars. Where tan spot occurs, marked increases in yields of large seed can be achieved by a single application of a foliar fungicide on cultivars susceptible to the disease. This will reduce cleaning losses and result in more marketable seed. Not all fungicides will give this result, and care should be taken in selecting a fungicide that has been shown to be effective in a particular location.

Additional index words: Pyrenophora tritici-repentis, **seed cleaning losses, leaf rust, powdery mildew, propiconazole, tebuconazole.**

INTRODUCTION

Seed quality is an important determinant of the performance of wheat (*Triticum aestivum* L.). Seed size is one component of seed quality that can affect stand establishment and grain yields. Sowing large seed has been shown to increase stand establishment, seedling vigour, and winter wheat yields (Evans and Bhatt, 1977; Spilde, 1989). Several factors can affect wheat seed size, including genotype (Fjell, Paulsen and Walter, 1985), environment (Shroyer and Cox, 1984), and foliar disease (Cunger, 1987; Guy, Oplinger, Wiersma and Grau, 1989).

Tan spot [caused by *Pyrenophora tritici-repentis* (Died). Drechs.] is a foliar disease of wheat that occurs worldwide (Hosford, 1981) and is particularly important where reduced tillage is practiced (Sutton and Vyn, 1990). Tan spot is an important disease of hard red winter wheat in Kansas with the potential to reduce yields by about 30% under moderate to severe epidemic conditions (Raymond, Bockus and Norman, 1985). The disease has been shown to negatively affect the number of seeds per head and 100-kernel weight (Shabeer and Bockus, 1988).

Routine use of foliar fungicides on wheat generally has not been economical in the central Great Plains of the US, where yield potential and grain prices are relatively low. However, their routine use on seed-production fields might be justified if it resulted in a significant seed size advantage. Fungicides have the potential to reduce cleaning losses of high-value seed because more large seeds are produced when foliar diseases are controlled. In addition, seed prices are frequently double those for grain, which makes this management practice more attractive to seed producers. The objectives of these experiments were to determine: 1) the potential increases in seed size that could be realised from nearly complete control of foliar disease on winter wheat; 2) the impact of single applications of foliar fungicides on seed size; and 3) the effects of wheat genotypes on the response of seed size to fungicides. These objectives were studied using tan spot as the primary foliar disease.

MATERIALS AND METHODS

Three field experiments were established near Manhattan, Kansas, USA, during the 1989-1990 (one location) and 1990-1991 (two locations) crop seasons. In the first year, plots were arranged in a randomised complete-block design with five replicates and 12 treatments in a split-plot arrangement. Main plots were four cultivars that varied in susceptibility to *P. tritici-repentis*: 'Auburn' (resistant); 'Karl' (resistant); 'Norkan' (susceptible); and 'TAM 105' (susceptible). Subplots (1.22 x 7.62 m) were three levels of disease control achieved by: no fungicide application (no control, diseased); one application of propiconazole (Tilt 3.6E, 292 ml ha^{-1}) at flag leaf emergence (Feekes 8) (partial control); and mancozeb (Dithane M-45 80W, 2.24 kg ha^{-1}) applied once per week from 2 April (leaf sheaths strongly erected, Feekes 5) until maturity (Feekes

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11.4) (maximum control, "healthy"). The latter treatment was begun about the time primary inoculum of the tan spot pathogen was being released from fruiting bodies in the spring. All fungicides were applied in 187 l water ha^{-1} using a back-pack sprayer with a boom having three flat-fan nozzles.

Sowing took place on 29 September 1989 at 67.2 kg ha^{-1}, and standard wheat management practices were followed. Subplots were inoculated on 7 November with air-dried oat kernels colonised by *P. tritici-repentis* at the rate of 190 g per subplot. This inoculation procedure mimics the disease cycle of the fungus (Raymond et al., 1985). During fall (autumn) and winter, the pathogen on the oat kernels produces the sexual spore stage, which initiates the disease the following spring. After this, secondary spread of the pathogen occurs from infected leaves to produce the epidemic (Rees and Platz, 1980).

Severity of powdery mildew [caused by *Blumeria graminis* (DC.) E.O. Speer f. sp. *tritici* (syn. *Erysiphe graminis* DC. f. *sp. tritici* EM. Marchal)] was determined on 18 May (anthesis, Feekes 10.5.1) by rating the percentage area affected on the top three leaves of 25 randomly selected tillers per subplot. Tan spot was evaluated on 4 June 1990 (dough stage, Feekes 11.2) by rating 25 randomly selected flag leaves per subplot for percentage area affected by disease. Wheat was harvested on 2 July with a small-plot combine, and grain yields were calculated. Subsequently, the amount of seed in each of three size fractions was determined by passing grain through two slotted screens [0.238 x 1.91 cm (6/64 x 3/4 in.) and 0.198 x 1.91 cm (5/64 x 3/4 in.)].

During 1990-1991, an identical experiment was established, except that the cultivar Auburn was not included and tebuconazole (Folicur 3.6F, 336 ml ha^{-1}) applied at boot stage (Feekes 10) was substituted for the Tilt treatment. Sowing occurred on 10 October 1990, inoculum was applied on 13 November, tan spot and leaf rust [caused by *Puccinia recondita* Roberge ex Desmaz. f. sp. *tritici]* were rated on 25 flag leaves per subplot on 30 May 1991 (dough), and harvest was on 17 June.

An additional experiment to evaluate effects of rate and timing of fungicides was established during 1990-1991 utilising a randomised complete-block design with seven treatments and four replications. TAM 105 winter wheat was sown on 4 October 1990 into plots 1.22 x 7.62 m and inoculum of *P. tritici-repentis* (200 g per plot) was applied on 13 November. The seven treatments included: 1) "healthy" plots sprayed once per week with Dithane M-45 80W (2.25 kg ha^{-1}) plus triadimefon (Bayleton 50DF, 70 g ha^{-1}) beginning on 19 March (leaf sheath strongly erected) until maturity; 2) nonsprayed; 3) Tilt 3.6E (292 ml ha^{-1}) applied at flag leaf emergence; 4) Folicur 3.6F (336 ml ha^{-1}) applied at flag leaf emergence; 6) Folicur (336 ml ha^{-1}) applied at the boot stage; and 7) Dithane M-45 80W (2.24 kg ha^{-1}) plus Bayleton 50DF (140 g ha^{-1}) applied at the boot stage. Tan spot and leaf rust were evaluated on 29 May 1991 (soft dough) by rating percentage of flag-leaf area affected as described above. Harvest was on 17 June, and the amount of seed in each size fraction was subsequently determined as described above.

Statistical Analysis

Disease severity scores were arcsine square-root transformed before analysis and then back transformed for presentation. Data were analysed using SAS (SAS Institute, Inc., Cary, NC) by Analysis of Variance (ANOVA) followed by LSD ($P < 0.05$) for mean separation. Total grain yields and yields of large seed (> 0.238 cm in diameter) per hectare were calculated and subjected to ANOVA followed by LSD ($P < 0.05$). For clarity, data on yields of medium (0.238-0.198 cm) and small (< 0.198 cm) seed were omitted, because trends for them were negatively correlated with those for large seed and the percentage large seed was of particular interest in these experiments.

RESULTS

During 1989-1990, powdery mildew occurred in addition to tan spot. Disease severities for mildew were much lower than those for tan spot (Table 1), and warm weather following anthesis halted mildew development. Cultivar reactions to powdery mildew paralleled their reactions to tan spot. No other foliar diseases of any significance were noted at the site.

Significant interactions occurred between main and subplot treatments for three of the four traits measured (tan spot, grain yields, and large seed) but not for mildew severity. Because of the interactions, pooled main- and subplot-means are not presented. Application of Tilt significantly reduced severities of powdery mildew and tan spot on all cultivars except for cv. Karl, which is resistant to both diseases (Table 1). However, no significant effects on grain yields or yields of large seed were noted with Tilt. The "healthy" treatment did not significantly reduce mildew scores when compared with the nonsprayed control; however, it did reduce tan spot on all cultivars except cv. Karl. Significant grain yield increases were obtained with this treatment from the susceptible cultivars but not from the resistant ones. Similarly, increases in production of large seed with the "healthy" treatment were significant only for susceptible cultivars (Table 1).

During 1990-1991, leaf rust occurred in addition to tan spot. Disease severities for rust were not as high as those for tan spot, and the cultivar reactions to leaf rust paralleled those to tan spot (Table 2). No other significant foliar diseases were noted.

Significant interactions occurred between main plots and subplots for all four parameters measured (leaf rust, tan spot, grain yields, large seed). Application of Folicur significantly reduced leaf rust and tan spot ratings relative to the nonsprayed control except for tan spot on cv. Karl

Table 1. Effect of winter wheat genotype and foliar fungicides on foliar diseases, grain yields, and amount of large seed produced: 1989-1990.

Cultivar	Fungicide	Powdery mildew[1] (18 May)	Tan spot[1] (4 June)	Grain yields (kg ha^{-1})	Grain yields Increase (kg ha^{-1})	Grain yields Increase (%)	Large seed[5] (kg ha^{-1})	Large seed Increase (kg ha^{-1})	Large seed Increase (%)
Auburn	None	6.1 ef[2]	29.5 e	2680 ef	-	-	1439 e	-	-
Auburn	Tilt[3]	1.9 g	20.6 f	2807 de	127	4.7	1722 cde	283	19.7
Auburn	Healthy[4]	3.7 fg	22.1 f	2775 de	95	3.5	1695 de	256	17.8
Karl	None	9.4 cde	42.4 cd	2913 de	-	-	2098 bcd	-	-
Karl	Tilt	6.9 def	38.5 d	3157 cd	244	8.4	2340 b	242	11.5
Karl	Healthy	6.2 ef	38.2 d	3173 cd	260	8.9	2441 b	343	16.3
Norkan	None	20.1 a	74.8 a	2356 f	-	-	1614 e	-	-
Norkan	Tilt	13.3 bc	55.7 b	2696 ef	340	14.4	1749 cde	135	8.4
Norkan	Healthy	15.3 ab	50.1 bc	2998 de	642	27.2	2145 bc	531	32.9
TAM 105	None	13.3 bc	72.7 a	3630 b	-	-	2414 b	-	-
TAM 105	Tilt	5.3 ef	50.9 b	3555 bc	-75	-2.1	2381 b	-33	-1.4
TAM 105	Healthy	11.8 bcd	36.1 de	4272 a	642	17.7	3195 a	781	32.4

[1] Percentage leaf area affected.
[2]Values within a column followed by common letters are not significantly different according to ANOVA and LSD ($P < 0.05$).
[3]Tilt 3.6E (292 ml ha-1) applied at flag leaf emergence (Feekes 8).
[4]Dithane M-45 80W (2.24 kg ha-1) applied weekly from 2 April until maturity (Feekes 11.4).
[5]> 0.238 cm in diameter.

Table 2. Effect of winter wheat genotype and foliar fungicides on foliar diseases, grain yields, and amount of large seed produced: 1990-1991.

Cultivar	Fungicide	Leaf rust[1] (30 May)	Tan spot[1] (30 May)	Grain yields (kg ha^{-1})	Grain yields Increase (kg ha^{-1})	Grain yields Increase (%)	Large seed[5] (kg ha^{-1})	Large seed Increase (kg ha^{-1})	Large seed Increase (%)
Karl	None	5.4[2] b	8.8 cd	3980 cd	-	-	3194 bc	-	-
Karl	Folicur[3]	0.1 c	4.7 de	3890 cd	-90	-2.3	3198 bc	4	0.1
Karl	Healthy[4]	0.1 c	2.3 c	4022 cd	42	1.1	3573 ab	379	11.9
Norkan	None	17.1 a	39.2 a	3773 d	-	-	2531 d	-	-
Norkan	Folicur	0.6 c	22.6 b	4229 bc	456	12.1	3266 bc	735	29.0
Norkan	Healthy	0.0 c	14.3 bc	4563 ab	790	20.9	3595 ab	1064	42.0
TAM 105	None	13.7 a	48.7 a	3996 cd	-	-	2894 cd	-	-
TAM 105	Folicur	0.1 c	4.3 de	4659 a	663	16.6	3865 a	971	33.6
TAM 105	Healthy	0.2 c	1.5 e	4733 a	737	18.4	4026 a	1132	39.1

[1] Percentage leaf area affected at the dough stage (Feekes 11.2).
[2] Values within a column followed by common letters are not significantly different according to ANOVA ($P < 0.05$).
[3]Folicur 3.6 F (336 ml ha^{-1}) applied at boot stage (Feekes 10).
[4]Dithane M-45 80W (2.24 kg ha^{-1}) applied weekly from 19 March until maturity (Feekes 11.4).
[5]> 0.238 cm in diameter.

(Table 2). This treatment significantly increased grain yield from the susceptible cultivars (Norkan and TAM 105) but not from cv. Karl (resistant). The "healthy" treatment reduced ratings for both diseases on all cultivars but increased grain yields only from the susceptible ones. Similarly, significant increases in the amount of large seed produced were obtained with both the Folicur and "healthy" treatments, but only from susceptible cultivars (Table 2).

At the second site during 1990-1991, all foliar fungicide treatments resulted in significantly reduced leaf rust and tan spot severities relative to the nonsprayed control (Table 3). A corresponding grain yield increase occurred with all treatments except Dithane plus Bayleton; however, none of the single applications of fungicide increased yields to the level of the "healthy" treatment. Increases in large seed paralleled those obtained for grain yield, except that Tilt did not significantly increase the amount of large seed relative to the nonsprayed control.

DISCUSSION

The results corroborate other reports (Beuerlein, Oplinger and Reicosky, 1989; Guy and Oplinger, 1989; Karlen and Gooden, 1990) that grain yields of wheat in the US can be increased by a single application of foliar fungicide. Increases are usually achieved only on cultivars susceptible to one or more foliar diseases that are active at the site. The amount of large seed produced can also be significantly increased by fungicide application. Here again, increases will be realised only on susceptible cultivars. Significant cultivar (main) by fungicide treatment (subplot) interactions were due to the differential responses of resistant and susceptible cultivars. As expected, those cultivars with high levels of resistance (Auburn and Karl) did not respond to foliar fungicides during either ofthe two years. However, non significant increases of 12-20% (242-283 kg ha^{-1}) in the amount of large seed produced by resistant cultivars were obtained with a single fungicide application during one year (Table 1).

Other authors have reported that wheat genotype affects the production of large seed (Fjell *et al.*, 1985; Shroyer and Cox, 1984). Our results imply that the effect of genotype could be determined to a certain extent by the inherent resistance of a cultivar to foliar diseases. The amount of large seed from resistant cultivars was not increased by fungicide application, indicating that they were not adversely affected by foliar diseases. Conversely, yield of large seed from susceptible cultivars was significantly increased by fungicides, indicating that their susceptibility can influence the amount of large seed they produce. Nevertheless, resistance is not the sole determinant of genotype effects on seed size, because the yields of large seed from the nonsprayed controls of cultivars TAM 105 (susceptible) and Karl (resistant) were not significantly different (Tables 1 and 2).

The inclusion of the "healthy" treatment in our experiments allowed a more accurate estimate of the total impact of foliar disease on seed size for both resistant and susceptible cultivars. In all three experiments, the amount of large seed produced by susceptible cultivars was increased 32-44% with the "healthy" treatment, indicating substantial

Table 3. Effect of rate and timing of foliar fungicides on foliar diseases, grain yields, and amount of large seed produced by TAM 105 winter wheat: 1990-1991.

Fungicide rate (ha^{-1})	Plant growth stage	Leaf rust[1] (29 May)	Tan spot[1] (29 May)	Grain yields (kg ha^{-1})	Grain yields Increase (kg ha^{-1})	Grain yields Increase (%)	Large seed[4] (kg ha^{-1})	Large seed Increase (kg ha^{-1})	Large seed Increase (%)
Healthy[2]		0.1 e[3]	0.4 e	5243 a	913	21.1	4540 a	1393	44.3
None		16.1 a	37.6 a	4330 c	-	-	3147 d	-	-
Tilt 3.6E, 292 ml	8	7.1 b	15.4 bc	4664 b	334	7.7	3517 cd	370	11.8
Folicur 3.6F, 336 ml	8	2.0 cd	12.2 cd	4829 b	499	11.5	3820 bc	673	21.4
Folicur 3.6F, 504 ml	8	0.8 de	9.0 d	4786 b	456	10.5	3961 b	814	25.9
Folicur 3.6F, 336 ml	10	0.1 e	9.1 cd	4845 b	515	11.9	3813 bc	666	21.2
Dithane M-45 80W, 2.24 kg plus Bayleton 50DF, 140g	10	3.2 c	22.2 b	4601 bc	271	6.3	3585 bc	438	13.9

[1]Percentage leaf area affected at dough stage (Feekes 11.2).
[2]Dithane M-45 80W (2.24 kg ha^{-1}) plus Bayleton 50DF (70 g ha^{-1}) applied weekly from 19 March until maturity (Feekes 11.4).
[3]Values within a column followed by common letters are not significantly different according to ANOVA and LSD ($P < 0.05$).
[4]> 0.238 cm in diameter.

injury from foliar diseases, mainly tan spot. Control of diseases on these cultivars resulted in 531-1393 kg ha-1 additional large seed. Even then, our estimates of the amount of damage are conservative, because complete foliar disease control was not achieved. In the "healthy" treatments during the 1989-1990 experiment, and for tan spot on cv. Norkan in 1990-1991, significant amounts of leaf area were affected by disease even though foliage had been sprayed once per week (Tables 1 and 2).

A significant difference occurred between fungicides in their effects on production of large seed. Tilt did not significantly increase the amount of large seed in either of the two experiments where it was used (Tables 1 and 3). This was not due to the lack of potential for increases, because the "healthy" treatment resulted in a significant increase in the amount of large seed produced. Conversely, Folicur application resulted in significant increases of 21-34% (673-971 kg ha^{-1}) for large seed from susceptible cultivars in both experiments where it was included (Tables 2 and 3). The differences between the two fungicides could not be explained entirely by differences in timing of application. Although Folicur was applied later than Tilt (boot versus flag leaf emergence), it produced similar increases when it was applied also at flag leaf emergence (Table 3). Folicur was applied at a 15% higher rate than Tilt; however, the specific activity of the fungicides against *P. tritici-repentis* over time is not known.

In other reports (Lawless, 1988, 1989, 1990), Tilt has been shown to significantly increase the amount of large seed produced. In those experiments, leaf rust was the primary foliar pathogen with no tan spot present and Folicur was not included. Therefore, different diseases and different environments may affect the results obtained from a particular fungicide, and several fungicides should be compared within each locale before a recommendation is made.

Seed producers who are growing cultivars known to be susceptible to foliar diseases could benefit from foliar fungicide application. Production of large seed by these cultivars can be markedly reduced by foliar diseases such as tan spot. As already mentioned, it is important to select a fungicide that has been shown to produce a significant increase in large seed in that environment. In these experiments, Folicur resulted in increases that were 48-86% of those obtained from the "healthy" treatment, demonstrating the potential for a high degree of disease control even from a single application. Such increases (666-971 kg ha^{-1}) would reduce the amount of seed lost during cleaning and more than offset the application cost. Assuming that fungicide and application costs are US\$43.00 ha^{-1} (US\$17.50 A^{-1}) and seed sells for US\$27.50 100 kg^{-1} (US\$7.50 bu^{-1}), net returns would be US\$140.00-\$224.00 ha^{-1}. Lawless (1990) reported that foliar fungicide use in western Kansas was economic for seed production even though such use was not economic for grain production. The results reported here indicate that routine fungicide use on seed-production fields should also be considered for areas such as eastern Kansas, where tan spot can be a yield-limiting factor.

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