Effect of Fungicide Application Timing on Control of Powdery Mildew and Grain Yield of Winter Wheat

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ABSTRACT

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Wheat cultivars Becker and Caldwell in 1987 and Becker and AGRA GR855 in 1988 were treated with a single foliar application of triadimefon fungicide at six different growth stages (GS), from GS 6 (first node visible) to GS 10.5.4 (end of flowering). Generally, applications at GS 6 and GS 8 prevented further development of powdery mildew, except on Becker in 1988, when an increase in disease severity was detected 18 days after treatment at GS 6. Plots treated as late as GS 9–10 in 1987 and GS 10.3 in 1988 had significantly ($P = 0.05$) lower values for area under the disease progress curve (AUDPC) than untreated plots. Yield of fungicide-treated plots was significantly greater than that of the untreated control when fungicide was applied at or before GS 10.3 for Becker and Caldwell in 1987, at GS 6 for Becker in 1988, and at GS 6 and GS 9–10 for AGRA GR855 in 1988. Results indicate that early (at GS 6–8) applications of fungicide provide greater powdery mildew control and higher yield than applications later in the season.

Additional keywords: chemical control, *Erysiphe graminis* f. sp. *tritici*, *Triticum aestivum*, yield loss

Powdery mildew, caused by *Erysiphe graminis* DC. f. sp. *tritici* E. Marchal, causes significant yield losses in winter wheat (*Triticum aestivum* L.) in Ohio (8–10). Because of variation in disease intensity from year to year and from field to field, recommendations for fungicide applications have been based on field scouting and disease severity at specific growth stages of the crop (8). A single foliar fungicide application has been effective in reducing disease losses on susceptible and moderately susceptible cultivars when applied at early to mid-boot growth stages (Feekes's growth stages 9 and 10 [5]) and environmental conditions favor disease development (9,10).

In a field study designed to determine the relationship between yield components and powdery mildew severity, Royse et al (14) found that powdery mildew on the lower leaves at an early growth stage (GS 6) had much greater effect on yield than expected. Our studies (9) with the systemic seed treatment triadimenol (Baytan) and studies conducted by others (1,2,6,7) also indicated that yield responses were dependent on early-season control of powdery mildew. Yield increases were attributed to early disease control because triadimenol seed treatment began to lose efficacy as plants approached boot stage. This was evident as an increase in the level of powdery mildew on plants at later growth stages and as a significant yield difference between plots planted with triadimenol-treated seed and those planted with seed treated by a standard method, which had no effect on the level of powdery mildew (9).

One application of a systemic, ergosterol-biosynthesis-inhibiting (EBI) fungicide would be more economical on a low unit-value crop like wheat, especially since the cost of application is frequently one-third of the overall cost of using a fungicide. Additionally, cost for multiple spray applications are not consistently offset by proportionately higher yields, even though disease control may be improved (7,13,15).

Control of foliar wheat diseases has been based on protection of the upper leaves of the plant from severe infection. For disease control, protection is needed from flag leaf emergence to the end of flowering, a period of 28–36 days in Ohio (8). Under most circumstances, activity of the sterol-inhibiting fungicides lasts 18–21 days. Thus, choosing the proper time to apply the fungicide to control early-season diseases, such as powdery mildew, and late-season diseases, such as leaf rust (caused by *Puccinia recondita* Rob. ex Desm. f. sp. *tritici*) and Septoria nodorum leaf blotch (caused by *Septoria nodorum* (Berk.) Berk.), has been difficult. Federal labeling has restricted the application timing of the highly efficacious fungicide propiconazole (Tilt) to flag leaf emergence or before. These restrictions affect the usefulness of this material because of potential yield losses due to development of late-season diseases during some years. In years when diseases do not develop by flag leaf emergence, growers apply the fungicide as a protectant. This practice may result in unnecessary pesticide usage when disease severity is low or leaf rust or Septoria leaf blotch do not develop because of unfavorable environmental conditions.

The purposes of this study were to: 1) determine the effect of applying an EBI fungicide at different wheat growth stages on the development of powdery mildew epidemics and 2) determine the yield differences associated with fungicide application timing. This information is needed to better plan integrated disease control strategies.

MATERIALS AND METHODS

Plots were established at the Ohio Agricultural Research and Development Center, near Wooster. Fields were maintained under a corn-soybean-oat-wheat rotation. After plowing, plots were fertilized with 336 kg/ha of N-P-K (6-24-24), then disked before planting. Plots were planted with 135 kg/ha of seeds, using a seven-row drill with 17.8 cm between rows, on 18 October 1986 and 6 October 1987. Both plots were on Wooster silt loam soil, and field sites were within 200 m of each other. Plots were top-dressed with 100 kg/ha of nitrogen (as ammonium nitrate) on 18 March 1987 and 31 March 1988. Throughout the rest of this paper, experiments are identified by the year in which they were harvested. Plots were harvested with a plot combine on 17 July 1987 and 8 July 1988.

Wheat cultivars used in field trials were Becker (PI 494524) and Caldwell (CI 17897) in 1987 and Becker and AGRA GR855 (PI 508286) in 1988. Before being planted, seed were treated with a combination of carboxin (17% a.i.) and thiram (17% a.i.) (Vitavax 200) at 260 ml/100 kg of seed. This treatment has no effect on the development of powdery mildew (9).

Triadimefon (Bayleton) (1.8 EC, 22.5% a.i.) was applied as a foliar spray in 187 L/ha of water with a CO_2-pres-

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surized backpack sprayer with a constant boom pressure of 207 kPa. In 1987, foliar fungicide treatments were applied on 1, 7, 18, 27, or 29 May or 5 June (day 121, 127, 138, 147, 149, or 155) and in 1988, on 7, 11, 17, 27, or 31 May or 6 June (day 128, 132, 138, 148, 152, or 158). These dates corresponded to Feekes's growth stages (GS) 6, 8, 9–10, 10.3, 10.5.1, and 10.5.4, respectively (5).

Field plots were arranged in a split-plot design with four replicated blocks. Wheat cultivars were planted as subplots, and fungicide application timings were whole-plot treatments. Experimental units were one seven-row drill strip wide (125 cm) × 10.5 m long. All experimental units were adjacent to one another, with a 22-cm space between outside rows for traffic. No effort was made to restrict interplot interference.

Disease severity was evaluated on 4, 11, 18, and 26 May and 3 June in 1987 (days 124, 131, 138, 146, and 154) and on 9, 14, 19, 25, and 31 May in 1988 (days 130, 135, 140, 146, and 152). These dates corresponded to GS 6, GS 8, GS 9–10, GS 10.3, and GS 10.5.1 in 1987 and to GS 8, GS 9, GS 9–10, GS 10.1, and GS 10.5.1 in 1988. In 1987, Caldwell advanced through growth stages slightly faster than Becker so that by heading (GS 10.3), Caldwell was 3 days ahead of Becker. In 1988, Becker and AGRA GR855 developed at nearly the same rate and flowered (GS 10.5.1) within 1 day of each other. Ten tillers were destructively collected, at random, from each experimental unit for assessment. Powdery mildew severity was assessed on a 0–10 scale (10), where 0 = 0 to trace of leaf area covered by lesions, 1 = leaf 4 with trace to 50%, 2 = leaf 3 with 1–5%, 3 = leaf 3 with 5–15%, 4 = leaf 3 with >15%, 5 = leaf 2 with 1–5%, 6 = leaf 2 with 5–15%, 7 = leaf 2 with >15%, 8 = leaf 1 (flag) with 1–5%, 9 = leaf 1 with 5–15%, and 10 = leaf 1 with >15% of area covered. The disease assessment keys developed by James (4) were used to determine the percentage of leaf area covered by powdery mildew lesions. Previous research indicated that this assessment scale adequately represented disease severity and was correlated with yield losses (10). A mean severity score of the tillers was calculated to represent powdery mildew severity for each experimental unit. No other foliage disease was observed within plots during either year of the study.

Area under the disease progress curve (AUDPC) was calculated for each experimental unit using the severity scores at each assessment time (3,11,12). Analysis of variance (ANOVA) was used to determine the effect of fungicide application timing on disease severity at each assessment time, AUDPC, and yield for each cultivar within years. Fisher's least significant difference (LSD) was determined to compare means when an experimental factor was significant. Linear contrasts also were used to determine if there was a significant trend in means as fungicide application was postponed from GS 6 to GS 10.5.4. Weather data for April, May, and June of each year were obtained from the Ohio Auto-weather Network Station located 1.5 km from the field plots.

RESULTS

Weather conditions during spring and early summer of 1987 and 1988 were favorable for development of powdery mildew. In 1987, precipitation for April, May, and June was 73, 60, and 128% of normal for these months, respectively, but the mean temperature for this time period was warmer than normal, i.e., 1.5 C above the long-term (89-yr) mean. In 1988, precipitation for April, May, and June was much below normal, i.e., 65, 32, and 13% of the long-term mean for these months, respectively, and mean temperature was only 0.9 C above normal for this period. Although the amount of precipitation was low during the 1988 season, powdery mildew apparently developed because of high relative humidity maintained by dense wheat stands and early morning dew.

In 1987 and 1988, powdery mildew was present on the fourth leaf of Becker by flag leaf emergence (GS 8) (Fig. 1A and B). Disease progressed rapidly in the untreated control plots of this cultivar until flowering (GS 10.5.1), at which time no further disease assessments were

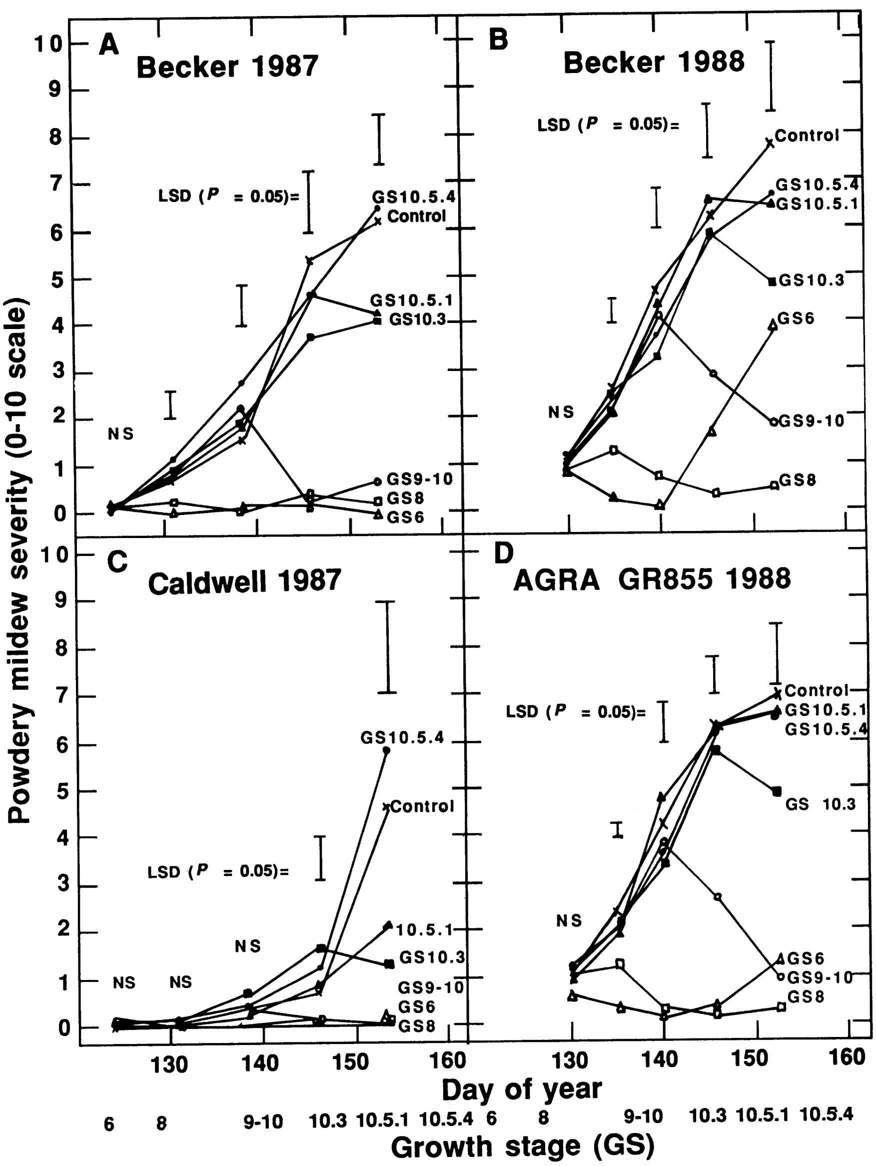

Fig. 1. Disease progress curves illustrating the development of powdery mildew on two winter wheat cultivars in 1987 and 1988 where triadimefon was applied once at the growth stages indicated. Severity of powdery mildew was assessed five times, from GS 6 (first node visible on elongating stem) to GS 10.5.1 (beginning flowering). Disease severity was based on a 0–10 scale, where 0 = 0 to trace of leaf area covered by lesions, 1 = leaf 4 with trace to 50%, 2 = leaf 3 with 1–5%, 3 = leaf 3 with 5–15%, 4 = leaf 3 with >15%, 5 = leaf 2 with 1–5%, 6 = leaf 2 with 5–15%, 7 = leaf 2 with >15%, 8 = leaf 1 (flag) with 1–5%, 9 = leaf 1 with 5–15%, and 10 = leaf 1 with >15% of area covered.

made. In 1987, Becker had 5–15% of the area of leaf 2 covered by lesions by GS 10.5.1 (rating = 6), and in 1988 the flag leaves on some of the tillers had 1–5% of the area affected (rating = 8). Disease development on AGRA GR855 was similar to that observed on Becker in 1988 (Fig. 1D), but disease levels were only slightly lower. In 1987, powdery mildew was restricted to the lower leaves of Caldwell until heading (GS 10.3) and then progressed to the second leaf on some tillers by flowering (GS 10.5.1) in the untreated control plots (Fig. 1C). Powdery mildew did not cause severe damage to flag leaves of any cultivar during either year of the test.

Triadimefon treatments applied at GS 6 (first node visible) or GS 8 (flag leaf emergence) prevented further development of powdery mildew on Becker in 1987 (Fig. 1A). On Caldwell, application at GS 6, GS 8, and GS 9-10 prevented further disease development in 1987 (Fig. 1C). In 1988, powdery mildew increased in severity after GS 10 (boot stage) in plots treated at GS 6, but disease severity remained low in plots treated at GS 8 (Fig. 1B and D). The level of disease severity by GS 10.5.1 in plots treated at GS 6 was significantly different (P = 0.05) from that in plots treated at GS 8 only for Becker in 1988 (Fig. 1B). The severity of powdery mildew decreased after fungicide application at GS 9–10 (beginning boot) on Becker in 1987 and on Becker and AGRA GR855 in 1988 (Fig. 1A, B, and D). This decline in severity was caused by reduction in the number of visible powdery mildew lesions on leaves over time. Lesions turned from cottony white to a light tan within several days after treatment. As time advanced, these lesions became more diffuse and difficult to detect. Applications of triadimefon at GS 10.3 (head emergence) prevented further development of powdery mildew or caused a slight decline in disease severity by the next date of disease assessment on all cultivars in both years. The effect of fungicide application at GS 10.5.1 (flowering) and at GS 10.5.4 (the end of flowering) on further disease development was not determined because disease assessments were terminated at flowering and disease levels did not increase after flowering.

Timing of fungicide application had a statistically significant (P = 0.05) effect on AUDPC and yield of Becker and Caldwell in 1987 and of Becker and AGRA GR855 in 1988 (Table 1). Disease severities were generally higher in 1988 than in 1987, as evidenced by the AUDPC values for Becker during both years. Mean AUDPC values for plots representing fungicide applications made at or before GS 9-10 in 1987 and at or before GS 10.3 in 1988 were significantly lower than AUDPC values for the nontreated control plots (Table 1). No significant differences (P = 0.05) were detected in AUDPC values between application of fungicide at GS 6 and at GS 8 in either year. Generally, AUDPC values increased as fungicide application was delayed from GS 8 to GS 10.5.4. Linear contrasts indicated a significant (P = 0.05) increasing trend in AUDPC over this period for both cultivars each year.

Overall yield was lower for cultivars tested in 1988 than for those tested in 1987 (Table 1). Significant yield differences over the control were detected for plots with fungicide applications made at or before GS 10.3 on both cultivars tested in 1987. In 1988, however, Becker had a significant difference in yield only when the fungicide was applied at GS 6, whereas AGRA GR855 had a significant yield increase when the fungicide was applied at either GS 6 or GS 9–10. In general, the percentage change in yield compared with that of the control was less in 1988 than in 1987. Linear contrasts indicated a significant declining trend in yield as fungicide application was delayed from GS 6 to GS 10.5.4.

DISCUSSION

Triadimefon was highly effective in controlling powdery mildew in these experiments. Usually within 4–5 days after treatment, visible differences in lesion color and density could be detected, resulting in lower assessment scores for fungicide-treated plots. The overall level of disease severity was considered relatively low during the 2-yr test, compared with previous years (9,10), because disease did not progress to the flag leaves by flowering. Under usual environmental conditions at this location on susceptible cultivars, powdery mildew develops on the lower leaves by GS 6 and advances rapidly onto the third and second leaves by GS 10 (boot stage). Powdery mildew then develops on the flag leaf until high temperatures, presumably, prevent further spread by GS 10.5.4 (the end of flowering). Severity scores may be as high as 9 (on the 0–10 scale) by flowering (9,10). Disease severity scores for Becker at flowering were 4.1 and 6.0 in 1987 and 1988, respectively.

Although disease severity scores were relatively low in nontreated plots by flowering, significant yield differences were detected over the nontreated controls. Yield response to fungicide application was greater in 1987 than in 1988, although AUDPC values were higher in 1988 than in 1987 (Table 1). This lower yield response probably was due to the extremely low soil moisture levels that prevailed during the grain-filling period in 1988, indicating that low soil moisture was a greater limiting factor to yield than powdery mildew severity.

Table 1. Effect of timing single applications of foliar fungicide on severity of powdery mildew and yield of wheat cultivars in 1987 and 1988

	1987						1988					
	Becker			Caldwell			Becker			AGRA GR855		
Fungicide application timing[a]	Disease severity at application[b]	AUDPC[c]	Yield[d] (kg/ha)	Disease severity at application	AUDPC	Yield (kg/ha)	Disease severity at application	AUDPC	Yield (kg/ha)	Disease severity at application	AUDPC	Yield (kg/ha)
GS 6	0.1	0.04*[e]	5,126*	0.0	0.01*	4,628*	0.9	1.02*	3,078*	0.6	0.37*	2,822*
GS 8	0.1	0.13*	5,099*	0.0	0.01*	4,756*	1.3	0.70*	2,829	1.2	0.53*	2,809
GS 9-10	2.2	0.88*	4,944*	0.5	0.16*	4,641*	4.1	2.65*	2,937	3.9	2.24*	2,863*
GS 10.3	3.7	2.08	4,742*	1.5	0.73	4,452*	5.9	3.78*	2,748	5.8	3.61*	2,742
GS 10.5.1	4.1	2.31	4,506	2.1	0.67	4,291	6.0	4.22	2,755	6.6	4.20	2,533
GS 10.5.4	6.5	2.97	4,479	5.9	1.16	4,156	6.1	3.80	2,715	6.6	3.97	2,573
No treatment		2.74	4,365		0.88	4,122		4.46	2,782		4.26	2,587
LSD (P = 0.05)		0.68	202		0.58	229		0.60	269		0.46	236

[a] Fungicide applied at different growth stages based on the Feekes scale (5).

[b] Disease severity based on a 0–10 scale, where 0 = 0 to trace of leaf area covered by lesions, 1 = leaf 4 with trace to 50%, 2 = leaf 3 with 1–5%, 3 = leaf 3 with 5–15%, 4 = leaf 3 with >15%, 5 = leaf 2 with 1–5%, 6 = leaf 2 with 5–15%, 7 = leaf 2 with >15%, 8 = leaf 1 (flag) with 1–5%, 9 = leaf 1 with 5–15%, and 10 = leaf 1 with >15% of area covered.

[c] Area under disease progress curve calculated according to Fry (3) using assessments based on the 0–10 scale recorded on day 124, 131, 138, 146, and 154 in 1987 and day 130, 135, 140, 146, and 152 in 1988. Calculated AUDPC was divided by the duration of the assessment period to produce a value ranging from 0 to 10.

[d] Yield based on grain weight at 13.5% moisture.

[e] Asterisk indicates statistical difference from no treatment control based on Fisher's least significant difference test at P = 0.05.

Results of this study indicate that fungicide applications for powdery mildew control should be made early in the season when disease is restricted to the lower leaves. Fungicide applications at GS 6 or GS 8 provided the greatest disease control on the three cultivars tested and, generally, the highest yield. These results agree with previous studies on the significance of early-season development of powdery mildew on yield losses (1,2,6,7,9,14). Under most situations, only single fungicide applications appear economical in Ohio (8,9). On an economic basis, the difference in yield when fungicides are applied at GS 6 or GS 8 or a little later, at GS 9–10 or GS 10.3, was relatively small (Becker = 384 kg/ha and Caldwell = 304 kg/ha in 1987). Early fungicide applications would be beneficial in areas where powdery mildew was the most prevalent disease. In areas where yield losses from late-season diseases are expected to be high, such as from leaf rust, fungicide applications would probably be more effective if delayed until GS 10–10.3. Because of the observed loss in efficacy of triadimefon within 18 days (e.g., Becker in 1988 [Fig. 1B]), earlier applications may be ineffective against leaf rust. This would be especially important if economics dictated the use of only one application of a broad-spectrum fungicide or fungicide combination. A later application, presumably, would control powdery mildew early enough to prevent high yield losses in addition to protecting plants from late-season diseases before fungicide efficacy was lost. A more advantageous approach would be to time the fungicide application according to forecasted severity of powdery mildew as well as late-season diseases. Current research is directed toward this goal.

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