Effect of Timing of Foliar Fungicides on Wheat Disease Control and Yield Increases

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ABSTRACT

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Control of foliar pathogens of winter wheat (*Triticum aestivum*) cultivars Arkan and Newton at several growth stages by application of triadimefon foliar sprays was observed in the 1985 and 1986 crop years. Single sprays of triadimefon on Newton at early dough and heading growth stages resulted in yield increases of 47 and 68%, respectively, in 1985 and of 24 and 39%, respectively, in 1986. Yield increases for Arkan with fungicide application at early dough and heading growth stages were 3 and 11%, respectively. Area under disease progress curve (AUDPC) ($r = -0.79$) and percent severity ($r = -0.81$) of leaf rust were negatively correlated with yield, whereas AUDPC ($r = 0.53$) and severity ($r = 0.61$) of leaf rust were positively correlated with percent yield increase. AUDPCs of Septoria leaf blotch ($r = -0.60$) and tan spot ($r = -0.85$) were also negatively correlated with yield. However, no significant effect of foliar fungicide treatment on control of either Septoria leaf blotch or tan spot was detected by Waller-Duncan's multiple range test ($P = 0.05$).

Leaf rust caused by *Puccinia recondita* Rob. ex Desm. f. sp. *tritici*, Septoria leaf blotch caused by *Mycosphaerella graminicola* (Fuckel) Schroeter, and tan spot caused by *Pyrenophora tritici-repentis* (Died.) Drechs. are three of the most common and severe foliar diseases of wheat (*Triticum aestivum* L.) in the hard red winter wheat region of the United States (16). Yield reductions caused by wheat leaf rust have been measured at greater than 50% (3,13). Under epidemic conditions, yield losses caused by Septoria leaf blotch may range from 30 to 50% on susceptible cultivars (7,18) and losses caused by tan spot may range from 20 to 50% (12,15).

Several models for estimating disease development and crop loss have been developed (3,4). The fungicides benomyl and triadimefon applied as foliar sprays have shown promise for control of Septoria leaf blotch and leaf rust, respectively (1,2,5). Triadimefon and/or triadimenol have been reported to be useful for early season control of Septoria leaf blotch, leaf rust, or tan spot (2,10,11). Currently, fungicides are not routinely used in the hard red winter wheat region because of the high cost of application on large acreages and the relatively low grain yield potential under prevailing environmental conditions. When conditions do favor development of epidemics, the application of fungicides may be cost-effective.

Yield increases resulting from control of individual foliar pathogens of wheat have been extensively documented (2,5,7,12,13). Most of these studies, however, are directed at determining the effect of a host-pathogen relationship within a single disease pathosystem rather than the interactive effects of two or more pests. The occurrence of only one disease on a wheat crop is rarely observed under field conditions.

Leaf rust, Septoria leaf blotch, and tan spot are frequently found interacting in commercial fields and have been the leading causes of substantial wheat yield losses in Kansas over the last 10 yr (16). The objective of this research was to control foliar wheat diseases at specific wheat growth stages to determine the effect on the final disease severity, the subsequent grain yield increases due to disease control, and the interaction among foliar wheat diseases through analysis of final disease severity and area under disease progress curve (AUDPC) data.

MATERIALS AND METHODS

Field experiments were conducted on a Chase silty clay loam at the Rocky Ford Experimental Farm, Manhattan, KS. Planting dates were 13 October 1985 and 7 October 1986. Two winter wheat cultivars, Newton and Arkan, were sown in 1.22-m wide drill strips at a rate of 78.6 kg/ha.

Seventy-two 7.6 × 6.1 m plots of Newton were used in 1985, and 66 4.9 × 6.1 m plots of Newton and 50 4.9 × 6.1 m plots of Arkan were used in 1986. Treatments consisted of triadimefon at 153.6 g a.i./ha in 1985 and 230.5 g a.i./ha in 1986 and/or of mancozeb at 2.25 kg a.i./ha applied with a sprayer at a volume of 225 L/ha. Applications were made at the boot, late boot, heading, and early dough growth stages (Tables 1 and 2).

Leaf rust development was initiated by either natural inoculum or inoculation with urediniospores of *P. recondita*. Because Newton was susceptible to the prevailing *P. recondita* population and overwintering occurred (6), natural infection caused epidemic levels of leaf rust in both 1985 and 1986. Arkan was inoculated with urediospores of *P. recondita* (PRTUS6) because the prevailing pathogen population was not

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Table 1. Effect of wheat foliar disease fungicide treatments on subsequent test weight and percent yield increase of the winter wheat cultivar Newton, 1985

Treatment, growth stage[x]	Test weight (g/L)	1,000 Kernel weight (g)	Percent yield increase[y]
Control (unsprayed)	711 a[z]	29.5 a	...
Triadimefon 5% granular, late boot	750 c	31.5 c	46.6 a
Triadimefon, early dough	720 b	30.3 b	46.9 a
Triadimefon 5% granular, boot + triadimefon, heading	742 c	30.9 c	52.3 a
Mancozeb, heading + early dough	746 c	31.1 c	52.2 a
Triadimefon, heading	749 c	31.4 c	68.0 b

[x] Triadimefon, 153.6 g a.i./ha, applied at late boot, heading, or early dough. Mancozeb, 2.25 kg a.i./ha, applied at heading and early dough.

[y] Calculated by subtracting control yield from treatment yield and dividing by control yield.

[z] Means within a column followed by the same letter are not significantly different at $P = 0.05$ according to Waller-Duncan test.

virulent on Arkan.

P. recondita inoculum was obtained by transplanting field-grown plants of Trison into 15-cm-diameter plastic pots at late boot growth stage and placing them in the greenhouse at 21 C for 7 days. Plants were inoculated with an oil suspension of PRTUS6 and incubated in a dew chamber at 21 C for 16 hr. The plants were returned to the greenhouse for 10 days at 21 C to allow leaf rust development. One pot with 80% leaf rust severity was placed within the upwind (south) end of each drill strip of the experimental plots and left there for 1 wk. No attempt was made to artificially inoculate the plots with either of the other two pathogens because symptoms were present before boot growth stage.

Percent leaf area affected (severity) of leaf rust, Septoria leaf blotch, tan spot, and other diseases was estimated visually (17). Disease severity was recorded weekly beginning at late joint growth stage and continuing until early dough growth stage. An average rating for each replication was recorded for each disease observed. Grain yield, test weight, and 1,000 kernel weight were recorded for all experimental plots.

AUDPC (14) was calculated for leaf rust, Septoria leaf blotch, and tan spot observed on Newton and leaf rust and Septoria leaf blotch observed on Arkan for each of the treatments. Percent yield increase for plots treated with triadimefon applied at heading or early dough growth stage compared with plots receiving no fungicide was calculated by subtracting the control yield from the treatment yield and dividing by the control yield. Disease severity at early dough growth stage, AUDPC, percent yield increase, and yield were subjected to analysis of variance and mean separation by using the general linear model procedure of the Statistical Analysis Systems (SAS Institute, Inc., Cary, NC) and the Waller-Duncan *k*-ratio *t* test. Correlation coefficients also were calculated using SAS for the variables percent yield increase, yield, AUDPC, and disease severity at early dough growth stage for each of the treatments. The interaction among diseases was studied through statistical analysis of AUDPC and disease severity using the general linear model procedure of SAS. A significance level of $P = 0.05$ was used in all statistical tests.

RESULTS

The extremely mild winters and wet springs in both 1985 and 1986 favored early development of leaf rust before Septoria leaf blotch or tan spot could become established (6). Septoria leaf blotch was confined to the lower leaves and rarely exceeded 30% severity on the flag to second leaves. Tan spot severity reached 10% on the flag to second leaves on Newton, whereas only trace amounts were observed on Arkan.

Leaf rust was severe on the flag (70–90%) and lower (80–100%) leaves of Newton in both years for all treatments except for triadimefon applied at heading (30–50%), for mancozeb applied weekly from heading growth stage to early dough growth stage (30–50%), and for mancozeb applied weekly for 3 wk after an application of triadimefon at heading (10–30%). For Arkan, low levels of leaf rust severity (1–10%) were observed on the flag leaf only in the experimental units receiving no fungicide or receiving triadimefon at early dough growth stage. Whereas Septoria leaf blotch severity for both cultivars was low (<20%) and confined to the lower leaves, the combination of Septoria leaf blotch and leaf rust resulted in 90–100% of the lower foliage becoming necrotic 2–3 wk earlier than that on treated plants. Tan spot also was present on the lower leaves of the canopy but was detected only in Newton and was observed at levels greater than 10% in only one of the plots in 1986.

The general linear models procedure of SAS was used to determine if the pathogens interacted, with percent yield increase as the dependent variable vs. combinations of leaf rust, Septoria leaf blotch, and tan spot AUDPCs, and with disease severities as the independent variables. The combination of AUDPC variables of leaf rust, Septoria leaf blotch, and the leaf rust × Septoria leaf blotch interaction resulted in a *F* value of 10.07 for the leaf rust × Septoria leaf blotch interaction, which was significant at the $P = 0.01$ level. Also, in combining the disease severity variables of leaf rust, Septoria leaf blotch, and leaf rust × Septoria leaf blotch in the model, a *F* value of 10.42 significant at the $P = 0.01$ level was obtained for the leaf rust × Septoria leaf blotch interaction. Analysis of AUDPC, severity, and yield data indicates a negative interaction among the pathogens. Because of the low incidence of tan spot, no significant interaction was observed between leaf rust and tan spot or between Septoria leaf blotch and tan spot.

In 1985, leaf rust severity was significantly reduced by triadimefon applied at heading (50%) and by mancozeb applied at both heading (40%) and early dough growth stages (60%) compared with the untreated controls (100%). The grain yield with triadimefon applied at heading was significantly greater than that with all other treatments. Percent yield increases with mancozeb and the triadimefon treatments applied at early dough growth stage also were significantly greater than that with the unsprayed control (Table 1). Significant differences in test weight and 1,000 kernel weight were measured among treatments. Triadimefon applied at early dough growth stage resulted in a significantly greater test weight and 1,000 kernel

Table 2. Effect of foliar fungicide treatments on severity and AUDPC of leaf rust (LR), Septoria leaf blotch (SLB), and tan spot (TS) and subsequent percent yield increase of winter wheat cultivars Newton and Arkan

	AUDPC[w]			Percent disease severity[x]			
Treatment, growth stage[v]	**LR**	**SLB**	**TS**	**LR**	**SLB**	**TS**	**Percent yield increase**[y]
Newton							
Control (unsprayed)	9.6 a[z]	5.5 a	1.2 a	68 a	25 a	7 a	...
Triadimefon, early dough	10.0 a	5.4 a	1.4 a	67 a	25 a	8 a	24.3 bc
Triadimefon, heading	6.3 b	5.0 a	1.1 a	35 b	13 a	5 a	39.4 b
Triadimefon, heading + mancozeb	6.0 b	5.3 a	1.5 a	20 b	14 a	6 a	52.2 a
Arkan							
Control (unsprayed)	1.9 a	4.2 a	...	24 a	33 a	...	...
Triadimefon, early dough	2.2 a	4.1 a	...	24 a	31 ab	...	3.0 a
Triadimefon, heading	1.1 b	3.6 a	...	2 b	24 c	...	11.4 a
Triadimefon, heading + mancozeb	0.3 c	4.0 a	...	10 b	28 b	...	9.9 a

[v] Triadimefon, 230.5 g a.i./ha, applied at early dough and heading. Mancozeb, 2.25 kg a.i./ha, applied at weekly intervals for 3 wk after application of triadimefon at heading.

[w] Area under disease progress curve.

[x] Rated at early dough by visual observation of percent leaf area covered.

[y] Calculated by subtracting control yield from treatment yield and dividing by control yield.

[z] Column means within a cultivar followed by the same letter are not significantly different at $P = 0.05$ according to Waller-Duncan test.

weight than the untreated control, and mancozeb applied at heading and early dough growth stages and triadimefon applied at heading resulted in significantly greater test weight and 1,000 kernel weight than triadimefon applied at early dough growth stage.

In 1986, leaf rust severity and AUDPC were significantly reduced on both Newton and Arkan by triadimefon applied alone at heading or followed by three weekly applications of mancozeb (Table 2). Triadimefon applied alone at heading or followed by weekly mancozeb treatments also resulted in significantly less severe Septoria leaf blotch on Arkan, despite no significant differences among AUDPCs. No significant differences were observed for AUDPC and disease severity of either Septoria leaf blotch or tan spot on Newton. Tan spot did not develop beyond trace amounts on Arkan. Thus, because of low levels of infection and the ineffectiveness of triadimefon against tan spot, no significant effect on yield was measured either year.

There was a significant difference in leaf rust severity and AUDPC but not yield between the untreated control and the treatments of triadimefon applied at heading in Arkan. Although not significantly different, there was a trend toward greater yields associated with a decrease in disease severity and AUDPC. For Newton, there were significant differences in leaf rust severity and AUDPC, as well as significant differences in yield and percent yield increase. The triadimefon plus mancozeb treatment resulted in the greatest yield, followed by triadimefon at heading and early dough growth stages, and the untreated control had successively lower yields. AUDPC ($r = -0.79$) and severity ($r = -0.81$) of leaf rust were negatively correlated to yield, whereas AUDPC ($r = 0.53$) and severity ($r = 0.61$) of leaf rust were correlated positively to percent yield increase. AUDPCs of Septoria leaf blotch ($r = -0.60$) and tan spot ($r = -0.85$) were also negatively correlated with yield, although there appeared to be no significant effect of foliar fungicide treatment on the control of Septoria leaf blotch or tan spot in these plots.

DISCUSSION

Single applications of triadimefon effectively reduced the severity of leaf rust epidemics and contributed to yield increases of wheat in both 1985 and 1986. The greatest yield increase was obtained with a triadimefon treatment applied at heading on Newton. In 1986, triadimefon applied at heading produced significant yield increases in both Newton and Arkan. Triadimefon applied at early dough growth stage resulted in the smallest yield increases for Arkan and Newton during both years. Similar results were reported by Lipps (9), who evaluated single applications of foliar fungicides for control of wheat diseases.

Treatments involving two or more applications of fungicide also reduced the severity of foliar diseases and resulted in yield increases similar to those obtained with the application of triadimefon at heading. Other studies have shown that two or more applications of foliar fungicides reduce severity of foliar diseases and significantly increase grain yield of winter wheat (1,5,8). Multiple applications are not economically justified in most cases, however.

Yield increases in 1985 and AUDPC and yield increases in 1986 indicate that application of triadimefon at the early dough growth stage was not as effective as application at heading or as the combination of triadimefon applied at heading and mancozeb applied weekly for 3 wk after heading. However, the yield resulting from the application of triadimefon at early dough growth stage, although statistically significant only in 1985, was greater than that of the control treatment in both years.

Results of this study indicate that a single, well-timed systemic fungicide application can effectively reduce the severity of foliar disease and significantly increase yield. Similar conclusions were reached in studies by Cook (5) and Brown (2). Application of triadimefon on Newton at heading resulted in significant yield increases in 1985 and 1986. Triadimefon granules produced similar results when applied at the boot growth stage in 1985 (Table 1). These 1985 yield increases were probably due to the early control of Septoria leaf blotch and absence of tan spot earlier in the season. Yield increases for Arkan in either year were not as great as those for Newton because of the foliar disease resistance of Arkan and the susceptibility of Newton.

Even though leaf rust severities had reached 80% on the flag leaf of Newton before application of triadimefon at early dough growth stage, a significant yield increase ($P = 0.05$) was still obtained. Application of triadimefon at heading produced the greatest yield increases. The increase provided by treatment at early dough growth stage, however, indicates that even a late application of a systemic fungicide may result in significant yield increases.

The use of foliar fungicide treatments has been virtually nonexistent in the hard red winter wheat region of the United States. The results of this study, however, indicate that fungicides have potential as foliar treatments for wheat under severe foliar disease epidemic conditions, such as those experienced in 1985 and 1986. In times when severe epidemics of leaf rust do occur, a single application of a systemic fungicide would be another effective tool in a foliar disease control program.

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