Relation of Application Timing to Efficacy of Triadimefon in Controlling Apple Powdery Mildew

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ABSTRACT

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Apple (cv. Rome Beauty) trees were sprayed to runoff with triadimefon at 37.5 mg a.i./L during specific periods of each of three growing seasons. Applications were made at the tight-cluster (TC) phenological stage through the fourth-cover (4C) in 1980 and from TC through the second-cover (2C) in 1981. In 1982, the program evaluated the effectiveness of single and paired consecutive sprays at the bloom (B) and petal-fall (PF) stages and at the first-cover (1C) and second-cover (2C) sprays. Certain applications were more effective than others in reducing the incidence of secondary mildew. Applications at TC and the pink (P) stage could be eliminated without loss in disease control. The period from bloom through the second-cover spray was found to be the most critical time in which to control mildew with triadimefon. Earlier sprays during this period were more effective in controlling mildew on vegetative shoots, whereas the later sprays were more effective on bourse shoots. In 1982, two applications of triadimefon (PF+1C) were as effective as four applications (B+PF+1C+2C) on trees with low primary inoculum. The importance of shoot type on which mildew was assessed and the level of primary inoculum were important factors in determining fungicide efficacy.

The control of apple powdery mildew on shoots, leaves, and buds is accomplished by the multiple application of fungicides during the growing season. Based on the protective properties and modes of action of fungicides such as dinocap, benomyl, thiophanate-methyl, and sulfur, spray recommendations have been developed in which apple growers are advised to apply the first fungicide for powdery mildew control at or before the tight-cluster phenological stage and to continue applications, where warranted, until the cessation of terminal growth (1-4,9,16,17). In the Middle Atlantic states, this can result in eight or more sprays being applied to highly susceptible cultivars (18). With the development and registration of fungicides such as triadimefon that have curative properties by inhibiting ergosterol biosynthesis, it is important to determine whether these existing spray recommendations are applicable. Furthermore, judicious use of these new fungicides is warranted because of serious concern over the development of resistance and cross-resistance (8,11,15) in pathogen populations.

The objective of this study was to determine the relation of application timing to efficacy of triadimefon for the control of secondary infections of apple powdery mildew. A preliminary report has been published (5).

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MATERIALS AND METHODS

During 1980–1982, triadimefon (Bayleton 50WP) was applied at a rate of 37.5 mg a.i./L to apple (cv. Rome Beauty) trees on seedling rootstock having individual canopy volumes of about 25 m^3. Five to six single-tree replicates, arranged in a randomized complete block design, were sprayed with a single-nozzle spray gun at 3,800 kPa to runoff at 30 L per tree at specific periods during each growing season. Applications were made at the tight-cluster (TC) phenological stage through the fourth-cover (4C) in 1980 and from TC through the second-cover (2C) in 1981 (Tables 1 and 2). The spray program was modified in 1982 to examine the effectiveness of individual and paired consecutive sprays applied at bloom (B) and petal-fall (PF) and at the first-cover (1C) and 2C (Table 3).

In 1980, treatments (spray regimens) were randomly assigned to trees with varying numbers of primary mildew infection sites (PMIS) per tree. PMIS were the infected terminal shoots developing from apical buds in which the fungus had overwintered. To minimize the possible effects of variation in amounts of primary inoculum on the efficacy of the spray programs, PMIS were pruned from the trees in 1981 to establish a uniform level of primary inoculum within blocks. In 1982, the level of primary inoculum was tested as a factor in the experiment. Two levels of primary inoculum were established within certain treatments; one contained 0–15 PMIS per tree and the other, 18–48 PMIS per tree.

The incidence of secondary infections was determined each year after the last spray application using a standard procedure (10) in which mildew incidence was assessed on all leaves on 10–15 vegetative terminal shoots selected from the periphery of each tree at a height of about 1.5 m from the ground. In 1982, mildew was assessed on vegetative terminal shoots and also on shoots that had developed from vegetative buds in the blossom cluster (bourse shoots).

Statistical differences between treatment means were detected using Student's *t* test on preplanned contrasts. In order to control the overall probability of error in each contrast set, α levels for each set of 's' contrasts were calculated from α/s, where $1 - \alpha = 0.90$ was the Bonferroni family confidence coefficient (14).

RESULTS AND DISCUSSION

In 1980, the TC application did not significantly contribute to reducing mildew incidence. The incorporation of the B, 1C, or 2C application into the spray program significantly reduced the amount of disease (Table 1, contrasts 2, 4, and 5). A spray program consisting of a series of five applications from TC through 2C was as effective in reducing the incidence of mildew as a series of six applications from TC to 3C or a series of seven applications from TC to 4C (Table 1, contrasts 6 and 7).

In 1981, there was no significant difference in disease incidence between nontreated trees and trees treated at TC (Table 2, contrast 1). Trees treated at TC and at the pink (P) stage, however, had significantly less mildew than nontreated trees and trees treated only at TC (Table 2, contrasts 2 and 3). As the B, PF, 1C, and 2C applications were added into the spray program, there was a general decrease in disease incidence, but no significant differences were detected (Table 2, contrasts 4, 5, 6, and 7).

In comparing the spray program containing TC+P+B+PF+1C+2C applications with the TC+P+B+PF and

B+PF+1C+2C programs, the six-application program did not result in less disease than the two four-application programs (Table 2, contrasts 8 and 9). The TC+P+B+PF and B+PF+1C+2C spray programs did not differ significantly from each other in disease control (Table 2, contrast 10).

In 1982, data were collected not only from vegetative shoots, as in 1980 and 1981, but also from bourse shoots. Although an analysis of variance revealed no significant shoot effect ($P = 0.1889$), there was a significant spray program × shoot interaction ($P = 0.0004$). Differences in incidence of mildew on the two types of shoots were apparent in certain contrasts between treatments applied to trees (Table 3).

Of the single applications at B, PF, 1C, or 2C, all but the 2C application significantly reduced the incidence of mildew on vegetative and bourse shoots when compared with nontreated trees (Table 3, group I contrasts). The incidence of mildew on vegetative shoots on trees treated with a single application at B, PF, or 1C was not significantly different (Table 3, group II, contrasts 1, 2, and 4) but was significantly less than the incidence on trees treated only at 2C (Table 3, group II, contrasts 3, 5, and 6). On bourse shoots, the 1C application was clearly the most effective single application (Table 3, group II, contrasts 2, 4, and 6).

Group III contrasts (Table 3) show whether two consecutive applications resulted in a difference in disease incidence compared with the component single sprays. No significant difference in mildew incidence on vegetative and bourse shoots was detected between trees sprayed at B vs. B+PF (Table 3, group III, contrast 1). The incidence of mildew on bourse shoots was not significantly different on trees receiving a single spray at PF vs. two consecutive sprays at B+PF, but control was significantly better with two applications on vegetative shoots (Table 3, group III, contrast 2). Thus, the B application was as effective as B+PF applications in controlling mildew on vegetative shoots, whereas either the B or the PF spray was as effective as the B+PF applications on bourse shoots. The combination of either the B+PF or the PF+1C application was more effective on vegetative shoots than the PF alone (Table 3, group III, contrasts 2 and 3). On both types of shoot, the 2C application did not contribute significantly to mildew control; an application at 1C was as effective as 1C+2C applications (Table 3, group III, contrast 5).

Of the 1982 spray programs having two consecutive applications, the PF+1C program resulted in the lowest incidence of mildew on both vegetative and bourse shoots (Table 3, group IV). On bourse shoots, the PF+1C program was more effective in controlling mildew than either the B+PF or the 1C+2C program (Table 3, group IV, contrasts 1 and 3) and was as effective as the B+PF+1C+2C program (Table 3, group V, contrast 2). On vegetative shoots, no difference in incidence of mildew was detected between the PF+1C and B+PF programs (Table 3, group IV, contrast 1) and, unlike the bourse assessment, the B+PF+1C+2C program was more effective than the PF+1C program (Table 3, group V, contrast 2).

Since there was no significant mildew level × spray program interaction ($P = 0.6254$ and $P = 0.3411$ for vegetative and bourse shoot data, respectively), the same spray programs at both levels of primary inoculum were combined for each shoot type and analyzed. This analysis clearly showed differences in fungicide efficacy in relation to time of application and shoot type (Table 4). The B+PF program and the 1C+2C program were reversed in ranking between the shoot types.

These differences between vegetative and bourse shoot assessments may be explained in terms of differences between the relative numbers of susceptible leaves on the two types of shoots at different times during the growing season. Fruit buds opened first in the spring, producing a whorl of about seven or eight leaves and the developing flowers. The vegetative buds opened later and produced a succession of leaves on the extending shoot. At the time of bloom, approximately eight or nine leaves were present on vegetative shoots, whereas the initial whorl of leaves and only one or two immature leaves on the elongating shoot had developed from the vegetative bud in the blossom cluster. Age is a factor in the susceptibility of apple leaves to powdery mildew (6,7,12), and vegetative shoots had a greater number of younger, susceptible leaves at the time during the growing season when infection first occurred. Spray applications just prior to or at bloom would, therefore, control mildew relatively more on vegetative shoots, as the data indicated. Vegetative shoots tended to cease terminal growth earlier than bourse shoots; bourse shoots continued to produce leaves later into the growing season. At the time of the 2C application (8 June) in 1982, about 80% of all vegetative shoots used in the mildew assessment had ceased producing new leaves. On the same trees, 25 shoots were randomly selected on the basis of showing continued leaf formation on 9 and 17 June; 90 and 96% of these actively growing shoots on those dates, respec-

Table 1. Comparisons between spray programs of triadimefon at 37.5 mg a.i./L for control of powdery mildew on vegetative shoots of apple (cv. Rome Beauty) trees in 1980

Contrasts[x] No.	Description		Leaves infected (%)	$PR > \|t\|$[y]
1	TC[z]	vs. NT	53.0 vs. 40.5	0.0027*
2	TC+B	vs. TC	27.1 vs. 53.0	0.0001*
3	TC+B+PF	vs. TC+B	29.5 vs. 27.1	0.5441
4	TC+B+PF+1C	vs TC+B+PF	18.3 vs. 29.5	0.0067*
5	TC+B+PF+1C+2C	vs. TC+B+PF+1C	8.2 vs. 18.3	0.0130*
6	TC+B+PF+1C+2C+3C	vs. TC+B+PF+1C+2C	8.1 vs. 8.2	0.9899
7	TC+B+PF+1C+2C+3C+4C	vs. TC+B+PF+1C+2C+3C	7.3 vs. 8.1	0.8362

[x] $H_0{:}\mu_1 = \mu_2$, $H_1{:}\mu_1 \neq \mu_2$; $MS_E = 46.252$; $DF_E = 45$; $DF_T = 60$.
[y] To provide a yearly Bonferroni family confidence coefficient of 0.90, probabilities less than 0.0143 indicate a significant difference (*).
[z] Applications were made on: 23 April, tight cluster (TC); 7 May, bloom (B); 14 May, petal-fall (PF); 28 May, first cover (1C); 11 June, second cover (2C); 25 June, third cover (3C); and 11 July, fourth cover (4C). NT = nontreated.

Table 2. Comparisons between spray programs of triadimefon at 37.5 mg a.i./L for control of powdery mildew on vegetative shoots of apple (cv. Rome Beauty) trees in 1981

Contrasts[x] No.	Description		Leaves infected (%)	$PR > \|t\|$[y]
1	TC[z]	vs. NT	43.3 vs. 40.6	0.5327
2	TC+P	vs. NT	25.1 vs. 40.6	0.0001*
3	TC+P	vs. TC	25.1 vs. 43.3	0.0001*
4	TC+P+B	vs. TC+P	26.9 vs. 25.1	0.5516
5	TC+P+B+PF	vs. TC+P+B	20.0 vs. 26.9	0.0260
6	TC+P+B+PF+1C	vs. TC+P+B+PF	17.9 vs. 20.0	0.4836
7	TC+P+B+PF+1C+2C	vs. TC+P+B+PF+1C	14.4 vs. 17.9	0.3510
8	TC+P+B+PF+1C+2C	vs. B+PF+1C+2C	14.4 vs. 16.8	0.5905
9	TC+P+B+PF+1C+2C	vs. TC+P+B+PF	14.4 vs. 20.0	0.1351
10	B+PF+1C+2C	vs. TC+P+B+PF	16.8 vs. 20.0	0.3765

[x] $H_0{:}\mu_1 = \mu_2$, $H_1{:}\mu_1 \neq \mu_2$; $MS_E = 53.7738$; $DF_E = 55$; $DF_T = 72$.
[y] To provide a yearly Bonferroni family confidence coefficient of 0.90, probabilities less than 0.0111 indicate a significant difference (*).
[z] Applications were made on: 13 April, tight cluster (TC); 22 April, pink (P); 28 April, bloom (B); 6 May, petal-fall (PF); 18 May, first cover (1C); and 4 June, second cover (2C). NT = nontreated.

Table 3. Comparisons between spray programs of triadimefon at primary inoculum level I[v] for control of powdery mildew on apple (cv. Rome Beauty) trees in 1982

Group[w]	Contrasts[x] No.	Description			Vegetative shoots Leaves infected (%)	$PR > \|t\|$[y]	Bourse shoots Leaves infected (%)	$PR > \|t\|$[y]
I	1	B[z]	vs.	NT	33.0 vs. 55.0	0.0001*	39.4 vs. 47.8	0.0132*
	2	PF	vs.	NT	34.2 vs. 55.0	0.0001*	36.8 vs. 47.8	0.0018*
	3	1C	vs.	NT	37.3 vs. 55.0	0.0001*	28.7 vs. 47.8	0.0001*
	4	2C	vs.	NT	52.8 vs. 55.0	0.5524	41.9 vs. 47.8	0.0764
II	1	B	vs.	PF	33.0 vs. 34.2	0.7081	39.4 vs. 36.8	0.4416
	2	B	vs.	1C	33.0 vs. 37.3	0.1828	39.4 vs. 28.7	0.0022*
	3	B	vs.	2C	33.0 vs. 52.8	0.0001*	39.4 vs. 41.9	0.4378
	4	PF	vs.	1C	34.2 vs. 37.3	0.3330	36.8 vs. 28.7	0.0163*
	5	PF	vs.	2C	34.2 vs. 52.8	0.0001*	36.8 vs. 41.9	0.1270
	6	1C	vs.	2C	37.3 vs. 52.8	0.0001*	28.7 vs. 41.9	0.0002*
III	1	B	vs.	B+PF	33.0 vs. 25.3	0.0231	39.4 vs. 32.2	0.0329
	2	PF	vs.	B+PF	34.2 vs. 25.3	0.0093*	36.8 vs. 32.2	0.1579
	3	PF	vs.	PF+1C	34.2 vs. 18.6	0.0001*	36.8 vs. 17.5	0.0001*
	4	1C	vs.	PF+1C	37.3 vs. 18.6	0.0001*	28.7 vs. 17.5	0.0013*
	5	1C	vs.	1C+2C	37.3 vs. 32.9	0.1733	28.7 vs. 25.9	0.3812
	6	2C	vs.	1C+2C	52.8 vs. 32.9	0.0001*	41.9 vs. 25.9	0.0001*
IV	1	B+PF	vs.	PF+1C	25.3 vs. 18.6	0.0453	32.2 vs. 17.5	0.0001*
	2	B+PF	vs.	1C+2C	25.3 vs. 32.9	0.0248*	32.2 vs. 25.9	0.0571
	3	PF+1C	vs.	1C+2C	18.6 vs. 32.9	0.0001*	17.5 vs. 25.9	0.0132*
V	1	B+PF	vs.	B+PF+1C+2C	25.3 vs. 5.8	0.0001*	32.2 vs. 11.8	0.0001*
	2	PF+1C	vs.	B+PF+1C+2C	18.6 vs. 5.8	0.0003*	17.5 vs. 11.8	0.0835
	3	1C+2C	vs.	B+PF+1C+2C	32.9 vs. 5.8	0.0001*	25.9 vs. 11.8	0.0001*

[v] Level I = 0–15 primary mildew infection sites per tree.
[w] Comparisons between spray programs are grouped according to type of contrast.
[x] $H_0: \mu_1 = \mu_2$, $H_1: \mu_1 \neq \mu_2$; $MS_E = 25.85$; $DF_E = 35$; $DF_T = 89$.
[y] To provide a Bonferroni family confidence coefficient of 0.90 for each group of contrasts, probabilities less than 0.0250, 0.0167, 0.0167, 0.0333, and 0.0333 in groups I–V, respectively, indicate a significant difference (*).
[z] Applications were made on: 6 May, bloom (B); 14 May, petal-fall (PF); 25 May, first cover (1C); and 8 June, second cover (2C). NT = nontreated.

Table 4. Control of powdery mildew on apple (cv. Rome Beauty) trees sprayed with triadimefon at 37.5 mg a.i./L at various times from bloom through second cover in 1982[x]

Time of spray application[y] B	PF	1C	2C	Leaves infected (%) Vegetative shoots	Bourse shoots
–	–	–	–	57.3 a[z]	49.0 a
–	–	+	+	36.0 b	25.4 c
+	+	–	–	26.9 c	34.6 b
–	+	+	–	22.0 d	20.4 d
+	+	+	+	6.0 e	12.3 e

[x] Means were combined for the two primary inoculum levels of each spray program for both shoot assessments.
[y] Applications were made on: 6 May, bloom (B); 14 May, petal-fall (PF); 25 May, first cover (1C); and 8 June, second cover (2C). + = Fungicide applied, – = no fungicide applied.
[z] Means followed by the same letter are not significantly different ($P = 0.05$) according to Duncan's multiple range test.

tively, were bourse shoots. At that time of the season, spray applications would affect mildew development more on bourse shoots because of the young, susceptible leaves present.

These differences between mildew development on bourse and vegetative shoots have important implications. On cultivars that tend to be biennial bearers, consideration of the predominant shoot type would be essential in the development of effective spray programs. Also, an awareness of possible shoot differences is important when selecting an assessment method to evaluate spray programs. Interpretation of the effect of a spray program can vary according to what shoot type is selected for assessment.

The level of primary inoculum was a significant factor in the five 1982 spray programs in which it was tested (Table 5). The overall mean for level I (0–15 PMIS per tree) was significantly different from that for level II (18–48 PMIS per tree) at $P = 0.0044$ and $P = 0.0279$ for vegetative and bourse shoots, respectively. There was no significant mildew level × spray program interaction ($P = 0.6254$ and $P = 0.3411$ for vegetative and bourse shoot data, respectively), nor was there a significant overall effect of shoot type ($P = 0.1224$). There was a significant spray program × shoot interaction ($P = 0.0001$).

When the first fungicide application was delayed to PF or 1C, the level of primary mildew became a significant factor in secondary mildew incidence on vegetative shoots. On bourse shoots, no statistical difference was detected. Lalancette and Hickey (13) reported that trees with higher levels of primary mildew had greater rates of disease progress. Thus, the level of primary inoculum should be considered when decisions are made to delay the first fungicide application past bloom.

A disease management program with a minimum number of fungicide applications, effectively timed, optimizes economic benefits and reduces the threat of resistance and cross-resistance. Although early-season applications of mildewcides such as dinocap, benomyl, thiophanate-methyl, and sulfur are generally recommended (1–4,9,16,17), we have found that with triadimefon, applications at TC+P could be eliminated without significant loss of disease control. Our results have defined the period from bloom through the second-cover spray as the most effective time in which to manage mildew using triadimefon, with the earlier sprays during this period being more effective in controlling mildew on vegetative shoots and the later sprays more effective on bourse shoots. In summary, this study

Table 5. Comparisons between spray programs of triadimefon at two levels[w] of primary inoculum for control of powdery mildew on apple (cv. Rome Beauty) trees in 1982

Contrasts[x]				Vegetative shoots		Bourse shoots	
No.	Level I	vs.	Level II	Leaves infected (%)	$PR > \|t\|$[y]	Leaves infected (%)	$PR > \|t\|$[y]
1	NT[z]	vs.	NT	55.0 vs. 59.4	0.1362	47.8 vs. 50.2	0.3464
2	B+PF	vs.	B+PF	25.3 vs. 28.5	0.2248	32.2 vs. 37.1	0.0656
3	PF+1C	vs.	PF+1C	18.6 vs. 25.4	0.0120*	17.5 vs. 23.4	0.0277
4	1C+2C	vs.	1C+2C	32.9 vs. 39.2	0.0190*	25.9 vs. 24.9	0.7071
5	B+PF+1C+2C	vs.	B+PF+1C+2C	5.8 vs. 6.3	0.8591	11.8 vs. 12.8	0.6955

[w] Level I = 0–15 primary mildew infection sites per tree; level II = 18–48 primary mildew infection sites per tree.
[x] $H_0{:}\mu_1 = \mu_2$, $H_1{:}\mu_1 \neq \mu_2$; $MS_E = 16.45$; $DF_E = 39$; $DF_T = 99$.
[y] To provide a Bonferroni family confidence coefficient of 0.90, probabilities less than 0.0200 indicate a significant difference (*).
[z] Applications were made on: 6 May, bloom (B); 14 May, petal-fall (PF); 25 May, first cover (1C); and 8 June, second cover (2C). NT = nontreated.

has shown the importance of time of application of triadimefon, of the type of shoot on which disease assessment is made, and of the level of primary inoculum in assessing fungicide efficacy.

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