Fungicide Influence on the Relationship between Incidence and Severity of Powdery Mildew on Apple

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ABSTRACT

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The previously quantified relationship between disease severity (amount of leaf tissue affected by disease) and disease incidence (proportion of diseased leaves) for powdery mildew on apple was evaluated under different fungicide control regimes. Data were selected to eliminate external effects due to seasonal, cultivar, and location variation. Five fungicide treatments including captan, benzimidazoles, pyrazophos plus captan, bupirimate with or without captan, and triadimefon produced statistically equivalent incidence/severity (I/S) relationships. The I/S relationship for benzimidazole plus oil was significantly different from that for bupirimate, with or without captan, and for triadimefon. The I/S on untreated trees was significantly different from all fungicide relationships except benzimidazole plus oil and pyrazophos plus captan. Mode of fungicidal action may affect the I/S relationship. A re-analysis of fungicide efficacy data demonstrated how the general relationship could be used to evaluate different treatments based on severity ratings derived from incidence data.

Additional key words: disease assessment, disease survey, *Malus pumila, Podosphaera leucotricha.*

The relationship between disease incidence (proportion of plant units diseased) and severity (the amount of plant tissue affected) has been shown to be stable under some conditions (8,14,15) and to be useful for disease survey and assessment (4). Within a group of plots or orchards, severity of secondary infection of apple (*Malus pumila* Miller) by powdery mildew (*Podosphaera leucotricha* (Ell. and Ev.) Salm.) can be estimated from incidence after initially determinating a relationship in a subplot (15). The initial determination is needed because the relationship does not remain the same from year to year. However, the relationship has been shown to be consistent among climatologically similar locations and among certain apple cultivars (4,15).

The fungicides used to control powdery mildew vary in modes of action (2). The traditional fungicides (eg, sulfur or dinocap) are surface protectants that suppress fungal growth and sporulation either by direct contact or vapor phase activity. Most of the systemic fungicides inhibit hyphal and haustorial growth and sporulation, and some also exhibit vapor phase activity (2,6).

The effect of any fungicide or its mode of action on the disease incidence/severity (I/S) relationship of powdery mildew on apple was unknown. Rayner (13) used a similar relationship to evaluate fungicide efficacy in the control of rust on coffee.

We undertook this study to determine if the I/S relationship of powdery mildew on apple was altered by different fungicides.

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MATERIALS AND METHODS

Data were collected from mildewicide-evaluation orchards in the central New York region as described previously (15). The earlier study had shown that the I/S relationship was not altered by orchard location or cultivar (McIntosh, Idared, or Cortland). However, I/S relationships in different years were often significantly different, so data used in this study for comparison of fungicide effects were taken from years in which the relationship was statistically equivalent (1970, 1972, 1974, and 1975).

Fungicides. Trees were sprayed three to nine times with the following compounds: captan (*N*-trichloromethylthio-4-cyclohexene-1,2-dicarboximide) (Captan 50% a.i. W, Stauffer Chemical Co., Mountain View, CA 94040) at 1,200 or 2,400 mg a.i. L^{-1} water; benzimidazoles as either benomyl (methyl 1-[butylcarbamoyl]-2-benzimidazolecarbamate) (Benlate 50% a.i. W, E.I. du Pont de Nemours Co., Wilmington, DE, 19898) at 300 mg a.i. L^{-1} water or a proprietary benzimidazole (RH3928, Rohm and Haas Co., Philadelphia, PA 19105) at 450 mg a.i. L^{-1} water and 1,800 mg a.i. L^{-1} benzimidazole plus oil as benomyl at 150 mg a.i. L^{-1} water and oil (Volck 70 Supreme Oil, Chevron Chemical Co., San Francisco, CA 94120) at either 1.25 or 3.75 ml L^{-1} water; pyrazophos (2-[*O,O*-diethylthionophosphoryl-5-methyl-6-carbethoxypyrozolo-[1, 5 α] pyrimidine) (Afugan 30% a.i. EC, American Hoechst Corp., North Hollywood, CA 91605) at 0.078 or 0.625 ml a.i. L^{-1} water in combination with captan at 1,200, 1,800, or 2,400 mg a.i. L^{-1} water; bupirimate (5-butyl-2-ethylamino-6-

methylpyrimidine-4-yl dimethylsulfamate) (Nimrod 25% a.i. EC, ICI America Inc., Goldsboro, NC 27530) at 0.312 or 0.625 ml a.i. L^{-1} water, alone or in combination with captan at 2,400 mg a.i. L^{-1} water; triadimefon (1-[4-chlorophenoxy]-3,3-dimethyl-1-[1*H*-1,2,4-triazol-1-yl]-2-butanone) (Bayleton 25% a.i. W, Mobay Chemical Corp., Kansas City, MO 64120) at 75 and 150 mg a.i. L^{-1} water. Captan was used in combination with some of the treatments to control foliar diseases other than powdery mildew. Applications were made to runoff with a handgun sprayer operated at 3,447 kPa.

Disease assessment. Mildew evaluations were made in August of each year by collecting 15–25 vegetative terminals from each tree. Individual leaves represented the sampling unit, and they were rated for the absence or presence of mildew and the number of secondary lesions when mildew was present. A maximum lesion count of 10 was given to heavily infected leaves. The data were reduced prior to analysis by summing the lesion counts for each leaf position on all terminals of a tree and dividing by the total number of leaves rated on the tree. Thus, the final data represented average number of lesions (severity) and the proportion of infected leaves (incidence) for each tree in a fungicide treatment. The relationship between incidence and severity was linearized by taking the square root of severity (15) and was finally expressed as a weighted regression equation (9). Equations were developed for each chemical treatment and the untreated check trees. The homogeniety of residual variance was tested with Barlett's procedure (1), then differences between regression intercept and slope coefficients were determined with a multiple comparison test for coefficients with unequal observations ($P = 0.01$) (7).

Validation. Mildewicide efficacy data from Highland, NY, for 1974 (10), 1975 (11), and 1976 (12, and *unpublished*), involving apple cultivars McIntosh or Cortland, were reevaluated from the original incidence and severity data. In these tests, severity (S) was expressed as percent leaf area infected. Earlier work indicated that the same general I/S relationship existed when severity was measured as lesions per leaf or percent leaf area infected (15). Three regression equations representing the I/S relationship for each year were derived from a subset of incidence and severity data consisting of a single replicate of all treatments from each respective year. Each relationship was then applied to the full set of incidence data for that year to derive estimated severity ($\hat{S}$). Fungicide treatment means were calculated and compared for both S and $\hat{S}$ (5).

RESULTS

The general relationship between incidence and severity of apple powdery mildew remained relatively uniform for all fungicide treatments (Fig. 1), even though the different chemicals resulted in different levels of severity and incidence from which the relationship was calculated. Unsprayed trees had 59–100% of the leaves infected and averaged 2.7–9.4 lesions per leaf (Fig. 1A). Captan-treated trees had 27–92% of the leaves infected and averaged 1.2–6.7 lesions per leaf (Fig. 1E). The most effective chemical treatment, pyrazophos plus captan (Fig. 1C), resulted in 3–28% infected leaves and averaged 0.1–1.0 lesions per leaf. The incidence and severity ranges for the other chemical treatments fell between the extremes of the unsprayed controls and the pyrazophos plus captan except for a slightly lower minimum incidence with bupirimate.

When pooled, the residual variances from each of the regression lines were homogeneous, which allowed statistical comparison of the regression coefficients. The intercept coefficients of each chemical treatment were statistically equivalent ($P = 0.01$) but the slope coefficients of the benzimidazoles plus oil data was significantly greater than those of bupirimate (with or without captan) and triadimefon (Table 1). The absence of a fungicide treatment significantly lowered the intercept compared to fungicide treatments while the slope coefficient was significantly equivalent to only benzimidazoles plus oil and pyrazophos plus captan (Table 1). The relationship ranged from $\sqrt{S} = -0.73 + 3.70$ I for the unsprayed trees to $\sqrt{S} = 0.33 + 2.15$ I for the triadimefon-treated trees. The coefficients of determination (R^2) ranged from 88.6% for the unsprayed treatment to 96.3% for the triadimefon treatment. All slope coefficients differed significantly from 0 ($P = 0.01$); however, only pyrazophos plus captan, bupirimate, and triadimefon had intercept coefficients that differed significantly

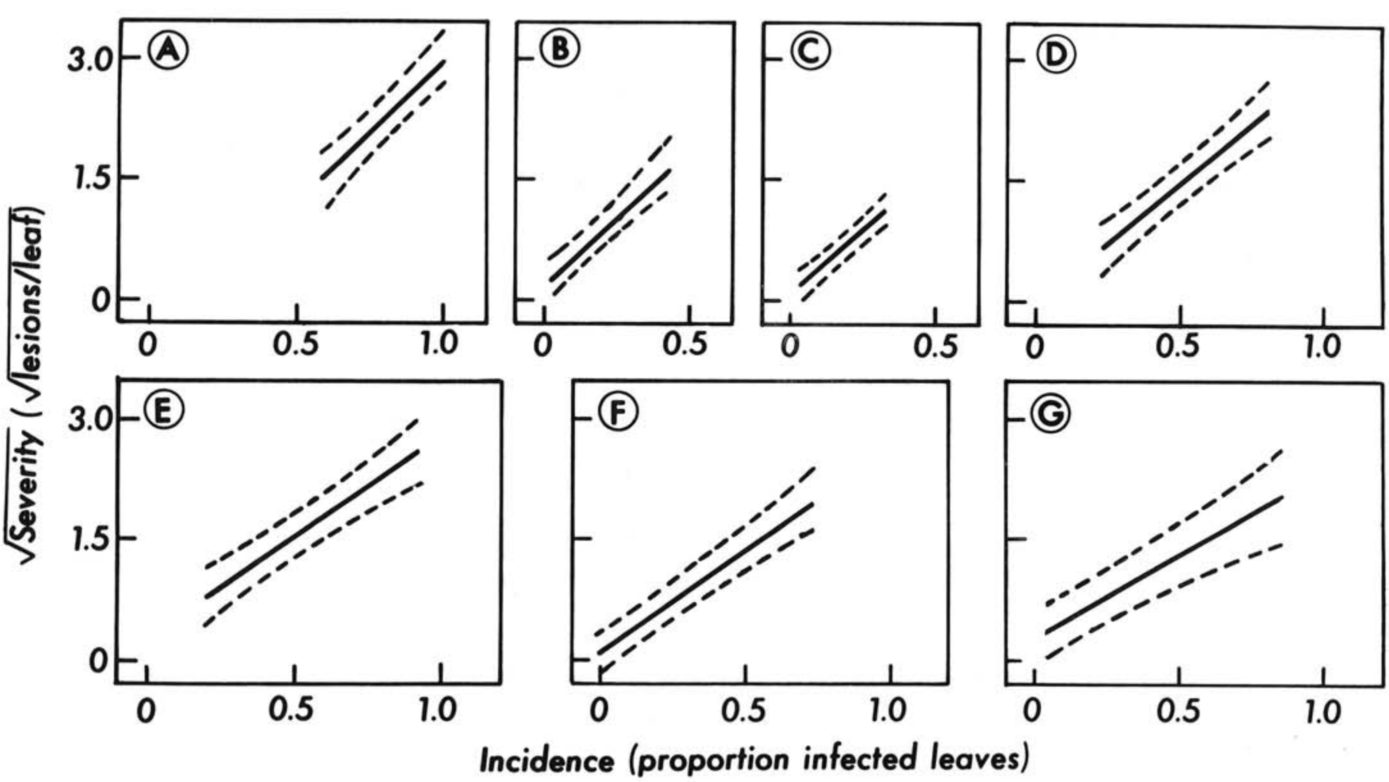

Fig. 1. Regression lines of severity vs incidence of apple powdery mildew for control and fungicide treatments. Dotted lines represent 90% confidence interval of the regression lines. **A,** Unsprayed; **B,** benzimidazole plus oil; **C,** pyrazophos plus captan; **D,** benzimidazole, **E,** captan; **F,** bupirimate with and without captan; and **G,** triadimefon.

from 0 ($P = 0.01$).

Validation. Comparison of fungicide treatments to control apple powdery mildew at Highland, NY, indicated that severity values can be predicted from incidence data and that mean separation tests closely approximate mean separation with real severity data (Table 2). Mean separation according to incidence often produced a different separation pattern compared to separation according to severity (Table 2). However, the $\hat{S}$ mean separation based on incidence data closely approximated the true S data. The actual S means were very similar to the $\hat{S}$ data that <4% difference within the 1974 and 1975 data and <2% difference in the 1976 data (Table 2).

DISCUSSION

The I/S relationship of *P. leucotricha* conidial infection of apple leaves does vary with the different fungicides used to control the disease. The intercept coefficient of the different fungicide relationships remained quite constant. The only statistically significant variation was in the no-spray control treatment (Table 1). It is unwise to interpret this difference because the intercept is considerably outside the range of intercepts indicated by analysis of the no-spray treatment data (Fig. 1A). Unfortunately there is no incidence level within the range of every treatment data set; thus, it is difficult to compare specific predicted severity values in each treatment.

The slope coefficients provide the most information on the I/S relationship. Mildew lesion numbers increased more rapidly for each increase in incidence in the no-spray treatment than did lesion numbers in any chemical treatment. A larger slope indicates that more successful infections occurred. Benzimidazoles plus oil allowed a significantly faster increase in lesion number for each increase in incidence than did bupirimate (with or without captan) or triadimefon. While benzimidazole plus oil was one of the best powdery mildew controls as evidenced by the reduced incidence and severity levels compared to the other treatments (Fig. 1), when infection took place, more leaf lesions developed compared to those that developed at similar incidence levels in trees that received the other chemical treatments. Oil is known to enhance the activity of benzimidazoles (16,17) but the slopes for benzimidazoles alone are not significantly different from those for benzimidazoles plus oil so it is not possible to associate the higher rate with the addition of oil.

Captan caused an intermediate I/S slope statistically similar to the other chemical treatments. However, captan is of little use in the control of *P. leucotricha*. While some studies have shown it to slow the growth of the pathogen (3), it is usually considered to have no effect on this disease and may even enhance it by controlling competing organisms (2). Our validation data illustrated this latter fact where slightly (although not significantly) more mildew occurred on the captan-treated leaves than on the unsprayed checks (Table 1; 1974; treatments 7-captan, 10-check). We used combinations with captan to minimize the effect of other foliar diseases and considered the effect of captan on powdery mildew development to be minor compared to the effect of the other compound. Nevertheless, captan alone produced an I/S slope that was significantly smaller than the no-spray treatment. Incidence and severity levels were higher than other chemical treatments (Fig. 1) but given an equivalent incidence level, captan did reduce the number of lesions per leaf compared to the check.

The bupirimate with and without captan and the triadimefon treatments produced I/S slopes that were significantly smaller than the check, benzimidazole plus oil, and pyrazophos plus captan treatments. While all fungicides used in these tests, except captan,

TABLE 1. Comparison of coefficients from regression lines of severity vs incidence of apple powdery mildew separated according to various types of fungicide treatments

Treatment	No. of trees	Regression coefficient Intercept	Slope	R^2 (%)[y]
No spray	16	−0.73 A[z]	3.70 A[2]	88.6
Benzimidazole + oil	9	0.26 B	3.29 AB	92.2
Pyrazophos + captan	11	0.18 B	2.97 ABC	93.2
Benzimidazole	18	0.18 B	2.61 BC	91.9
Captan	11	0.29 B	2.43 BC	92.3
Bupirimate ± captan	10	0.19 B	2.30 C	95.5
Triadimefon	6	0.33 B	2.15 C	96.3

[y]Coefficients of determination (R^2) are only approximate owing to use of the weighted-least-squares procedure (9).

[z]Coefficients followed by the same letter are not significantly different from each other based on a coefficient comparison test ($P = 0.01$) (7).

TABLE 2. Comparison of fungicide treatment means of incidence (I) (percent leaves infected), severity (S) (percent leaf area infected), and predicted severity ($\hat{S}$)[u](percent leaf area infected) for powdery mildew on apple

1974[v]				1975[w]				1976[x]			
Treatm no.	I (%)	S (%)	$\hat{S}$ (%)	Treatm. no.	I (%)	S (%)	$\hat{S}$ (%)	Treatm no.	I (%)	S (%)	$\hat{S}$ (%)
7	57.7 A[y]	19.0 A	22.7 A	11[z]	38.4 A	12.2 A	16.2 A	12[z]	24.2 A	9.2 A	9.9 A
10[z]	47.2 A	16.5 A	18.8 A	9	24.6 AB	7.5 AB	6.6 B	2	12.4 B	3.6 B	2.5 B
8	50.9 A	19.7 A	16.6 A	10	25.5 AB	7.5 AB	6.5 B	1	7.3 BC	2.2 B	1.6 B
4	30.5 B	8.4 B	8.6 B	6	11.8 BC	3.6 B	2.9 B	10	4.2 BC	1.0 B	0.5 B
3	17.1 C	6.5 BC	5.0 BC	7	15.6 BC	3.6 B	2.7 B	7	4.2 BC	0.8 B	0.5 B
6	20.7 BC	6.4 BCD	4.9 BC	1	15.5 BC	3.4 B	2.2 B	11	2.5 C	0.6 B	0.3 B
5	20.5 BC	5.4 BCD	3.9 BC	2	13.6 BC	2.9 B	2.0 B	6	1.9 C	0.3 B	0.2 B
1	11.4 CD	3.0 CDE	2.5 BC	3	8.4 BC	2.5 B	1.8 B	3	1.7 C	0.2 B	0.2 B
2	4.7 D	1.1 DE	1.3 C	8	12.7 BC	2.4 B	1.2 B	8	0.0 C	0.0 B	0.0 B
9	0.0 D	0.0 E	0.6 C	4	6.6 C	2.4 B	1.2 B	4	0.0 C	0.0 B	0.0 B
				5	8.4 BC	1.7 B	0.8 B	9	0.0 C	0.0 B	0.0 B
								5	0.0 C	0.0 B	0.0 B

[u] $\hat{S}$ was derived from the regression of $\sqrt{S}$ vs I for each of the 3 yr.

[v] Treatment numbers correspond to the order of treatment names in Table 2, reference 10, for McIntosh apple trees. I data are the average arc sine transformations of percent leaves infected based on 75 leaves in each of four replications. S and $\hat{S}$ data based on arc sine transformations of averaged Barrett-Horsfall ratings of 75 leaves in each of four replications. $\hat{S}$ derived from one replication of the I data.

[w]Treatment number corresponds to the order of treatment names in Table 2, reference 11, for McIntosh apple trees. I data is the average arc sine transformation of percent leaves infected based on 100 leaves in each of three replications. S and $\hat{S}$ data based on the arc sine transformation of averaged Barrett-Horsfall ratings of 100 leaves in each of three replications. $\hat{S}$ derived from one replication of the I data.

[x] Treatment number corresponds to the order of treatment names in Table 1, reference 12, for Cortland apple trees (*unpublished*). I data is the average arc sine transformation of percent leaves infected based on 120 leaves in each of three replications. S and $\hat{S}$ data based on the arc sine transformation of averaged Barrett-Horsfall ratings, of 120 leaves in each of three replications. $\hat{S}$ derived from one replication of the I data.

[y] Treatment means followed by the same letter within a column are not significantly different from each other based on Waller-Duncan's exact Bayesian K-ratio LSD rule ($P = 0.01$) (5).

[z] Unsprayed control treatment.

are systemic, only bupirimate and triadimefon have strong vapor phase activity (2,6). Pyrazophos has limited vapor phase activity (2). This type of fungicidal activity effectively redistributes the fungicide to the site of infection. Possibly bupirimate and triadimefon reduced the number of successful infections to such an extent that it is reflected in the I/S slope term.

The actual differences in the I/S relationship caused by various chemical treatments are not intrinsically large. The general relationship, that the percentage of infected leaves is linearly related to the square root of the number of lesions per leaf, is evident in each fungicide treatment. We believe the amount of information lost by pooling all treatments in a fungicide efficacy trial to form a single-experiment relationship is minimal compared to the savings in time and effort required to measure incidence rather than severity. To validate this concept we reanalyzed some previously developed mildewicide efficacy data (10–12, and *unpublished*) to compare differences between treatments separated by severity data and treatments separated by severity ratings derived from incidence data. The three tests presented in Table 2 demonstrated that predicted severity (S) values come very close to real severity (S) values. Differences between the two ratings never amounted to more than 4%, which indicates the subjective quality of the general I/S relationship. The validation data also indicate that severity rating methods may vary (number of lesions per leaf, or percent leaf area infected); but as long as severity is a measure of the amount of disease, the general relationship of $\sqrt{S} \propto I$ is valid.

We conclude that it is possible to evaluate fungicides by using disease incidence data alone to achieve mean separations with the same degree of accuracy as those obtained by using disease severity measurements. However, it is important to remove variability due to such factors as seasonal trends, which are known to affect the I/S relationship (8,15), before predicting disease severity from incidence data alone.

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