The Effect of Fungicide Schedules and Inoculum Levels on Early Blight Severity and Yield of Potato

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ABSTRACT

Christ, B. J., and Maczuga, S. A. 1989. The effect of fungicide schedules and inoculum levels on early blight severity and yield of potato. Plant Disease 73:695-698.

Several fungicide spray schedules were evaluated for their effect on controlling potato early blight under Pennsylvania growing conditions. Disease severity and lesion number were lowest when fungicide sprays were initiated before flowering of the potato plant. Lowest disease incidence and highest yield of U.S. no. 1 tubers occurred in plots with low inoculum density and in plots where fungicide sprays were initiated before flowering. Whereas fungicide spray schedules had a significant effect on yield in 1985, there was no effect on yield in 1986. The relationship between lesion number and yield in 1985 was not highly correlated. Inoculum level was directly proportional to the early blight severity that occurred during the 1986 growing season.

Early blight of potato (*Solanum tuberosum* L.), caused by *Alternaria solani* Sorauer, is the major foliar disease on potatoes in Pennsylvania. The most common and effective control method is the application of fungicides starting 6–7 wk after planting (1,3,5). Early blight can be adequately controlled by relatively few fungicide applications if the initial application is properly timed (1,3).

Several methods were developed to determine when protectant fungicide sprays should be initially applied for controlling early blight on potato (2–4). Spore trapping appeared to be the most reliable method, but was tedious to perform (4). Pscheidt and Stevenson (8) evaluated several forecasting methods for predicting and controlling early blight on potatoes in Wisconsin. One of their forecasting methods included FAST (forecasting of *A. solani* on tomato), which uses temperature, rainfall, relative humidity, and leaf wetness to calculate severity values.

The objective of this study was to determine the effects of various fungicide schedules and inoculum levels on early blight severity and yield of potato for Pennsylvania growing conditions.

Contribution No. 1651, Department of Plant Pathology, Pennsylvania Agricultural Experiment Station.

Authorized for publication 15 September 1987 as Journal Series Paper No. 7776.

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Accepted for publication 28 February 1989 (submitted for electronic processing).

MATERIALS AND METHODS

Field experiments were conducted in 1985 and 1986 at The Pennsylvania State University's Agricultural Research Center at Rock Springs, PA. Potatoes (cultivar Norchip) were planted with a two-row mechanical planter into a 0.41-ha plot on 14 May of each year. In 1985, certified seed was cut and treated with mancozeb dust (Dithane M-45, Rohm & Haas; 8% a.i.) before planting. In 1986, untreated, certified seed pieces were planted. In both years, seed pieces were spaced approximately 23 cm within the row with 0.98 m between rows. The soil type was a Hagerstown silt loam.

The herbicide EPTC (Eradicane, Stauffer Chemical Co.; 467 g a.i./ha) was applied several weeks before planting in both years for preemergence weed control. In both years, plots were fertilized with 89-89-89 kg/ha N-P-K in furrow at planting. Aldicarb (Temik 15G, Union Carbide) was applied in furrow at a rate of 505.7 g a.i./ha in 1985 and at a rate of 842.8 g a.i./ha in 1986. Fenvalerate (Pydrin 2.4 EC, Shell Chemical Co.; 124.6 g/ha a.i.) was applied once in 1985 to control the Colorado potato beetle (*Leptinotarsa decemlineata* Say). In 1986, azinphos-methyl (Guthion 2S, Mobay Chemical Co.; 387 ml a.i./ha) and permethrin (Ambush, ICI Americas, Inc.; 97 ml a.i./ha) were each applied once to control the Colorado potato beetle. Plants were cultivated and hilled as necessary.

All fungicide sprays were applied in water by a tractor-mounted sprayer with both drop and fixed nozzles (three nozzles per row) and a spray volume of 55.7 L/ha at 207 kPa. The fungicide mancozeb (Dithane M-45, Rohm & Haas; 1.8 kg a.i./ha) was used for all fungicide treatments in both years. Before harvest, plots were vine-killed with a 5:1 mixture of dinitro (Dow General Weed Killer, Uniroyal Chemical Co.; 581 ml a.i./ha) and diesel fuel. Potatoes were hand-harvested from the center row of each three-row treatment plot in mid-September of each year. All harvested tubers were graded into U.S. no. 1 (12) and cull sizes and were then weighed.

The isolate of *A. solani* used in this study was recovered from potato leaves collected in the field at Rock Springs in 1984. The organism was maintained on V-8 juice agar at 21 C for 7 days and then placed at 4 C for long-term storage. Plugs of 7-day-old cultures were transferred into 10 ml of sterile distilled water, agitated, poured onto water agar, and incubated under cool-white fluorescent diurnal light with a 12-hr photoperiod at 21 C to induce sporulation. When conidia were produced, an aqueous solution containing five drops of Tween 20/100 ml was added to the petri dish and the cultures were scraped to release the conidia. Conidial suspensions were filtered through double layers of cheesecloth, and the conidial concentrations were determined with a hemacytometer.

1985 Field season. Treatments were replicated seven times in a completely randomized design. Treatment plots consisted of three adjacent rows 9.1 m long with a 2.44-m alleyway at the end of the rows to separate plots. Buffer rows were not used to separate plots across rows because only the center row of plants was sampled throughout the growing season.

The FAST system (7) at two different severity levels (16 and 20 severity values based solely on leaf wetness periods and temperature), the BLITECAST forecasting system (6), and an unsprayed treatment were tested along with five treatments that used physiological parameters as a guide to begin fungicide sprays (Table 1). The initiation of the FAST system also was modified to begin the spray program at flowering rather than waiting for 35 severity values to accumulate.

Two plants in the center row of each plot were inoculated by spraying 10 ml of a conidial suspension (100 conidia/ml) of *A. solani* to leaves on the lower one-third of each plant. Inoculations were performed on 9 July at dusk so that leaves would remain wet for a minimum of 8 hr following inoculation. Early blight lesions were counted on all plants in the center row of each treatment plot on 18 and 29 July and 16 August. The number of lesions on all plants in the center row of each treatment plot was used to calculate the area under the disease progress curve (AUDPC) (11). Data for the number of lesions, AUDPC, and weight of U.S. no. 1 tubers were subjected to analysis of variance, correlation, and mean separation tests (Waller-Duncan k-ratio t test).

1986 Field season. The five treatments included in 1986 were weekly fungicide sprays that were initiated based on specific physiologic or disease parameters (Table 1). In addition, four inoculum levels were tested to evaluate the effect of inoculum level on early blight severity and yield. Each fungicide treatment was replicated six times and was nested within inoculum levels for a total of 120 treatment plots.

Treatment plots consisted of three adjacent rows, 2.8 m long, with a 1.5-m buffer of untreated potato plants between each plot within the row. Buffer rows were not used to separate plots across rows because only plants in the center row were sampled throughout the growing season. The field was separated into four blocks (inoculum levels) of 15 rows, and each block was separated by three rows of field corn to minimize interblock interference.

Five potato plants in the center row of each experimental unit were inoculated with a conidial suspension of *A. solani* on 28 June 1986. Inoculation procedures used were the same as those used in 1985. Approximate number of conidia applied to treatment plots within the four inoculum levels were 0, 1×10^3, 1×10^4, or 1×10^5. Two stems from each inoculated plant in each treatment plot were tagged and numbered for repeated sampling throughout the growing season. Assessments of severity were initiated on 11 July and were conducted four times during the growing season on all leaves of the 10 tagged stems in each treatment plot with the aid of diagrams of the Reifschneider rating system (10). Mean severity values for each treatment plot were calculated by summing the severity of each leaf, dividing by the total number of leaves per stem, and averaging over the 10 stems. Incidence of disease was calculated from severity ratings on a percentage basis by summing the number of diseased leaves per stem and dividing by the number of living leaves per stem. The percentage of dead leaves per stem was also recorded. Mean values were calculated for incidence and percent of dead leaves for each treatment plot.

Analysis of variance tests were performed on the disease variables (severity, incidence, and percent of dead leaves) using the AUDPC values generated for these variables over the four assessments. In addition, data from the 8 August assessment were analyzed because this was the last date that plants in all treatment plots were assessed on the same day.

Three yield components, weight, proportion, and number of U.S. no. 1 tubers, were analyzed. Analyses of variance that had significant treatment differences were subjected to a mean separation (Waller-Duncan k-ratio t test). Inoculum level differences used the mean square value of replications within inoculum level as an error term, and analyses having significant differences for inoculum level were tested for pairwise differences by the Waller-Duncan k-ratio t test. Correlations were

Table 1. Summary of fungicide applications during the 1985–1986 growing seasons for all treatments

Treatment schedule[a]	Weeks after planting 6	7	8	9	10	11	12	13	Total no. of sprays
1985									
Weekly sprays initiated									
Before flowering	...	X[b]	X	X	X	X	X	X	7
At flowering	...	...	X	X	X	X	X	X	6
After flowering (1 wk)	...	...	...	X	X	X	X	X	5
After flowering (2 wk)	...	...	...	...	X	X	X	X	4
After inoculation	...	X	X	X	X	X	X	X	7
BLITECAST	...	...	...	...	...	...	X	X	2
FAST (16 sv)	...	...	...	...	X	...	...	X	2
FAST (20 sv)	...	...	...	...	...	X	...	X	2
Control (no spray)	...	...	...	...	...	...	...	...	0
1986									
Weekly sprays initiated									
Plant height 20–25 cm	X	X	X	XX[c]	X	X	X		8
Before flowering (1 wk)	X	X	XX	XX	X	X	X		9
After flowering (2 wk)	...	...	X	XX	X	X	X		6
First disease appearance	...	...	...	X	X	X	X		4
Control (no spray)	...	...	...	...	...	...	...		0

[a] BLITECAST = forecasting system used for prediction of *Phytophthora infestans*, FAST = forecasting system used for *Alternaria solani* on tomato with a total severity value (sv) of 16 or 20. In 1985, the treatments before flowering and after inoculation differ only by different spray dates in the first week.
[b] Plots were sprayed once during the week (7-day spray schedule).
[c] Plots were sprayed twice during the week (4-day spray schedule).

Table 2. Mean number of early blight lesions[w] on three dates, area under disease progress curve, and yield of U.S. no. 1 tubers of potato cultivar Norchip for each treatment in the 1985 growing season

Treatment schedule	Mean no. of lesions per treatment plot 18 July	29 July	16 August	AUDPC[x]	Yield of U.S. no. 1 tubers (kg/ha)
Weekly sprays initiated					
Before flowering	15.4 a[y]	59.1 a	700.0 a	7,242.4 a	6,211.7 a
At flowering	32.3 a	155.8 abc	1,650.0 ab	17,300.4 ab	5,999.0 ab
After flowering (1 wk)	34.0 abc	121.0 ab	1,771.0 ab	17,886.9 ab	5,618.9 bc
After flowering (2 wk)	69.0 bcd	237.0 abcd	2,168.0 abc	23,333.9 b	5,850.0 abc
After inoculation	20.0 ab	54.6 a	880.0 a	8,821.3 a	5,948.7 ab
BLITECAST	96.0 d	433.0 de	3,531.9 bcd	38,589.9 c	5,706.4 bc
FAST (16 sv)[z]	80.0 cd	306.0 bcde	4,329.0 d	43,832.4 cd	5,488.4 cd
FAST (20 sv)	65.0 abcd	351.0 cde	4,064.0 cd	42,060.0 c	5,548.0 cd
Control (no spray)	87.0 d	489.0 e	5,166.0 d	54,052.6 d	5,184.6 d

[w] Lesions caused by *Alternaria solani*.
[x] Area under disease progress curve (11).
[y] Means followed by the same letter within a column are not significantly different ($P = 0.05$) according to Waller-Duncan's k-ratio t test, $k = 100$.
[z] Severity values (7).

Table 3. Severity and incidence of early blight and percent of dead leaves on 8 August, area under disease progress curve, and weight of U.S. no. 1 tubers as influenced by four inoculum levels of *Alternaria solani* in 1986

Inoculum level[x]	Severity		Incidence		Percent of dead leaves		Weight of U.S. no. 1 tubers (kg/plot)
	8 August	AUDPC[y]	8 August	AUDPC	8 August	AUDPC	
0	1.1 a[z]	6.0 a	17.9 a	87.3 a	20.4 a	96.0 a	3.14 b
1×10^3	4.9 b	34.1 a	54.1 b	369.4 b	27.4 ab	218.5 b	3.07 b
1×10^4	8.1 c	81.5 b	70.2 c	702.0 c	36.7 b	339.4 c	2.42 a
1×10^5	10.8 c	122.8 c	93.3 d	1,011.3 d	47.8 c	540.1 d	2.29 a

[x] Number of *Alternaria solani* conidia per treatment plot.
[y] Area under disease progress curve (11).
[z] Means followed by the same letter within a column are not significantly different ($P = 0.05$) according to Waller-Duncan's k-ratio t test, $k = 100$. Values listed are average of 30 treatment plots per inoculum level.

calculated between disease and yield components. Relationships between disease variables and inoculum level were investigated with linear regression.

RESULTS

1985 Field season. Lesion numbers on 18 July and the AUDPC value were significantly lower in the treatment where fungicide sprays were initiated before flowering than in treatments where fungicide sprays were initiated 2 wk after flowering or in treatments using the recommendations of the two FAST systems or BLITECAST (Table 2). On 18 July assessments, all sprayed treatments had fewer lesions, but not necessarily significantly less than nonsprayed treatments; at this assessment, the BLITECAST treatment had no fungicides applied.

Treatments where weekly fungicide sprays were initiated before flowering had significantly greater U.S. no. 1 tuber weights than treatment plots sprayed by recommendations of the two FAST systems or BLITECAST (Table 2). All sprayed treatments had greater U.S. no. 1 tuber weights than nonsprayed treatments, but the difference was not significant in all cases.

Correlations calculated between lesion number, AUDPC, and weight of U.S. no. 1 tubers indicated that lesion number on 16 August was most highly correlated with AUDPC values ($r = 0.99$). Correlation coefficients between weight of U.S. no. 1 tubers and lesion number or AUDPC were low.

1986 Field season. There were significant differences in severity, incidence, and percent of dead leaves among inoculum levels on 8 August and for AUDPC (Table 3). In all cases, treatments that received no additional inoculum had significantly lower severity, incidence, and dead leaf values than treatments receiving a 1×10^4 or 1×10^5 conidia per treatment plot. As inoculum levels increased, severity, incidence, and dead leaf values increased. There were significant differences among inoculum levels with regard to the weight of U.S. no. 1 tubers (Table 3). The higher two inoculum levels (1×10^4 and 1×10^5) had lower tuber weights compared with the other two inoculum levels.

Table 4. Severity, percent of dead leaves on 8 August, and weight, number, and percent of U.S. no. 1 tubers as influenced by fungicide spray schedules in 1986

Treatment schedule	Fungicide sprays	Severity (%)	Dead leaves (%)	U.S. no. 1 tubers Weight (kg/plot)	U.S. no. 1 tubers Number	Percent of U.S. no. 1 tubers
Weekly sprays initiated						
Plant height 20–25 cm	8	4.2 a[z]	25.4 a	2.82 a	27.9 a	68.0 a
Before flowering (1 wk)	9	4.6 a	28.8 ab	2.90 a	27.5 a	68.0 a
After flowering (2 wk)	6	4.1 a	30.9 b	2.87 a	26.8.a	69.0 a
First disease appearance	4	7.0 b	35.2 c	2.69 a	24.7 ab	67.0 ab
Control (no spray)	0	11.3 c	45.0 d	2.38 a	23.2 b	61.0 b

[z] Means followed by the same letter within a column are not significantly different ($P = 0.05$) according to Waller-Duncan's k-ratio t test, $k = 100$. Values listed are average of 24 treatment plots per fungicide schedule.

There were significant differences between treatments for severity, incidence, and dead leaf values on 8 August and for AUDPC when averaged over the four inoculum levels. There was no inoculum level by treatment interaction for severity and percent of dead leaf values on 8 August or for yield components, but there were significant differences among treatments (Table 4). The nonsprayed control had significantly higher severity and percent of dead leaves than the treatments receiving fungicide sprays, but yield was not significantly different. There was a significant difference between the nonsprayed control and the fungicide treatments with regard to the proportion and number of U.S. no. 1 tubers, but the difference was not significant for weight (Table 4). Because of significant inoculum level by treatment interactions, the AUDPC values of severity, incidence, and percent of dead leaves for individual inoculum levels were analyzed separately to evaluate treatment effects.

The nonsprayed control plots had significantly higher AUDPC values for severity and incidence at inoculum levels 0 or 1×10^3 (Table 5). At the higher two inoculum levels, the nonsprayed treatment was not significantly different from the treatment receiving four sprays. The treatments receiving six, eight, or nine sprays were not significantly different in AUDPC values for severity or incidence at any inoculum level. Within inoculum levels 0 or 1×10^5, there were no differences among treatments for weight of U.S. no. 1 tubers.

Correlations calculated between yield and disease variables indicated that there was a negative correlation. However, coefficients were low ($r = -0.39$ to -0.47). The disease variables on 8 August were highly correlated to their respective AUDPC values ($r = 0.90$ to 0.93), and AUDPC values between severity and incidence were highly correlated ($r = 0.92$).

Regression analysis indicated that as inoculum level increased, severity, incidence, and percent of dead leaves increased (Table 6). There was not as significant a relationship between number of sprays and the disease variables.

DISCUSSION

Fungicide sprays initiated 1 or more wk after flowering were less effective in controlling early blight of potato than sprays initiated before flowering. Fungicide sprays initiated at the first appearance of early blight were ineffective in controlling the disease.

Weight of U.S. no. 1 tubers was higher and disease incidence and severity were lower in treatment plots where weekly fungicide sprays were initiated 1 wk before flowering. Flowering (i.e., physiological age) appears to be a good indicator for the initiation of fungicide sprays with the cultivar Norchip.

Fungicide forecasting systems that are available for early blight of tomato and late blight of potato need modification in order to control early blight of potato. The FAST system (7), developed in Pennsylvania for early blight of tomato, has been tested on potatoes in Wisconsin.

This system was found to be as effective in controlling early blight of potato as weekly fungicide sprays that were initiated when plants were 20–25 cm tall (8). For tomatoes, 35 total severity values are allowed to accumulate before the initial fungicide spray is applied. Cumulative severity values from the S and R tables that indicate when to spray after the first 35 total severity values are 11 and 8, respectively. For potatoes, FAST was not initiated until flowering because the 35 severity values accumulate too rapidly during spring conditions in Pennsylvania. The cumulative severity values from the S table used to indicate when to spray were increased to either 16 or 20 because of the rapid accumulation of severity values that occurred in the early part of the growing season. These two FAST treatments were ineffective in controlling early blight of potato. The lower severity values used for tomatoes might provide for more fungicide sprays and, therefore, better control. Pscheidt and Stevenson (8) modified the temperature portion of the FAST system and increased the R value from 8 to 10 for optimal timing of sprays on potatoes in Wisconsin. As suggested by Pscheidt and Stevenson (8), the R table of FAST, which uses temperature, rainfall, and humidity, may have provided better control of early blight than using only the S table, which uses temperature and hours of leaf wetness.

The BLITECAST system (6) was tested without modification in 1985 because growers using the BLITECAST system may not have applied fungicide sprays early enough to control early blight. BLITECAST proved ineffective in controlling early blight during the warmer summer months of 1985. Epidemics of late blight are favored by cool and moist conditions, whereas early blight epidemics are favored by warm and moist conditions (6,9).

In 1986, the greatest weight of U.S. no. 1 tubers was produced when plots were sprayed with fungicides before flowering. Treatments that were inoculated with *A. solani* had a higher percentage of dead leaves, increased incidence and severity of disease, and reduced weight of U.S. no. 1 tubers than noninoculated treatment plots. In Pennsylvania, fungicide sprays for early blight must be initiated before or at flowering on the cultivar Norchip, and it is recommended that BLITECAST alone not be used to initiate sprays in areas where early blight is a problem. Only Norchip, which is susceptible to early blight, was evaluated in this study. Initiation of sprays may be later for other cultivars that are moderately resistant to early blight.

Table 5. Area under disease progress curve values of early blight severity, incidence and percent of dead leaves, and weight of U.S. no. 1 tubers as influenced by inoculum level and number of fungicide sprays in 1986

Inoculum level[w]	No. of fungicide sprays[x]	AUDPC[y] Severity	Incidence	Dead leaves (%)	Weight of U.S. no. 1 tubers (kg/plot)
0	9	0.95 b[z]	25.26 b	114.79 a	3.27 a
	8	0.64 b	22.47 b	53.11 a	2.74 a
	6	2.16 b	54.87 b	101.11 a	3.42 a
	4	6.13 b	107.14 b	68.38 a	3.35 a
	0	19.97 a	226.76 a	142.74 a	2.93 a
1×10^3	9	16.58 c	272.66 cd	217.00 b	3.30 ab
	8	13.87 c	249.69 d	109.15 c	3.32 ab
	6	24.91 c	353.54 bc	194.92 bc	3.68 a
	4	44.89 b	432.13 b	256.51 ab	2.18 b
	0	70.14 a	539.19 a	314.85 a	2.85 ab
1×10^4	9	54.97 b	565.17 b	200.54 c	2.40 ab
	8	50.17 b	565.39 b	215.45 c	2.60 ab
	6	60.16 b	632.28 b	348.91 b	2.16 ab
	4	112.32 a	884.96 a	461.54 a	2.91 a
	0	130.01 a	862.43 a	470.81 a	2.03 b
1×10^5	9	109.51 b	955.07 b	466.16 c	2.59 a
	8	80.55 c	915.18 b	458.30 c	2.61 a
	6	109.08 bc	948.06 b	508.36 bc	2.23 a
	4	138.52 ab	1,077.46 a	560.70 b	2.30 a
	0	176.26 a	1,160.53 a	706.76 a	1.70 a

[w] Number of conidia applied to treatment plots.
[x] Sprays initiated according to treatments in Table 1.
[y] Area under disease progress curve (11).
[z] Means followed by the same letter within a column and inoculum level are not significantly different ($P = 0.05$) according to Waller-Duncan's k-ratio t test, $k = 100$.

Table 6. Regression of area under disease progress curve values for severity, incidence, and percent of dead leaves on inoculum level of *Alternaria solani*

Log_{10} AUDPC[w]	Intercept[x]	Slope[y]	R^2[z]
Severity	−0.15	0.60	0.86*
Incidence	1.38	0.44	0.87*
Percent of dead leaves	1.64	0.28	0.97**

[w] Area under disease progress curve (11).
[x] Intercept of regression line.
[y] Regression coefficient or slope of regression line.
[z] Coefficient of determination, an estimate of the amount of variation explained by the model. Asterisks indicate significance of the model: * = $P < 0.10$, ** = < 0.05.

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