Influence of Selected Protectant Fungicides and Host Resistance on Simple and Complex Potato Late Blight Forecasts

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ABSTRACT

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Models of the initial deposition, weathering, and efficacy of triphenyltin hydroxide and captafol were developed and used in simulation studies designed to construct simple and complex potato late blight forecasts. The complex forecast recommended fungicide applications according to weather conditions, cultivar resistance, and fungicide type. In the simple forecast, sprays were recommended at fixed intervals according to cultivar resistance and fungicide type. In field experiments, spraying according to either method held final disease to levels of <5%. Fewer sprays were recommended for the moderately resistant cultivars than for the more susceptible cultivars.

Potato late blight, induced by *Phytophthora infestans* (Mont.) DeBary, is potentially an important threat to commercial potato production in the northeastern USA. Large quantities of fungicides are currently used to control the disease (1). Increasing costs of application and concern about the environmental impact of these materials have stimulated efforts to develop methods for increasing the efficiency of fungicide use. Some methods are disease "forecasting" (6,9,12) and the use of resistant cultivars.

Because of the pathogenic variability of *P. infestans*, the use of race-specific host resistance has not been successful (17). The present level of rate-reducing resistance in commercial cultivars cannot alone control late blight adequately when conditions are favorable for late blight. However, such resistance contributes to efficient management when used with periodic applications of protectant fungicides (6).

A weather-sensitive forecast system that incorporates the effects of host resistance has been evaluated (8). This forecast was derived by using analysis of simulation models that described pathogen development (2), the initial deposition of a chlorothalonil fungicide (3), and its subsequent weathering, redistribution, loss, and efficacy (4).

Because both the nature of the active ingredient and the type of formulation affect fungicide tenacity and efficacy, this forecast system (8) is only known to be valid with chlorothalonil. Knowledge of characteristics of other fungicides should permit the adaptation of this forecast system for use with them.

A forecast that is responsive to weather may be difficult for certain growers to accommodate, particularly those who rely on custom applicators. Fixed application schedules may be more acceptable to some commercial growers than weather-sensitive forecasts. Cultivar resistance can be incorporated into fixed-interval application by adjusting fungicide concentration or application frequency. Guidelines for adjusting fungicide concentration to complement cultivar resistance have been prepared (8), but guidelines for adjusting fixed-interval applications to complement cultivar resistance have not been described. We have therefore constructed preliminary guidelines for different fixed-interval applications to cultivars in different resistance classes. Analyses based on existing fungicide (3,4) and pathogen (2) simulation models are appropriate for predicting optimum application intervals for fungicides with diverse characteristics on cultivars that are susceptible, moderately susceptible, or moderately resistant to *P. infestans*.

The objectives of this investigation were to generalize an existing weather-sensitive forecasting system for use with two additional fungicides, triphenyltin hydroxide (TPTH) and captafol; to predict, from simulation analysis, fixed-interval application schedules for cultivars of diverse resistance; and to evaluate the two techniques in field experiments. Preliminary reports of portions of this work have been published (15,16).

MATERIALS AND METHODS

Characterization of fungicides. Detailed descriptions of three fungicide characteristics were needed. Tenacity and fungal toxicity of each fungicide were determined experimentally. Estimates of initial depositions in various canopy levels were obtained from previous studies (3) and are applied to TPTH and captafol in Table 1.

The effects of rainfall and deposit age on removal of fungicides were determined in greenhouse experiments. Potato plants, *Solanum tuberosum* L. 'Norchip' and 'Kennebec', were grown in a greenhouse for 4–6 wk in a peat-vermiculite mixture (1:1, v/v) containing 0.4 kg each of N, P, and K per cubic meter of mixture.

TABLE 1. Estimates of initial triphenyltin hydroxide and captafol deposits throughout various canopy levels used in computer simulations studies[a]

	Estimated fungicide deposit (μg a.i./cm^2 leaf tissue)			
	Triphenyltin hydroxide LAI[b]		Captafol LAI[b]	
Canopy level (cm)	<2.5	>2.5	<2.5	>2.5
>45	1.16	0.62	2.63	1.40
45–30	1.16	0.62	2.63	1.40
30–15	0.47	0.61	1.02	1.25
<15	0.47	0.04	1.02	0.87

[a] Calculated from data from (4).

[b] LAI = Leaf area index class.

Small droplets (5 μl) of aqueous suspensions of a TPTH fungicide (Super Tin, 4F) or a captafol fungicide (Difolatan 4F) were applied to leaflets of the potato plants. Concentrations were 0.30 g a.i./L (captafol) and 0.62 g a.i./L (TPTH). Fungicides were applied 0.1, 1, 5, and 7 days before application of rainfall.

Rainfall was applied to plants in an apparatus at the Boyce Thompson Institute, Ithaca, NY. Plants were placed on a 2.44-m-diameter turntable rotated at 10 rpm. Rainfall was simulated with two overhead sprinklers equipped with hollow-cone nozzles (Delvan RD Raindrop Orifice #5). Pressure was maintained at 2.67 kg/cm^2. After rainfall had ceased and leaves had dried, 12-mm-diameter leaf disks were removed and placed in sterile 23-mm-diameter test tubes. Samples were frozen at -10 to 0 C for 18–24 hr.

Fungicide residues were quantified by using a bioassay based on the growth of *Saccharomyces cerevisiae* in a liquid medium. The medium was composed of Difco potato-dextrose broth (24 g/L) containing 0.05 g of streptomycin sulfate and 0.05 g of chloramphenicol per liter. Yeast cells obtained from 24-hr cultures grown on a potato-dextrose agar were added to the bioassay medium to obtain an initial yeast concentration of $\sim 3.0 \times 10^5$ cells per milliliter.

Medium (10 ml for samples of TPTH, 20 ml for samples of captafol) was dispensed into tubes (25-mm diameter) containing leaf disk samples. Tubes were placed on a rotary shaker (150 rpm) at a 45-degree angle and incubated for 24 hr at room temperature. Turbidity was measured using a Spectronic 20 spectrophotometer (Bausch & Lomb Co.) at 650 nm. During each experiment a standard curve relating turbidity (absorbance) to the logarithm of fungicide concentration was produced by using linear regression (10). Typical coefficients of determination (r^2) were between 96 and 98% for TPTH and 86 and 98% for captafol. The sensitivity of the assay was calculated to be less than ± 0.03 μg a.i. of captafol and ± 0.06 μg a.i. of TPTH.

Data from rainfall experiments were used to develop multiple regression models relating the proportion of the original deposit remaining to rainfall and time since application. Patterns of redistribution throughout the potato canopy were assumed to be similar to those described previously for chlorothalonil (3).

Fungal toxicity was determined by constructing dose response curves relating fungicide concentration to the development of lesions on inoculated potato plants. Plants of the cultivar Norchip, 6–8 wk old, were used. Five leaflets per plant were sprayed with one of five concentrations of each fungicide. Fungicides were applied with an atomizer connected to a timing device, calibrated to deliver known volumes (4.19 ± 0.39 μl/cm^2, $N = 5$) per unit area. Fungicides were dried for 3–6 hr under greenhouse conditions.

Leaflets were inoculated with an isolate of *P. infestans* (Race 1) grown for 15 days on a lima bean-V8 medium (13). Inoculum was prepared by washing plates with deionized water; the concentration was adjusted to 12,000 sporangia per milliliter. A 20-μl droplet of this suspension was placed on each of the 25 treated leaflets and spread over their surfaces. Plants were placed in a chamber held at 20 C for 3–4 days. Relative humidity was maintained at or near 100% for 18 hr after inoculation. Lesion counts were made 3–4 days after inoculation. The effect of fungicide was determined by comparing numbers of lesions on fungicide-treated leaves with those on leaves not treated with fungicide (control). The proportion of control was obtained by dividing the number of lesions on fungicide-treated leaflets by the number observed on untreated (control) leaflets. Dose-response curves were constructed for each fungicide by regressing the probit of the proportion of control against fungicide amount.

Generalization of weather-sensitive forecasts. Computer simulations were performed to generalize an existing weather-sensitive forecast system (8) for use with TPTH and captafol. The existing system recommended chlorothalonil applications when weather favored epidemic development and/or when residues had declined below certain thresholds.

The degree to which weather favored epidemic development was quantified in terms of blight units (8). Blight units are calculated daily according to the length of the period of high relative humidity, the temperature during this period, and the level of cultivar resistance (8). Blight units were accumulated more rapidly for susceptible than for moderately resistant cultivars (8).

The influences of captafol and TPTH on late blight development were predicted from data describing their tenacity and fungal toxicity using a computer simulation model (4). Declines in foliar fungicide levels were quantified in terms of fungicide units.

To determine appropriate blight unit and fungicide unit thresholds, computer simulations of five growing seasons of diverse weather were performed. Weather data were typical of central New York state (5). The effects of fungicide applications were simulated when different blight unit and fungicide unit thresholds were exceeded. Thresholds that held disease below acceptable levels (<3% loss in marketable yield) and recommended fungicide applications at economically feasible intervals were identified.

Determination of fixed-interval applications. Simulation analyses were also performed to predict the effects of fixed-interval fungicide applications on disease development and management costs for cultivars of diverse resistance and for different fungicides. Five seasons of diverse weather (5) were simulated by using the computer. Sprays were simulated at different intervals. Models of fungicide dynamics (3,4) and pathogen development (2) were used to predict fungicide and cultivar influences on disease development. Optimum fixed-interval applications were identified as those intervals that minimized costs. Costs of disease-induced losses and costs of applying fungicides were estimated as $30/ha for fungicide applications and 33,600 kg/ha yield at $0.09/kg, respectively. A 1% yield loss was estimated to be equivalent to a loss of $30/ha.

Evaluation of fungicide timing techniques. Field experiments were performed in 1982 in two different environments (irrigated and not irrigated) to evaluate the generalized weather-sensitive forecast and the fixed intervals adjusted to cultivar resistance. The fungicides chlorothalonil, TPTH, and captafol were used to evaluate the weather-sensitive forecast. Chlorothalonil was also used to evaluate the efficacy of fixed-interval applications adjusted to complement cultivar resistance.

Experimental units consisted of small plots of potatoes four rows wide (0.9 m between rows) and 3.6 m long. Plots were separated by 4.57 m of fallow ground on all sides. This plot size and spacing had been shown to limit interplot interference to an acceptable level (11). The irrigated location was about 500 m from the unirrigated location at a research farm at Freeville, NY. At the irrigated location, sprinkler irrigation was applied from 0700 to 0745 and from 1900 to 1945 hours at 2.3 mm/hr. Field plots were arranged in three randomized complete blocks at the unirrigated location and four randomized complete blocks at the irrigated location. Unsprayed controls were established at least 35 m from other plots to ensure that conditions suitable for disease development had been satisfied.

Foundation or certified seed pieces were planted on 26 May at the irrigated location and on 2 June at the unirrigated location. Two cultivars with different levels of rate-reducing resistance were used: Hudson (susceptible) and Kennebec (moderately resistant) (7). Kennebec seed pieces were whole tubers of ~50 g. Hudson seed pieces were portions of tubers, weighed about 50 g, and were treated with mancozeb dust before planting. Fertilizer (168 kg N, 74 kg P, and 139 kg K/ha) and the insecticide aldicarb (3.3 kg a.i./ha) were applied at planting. Herbicide was applied before emergence (linuron 50 WP, 1.7 kg a.i./ha) or after emergence (metribuzin, 0.14 kg a.i./ha). The insecticides parathion (Parathion 8 EC, 0.56 kg a.i./ha), carbaryl (Sevin 50 WP, 1.12 kg a.i./ha), and oxydemetonmethyl (Meta-systox-R, 0.56 kg a.i./ha) were applied once or twice as needed during July and August. A vine killer (dinoseb, 4.7 L/ha) was applied on 10 September.

Fungicides were applied with a tractor-mounted hydraulic spray boom calibrated to deliver 935 L of spray per hectare. Fungicides, formulations, and rates used were: chlorothalonil (Bravo 500, Diamond Shamrock Co., 841 g a.i./ha), TPTH (Super Tin 4F, Griffin Corp., 245 g a.i./ha), and captafol (Difolaton 4F, Chevron Corp., 841 g a.i./ha). Fungicide applications began in late July and continued through 4 September.

Plots at the irrigated location were inoculated on 2 and 3 August.

A potato shoot in the center of each plot was sprayed with a sporangial suspension (12.5×10^4 sporangia in 25 ml water) of *P. infestans* (race 1,3,4,5,7). At the unirrigated location, inoculum was provided from nearby experiments.

Disease development, based on a key described previously (6), was assessed visually every 3–7 days until application of vine killer. The area under the disease progress curve was calculated as described by Shaner and Finney (14). Treatment means were separated by using orthogonal comparisons (10).

On 28 and 29 September, the center two rows of plots in the irrigated field were harvested. On 19 October, tubers were graded and inspected visually for tuber blight. Weights of all tubers and of those blighted were obtained for each plot.

RESULTS

Characterization of fungicides. Fungicides varied in tenacity and in levels of fungal toxicity. Both fungicides were removed by rainfall according to modified negative exponential functions. The models were as follows

for TPTH:

$$P_t = \text{Exp}\,[0.169 - 0.561\,(\text{RAIN}_t)^{1/3} + 0.063\,[(\text{RAIN}_t)\,(t)]^{1/3}] \qquad R^2 = 0.898$$

and for captafol:

$$P_t = \text{Exp}\,[0.515 - 0.613\,(\text{RAIN})^{1/3} + 0.078\,[(\text{RAIN}_t)\,(t)]^{1/3}] \qquad R^2 = 0.836$$

in which P_t is the proportion of fungicide remaining after rainfall on day t, RAIN_t is the rainfall (mm) on day t, and t is the number of days since the last fungicide application. Predictions, generated from models of fungicide loss, are illustrated in Figs. 1 and 2. Tenacity of captafol and TPTH increased only slightly with age. In contrast, the tenacity of chlorothalonil deposits increased substantially with age (4). Within the interval of 0–10 mm of artificial rainfall, deposits of captafol were retained at higher levels than those of TPTH.

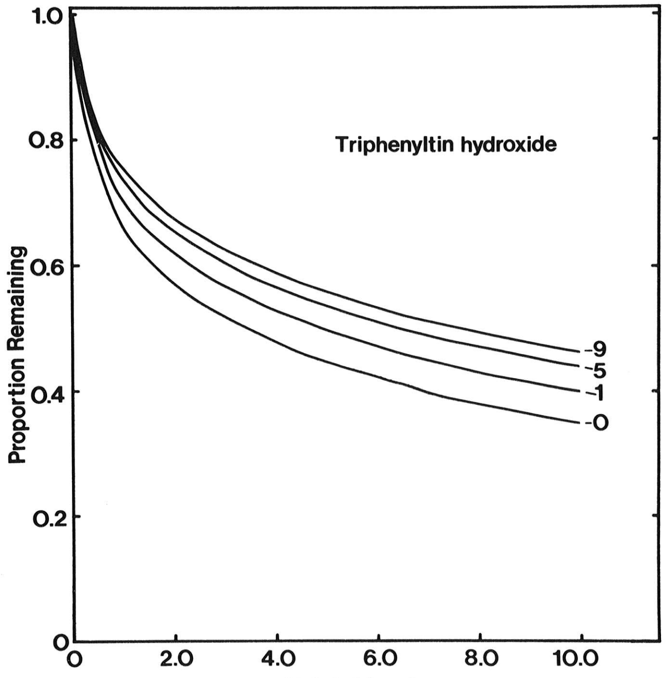

Fig. 1. Influence of rainfall and deposit age on the removal of triphenyltin hydroxide from potato foliage. Proportion remaining = proportion of original fungicide deposit remaining after artificial rainfall. Curves indicate responses of deposits aged for different periods before rainfall.

TPTH limited development of late blight lesions at considerably lower concentrations than captafol (Fig. 3) and at lower concentrations than those reported for chlorothalonil (2). Dose response curves used in simulation studies were:

for TPTH:

$$\text{Probit}\,(Y) = 4.91 + 12.8\,(X^{1/2}) \qquad R^2 = 0.998$$

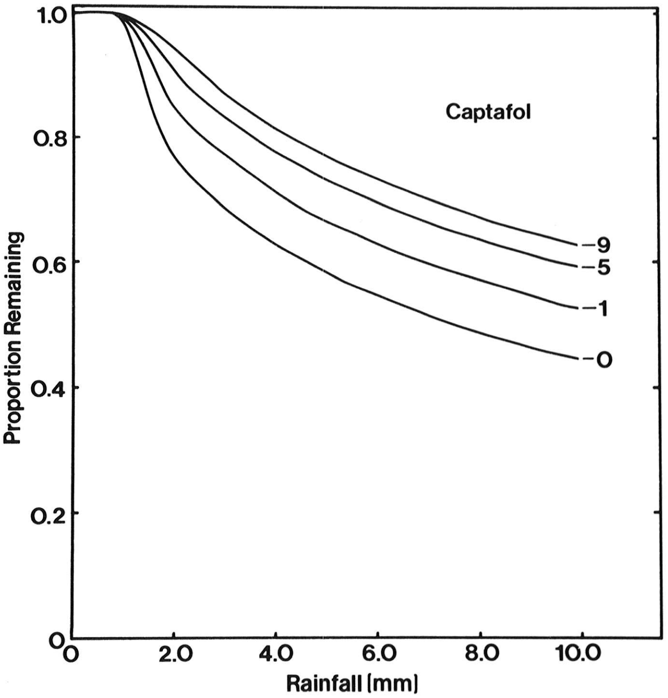

Fig. 2. Influence of rainfall and deposit age on the removal of captafol from potato foliage. Proportion remaining = proportion of original fungicide deposit remaining after artificial rainfall. Curves indicate responses of deposits aged for different periods before rainfall.

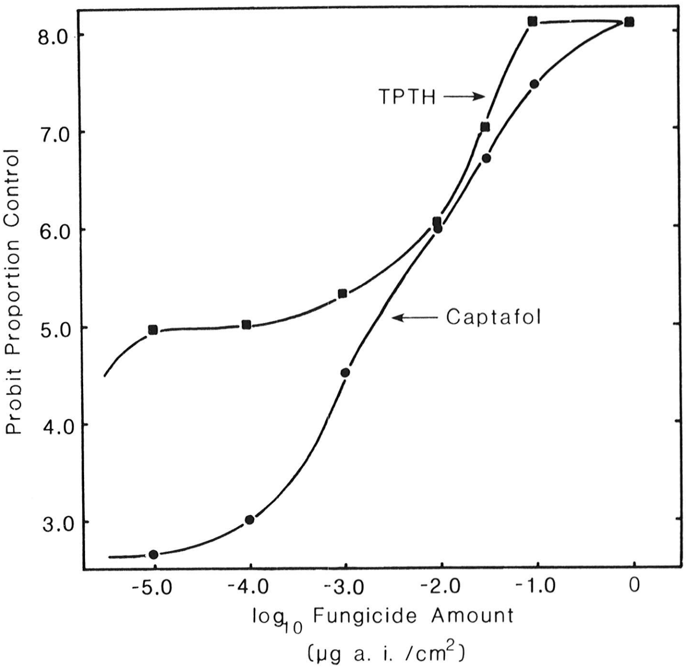

Fig. 3. Dose-response curves used in simulation studies for triphenyltin hydroxide and captafol.

and for captafol:

$$\text{Probit}\ (Y) = 8.90 + 1.46\ (\log_{10} X) \qquad R^2 = 0.984$$

in which Y is the proportion of control and X is the fungicide amount in μg a.i./cm^2 of leaf tissue.

Development of weather-sensitive forecasts. The tenacity and fungal toxicity of TPTH and captafol were used in computer simulations to predict influences of weather on removal of these fungicides from foliage and to predict the need for an additional spray application. Fungicide units quantified fungicide removal and are specific to a given fungicide (Tables 2 and 3; [8]). As in the previously developed system (8), before a spray was recommended, weather was allowed to be more favorable, and fungicide residue levels were allowed to decline to lower levels on the foliage of moderately resistant cultivars than on susceptible ones. The threshold for TPTH and captafol appear as decision rules in the generalized forecast (Table 4).

Fixed-schedule application intervals. Host resistance and fungicide characteristics influenced the application interval that minimized costs in simulation analyses. The effects of altering the application interval on costs and on simulated disease development are illustrated for a susceptible cultivar in Fig. 4. Frequent applications, although reducing losses due to disease, resulted in high fungicide costs. As application intervals increased, costs dropped to a minimum. As intervals were extended further, costs rose because disease-induced losses increased faster than the economic benefits of spraying less frequently. The interval that minimized costs was identified as the optimum application interval. For very susceptible cultivars, the optimum intervals were 6, 9, and 6 days for chlorothalonil, TPTH, and captafol, respectively. For moderately resistant cultivars, the optimum intervals were 11, 12, and 12 days for chlorothalonil, TPTH, and captafol, respectively. Presumably, the high efficacy of TPTH allowed for the relatively longer interval on very susceptible cultivars.

TABLE 2. Table for calculating fungicide units for triphenyltin hydroxide for the weather-sensitive forecast as determined by rainfall and the number of days since the last fungicide application

Days since application	Daily rainfall (mm)[a]							
1	<1	···	1	···	2	3	5	>7
2	<1	···	1	2	···	3	5	>7
3–6	<1	···	1	2	3	···	5	>7
7–10	<1	1	···	2	3	5	7	>9
>10	<1	1	2	···	3	5	>7	···
Fungicide units	1	3	4	5	6	7	8	9

[a] Each daily rainfall value represents the lower threshold needed to accumulate the corresponding number of fungicide units.

TABLE 3. Table for calculating fungicide units for captafol for the weather-sensitive forecast as determined by rainfall and the number of days since the last fungicide application

Days since application	Daily rainfall (mm)[a]								
1	<2	···	···	2	···	3	5	···	>7
2	<2	···	2	···	3	···	5	7	>9
3–4	<2	···	2	···	3	5	···	7	>9
5–6	<2	2	···	3	5	···	7	>9	···
7–8	<2	2	···	3	5	···	7	>9	···
9–10	<2	2	···	3	5	7	>9	···	···
>10	<3	···	3	···	5	7	>9	···	···
Fungicide units	1	2	3	4	5	6	7	8	9

[a] Each daily rainfall value represents the lower threshold needed to accumulate the corresponding number of fungicide units.

TABLE 4. Decision rules for generalized weather-sensitive forecast

	Cultivar resistance	
	Susceptible	Moderately resistant
Fungicide should be applied if it has not been applied within 5 days		
AND cumulative blight units since last spray exceed:	30	40
OR cumulative fungicide units since last spray of the indicated fungicide exceed:		
Chlorothalonil	15	25
Triphenyltin hydroxide	15	20
Captafol	15	20

Field evaluations of fungicide timing techniques. The generalized weather-sensitive forecast recommended different application intervals according to differences in host resistance, macroclimate, and fungicide type (Table 5). Under irrigated conditions disease developed rapidly in unsprayed plots. In all fungicide treatment plots the final level of disease was held to less than 5%; there were no significant differences in the disease severities among treatments, although different amounts of fungicides had been applied (Tables 5 and 6). Without irrigation, disease failed to develop to measurable levels in any treatment. Consequently, the unirrigated location did not provide an adequate test of the system.

Host resistance had a greater influence on spray recommendations under unirrigated than irrigated conditions. These differences were greatest for plots sprayed with chlorothalonil and least for plots sprayed with TPTH (Table 5).

Under irrigated conditions, fixed-interval applications of chlorothalonil (which had been adjusted to complement host resistance) suppressed disease as well as the application intervals recommended by the weather-sensitive forecast and as well as weekly applications of this fungicide (Table 6). The fixed-interval technique was superior to weekly fungicide applications in that disease was held to the same level on the moderately resistant cultivar as on the susceptible one, but fewer applications were made

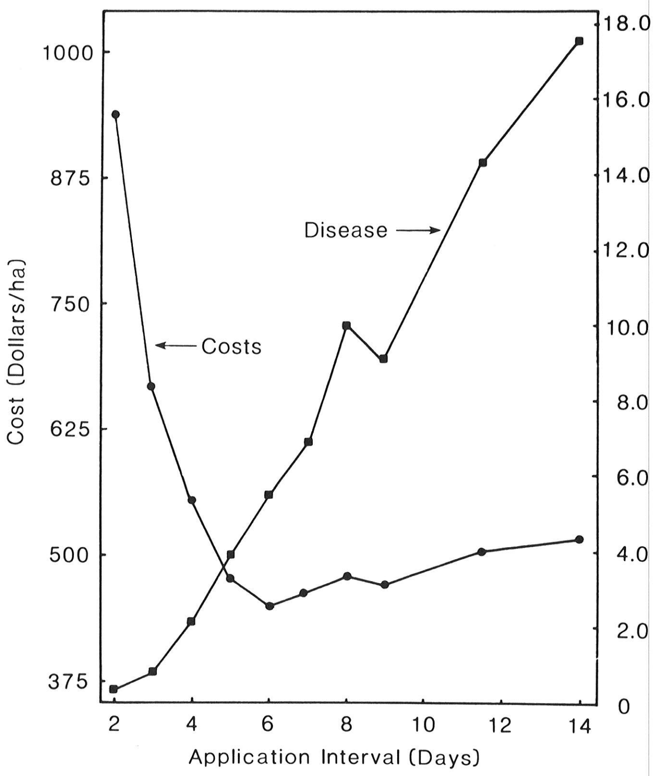

Fig. 4. Effect of fungicide application interval on simulated disease severity (area under disease progress curve) and production costs for chlorothalonil applied to a susceptible potato cultivar.

TABLE 5. Influence of fungicide, cultivar, and timing technique on potato late blight development and on fungicide application frequency

		Weather-sensitive forecast			7-day spray interval[a]
		Average spray interval[a] (days)			
Fungicide	Cultivar	Not irrigated	Irrigated	Disease severity (irrigated) (AUDPC)[b]	Disease severity (irrigated) (AUDPC)
Chlorothalonil	Hudson (S)	8.5	5.3	0.016 ± 0.008[d]	0.040 ± 0.016
	Kennebec (MR)	16.0	8.5	0.035 ± 0.017	0.017 ± 0.010
TPTH	Hudson (S)	7.0	5.4	0.026 ± 0.020	0.033 ± 0.030
	Kennebec (MR)	8.8	6.3	0.022 ± 0.013	0.081 ± 0.058
Captafol	Hudson (S)	8.5	5.4	0.071 ± 0.092	0.053 ± 0.008
	Kennebec (MR)	12.3	7.8	0.085 ± 0.016	0.072 ± 0.018

[a] Fungicide applications were first made to all treatments on 30 July 1982. Subsequent applications were timed according to the indicated technique through 9 September 1982.

[b] Area under the disease progress curve, in day-proportions. The AUDPC for unsprayed potatoes was 14.069 ± 0.199 for Hudson and 10.925 ± 0.790 for Kennebec.

[c] Hudson is susceptible (S) and Kennebec is moderately resistant (MR).

[d] Standard deviations of four replications. There were no significant differences ($P = 0.05$) in disease severity values due to fungicide type, cultivar resistance, or timing technique.

TABLE 6. Effects on potato late blight severity and average spray interval of various methods for timing chlorothalonil applications

Timing method	Cultivar	AUDPC[a]	Average spray interval (days)
Weather-sensitive forecast	Hudson (Susc.)	0.016	5.3
	Kennebec (Mod. res.)	0.035	8.3
Cultivar-adjusted fixed-interval	Hudson (Susc.)	0.047	7
	Kennebec (Mod. res.)	0.019	10
7-Day	Hudson (Susc.)	0.040	7
	Kennebec (Mod. res.)	0.017	7

[a] Area under the disease progress curve, in day-proportions. The AUDPC for unsprayed Hudson potatoes was 14.069 ± 0.199 and for unsprayed Kennebec was 10.925 ± 0.790. Differences between the AUDPC values are not significantly different according to Duncan's new multiple range test ($\alpha = 0.05$).

to the moderately resistant one.

At the irrigated location, unsprayed plots yielded significantly less ($\alpha = 0.01$) than sprayed plots. Cultivar resistance, fungicide type, or fungicide timing technique caused no significant differences in yield or percentage (by weight) of tubers blighted.

DISCUSSION

Tenacity and fungal toxicity of TPTH and captafol were characterized and then these characteristics were used to generalize a weather-sensitive system for timing chlorothalonil sprays on cultivars of different resistances. Simulation analysis was used to predict optimal thresholds for timing fungicides. In field tests of the weather-sensitive timing techniques, the recommended applications of TPTH and captafol suppressed late blight as well as did the recommended applications of chlorothalonil. For all fungicides, fewer sprays were recommended for moderately resistant than for susceptible cultivars, and more sprays were recommended when the microclimate was altered by sprinkler irrigation. Differences in fungicide properties had less influence on spray recommendations than did differences in cultivar resistance and differences in weather.

Fungicide characteristics were also used to predict fixed-interval applications appropriate for cultivars with different resistance characteristics in weather typical of upstate New York. In a field test, the recommended fixed-interval applications of chlorothalonil suppressed disease as well as did the applications recommended by the weather-sensitive forecast. The recommended fixed-interval applications were selected because they minimized average costs in five simulations using diverse weather. In very wet or dry seasons, however, the fixed-interval applications may not minimize costs; in very wet seasons fungicides may be applied less frequently than optimum, whereas in very dry years fungicides may be applied too frequently. The fixed-interval technique may be better suited to areas where weather does not fluctuate extensively from year to year.

LITERATURE CITED

1. Andrilenas, P. A. 1974. Farmer's use of pesticides in 1971—Quantities. Agric. Economics Rep. 268, Econ. Res. Serv., U.S. Dep. Agric., Washington, DC. 56 pp.
2. Bruhn, J. A., and Fry, W. E. 1981. Analysis of potato late blight epidemiology by simulation modeling. Phytopathology 71:612-616.
3. Bruhn, J. A., and Fry, W. E. 1982. A statistical model of fungicide deposition in a potato canopy. Phytopathology 72:1301-1305.
4. Bruhn, J. A., and Fry, W. E. 1982. A mathematical model of the spatial and temporal dynamics of chlorothalonil residues in a potato canopy. Phytopathology 72:1306-1312.
5. Bruhn, J. A., Fry, W. E., and Fick, G. W. 1980. Simulation of daily weather data using theoretical probability distributions. J. Appl. Meteorol. 19:1029-1036.
6. Fry, W. E. 1977. Integrated control of potato late blight—Effects of polygenic resistance and techniques of timing fungicide applications. Phytopathology 67:415-420.
7. Fry, W. E. 1978. Quantification of general resistance of potato cultivars and fungicide effects for integrated control of potato late blight. Phytopathology 68:1650-1655.
8. Fry, W. E., Apple, A. E., and Bruhn, J. A. 1983. Evaluation of potato late blight forecasts modified to incorporate host resistance and fungicide weathering. Phytopathology 73:1054-1059.
9. Krause, R. A., Massie, L. B., and Hyre, R. A. 1975. BLITECAST—A computerized forecast of potato late blight. Plant Dis. Rep. 59:95-98.
10. Little, T. M., and Hills, F. J. 1978. Agricultural Experimentation, Design and Analysis. John Wiley & Sons, New York. 350 pp.
11. Paysour, R. E., and Fry, W. E. 1983. Interplot interference: A model for planning field experiments with aerially disseminated pathogens. Phytopathology 73:1014-1020.
12. MacKenzie, D. R. 1981. Scheduling fungicide applications for potato late blight with BLITECAST. Plant Dis. 65:394-399.
13. Savage, E. J., Clayton, C. W., Hunter, J. W., Brenneman, J. A., Laviola, C., and Gallegly, M. E. 1968. Homothallism, heterothallism and interspecific hybridization in the genus *Phytophthora*. Phytopathology 58:1004-1021.
14. Shaner, G., and Finney, R. E. 1977. The effect of nitrogen fertilization on the expression of slow-mildewing resistance in Knox wheat. Phytopathology 67:1051-1056.
15. Spadafora, V. J., Fry, W. E., and Bruhn, J. A. 1983. Incorporating fungicide characteristics into potato late blight forecasts. (Abstr.) Phytopathology 73:375.
16. Spadafora, V. J., Apple, A. E., Bruhn, J. A., and Fry, W. E. 1983. Evaluation of simple and complex potato late blight forecasts. (Abstr.) Phytopathology 73:375.
17. Thurston, H. D. 1971. Relationship of general resistance: Late blight of potato. Phytopathology 61:620-626.