Comparison of Forecasting Methods for Control of Potato Early Blight in Wisconsin

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ABSTRACT

Pscheidt, J. W., and Stevenson, W. R. 1986. Comparison of forecasting methods for control of potato early blight in Wisconsin. Plant Disease 70:915-920.

Various forecasting methods were evaluated for their usefulness in predicting and controlling potato early blight under Wisconsin growing conditions. The spore trap and growing degree day methods used in Colorado did not provide reliable prediction of early blight in Wisconsin. A total of 300 physiological days (P-Days), however, occurred before the initial rise in airborne spore concentrations of *Alternaria solani*. P-Days were used to effectively initiate weekly protectant sprays in small experimental field plots and large commercial fields. FAST, developed for early blight prediction on tomatoes, was used successfully on potatoes in Wisconsin. A few modifications, however, are recommended for use on potatoes. Combining FAST and/or P-Days with BLITECAST may prove useful for the control of both early and late blight for Wisconsin potato growers.

Additional key word: epidemiology

Early blight of potato (*Solanum tuberosum* L.) caused by *Alternaria solani* (Ellis & Martin) Jones & Grout has been recognized as a problem in Wisconsin since 1892 (11,19). The most effective control measure has been the frequent application of protectant fungicides from early in the growing season until vinekill (2,4,6,8,12). Several methods and recommendations have been used for timing the initial and subsequent sprays of fungicides, including calendar dates and plant height (18). Wisconsin growers normally begin spraying potatoes for early blight control when plants are 20–25 cm tall (1). This occurs from about mid- to late June, depending on cultivar and planting date. Fungicides are subsequently applied once a week for the duration of the growing season, except during rainy weather, when the interval between sprays is shortened. An average of eight to 12 fungicide sprays are applied during a typical growing season, depending on grower, location of field, weather, and cultivar of potato.

Accepted for publication 6 April 1986 (submitted for electronic processing).

Harrison et al (5–7) developed two methods to initiate protectant fungicide sprays for potatoes grown in Colorado. One method initiated sprays when a dramatic rise in the number of airborne spores was detected (5,7). The other method used daily temperature data in a growing degree day (GDD) model to forecast the appearance of the first early blight lesions (M. D. Harrison and E. E. Nelson, *unpublished*). The first early blight lesions appeared in the San Luis Valley of Colorado when 650 GDD (base 7 C) had accumulated since planting while 1,155 GDD had accumulated in the eastern part of the state. Airborne spores were detected at both locations soon after the first lesions appeared.

Sands et al (21) used daily temperature data to calculate physiological days (P-Days), which aided in the prediction of potato yields. The minimum (7 C), optimum (21 C), and maximum (30 C) growth temperatures of the potato plant and the diurnal fluctuation of air temperature were used to calculate P-Days. Sands et al (21) observed that for any particular cultivar, the maximum bulking rate and cessation of bulking occurred on the same P-Day over several years. P-Days might be used like GDD to help time the first fungicide spray of the season.

Madden et al (15) developed the FAST (Forecaster of *Alternaria solani* on Tomato) predictive system for initiating and timing fungicide sprays on tomato (*Lycopersicon esculentum* Mill.) in Pennsylvania. FAST uses leaf wetness, air temperature, relative humidity, and rainfall to calculate daily severity and rating values that quantitatively represent conditions favorable for early blight development. A total of 35 severity values accumulated a few days before a large increase in the concentration of airborne spores occurred and was used to time initial fungicide applications. Subsequent field testing on tomatoes has shown that spray schedules based on FAST provide effective early blight control (17).

The purpose of this study was to evaluate these forecasting methods for predicting and controlling potato early blight under Wisconsin growing conditions.

MATERIALS AND METHODS

Evaluation of forecasting methods. Field evaluations were conducted during the 1980–1984 growing seasons with Russet Burbank potatoes at the Hancock Experiment Farm, Hancock, WI. Plots were planted in a randomized complete block design with each block replicated four times. Each experimental unit consisted of four 12-m rows in 1980–1982 and six 12-m rows in 1983 and 1984 (18).

Field plots were planted in early May each year using B-size certified seed potatoes. Soil type was a Kellner loamy sand. Plots were fertilized and treated with herbicides and insecticides according to standard practices for the Central Sands area (2). Supplemental water was applied during the growing season as overhead sprinkler irrigation. A single 12-m row from each of the treatments was harvested and graded in late September or early October. Specific gravity was measured by suspending 3.6 kg of potatoes from a hydrometer in water.

The protectant fungicide chlorothalonil (Bravo 500) was used to compare spray schedules at the labeled rate of 875 g a.i./ha (1.75 L/ha) in all plots each year. This fungicide was applied in water with a tractor-mounted boom sprayer equipped with Tee Jet disk-type nozzles. Metalaxyl (Ridomil 2E) at 89 g a.i./ha (0.37 L/ha) was applied once in 1981 (7 August) to control a light infestation of late blight (*Phytophthora infestans* (Mont.) de Bary). Late blight was not observed during any other year of evaluation.

Protectant fungicide sprays were initiated and timed according to the following protocols:

1. *Conventional.* Weekly sprays initiated when plants were 20–25 cm tall, which represented the current grower practice for early blight control in the Central Sands region (1).

2. *Spores.* Weekly sprays initiated when a dramatic increase in airborne spores was detected (7).

3. *1,000 GDD.* Weekly sprays initiated when 1,000 GDD had accumulated from emergence.

4. *300 P-Days.* Weekly sprays initiated when 300 P-Days had accumulated from emergence.

5. *FAST.* Initial spray applied after 35 severity values (based on leaf wetness and temperature) accumulated from emergence with subsequent sprays applied at 7-day intervals when ≥11 severity values accumulated in the last 7 days or at 5-day intervals when ≥11 severity values accumulated in the last 7 days and ≥8 rating values (based on temperature, humidity, and rainfall) had accumulated in the last 5 days (15).

6. *BLITECAST.* Initial spray applied after 18 severity values (based on relative humidity and temperature) accumulated from emergence with subsequent sprays applied at 5-, 7-, or 10-day intervals, depending on the accumulation of both blight-favorable days (based on rainfall and temperature) and severity values (13,23).

7 and 8. *Combination of FAST plus BLITECAST.* Initial spray applied when either 35 FAST total severity values or 18 BLITECAST severity values accumulated from emergence, with subsequent sprays timed according to the forecasting program that recommended the *shortest* spray interval.

9. *Unsprayed control.* No fungicide sprayed throughout the season.

$$\text{P-Days} = \left(\frac{1}{24}\right)\left[5P(T_{min}) + 8P\left(\frac{2T_{min}}{3} + \frac{T_{max}}{3}\right) + 8P\left(\frac{2T_{max}}{3} + \frac{T_{min}}{3}\right) + 3P(T_{max})\right]$$

$$\text{If } T < 7°C \text{ then } P(T) = 0$$

$$\text{If } 7 \le T < 21°C \text{ then } P(T) = 10[1-(T-21°C)^2/(21-7)^2]$$

$$\text{If } 21 \le T \le 30°C \text{ then } P(T) = 10[1-(T-21°C)^2/(30-21)^2]$$

$$\text{If } 30°C \le T \text{ then } P(T) = 0$$

Fig. 1. Formula used for calculating the accumulation of P-Days for a 24-hr period. T = temperature, T_{min} = daily minimum temperature, and T_{max} = daily maximum temperature.

Evaluation of P-Day forecasting method in commercial fields. Field plots used to evaluate the P-Day method were located within large (50-ha) commercial fields near Coloma, WI. The cultivar Russet Burbank was evaluated in both 1983 and 1984; the cultivars Superior and Norgold Russet were evaluated in seperate fields during 1984. Each treatment plot of Russet Burbank consisted of 80 rows 70 and 46 m long in 1983 and 1984, respectively. Superior plots also consisted of 80 rows 46 m long. Norgold Russet plots consisted of 20 rows 275 m long. The experimental design was a randomized complete block for each cultivar. Each field was a Plainfield loamy sand and was treated for insects, weeds, and optimal yield according to current recommendations (2). Supplemental water was applied to each field with a center-pivot irrigation system and an irrigation scheduling program (3). Four 6-m rows were harvested and graded from the center of each plot each year.

Table 1. Forecasting model value accumulation in relation to the first early blight lesions and *Alternaria solani* spores

		Forecasting model values[a]									
		First symptoms observed					Initial rise in airborne spores				
Forecast models	Days before observation	17 Jul. 1980	23 Jun. 1981	24 Jun. 1982	6 Jul. 1983	1 Jul. 1984	15 Jul. 1980	13 Jul. 1981	9 Jul. 1982	17 Jul. 1983	24 Jul. 1984
GDD[b] from planting	0	1,617	808	912	1,066	1,268	1,557	1,282	1,295	1,433	1,916
	5	1,490	739	834	978	1,163	1,427	1,163	1,186	1,284	1,779
	7	1,427	682	804	917	1,106	1,357	1,115	1,113	1,221	1,721
GDD from emergence	0	1,378	524	573	872	870	1,318	998	955	1,238	1,518
	5	1,251	456	495	784	765	1,188	880	846	1,090	1,381
	7	1,188	398	464	723	708	1,118	832	774	1,027	1,323
P-Days[c] from emergence	0	351	179	233	282	245	335	345	350	352	428
	5	322	147	202	247	213	307	313	316	333	404
	7	307	132	187	231	198	296	298	306	319	387
FAST											
(total severity values)	0	50	12	27	28	33	47	42	42	50	70
	5	41	10	21	21	31	37	34	35	40	64
	7	37	9	19	19	28	35	32	34	36	62
BLITECAST											
(severity values)	0	9	9	31	20	25	8	34	44	24	68
	5	5	5	23	18	25	3	23	37	21	64
	7	3	5	23	15	25	0	23	36	20	62
Days after planting		66	48	48	62	55	64	68	63	73	78
Days after emergence		50	23	31	37	31	48	43	46	48	54

[a] Example: In 1980 the first lesions of early blight were observed on 17 July. At this time 351 P-Days had accumulated from emergence, whereas 7 days before this date (July 10), 307 P-Days had accumulated.
[b] Growing degree days.
[c] Physiological days.

Fungicide treatments consisted of applying several chemicals with a ground sprayer or the center-pivot irrigation system (18). The protectant fungicide triphenyltin hydroxide (Super-Tin 4L at 365 ml/ha) mixed with maneb plus zinc (Manex 4F at 2.3 L/ha) was used in 1983. Mancozeb, maneb, and triphenyltin hydroxide were used alone or in combination during 1984. The first two fungicide treatments for the Russet Burbank and Superior plots and all treatments for Norgold Russet plots were applied in 1984 with a tractor-mounted boom sprayer. Subsequent fungicide treatments for the Russet Burbank and Superior plots were done by injecting fungicides into the water of a center-pivot irrigation system.

Fungicide treatments were initiated and timed according to either the grower's conventional schedule or the P-Day model. The conventional schedule was initiated when plants were 20–25 cm tall, and subsequent sprays were applied with assistance from BLITECAST (13,23). The P-Day model initiated fungicide sprays after a total of 300 P-Days had accumulated since emergence. Subsequent fungicide sprays were applied at the same interval used in the grower's conventional schedule.

Environment and disease monitoring. Air temperature and relative humidity were monitored with a hygrothermograph (Belfort Instrument Company, Baltimore, MD) housed in a white, wooden weather shelter (24) within the potato canopy about 10 cm off the ground. Leaf wetness was recorded with an Ag-Tech Dew-dynamics System (Ag-Tech Instrument Co., Savannah, GA) equipped with six electrical impedance grid dew sensors. Leaf wetness sensors were positioned at the top, middle, and bottom of the plant canopy, and readings were recorded at 15-min intervals. FAST spray schedules were based on wetness data from sensors located in the middle of the plant canopy.

Daily maximum and minimum temperatures were used to calculate GDD and P-Days. The daily accumulation of growing degrees was calculated by subtracting a base value of 7 C (45 F) from the daily average temperature. The accumulation of P-Days for a 24-hr period was calculated with the formula given in Figure 1.

Spores of *A. solani* were trapped with a battery-operated Rotorod sampler (Ted Brown Associates, Los Altos Hills, CA) equipped with I-type rods and coated with silicone grease. The spore sampler was located at canopy height near the hygrothermograph shelter and was adjusted to account for plant growth and senescence. A sampler was run for 12- or 24-hr periods three times a week in 1980. In subsequent years, samplers were run during a 4-hr interval usually starting at 0800 hours and ending at about 1200 hours each day for 5–7 days per week. All hours are based on central daylight savings time (CDST). A single sampler was used in 1980 and 1981; two samplers were used from 1982 to 1984.

The proportion of diseased tissue and amount of defoliation was estimated at weekly intervals using the 0–11 rating system of Horsfall and Barratt (9). One estimate was made for each of five 2-m^2 subsections per plot, and the average disease severity value for each plot was then computed (20).

All disease rating dates (t) and disease severity values (x) were used to calculate the relative area under the disease progress curve (AUDPC) for each plot by the following formula:

$$\text{Relative AUDPC} = \{\Sigma_{i=1}^{n} [(x_{i+1} + x_i)/2][t_{i+1} - t_i]\}/t_n - t_1.$$

Fisher's protected LSD procedure ($P = 0.05$) was used to compare treatments with respect to 1) disease ratings on each rating date, 2) AUDPC, 3) total yield, 4) yield of U.S. no. 1A, 5) undersized potatoes, 6) cull potatoes, and 7) specific gravity.

RESULTS

Evaluation of forecasting methods. Potential predictors of the first early blight lesions and the initial increase in airborne spores of *A. solani* are shown in Table 1. The initial rise in airborne spore concentrations was detected 11–23 days after the first lesions were observed, depending on the year. In 1980, however, spores were detected 2 days before the first lesions appeared. The initial spore increase was dramatic in 1980 and 1981, with a rise from virtually no spores to 12.2 and 25.7 spores per cubic meter of air, respectively, within 48–72 hr. The

Table 2. Timing of fungicide applications during the 1980–1984 growing seasons for each treatment

Treatment schedule[a]	Weeks after start of conventional schedule[b] 0	1	2	3	4	5	6	7	8	9	10	11	Total no. of sprays
1980													
Conventional	X[c]	X	X	X	X	X	X	X	X	X	X	X	12
Spore peak	–	–	–	–	X	X	X	X	X	X	X	X	8
1,000 GDD and 300 P-Days	–	–	X	X	X	X	X	X	X	X	X	X	10
FAST	–	–	–	X	XX[d]	X	X	X	–	X	X	X	9
BLITECAST	–	–	–	–	X	X	X	X	XX	X	X	X	9
Combination	–	–	–	X	XX	X	X	X	XX	X	X	X	11
1981													
Conventional	X	X	X	X	X	X	X	X	X	X	X	X	12
Spore peak and 1,000 GDD	–	–	–	X	X	X	X	X	X	X	X	X	9
300 P-Days	–	–	X	X	X	X	X	X	X	X	X	X	10
FAST	–	–	–	X	XX	–	X	X	X	X	X	X	9
BLITECAST	–	–	X	X	XX	X	X	XX	X	X	XX	X	13
Combination	–	–	–	X	XX	X	X	XX	X	X	XX	X	12
1982													
Conventional	X	X	X	X	X	X	X	X	X	X	X	X	12
Spore peak	–	–	–	–	–	–	–	–	–	–	–	–	0
1,000 GDD	–	–	–	X	X	X	X	X	X	X	X	X	9
300 P-Days	–	–	X	X	X	X	X	X	X	X	X	X	10
FAST	–	–	X	XX	XX	–	XX	X	X	–	–	–	9
BLITECAST	–[e]	X	X	XX	XX	X	XX	X	X	X	XX	–	15
Combination	–	–	X	XX	XX	X	XX	X	X	X	XX	–	13
1983													
Conventional	X	X	X	X	X	X	X	X	X	X	X	X	12
1,000 GDD	–	–	–	–	X	X	X	X	X	X	X	X	8
300 P-Days	–	–	–	X	X	X	X	X	X	X	X	X	9
FAST	–	–	–	X	XX	X	XX	X	X	X	XX	X	12
BLITECAST	–	–	X	X	X	XX	X	XX	X	XX	X	X	13
1984													
Conventional	X	X	X	X	X	X	X	X	X	X	X	X	12
1,000 GDD and 300 P-Days	–	–	–	X	X	X	X	X	X	X	X	X	9
FAST	–	–	X	X	X	X	X	XX	X	X	X	X	11

[a] Conventional = weekly sprays initiated when plants were 20–25 cm tall; spore peak = weekly sprays initiated when a dramatic rise in airborne spores was detected; 1,000 GDD and 300 P-Days = weekly sprays initiated when 1,000 growing degree days or 300 physiological days accumulated from emergence; FAST = forecasting program used for *Alternaria solani* on tomato; BLITECAST = forecasting program used for *Phytophthora infestans* prediction; and combination = sprays initiated according to FAST, subsequent sprays according to recommendation for shortest spray interval from either FAST or BLITECAST.

[b] The conventional schedule was initiated on 25 June 1980, 24 June 1981, 23 June 1982, 22 June 1983, and 20 June 1984.

[c] Indicates that plots were sprayed once during this week. Possible spray dates included Monday, Wednesday, or Friday of any given week.

[d] Indicates that plots were sprayed twice during this week.

[e] One fungicide applications was sprayed 2 wk before start of the conventional schedule.

initial increase in subsequent years was much more gradual, beginning with concentrations generally below one spore per cubic meter of air. None of the forecasting models consistently predicted the appearance of the first early blight lesions. A total of 300 P-Days or 35 FAST severity values, however, consistently occurred 5–10 days before the detection of the initial increase in airborne spores, with the exception of 1984.

The spray schedules used for each treatment in each year are given in Table 2. Most spray schedules were initiated after the conventional schedule, except BLITECAST in 1982, which initiated sprays 2 wk earlier than the conventional schedule. Each year, 12 sprays were applied throughout the season using the conventional schedule. Generally, spray schedules associated with BLITECAST used as many or more sprays than the conventional schedule within a shorter period. Spray schedules based on GDD, P-Days, or FAST generally used fewer sprays than the conventional schedule. A dramatic increase in spore concentrations was not detected until the end of the growing season in 1982, therefore, the treatment based on spore trapping was not sprayed.

Most treatments had significantly lower disease severity 2 wk before vinekill than untreated plots and were not significantly different from the conventional schedule each year with the exception of the treatment based on spore trapping (Table 3). Most treatments also had a significantly lower AUDPC than untreated plots and were not significantly different from the conventional schedule each year of evaluation (Table 4). The treatment based on spore traps, however, had a significantly higher AUDPC than the conventional schedule both in 1980 and 1982. Because of high insect pressure during the 1983 growing season, data on disease severity and yields were not included in this report.

The conventional schedule had the highest total yield in 1980, 1981, and 1984 and the highest U.S. no. 1As in 1980 and 1984 (Tables 5 and 6). FAST and the combination of FAST plus BLITECAST had the highest total yields in 1982. Unsprayed plots had the lowest yields and specific gravities each year. There were few significant differences between undersized or cull potatoes each year of evaluation (18).

Evaluation of P-Day forecasting method in commercial fields. The grower's conventional schedule was initiated on 23 June 1983, whereas the P-Day schedule was initiated 2.5 wk later on 11 July. The accumulation of 302 P-Days occurred on 5 July 1983. During 1984, the conventional schedule was initiated on 14 June, whereas sprays in plots using the P-Day model were started on 3 July for all three cultivars. Total P-Day accumulations on 3 July were 324, 349, and 282 in Russet Burbank, Superior, and Norgold Russet plots, respectively. The conventional schedule required two fungicide sprays more than the P-Day schedule in each year of the grower evaluation (Table 7).

Significant differences in individual disease ratings, AUDPC or yield were not generally detected between the two spray schedules except in Norgold Russet plots (Table 7).

Concentrations of airborne spores of *A. solani* were low throughout most of the growing seasons of both years. High concentrations were not detected until late August or early September. The first few spores detected in 1984 coincided with the harvest of the Superior potatoes. Wind direction measurements during this harvest indicated that the Rotorod sampler was downwind of the Superior field. A high concentration, 84 spores per cubic meter of air, was detected a few days after application of a vine desiccant to the Russet Burbank field in 1984.

DISCUSSION

Spore trapping. Treatments used in Wisconsin based on the spore trap method of Harrison et al (5–7) generally had higher levels of disease than other treatments. Dramatic increases in spore concentrations were not detected every year despite high disease severity. These data indicate that this method is far from ideal for control of early blight in Wisconsin.

GDD. Results obtained from field trials at Hancock, WI, and from several growers' fields scouted through an integrated pest management program

Table 3. Disease severity 2 wk before vinekill for each treatment during the 1980, 1981, 1982, and 1984 growing seasons

Treatment schedule[y]	Disease severity[z] 5 Sept. 1980	1 Sept. 1981	31 Aug. 1982	4 Sept. 1984
Conventional	15.6 a	33.8 a	54.4 a	37.5 ab
Spore peak	56.2 b	38.1 a	81.0 b	···
1,000 GDD	18.4 a	36.0 a	52.2 a	29.6 a
300 P-Days	18.4 a	38.2 a	49.4 a	36.8 ab
FAST	32.3 a	32.9 a	51.3 a	34.0 ab
BLITECAST	26.2 a	33.8 a	55.3 a	···
Combination	13.7 a	30.0 a	53.5 a	···
Control	91.8 c	64.9 b	77.3 b	79.3 c
FLSD	19.6	9.5	13.7	16.6

[y] Conventional = weekly sprays initiated when plants were 20–25 cm tall; Spore peak = weekly sprays initiated when a dramatic rise in airborne spores was detected; 1,000 GDD and 300 P-Days = weekly sprays initiated when 1,000 growing degree days or 300 physiological days accumulated from emergence; FAST = forecasting program used for *Alternaria solani* on tomato; BLITECAST = forecasting program used for *Phytophthora infestans* prediction; combination = sprays initiated according to FAST, subsequent sprays according to recommendation for shortest spray interval from either FAST or BLITECAST; and control = no fungicide applied.

[z] Disease severity was estimated at weekly intervals using the 0-11 rating system of Horsfall and Barratt (9). One estimate was made for each of five 2-m^2 subsections per plot, and the average disease severity value for each plot was then computed. Treatment means followed by the same letter(s) are not significantly different using Fisher's protected LSD procedure at the 5% level.

Table 4. Relative area under the disease progress curve (AUDPC) for each treatment during the 1980, 1981, 1982, and 1984 growing seasons

Treatment schedule[y]	AUDPC[z] 1980	1981	1982	1984
Conventional	0.16 a	0.21 abc	0.28 a	0.19 a
Spores	0.29 b	0.22 bc	0.43 b	···
1,000 GDD	0.18 a	0.21 abc	0.28 a	0.18 a
300 P-Days	0.18 a	0.21 abc	0.27 a	0.18 a
FAST	0.22 a	0.23 c	0.28 a	0.18 a
BLITECAST	0.20 a	0.20 ab	0.29 a	···
Combination	0.16 a	0.18 a	0.29 a	···
Control	0.48 c	0.33 d	0.42 b	0.33 b
FLSD	0.07	0.03	0.06	0.03

[y] Conventional = weekly sprays initiated when plants were 20–25 cm tall; Spore peak = weekly sprays initiated when a dramatic rise in airborne spores was detected; 1,000 GDD and 300 P-Days = weekly sprays initiated when 1,000 growing degree days or 300 physiological days accumulated from emergence; FAST = forecasting program used for *Alternaria solani* on tomato; BLITECAST = forecasting program used for *Phytophthora infestans* prediction; combination = sprays initiated according to FAST, subsequent sprays according to recommendation for shortest spray interval from either FAST or BLITECAST; and control = no fungicide applied.

[z] All disease rating dates (t) and disease severity values (x) were used to calculate the relative AUDPC using the following formula: relative AUDPC $= \{\Sigma_{i=1}^{n} [(x_{i+1} + x_i)/2][t_{i+1} - t_i]\}/t_n - t_1$. Treatment means followed by the same letter(s) are not significantly different using Fisher's protected LSD procedure at the 5% level.

(22) have not demonstrated a relationship between total GDD (base 4.5, 7, or 10 C) accumulated from planting or emergence and any phase of the early blight epidemic. Preliminary data led to the testing of 1,000 GDD accumulated from emergence as a trigger for initiation of weekly sprays in field trials (18). All measures of disease and yield were similar to the conventional schedule using an average of three fewer fungicide sprays. Although this method provided effective control of early blight, the accumulation of GDD in relation to the first early blight lesions and the initial increase in airborne spores (Table 1) indicated that the GDD model was not a reliable guide for initiating protectant fungicide sprays in Wisconsin (18).

P-Days. Schedules based on P-Day and GDD accumulation were able to effectively control early blight using an average of two sprays fewer than the conventional schedule. Unlike GDD, the accumulation of 300 P-Days predicted the initial increase in airborne spore concentrations. Use of 300 P-Days in experimental plots and large commercial fields has shown that a protectant spray program can be initiated later in the growing season than current convention without significantly increasing early blight severity or decreasing yields of either Russet Burbank or Superior potatoes.

Superior is an early-maturing, early-harvested crop sold primarily for processing and/or fresh markets and, therefore, essentially escapes the early blight epidemic if harvested in mid- to late July. This raises the possibility that even the two fungicide sprays that were applied using the P-Day schedule were unnecessary (Table 7). Early maturity means earlier susceptibility to early blight (10,14); however, the crop is harvested before full maturity (depending on current market prices). Spore trapping data indicate, however, that the harvest

Table 5. Total yield for each treatment during the 1980, 1981, 1982, and 1984 growing seasons

Treatment schedule[x]	Total yield (10^3 kg/ha)[y]			
	1980	1981	1982	1984
Conventional	46.7	40.5 d	39.3 bc	63.1 b
Spores	43.2	39.9 d	34.1 a	...
1,000 GDD	45.6	39.5 d	38.9 bc	62.1 b
300 P-Days	45.6	39.1 cd	39.3 bc	62.1 b
FAST	41.4	34.0 ab	40.6 c	58.3 a
BLITECAST	40.7	38.8 cd	35.7 ab	...
Combination	43.5	35.0 abc	40.6 c	...
Control	41.3	32.4 a	37.2 abc	56.5 a
FLSD	NS[z]	4.3	3.7	3.1

[x] Conventional = weekly sprays initiated when plants were 20–25 cm tall; Spore peak = weekly sprays initiated when a dramatic rise in airborne spores was detected; 1,000 GDD and 300 P-Days = weekly sprays initiated when 1,000 growing degree days or 300 physiological days accumulated from emergence; FAST = forecasting program used for *Alternaria solani* on tomato; BLITECAST = forecasting program used for *Phytophthora infestans* prediction; combination = sprays initiated according to FAST, subsequent sprays according to recommendation for shortest spray interval from either FAST or BLITECAST; and control = no fungicide applied.

[y] Based on the tuber fresh weight obtained from a single 12-m row of Russet Burbank potatoes. Treatment means followed by the same letter(s) are not significantly different using Fisher's protected LSD procedure at the 5% level.

[z] All treatment means were not significantly different at the 5% level.

Table 6. Yield of U.S. no. 1A potatoes for each treatment during the 1980, 1981, 1982, and 1984 growing seasons

Treatment schedule[x]	Yield (10^3 kg/ha)[y]			
	1980	1981	1982	1984
Conventional	27.3	23.2 c	24.8	49.9 c
Spores	24.5	22.8 c	20.9	...
1,000 GDD	24.4	22.2 bc	23.8	48.6 bc
300 P-Days	24.4	23.6 c	25.2	48.6 bc
FAST	20.5	15.8 a	25.4	44.7 ab
BLITECAST	20.6	20.3 abc	20.8	...
Combination	20.8	16.1 a	24.0	...
Control	22.9	16.9 a	21.4	43.7 a
FLSD	NS[z]	4.8	NS	4.8

[x] Conventional = weekly sprays initiated when plants were 20–25 cm tall; spore peak = weekly sprays initiated when a dramatic rise in airborne spores was detected; 1,000 GDD and 300 P-Days = weekly sprays initiated when 1,000 growing degree days or 300 physiological days accumulated from emergence; FAST = forecasting program used for *Alternaria solani* on tomato; BLITECAST = forecasting program used for *Phytophthora infestans* prediction; combination = sprays initiated according to FAST, subsequent sprays according to recommendation for shortest spray interval from either FAST or BLITECAST; and control = no fungicide applied.

[y] Based on the yield obtained from a single 12-m row of Russet Burbank potatoes. Treatment means followed by the same letter(s) are not significantly different using Fisher's protected LSD procedure at the 5% level.

[z] All treatment means were not significantly different at the 5% level.

Table 7. Relative area under the disease progress curve (AUDPC) and mean yield from plots within commercial potato fields treated according to the conventional and physiological-day (P-Day) spray schedules

Cultivar	Schedule	Total sprays (no.)	Relative AUDPC[a]	Yield (10^3 kg/ha)			
				Total	U.S. no. 1A	Undersized	Cull
			1983				
Russet Burbank	Conventional[b]	10	0.34	47.5	30.4	7.3	9.0
	P-Days[c]	8	0.26	45.1	28.1	6.7*[d]	8.4
			1984				
Russet Burbank	Conventional	10	0.65	53.9	44.7	7.6	1.6
	P-Days	8	0.69	54.4	44.0	8.4	2.2
Superior	Conventional	4	0.16	36.4	32.2	2.8	1.7
	P-Days	2	0.15	35.3	31.4	2.8	1.5
Norgold Russet	Conventional	6	0.34	40.9	32.2	8.7	6.1
	P-Days	4	0.39*[d]	41.4	31.9	9.2	4.8

[a] All disease rating dates (t) and disease severity values (x) were used to calculate the relative AUDPC using the following formula: relative AUDPC = $\{\sum_{i=1}^{n} [(x_{i+1} + x_i)/2][t_{i+1} - t_i]\} / t_n - t_1$.

[b] Conventional schedule initiated sprays when plants were 20–25 cm tall, and subsequent sprays were scheduled using BLITECAST.

[c] Physiological-days model initiated fungicide sprays after 300 P-Days accumulated from emergence.

[d] Significantly different at $P = 0.05$.

of the Superior crop contributed airborne inoculum to the adjacent Russet Burbank field. Omitting the fungicide sprays from early-season potatoes may favor problems in adjacent late-season potatoes.

Delaying fungicide sprays in the Norgold Russet field resulted in increased disease severity. This may have been due to several factors. Norgold Russet was found to be more susceptible to early blight than Superior or Russet Burbank (W. R. Stevenson and J. W. Pscheidt, *unpublished*). In addition, this field had been planted to potatoes the previous year and potentially had increased primary inoculum levels. These results suggest that a closer look at Norgold Russet is necessary before this forecasting system can be recommended for this cultivar. The P-Day threshold may have to be lowered for high disease risk situations.

FAST. FAST, in its original form, was successfully applied to irrigated potatoes in Wisconsin for control of early blight. Disease severity in plots treated with the FAST schedules was not significantly different from disease severity in plots sprayed according to the conventional schedule for an average of 2.5 fewer fungicide sprays. Cumulative severity and rating values other than 11 and 8, respectively, did not seem to provide consistent, effective control of early blight. Yields from these plots varied from the highest in 1982 to near the lowest in 1981 and 1984.

Despite low concentrations of spores and seemingly unfavorable weather for disease development in 1983, FAST indicated a frequent need for a 5-day spray schedule. A P-Day modification of the temperature portion of the rating model was incorporated into a "modified FAST" in 1984. The condition where temperatures above or below 21 C were considered favorable and unfavorable was replaced with a condition where P-Days above or below 8 were favorable or unfavorable, respectively. In addition, the 5-day total rating threshold was raised from 8 to 10. This modification would have recommended a similar number of fungicide sprays as the normal FAST schedule during 1980–1984 but would have recommended fewer sprays during 1983.

BLITECAST. BLITECAST was developed to predict late blight development (13) and affords early blight control only by intensive spraying for late blight. Control of early blight was not significantly different from the conventional schedule each year of evaluation, but an average of one additional fungicide spray was applied. Similar results were obtained by Nutter and MacHardy (16) in 1977. These data indicate that if growers follow a strict BLITECAST schedule (23), early blight will be controlled effectively.

Combined programs. The shortest recommended fungicide spray intervals generated by a combination of FAST and BLITECAST were usually set by BLITECAST. The utility of combining these programs for a comprehensive control program for the Central Sands region of Wisconsin may be of value. The benefit of FAST, however, can only be obtained if leaf wetness data are available. Equipment used to obtain leaf wetness data can be expensive, cumbersome, and hard for a grower to maintain. The calculation of P-Days and the rating model of FAST, however, use weather parameters already collected for BLITECAST. An integrated program using 300 P-Days to initiate sprays and/or the modified model of FAST to time subsequent sprays in conjunction with BLITECAST could be used to control both early blight and late blight in Wisconsin. This method would not require any special data or equipment that is not already in use for BLITECAST.

ACKNOWLEDGMENTS

We wish to thank Bob and Steve Diercks, Coloma Farms, Coloma, WI, for their assistance and cooperation on this project. This research was supported in part by the Wisconsin Potato Industry Board and the College of Agricultural and Life Sciences, University of Wisconsin-Madison Project 2548.

LITERATURE CITED

1. Binning, L. K., Wyman, J. A., and Stevenson, W. R. 1982. Chemical recommendations in commercial potato production. Univ. Wis. Coop. Ext. Programs Fact Sheet A2352.
2. Curwen, D., Kelling, K. A., Schoenemann, J. A., Stevenson, W. R., and Wyman, J. A. 1984. Commercial potato production and storage. Univ. Wis. Ext. Bulletin A2257.
3. Curwen, D., and Massie, L. R. 1984. Potato irrigation scheduling in Wisconsin. Am. Potato J. 61:235-241.
4. Douglas, D. R., and Groskopp, M. D. 1974. Control of early blight in eastern and southcentral Idaho. Am. Potato J. 51:361-368.
5. Harrison, M. D., Livingston, C. H., and Oshima, N. 1965. Epidemiology of potato early blight in Colorado I. Initial infection, disease development and the influence of environmental factors. Am. Potato J. 42:279-291.
6. Harrison, M. D., Livingston, C. H., and Oshima, N. 1965. Control of early blight in Colorado. Fungicidal spray schedules in relation to the epidemiology of the disease. Am. Potato J. 42:319-327.
7. Harrison, M. D., Livingston, C. H., and Oshima, N. 1965. Control of early blight in Colorado II. Spore traps as a guide for initiating applications of fungicides. Am. Potato J. 42:333-340.
8. Harrison, M. D., and Venette, J. R. 1970. Chemical control of potato early blight and its effect on potato yield. Am. Potato J. 47:81-86.
9. Horsfall, J. G., and Barratt, R. W. 1945. An improved grading system for measuring plant diseases. (Abstr.) Phytopathology 35:655
10. Horsfall, J. G., and Huberger, J. W. 1942. Causes, effects and control of defoliation on tomatoes. Conn. Agric. Exp. Stn. New Haven Bull. 456.
11. Jones, L. R. 1893. The new potato disease or early blight. Annu. Rep. Vt. Agric. Exp. Stn. 6:66-70.
12. Jones, L. R. 1912. Potato diseases in Wisconsin and their control. Univ. Wis. Exp. Stn. Circ. Inf. 36.
13. 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.
14. LeClerg, E. L. 1946. Breeding for resistance to early blight in the Irish potato. Phytopathology 36:1011-1015.
15. Madden, L., Pennypacker, S. P., and MacNab, A. A. 1978. FAST, a forecasting system for *Alternaria solani* on tomato. Phytopathology 68:1354-1358.
16. Nutter, F. W., and MacHardy, W. E. 1981. Timing of additional sprays for control of potato early blight (*Alternaria solani*) when following a late blight forecasting spray schedule in New Hampshire, U.S.A. Prot. Ecol. 3:47-54.
17. Pennypacker, S. P., Madden, L. V., and MacNab, A. A. 1983. Validation of an easrly blight forecasting system for tomatoes. Plant Dis. 67:287-289.
18. Pscheidt, J. W. 1985. Epidemiology and control of potato early blight, caused by *Alternaria solani*. Ph.D. thesis. University of Wisconsin, Madison. 242 pp.
19. Rands, R. D. 1917. Early blight of potato and related plants. Wis. Agric. Exp. Stn. Res. Bull. 42.
20. Redman, C. E., King, E. P., and Brown, I. F. 1974. Tables for converting Barratt and Horsfall rating scores to estimated mean percentages. Eli Lilly and Company Research Laboratories. Elanco Products Company, Indianapolis, IN.
21. Sands, P. J., Hackett, C., and Nix, H. A. 1979. A model of the development and bulking of potatoes (*Solanum tuberosum* L.). I. Derivation from well-managed field crops. Field Crops Res. 2:309-331.
22. Shields, E. J., Hygnstrom, J. R., Curwen, D., Stevenson, W. R., Wyman, J. A., and Binning, L. K. 1984. Pest management for potatoes in Wisconsin—A pilot program. Am. Potato J. 61:508-516.
23. Stevenson, W. R. 1983. An integrated program for managing potato late blight. Plant Dis. 67:1047-1048.
24. Van Arsdel, E. P. 1963. A simple weather instrument shelter for plant disease investigations. U.S. For. Serv. Res. Note LS-18.