A Simple Day-Degree Model for Initiating Chemical Control of Potato Early Blight in Colorado

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ABSTRACT

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A simple day-degree (DD) model was developed to predict appearance of the first early blight (*Alternaria solani*) lesions on potato foliage in two potato production areas of Colorado. The model, based upon accumulated day-degrees above 7.2 C (45 F) from the date of planting, effectively predicts the beginning of secondary spread of the pathogen. Accumulated day-degrees-centigrade (DDC) required for appearance of first lesions is 361 in the San Luis Valley, a high mountain valley, and 625 DDC in northeastern Colorado, an area with lower elevation. Growers use the DD information to time the initial fungicide application to minimize the cost of early blight control. Subsequent applications are made according to label directions. Different day-degree thresholds may need to be established if the model is to be used in other potato production areas. In Colorado, where growers do not routinely apply fungicides for the control of late blight (*Phytophthora infestans*), the model effectively reduces fungicide use by as much as four applications.

Additional keywords: epidemiology, sporè dispersal

Potato early blight, caused by *Alternaria solani* (Ell. & G. Martin) Sor., is a recurring problem in Colorado and other states (2,5,7,13). Infection of foliage by *A. solani* defoliates plants and reduces tuber yield (2,9). Spores produced on leaves contaminate soil and cause tuber infections through wounds made during harvest (15). In Colorado, storage losses from tuber blight can be particularly severe on white, smooth-skinned cultivars grown for processing or when tubers are harvested before maturity and, therefore, are more easily wounded (15,16). Increased disease severity is favored by alternating wet and dry conditions in the plant canopy (2,10). Thus, the increased use of overhead sprinkler irrigation in Colorado and other states has made control imperative.

Most approaches to control of foliar early blight have depended on the use of protectant fungicides, but the criteria used to determine proper time of initial fungicide application have varied widely (13). In Colorado and Idaho, research has shown that the onset of fungicide applications should coincide with the first appearance of airborne spores of the pathogen, the time of secondary sporulation. This coincides with the time of "first" or "primary" lesion appearance on lower leaves, another criterion used by some to indicate when fungicide applications should begin (2,8). In Idaho and Colorado, foliar sprays applied before secondary sporulation contribute nothing to the control of early blight and it is possible to reduce the total number of fungicide applications with no measurable effect on disease severity, tuber yield, and quality by properly timing the first application (2,8). An accurately timed application is desirable for both economic and environmental reasons.

Determining the time of secondary sporulation, with the aid of spore traps or by careful observation of foliage for the first lesion, requires little training, but considerable time. Also, spore-trapping data may be difficult to interpret for areas where spores of other pathogens, similar in appearance to those of *A. solani*, are present. For example, *A. porri* (Ellis) Cif., the cause of purple blotch of onion, has spores that can be confused with those of *A. solani* (3,4). Further, depending on the efficiency of the spore trap used, airborne spores are often not detected until 5–10 days after the appearance of primary lesions, and growers have little warning of the need for initial protectant fungicide applications. If environmental conditions are favorable for rapid disease development and/or large areas are involved, it may not be possible for the grower to make the initial application at the proper time. A disease prediction model that provides sufficient time to plan initial fungicide applications would be more useful for growers.

This paper describes a simple model used to predict time of secondary sporulation of *A. solani* based on day-degree (DD) accumulation from planting. This model is used by potato growers in the San Luis Valley and the northeastern plains of Colorado to determine when control programs should begin. The accuracy of the model was verified by observation of disease development in the field and by comparison with traditional methods (including spore trapping) of timing initial fungicide applications.

MATERIALS AND METHODS

The initial production of secondary spores by *A. solani* is coincident with the appearance of primary foliar lesions. Since sporulation of *A. solani* occurs most readily on older, more senescent tissue, lesions will appear first on lower (older) leaves (10). Because the degree of senescence is related to plant growth and maturity, the early blight prediction model described was based on DD accumulation required for development of primary lesions. Planting dates were used as the starting point for accumulation of day-degrees with a base temperature of 7.2 C (45 F) (1). Temperature records were in degrees Fahrenheit, and day-degrees-celsius (DDC) were calculated daily using the formula [(maximum + minimum)/2]−7.2 = DDC. Day-degrees-Fahrenheit (DDF) values are calculated using the same formula, except using Fahrenheit values and a threshold of 45 F. Negative daily DDC or DDF values are not included in the sum, thus showing no accumulation during that time period. The DDC sum, cumulative daily from planting date to the appearance of primary lesions and secondary spores, was calculated over several growing seasons to establish its predictive value. Field trials were made in the two primary potato producing areas in Colorado: the San Luis Valley near Center, CO (elevation 2,317 m) and the northeastern plains area near Wiggins, CO (elevation 1,316 m).

1978 Field trials. Treatment plots were

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established in a commercial field of cv. Russet Burbank in the San Luis Valley. The field was irrigated by a center pivot overhead sprinkler system. A CR21 microcomputer data-logger (Campbell Scientific, Inc., Logan, UT 84321) was installed in a small, shielded weather station 75 cm above the ground and programmed to monitor air temperature and calculate DDF accumulation. A Kramer-Collins continuous-sampling spore trap (G-R Electric Manufacturing Co., Manhattan, KS) was installed within the field about 25 cm above the ground to monitor presence of spores of *A. solani* (12).

Twenty-one subplots, each 4 rows wide and 7.6 m long, were established in the field in a randomized complete block design consisting of three replications and seven treatments. Plots were sprayed with Bravo 500 (chlorothalonil) fungicide at the rate of 1.75 L of product/ha with a tractor-drawn boom sprayer that delivered 290 L/ha of spray at 620 kPa. Seven spray schedules (treatments) were compared to determine the relationship of spray timing to disease severity. Spray schedules began on 19 June, 3 July, 17 July, 31 July, 14 August, and 28 August and were compared with an untreated control (no fungicide, no water applied). After a schedule began, fungicide was reapplied at 2-wk intervals. The total number of applications for the treatments ranged from 6 to 1 for the schedules begun on 19 June and 28 August, respectively.

Several hundred plants were examined regularly to determine when the first lesions appeared on lower leaves. After first lesions were detected, disease readings were made to assess treatment effects on disease severity. Disease readings were made by estimating the percentage of leaflets infected on 6–12 plants per treatment plot using a scale of 0–11 (11) and by counting the number of lesions per leaflet on a random sample of 10 leaves per treatment plot. Means were calculated, data were analyzed by analysis of variance, and means were separated by Tukey's HSD test (14).

Cumulative DDF values were calculated [DDC = (0.556 × DDF)] and compared with the approximate dates when the first lesions appeared in the field and when the first airborne spores were trapped. Weather data and notes from research plots were used to estimate DDF accumulation required for first lesion appearance for 1969 and 1977, years in which lesions appeared unusually early in the San Luis Valley. Day-degree data from 1969, 1977, and 1978 were used to determine criteria used for initiating fungicide applications for 1979 field trials located in the San Luis Valley.

1979 Field trials. Studies were made in both the San Luis Valley and northeastern plains potato production areas. Field plots in the San Luis Valley were irrigated by surface (furrow) irrigation and those in the northeastern plains area were irrigated by an overhead center-pivot sprinkler system. Air temperature was monitored using calibrated maximum-minimum thermometers during the early part of the growing season and a microcomputer (described above) during the latter part.

In the San Luis Valley, a randomized block experimental design including six fungicide application schedules (treatments) and four replications was used. Fungicide applications were made with a tractor-drawn boom sprayer calibrated to deliver a total volume of 409 L/ha at 276 kPa. Bravo 500, at the rate of 2.3 L of product/ha, was applied as required for each treatment. Continuous sampling for spores of *A. solani* was done as described for 1978 and plants were observed to determine when the first lesions appeared. The estimated percentage of leaflets infected was determined and data were

Table 1. The relationship of day-degree accumulation from planting to first appearance of early blight lesions and airborne spores at two locations in Colorado

Year	Planting	First lesion appearance	Airborne spore detection	Day-degree accumulation[y] DDC	DDF
		San Luis Valley			
1969	16 May	4 July	NA[z]	347	624
1977	19 May	5 July	NA	366	659
1978	18 May	15 July	20 July	365	657
1979	22 May	19 July	19 July	388	698
1980	13 May	15 July	25 July	363	652
		Northeastern plains			
1979	20 May	14 July	NA	626	1,125
1980	10 May	16 July	25 July	642	1,155
1981	11 May	12 July	NA	587	1,056
1982	10 May	22 July	NA	652	1,172

[y] Accumulations are from the time of planting until primary lesion appearance. DDC = day-degrees-centigrade scale, DDF = day-degrees-Fahrenheit scale where DDC = (0.556 × DDF).
[z] NA = not available.

Table 2. The effect of different schedules of fungicide applications on the incidence and severity of early blight foliage infection in the San Luis Valley in 1978

First application	Applications (no.)	Estimated leaflets infected (%)[y]	Average no. lesions per leaflet[y]
19 June	6	78 c[z]	2.9 c[z]
3 July	5	83 c	2.5 c
17 July	4	90 c	3.7 c
31 July	3	91 bc	3.1 c
14 August	2	97 ab	5.5 bc
28 August	1	97 ab	12.2 a
Control	0	97 a	9.7 ab

[y] Treatment plots were evaluated on 29 August.
[z] Treatment means followed by different letters differ significantly ($P \leq 0.05$). Mean separation was done using Tukey's HSD test.

Table 3. The effect of spray timing using several methods on the severity of early blight in the San Luis Valley in 1979

Timing criterion	Date of first application	Applications (no.)	Estimated leaflets infected (%)[x]
None	...	0	6.9 a[y]
None (normal schedule)	10 July	5	0.4 b
Airborne spores	23 July[z]	4	1.2 b
334 DDC (600 DDF)	13 July	4	0.4 b
375 DDC (675 DDF)	17 July	4	0.6 b
417 DDC (750 DDF)	23 July	4	0.2 b

[x] Treatment plots were evaluated on 4 September.
[y] Treatment means followed by different letters differ significantly ($P \leq 0.05$). Mean separation was done using Tukey's HSD test.
[z] Airborne spores were first detected on 19 July.

analyzed as described for 1978.

The field plot in the northeastern plains area consisted of a commercial field of cv. Monona potatoes, for which the planting date was known. Several hundred randomly selected plants were periodically examined to determine when primary lesions appeared in relation to DDF accumulation.

1980 Field trials. Plots at both locations included three potato cultivars, Russet Burbank, Norchip, and Monona. Treatment plots in the San Luis Valley were replicated four times in a randomized complete block design. Treatments in the northeastern plains included six fungicide schedules and a nontreated control, each replicated twice. All spray schedules were initiated sequentially at approximately 10-day intervals and, after a treatment schedule began, fungicide was reapplied at 10-day intervals. Bravo 500 was applied at a rate of 2.3 L of product/ha in a total volume of 945 L/ha at 483 kPa. Plots in the San Luis Valley were not treated with fungicide but were observed to determine when primary lesions appeared in each of the three cultivars tested in relation to DDF accumulation. A hygrothermograph and microcomputer were installed at each location to determine DDF accumulation. Two weather vane spore traps (8) were also installed at each location to detect the first appearance of airborne spores.

The severity of foliar early blight infection was determined by estimating the percentage of leaflets infected, and data analysis was done as described above for 1978.

1981 Field trials. Field trials were located in the northeastern plains area only. Treatment plots were planted in a randomized complete block design consisting of three replications of six fungicide application schedules. Fungicide schedules and applications were similar to those for 1980, except the total volume was reduced to 776 L/ha applied at 414 kPa. Data for DDF accumulation, time of primary lesion appearance, and disease severity were collected and analyzed as described for 1980. The average number of lesions per leaflet was determined by direct counts.

RESULTS

The relationship of day-degree accumulation to time of first lesion appearance and secondary sporulation. Data for the San Luis Valley (Table 1) show that the required DDC accumulations for first lesion appearance ranged from 347 to 388 (624–698 DDF) for the 5 yr tested. Airborne spores were trapped 5–10 days after primary lesion appearance in both the San Luis Valley and northeastern plains with one exception, when spores were trapped on the same date (Table 1). A calculated DDF threshold of 650 (361 DDC) was adopted for the San Luis Valley. This gave growers an easily remembered threshold value and allowed 7–10 days to prepare for fungicide application before the appearance of spores of *A. solani*. Data for the northeastern plains (Table 1) show that the required DDC accumulations for first lesion appearance ranged from 587 to 652 (1,056–1,172 DDF). An average DDC value of 626 (1,125 DDF) was chosen as a threshold, which gave growers sufficient time to prepare for initial fungicide applications.

The effect of different fungicide application schedules on early blight control. Data for the severity of early blight observed in treatment plots were collected several times during each growing season, but only data for the final readings are shown (Tables 2–5).

Disease data for 1978 field trials are shown in Table 2. Results for the percentage of leaflets infected show that applications made as late as 31 July provided disease control not significantly different ($P \leqslant 0.05$) from the treatment initiated on 19 June. When the average number of lesions per leaflet are compared, schedules initiated on or before 14 August provided the same level of disease control as the 19 June treatment schedule ($P \leqslant 0.05$). Primary lesion appearance occurred on 15 July and secondary spores were detected initially on 20 July in 1978 (Table 1).

Data for 1979 field trials (Table 3) show that fungicide applications that begun using spore-trapping data or accumulations of 334, 375, or 417 DDC (600, 675, or 750 DDF, respectively) provided disease control equivalent to the "normal schedule" initiated on 10 July ($P \leqslant 0.05$). These results showed that at least one fungicide application was unnecessary.

Observations of foliage in both field trials during 1980 showed that, for each location, early blight lesions appeared at approximately the same time in each of the three cultivars. Data for fungicide application schedules made in the northeastern plains show that treatments initiated on or before 6 August provided disease control equivalent to that obtained for the schedule initiated on 25 June ($P \leqslant 0.05$). Data for 1981 show that in the northeastern plains (Table 5) fungicide treatments initiated as late as 10 August gave control that was not significantly different from the treatment initiated 1 July, when the estimated percentage of leaflets infected is compared ($P \leqslant 0.05$). When the average number of lesions per leaflet are compared, fungicide applications initiated on or before 30 July provided control equal to the 1 July schedule ($P \leqslant 0.05$). All fungicide application schedules significantly ($P \leqslant 0.05$) reduced disease severity when compared with the nontreated control. Four and three fungicide applications could have been eliminated by timing initial fungicide applications using the day-degree (DD) model in 1980 and 1981, respectively.

DISCUSSION

The time of first lesion appearance and sporulation of *A. solani* is closely related to plant maturity. Since plant maturity is related to day-degree (DD) accumulation and little root or shoot growth occurs in potatoes at or below 7.2 C (45 F) (1), it was possible to develop a DD model based on a 7.2 C (45 F) threshold for

Table 4. The effect of different schedules of fungicide application on early blight control in the northeastern plains in 1980

First application	Applications (no.)	Estimated leaflets infected (%)[y]
25 June	7	0.9 c[z]
3 July	6	1.3 bc
14 July	5	1.4 bc
25 July	4	1.6 bc
6 August	3	1.5 bc
15 August	2	7.2 ab
Control	0	19.6 a

[y] Plants were evaluated on 2 September.
[z] Treatment means followed by different letters differ significantly ($P \leqslant 0.05$). Mean separations were done using HSD Tukey's test. Data for cultivars are combined (P interaction $\geqslant 0.05$).

Table 5. The effect of different schedules of fungicide applications on the incidence and severity of early blight foliage infection in the northeastern plains in 1981

First application	Applications (no.)	Estimated leaflets infected (%)[y]	Average no. lesions per leaflet[y]
1 July	7	81 b[z]	2.1 c[z]
10 July	6	91 b	3.6 c
20 July	5	82 b	2.5 c
30 July	4	85 b	3.9 c
10 August	3	90 b	7.6 b
Control	0	100 a	16.0 a

[y] The estimated percentage of leaflets infected was determined on 1 September and the average number of lesions per leaflet was determined on 21 August.
[z] Treatment means followed by different letters differ significantly ($P \leqslant 0.05$). Means were separated using Tukey's HSD test.

prediction of secondary spread of *A. solani*. The model intentionally does not consider the physiology of the pathogen, and this may account for the different DD thresholds required at the different locations tested. For example, there is no allowance for a maximum temperature threshold in the model above which *A. solani* will not sporulate (10). Therefore, the typically warmer temperatures present in the northeastern plains may account for the greater DD threshold there for sporulation of the fungus. Another explanation for the different thresholds in the two areas is that the DD values are also an indirect measurement of an unidentified parameter, for example, solar radiation. Data suggest that similar models can be established for other potato-producing areas by comparing accumulated DD values with the appearance of primary lesions and airborne spores.

The relatively stable environmental conditions of Colorado probably contribute to the simplicity of the DD model. Potato foliage in Colorado is typically exposed to alternating periods of wet and dry from heavy dews and drying days, as well as from the extensive use of overhead sprinkler irrigation. Therefore, environmental conditions necessary for sporulation and secondary spread of the pathogen are normally present once the temperature threshold is reached (6). Models developed for other potato production areas where conditions are not so consistently favorable for infection and secondary spread may need not only to determine when DD thresholds are reached, but also to determine when conditions favorable for secondary spread (sporulation and infection) occur as well.

Since its development, the simple DD model described in this report has proven effective and popular for timing initial fungicide applications in the San Luis Valley from 1980 through 1987. Growers receive a recorded message by telephone from the Colorado State University San Luis Valley Research Center to determine DDF values in relation to planting date. In the northeastern plains, individual growers calculate their own DDF values and initiate spray programs according to the model as adjusted to their field location. This is in contrast to the labor-intensive gathering of spore-trapping data, or observing plants for symptoms, neither of which may provide sufficient lead time for timely fungicide application. The DD thresholds we empirically selected reflected a compromise among a number of variables such as planting date, natural ranges in temperature within a given potato production area, and canopy development in individual fields. They also provided sufficient lead time to allow growers to react to predictions in contrast to spore-trapping methods, which provided little or no lead time. The DD threshold can be adjusted, through trial and error, to fit the individual grower's needs. For example, in areas where less disease pressure exists, there may be more flexibility in the model, but such adjustments need to consider the possibility of interfield spread of spores. If the model is used in other potato production areas, different DD thresholds may need to be established. The model effectively reduces fungicide applications in Colorado where growers do not routinely apply fungicides to control late blight (*Phytophthora infestans* (Mont.) de Bary).

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