Letter to the Editor

Computer Simulation Raises Question About Timing Protectant Fungicide Application Frequency According to a Potato Late Blight Forecast

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Plant disease forecasts are used to increase the efficiency and effectiveness of control efforts by allocating those efforts according to identified need. For more than 50 years plant pathologists in Europe and North America have worked to develop procedures for forecasting potato late blight, which is induced by *Phytophthora infestans* (Mont.) d By. We have used computer simulation of late blight and fungicide dynamics to evaluate the efficacy of one of these forecasting procedures and were surprised to find that simulated fungicide applications according to the forecast did not suppress disease any more effectively than simulated applications at regular time intervals.

The threat of late blight and, therefore, the need for fungicide, depends heavily on weather and the supply of fungal inoculum. Late blight is favored by moderate temperatures (12–20 C) and abundant moisture. Conceivably, if growers applied fungicide according to weather conditions or inoculum supply instead of relying on the commonly used regular calendar schedules, they could reduce fungicide use on average without risking increased disease. This approach would benefit growers by reducing production costs and crop losses, and could enhance environmental quality by reducing the use of fungicide. Inoculum is difficult to monitor, and disease may not be detectable in time to prevent losses that greatly exceed the cost of fungicide, but weather can be monitored fairly easily and used as a basis for adjusting fungicide use. Blitecast is one of the models used for adjusting fungicide application according to weather factors (7,8).

The objective of this study was to evaluate the economic benefits of scheduling fungicide applications with Blitecast relative to regular fungicide applications in simulations in which the confounding effects of inoculum levels and weather could be controlled. Ideally, in such a comparison, the net revenue from potatoes grown with Blitecast should be compared with that from potatoes grown with regular fungicide applications for the range of conditions that can occur in commercial potato fields. It would be difficult and very expensive to attempt a comprehensive evaluation of Blitecast with this range of conditions in growers' fields or experimental plots. Computer models of late blight development (1) and fungicide effectiveness (2,3) allowed inexpensive comparison of Blitecast and regular applications over a range of conditions and with greater control than would have been possible in the field.

The economic evaluation of Blitecast is further hindered by the difficulty of determining how much late blight reduces crop value and increases production costs. In commercial potato fields in the northeastern United States, defoliation from late blight rarely progresses far enough to significantly reduce tuber quantity or size because growers regularly apply fungicide to suppress the disease and respond to outbreaks by increasing fungicide use and destroying severely infected plants. The most common and potentially most costly effect of late blight on crop value is tuber infection, the occurrence and consequences of which are unpredictable. Infection of the foliage any time after tuber initiation can be associated with tuber infections. If growers suspect that tubers may be infected, they may inspect their crop more intensively during harvest and grading and may change storage and marketing practices.

We chose not to hypothesize functional relationships between foliar infection, tuber infection, and grower's responses, but instead we inferred the economic performance of Blitecast and regular applications on the basis of verified relationships between fungicide use and defoliation from late blight. Our only assumption in relating defoliation to the performance of Blitecast-scheduled and regular applications was that lower defoliation was preferable to higher defoliation. We evaluated performance in terms of both defoliation and fungicide use. It is not yet possible to combine the two into a single measure such as net revenue. Although this two-dimensional comparison gave inconclusive results when lower fungicide use was associated with higher defoliation, it was consistent with the strengths of the models and our understanding

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of late blight and was adequate for drawing conclusions about the efficacy of fungicide timing techniques.

We compared Blitecast-scheduled (original description [7]) and regular applications for a moderately susceptible potato cultivar (eg, Katahdin) by using 10 yr of rainfall and temperature data recorded at Geneva, NY. High relative humidity data were generated from the records of rainfall and temperature with a stochastic function estimated from three seasons of continuous relative humidity and temperature measurements in the potato crop canopy. This functional relationship between relative humidity, rainfall, and temperature was representative for microclimates favorable for late blight. Microclimates less favorable for late blight were generated by subtracting 1 and 2 hr, respectively, from each daily period of high relative humidity in the data set for the favorable microclimate.

TABLE 1. Average percent of potato plant defoliated from late blight and average number of fungicide applications scheduled by the Blitecast and 7-day-interval models for 10 simulated seasons

	Microclimate		
Treatment	Favorable	Moderately favorable[a]	Unfavorable[a]
	Percent defoliated		
High inoculum Blitecast	40.1 (7.9)[b]	34.1 (8.6)	23.2 (8.9)
High inoculum 7-day	35.2 (8.2)	21.2 (8.5)	10.9 (5.2)
Moderate inoculum Blitecast	16.3 (6.0)	16.5 (9.1)	9.5 (4.6)
Moderate inoculum 7-day	15.2 (6.7)	10.0 (6.1)	3.9 (3.4)
Low inoculum Blitecast	0.2 (0.1)	1.0 (0.7)	0.1 (0.0)
Low inoculum 7-day	0.4 (0.3)	0.2 (0.2)	0.0 (0.0)
	Avg no. of applications		
Blitecast	10.6	8.7	6.6
7-day	10.0	10.0	10.0

[a]Weather data for the moderately favorable and unfavorable microclimates were generated by subtracting 1 and 2 hr, respectively, from each daily period of high relative humidity in the data set for the favorable microclimate.

[b]Values in parentheses are standard deviations of average defoliation.

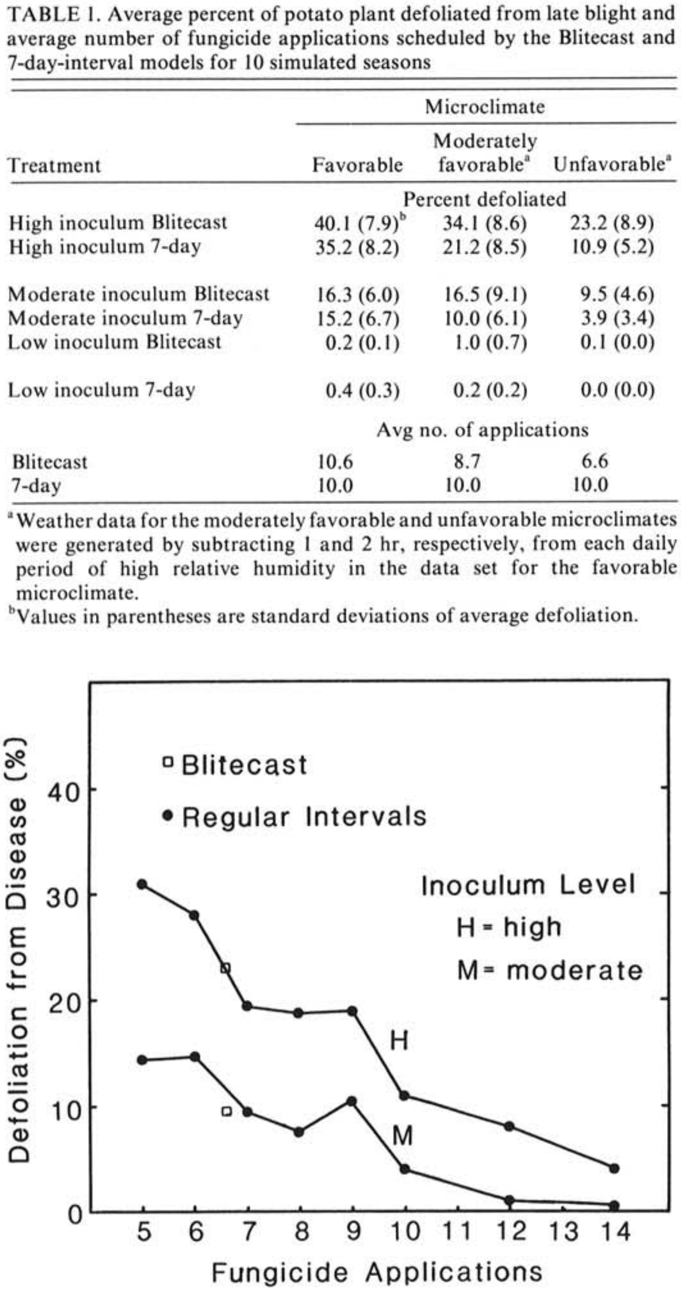

Fig. 1. Average percent of potato plant defoliated from late blight and the average number of fungicide applications scheduled for 10 simulated seasons by Blitecast and a range of regular intervals for a microclimate unfavorable for disease. Regular intervals ranged from once every 14 days (five applications per season) to once every 5 days (14 applications per season).

In addition to modeling the production and dissemination of inoculum within a 50-m^2 plot, the simulation included the influx of inoculum into the plot from exogenous sources (eg, cull piles, potato fields, and home gardens). The daily influx of inoculum varied according to the favorability of the weather for late blight. The favorability of the weather was rated in "blight units" (BU) on a scale from 0 to 6 based on the rate of development of late blight in the model under those weather conditions (6). Blitecast-scheduled and regular fungicide intervals were compared at three levels of exposure to inoculum. At the low exposure, the influx per day was 2^{BU} of sporangia (the number *2* raised to the power equal to the blight units for that day); at the moderate exposure, the influx was 6^{BU}; and at the high exposure, the influx was 10^{BU}.

For both Blitecast-scheduled and the regular-interval applications, the first fungicide application was made on day 50 of the 120-day season. For Blitecast, the relative humidity, temperature, and rainfall data were evaluated every 4 days beginning on day 55 to select one of four options: no further applications of fungicide at least until the next evaluation of weather data, reevaluation of weather data in 2 days, application of fungicide on a 7-day interval, and application on a 5-day interval.

In the simulation experiment, Blitecast-scheduled fungicide applications, on average, did not suppress late blight more effectively with less fungicide than did the common grower practice of weekly fungicide applications. For the microclimate favorable for late blight, Blitecast on the average called for more applications of fungicide than did regular weekly applications (Table 1), but at the high and moderate inoculum levels, Blitecast fungicide scheduling did not suppress disease as strongly as the weekly applications. For the moderately favorable microclimate, Blitecast scheduling recommended fewer fungicide applications than did the weekly schedule, but the reduction was small and it was associated with increases in disease (Table 1).

For the unfavorable microclimate, Blitecast resulted in an average of 3.4 fewer fungicide applications than the 7-day interval, a savings of between \$32 and \$77 per ha (\$13–\$31/a) depending on the fungicide and method of application (4). This savings could be substantially greater than the cost of collecting and using the weather data for Blitecast, but the savings were realized without increased defoliation only when exposure to inoculum was low. In a comparison between Blitecast and a range of intervals for the two higher inoculum levels in the unfavorable microclimate, fungicide applications timed according to Blitecast did not suppress late blight more effectively than approximately the same number of applications equally spaced over all 10 seasons (Fig. 1). Consequently, the potential advantage of Blitecast in unfavorable microclimates appeared to result from lower average fungicide use

TABLE 2. Numbers of fungicide applications and resulting defoliation in field plot comparisons of Blitecast-scheduled and weekly-scheduled applications

		Test 1[a]		Test 2[a]	
Year	Model	Applications	Final disease (%)	Applications	Final disease (%)
1975	Blitecast	8	44	8	23
	7-day	9	15	9	13
1979	Blitecast	9	18	9	2
	7-day	8	30	8	3
1980	Blitecast	5	91	5	44
	7-day	7	87	7	22
1981	Blitecast	8	79	9	2
	7-day	7	92	7	2
Means	Blitecast	7.6	38		
	7-day	7.8	33		

[a]Tests 1 and 2 were conducted at different locations or with different cultivars.

rather than improvement in the timing of applications within or among seasons.

The surprising results of the simulation study caused us to reassess our field experiments with Blitecast (5,6). As in the simulation experiment, we evaluated only the portion of Blitecast that adjusts the frequency of fungicide applications, and not the portion that schedules the first application of the season. Disease suppression and numbers of applications were similar whether applications were made weekly or timed by Blitecast (Table 2). Thus, results of our field experiments also provide little argument for using Blitecast to schedule fungicide application frequency.

We concluded that the original version of Blitecast does not schedule applications more effectively than the 7-day schedule used by many growers in locations typified by late-blight favorable microclimates. In other locations, an appropriate longer fixed-interval schedule appears to be more effective than Blitecast. One explanation is that Blitecast schedules applications after infections are initiated, but the protectant fungicides (both in simulations and in actual practice) act mainly to prevent new infections and do not suppress established ones. However, if inoculum is likely to be extremely low (a safe assumption in some years), Blitecast should enable a grower to reduce fungicide applications in unfavorable microclimates. Blitecast might also enable a grower to predict an appropriate average fixed-interval.

We understand that changes in Blitecast made by several research groups might increase its effectiveness in timing the frequency of fungicide applications. For example, Stevenson (10) suggested that the "no spray" recommendation be replaced by a "10-day spray interval." We are currently evaluating the efficacy of another potato late blight forecast model with a similar provision (6).

The effectiveness of Blitecast for scheduling fungicide applications might be increased if it was used in combination with newly available systemic fungicides that can kill the pathogen in infected tissue and with more reliable weather forecasts that would enable fungicide applications in anticipation of infection periods. Our conclusions about the original version of Blitecast also may be relevant to other disease forecasts that recommend application of protectant fungicide after, rather than before, conditions have been favorable for infection.

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