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# Scheduling Fungicide Applications for Potato Late

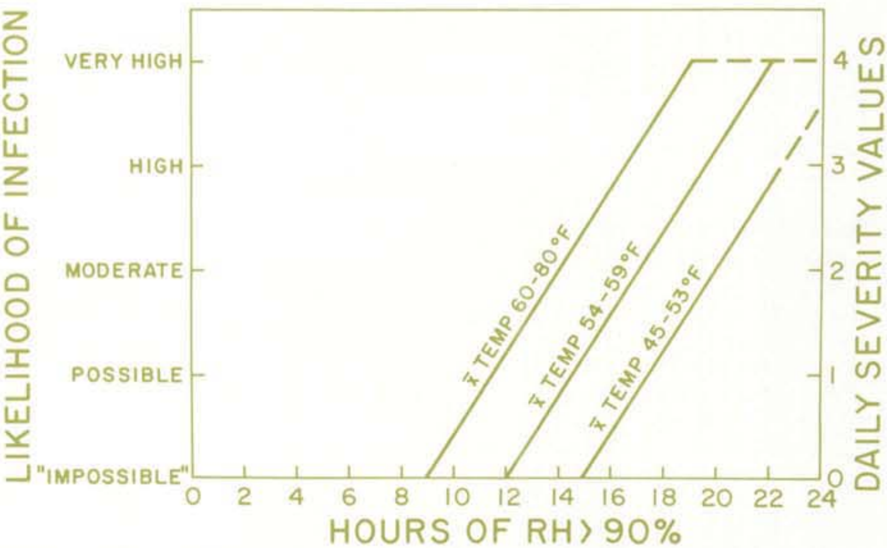


**Fig. 1. Relationship of the duration of high relative humidity periods and the average temperature during that period to the likelihood of infection and the corresponding severity value.**

Potato late blight caused by *Phytophthora infestans* (Mont.) de Bary is undoubtedly the most feared disease of potato production in the rain-fed northeastern United States. The association of "blight weather" with major outbreaks of the disease has long been known. The following passage is from a 1912 encyclopedia (1):

> It has been proven beyond doubt that a particular fungus always accompanies this peculiar and destructive disease. This mysterious fungus, *Phytophora infestans* [*sic*], apparently much more destructive in Europe than in America, runs through a strange life cycle every year, and is by no means easily kept at bay. It is believed that, except in temperatures below 40° and above 77° F, [it] is always present, ready to pounce upon a weak potato-plant, and liable to develop into an epidemic should the climatic conditions be favorable to fungus-life. These conditions are damp, dull, calm weather, and a moist or wet soil enveloped in mists morning and evening.

With the availability of effective agricultural chemicals for controlling late blight, potato growers have been successful in protecting their crop from destruction—at a price. Weekly sprays of protectant fungicides come at a tremendous cost to the grower—and to the environment. In the search for better ways to schedule fungicide applications for managing the disease, many research projects have focused on the weather associated with late blight epidemics. Several very important success stories in both Europe and North America during the late 1940s and 1950s represented significant breakthroughs in quantifying blight weather. Then, in the early 1970s a computerized potato late blight fungicide scheduling system known as BLITECAST was developed at The Pennsylvania State University under the direction of Raymond A. Krause (8).

## What Is BLITECAST?

BLITECAST is the synthesis of two earlier fungicide spray scheduling systems developed by USDA researchers working at separate institutions. The Hyre system, developed by Russell A. Hyre, interprets rainfall patterns with temperatures indicating the potential for late blight epidemics (5–7). The Wallin system, developed by Jack R. Wallin, interprets the epidemiologic consequences of extended periods of high relative humidity and the temperatures during those periods (14,16).

Prior to BLITECAST, scheduling fungicides for potato growers was difficult because the algorithms were judged too complex for manipulation by potato growers and because exchanging the information via postcards was too slow. BLITECAST combined the two earlier systems into a fast and unique information delivery system (8).

The availability of high-speed mainframe computers with time-sharing and remote job entry provided an ideal opportunity for fungicide scheduling for potato growers. BLITECAST was offered as a free service by The Pennsylvania State University during 1970–1976 and was an overwhelming success. Potato growers throughout the state of Pennsylvania—indeed, from Maine to Florida and as far west as Michigan—utilized the service by telephone. Participating growers collected the necessary weather information on a recording hygrothermograph and rain gauge. Each week they phoned the summarized weather information to a computer terminal operator at The Pennsylvania State University. During the course of the 3-minute phone conversation the weather data could be processed by the computer and a recommendation made to the grower. The service became so successful that others began offering BLITECAST independently of The Pennsylvania State University.

BLITECAST as a subscription service was not successful. To understand why, one needs to know the assumptions underlying the system and the attitude of the growers toward participation in "for a fee" pest management/information delivery systems

## How BLITECAST Works

BLITECAST has two triggers, either of which can issue a recommendation to begin considering spraying for the cropping season. One trigger is pulled after 10 consecutive blight-favorable days, said to occur when the 10-day cumulative rainfall exceeds 3 cm and the 5-day average daily temperature does not exceed 25.5 C. The other trigger is activated when the accumulated severity values exceed 18–20 units.

Figure 1 shows Wallin's relationship of relative humidity and temperature to the likelihood of potato late blight infection and the corresponding severity value (14). For instance, infection is understood to proceed slower at low temperatures and require a longer period of high relative

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# Blight with BLITECAST

humidity. The likelihood of infection can range from "impossible" to very high, depending on the temperature range and the duration of relative humidity. Arbitrary units ranging from 0 to 4 are assigned to this relationship. In the case of blight weather, when relative humidity duration might be 19 hours with an average temperature of 21 C (70 F), one would expect a very high likelihood of infection, and a severity value of 4 would be assigned. On a day of nonblight weather with, say, only 2 hours of relative humidity greater than 90%, infection would not be likely and the severity value would be 0.

The severity values assigned to particular weather patterns are similar—but not identical—to the Beaumont units used in Europe to forecast potato late blight. By the Beaumont rule, periods of not less than 48 consecutive hours of relative humidity above 75% and temper-

**Table 1.** Spray schedule recommendations for BLITECAST based on weekly accumulated severity values

| | Total weekly severity values | | | | |
|---|---|---|---|---|---|
| **Rainfall** | **0–2** | **3** | **4** | **5–6** | **7 or more** |
| Low | No spray | No spray | Alert | Moderate spray | Heavy spray |
| High | No spray | Alert | Moderate spray | Heavy spray | Heavy spray |

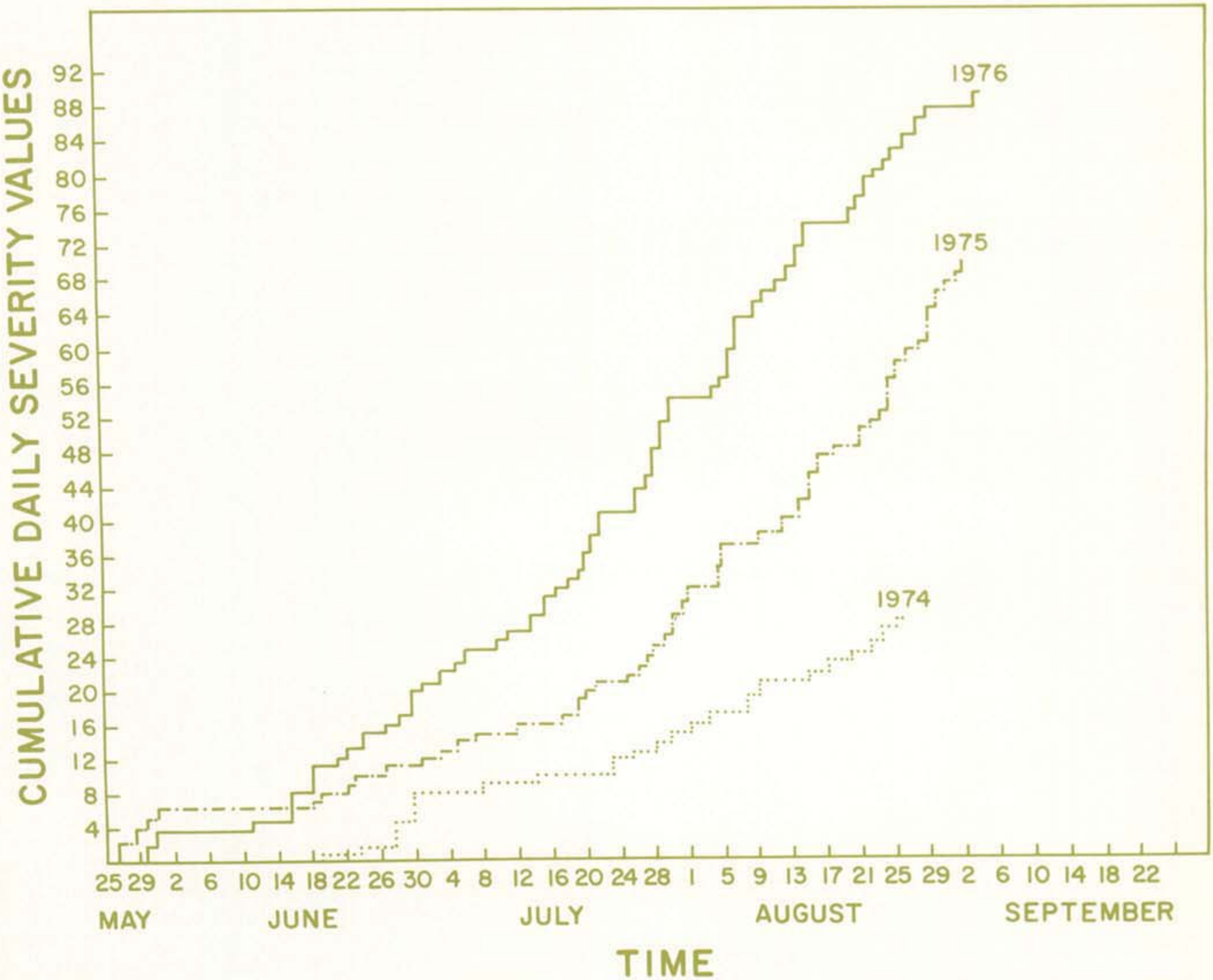


**Fig. 2. Cumulative daily severity values for one cooperating BLITECAST station in Pennsylvania during three successive growing seasons.**

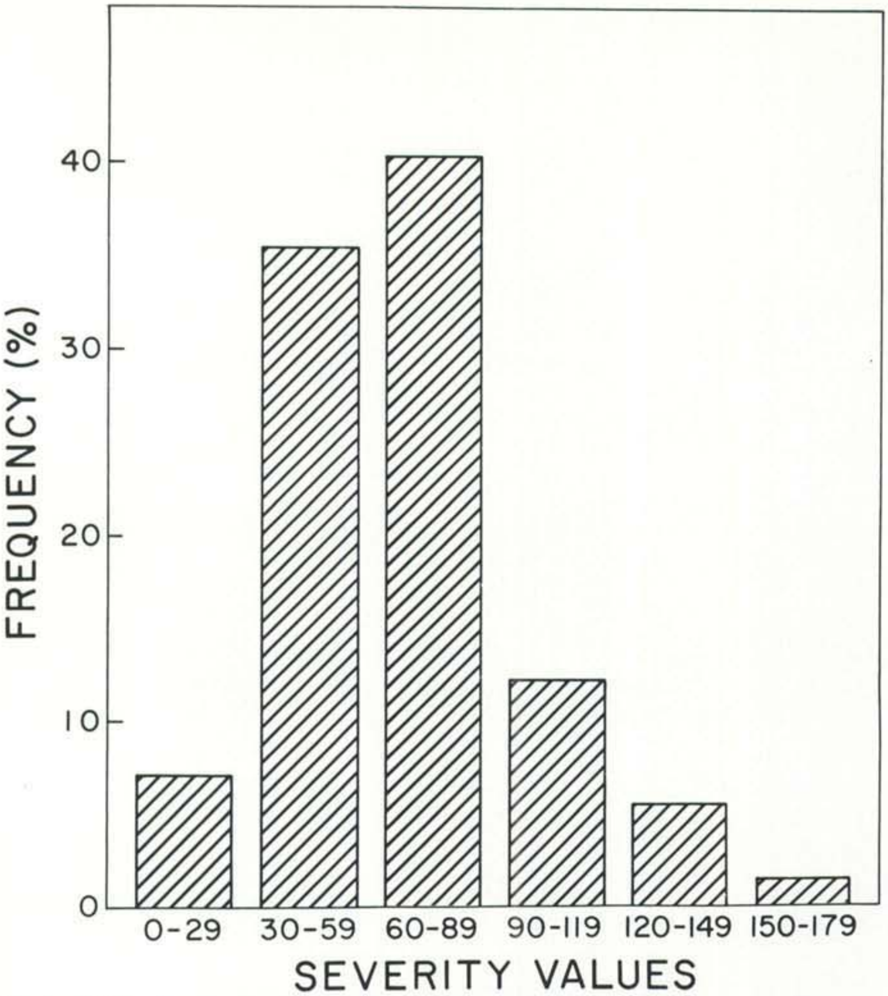


**Fig. 3. Distribution of cumulative total severity values for all cooperating BLITECAST stations in Pennsylvania for the 1974, 1975, and 1976 growing seasons. Stations with low values would be expected to be less threatened by late blight than those with high values.**

ature above 10 C (50 F) are expected to be followed by outbreaks of late blight within 2–3 weeks (3). For BLITECAST, the accumulation of weather data must begin with the "green row" stage of crop development when rows of emerged plants are first visible in the field. When sufficient rainfall or periods of high relative humidity are recognized by the system, the triggers advise participating growers to be alert for blight within 1–2 weeks, and the second phase of the fungicide scheduling begins.

Fungicide spray recommendations are made by BLITECAST on a week-to-week basis according to rainfall and total weekly severity values (Table 1). Low rainfall is distinguished from high rainfall by the number of days during the previous 7 that were "rain favorable." Weeks with 5 or more rain-favorable days are considered to be of high rainfall. A day is considered to be rain-favorable when the 5-day average temperature is below 25.5 C and the total rainfall for the previous 10 days is 3 cm or more. A day with a minimum temperature below 7.2 C is considered unfavorable for late blight development.

For a week with only a few rain-favorable days, growers are advised not to spray unless five or more severity values are accumulated; with seven or more severity values, an intense spray schedule is recommended. During weeks of frequent rain, the spray recommendations from BLITECAST are intensified. During a rainy week, three severity values indicate that growers should be alert to a potential late blight outbreak and four or more severity values indicate the crop should be sprayed.

The cumulative severity values on one farm in Pennsylvania for three successive growing seasons (Fig. 2) illustrate how conditions can vary from year to year. Similarly, during the 1974, 1975, and 1976 growing seasons, 81% of the BLITECAST stations in Pennsylvania had cumulative severity values below 90, with 42% below 60 (Fig. 3). By recognizing such differences, BLITECAST prevents the needless use of pesticides as well as indicating the need for increased protection.

## Epidemiology of BLITECAST

More of the assumptions of BLITECAST must be explained to understand the epidemiology. These assumptions are critical to assessing the actual risks of deploying such an information delivery system.

The source of inoculum that initiates late blight epidemics continues to be an unresolved point. BLITECAST sidesteps this issue by assuming the inoculum is there, hopefully in low frequency. When one considers that tubers can be infected and that two tons of seed are needed to plant a hectare of potatoes, the likelihood of initial inoculum coming from seed is quite high.

Whatever the source of the initial disease, a primary assumption of BLITECAST is that the epidemic begins at very low intensity. In a large potato field, the potential for independent foci might exist in one or more places, and the beginning of a focus might be one lesion on one plant in a thousand. This would be roughly equivalent to 0.0001% disease—admittedly well below the detection abilities of even the best trained scout.

The next assumption is that the epidemic will progress exponentially as a compound interest epidemic that can be described by "Vanderplankian methodology." The initial disease severity of 0.0001% is transformed to logit −13.82 and then projected for three assumed apparent infection rates (Fig. 4). The time scale is BLITECAST severity values rather than days, the more traditional measure of time. Not all days in an epidemic are equal, and BLITECAST severity values provide a convenient analytical measure of epidemiologic time.

The two decision thresholds critical to BLITECAST are indicated at logit −7 and logit −4.5 (Fig. 4). The first threshold is at 0.1% disease severity (logit −7) and for the average potato cultivar represents the accumulation of about 18–20 BLITECAST severity values. At this point, the second BLITECAST trigger signals the beginning of the week-to-week scheduling of fungicide applications. As noted on the spray threshold line, however, potato cultivars vary in rate-limiting resistance to late blight.

The second threshold (logit −4.5) represents the "cease forecasting" line. Most growers discover blight at about 1.0% disease severity. When this happens, the grower is advised to quit the BLITECAST system and begin a regular fungicide spray program to hold back the epidemic.

The area between logit −7 and logit −4.5 is where BLITECAST operates on a week-to-week roulette game involving a high degree of risk. Once one of the two triggers has been pulled, BLITECAST uses last week's weather to schedule next week's fungicide protection. Although I am unaware of any week-to-week correlation of blight weather, this is a fundamental assumption of BLITECAST that must be recognized. For the average potato cultivar, about 8–10 severity values will be needed for the epidemic to progress from 0.1 to 1.0% disease severity. In the game of blight roulette, BLITECAST gambles from week to week that 8–10 severity values will not accumulate all at once.

During most growing seasons, the gamble appears to pay off. The hazards come from two critical areas. First, if the initial amount of disease is greater than assumed, the epidemic's progression toward the spray threshold will be quickened. For that reason, high-quality seed and very good sanitation practices are absolutely essential to eliminate secondary sources of inoculum. The second hazard comes from differences in cultivars. Those not possessing a measure of rate-limiting resistance (such as Russet Rural) can reach the spray threshold by 12 severity values and 1.0% disease severity by 18. Obviously, the wrong cultivar coupled with high seed infection and poor sanitation practices (such as old potato cull piles on the farm) would spell disaster if fungicides were scheduled according to BLITECAST.

## Alternate Information Systems

When BLITECAST did not succeed as a subscription service, several individuals saw that alternate information delivery systems might be more acceptable to growers and at the same time eliminate the costly computer required for BLITECAST (10,11,13). We began developing several information delivery systems to discover what factors play roles in grower acceptance of fungicide scheduling systems. Our first project was to develop an on-site microcomputer specific for BLITECAST. The result is the Blitecaster, a battery-operated computer that, when positioned in the potato field, collects, interprets, and numerically displays the BLITECAST fungicide recommendations. Commercial units are available from Campbell Scientific Inc., P.O. Box 551, Logan, UT 84321 (12). The units, available since 1977, have been successful with a modest number of growers but are not widely accepted.

Our next information delivery system employed the Texas Instruments Model TI-59 hand-held programmable calculator (Fig. 5). This effort combined the original BLITECAST algorithm with a green peach aphid management system for potatoes to schedule both pesticide sprays (17). Through the use of magnetic cards for program and data entry and storage in the TI-59, growers are able to interpret weather data collected on a recording hygrothermograph and rain gauge. The system was tested with 12 Pennsylvania potato growers for 2 years and judged moderately successful. Some growers were very enthusiastic, others were totally disinterested.

Another system uses the Radio Shack TRS-80 Model I level 2 minicomputer (Fig. 5) to process weather information in much the same way the original BLITECAST system was interpreted on the main-frame computer (11). We had hoped that county agent offices in the major potato-growing regions in Pennsylvania would offer this system as a service, but no interest has been expressed so far.

## Risks of BLITECAST

BLITECAST is a paradox. On the one hand, the potential exists for decreasing pesticide usage. This could benefit growers directly by reducing costs and society indirectly by reducing damage to the environment. On the other hand, BLITECAST represents a real risk to the participating potato grower—a risk not yet adequately assessed. We have begun unraveling this paradox through the use of computer simulation. One by-product of all the past efforts is extensive computer files of BLITECAST weather data that can be used for simulation studies.

We have used computer simulations to take a look at three aspects of the potential of BLITECAST: cost/benefit, risk, and modification to the original algorithm.

We calculated the benefits that could have been realized if BLITECAST had been used statewide in Pennsylvania during 1974–1976 (Table 2). Computer simulation was used to track the likely disease progress for all cooperating blight stations, and the data were summarized by county and condensed to statewide totals for comparison. The initial amount of disease was assumed to be very high (0.002%), and the estimates were therefore conservative. The average number of sprays that would have been saved appears small, but the potential reduction across the state in tons of fungicide used and dollars spent would have been tremendous. The potential benefits are increased further when BLITECAST is complemented with a resistant cultivar.

The risks of BLITECAST to the individual grower, however, far exceed the potential benefits in savings of fungicide costs. Growers, recognizing that the production cost for potatoes exceeds $2,000/ha, ask, "Why should I risk $2,000 to save perhaps $19 or $38 for skipping one or two fungicide applications?" Other growers state, "I spray once a week so that I can sleep at night!"

Our computer simulations of the BLITECAST strategy indicate that the risks of the system are indeed unacceptably high unless strict attention is paid to seed quality and good sanitation practices. The likelihood of exceeding 1.0% disease severity sometime during the growing season demands that good management practices be followed stringently.

Modifications to the BLITECAST algorithm have been proposed to simplify aspects of the system (2,10,13). Using computer simulation to look at potential modifications, we discovered that the trigger activated after 10 consecutive rain-favorable days can be pulled after 7 days, with apparently few consequences. Weather data collected from 127 blight

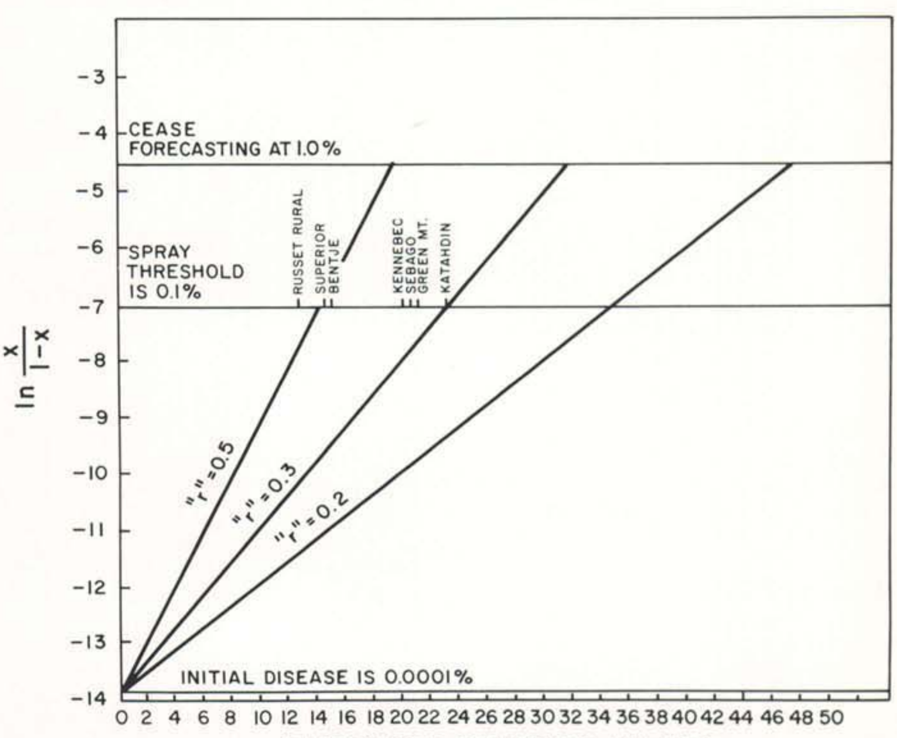


**Fig. 4. Description of the epidemiologic assumptions of BLITECAST as low initial disease (logit −14), differences in apparent infection rates for selected cultivars as a function of BLITECAST severity values, and the two key BLITECAST thresholds at which critical activities should occur. Cultivar reactions taken from Latin (9).**

**Table 2.** Potential savings that could have resulted from statewide implementation of BLITECAST in Pennsylvania during 1974–1976[a]

| | | Savings with susceptible cultivar[b] | | | Savings with resistant cultivar[b] | | |
|---|---|---|---|---|---|---|---|
| Year | Hectares | Sprays (no.) | Fungicide (kg) | Dollars | Sprays (no.) | Fungicide (kg) | Dollars |
| 1974 | 12,578 | 2.1 | 60,752 | 501,862 | 2.6 | 75,216 | 621,353 |
| 1975 | 12,468 | 1.2 | 34,412 | 284,270 | 1.1[c] | 31,544 | 260,581 |
| 1976 | 10,741 | 2.5 | 61,761 | 510,198 | 2.9 | 71,642 | 591,829 |
| Total | 35,787 | | 156,925 | 1,296,330 | | 178,402 | 1,473,763 |

[a] Calculations assumed a fungicide application rate of 2.3 kg/ha and an application cost of $19/ha.

[b] Potential apparent infection rate was calculated at 0.5 units/units/day for the susceptible cultivar and at 0.2 units/units/day for the resistant cultivar.

[c] Simulated results for 1975, a severe late blight year in southeastern Pennsylvania, forced the susceptible cultivar off BLITECAST earlier than the resistant cultivar. While the susceptible cultivar received weekly recommendations the resistant cultivar continued to receive 5-day recommendations and thus received more sprays than the cultivar sustaining more disease.

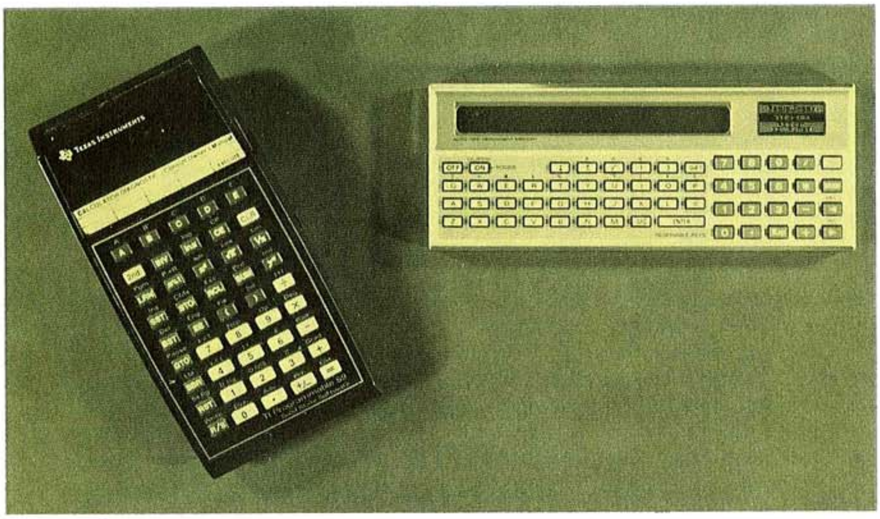

**Fig. 5. Two hand-held computers with power to accommodate BLITECAST: (left) Texas Instruments' TI-59 and (right) Radio Shack's TRS-80.**

stations during the 1974, 1975, and 1976 growing seasons were used to compare the number of spray applications recommended by the standard (10 days) and modified (7 days) algorithms. No differences were detected in 115 of the 127 comparisons; the modified algorithm called for one or two fewer applications in two of the remaining 12 comparisons and for one to four or more applications in 10. With the modified algorithm, BLITECAST can be programmed for hand-held minicomputers such as Radio Shack's TRS-80 (Fig. 5). Computer simulations will allow us to search for other such options in interpreting blight weather.

## More Work Suggested

Other improvements that can be made to the BLITECAST strategy deserve research attention. Differences among potato cultivars for apparent infection rates have been well demonstrated (4,9). These differences can be made to be interdependent with fungicide scheduling (4). In its present form, however, BLITECAST assumes the average reaction of a cultivar for resistance. Furthermore, differences in fungicides cannot be accommodated, to the dismay of several fungicide manufacturers.

Flexibility in BLITECAST could be attained by communicating the accumulated late blight severity values to growers instead of recommending spray intervals. "Look-up" tables for interpreting severity values could incorporate cultivar and fungicide differences, and late blight alerts could be automatic when severity values become critical during the growing season.

At present, BLITECAST does not forecast per se; all interpretations of blight weather deal with past events. Wallin and Riley (15) reported on the use of regional weather map analysis to truly forecast late blight. Unfortunately, their efforts were never incorporated into BLITECAST. With today's meteorologic technology, weather map interpretation and projection could greatly enhance the system. Severity values could be estimated days in advance, and growers would be better able to plan fungicide spray schedules.

BLITECAST could also provide the focal point for pesticide management strategies. New, highly specific fungicides are being developed for potato late blight, and if past patterns are indicative, tolerance to these compounds is likely. For more effective use of these new chemicals, I propose two drastic changes in present philosophy. First, highly selective fungicides should never be used in potato seed production. They should be used only in commercial potato production and then solely as a backstop to BLITECAST. By this strategy, if and when BLITECAST scheduling failed to manage late blight and disease severity exceeded tolerable levels, aerial application of a highly specific, systemic, eradicative fungicide would be permitted. Critical action levels would vary with intended crop use (ie, immediate processing vs. storage), as the amount of tuber infection is inversely related to storability.

Second, BLITECAST and highly specific fungicides should never be used together for potato seed production. BLITECAST allows some buildup of foliar late blight, thereby increasing the likelihood of tuber infection. The incidence of seed tuber infection greatly influences the course of an epidemic. It seems axiomatic that growers using seed obtained from seed growers who also used BLITECAST are taking extraordinary risks with the primary assumptions of BLITECAST. The superimposition of fungicide-tolerant isolates arriving on seed in greater amounts is double jeopardy!

BLITECAST should be expanded to include other pests of potato. Such integration has obvious savings from coincident environmental monitoring and information delivery. More important, several pests are often controlled by a single pesticide. One consequence of sharply reducing the frequency of foliar sprays for late blight could be contributing to periods of vulnerability of the crop to other diseases, such as early blight caused by *Alternaria solani*. Much more work must be devoted to this relationship.

Growers are unwilling to underwrite the entire cost of fungicide scheduling systems and assume all the risks. The success of future pesticide information delivery systems may well depend on using tax dollars to subsidize them and to provide participating farmers with crop loss insurance in the event a system fails.


## Acknowledgments

I wish to acknowledge the invaluable contributions of Deborah Krawczak, formerly an undergraduate student in computer science at The Pennsylvania State University and now a graduate student in computer science at Stanford University. Ms. Krawczak conducted the computer simulations reported in this paper as well as many other computer applications for our project on plant disease management. I am also very grateful for the excellent cooperation we have received from Zane Smilowitz (my counterpart in our Department of Entomology) in all aspects of the on-farm testing of various information delivery systems for potato pest management.


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