Web-Interactive Integration of Regional Weather Networks for Risk Management of Late Blight in Potato Canopies

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Abstract: Management of late blight (*Phytophthora infestans*) of potato (*Solanum tuberosum*) in the U.S. is dependent on multiple foliar fungicide applications. In-canopy temperature and relative humidity conditions influence the spread of late blight when inoculum is present. A web-interactive system was created and implemented at Michigan State University for the management of potato late blight. The system integrates regional automated weather network data, fungicide rates, and application timing intervals. Management recommendations concerning type and frequency of fungicide application for 30 Michigan sites were updated daily. From 1997 to 2000, the use of weather data in grower decision making process increased from 52 percent to 90 percent of the potato production in Michigan. Field experiments were conducted in 2001 to compare late blight incidence in plots treated according to web system recommendations with those treated according to standard practice. Under heavy disease pressure, late blight lesions developed in the plot treated with standard fungicide rates two weeks before the plot treated according to weather-based recommendations.

Late blight of potato, caused by *Phytophthora infestans* (Mont. de Bary), has recently re-emerged as a major threat to potato (*Solanum tuberosum*) production worldwide (Inglis et al., 1996; Fry and Goodwin, 1997). Late blight spreads in potato canopies by continuous leaf and stem infection (Figure 1) when inoculum is present and favorable environmental conditions, typically moist cool weather, exist (Fry and Smart, 1999). Prior to 1992, North American populations of *P. infestans* (A_1 mating type) were easily controlled by metalaxyl-based fungicide applications, but a new aggressive genotype (US8, A2 mating type, metalaxyl-insensitive) has replaced the previous clonal lineage. The foliage of all available commercial potato varieties is highly susceptible to current *P. infestans* populations (Inglis et al., 1996; Douches et al., 1997). The cost of protecting potato crops in the United States against late blight is estimated at $287.8 million annually (Guenthner et al., 2001).

No fungicides presently in use completely arrest epidemic development, and even plants protected with five-day fungicide applications at a maximum rate of active ingredient become infected when environmental conditions are conducive to late blight development and inoculum is plentiful (Mayton et al., 2001; Stein and Kirk, 2002). Estimation of conducive conditions and appropriate application of controls is crucial to management as infected plants reach 100 percent foliar infection approximately 25 days after initial inoculation (Baker et al., 2000; Mayton et al., 2001).

Because conditions are only sporadically favorable and inoculum is not always present, timely and effective management recommendations are critical to the economics of potato production. The Upper Great Lakes region is important in the study of late blight field epidemic characteristics as the disease occurs more sporadically than in other U.S. production areas because of the variability of growing season weather conditions. The control of potato late blight and estimation of associated field conditions throughout the growing season have continued to be top research priorities for the Michigan potato industry since 1995 (MPIC, 1997, 2000).

Potato late blight prediction models have been used to estimate favorable environmental conditions for epidemic risk and fungicide recommendations appropriate to that risk for more than 50 years (Beaumont, 1947; Cook, 1949; Nugent, 1950; Wallin, 1962). Over 20 models have been developed that employ temperature and moisture inputs from either in-canopy on-site automated weather stations or off-site regional stations (Wallin and Schuster, 1960; MacKenzie, 1981; Anonymous, 2001). Traditionally, growers and other users have been expected to purchase their own weather station, a personal version of a disease model software package, or the risk data summary itself to take full advantage of weather conditions in management decision making processes.

The model implemented from 1999 to 2001 by Michigan State University (MSU) for extension and outreach to Michigan growers differed from traditional systems in several ways. The system was internet-based and interactive, allowing growers to access site-specific, weather-based recommendations through their personal computer without the purchase or installation of additional equipment and/or software. The weather network incorporated geographic proximity of known late blight infection and data from both in-canopy and off-site regional weather stations into daily risk estimates and management recommendations for approximately 30 locations in Michigan. Recommendations included application timing and spray rates for common fungicides.

Disease Models and Late Blight

Late blight disease models are traditionally dependent on extended leaf wetness duration, approximated by 90 percent relative humidity (normally measured at 2m above canopy), and air temperatures between thresholds of 7.2 and 27.0°C which are conducive for *P. infestans* infection risk (Wallin, 1962). Microclimate-based late blight models were established originally in the 1940's and fungicide spray programs and other management decisions have been based on the accumulation of 'blight favorable days', or thresholds of disease severity values, since the 1960's (Beaumont, 1947; Wallin and Schuster, 1960; Wallin, 1962; MacKenzie, 1981). Wallin disease severity values (DSV), ranging from 0 (no risk) to 4 (severe risk), became standard in estimating potato late blight risk (MacKenzie, 1981) using both the number of hours above the relative humidity threshold and the air temperature during that time (Table 1). The traditional Blightcast model, developed during predominance of the US1/A1 genotype, recommended the initiation of fungicide applications after ten consecutive favorable days or the accumulation of 18 DSV after May 1 (MacKenzie, 1981).

A 90 percent relative humidity threshold was historically used to estimate leaf wetness in late blight models. However, the 90 percent criterion often underestimated leaf wetness duration, especially on days when dew, as opposed to precipitation, was the primary source of canopy moisture (Thompson, 1981). The 90 percent criterion is not considered the best leaf wetness estimate for disease alert systems and other applications of leaf wetness, especially in ground crop situations where dew is an integral aspect of wetness duration and canopy structure is dense (Gleason et al., 1994).

MSU Late Blight Management Model

Michigan State University has been using a modified Wallin-type model for making management recommendations to growers since 1999 (Baker et al., 2000). The model was adapted for use with hourly temperature and relative humidity data during the growing season. Each of the hourly values above the relative humidity threshold were assigned to a particular Wallin-based temperature category and summed for each day.

Relative Humidity Thresholds

Although a 90 percent relative humidity threshold has been standard for the approximation of leaf wetness in late blight models, the MSU model used 80 percent. Given the dense structure of a potato canopy, relative humidity may be higher in the canopy than the ambient air. Figure 2 shows the relationship between canopy and ambient relative humidity. Hourly relative humidity data were recorded at Entrican, MI during the growing season in 1997, 1998 and 1999. Mean and standard deviation of the ambient relative humidity per one percent intervals of canopy relative humidity are shown with respect to the 90 percent criterion for estimating leaf wetness and the line of 1:1 relationship between canopy and ambient relative humidity. Ambient values were on average 5-7 percent lower than those recorded in the canopy air, with standard deviations ranging from 3-5 percent. At 80 percent ambient, the canopy relative humidity was within one standard deviation of 90 percent, and at 83 percent ambient, the canopy mean relative humidity was 90 percent. Given these results, a large percentage of hours when the canopy relative humidity was near 90 percent would not be counted if the ambient threshold for DSV accumulation was greater than 80 percent.

Comparison of disease severity accumulations in the canopy and ambient air at different relative humidity thresholds also indicated that the 90 percent ambient relative humidity threshold was insufficient for estimating canopy conditions (Figure 3). The 90 percent criterion has been shown in previous studies to underestimate leaf wetness duration in ground crops and to be less than optimal for disease alert systems (Thompson, 1981; Giesler et al., 1996). The 80 percent ambient threshold, however, consistently overestimated the 90 percent canopy threshold in terms of disease risk. Given the closeness of disease severity value accumulations between 80 percent ambient and 90 percent canopy on day 100 in 1998, and day 51 in 1999, a lesser ambient threshold would be prone to occasional but serious underestimation in disease risk, especially during periods of strongly increasing DSV accumulation.

Management Recommendations

Recommendation triggers were established for varying fungicide application rates based on favorability of environmental conditions and the geographic proximity of known potato late blight infections (Table 2). Unless otherwise specified, the recommendations followed a typical seven day spray schedule, modifying type and rate of fungicide application.

No fungicide initiation threshold was used in the MSU system, since growers began fungicide sprays soon after emergence regardless of conditions. Instead, 30 DSV was used as a threshold to increase fungicide rate. This threshold is arbitrary but likely to approximate the time when sufficient canopy moisture to initiate a late blight epidemic has been reached. 50-year means (calculated from 1948 to 1999) in the 30 DSV threshold for the Upper Great lakes region indicate that this threshold typically occurs in late July, early August (Baker et al., 2002) when canopy density is at its peak (Allen and Scott, 1992).

If the total DSV accumulation from the last seven days was less than 3 and the total since emergence was less than 30, the lowest labeled rate of protectant fungicide was recommended at the maximum application interval (green level). As soon as either of these thresholds was crossed, the highest labeled rate of protectant fungicide was recommended or, if it was near the end of the season during early senescence, a protectant was recommended in conjunction with an organotin-based compound (yellow level). During intervals when extremely favorable conditions existed, given that the seven day DSV total exceeded 20 or late blight lesions had been positively identified in the county, additional options were given for varying geographic proximity of known late blight (orange level). If foliar late blight was within two to five miles (pink level), a full rate of systemic fungicide was recommended or a protectant in conjunction with an organotin-based compound. When positively identified potato late blight infection existed within the same field or within a one mile radius of the field, this strongest recommendation was changed from a seven day to a five day spray interval (red level).

General recommendations were supplemented with a detailed table of recommended spray rates under each color/level of recommendation for common fungicides (http://potato.msu.edu/users/weather/fungrate.htm).

Technical (Web-based) Implementation of Model

Weather station locations used in the daily update of risk information and management recommendations came from both in-canopy and external sources. A series of in-canopy stations download data directly to MSU Late Blight Laboratory computers on a daily basis. The Michigan Automated Weather Network (MAWN) expanded over the 3 years of this project from approximately 15 to 30 sites around the state. Hourly data from these stations were published in html twice daily.

The Perl programming language was used to integrate weather information from the two weather networks into a single risk management site. A Perl program ran once daily for each weather station. Depending on station type, the program first retrieved the last 24 hours of data from a downloaded data file or the appropriate html address. A disease severity value was assigned based on the relative humidity and temperature characteristics of the day. The new DSV and the date were appended to a location specific risk file. This file was then used to calculate accumulated risk values and make a decision regarding corresponding fungicide application recommendations using a start and end date. Site-specific web pages used a fixed start date based on field knowledge of emergence and a fixed end date as the last known update. An additional interactive emergence site allowed growers to input a start date for the current growing season for any station into a web form and calculate values through the last known update. A separate text file recorded whether late blight lesions had been found in the county and was updated manually once the disease was confirmed.

For site-specific web pages, each DSV and recommendation was stored in its own individual text file. These text files were then linked to their respective web pages as server-side-includes, so that risk estimates and underlying values were updated as soon as Perl programs finished running each morning. The emergence specific calculator that ran based on web forms, incorporated the values and recommendation directly into the cgi created web page output.

Field implementation of model

Field trials were established beginning during the 2001 growing season. At both the MSU Potato Research Facility in Entrican, MI (Montcalm County) and the Muck Soils Research Farm in Bath, MI (Clinton County) side-by-side research plots were treated with fungicide regimes based either on the web available risk data or the standard seven day fungicide schedule used by the research farm. The 2001 growing season was quite unusual in the number of disease severity values accumulated in late May and early June. Potato late blight was found unusually early in Entrican (June 15) after volunteer plants emerged that had been infected during the previous year's epidemic. The field plot in Entrican was under the (orange) highest labeled rate of protectant fungicide on a seven-day schedule from the first spray date throughout the season. This fungicide application regime, therefore, did not differ significantly from the standard seven-day application scheme used at the research farm. At Entrican, no late blight was found at the facility in either research plot. Manual late blight inoculation at Bath ensured heavy disease pressure. Late blight lesions developed in the plot treated with standard fungicide rates two weeks before the plot treated according to weather-based recommendations.

Discussion and Conclusion

The web interactive system employed by MSU limited grower investment in terms of both money and time while providing site-specific late blight risk information and recommendations for management decisions. Interest in the web-based was strong and, in the three seasons since its inception, the system has repeatedly been improved. Improvements in form and interactive capabilities have been based on grower and county extension agent suggestions. From 1997 to 2000, the use of weather data in grower decision making process increased from 52 percent to 90 percent of the potato production in Michigan (MPIC, 1997, 2000). Verification of the system, as compared to standard rate 7-day fungicide schedules, will continue for the next few years.

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Figure 1. Late blight (*Phytophthora infestans*) infection in the potato canopy at the MSU Muck Soils Research Farm. Symptoms include water-soaked lesions on leaves and stems leading to complete defoliation of the canopy.

Figure 2. Comparison of in-canopy and ambient air relative humidity from potato canopies at the MSU Potato Research Farm, Entrican, MI during the growing seasons of 1997, 1998, and 1999. Mean (●) and standard deviation (error bars) of ambient relative humidity are shown for each one percent interval of canopy air relative humidity (approximately 125 ambient values per canopy percentage). The grid lines are shown for clarity.

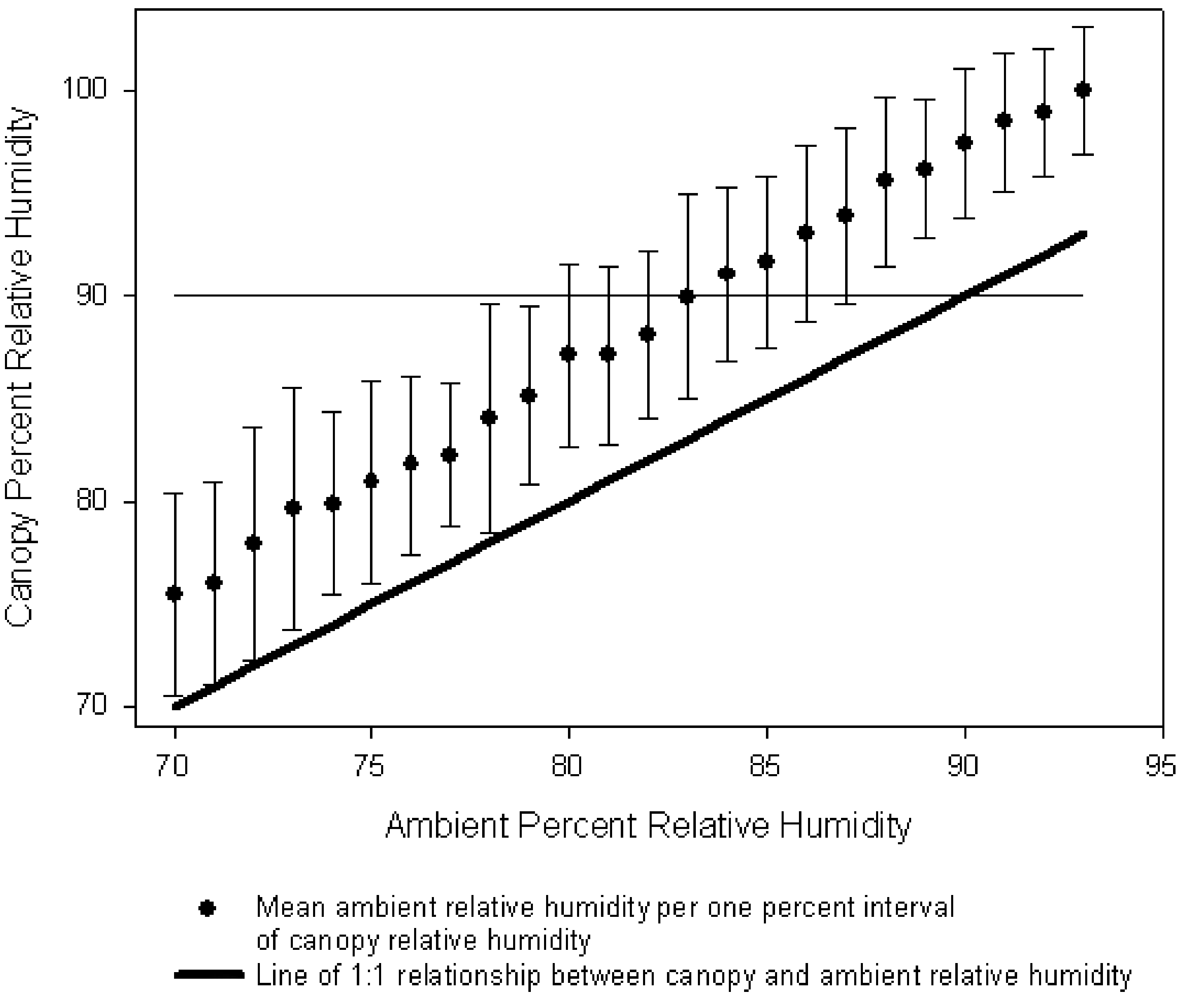
Figure 3. Disease severity value (DSV) accumulations for 1997, 1998, 1999 at Entrican MI. DSV were based on relative humidity thresholds of 90 percent in the canopy (●) and both 80 (●) and 90 (○) percent in the ambient air. DSV were accumulated in days after potato emergence and hilling, when sensors were placed in the canopy (approximately May 15-30).

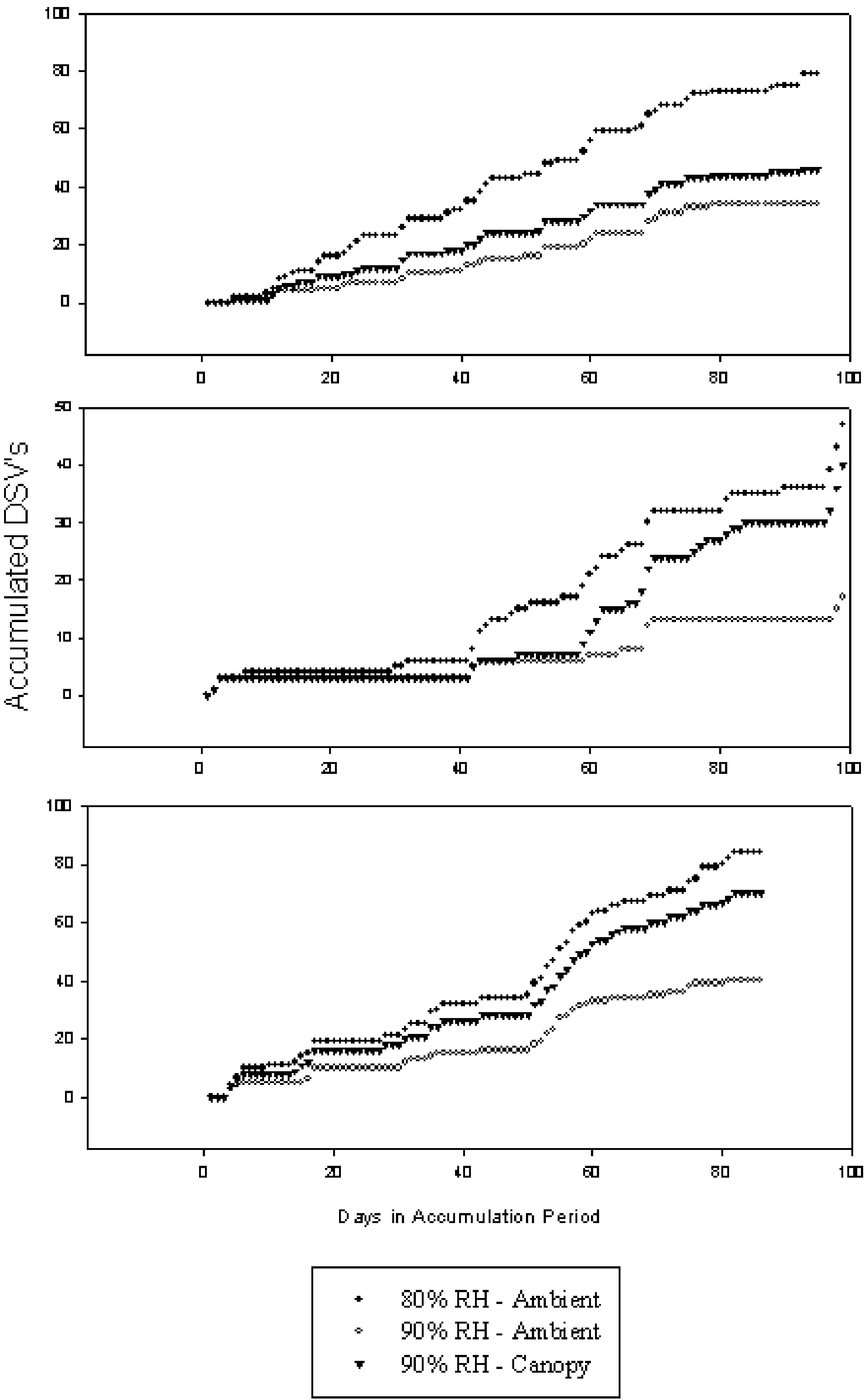
Table 1. Environmental parameters used for disease severity value (DSV) calculation [based on MacKenzie (1981)].

	Disease severity values for number of hours with 90% relative humidity				
Temperature	0 (none)	1 (minimal)	2 (slight)	3 (moderate)	4 (severe)
7.2-11.7 C (45-53 F)	< 16 hours	16-18 hours	19-21 hours	22-24 hours	n/a
11.7-15.0 C (54-59 F)	<13 hours	13-15 hours	16-18 hours	19-21 hours	22-24 hours
15.0–27.0 C(60-80 F)	<10 hours	10-12 hours	13-15 hours	16-18 hours	19-24 hours

Table 2. Environmental and geographic triggers and associated fungicide application recommendations for potato late blight.

Level	Environmental conditions	Geographic proximity	Application interval	Fungicide application recommendation
Green	7-Day total <= 3 - AND - Season total < 30	- AND – No known infection	7 days	Protectant: lowest label rate
Yellow	7-Day Total >= 3 - OR - Season Total > 30	- AND – No known infection	7 days	Protectant: highest label rate
Orange	7-Day Total >= 21	- OR – Infection in county	7 days	Protectant highest label rate – OR – Protectant + organotin during early senescence
Pink	Not relevant	Infection within 2-5 miles	7 days	Systemic full rate – OR – Protectant + high rate organotin
Red	Not relevant	Infection within 1 mile	5 days	Systemic full rate – OR – Protectant + high rate organotin


100
90
80
70
Canopy Percent Relative Humidity
70
75
80
85
90
95
Ambient Percent Relative Humidity
Mean ambient relative humidity per one percent interval of canopy relative humidity
Line of 1:1 relationship between canopy and ambient relative humidity



Accumulated DSV's
Days in Accumulation Period
100
80
60
40
20
0
0
20
40
60
80
100
50
40
30
20
10
0
0
20
40
60
80
100
100
80
60
40
20
0
0
20
40
60
80
100
80% RH - Ambient
90% RH - Ambient
90% RH - Canopy