This is a research project. The research is required to provide data to achieve the overall goal, which is: *to enable fungicides to be used more efficiently in late blight management.* Late blight is a major constraint in both potato production and in tomato production, so experiments will occur in both agro-ecosystems. The delivery mechanism for information is a web-based interactive Decision Support System (DSS) that provides information to growers in real-time. Experiments to expand and improve the DSS are proposed. Evaluations of the final DSS will be conducted in research plots on research farms and in demonstration plots on growers' farms. The improvements to the DSS include: i) expansion of the system to include tomato late blight as well as potato late blight; ii) expansion of the system to include effective fungicides of low environmental impact; iii) identification of the conditions calling for the "first" fungicide application in tomatoes; and iv) development of active alerts to be sent to users when "high risk" conditions occur.

Innovations and strengths of the DSS include:

- easy, automated access to highly specific historical weather
- easy, automated access to real-time "farm-specific" weather forecasts.
- easy, real-time access to traditional late blight forecasts using *forecast weather* as well as historical weather
- real-time, interactive access to predictions from a complex simulation model of late blight
- active alerts based on *proximity to a known source of the pathogen* as well as on weather

Decision Support System for tomato and potato late blight.

I. PROBLEM, BACKGROUND AND JUSTIFICATION

Problem: Tomato and potato late blights caused by *Phytophthora infestans* have re-emerged as the most devastating diseases afflicting tomatoes and potatoes. Both diseases are spectacularly explosive and if these become established on susceptible unprotected crops, significant crop loss is inevitable. The summer 2009 in the Northeast (Barber 2009) and recent production seasons in Florida provided the most recent examples of the explosive nature of this disease on both crops.

The disease is persistent in potato production because the pathogen has very effective mechanisms to persist between seasons (infected seed tubers, infected tubers that are discarded on farm, infected volunteers). Consequently, commercial potato growers are conditioned to expect late blight when the weather favors the disease and make “insurance sprays” even when there is no local source of inoculum. Thus, even when potato late blight has not been reported in their region, potato growers in rain-fed production areas such as in the eastern and Midwestern USA apply massive amounts of fungicide. For example in 2001 potato growers in the USA applied more than 2000 tons of active ingredients to suppress this disease (Anonymous 2004), but many of these sprays were not needed.

Tomato late blight is a chronic problem in tomato production in South Florida and has occurred in south Florida on tomato and potato every season since 1993 except once in 2003 (Roberts et al. 2008; Tombolato 2002; Weingartner and Tombolato 2002) . Environmental conditions in south Florida are generally favorable for late blight development with moderate temperatures and adequate nighttime durations of leaf wetness during the production season. Because of the high value of Florida tomatoes (>$800,000,000) fungicides are used intensively.

During the 2004-05 production season in Florida, a different late blight was recognized by growers who reported that the disease on tomato was very aggressive and fungicides were not nearly as effective to control the disease as compared to previous seasons. Similarly, growers along the northeast growing region of the US reported the same phenomenon later in the same season. Characterization of *P. infestans* isolates from tomato documented a new, unique genotype of *P. infestans* with apparently increased aggressiveness that confirmed field reports (Roberts et al. 2008; Schultz et al. 2006) (Deahl et al., unpublished). Subsequently, this genotype was not detected, however, characterization of tomato isolates from the past three years showed that they are also unique compared to previously documented *P. infestans* US clonal lineages and genotypes, and one appears to have been distributed as far north as Maine (unpublished results P. D. Roberts, W. E. Fry). Thus there is a likely connection between Florida tomatoes and late blight along the eastern seaboard. The mechanism by which this clonal lineage persists between seasons is currently unknown. The persistence of the pathogen and unpredictability of the disease has stimulated the use of much fungicide particularly on a preventative basis. Better tools to time fungicide applications are needed so that fungicide is used when needed and unnecessary applications are avoided.

Both potato and tomato late blight were severe during summer 2009 in Northeastern USA – for old and new reasons. The old reason was that potato tubers infected with the US8 strain initiated a few outbreaks on commercial potato production early in the season (unpublished results). However, tomatoes (and subsequently potatoes) were also at risk for a new reason – infected tomato transplants were sold in big box stores throughout the Northeast in mid-late June. These transplants were infected with the new "tomato" strain (detected in Florida), and when planted in home gardens initiated the pandemic. On both crops, improved forecasts and alerts are required to aid disease suppression. Our proposal will *make those forecasts and alerts readily available in real time*. We will modify and evaluate a prototype web-based decision support system (DSS). The DSS will be available to producers and advisors and will provide new resources to predict the need for intervention strategies. Since field production in Florida is ending when the northern regions are beginning production, improved communication and monitoring of the disease in tomato in Florida as outlined in this proposal will provide an extremely valuable early alert of the late blight potential along the east coast.

Background. *Phytophthora infestans,* the Irish potato famine pathogen, continues to devastate potatoes and tomatoes worldwide with global costs of billions of dollars annually (Fry and Goodwin 1997a; Haverkort et al. 2008)). Recent migrations of exotic strains have exacerbated a serious situation (Fry and Goodwin 1997b). The disease is a threat even in the dry, irrigated areas of the Pacific Northwest, because overhead irrigation creates an environment favorable to late blight. During some seasons losses have been staggering (Johnson et al. 2000; Johnson et al. 1997).

The decision support system (DSS) that we propose to modify and make available for real-time grower decisions is web-based, and links several models into a system that can be used to predict disease dynamics based on weather and management tactics. There are several innovations in this DSS: i) it automatically accesses a weather forecast that is essentially farm-specific (on a 2 km grid); ii) it includes the weather forecast as well as observed (historical) weather to inform a standard potato late blight forecast (Blitecast); iii) these weather data drive a simulation model of the late blight disease that also integrates the effects of host resistance and fungicide. The simulator thus provides a prediction of disease development seven days into the future as a function of future weather and future fungicide selected by the user. This interactive system will enable well-informed decisions about the use of fungicides which will lead to more effective and more efficient use of fungicide.

The DSS will have a significant education component. The user will be able to observe how late blight is affected by: i) diverse resistant cultivars; ii) proximity to an inoculum source; iii) diverse fungicides; and iv) diverse types of weather. Because resistant cultivars require less fungicide than do more susceptible cultivars (Fry 1978; Fry et al. 1983; Novy et al. 2006; Shtienberg and Fry 1990b; Stevenson et al. 2007), choice of a more resistant cultivar will enable a reduction in fungicide use. In this regard, we expect the DSS to be of particular value to organic growers. The relative resistances of many of the most popular potato cultivars grown in the Northeast have been quantified experimentally [see references such as (Forbes et al. 2005; Inglis et al. 1996)].

Characteristics of cultivars are currently part of the prototype DSS. Unfortunately, most commercially available tomato cultivars are quite susceptible.

The topics of this proposal fit many stakeholder priorities for the Northeast:

- The *"IPM Needs and Priorities for Vegetable Crops and Strawberries in the Northeast Region, 2009"* (http://northeastipm.org/work_vegpriority2009.cfm identifies tomato and potato late blight as "priority pests" for IPM research. (Phytophthora diseases of solanaceous crops have been identified consistently as important targets for IPM.)
- This proposal also targets new and re-emerging pests (i.e. late blight) as important subjects for effort (http://northeastipm.org/work_vegpriority2009.cfm).
- This proposal identifies improvements in "forecasting" and the use of modeling to aid pest management as high priority (http://northeastipm.org/work_vegpriority2009.cfm).
- The *Northeast Research, Extension, and Academic Program Committee for IPM (NEREAP)* priorities include: "Use of web-based technologies for IPM decision making." and "IPM packages for diversified, high value crop producers."
- *PMAP Priorities for FY 2007*: 5. "Develop IPM tactics for critical or emerging pests of regional or national magnitude".

Justification: Late blight of potatoes and late blight of tomatoes are diseases that require constant vigilance. Because of their unpredictable occurrence and devastating potential, growers often apply fungicide that is not necessary. On the other hand when either disease erupts, it can devastate susceptible crops that are unprotected. Thousands of tons of fungicide are used each year to suppress these diseases. Not surprisingly, there is increasing pressure on growers to reduce the amount of pesticide used. [For example, McDonalds announced in Spring 2009 that it will review pesticides and pest management practices on potatoes for fries (Alexander 2009).] Fuel and pesticide costs have caused potato growers in NY to seek mechanisms to safely reduce the number fungicide applications (Gary Mahany, Mahany Farms, personal communication). The proposed Decision Support System will enable growers to safely reduce the number of unneeded fungicide applications they apply and to reduce the environmental impact of their fungicides. This DSS is totally different from earlier simple disease forecasts for many reasons, but two are that: i) it uses future weather as well as past weather in assessing the need for a fungicide application and ii) it uses a mechanistic simulation model in "real-time" to illustrate the probable impact of future weather and future fungicide applications. The DSS has very strong educational value concerning the effect of weather and future fungicide applications.

As demonstrated in the recent 2009 outbreak, it is highly probable that late blight outbreaks in Florida impact the tomato production in northern states. The tie-in of Florida observations and action to decisions in the Northeast will not only be beneficial in determining late blight outbreak status and potential threat to these later northern plantings but will also foster sharing of state resources to mitigate this common problem.

II OBJECTIVES AND ANTICIPATED IMPACTS.

Our overall goal is to enable growers to reduce the environmental impact of fungicides used in their production systems. Reduction of the environmental impact of fungicides will occur both by choice of fungicide and by eliminating some fungicide sprays. The goal will be achieved via use of a Decision Support System (DSS). Achievement of several sub-objectives is necessary to achieve the overall goal.

Objectives:
1. Expand a web-based Decision Support System (DSS) for potato late blight management to also include tomato late blight.

2. Expand the DSS to include the effects of the most effective and environmentally benign fungicides currently available for suppression of potato late blight and tomato late blight.

3. Develop a conceptual model to predict the first occurrence in late blight in south Florida tomato production.

4. Develop an active function in the DSS to alert growers and pest management specialists to "high risk conditions".

5. Evaluate the potential of the expanded DSS to aid growers to reduce the environmental impact of their production practices.

Anticipated Impacts:
Fulfillment of the above objectives will have several impacts. The most important end result is that fungicides will be used when needed (and not when not needed) with an overall reduction in the amount of fungicide used. Clearly, the judicious use of fungicides supports the IPM initiative and decreases environmental and human health impacts, decreases the monetary input to produce the crop, and targets fungicide application for maximum effectiveness. The DSS will provide a tool for users to make disease management decisions based upon science-based disease information. In order to achieve this end result the grower or pest management specialist will become aware of the various factors that influence the diseases. Through experience with the DSS, users will become much more knowledgeable about the effects of weather on late blight development, about the impact of resistant cultivars on late blight development and about the effects of diverse fungicides on late blight development. The DSS enables farm-specific recommendations so that large producers will be able to tailor late blight suppression programs for specific farms with specific cultivars.

III. APPROACH AND PROCEDURES:

1. 1. Expand a web-based Decision Support System (DSS) for potato late blight management to also include tomato late blight.

Procedure. A prototype of the DSS has been constructed for potatoes. In order to provide context for the projected improvements, it is appropriate to describe the current situation. The prototype DSS is available at (http://blight.eas.cornell.edu/blight_dev/). [Reviewers can access the system using an ID name of "reviewer" and a password of "ne-ripm". A reviewer can evaluate the system at this web-site. The URL takes one to archived weather (2008 season and 2009 season). Additionally, each weather forecast for each day is also archived. The website is currently using weather data from the Cornell University Thompson Research Farm located near Ithaca.] Sample screens from the 2009 production season in New York are illustrated in the addenda. The DSS uses color in several respects. For example, predictions based on historical weather data are presented in the color green, whereas predictions based on weather forecasts are presented in the color red. Because of the dominant effect of weather on late blight, weather data are dominant drivers of the system. In real time, the DSS obtains historical weather from the weather station nearest the production field (identified by longitude and latitude or by GPS coordinates.) Some growers in NY have purchased their own weather stations and because they are tied into the Northeast Weather Association (NEWA) the historical weather come from their own farms. In addition to historical (observed) weather, the system also obtains a weather forecast from the National Weather Service. The weather forecast is obtained from a grid that is about 2 km between points. Thus the weather forecast can be very specific to a given production field. Relative humidity and temperature are forecast seven days into the future, but rainfall is forecast only three days into the future – due to high uncertainty associated with rainfall. Typical weather data are illustrated in the addenda.

The forecast weather data can be used to predict future disease development. The most accurate integrator of the diverse influences is a mechanistic simulation model (Andrade-Piedra et al. 2005a; Andrade-Piedra et al. 2005b; Andrade-Piedra et al. 2005c) that is available via the DSS. Because late blight on tomato is influenced by weather conditions in the same way as is potato late blight (Becktell et al. 2005a; Becktell et al. 2005b; Becktell et al. 2006), the simulation model (adjusted for host resistance) can also predict future late blight development on tomato.

The weather data are used in several ways. First, the historical weather data are used to drive conventional late blight forecasts e.g. Blitecast, (Krause and Massie 1975), or Simcast (Grünwald et al. 2002). Second, and differently from other systems, the weather forecasts are used to make predictions as to what these disease forecasts will state up to seven days into the future. Thus if a grower is using one of these systems, the DSS will enable a prediction of what the forecast will indicate up to seven days into the future.

The simulation model also reflects the effects of the fungicide chlorothalonil via additional algorithms (Bruhn and Fry 1982a; Bruhn and Fry 1982b). One output is a prediction of the average residue of chlorothalonil on potato foliage (see addendum). Thus the simulation model integrates the effects on late blight development of past and future weather, host resistance and past and future chlorothalonil applications. These outputs are available as a disease progress curve or as a listing of model output.

Procedure: Epidemics of tomato late blight in Florida will be analyzed for the impact of weather on disease development using historical data (unpublished, P.D. Roberts) and also via experiments to be conducted during the 2009-2010 and 2010-2011 production seasons. Small plots (6 m x 6m) with six replications will be used. The plots will be monitored for late blight development, will be inoculated as soon as late blight is observed in the area and will be assessed as previously described (Smart et al. 2007). Using these data, the DSS will be adjusted to include tomatoes as a host (choice of host/resistance is currently a variable in the DSS).

2. Expand the DSS to include the effects of the most effective fungicides currently available for suppression of potato late blight and tomato late blight.

Procedure: Both PIs have data on the effectiveness of fungicides, and these data will be used to modify the DSS to include the effects of these additional fungicides. For potato the additional fungicides include copper and Oxidate (available for organic producers), Revus Top, Ranman, Previcur Flex, and Gavel. For tomato, in addition to those previously listed we will include Presidio, Tanos, Curzate, Quadris and Evito. Most of these fungicides have low toxicity to non-target organisms (e.g. mammalian LD50 values in the range of 2000-5000 mg/kg) and low environmental impact (Kovach et al. 2009).

Additionally, both PIs will specifically include these fungicides in field trials to validate model predictions. The potato trials will be conducted at the Thompson Vegetable Research Farm near Ithaca NY using techniques previously described (Shtienberg and Fry 1990a). Weather data required to drive the models will be acquired and plots will be assessed two-three times per week for late blight development. The experimental design will be a replicated complete block with four replications. Plots will be planted very late (early July) so that the plants will still be vigorous at the end of the normal season (when they will be inoculated if there is no naturally occurring late blight). Fungicides will be applied weekly at label rates.

Tomato trials in Florida will be conducted in the late fall and early spring season to potentially target both the initial outbreak occurring any time from November to February and the persistence into the spring crop. Experiments will be conducted at the research station in Florida essentially as described above using a randomized complete block with four replications and weekly fungicide sprays. Plants in plots will be observed weekly until detection of symptoms of late blight and then assessed for disease severity at 2 to 3 day intervals. The differences between means for disease severity or area under the disease progress curve (AUDPC) will be analyzed by ANOVA using SAS and means tested by LSD.

3. Develop a conceptual model to predict the first occurrence in late blight in south Florida tomato production.

Procedure: While there are predictions in potato disease forecasts (e.g. Blitecast and most others) of a period of time before which fungicide applications are unnecessary, there are no such predictions for tomato late blight. Although this is not explicitly stated, potato late blight forecasts assume that it takes quite some time for infected tubers to initiate foliar infections, and prior to this event, foliar fungicide applications have no beneficial effect. The source of inoculum in the tomato production system remains unknown; tomato seed is not considered to be an inoculum source. However, we will investigate if there is also a period of time in the tomato production system of south Florida before which foliar fungicides are unnecessary. The influence of regional weather patterns in South Florida will be compared to the first reports of late blight occurrence on tomatoes to determine if correlations between weather variables and first occurrences can be detected. The date of first detection in south Florida has been recorded yearly since 1998 (Roberts et al. 2008) and historical weather data including temperature, rainfall, windspeed, relative humidity, dewpoint, and other parameters for these years will be obtained from the Florida Automated Weather Network (FAWN http://fawn.ifas.ufl.edu/). Additionally, Blitecast will be evaluated to determine if this disease forecast can be applied usefully to the tomato production system. If neither of these approaches is successful, we will identify a period of favorable weather that will result in successful infection and reproduction of *P. infestans* and use this weather to define the time after planting at which the initial fungicide application should be made. Of particular interest is the role of rain events in triggering late blight outbreaks.

4. Develop an active function in the DSS to alert growers and pest management specialists to "high risk conditions".

Procedure. The prototype of the DSS does not contain an "active" function to warn a user of "high risk conditions", so we propose to include a function that will *actively* alert a user to any of several "high risk" situations. There will be two types of active alerts: i) an automated e-mail alert and ii) a pop-up message when the user logs on to the system. There are three types of "high risk conditions". The first is triggered by observed weather that identifies the first spray of the season (18 severity values in Blitecast). The second will be a prediction of the first spray of the season using weather criteria, but driven by the weather forecast in conjunction with observed weather. The third active alert will be triggered by weather known to favor sporulation, dispersal and infection, so that if a source of the pathogen is in the region, an "*inoculation alert*" will be posted. The algorithm for this alert will be generated from unpublished data (H. S. Mayton and W. E. Fry) that quantify the number of sporangia that are released from a source (illustrated in Figure 1). It has been determined previously that dispersal is stimulated by a strong decrease in relative humidity after a night of very high relative humidity. However, our data enable us to develop semi-quantitative relationships, so that at least order of magnitude predictions can be derived. Additionally, we know that bright sunlight is likely to kill sporangia in transit (mean survival time < 15 min) ((Mizubuti et al. 2000)), but that sporangia dispersed during cloudy weather have a much longer survival time (mean survival time > 180 min) (Mizubuti et al. 2000). Using these relationships we will construct models that predict the likelihood of viable sporangia arriving at a target field if the source of late blight is known. These models will also enable semi-quantitative estimates of the numbers of sporangia that might arrive and the probability that these will initiate infections. These models will be used to construct the "*inoculation alert*". Because the DSS uses forecast weather, we will also identify probable "*inoculation alerts*" seven days into the future. The "*inoculation alert*" will be constructed so that the user can adjust it to account for proximity to a known source of the pathogen. For example, sources within a kilometer of a production field will produce higher "*inoculation alerts*" than sources 10 km distant.

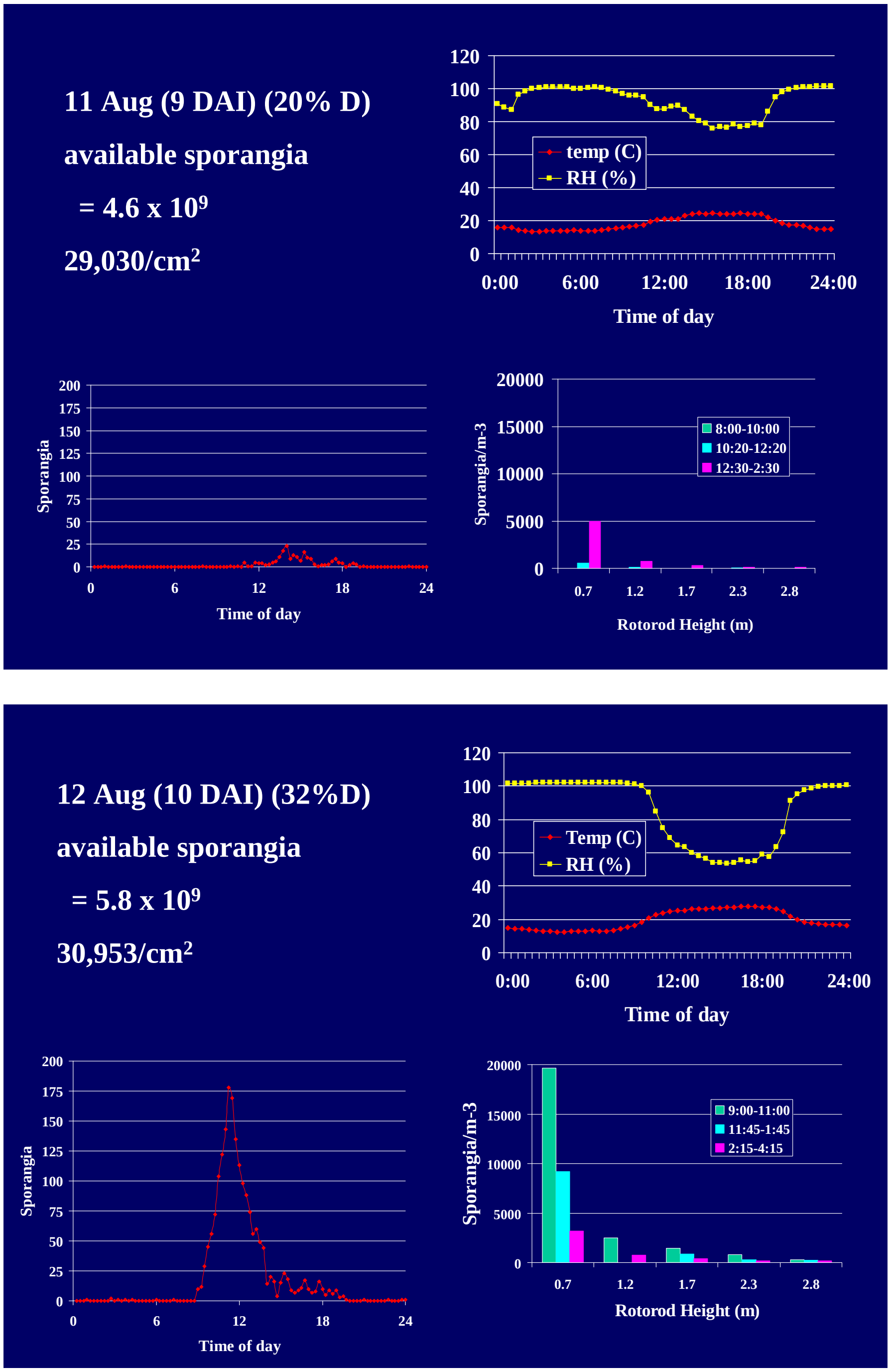

Figure 1 Dispersal of *P. infestans* sporangia from a source on a cloudy day (top) and a sunny day (bottom). The number of available sporangia on lesions was obtained by counting sporangia from a sampling of lesions in the source and then estimating the number of lesions in the source by counting the number of lesions in a small area and then expanding this to the total source. The number of sporangia released (sporangia per cubic meter of air) was obtained from rotorod spore samplers placed at 0.7, 1.2, 1.7, 2.3 and 2.8 m above the soil. (The canopy was about 0.7 m.) The dynamics of sporangia release were obtained using a Burkhard spore trap.

5. Evaluate the potential of the expanded DSS to aid growers to reduce the environmental impact of their production practices.

Procedure. Two types of evaluations will be conducted in each of the agro-ecosystems. The first type of evaluation will be in research plots -- in south Florida on tomatoes, and in upstate NY on potatoes. The plots will be treated with fungicide using decisions informed by the DSS or according to standard grower practice. Disease suppression and fungicide use will be compared to these in untreated plots and to these in plots treated according to standard grower practice. These plots will be larger (10m x 10m) than those that we use for standard fungicide evaluations and will be separated from each other by at least 10 m. Again, the experiments will use a randomized complete block design, with four replications. Experiments in research plots will occur in the tomato production system in 2010-2011, and in the potato system in upstate NY in summer 2010.

The second type of evaluation will occur on growers' farms. Two conventional tomato growers in south Florida and two conventional potato growers and two organic growers in NY will each use the DSS to inform their late blight suppression activities. These evaluations will be conducted on tomatoes in 2011-2012, and on potatoes in the summer 2011. We will compare grower results (disease suppression, amount of fungicide used, and environmental impact of fungicide) using the DSS, with that of their standard practice (or with that of their non-DSS user neighbors). The DSS is theoretically applicable any place in the USA, but it will need to be adjusted to enable the acquisition of historical weather data, and also to obtain weather forecasts. Dr. Art Degaetano will be responsible for assuring that the DSS will work appropriately in Florida.

Timetable

Objective	Task	completion date
1. include tomato late blight into DSS	a. Record epidemics in tomatoes and associated weather b. adjust simulator (programming) to reflect late blight in tomatoes	a. spring 2011 b. spring 2011
2. include additional fungicides into DSS	a. record effects of diverse fungicides on potato late blight and tomato late blight b. adjust simulator (programming) to reflect effects of additional fungicides on potato and tomato late blight.	a. fall 2010 (potato) spring 2011 (tomato) b. spring 2011
3. develop conceptual model of tomato late blight first occurrence in FL	Compare historical occurrences of first appearance of late blight with weather patterns to associate particular weather patterns with first occurrences	Late spring 2011
4. incorporate active "alerts" into the DSS	a. analysis of unpublished experiments to construct the "inoculation alerts". b. adjust DSS to actively inform users of "high risk conditions" (programming)	a. spring 2011 b. spring 2010
5. evaluate potential impact of improved DSS on environmental impact of late blight management	a. evaluate the DSS under stress test (disease present) conditions in research plots. b. evaluate the DSS under grower conditions (disease may not be present)	a. fall 2011 (potato) b. spring 2012 (tomato)

IV. EVALUATION PLAN.

The overall goal of this project is to reduce the environmental and economic impact of fungicides used in the management of late blight on potatoes and tomatoes while maintaining excellent suppression of late blight. This goal will be achieved using the improved Decision Support System (DSS). A prototype of the DSS has been constructed and initial reactions from growers have been recorded and some suggestions have been incorporated into the prototype. However, several changes are required to convert the DSS into a more useful tool in integrated management of potatoes and tomatoes. These modifications are identified in objectives 1-4. Accomplishment of these objectives will be evident when the DSS is modified as suggested. Comments about each objective are as follows:

Objective 1 is to expand the prototype web-based Decision Support System (DSS) to include tomato late blight as well as potato late blight. Success in achieving this goal will be determined by comparing epidemics of tomato late blight in small research plots in Florida with predictions generated from the modified simulation model in the DSS. Disease progress observed in research plots will be compared to simulated disease progress curves generated by the DSS. In a similar manner, epidemics of potato late blight in small research plots in upstate NY will be compared to predictions from the DSS. Model predictions that are similar to observed epidemics [as done by Andrade-Piedra et al, (Andrade-Piedra et al. 2005b)] will be evidence of success. Most of the modifications will be accomplished by a programmer with guidance from W. Fry.

Objective 2 is to expand the DSS to include the effects of the most effective and environmentally benign fungicides currently available for suppression of potato late blight and tomato late blight. The DSS currently models only chlorothalonil, a fungicide with a high environmental impact (Kovach et al. 2009). Other fungicides to be included will have much less environmental impact. Success in achieving objective 2 will require two steps. The first is to incorporate the effects of such fungicides into the DSS. Data on which the programming will be based will be provided by the two PI’s. The programming will be accomplished at Cornell under the guidance of W. Fry and will be achieved when a functional model is completed. The second step is to demonstrate that the models simulate the system accurately. This demonstration will be achieved when the model predictions using the additional fungicides are shown to be similar to observed epidemics of tomato late blight or of potato late blight against which the newly incorporated fungicides are used. Comparison of observed epidemics in field plots to simulations are scheduled for Florida (tomatoes) and NY (potatoes).

Objective 3 is to develop a conceptual model to predict the first occurrence of late blight in south Florida tomato production. If a relation between first occurrence of late blight is associated with particular weather patterns, then that relationship will be incorporated into the DSS, and this will signal success in achieving the goal. However, achievement of this goal may be elusive because there may be too few data, i.e. there may be too few years in which the first occurrence of late blight on tomato can be compared to particular weather patterns. In that event, we will publicize the first occurrence of late blight broadly through the growing region and subsequent management efforts will be informed by the use of "inoculation alerts" (described in objective 4).

Objective 4 is to develop an active function in the DSS to alert growers and pest management specialists to "high risk conditions". The alerts will be both automated e-mail messages and pop-up messages when a user logs in to the system. The "*blight favorable weather*" alerts are already defined, and the "*inoculation alerts*" will be developed as described above. Evaluation of the algorithm will be more difficult. Experimental evaluation may be economically impossible because of the very large scale on which such an experiment would have to be constructed. Additionally, because knowledge of all sources of *P. infestans* in a region is never absolute, any experimental or *post facto* analysis is by definition incomplete. However, if the algorithm is logical and fits the data from which it was constructed, and if it fits known situations, then we will have confidence to use it as a guide in the DSS for adjusting the intensity of intervention.

The foregoing objectives and procedures are all directed at enhancing and improving the DSS. The most important aspect is to determine the degree to which additional and "real-time" information about weather, cultivar resistance, and fungicide effect provided by the DSS will enable growers to reduce the environmental impact of fungicides while maintaining appropriate suppression of late blight. Therefore, the final objective of this proposal addresses that goal. It is: "*5. Evaluate the potential of the expanded DSS to aid growers to reduce the environmental impact of their production practices*." Evaluations are planned under stress (disease) conditions in research plots and under commercial grower conditions. We will measure the amount of fungicides used, the environmental impact of those fungicides and the degree of disease suppression in the research plots treated according to standard grower practice and in those treated as informed by the DSS. Decrease in the amount of fungicide used, decrease in the environmental impact of the fungicide used and grower-acceptable disease suppression in the DSS plots compared to the plots treated according to standard grower practice will be indicators of success. We will also evaluate use of the DSS by commercial growers by comparing their fungicide use (amount and environmental impact) with that of their neighbors and by asking their degree of satisfaction (or frustration) with the program. However, we cannot assure that these commercial growers will experience late blight, and so these evaluations may occur under disease-free conditions.

While the small number of evaluations allowed under this proposal is obviously a tiny subset of the range of conditions experienced by potato growers and tomato growers, these evaluations are a very positive start. Success in these evaluations will lead to increased interest among potato and tomato growers and will support more ambitious outreach subsequently. Our plan to include organic growers in the evaluation plan and to include Oxidate and copper based-fungicides in the DSS provides an avenue to reach a very active and vocal audience that mobilizes public opinion.

The DSS is potentially applicable to any potato or tomato production system in the continental USA. The simulation model is mechanistic and is not specific to any particular agro-ecosystem (Andrade-Piedra et al. 2005c). Additionally, no other feature of the DSS is regionally specific. Because both potato and tomato late blight can be, and have been, problematic in most of these tomato- and potato-production systems, the DSS could have a very major impact if applied throughout the country. Therefore, the joint development and testing of the DSS for tomato at the two geographically diverse locations in this proposal will also help determine the feasibility or potential applicability of using DSS throughout the US. Weather forecasts are available throughout the country on-line, and local, on-farm weather stations can be tied into the system. Thus benefits from the using the DSS are potentially broadly available.

A logic model for this project is the following:

Inputs:

- Money
- People (meteorologists, technical staff, research staff, farm staff, programmers and extension staff).

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Audience (potato and tomato growers) Activities:

- use and evaluation of the DSS interface
- thinking about integrated disease management
- presentations at grower meetings
- observation of plots (fields) treated according to the DSS and standard grower practice

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Short term impact:

- decreased environmental impact of fungicides in the target production areas
- decreased use of fungicide compared to standard grower practice
- increased awareness by growers and field managers of environmental impacts of fungicides
- increased awareness by growers and field managers of impacts of host resistance
- increased awareness by growers and field managers of impacts of future weather
- increased awareness and interest in the DSS by growers and field managers.

V Key Personnel:

W. E. Fry : PI.
Responsibilities include oversight of the DSS modifications, conceptual changes and development of new models and algorithms, acquisition of new data concerning fungicide effects on potato late blight, oversight of developing “high risk alerts” in the DSS; evaluation of simulator predictions in research plots, evaluation of the DSS in research plots and evaluation of the DSS in grower applications.

P. D. Roberts: Co-PI:
Responsibilities include evaluating fungicide efficacy to suppress tomato late blight in Florida; development of a conceptual model for the “first occurrence” of tomato late blight in the Florida production system; evaluation of the DSS to suppress tomato late blight in research plots; evaluation of the DSS in commercial tomato production in Florida.

A. Degaetano, Collaborator:
Responsibilities include adjusting the DSS for application in Florida

M. McGrath, Collaborator
Evaluation of the DSS in commercial (conventional and/or organic) tomato and potato production on Long Island, NY

T. A. Zitter, Collaborator
Evaluation of the the DSS in commercial (conventional and/or organic) potato and tomato production in upstate NY.

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Appendix: Screens from the web-based DSS

Typical "weather" screens from the Decision Support System using data from 2009 at the Thompson Research Farm, near Ithaca NY.

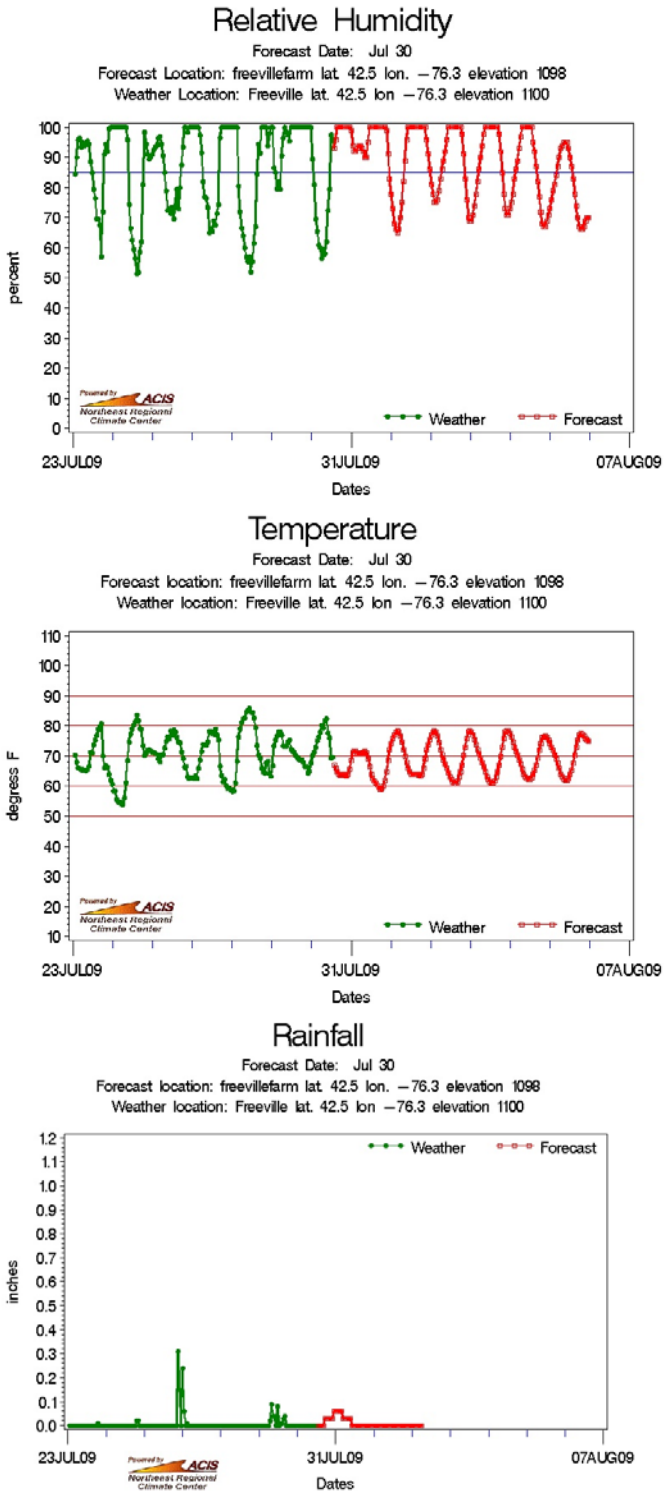
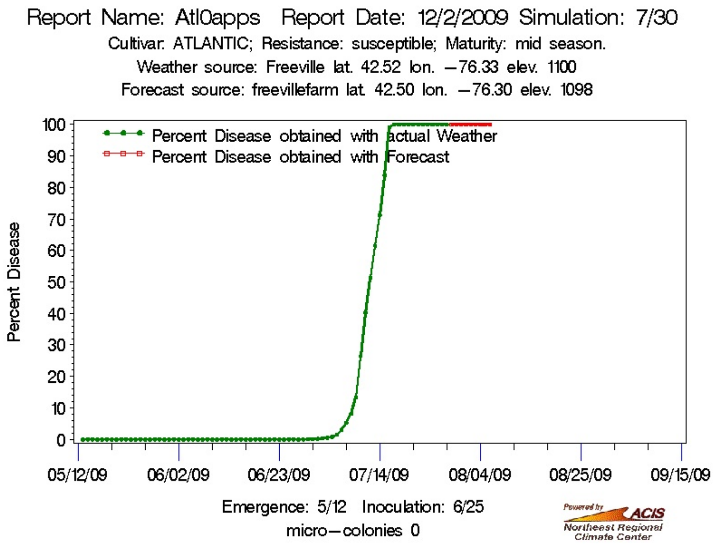
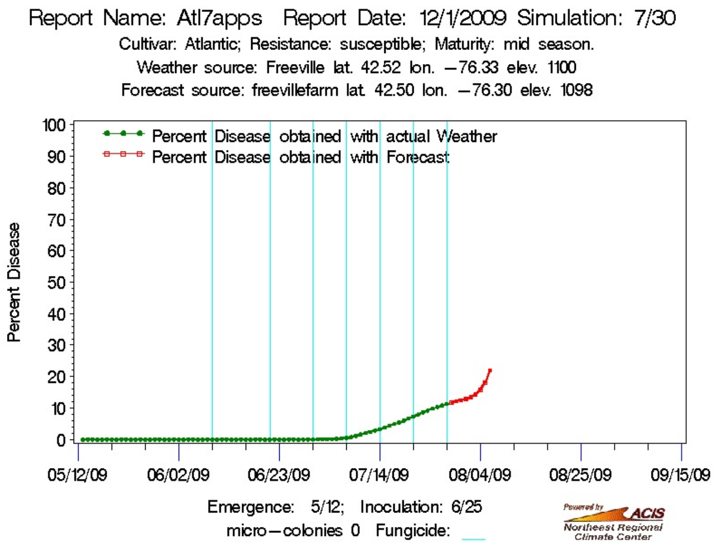
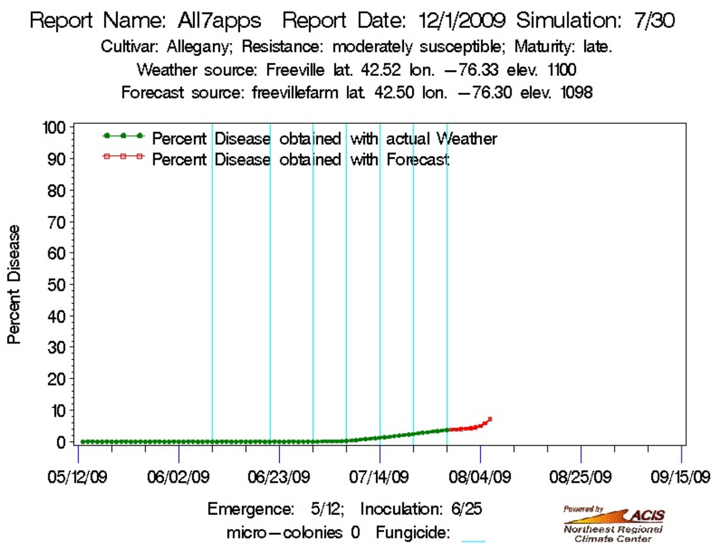


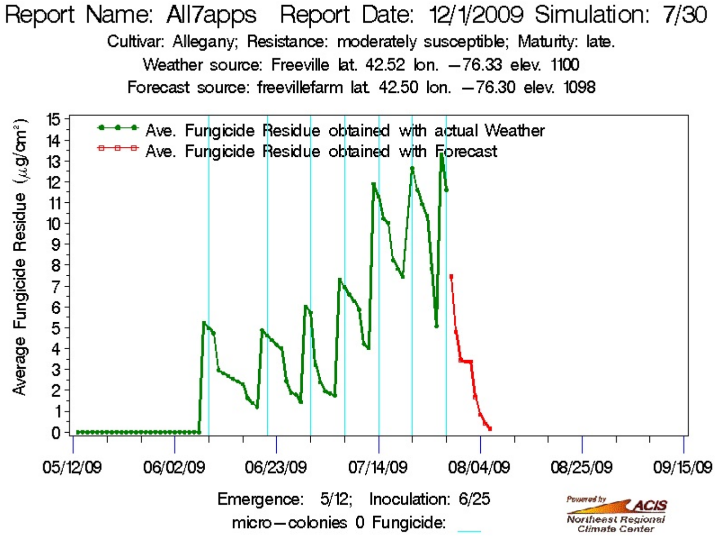
Figure 1. Weather data for 30 July 2009 at the Freeville Farm near Ithaca NY. The traces in green are observed data from the nearest weather station (on farm), and the red traces are predictions from the National Weather Service. These data are used to drive traditional disease forecasts. Some of the users during summer 2009 checked the weather almost daily.







Disease progress curves predicted by the DSS simulator using data for summer 2009 at the Thompson Vegetable Research Farm near Ithaca NY. The top two graphs illustrate predicted late blight in the susceptible cultivar Atlantic without (above) and with (middle) fungicide applications. The fungicide applications are indicated by the vertical lines. The green traces were obtained using historical (observed) weather, whereas the red lines were obtained using weather forecast on 30 July. The bottom graph illustrates the effect of the greater resistance in the cultivar Allegany compared to Atlantic.



Fungicide (chlorothalonil) dynamics on potato foliage as predicted by the simulator. The green lines were generated using observed (historical) weather, and the red lines were generated using forecast weather.

Freeville/freevillefarm: BliteCast Report

http://blight.eas.cornell.edu/blight_dev/blightDev_den

Blitecast Severity Values

Observed Weather: (5/12/2009 to 7/30/2009) Location: Freeville

Forecast Weather: (7/30/2009 to 8/6/2009) Location: freevillefarm

Simulation Date: 7/30/2009

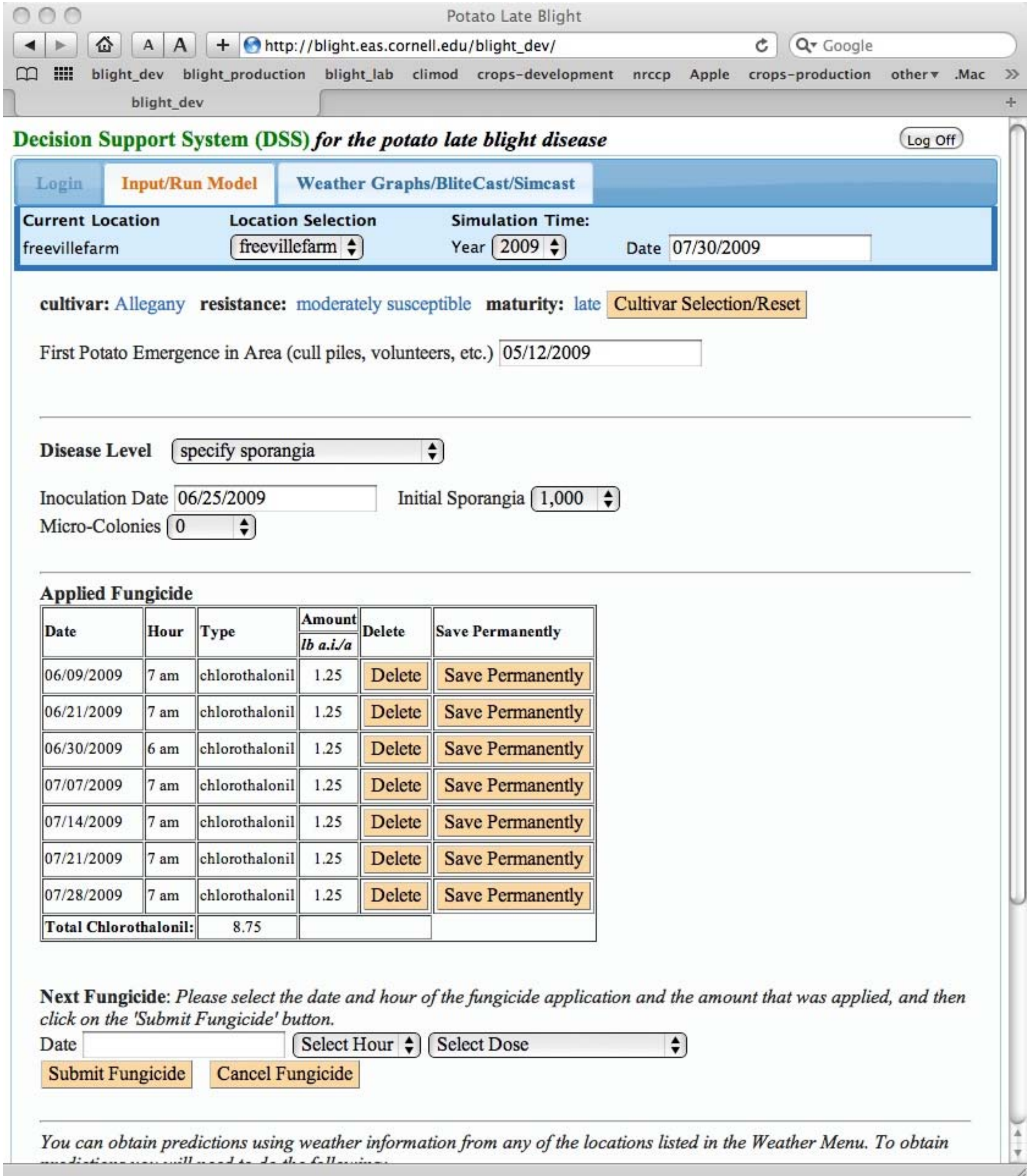
color legend:	white background: actual Temperature, Relative Humidity	beige: forecast Temperature, Relative Humidity	red letters: season's 1st disease forecast alert	orange letters: subsequent disease forecast alerts	green: fungicide application

BliteCast rules:

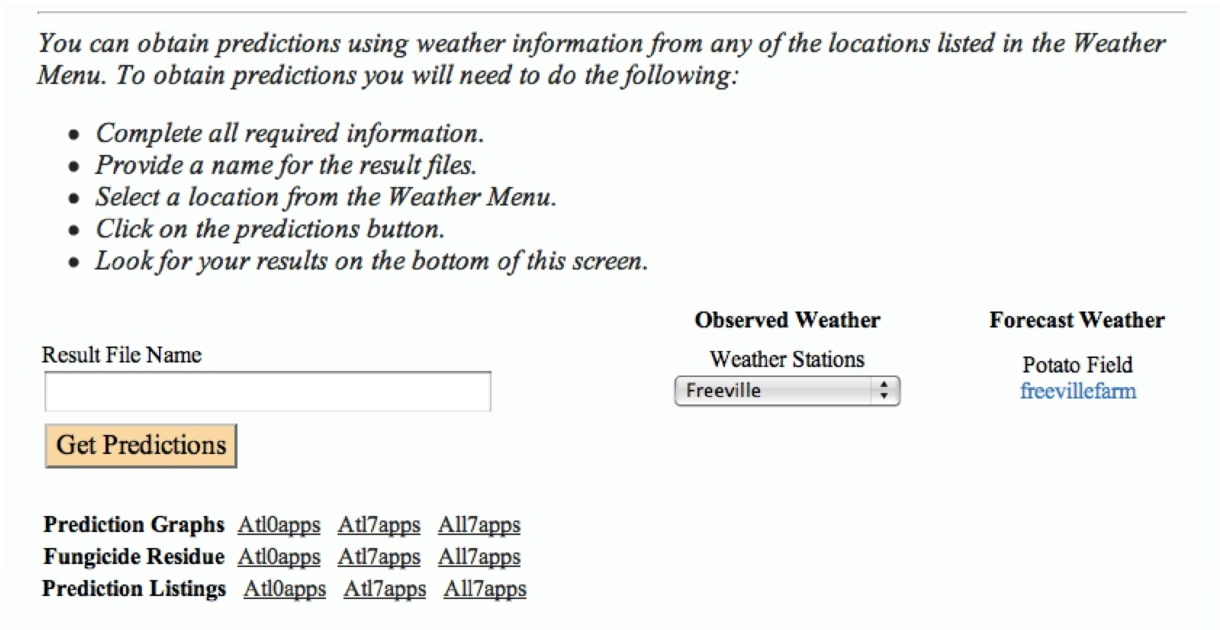
- season severity of 18 identifies need for the first fungicide application.
- an accumulated severity value of 7 after a fungicide application identifies the need for a subsequent fungicide application

Fungicide Date	Wet periods			Ave Temp(F)	Severity Values		
	start	end	hrs.		daily	accum. since last fung. appl.	season accum.
	8/6 1 am	8/6 9am	8	63	0	20	98
	8/4 11pm	8/5 10am	11	64	1	20	98
	8/3 10pm	8/4 12noon	14	65	2	19	97
	8/2 11pm	8/3 12noon	13	64	2	17	95
	8/1 10pm	8/2 1pm	15	66	2	15	93
	§ 7/31 9pm	8/1 11am	14	63	3	13	91
	§ 7/30 9pm	7/31 9pm	24	68	5	10	88
	7/29 1pm	7/30 9am	20	70	4	5	83
	7/28 10pm	7/29 8am	10	67	1	1	79
7/28 7am	7/27 9pm	7/28 9am	12	61	1	0	78
	7/26 9pm	7/27 10am	13	65	2	9	77
	7/26 12mid.	7/26 9am	9	70	0	7	75
	7/25 8pm	7/25 11pm	3	71	0	7	75
	7/24 6pm	7/25 10am	16	60	3	7	75
	7/24 12mid.	7/24 9am	9	66	0	4	72
	7/22 9pm	7/23 10am	13	68	2	4	72
	7/21 8pm	7/22 11am	15	62	2	2	70
	7/21 6pm	7/21 7pm	1	66	0	0	68

Blitecast report from 30 July 2009 for the Thompson Vegetable Research farm near Ithaca NY. Each time a fungicide application is made (green shading), the Severity Values are adjusted back to zero. The total number of Severity Values accumulated in the season is also indicated.



Main page (top) in the Decision Support system on 30 July 2009 for the Thompson Vegetable Research farm (Freeville Farm), near Ithaca NY. This screen illustrates that one can choose cultivar (and its resistance level). For simulation purposes, one can adjust the occurrence (and amount) of late blight. In this screen, inoculation occurred on 25 June. Also in this screen, chlorothalonil has been applied 7 times. The bottom half of the screen follows on the next page.



Main page (bottom) of the Decision Support System. Three simulations have been conducted and a disease progress curve (prediction graph), fungicide residue graph, and listing of the values in the simulator (not shown) are all available for each simulation. These are available by by clicking on the title of the report. The three disease progress curves on the first page of this addendum are the three "prediction graphs" listed on this page.

Project Directors: Bill Fry (Cornell University), Pam Roberts (University of Florida).
Collaborators: Art Degaetano, Meg McGrath, Tom Zitter (all at Cornell).

Project Title: Decision Support System for tomato and potato late blight.

Project Type: Research

Project Summary: This is a research project. The research is required to provide data to achieve the overall goal, which is: *to enable fungicides to be used more efficiently in late blight management.* Late blight is a major constraint in both potato production and in tomato production, so experiments will occur in both agro-ecosystems. The delivery mechanism for information is a web-based, interactive Decision Support System (DSS) that provides information to growers in real-time. Experiments to expand and improve the DSS are proposed. Evaluations of the final DSS will be conducted in research plots on research farms and in demonstration plots on growers' farms. The improvements to the DSS include: i) expansion of the system to include tomato late blight as well as potato late blight; ii) expansion of the system to include effective fungicides of low environmental impact; iii) identification of the conditions calling for the "first" fungicide application in tomatoes; and iv) development of active alerts to be sent to users when "high risk" conditions occur. Innovations and strengths of the DSS include:

- easy, automated access to highly specific historical weather
- easy, automated access to real-time "farm-specific" weather forecasts.
- easy, real-time access to traditional late blight forecasts using *forecast weather* as well as historical weather
- real-time, interactive access to predictions from a complex simulation model of late blight
- active alerts based on *proximity to a known source of the pathogen* as well as on weather

Problem: Tomato and potato late blights caused by *Phytophthora infestans* have re-emerged as the most devastating diseases afflicting tomatoes and potatoes. Both diseases are spectacularly explosive and if these become established on susceptible unprotected crops, significant crop loss is inevitable. These diseases are likely wherever potatoes or tomatoes are grown. The summer 2009 in the Northeast (Barber 2009,New York Times) and recent production seasons in Florida have provided the most recent examples of the explosive nature of this disease on both crops. Commercial potato growers are conditioned to expect late blight when the weather favors the disease. Thus, even when potato late blight has not been reported in their region, potato growers in rain-fed production areas (such as in the eastern and Midwestern USA) apply massive amounts of fungicide. For example in 2001, potato growers in the USA applied more than 2000 tons of active ingredients to suppress this disease. Tomato late blight is a chronic problem in tomato production in South Florida and except for 2003, has occurred in south Florida on tomato and potato every season since 1993. Because of the high value of Florida tomatoes (>$800,000,000) fungicides are used intensively.

Background. Both diseases were severe during summer 2009 in Northeastern USA. Commercial growers in New York spent millions of dollars in 2009 to suppress this disease (personal communication from several growers in New York). Furthermore, organic growers and home owners either lost their crops or used large amounts of materials to suppress these diseases. On both crops, improved forecasts and alerts are required to aid disease suppression. One objective of this proposal is *to make those forecasts and alerts readily available in real time*. We will modify and evaluate a proto-type web-based decision support system (DSS). Growers at a meeting in upstate New York on 8 December 2009 indicated that they wanted a prototype of the DSS to be available to all growers in the state for the 2009 production season. We're working on making the prototype available to producers and advisors. However, the modifications we propose will improve the DSS quite significantly. Our efforts in this proposal are a proof of concept, but with that proof of concept the DSS can easily be extended to any production system in the USA. Since field production in Florida is ending when the northern regions are beginning production, improved communication and monitoring of the disease in tomato in Florida will provide an early alert to the late blight potential along the east coast.

The prototype DSS is available at (http://blight.eas.cornell.edu/blight_dev/). [Reviewers can access the system using an ID name of "reviewer" and a password of "ne-ripm". The URL takes one to archived weather (2008 season and 2009 season). Additionally, each weather forecast for each day is also archived. The website is uses weather data from the Cornell University Thompson Research Farm located near Ithaca.] Because of the dominant effect of weather on late blight, weather data are dominant drivers of the system. The DSS obtains historical weather data from the weather station nearest the production field and it obtains a weather forecast from the National Weather Service. The weather forecast is obtained from a 2km grid, and is thus very specific to a given production field.

Stakeholder priorities: This proposal fits many stakeholder priorities. For example i) *Phytophthora infestans* is a "priority pest", and the disease it causes (late blight) is a re-emerging disease; ii) the proposed research deals with forecasts and the use of models in IPM; the proposal deals with web-based technology; and the late blight disease is a national problem.

Justification: Large amounts of fungicide are used each year to suppress potato late blight and to suppress tomato late blight – often with weekly sprays. There is pressure from many sources to reduce the amount fungicide released into the environment. Even McDonalds has announced that it will review pesticides and pest management practices on its potatoes. Growers want to reduce the amount of fungicide because of environmental, economic and health concerns. The DSS that we propose to modify and evaluate will facilitate knowledgeable reduction of the number of applications and reduction of the environmental impact of fungicides used to suppress late blight.

Objectives: The overall goal is to enable growers to reduce the number of applications and to reduce the environmental impact of fungicides to suppress late blight. There are five sub objectives: 1. Expand a web-based Decision Support System (DSS) for potato late blight management to also include tomato late blight. 2. Expand the DSS to include the effects of the most effective and environmentally benign fungicides currently available for suppression of potato late blight and tomato late blight. 3. Develop a conceptual model to predict the first occurrence in late blight in south Florida tomato production. 4. Develop an active function in the DSS to alert growers and pest management specialists to "high risk conditions". 5. Evaluate the potential of the expanded DSS to aid growers to reduce the environmental impact of their production practices.

Anticipated outcomes: The most important outcome is that fungicides will be used when needed and not when not needed with an overall reduction in the amount of fungicide used. Clearly, the judicious use of fungicides supports the IPM initiative and decreases environmental and human health impacts, decreases the monetary input to produce the crop, and targets fungicide application for maximum effectiveness. The DSS will provide a tool for users to make disease management decisions based upon science-based disease information. Through experience with the DSS, users will become much more knowledgeable about the effects of weather on late blight development, about the impact of resistant cultivars on late blight development and about the effects of diverse fungicides (including materials available to organic growers) on late blight development. The DSS enables farm-specific recommendations so producers will be able to tailor late blight suppression programs for specific farms with specific cultivars. The DSS is scale neutral, so that stakeholders with small operations will derive as much benefit as stakeholders with large operations. It will also be as useful to organic growers as it is to conventional growers because it will provide useful information about weather, and cultivar resistance as well as about chemicals available to organic growers.

Relevance Criteria: The proposal meets the Relevance Criteria because:

1. The DSS will reduce risks to the environment by reducing the number of applications and environmental impact of fungicides used.
2. The DSS will reduce risks to human health by reducing the number of applications and environmental impact of fungicides used.
3. The DSS has stakeholder support – as evidenced by seed funding from the Empire State Potato growers and by the recent interest described above.
4. The DSS focuses on a pest found in more than five states.
5. The DSS will fill a niche (there is no real-time DSS using an accurate simulation model).
6. The proposal involves two states in active partnership.
7. The DSS will advance IPM in three years.
8. The proposal is interdisciplinary, involving plant pathologists and meteorologists.
9. The DSS will reduce dependence on chemical pesticides.
10. The DSS addresses a problem with large economic implications.
11. The DSS addresses concerns of organic as well as conventional growers.
12. The proposal addresses an emerging problem in agricultural and home garden settings.
13. Recent experience suggests an enthusiastic reception by the target audience.
14. The DSS advances IPM practice and is more cost effective than the status quo.