Progress Report for Southern Region Small Fruit Consortium

PROJECT TITLE:
Development of a web-interface for grape and apple regional risk assessment system (2013-E04)

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A) OBJECTIVES

1) Development of web-interface for apple and grape risk assessment system
2) Transfer MaryBlyt into a GIS-based module in order to generate daily risk maps

B) Project executive summary:

Although majority of growers in VA practice IPM (Integrated Pest Management), the usage of fungicide is still high. On average, a wine grape grower applies 12-15 times per season. Each pathogen has its own conditions for infection, which is often controlled by temperature and wetness period. In addition, for some of major diseases on grape and apple, there are fungicides that have kick-back activities (i.e., grower can apply after an infection takes place). Therefore, if we can inform growers whether the last (or future) rain event was an infection event or not, it can help reducing the use of fungicides, especially in a dry season.

A risk assessment tool that provides specific information about the risk of disease development can be a very useful tool for growers' fungicide decision-making, especially for intensively managed crops such as grape and apple (Gadoury et al., 1990). For both grape and apple, many of major disease have been studied and many

mathematical and conditional models are available; however, it is very difficult for growers to implement these models. It may be due to the complexity of the model, lack of weather data, cost associated with implementation of weather stations (and also models, which is often sold as a product).

Understanding the importance of disease risk assessment information, our lab has launched a blog called "Virginia Grape Disease Updates" since 2009 season. In addition to general discussion on grape disease management and disease biology, I update the blog each time infection event was observed in Winchester area. Although it is geographically limited to Winchester area, it received a very good attention from growers. Over the past five seasons, we have received more than 33,000 page-views from 7,500 unique visitors (63% are returning visitors) from more than 100 different countries. This results shows the growers are actually using risk information to adjust their spray schedules. Our collaborator, Dr. Keith Yoder also maintains a successful blog about apple disease management. Both of our blogs are geographically limited to Winchester area; however, grapes and apples are grown in much wider area in VA and surrounding states.

Therefore, our group has been working to develop a map-based grape and apple disease risk assessment system, which utilize regional level weather information to evaluate risks of major diseases of grape and apple. We envision that in the future, it will be a component of risk assessment system where it will provide aids for IPM that will be tailored to the specific conditions for each grower. I.e., The system will provide a report of grape or apple disease risk snap-shot that includes history and forecast of disease risk at the site of interest, provide site-specific information based on user inputs, and maps will be generated to support areas that is not covered by existing weather stations.

The funding from SRSFC was requested as a part of a large project, where we proposed was to establish a framework for the disease risk assessment system (Table 1). This year's funding was to aim to finish up the first phase of the system by developing a web-interface, and also incorporating more apple disease models, especially MaryBlyt. We believe that we accomplished many of objectives that we have originally proposed (please see the table below). We have established:

1. A collaborative team between Virginia Tech's Department of Plant Pathology, Physiology, and Weed Science (PPWS) and Center for Geospatial Information Technology (CGIT)
2. Established network protocol to import RTMA weather data from the NOAA's server to CGIT server
3. Several candidate grape disease models were selected and transformed into GIS modules
4. In-season data from the past were run with the GIS module to validate the models

There were few things that were proposed, but altered or not accomplished during this year. Unfortunately, we were not able to finish the portion of the work we proposed for this period due to the reasons listed below. The major reason was that two of people who were actively working on this project left the program in the first quarter of 2013 due to their career changes. We have re-grouped since then, and have been working and will work on the program in the future; **however, we are NOT requesting additional funding from SRSFC this year for this project. We have granted one-year extension.**

1. Weather data sharing between PSU and VT
    a. It was established in 2010 with help of PSU climatology team; however, we subsequently find a way to directly obtain data from the NOAA, which can eliminate the risk of depending on PSU weather server. *This change actually helps to expand our service to other southern states in the future.*
2. Apple disease models
    a. We have worked with Dr. Alan Biggs at West Virginia University, and he generously gave us a permission to use his fire blight program; however, this program requires more user inputs that could be an issue with our system. Therefore, our group is still in a process of creating its GIS module.
3. Public deployment of the alpha system (Web page)
    a. Originally we were planning to deploy a version of the system to selected growers to validate the models; however, presentation of past maps and automation of mapping process has been a bottleneck of the system, and we have been seeking the best method. Since mapping has been

successful for several of our diseases, our current plan is a deployment of the alpha system for 2014 growing season.

Table 1. Proposed Objectives from the Original Proposal

Phase	Timeline		Objective	Impact
I Development of the base system A) Disease risk assessment system **(proposed here)**	2009-2013	1	Creating the infrastructure: a) Set up a data server; b) Create a web interface; c) Data management	Establish a weather data sharing structure between PSU and VT system
		2	Initial development of grape disease risk assessment tool *2009-2011*: Selection of candidate models based on previous studies (*on-going as of 2009 season*) *2010-2012*: Initial system run: testing and calibration of GIS modules, a hindcast of disease risks with existing datasets	
		3	Public deployment of the alpha system of disease maps (2013)	

Materials and Methods

1. Web Crawler - Application for Automatic download of Weather data

- The National Centers for Environmental Prediction (NCEP) hosts free weather data called RTMA, in NOAA servers via FTP connections. These weather data are in grb2 formats. Grb2 files are an extension of raster format, used to store multidimensional variables in grid format. RTMA data was the primary source of weather information for the project and it provides 11 weather variables, namely: pressure, temperature, dew point, u-component and v-component of wind velocity, specific humidity, wind direction, and standard errors in pressure, temperature, dew point, wind velocity and specific humidity. Our models are using temperature, dew point, and relative humidity (calculated from temperature and relatively humidity)
- Data files change every day with each link proving the entire list of weather for each day. This means that harvesting the data, requires keeping track of the NOAA data online, every day. Thus, an automatic application was programmed using C# .NET (Note: all applications listed in this report is available through request).

2. Grib2 format to NetCDF conversion App

- Need: grb2 file cannot be directly converted to an ArcGIS compatible format. Each Grib2 message has to be 1st converted to individual NetCDF file which in then has to be converted to a .TIFF format (which is an ArcGIS model builder supported format of raster data). Only grib files (*.grb) are readable in ArcGIS 10x, grb2 format is not supported in ArcGIS 10x versions. Also, it is convenient to automatically generate NetCDF data using an application than executing individual command line options for each weather variable on input grb2 data file.
- Thus, there is a need for an intermediate program to complete the data processing before using the weather data in risk modeling in ArcGIS. The only possible way to read these weather products into ArcGIS is by converting them to NetCDF and then rasterizing the NetCDF files to .TIFF format. Only 1 Grib Message (weather variable) can be converted into a NetCDF file at a time, and for this product, messages 3, 4 and 12 are required for temperature, dew point and relative humidity respectively. Thus, an app (degrib_to_netcdf.zip) has been developed to generate NetCDF files of temperature, dew point and relative humidity.

3. NetCDF to .TIFF Conversion

- Python scripts (dewNetcdfRaster.py, specificHumNetcdfRaster.py, and TempNetcdfRaster.py) were developed to convert the Specific Humidity, Temperature & Dew Point NetCDF files to .TIFF raster data.

4. GIS Risk Models

4.1 Description of the model

- *The selection of candidate disease models:* the selection was made based on past usage (i.e., popularity among scientists and growers) and availability (Table 2)
- The model was developed to forecast production at an interval of 6 hours every day (depending on the availability of data in the folder). The model was constructed in ArcGIS 10 developed by ESRI. It was put together using its visual modeling functionality known as Model Builder. Model Builder allows complex models to be built visually and performs task simultaneously. Spatial Analyst, Data Management tools and Multi Dimension tools were the important tools used for the forecast model required number of raster based calculations; these allow the display, creation, manipulation and analysis of grid raster data.

Table 2. List of candidate grape disease models

Model	Parameters	Disease risk criteria
T_{obs} = average temperature during wetness period (LW) LW_{obs} = time (in hour) of wetness period		
Botrytis model 1 (Nair and Allen 1993)		
$I = I_{max} \bullet [1 - \exp[-(Q - t / K_{time})^2]]$ where $Q = \exp[-((T_{obs} - T_{opt}) / K_{temp})^2)]$ and $t = LW_{obs}$	Tmin 5 Tmax 30 Imax 100 Topt 20.8 Ktime 13.9 Ktemp 8.9	IF 0 ≤ I< 20 then $Risk_{bot}$ = low IF 20 ≤ I < 50 then $Risk_{bot}$ = Moderate IF I ≥ 50 then $Risk_{bot}$ = high
Powdery Mildew model 1 (Sall 1979)		
PT = 0 if $T_{obs} \leq 0$ PT= $0.000241 \cdot T_{obs}^{2.06737} \cdot (35\text{-}T_{obs})^{0.72859}$ if $0<T_{obs}<35$ PT = 0 if $T_{obs} \geq 35$		IF 0 ≤ PT< 0.2 then $Risk_{PM}$ = low IF 0.2 ≤ PT < 0.5 then $Risk_{PM}$ = Moderate IF PT ≤ 0.5 then $Risk_{PM}$ = high
Black Rot model 1 (based on Spotts 1977)		
If T_{obs} <10 then $Risk_{BR}$ = low If T_{obs} > 10 then Y = 6.6116027 – 0.0358765* T_{obs} + 0.0920909*(T_{obs} – 21.0556)^2 – 0.0039294*(T_{obs} –21.0556)^3 If LW_{obs} > Y then $Risk_{BR}$ = high Else if $Risk_{BR}$ = low		
Phomopsis model 1 (Erincik et al 2003)		
$Y = \text{alpha} \cdot t^{\text{beta}} \cdot (1 - t)^{\text{gama}} \cdot W_{obs}^{\text{epsiron}}$ Where $t = (T - T_{min})/(T_{max} - T_{min})$	apha 2.04 beta 3.47 gamma 4.86 epsiron 1.6 Tmin 5 Tmax 35	IF 0 ≤ y< 0.07 then $Risk_{phom}$ = low IF 0.07 ≤ PT < 0.15 then $Risk_{Phom}$ = Moderate IF PT ≤ 0.15 then $Risk_{Phom}$ = high

4.2 Black Rot, Phomopsis, and Botrytis Models

Black Rot, Phomopsis, and Botrytis models require leaf wetness (referred to as LW) as a parameter in their equations. Leaf wetness is a time (in hours) when leaves are wet after initiation of a rain event. Since RTMA data does not contain measurement of leaf wetness LW is estimated based on cumulative rain event value (figure 2). Thus, we need to estimate the leaf wetness duration using the existing RTMA parameters, namely, temperature and relative humidity. The P.I. has been using an estimation method proposed by Sutton (1984), which is based on rain fall incidence and RH. The preliminary results indicated a reasonable accuracy of disease prediction (Nita 2006).

- We developed two leaf wetness models to be compared. When relative humidity is more than 90% (model 1) or 95% (model 2), it is considered leaf wetness event. ArcGIS toolbox containing the blackrot models is shown as a figure 3. (Other models are shown in appendix III.)

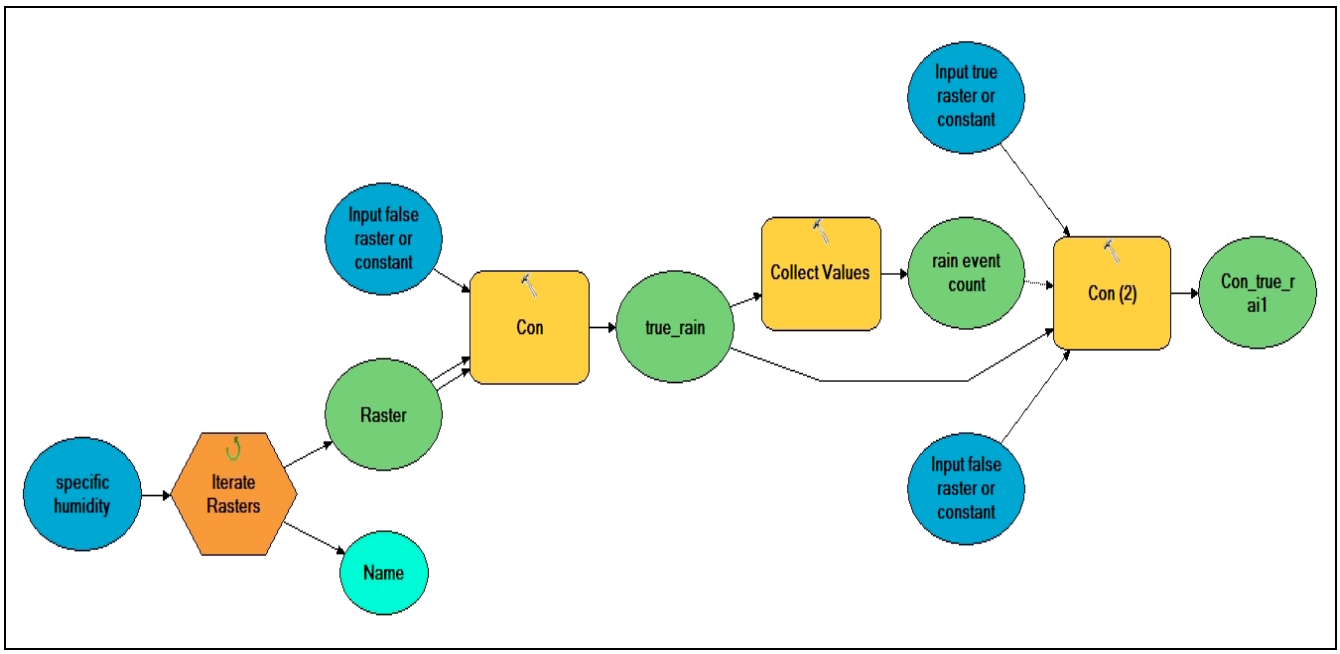

Figure 2: Count Leaf Wetness Events

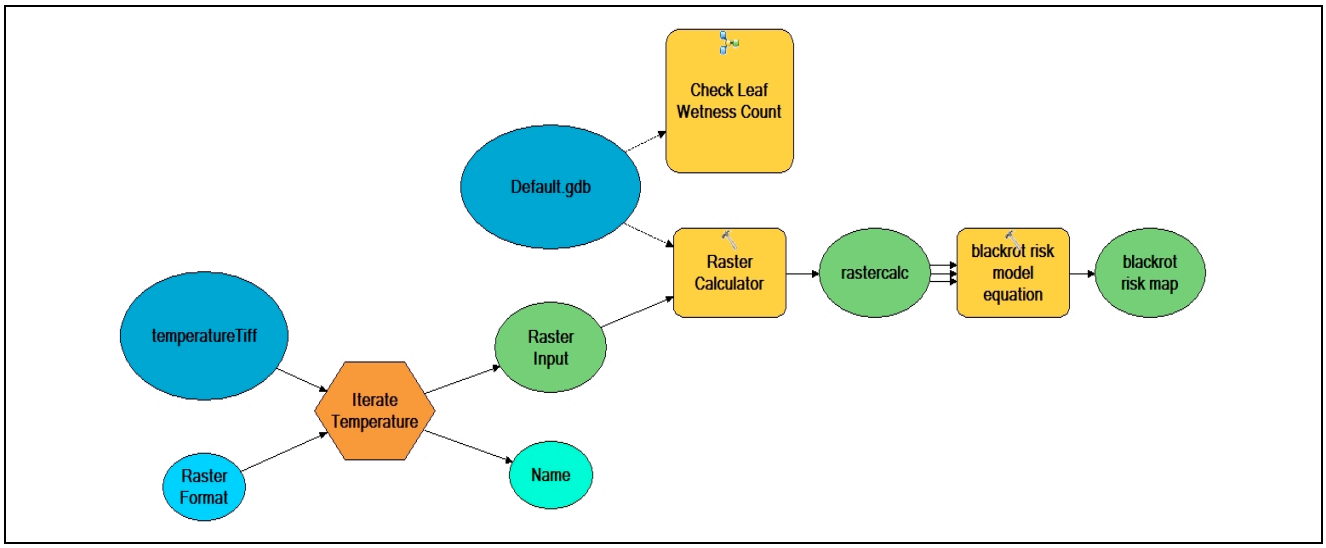

Figure 3: Blackrot risk model

Powdery Mildew Model:

- Since powdery mildew pathogen does not require rain for infection, powdery mildew model only use temperature as a parameter (fig. 4).

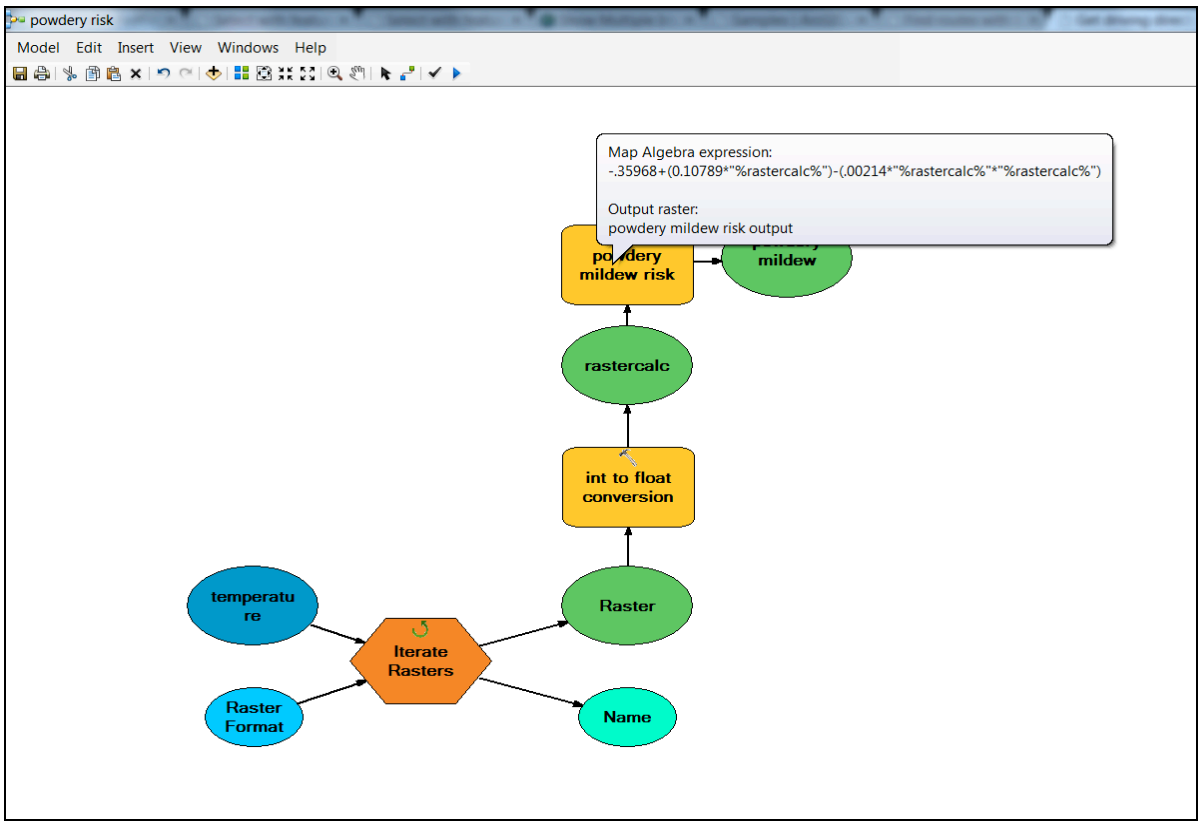

Figure 4: Powdery mildew risk model

Project Results

5. Master Scheduler Script

Once the GIS models are developed, all the above-described applications, these scripts and models are scheduled to be run inside a single python script so that it will generate maps everyday. This script called master-script.py will be scheduled using Windows Scheduler and run on a desktop PC to generate the raster images for maps (Fig. 5).

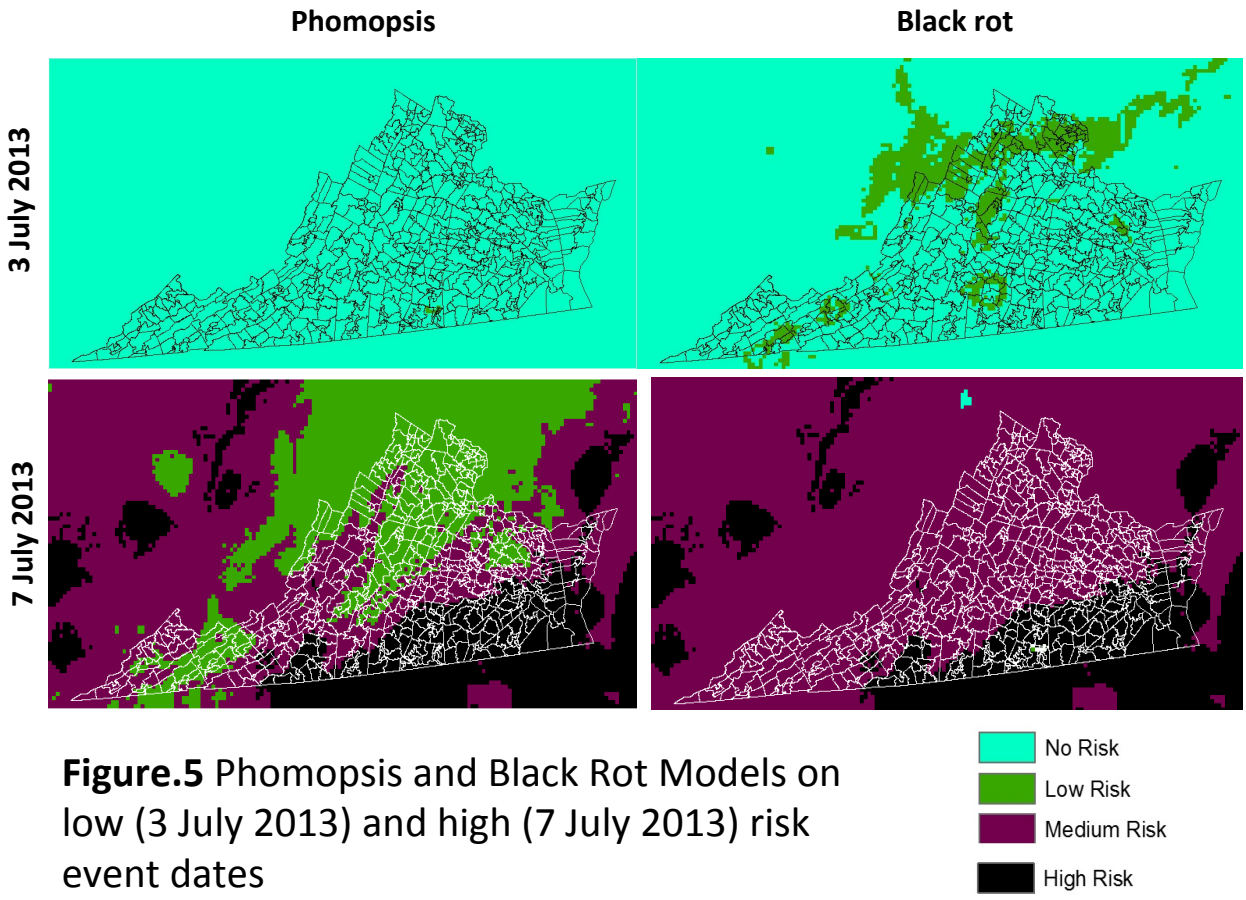

Figure.5 Phomopsis and Black Rot Models on low (3 July 2013) and high (7 July 2013) risk event dates

6. Work in Progress:

- **Apple models:** Some of apple models require more computations and user inputs. We are developing different modules to visualize apple disease risks.
- **Automated map generation:** Currently, data acquisition and map generation is semi-automated. Once we validate the accuracy and precision of the models, we will create a script to read weather data and generate maps every 6 hours.
- **Use of weather forecast:** RTMA also includes forecasted temperature and relative humidity. For some of disease models, this information will be utilized to forecast risks of disease development.
- **Progress of Web Interface:** A JavaScript client side application is being developed using ArcGIS API for JavaScript to consume the web maps published using ArcGIS Server 10.0. Our plan is to build website that updates the risk maps every day for each disease and provide a time slider function for users to slide through each raster layer. However, there is no time slider functionality for raster layers in ArcGIS API for JavaScript. Hence open layers are being explored currently to check if time slider functionality could be implemented. Otherwise, alternate user interface options like check boxes would be used to display the risk models for every 6-24 hour intervals.

Conclusions, Discussions, and Impacts

We have successfully created a framework for future grape and apple disease risk assessment system by obtaining detailed weather data, and converting them into several grape disease risk assessment models using GIS technologies. By processing weather information properly, this risk assessment system can provide summarized information of the risk of disease development with an easy to understand color-coded map format (Fig. 5). One of the purposes of the system is to provide an aid for fungicide and bactericide applications.

However, it is not our intension to have a system that will replace traditional fungicide recommendation programs. Instead, it will help educate growers to take another look at weather information, which is a major driving force of plant disease development. By doing so, this risk assessment system will help growers make a better decision when they refer to the fungicide recommendation programs. Some growers have been implementing weather monitoring equipment in their orchards and vineyards. For them, this system will serve as additional information to confirm their decision making. Many others may not have funds to purchase weather monitoring equipment, or they may think they do not have time to examine weather data to assess disease risks. For those growers, this system serves as an aid for their decision making which they did not have an access before.

Benefits of this system are not limited to the money and time saved by growers at the time of pesticide application. Precisely applied fungicide application can increase an efficacy of disease prevention, which leads to increase in quality and quantity of the yield (Madden et al., 2007). In addition, the impact on the environment should not be discounted. Excessively applied fungicide will be a threat to growers' (and their neighbors') health, and it has an impact on the environment through chemical drifts and run-offs. Moreover, the reduced use of fungicide will act as a preventative measure for the pesticide resistance development of pathogen populations (Bent 1978, Campbell and Madden 1990). Populations of both powdery and downy mildew pathogens of grape resistant to the QoI fungicide in Virginia have been documented (Baudoin et al, 2008), and apple powdery mildew and apple scab also has developed resistance to the QoI (Sallato 2006), and potentially DMI (Koller 2005). Use of this risk assessment system could reduce the use of the vulnerable fungicides, and it may prolong the product life of these fungicides. Considering the cost, time, and effort put into a fungicide development, also the potential concern on the public health, the impact of the risk assessment system is very high.

Having such a system will also benefit extension specialists and agent. State-wide information will help extension personnel to make recommendations to growers; especially if the field of the question is far from the office of the extension personnel, which is not uncommon in many of southern states. This system also provides a resource to other research and extension opportunities by collecting valuable weather information throughout Virginia and place into a dedicated server that can be accessible by specialists. The availability of weather information and the flexibility of the modular system will allow other projects to take an advantage of the system with ease. The data obtained in this project will be shared with others, and the database will be valuable for many disciplines. For example, this system can be adapted to predict the emergence of insects, such as grape berry moth (Tobin et al., 2001), which is based on a seasonal heat accumulation. Furthermore, it can be combined with existing mapping effort such as Virginia's vineyard suitability maps (Boyer 2000) to provide a more comprehensive picture of the viticulture in VA.

There are several challenges that have been addressed. One is the availability of the weather information at a local level. The RTMA technology is very sophisticated and suitable for creating maps. For example, the USDA's ipmPIPE system for soybean rust and other diseases uses the very similar technology; however, its grid is 5 km square. Some users may feel the resolution is not high enough. To provide more information, the proposed system incorporates data from weather stations across the state of Virginia; however, these stations are scattered around and some growers may not find the one close to their vineyard. In order to resolve this issue, we have contacted another pest-management weather database (www.uspest.org), and granted a permission to use their resources. We will submit our weather station data to their website very soon. We are also planning to submit some of models we have been working on.

Another challenge is the continuous funding. Often, many disease risk assessment efforts only last while funds are available, presumably due to high running cost. We would like to have a system that can run cost efficiently, so that the risk of termination of the service is minimal at the end of the funding cycle. The proposed system will be built on existing GIS applications using existing weather data, utilizing existing disease models (Table 2), and it will be designed to be as automated as possible once the system is built. Thus, it should require relatively low cost to build a system, and it will require very small maintenance in terms of both cost and time in a long run. The weather data acquisition and map display will be automated, and the disease model module will be independent of the system so that modification in disease risk assessment models can be made without affecting the whole system. Thus, once the system is established, cost associated for the maintenance of the system will be minimal, what required yearly will be fees for weather data (which is planned to be eliminated in the future), and other miscellaneous costs such as adding extra storage spaces.

Future direction: Often times, disease models are developed specifically for the geographical area of interest. The combination of geographical region, variety, and pathogen population (Campbell and Madden 1990) can influence the disease development; thus, it is very important to calibrate the model to the target area so that we can provide accurate information to growers. The proposed two phases of the system include the selection of a candidate model(s) for each disease, and translation of the models into the GIS modules for display, and validation of results using historical and in-season data. Validation of results can also be done by conducting a field experiment where you apply fungicide treatment based on the model outcome (Nita et al., 2007); however, that will be the scope of later phases of the project, and it will be handled individually as the need arises.

These challenges are not unique to this project, but common to any attempts to implement disease models to a practical use. Fortunately we have a group of collaborators with vast experience and variety of expertise to solve these issues one by one. This project will generate many opportunities to quantify the information to be published to contribute to the academic and the industry. Once the system is established and our ideas come to reality, this system will attract many other scientists and specialists, and it will be a good resource for student and grower education for the future generation. We hope that we can obtain the expansion of the projects (Phase II and beyond) will be funded soon.

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Appendix I

Table 1. A timeline of the proposed disease information systems and its impact (***original***)

Phase	Timeline	Objective		Impact
I Development of the base system A) Disease risk assessment system **(proposed here)**	2009-2013	1	Creating the infrastructure: a) Set up a data server; b) Create a web interface; c) Data management	Establish a weather data sharing structure between PSU and VT system
		2	Initial development of grape disease risk assessment tool *2009-2011*: Selection of candidate models based on previous studies (*on-going as of 2009 season*) *2010-2012*: Initial system run: testing and calibration of GIS modules, a hindcast of disease risks with existing datasets	
		3	Public deployment of the alpha system of disease maps	
II Initial runs A) Disease risk assessment system B) Grape and Apple disease information center	2009-2014	1	Validation of models by comparing model outputs with actual observations in the fields	
		2	Validation of weather station input by comparing with national weather service data and RTMA model results (*on-going as of 2009 season*)	
		3	Establishment of the web-interface for grape and apple disease information center	
		4	*2011-2014*: Initiation of experiments where participating plots will be using results of risk models to schedule fungicide application	– Student education – Public awareness development – Extension education
		5	Public deployment of the beta system that includes grape and apple disease information such as factsheets and pesticide spray recommendations (existing information will be fully utilized)	
III Public deployment A) Disease risk assessment system B) Grape and Apple disease information center	2013-2016	1	System deployment and feedback: a) System maintenance and evaluation, b) Conduct survey to obtain user comments and suggestions; c) Continuation of validation of models and weather stations	
		2	Use of disease risk assessment system as an extension education tool	
IV Value addition A) Disease risk assessment system B) Grape and Apple disease information center	2011-2016	1	Toward more comprehensive information system for grape management; 1) Implementation of other disease risk maps (Pierce's disease forecast, grape leafroll virus distribution map, etc); 2) Establish links to existing disease databases (e.g., ipmPIPE products) and other information sources 3) Establish apple disease module which is another important fruit crop in VA	– More extended collaboration among faculties and institutions – Extension education beyond mid-Atlantic grape and apple production
		2	Expansion of the system beyond VA and plant pathology: 1) Continuation of the validation of the system; 2) Expansion of the system to other states; 3) Consult viticulturists and entomologists for application of the system; 4) Expansion of the system beyond grape plant pathology.	

Appendix II

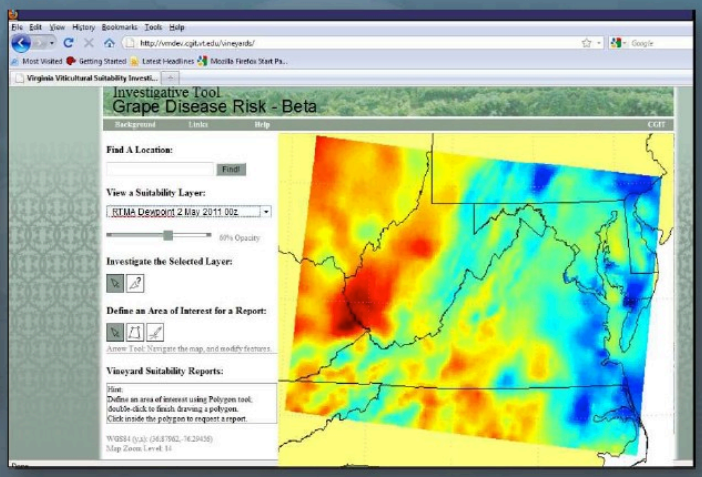
A copy of poster presented at 2012 GEOINT Symposium in Orlando, FL (October 8 – 11, 2012).

Selected Project: Grape Disease Forecasting

CGIT is creating a predictive model to assess blight risks in grapes. The model considers blossom, canker, shoot, and trauma blight conditions to show infection risks (low to high) to determine risks two days in advance using forecasted weather information.

The model will generate hourly risk prediction rasters to determine when the symptoms of blights would occur. This can help growers to make decisions on the need for blight-preventive measures.

Botrytis cinerea on grapes
Source: davitydave, Wikimedia Commons



Read RTMA climate data. Accept user inputs for phenology, wetness, and spray conditions.

↓

Calculate Degree Day and Epiphytic Insect Potential.

↓

Do symptoms indicate blight conditions: trauma, shoot, canker and blossom?

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NO:
Repeat previous steps.

YES:
1. Calculate probability of blight occurrence and the area of grapes being affected.
2. Assign risk scores
3. Calculate weighted index.

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