Modifying critical thresholds in Simcast to achieve better late blight management for moderately susceptible potato and tomato crops

Honors Thesis

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Yuanhan Wu

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William Fry

Abstract

A decision support system (DSS) for potato and tomato late blight management has been developed to provide disease management recommendations. The system is comprised of two disease-forecasting tools as well as a simulator. Results from simulation and field experiments with the system have shown that the DSS schedules on moderately susceptible crops did not achieve sufficient disease suppression under certain circumstances. We used weather data from 2000 to 2010 from over 140 weather stations to generate spray schedules. We then inputted schedules into the simulator to get disease severity and fungicide use efficiency. We then modified the default critical value in the disease-forecasting tool, compared those results and got the critical thresholds by improving disease suppression while maintaining similar fungicide use efficiency. The primary objective of this research was to improve disease suppression for moderately susceptible cultivars while maximizing fungicide use efficiency. This change has subsequently been programmed into the on-line version of the DSS.

Introduction:

Phytophthora infestans (Mont.) de Bary, the oomycete causal agent of potato late blight, is causing significant loss to potato production globally. A total annual loss of $6.7 billion was estimated for related disease control efforts and yield loss (Haverkort et al., 2008). Late blight has proven to be equally devastating to tomato crops as well as potatoes. In 2009, a late blight epidemic struck major US tomato farms via contaminated tomato transplants of a major distributor (Fry et al., 2013).

A typical late blight management plan includes reducing disease introduction, survival, and infection rate of late blight. Late blight is extremely devastating and can destroy crops within a week (Danies et al, 2013). Fungicide application remains the most effective disease control method upon detection. Farmers generally adopt weekly spray schedules. This traditional spray scheme is inefficient given that weekly applications may not achieve the most efficient disease control (Danies et al, 2013). The development of the USABlight Decision Support System (DSS) makes a more efficient fungicide spray plan possible. Late blight disease development is typically sensitive to temperature and humidity. The optimal temperature for disease development is 15° C and the temperature that favors sporangia germination is 4° C. Additionally, high humidity generally favors late blight development (Danies et al, 2013). Crops with different resistant levels also react differently to the disease and require different fungicide application schedules. Lastly, weather condition also affects the amount of fungicide remaining on leaves -- which also influences the disease management. The DSS for potato late blight is a system that integrates available information (weather data, crop resistance, fungicide residue, etc.) to predict future disease severity and suggests fungicide application at critical timings based on the forecast. The system functions by quantifying the effect of weather in "severity values". Once the cumulative severity value goes over the critical threshold in the system a fungicide application is recommended.

Field evaluations of the BlightPro DSS have been conducted in year 2010, 2011, 2012, and 2013 (Shtienberg & Fry, 1990). Researchers compared the disease suppression level and number of fungicide applications of DSS schedules to weekly spray schedules. Experiments were conducted among all three resistant levels of crops (Susceptible, Moderately susceptible, and Moderately resistant). The results elucidate that the both DSS schedules and weekly schedules significantly suppressed the disease ($P<0.05$) for all three resistant levels. Further, there was no significant difference between the DSS group and weekly schedules ($P<0.05$) among those three groups (Ian Small, 2015). As for fungicide application, the number of sprays recommended by the DSS differed among the three categories. For Susceptible cultivars, the DSS recommended 24% more fungicide applications in average than the weekly schedule with a range form -91% to +91%. For moderately susceptible cultivars, the DSS recommended averagely 15% fewer applications relative to a weekly schedule. For moderately resistant cultivars, the DSS recommended 36% less applications in average than the weekly schedule with a range from -91% to 0% (Ian Small, 2015). Therefore, field evaluations of DSS proved the effectiveness of the system.

To expand the sample size of the comparison, Small et al have run computer simulations with 6912 simulations in 59 locations for 13 years (2010 to 2013). The result is present in the figure below.

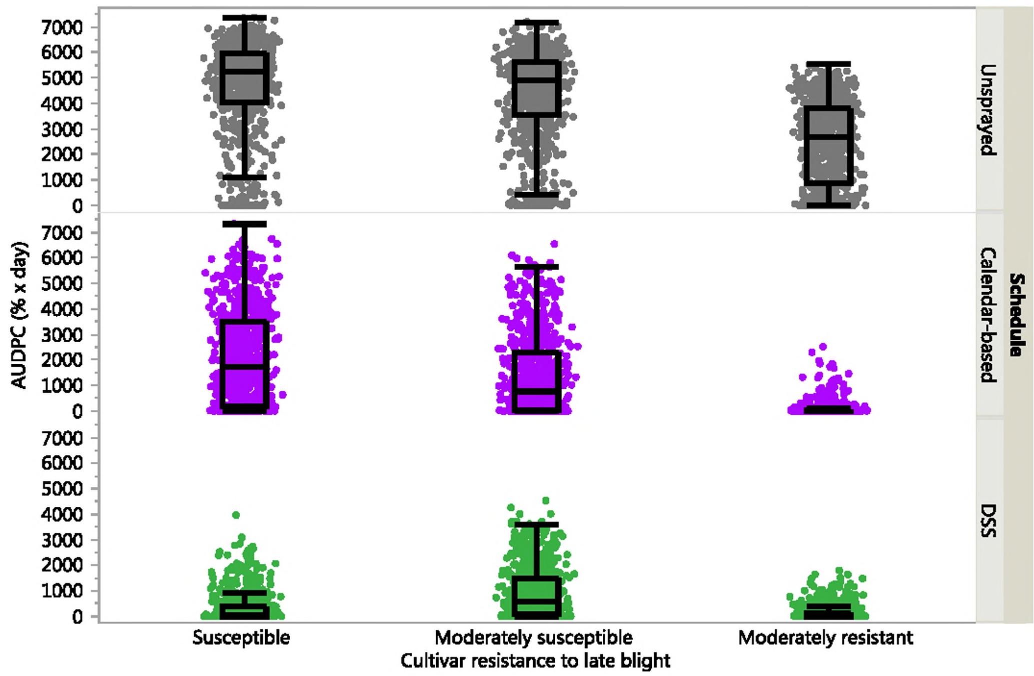

Figure 1. A group box plots showing field results of AUDPC of three spray schedules: Unsprayed, Calendar-based, and DSS. The green one indicates the DSS schedules (Ian Small, 2015). (**AUDPC** is defined as the Area under the Disease Progress Curve, which reflects the cumulative disease severity within a growing season. A disease progress curve is illustrated in Figure 2.)

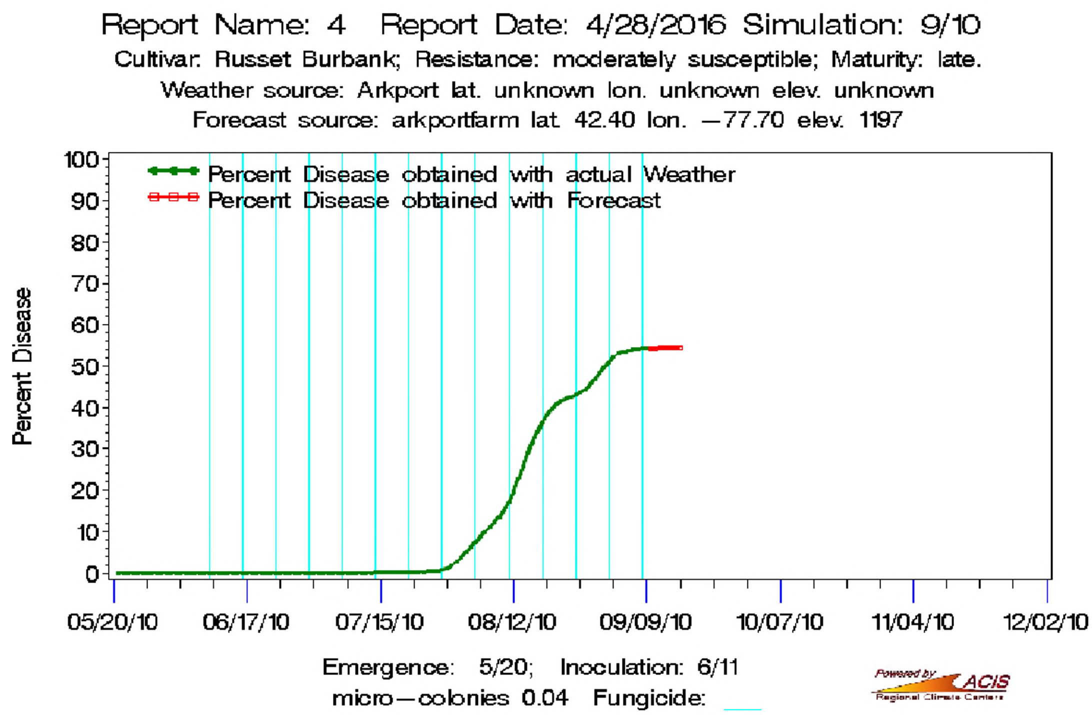

Figure 2. Disease Progress Curve. This is a disease progress curve for a weekly spray schedule of moderately susceptible crop. The vertical lines in blue indicate fungicide application while the green line indicates the disease progress curve up to date. The part of curve in red implies predicted disease curve in future (a week).

As demonstrated in figure 1, both the weekly schedule and the DSS schedule significantly reduced disease level from non-spray group. The DSS schedule further reduced the cumulative disease of susceptible and moderately susceptible cultivars. The cumulative disease level is slightly higher than weekly schedule in moderately resistant cultivar. However, for disease suppression in DSS schedules, the disease suppression for moderate susceptible cultivar is not as good as the other two categories.

Since fungicide applications are recommended once accumulated severity value goes over corresponding critical thresholds, we assert that by modifying default critical thresholds in the system, it is possible to obtain a result with lower cumulative disease severity for spray schedules recommended for moderately susceptible cultivars by the DSS system.

Materials and Methods:

Development of the USABlight DSS. The USABlight Decision Support System for late blight management was developed to integrate prevailing weather conditions, host resistance, and the degradation of fungicide into a disease forecasting system (http://blight.eas.cornell.edu/blight/) and made spray recommendations according to the forecast. The DSS has been named "BlightPro" and is well described by Small et al (2015). The DSS is comprised of two disease-forecasting tools, the Blitecast and Simcast (Krause et al., 1975), and a disease simulator (Andrade-Piedra et al., 2005). Basically, Blitecast determined the time before which a fungicide spray was necessary in northeastern regions while Simcast integrated prevailing weather data, crop resistance, and fungicide weathering into consideration (Fry et al, 1983). Therefore, Blitecast primarily determined when the first application occurred while Simcast was used to recommend subsequent sprays. Within Simcast, two critical thresholds were

used to recommend a spray. A positive blight unit value and a negative fungicide unit value were accumulated (increasing/decreasing). When either the blight unit value or the fungicide unit value went over (higher/lower) corresponding critical thresholds, a fungicide application was recommended.

Simcast Summary

Date	7/15	7/16	7/17	7/18	7/19	7/20	7/21
Blight Units	20	26	33	38	43	49	55
Fungicide Units	-8	-11	-15	-16	-17	-18	-19
Key							
	Below Threshold						
>=30	Blight Unit Threshold Exceeded						
<=-15	Fungicide Unit Threshold Exceeded						

Figure 3. A Simcast Summary report demonstrates how blight unit and fungicide unit works. The red color in the table indicates that a spray is necessary. (Ian small, 2015)

Weather data. Weather data was the primary information required by Simcast to generate spray schedules for selected cultivars. Weather data in this project were obtained from 67 weather stations from 6 major potato production states: New York, North Carolina, Massachusetts, Maine, Wisconsin and North Dakota. The time span of experiment is from 2000 to 2010. Weather data was collected from NRCC (**Northeast Regional Climate Center**), a network connecting all weather stations in northeast region. Only weather data from weather station that has less than 5% missing weather data were collected.

Fungicide. We used the protectant fungicide chlorothalonil 720 g L^{-1} as the default fungicide in our experiment. Chlorothalonil is a broad-spectrum nonsystematic foliar fungicide that is extensively used for blight control on potatoes (Garron et al, 2011). In the early stage of system development, chlorothalonil is the default and only fungicide in the system. Several field experiments have been conducted to validate the effectiveness of the system using chlorothalonil. With the development of the system, other fungicides, including mefenoxam, had been integrated into the system by doing field evaluations in multiple locations.

Experiment Set Up. The potato cultivar we used in our experiment is Yukon gold, which is categorized as a moderately susceptible cultivar in the system. Since weather conditions in North Carolina are different from the other states, we set up simulation differently. For North Carolina, we set the emergence date to be April the 10th and the season end date as July the 27th. For none North Carolina states, emergence date was set to be May the 30th and the season end date to be Sep the 15th. For all states, the disease date, which refers to the first time the disease is detected, is set to be a week after 18-severity value. To initialized late blight disease in the simulation system, we initialized the epidemic at a disease concentration of 0.001%.

Spray Schedules. For a weather station in a specific year, we typically put the whole year's weather data for that station into Simcast, in which, the system recommended fungicide applications based on the weather. As explained above, Simcast recommended spray schedules by comparing cumulative blight units and cumulative fungicide units to blight unit thresholds and fungicide unit thresholds. Therefore, for the same weather data, the system recommended spray schedules differently for cultivars of different resistance. We used weather data from 140 stations with less than 4% missing data from year 2000 to 2010 to generate 65640 different results.

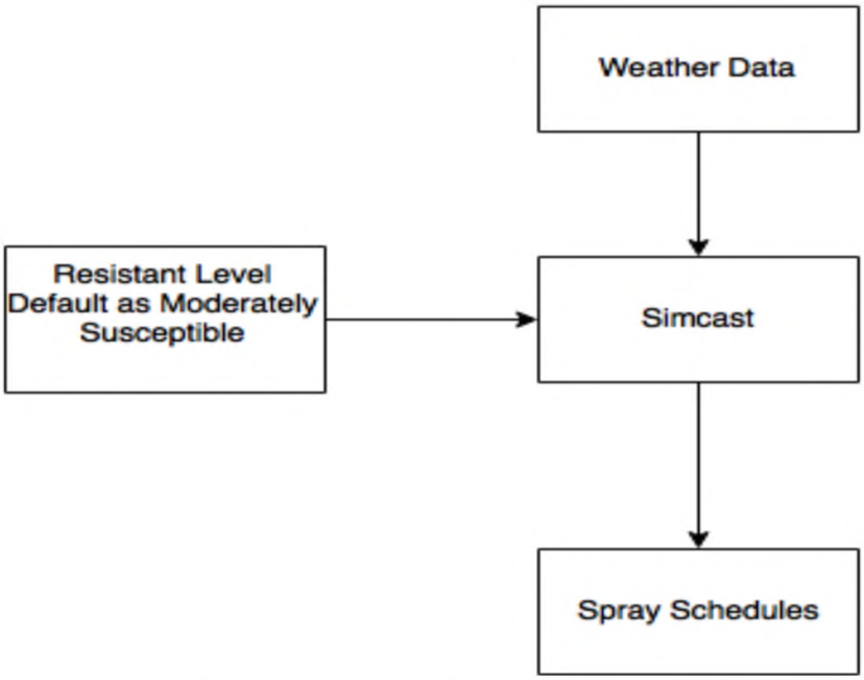

Figure 4. Procedures to generate spray schedules. Putting weather data into Simcast with the rsistance level set to moderately susceptible. Spray schedules for each location and each specific year were generated.

Disease Simulation. To obtain statistics needed for optimization, we put one spray schedule into the simulator, with the crop resistant level being moderately susceptible, and the simulator will draw the disease progress curve, return the cumulative disease (AUDPC), and the number of fungicide applications.

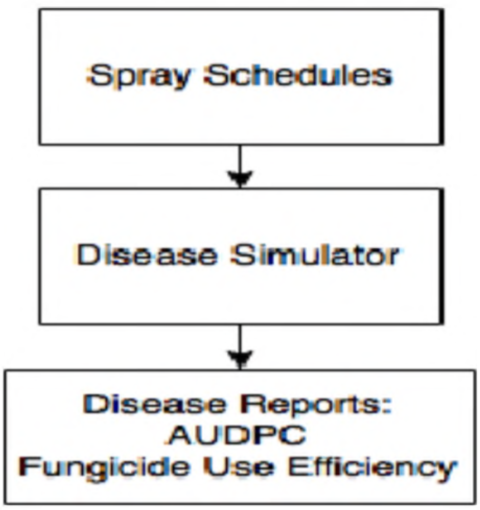

Figure 5. Simulation Procedure. Above is a typical simulation procedure for one particular spray schedule that associates with a specific location and a specific year.

Experiment Procedures.

This project aims at exploring differences in AUDPC and numbers of fungicide applications among different combinations of blight unit thresholds and fungicide unit thresholds. To get the right range of critical thresholds to work on, we first explored critical thresholds in 4 directions: low blight unit and high fungicide unit, low blight unit and low fungicide unit, high blight unit and low fungicide unit, and high blight unit and low fungicide unit. After running simulations for those 4 groups of critical thresholds, we came up with a matrix of sets of blight unit thresholds and fungicide unit thresholds for further analysis **(Figure 6).**

Critical fungicide unit \ Critical blight unit	32	33	34	35	36
-17	-17 32	-17 33	-17 34	-17 35	-17 36
-18	-18 32	-18 33	-18 34	-18 35	-18 36
-19	-19 32	-19 33	-19 34	-19 35	-19 36
-20	-20 32	-20 33	-20 34	-20 35	-20 36
-21	-21 32	-21 33	-21 34	-21 35	-21 36
-22	-22 32	-22 33	-22 34	-22 35	-22 36

Figure 6. A matrix of the blight unit thresholds and fungicide unit thresholds. Each set of blight unit and fungicide unit thresholds was used in Simcast to obtain corresponding simulation results.

For general procedure of this experiment, we first generated weather data from 140 weather stations in 6 states from 2000 to 2010. Then, we excluded weather data with more than 5% missing data. Those weather data were then put into Simcast to generate spray schedules. Schedules were put into the simulator and AUDPC and number of fungicide applications for each simulation was obtained. After that, we calculate the fungicide use efficiency (FUE) for each simulation and stack the data and get average AUDPC and average FUE for all replications within one set of critical thresholds. To calculate the FUE, we needed to run simulations for an additional non-spray schedule for each weather data.

Fungicide Use Efficiency (FUE) is defined as disease suppression per fungicide applications, where disease suppression is defined as the AUDPC of current experiment subtracting the AUDPC of non-spray group.

We then compared the average AUDPC and average FUE for each set of thresholds and found a combination that has a comparatively small difference from the FUE of default set while a significant reduction in AUDPC.

Results:

Weather Data. Since the missing weather data of each station differs from year to year, the list of weather stations are different for each year. For example, there are 14 weather stations providing weather data in North Carolina in 2000, but there are 16 such stations in North Carolina in 2001. Totally, 2188 different weather report form different locations from 2000 to 2010 were generated.

Spray Schedules. We input a matrix of 30 different combinations of critical thresholds. For each combination, we generated spray schedules for all the weather data mentioned above, which are 2188 spray schedules. After generating all the, the total number of replications are equivalent to 65640 field tests.

Matrix's AUDPC. We calculated the average AUDPC for each combination of blight unit threshold and fungicide unit threshold. Generally, as predicted, with the same blight unit threshold the cumulative disease severity increases with the fungicide unit threshold decreases. With the same fungicide unit threshold, the cumulative disease severity increases when blight unit threshold increases.

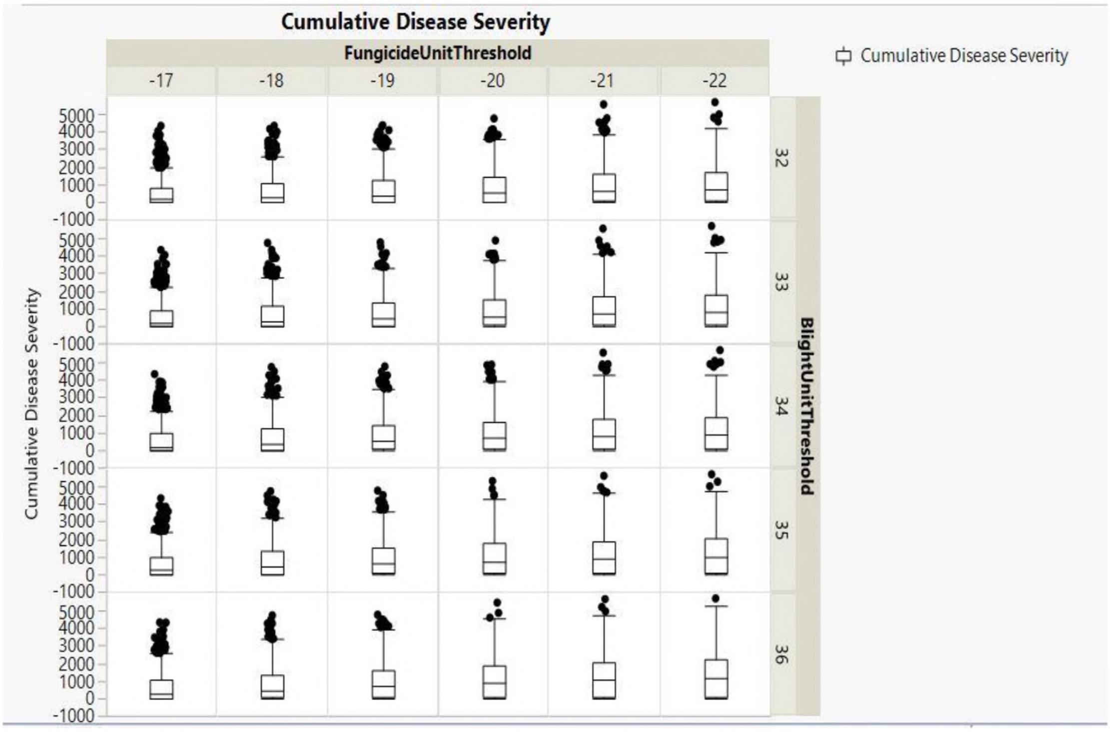

Figure 7. This is a graph depicting all cumulative disease severity values for 30 combinations of fungicide unit thresholds and blight unit thresholds. Within each combination, a box plot was constructed. The middle line indicated the mean, while the dots indicated the outliners.

Matrix's FUE. Using the formulas above, we calculated the FUE for each combination of critical thresholds. The trend of FUE with an increasing blight unit threshold and fixed fungicide unit threshold varies. The FUE for the defaulted group is 8.662121.

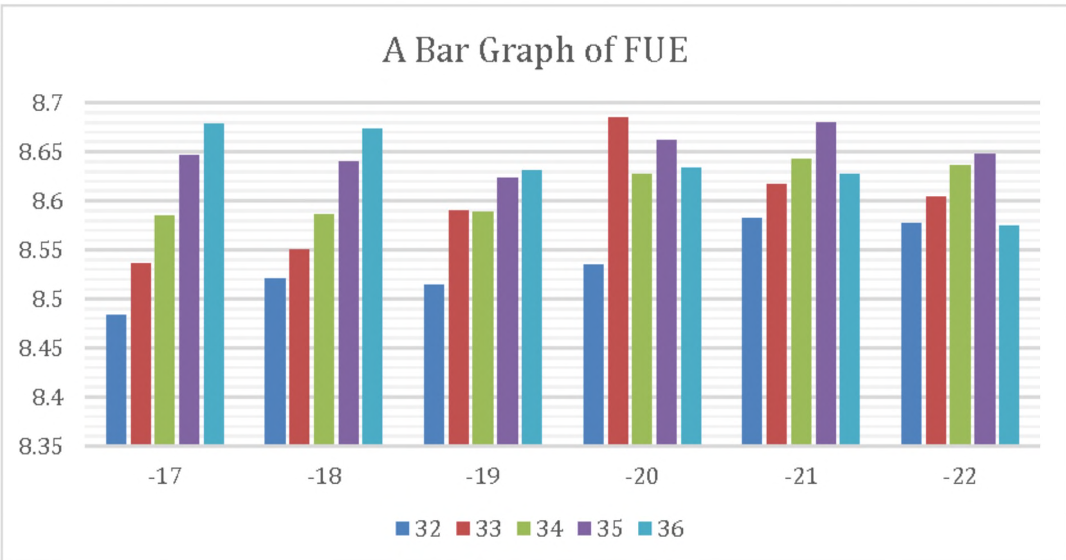

Figure 8. This is a group of box plots denoting FUE of each combination of critical

thresholds. Different colors indicated different blight unit thresholds. The blue is 32, red is 33, green is 34, purple is 35 and light blue is 36. Numbers in the X-axis denotes fungicide unit thresholds.

To obtain the optimal combination of critical thresholds, we decided to constrain the FUE to (>=8.63) which is -0.03 from the defaulted FUE 8.662121. We then selected the FUE with the smallest AUDPC. The new combination we then selected was 35 for blight unit threshold and -17 for fungicide unit threshold. For this new combination, the FUE is 8.646267 and the AUDPC is 616, with the AUDPC for the default set of combination being 1036. The AUDPC was suppressed over 40% while the FUE remains similar to the default combination. To better present the result, we constructed two contour plots.

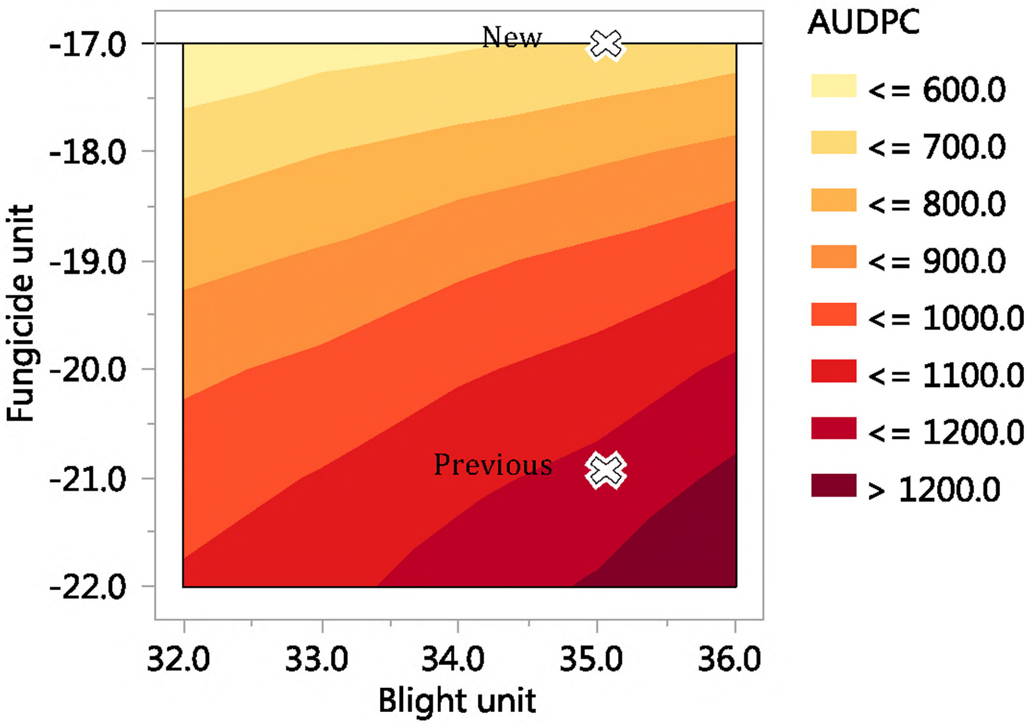

Figure 9. Contour plot of AUDPC for combinations of critical blight unit and fungicide unit thresholds. The X indicates either the previous combination of critical thresholds or the new combination of critical thresholds. The darkness of the color indicates the value of AUDPC (the darker the higher).

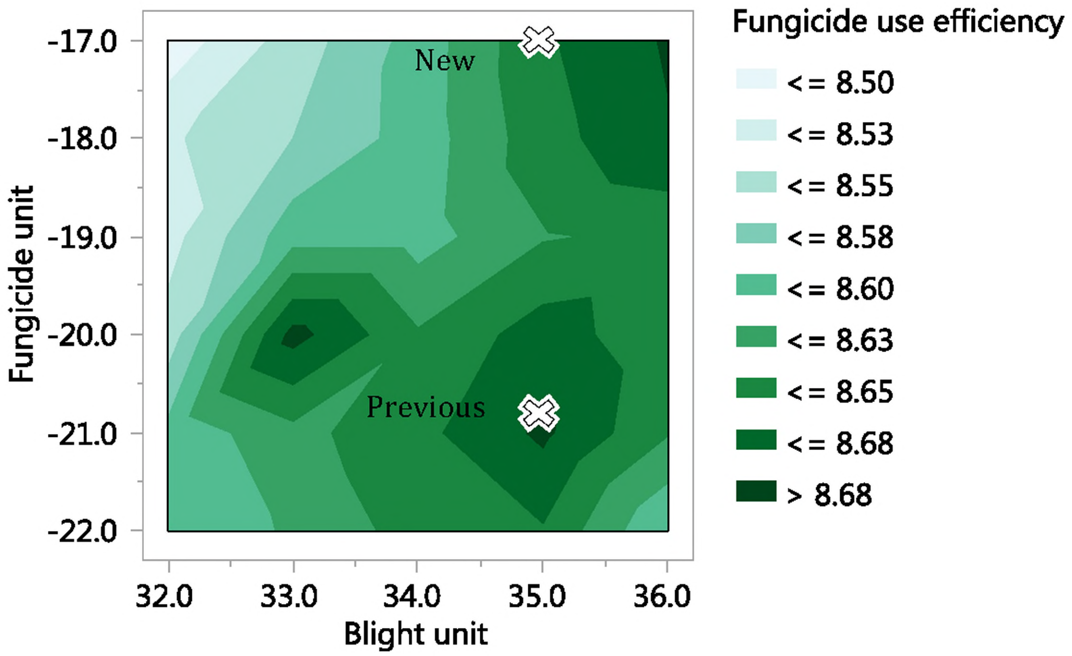

Figure 10. Contour plot of fungicide use efficiency for combinations of critical blight unit and fungicide unit thresholds. The X indicates either the previous combination of critical thresholds or the new combination of critical thresholds. The darkness indicates the value of fungicide use efficiency, the darker the higher.

From those two contour plots, you can clearly see the level of AUDPC and FUE indicating by the darkness of colors in the plots (The darker the higher). The AUDPC for the new combination is much lighter than the previous combination while the FUE remains similar darkness of color.

Conclusion:

Farmers rely heavily on decision support system for a more efficient way to spray. A system has been improved by the finding of this project to have similar disease suppression per spray while achieving 40% more disease suppression. Compared to the old version, the new version of DSS system recommends on average, slightly more fungicide applications than the weekly schedule (11.068 rather than 11) and 1 spray more in the season than the previous version. However, this change achieved much better disease suppression for the farmer, which should help to prevent further yield loss.

Literature Cited:

1. **Andrade-Piedra, J., Hijmans, R., Forbes, G., Fry, W., and Nelson, R. 2005. Simulation of potato late blight in the Andes. I: Modification and parameterization of the LATEBLIGHT model. Phytopathology. 95:1191-1199**
2. **Shtienberg, D., & Fry, W. (1990). Field and computer-simulation evaluation of spray-scheduling methods for control of early and late blight of potato. *Phytopathology, 80*(9), 772-777. doi:10.1094/Phyto-80-772**
3. **Small et al 2015a**
4. **Small, I.M.; Laura, J.; Fry, W. (2015b). Evaluation of the BlightPro Decision Support System for management of potato late blight using computer simulation and field validation. *Phytopathology.* 105(12):1545-54. doi: 10.1094**
5. **Fry, W.E., Apple, A.E., and Bruhn, J.A. 1983. Evaluation of potato late blight forecasts modified to incorporate host-resistance and fungicide weathering. *Phytopathology.* 73:1054-1059**
6. **Danies, G., Small, I. M., Myers, K., Childers, R. and Fry, W. E. 2013. Phenotypic Characterization of Recent Clonal Lineages of *Phytophthora infestans* in the United States. *Plant Disease.*** Pages 873-881
7. **Haverkort, A.J., Boonekamp, P.M., Hutten, R., Jacobsen, E., Lotz, L.A.P., Kessel, G.J.T., et al. 2008. Societal Costs of Late Blight in Potato and Prospects of Durable Resistance Through Cisgenic Modification. Potato Res. 51:47-57**
8. **Krause, R.A., Massie, L.B., and Hyre, R.A. 1975. Blitecast - computerized forecast of potato late blight. Plant Disease Reporter. 59:95-98**