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Accuracy of Rain Forecasts for Use in Scheduling Blight Management Tactics in the Columbia Basin of Washington and Oregon

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Late blight, caused by *Phytophthora infestans*, is a major disease that is capable of destroying potato crops in two to three weeks during disease favoring weather. Rain and mild temperatures favor the disease. Disease management is dependent on eliminating sources of initial infection and on fungicides. Fungicides are most effective when applied just before wet environmental conditions which favor infection. In trials conducted by Washington State University, fungicides applied prior to rainy weather that approximated a 14-day application schedule were as effective as a seven-day application schedule in controlling the disease at half the number of fungicide applications. A calendar based 14-day application schedule reduced late blight severity compared to the non-treated control but did not satisfactorily control the disease. Fungicide applied after rainy days are not effective in preventing infection.

Late blight forecasting systems are not effective at scheduling fungicide applications for managing the disease. Disease forecasting systems currently used in regions outside of the Columbia Basin schedule fungicide application based on the previous week's weather which is a poor predictor of current and future weather. Approximately 20 to 30 inches water/acre/growing season are applied by irrigation in the Columbia Basin, and the potato canopy after closure between rows is a favorable environment for late blight when irrigated. Substantial rain events increase the favorability for late blight development and greatly increase the spread of late blight inoculum within fields and to adjacent and nearby potato crops. Even though potato fields are irrigated, the number of rainy days and an associated lowered radiation are strong predictors of late blight.

Weather forecasts are available from various sources. The goal of this study was to evaluate rain forecasts for accuracy which could be used to schedule fungicide applications for managing potato late blight. Rain forecasts provided by Fox Weather, LLC, Fortuna, CA for seven locations in the Columbia Basin of WA and OR in 2010 and 2011 were evaluated for accuracy. The locations were Burbank, Ephrata, Richland, Sunnyside, Othello, Prosser, and Yakima WA and Hermiston OR. The rain forecast consisted of 24 hour total liquid precipitation (rainfall). Only measurable rainfall, amounts $\geq$ 0.25 mm were forecasted. Forecasts consisted of 15-day and 30-day predictions.

The 15-day forecasts were issued five days a week (Monday through Friday) from 5 May to 14 September in 2010 and 2 May to 31 August in 2011 (Table 1). The time period was from approximately three to five weeks before closure between rows to fall harvest which covers the time that late blight visually increases in the Columbia Basin. This time period will hereafter be referred as the test period. Rain forecasts were based on the Global Forecast System (GFS) model results and were hand-generated by forecasting meteorologist, Zane A. Stephens. The primary inputs for timing, and amount of precipitation were adjusted subjectively by the forecaster. Numbers of forecasts produced for each location were 93 in 2010 and 88 in 2011.

The 30-day forecasts for rain were obtained weekly from 16 May to 9 September in 2010 and 10 May to 1 September in 2011 (Table 2). The rain-cycle peak and length of period in days were determined subjectively from the cycles that were dominant at the time, including the Madden Julian Oscillation (MJO), the Pacific-North American cycle (PNA), and the Arctic Oscillation (AO) and the current and projected (within one month) pattern of sea surface temperature anomalies using the method developed by Fox Weather. Numbers of 30-day forecasts produced for each location were 14 in 2010 and 15 in 2011.

Actual amounts of rainfall were obtained for the same seven locations and time periods as the rain forecasts. Rain data were collected using automatic CR-1000 data loggers operated by Washington State University (AgWeatherNet, Prosser WA) or Oregon State University near each location. Data sets were created with actual and predicted precipitation matched by year, date, and location. Predicted and actual rainfalls were analyzed as binary events of either days with or without rain. A computer program was developed to manage and analyze data sets.

Accuracy of rainfall prediction was analyzed for the 15-day and 30-day forecasts. Accuracy was partitioned into sensitivity and specificity where specificity is the percentage of forecasted non-rainfall events classified correctly and sensitivity is the percentage of forecasted daily rainfall events classified correctly. Adjusted sensitivity was used to give a wider target than only one day for evaluating accuracy of forecasted rain events and included the forecasted day for rain plus the next two days. Therefore, adjusted sensitivity was the percentage of forecasted daily rainfall events classified correctly with a three day-target for success. The rationale for the three-day target was that a fungicide applied just before the first day would be effective in managing late blight throughout the three day period. A fungicide applied after rainfall would not be as effective in managing late blight. The maximum value for adjusted sensitivity was set at 100% to correspond to the concept of sensitivity and to treat the three days as one unit.

Results

Actual number of days with rain varied among locations as illustrated for data from Prosser and Othello in 2010 and 2011. The number of days in which rain was forecasted usually exceeded the number of days with actual rain for all locations and for both the 15-day and 30-day rain forecasts (Tables 1 and 2). Trends for accuracy were the same for the seven locations and data are presented only for Prosser and Othello to reduce repetition.

Specificity (accuracy of predicted non-rainy days) for the 15-day rain forecasts was generally greater than 70% during the test period at Prosser and Othello in 2010 and 2011 (Figs. 1 & 2). Mean sensitivity (accuracy of predicting rainy days) was equal to or above 60% for 4 of 58 sets of forecasts over five consecutive days. Adjusted sensitivity was equal to or above 60% for 32 of 58 sets of forecast over five consecutive days at the two locations for both years.

Specificity for days of the forecast for the 15-day forecasts generally was above 80%. Adjusted sensitivity was greater than 80% for the first six days of 15-days rain forecasts at both locations both years (Fig. 3). Sensitivity and adjusted sensitivity were initially relatively high and then decreased as days of the forecast increased from day 6 to day 14 (day 0 was the first day of the forecast) for the 15-day forecasts at Prosser in 2010 and 2011 (Fig. 3). The same trends occurred at Othello in 2010 and 2011 (data not shown). Mean sensitivity for combined 15-day forecasts from the first day of prediction (day0) to the last day (day14) was linearly reduced by a half to a third at Prosser in both years (Fig. 3). (The day the forecast was issued was considered day 0 and consequently the 15th day was day 14).

Adjusted sensitivity of the 15-day forecasts was compared between the month having the highest incidence of rain (May), and the month having the least incidence of rain (July). Adjusted sensitivity was considerably higher for May than July at both locations. As an example, data for both years at Prosser are illustrated in Figure 4. Adjusted sensitivity was 100% for at least the first seven days of the May rain forecasts at Prosser each year (Fig. 4).

Specificity and sensitivity for the 30-day forecasts were similar among locations through the late blight season in 2010 and 2011. Specificity was generally above 80% at both locations in both years. Sensitivity at Prosser was greater than 0.50 only for most of June in 2011 (Fig.5). Mean specificity was generally above 80% as forecast day increased during the 30-day forecasting period (Fig. 6). Mean sensitivity decreased to near zero after day 4 and 5 of the forecast but peaked higher at various times during the 30 day forecast (Fig. 6).

Discussion

The Columbia Basin is in a rain shadow of the Cascade Mountain Range and accurately forecasting when rain will occur is more difficult than forecasting when rain will not occur. In agreement, specificity for both the 15- and 30-day rain forecasts was high, generally above 80%. Knowing with reasonable confidence that rain is not going to occur can be helpful in making late blight management decisions. This can be advantageous during expected "dry periods," such as July, to lengthen intervals between fungicide applications.

Adjusted sensitivity for days of the forecast, as expected, was higher than sensitivity and was above 80% for at least the first six days of 15-day rain forecasts. Adjusted sensitivity was sufficiently high to be valuable in making late blight management decisions. Sensitivity was above 50% the first 2 to 3 days and below 50% after day 6 of the 15-day rain forecasts. Sensitivity alone would not be acceptable for making late blight management decisions in the Columbia Basin.

Sensitivity of 30-day rain forecasts was limited during dry seasonal periods and was attenuated further within a forecast as day from initiation progressed. For example, sensitivity over days of a forecast (day0 to day29) had a sharp reduction of accuracy from the first 15 days of a forecast compared to the last 15 days. The mean of forecasted days correctly predicting a rain event was 36.5% for the first 15 days and 7.3% for the last 15 days over the 2010 and 2011 test seasons at Prosser and Othello. Nevertheless, sensitivity of the 15- and 30-day rain forecasts was often above 50% during the "wetter' months of May and June and to day 6 for both the 15- and 30-day rain forecasts and could be valuable in predicting rainy days during these times. Because sensitivity and adjusted sensitivity decreased as days of the forecast increased, rain forecasts should be monitored daily when used for late blight management. Adequate time of at least two to three days to apply fungicide from the day of the forecast was usually available before rainy days.

The low performance in this study in predicting sensitivities and adjusted sensitivities after days 4 and 5 for the 30-day forecasts is related to the weak and intermittent characteristic of the westerlies during these seasons. The seasonably diminished strength of the westerlies and their occasional interruption by other patterns make it difficult to estimate the length of quasi-periodic variations in flow that are usually observed during other seasons. Such interruptions are often caused by monsoonal flow of moisture and rains from the southwestern US deserts, or subtropical high pressure that extends into Washington State during the summer. Sometimes, bursts in the westerlies can be anticipated, which can produce an occasional forecast for rain out 18-25 days that agrees well with the observations. However, with the techniques in use at the time, a consistent occurrence would not have been expected.

Rain forecasts can be helpful in scheduling fungicide applications in the for late blight management in the Columbia Basin. However, scheduling fungicide applications should not rely solely on targeting fungicide applications before rain. Growth stage of the crop, abundance and location of late blight inoculum in the region, and method of application are all important factors. Concerning crop growth stage, if late blight has not been detected in fields in the Columbia Basin, late blight fungicides are not needed before foliar closure between rows. However, fungicide applications should be continued until harvest if late blight is present in a field or neighboring fields. When inoculum is present in and adjacent to fields, fungicide applications are needed on a five to seven day schedule because wet periods from over-head irrigation will favor sporulation and infection. Periods with dew, especially when juxtaposed with wet periods from irrigation water, will favor infection. Furthermore two fungicide applications are needed when applied by air before the fungicide will be adequately distributed throughout the crop canopy for good protection.

A target window wider than one day improved forecast sensitivity. Adjusted sensitivity as evidence from this study has utility in scheduling late blight fungicides in the Columbia Basin. A rain forecast that was targeted one to two days before the actual day of rain is valuable for disease management in that a fungicide could be applied before the wet period so that infection could be prevented.

Acknowledgement This research was funded by an AFRI grant.

Table 1. Mean of predicted and actual number of days with rainfall forecasts of five consecutive days for 15-day rain forecasts for Prosser and Othello, WA in 2010 and 2011.

2010					2011				
Forecast	Prosser		Othello		Forecast	Prosser		Othello	
Set Range	Predict	Actual	Predict	Actual	Set Range	Predict	Actual	Predict	Actual
May10-May30	8.8	5.6	8.8	4.4	May9-May29	9.4	4.4	9.4	6.0
May17-June6	8.4	7.2	7.4	6.2	May16-June5	7.6	4.8	7.2	5.8
May21-June16	6.0	8.0	6.2	7.0	May23-June12	9.6	5.6	9.6	7.4
May31-June20	4.6	5.8	5.8	5.6	May30-June19	6.2	2.6	5.6	3.2
June7-June27	2.4	3.0	3.8	3.0	June6-June26	3.8	1.6	3.0	1.8
June14-July4	5.4	2.6	5.6	2.6	June13-July3	5.4	1.0	5.2	1.6
June21-July11	2.6	1.0	4.6	1.0	June20-July10	4.0	0.0	4.6	1.2
June28-July18	2.2	2.0	3.6	1.8	June27-July17	3.8	0.0	3.0	2.0
July5-July25	0.2	1.0	1.0	1.0	July4-July24	3.4	0.0	3.4	1.8
July12-Aug1	2.4	1.6	4.0	2.4	July11-July31	3.0	1.0	4.6	2.6
July19-Aug8	2.4	2.0	3.0	3.0	July18-Aug7	2.0	1.0	1.6	1.8
July23-Aug15	2.6	2.0	2.4	2.6	July25-Aug14	1.2	0.2	2.0	2.0
Aug2-Aug22	1.4	0.0	1.6	0.0	Aug1-8/21	0.4	0.0	1.0	2.0
Aug8-Aug29	1.8	0.0	2.2	0.0	Aug8-8/28	2.4	0.0	3.2	2.2
Aug16-Sep5	0.0	1.0	0.2	1.0	Aug15-Sep4	0.8	0.0	1.2	1.0
Aug23-Sep12	2.4	2.6	3.0	1.8	Aug22-Sep11	1.6	0.0	3.2	0.8
Aug30-Sep19	3.2	5.4	4.2	2.8	Aug25-Sep16	2.4	0.0	4.0	0.4
Sep6-Sep26	5.4	8.2	6.0	4.4					

Table 2. Predicted and actual number of days with rainfall relative to single 30-day rain forecasts for Prosser and Othello, WA in 2010 and 2011.

2010					2011				
Forecast	Prosser		Othello		Forecast	Prosser		Othello	
Range	Predict	Actual	Predict	Actual	Range	Predict	Actual	Predict	Actual
May16-Jun15	9	12	9	10	May10-Jun8	8	9	8	12
Jun1-Jun30	10	8	10	7	May17-Jun15	10	6	8	8
Jun10-July9	6	3	7	3	May24-Jun22	16	7	17	9
Jun15-July14	6	4	6	4	May30-Jun28	6	4	6	5
Jun18-July17	6	4	6	3	Jun8-July7	6	2	6	3
July1-July31	2	3	5	4	Jun13-July12	4	1	5	2
July13-Aug11	3	3	5	4	Jun20-July19	6	0	8	3
July19-Aug17	5	2	5	3	July1-July30	2	1	4	4
Aug1-Aug31	4	0	3	0	July12-Aug10	6	1	8	4
Aug3-Sep2	3	1	3	1	July20-Aug18	3	1	4	4
Aug9-Sep8	6	1	6	1	July28-Aug26	3	0	4	3
Aug17-Sep15	0	4	1	2	Aug10-Sep8	4	0	4	3
Aug26-Sep24	6	10	9	6	Aug16-Sep14	4	0	6	1
Sep6-Oct5	9	9	11	5	Aug24-Sep22	3	0	3	4
					Sep1-Sep30	3	0	3	4

Figure 1. Specificity, sensitivity and adjusted sensitivity for 15-day forecasts for rain over the test season at Prosser, WA in 2010 and 2011 (lines are 2-day moving average, squares and diamonds are actual values).

2010 2011

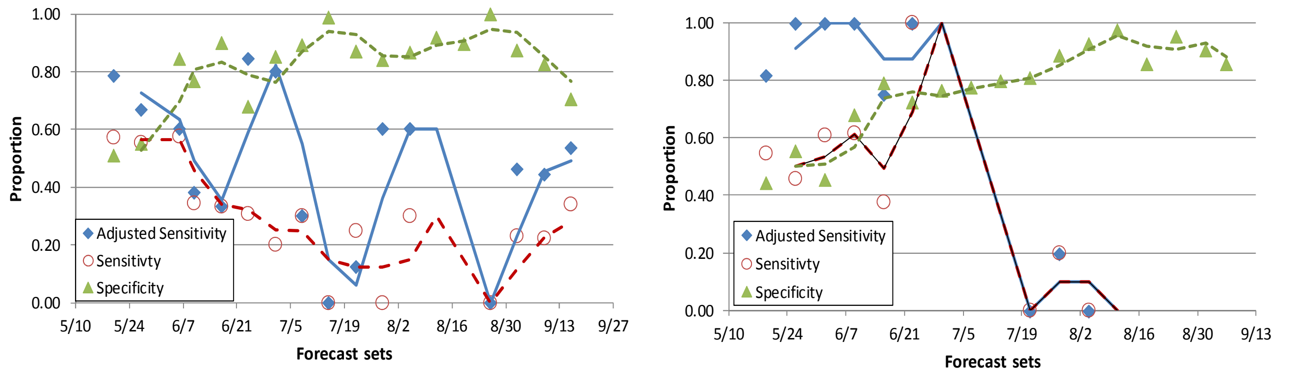


Figure 2. Specificity, sensitivity and adjusted sensitivity for 15-day rain forecasts over the test season at Othello, WA in 2010 and 2011 (lines are 2-day moving average, squares and diamonds are actual values).

2010 2011

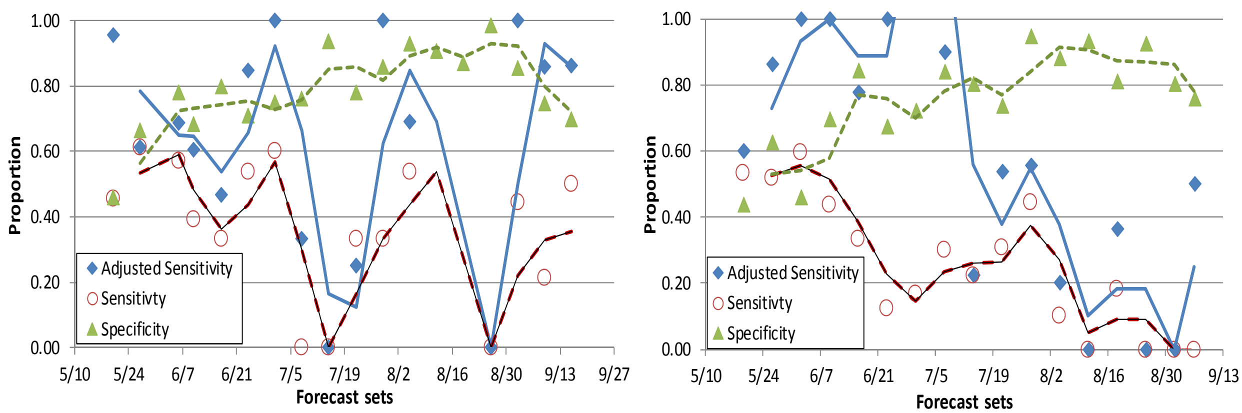
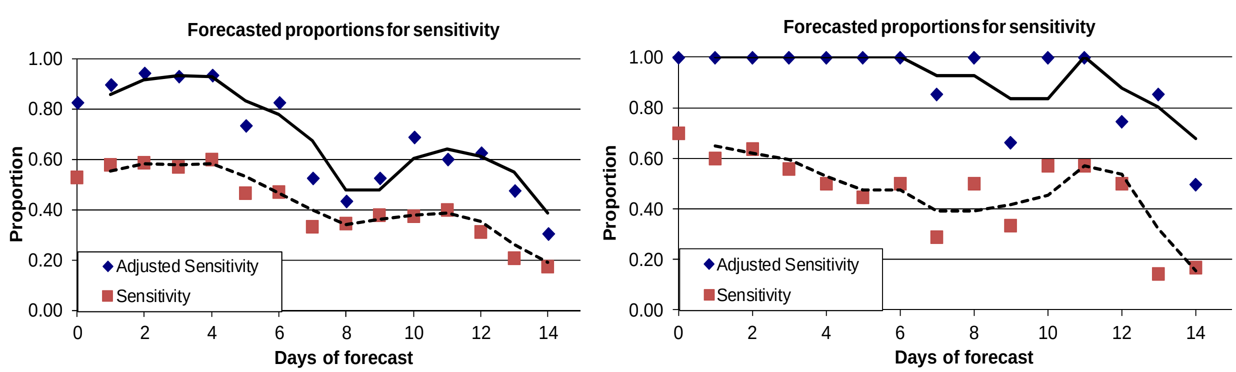


Figure 3. Mean adjusted sensitivity for 15-day rain forecasts over days of the forecast at Prosser, WA in 2010 and 2011.

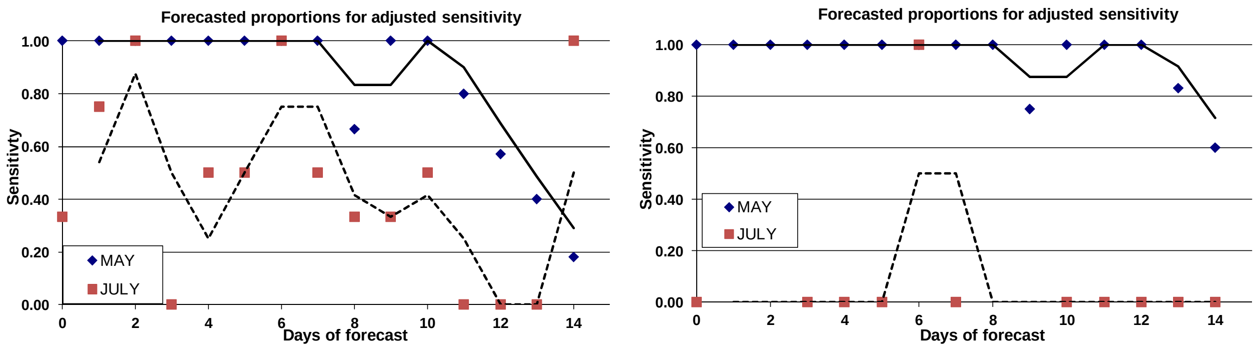
2010 2011



Number of forecasts: 93 from May through Sept. 2010; 88 from May through Sept. 2011.

Figure 4. Adjusted sensitivity for 15-day rain forecasts over days of the forecast at Prosser, WA for May and July in 2010 and 2011

2010 2011



Mean of 18 forecasts in May and 21 in July 2010; mean of 22 forecasts in May and 21 in July 2011.

Figure 5. Specificity, sensitivity and adjusted sensitivity for 30-day rain forecast over the test season at Prosser, WA in 2010 and 2011

2010 2011

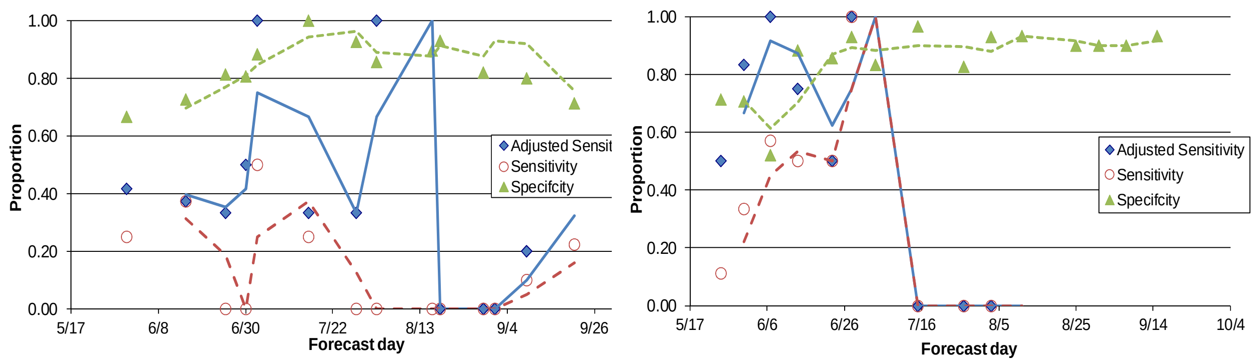


Figure 6. Specificity, sensitivity and adjusted sensitivity for 30-day rain forecasts over days of the forecast at Prosser, WA in 2010 and 2011

2010 2011