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Comparative analysis of models integrating synoptic forecast data into potato late blight risk estimate systems

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Abstract

Determinacy analysis, logistic regression, discriminant analysis and neural network models were compared for their accuracy in 5-day (120 h) forecasts of daily potato late blight risk according to a modified-Wallin disease severity model. For 12 locations in Michigan, variables derived from extended forecast data (MEX) from the National Weather Service model output statistics (MOS) were compared with those similarly derived from Unedited Local Climatological Data (ULCD) for the growing seasons 2001–2004. The most effective model for late blight risk prediction based on comparison with risk estimated with ULCD was a resilient propagation (Rprop) neural network model with 49 variables and 10 hidden nodes. The neural network model had significantly higher overall accuracy than the other models, and was particularly successful at predicting risk values in June, July, and August when knowledge of potato late blight risk is most critical to growers making management decisions with regard to fungicide sprays and irrigation scheduling. The neural network model was also significantly more accurate than the regional average of days with no late blight risk (0.72%). For each of the four models, monthly accuracy at any single station was negatively correlated with the percentage of days per month classified as risk days for potato late blight ($P = 0.01$). Although no validation with disease data was conducted, such models are still useful in the context of advising growers of forecast conditions that may be favorable for late blight according to model values, such as Wallin style disease severity values, with which they are familiar.
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1. Introduction

A wide variety of economically important crop diseases are closely related to growing season weather conditions. Air temperature and canopy moisture associated with dew or precipitation, as well as wind speed and direction, solar radiation, soil temperature and water availability, can influence the biological interaction between pathogen and host. As a result, an increasing number of expert systems in plant pathology rely on estimates of disease risk based on local weather conditions for informing management decisions. The demand for decision support systems and associated automated weather systems and internet modules is well described by Magarey et al. (2002).

Potato late blight models based on temperature and relative humidity have been extensively implemented since the 1960s for the reduction of fungicide use (Wallin, 1962; Mackenzie, 1981). Over 20 models have been developed that

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utilize temperature and moisture inputs from in-canopy, on-site automated weather stations or off-site regional stations. Such models work to limit grower expenditures and reduce the amount of chemical released to the environment while achieving optimal control of potato late blight. Historically these models have used weather data that is at best real-time. The incorporation of extended range forecast data into disease risk systems render these systems even more valuable by providing prediction of risk conditions up to several days in advance of their occurrence.

Sixty-hour predictions from NWS synoptic model output statistics (MOS) have been used to forecast periods of high relative humidity, but with a questionable level of accuracy for plant disease control models (Wilks and Shen, 1991). Accuracy was limited ultimately by the dew point component of the MOS guidance. When similar data were incorporated into probability forecasts for potato late blight disease risk categories, simulated results seemed acceptable for use in the field, but only within a limited time frame. With perfect knowledge as a proxy for 24 h prediction, area under the disease progress curve decreased about 5% for late blight field infections (Raposo et al., 1993). However these results have been difficult to verify due to lack of inoculum and the simulation approach taken in the analysis.

Extended range forecast model output statistics (MOS) including 192 h maximum and minimum daily temperatures have been produced by the National Weather Service NWS since 1994 with the Global Forecast System (GFS) numerical model (Carrol and Maloney, 2004). Since that time, probability of precipitation estimates (PoP), temperature at specified hours, dew point temperatures, cloud cover, wind speed, and quantity of precipitation estimates (QPF) have been added to the original MOS alphanumeric message (Erickson and Dallavalle, 2000). The older FOX GFS MOS system was discontinued at the end of 2002–2003 and was replaced by the new extended forecast system (MEX) including 18 variables in 192 h forecasts. The MEX system was verified from 2000 until the discontinuation of the FOX system, and showed improvements in the accuracy of warm season temperatures and in PoP (Carrol and Maloney, 2004), both of which are critical in the modeling of crop growth and disease variables accurately. The improvements in the model outputs have led to use of the extended range MOS in forecasting streamflow (Clark and Hay, 2004) and freezing rain episodes (Cheng et al., 2004). While commercial firms marketing weather forecast products to growers have incorporated extended range forecasts into their plant disease risk models since the mid 1990s (Magarey et al., 2002), there has been little discussion in the literature as to the types of models used for predictions or the accuracy of these model forecasts. This is especially true of the MEX model that first became publicly available during the 2003 growing season. Recent applications have shown extreme biases and low skill for large portions of the U.S. in the model output, but these biases do not preclude the results from being useful in derived forecast situations (Clark and Hay, 2004).

This paper compares four types of models for incorporating extended range forecast data into a potato late blight risk system for Michigan by predicting risk on a Boolean scale (0, no risk; 1, risk). A method was developed to derive hourly microclimate variables associated with potato late blight risk from the available MEX MOS alphanumeric message. Data directly available in the MOS, as well as those data values derived as secondary data, were used as input variables into determinacy analysis, logistic regression, discriminant analysis and neural network models. No field assessments of late blight occurrence or severity were conducted. However, the accuracy and the appropriateness of each of four techniques in predicting daily late blight risk using a Wallin-type disease severity value system for 24, 48, 72, 96 and 120 h forecasts was assessed through comparison with similar values derived from Unedited Local Climatological Data (ULCD).

2. Materials and methods

2.1. Derivation of hourly and daily risk values from forecast data

One hundred and twenty hour late blight risk predictions were calculated from NWS medium range forecasts for each of 12 stations in Michigan for each growing season (1 May–30 September) from 2001 to 2004. Station locations and their respective station identifier included: Alpena, APN; Kalamazoo, AZO; Benton Harbor, BEH; Holland, BIV; Newberry, ERY; Escanaba, ESC; Flint, FNT; Grand Rapids, GRR; Houghton Lake, HTL; Ironwood, IWD; Jackson, JXN; Saginaw, MBS. In total, 24,573 daily predictions were tested.

A modified-Wallin disease severity value (DSV) model (Wallin, 1962) is currently used to calculate the risk of potato late blight by Michigan State University (MSU) for daily distribution to Michigan potato growers through a web accessible management recommendation site (Baker et al., 2005; MSU, 2005). For purposes of this paper, the MSU model was used without modification. This paper does not attempt to justify or increase the quality of the current system, but focuses strictly on the integration of NWS predictions within this system's framework. The MSU model

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