REAL-TIME DISEASE PREDICTION AND FORECASTING FOR THE MANAGEMENT OF PECAN SCAB

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BACKGROUND

Pecan scab, caused by the fungus *Cladosporium caryigenum* (syn. *Fusicladium effusum*), is the most important and destructive disease of pecans.Pecan scab is most damaging to the fruit. Like other parts of the tree, the newly developing shucks can be very susceptible, and as they age, the level of susceptibility decreases. Pecan scab infection can lead to decreased yield and a reduction in the quality of fruit. Scab can induce fruit drop and under-sizing by cutting off water and nutrient flow while fruit is developing (Gottwald, 1985). Percent oil and moisture are often reduced, leading to lower quality fruit (Gottwald, 1985).

Weather variables that play an important role during pecan scab epidemics include leaf wetness, relative humidity, temperature, wind, and rain. For *C. caryigenum,* temperature has been well studied in fungal populations from Georgia. In those studies, growth of *C. caryigenum* occurred from 15 (59°F) to 30°C (86°F). Growth was slow at 15°C (59°F) and increased to a maximum rate of growth at 20°C (68°F) with 48 hours of continuous leaf wetness. Growth gradually declined between 20°C (68°F) and 30°C (86°F) with 48 hours of leaf wetness (Gottwald, 1985).

Weather variables also play an important role in spore (conidial) dispersalevents. Spore dispersal is facilitated by wind and rainfall runoff. In Georgia, spore dispersal occurring via heavy rainwater runoff was minimal. However, maximum quantity of spores were captured after periods of light rain showers and multiple consecutive days that had 10-18 hour periods of relative humidity greater than 90% (Gottwald, 1982). During prolonged rainstorms, the greatest occurrence of spore dispersal was documented during the first few hours of these rain events. As the rain events progressed through time, the number of spore dispersal events decreased (Gottwald, 1982). Numerous studies have demonstrated that highest levels of aerial spore dispersal result after a drop in humidity, either after the morning hours when relative humidity drops from its daily high, or following a rainstorm (Gottwald, 1982; Gottwald and Bertrand, 1982; Latham, 1982).

Several methods have been developed to better schedule fungicide applications including calendar dates, growth stage of the tree, and disease prediction models.In many areas of the United States where pecan scab epidemics are severe, calendar-based programs have traditionally been the method of choice for scheduling fungicide applications. In a calendar-based program the schedule might include 2 pre-pollination sprays, starting in late March or early April, followed by 6 cover sprays, with the final spray occurring in August. Using this calendar-based schedule, a minimum of 8 sprays would be applied during the growing season. During periods when weather is not favorable for scab increase, unnecessary fungicide applications may be applied. This is not only inefficient and expensive, but the practice can result in populations of *C. caryigenum* that are resistant to fungicides, rendering those chemicals ineffective. Resistance to propiconazole and fenbuconazole has been identified in Georgia (Reynolds, Brenneman, and Bertrand 1997). Other advantages associated with avoiding unnecessary application of fungicides include reduced human exposure and reduced chemical input to the environment (Sutton, 1996).

The Oklahoma Agweather Pecan Scab Model was developed at Oklahoma State University during the mid-1990s. The model is currently available to Oklahoma growers via the Oklahoma Mesonet (agweather.mesonet.org)(Driever, 1998). The model assesses the need for a fungicide application using cultivar susceptibility, relative humidity, and temperature as inputs. Timing of fungicide application is dependent on the accumulation of periods of weather favorable for scab development termed a 'scab hour'. A scab hour is defined as an hour in which the average relative humidity is greater than or equal to 90% and average temperature is greater than or equal to 70°F (21°C). A highly susceptible cultivar should be sprayed after ten scab hours, a moderately susceptible cultivar after twenty scab hours, and a resistant cultivar after thirty scab hours (Sutherland et al., 2005). Weather data is collected from 120 meteorological-grade stations throughout the state that are maintained by the Oklahoma Mesonet. Each county in Oklahoma has at least one station that measures weather conditions every five minutes. Weather variables measured include but are not limited to temperature, relative humidity, solar radiation, and rainfall.

Some Oklahoma growers have reported that improvements in the accuracy of the model are needed. Growers have indicated that the model often underpredicted disease events. There are numerous reasons for this phenomenon. Perhaps growers have an unreasonable expectation for scab damage that does result even if fungicides are applied according to the model. Growers should note that low levels of scab typically do not result in economically significant damage to the crop. However, re-evaluation of the model parameters may also identify weaknesses in the current pecan scab model. This area has been the main focus of the research presented here. Our techniques use statistical approaches that are relatively new to the field of plant pathology. Combining detailed weather data and statistical-based techniques has resulted in several new pecan scab prediction models.

METHODOLOGY

To develop the new pecan scab model, disease data (fruit severity) were collected weekly, every two weeks, or monthly depending on locations and year. Data were from the cultivars 'Burkett' located in Burneyville, OK (1994 and 1995), 'Schley' located in Vinita, OK (1995) and Sparks, OK (1996), Natives located in Sparks, OK (1996), 'Pawnee' located in Madill and Perkins, OK (2009), and 'Meramec' located in Perkins, OK (2009). Average daily weather data were collected from the Oklahoma Mesonet station in the closest proximity to each research location. Treatments included non-treated controls and various sequences of fungicide applications in order to create varying levels of severity.Fungicide products used for the study were all commercially available products that wereapplied in proper rotation. Daily weather data were converted to moving averages with respect to days between disease ratings for selected weather variables. Rainfall (≥0.10 in.) and disease severity (≥25%) thresholds were converted to binomial variables where 1 was above and 0 below the threshold for each variable. Weather variables were used as independent variables and disease severity (DS) as the dependent variable using generalized estimating equations (GEE). This technique allowed for adjustment in the model building to account for dependence between disease observations, which is a confounding factor when developing statistical models. Goodness of fit was determined using the quasi-log-likelihood under the independence model information criteria adjusted for number of model parameters (QICu). Minimizing QICu demonstrates better model fit. The statistical model was then converted to an applied form that could be used to calculate the probability of damaging scab severity. Probabilities were plotted against pertinent weather variables to identify weather thresholds that were favorable for disease. To identify important weather variable thresholds, probabilities ≥ 0.50 were used to denote a significant disease event.

RESULTS AND DISCUSSION

There were 249 observations of disease severity used in the model building process. The best model (model 1) included moving averages of air temperature, relative humidity, total daily radiation, and the presence or absence of a rain event (QICu = 168). In model 1, probability of the occurrence of pecan scab was positively related to increasing air temperature and relative humidity. However, the occurrence of pecan scab was inversely related to increasing radiation and rain events. During subsequent model performance evaluations, average total radiation was held constant and no rain events were assumed. Under these conditions, temperatures near 68°F (20°C) and a relative humidity ≥ 95% were required for a high probability of damaging levels of scab. According to this model, as average temperatures increase above 68°F (20°C), damaging levels of scab are likely to develop at lower levels of humidity (Fig 1).

The second best model (model 2) included moving averages of dew point, total daily radiation, and the presence or absence of a rain event (QICu = 177). While the fit of model 2 did not appear as good as that of model 1, model 2 uses one less input variable. In model 2, probability of the occurrence of pecan scab was positively related to increasing dew point. However, the occurrence of pecan scab was inversely related to increasing radiation and rain events. During model performance evaluations, no rain events were assumed. Under these conditions, dew points near 71°F (22°C) were required for a high probability of damaging levels of scab under moderate solar radiation (~20 MJ/m^2). As dew point increases, high likelihood of damaging levels of pecan scab exists at even high levels (~30 MJ/m^2) of radiation (Fig. 2).

Because it is assumed that rain events generally result in high levels of pecan scab, focus was placed on models developed assuming no rain events. In Oklahoma, rain events can be infrequent and sporadic yet pecan scab can increase. During these periods humidity is often high and temperature differences during the day and night hours are large resulting in significant dew events. Therefore, the fact that humidity and dew point are important in predicting pecan scab in our model development is not surprising.

These results indicate that while growers have expressed concern about the performance of the Oklahoma threshold-based pecan scab advisory, the thresholds appear to be within reason. The models developed here indicate that at temperatures at or above 70°F (21°C) damaging levels of pecan scab can result. Furthermore, wetting events as that result from dew formation (or high humid-

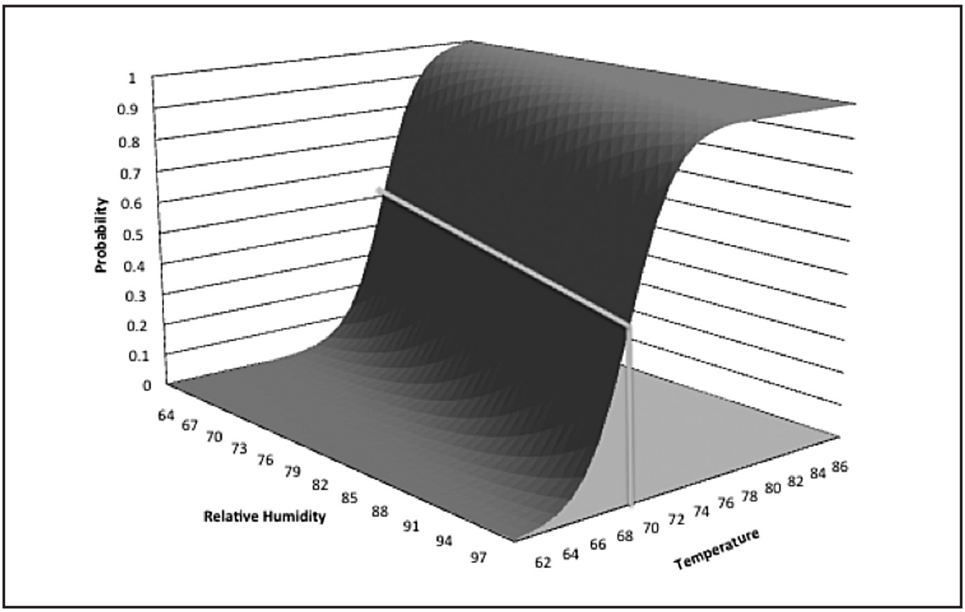

Figure 1. Response surface for model 1 illustrating the influence of average relative humidity and average air temperature on the probability of pecan scab development. The color change and bright green line indicate the 50% action threshold necessary to assume a high probability of damaging levels of pecan scab.

ity) are enough to potentially result in disease, even when rain is not involved. Model 1 further suggests that the humidity threshold in the current Oklahoma pecan scab advisory could be reduced. As temperature increases, lower humidity levels are sufficient for a high probability of scab. Perhaps reducing the relative humidity threshold of the Oklahoma advisory from 90% to 85% would reduce any false negative scab predictions that the advisory provides. More validation studies are needed to verify the usefulness of these new models for use in spray advisories. However, they do provide insight into the favorable weather conditions that result in pecan scab when rain events are not involved.

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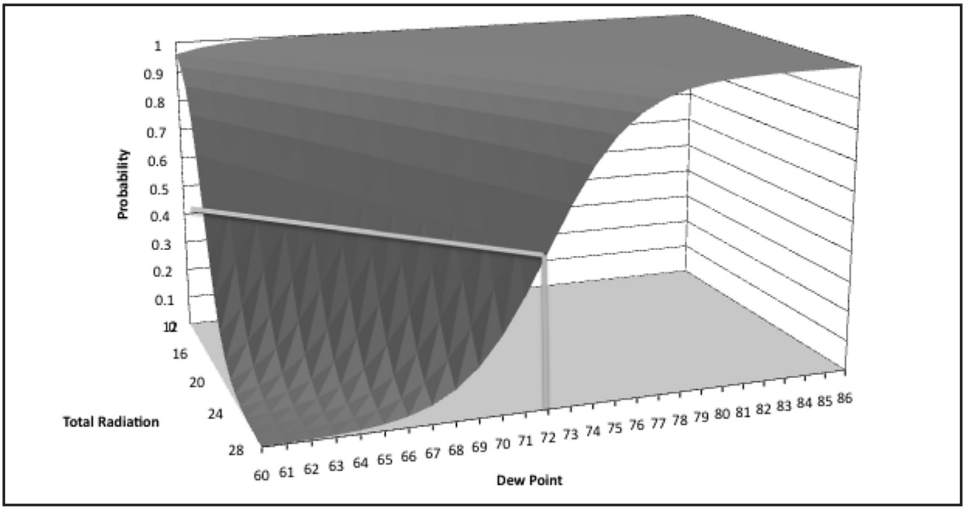

Figure 2. Response surface for model 2 illustrating influence of average dew point and average total radiation on the probability of pecan scab development. The color change and bright green line indicate the 50% action threshold necessary to assume a high probability of damaging levels of pecan scab.