DEVELOPMENT OF A THRESHOLD MODEL FOR SCHEDULING FUNGICIDE APPLICATIONS TO CONTROL PECAN SCAB

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1991

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1995

Submitted to the Faculty of the
Graduate College of the
Oklahoma State University
in partial fulfillment of
the requirements for
the Degree of
DOCTOR OF PHILOSOPHY
May, 1998

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ACKNOWELDGMENTS

I wish to express my deepest appreciation to my major advisor, Dr. Sharon von Broembsen for her enthusiastic support, constructive guidance, encouragement, and friendship throughout our time of acquaintance. My sincere appreciation also extends to committee members Dr. Michael Smith, Dr. James Duthie, and Dr. Larry Singleton, whose guidance, cooperation, and friendship has made this program of study an enjoyable learning experience. My thanks to the faculty and students of the Department of Plant Pathology for their interest, guidance, and friendship; and also to the department for the support provided during the course of my studies. Grateful appreciation also goes to Dr. J.D. Carlson of the Department of Biosystems and Agricultural Engineering for his help and cooperation. I would also like to thank Oklahoma State University for the grant that provided inter-disciplinary research and expanded the research to a usable product.

Special appreciation is extended to my wife, Connie, and my sons for their love, patience, and sacrifice throughout this learning process. Addtionally, special thanks is given to my parents and parents-in-law for their encouragement and understanding.

Finally, I would like to praise God for providing me with this opportunity and His strength that guided me through the entire process.

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CHAPTER I

INTRODUCTION

Background Information of Host and Pathogen.

The pecan tree, *Carya illinoensis* (Wang.) C. Koch, is a hardwood perennial that is native to the United States. The tree produces the pecan nut that is grown as a crop. The pecan was originally found along the Mississippi River and it's tributaries (Anderson, 1994; Brison, 1974), and is also now grown extensively in the southeastern and western U.S. and Mexico. In 1978 the U.S. Department of Commerce (1978) identified 48, 432 acres of pecans under production in Oklahoma. Of these, 37,384 acres or 77% were native pecans. The 1992 census of Oklahoma agriculture (U.S. Department of Agriculture) showed that 61,810 acres of pecans were in production. The 1992 census shows a greater than 27% increase in acreage under pecan production over the 1978 census. A survey in 1996 with a 25% return on questionnaires revealed 24,296 acres of pecans were being cropped in which 16,764 acres (66%) were native trees with the balance were cultivars (Render and Associates, 1996). This survey suggests there was an increase in acreage of cultivars in Oklahoma between 1978 and 1996.

Oklahoma produced an average of 12 million pounds of pecans per year between 1992 and 1996 with average annual sales for all pecans of $8,719,000. Compared to the twenty years previous (averaged from five year intervals) this was a production increase of more than 27% and an increase of sales of more than 90% (Bay and Howard, 1996). For the same periods, improved cultivar production increased by nearly 21% and sales increased by 74% with average annual sales between 1992 and 1996 of $1, 334,000.

These figures show that in Oklahoma the pecan industry is expanding and sales are increasing. As acreage planted in pecans increases and uniform plantings of desirable cultivars reach maturity, the probability of higher pressure from diseases and insect pests becomes more likely. With a low input crop like pecans, this will result in an increased need to control all pests and diseases in a cost efficient manner.

Pecan scab, caused by the fungal pathogen *Cladosporium caryigenum* (Ell. et Lang.) Gottwald, is the most important disease that affects pecan production in most areas where the crop is grown. *C. caryigenum* was first described in 1885 by G. Winter (Demaree, 1928). Since that time the fungus has been taxonomically reclassified and described several times (Orton, 1905; Demaree, 1928; Hughes, 1953; Lentz, 1957; Gottwald, 1982). Synonyms for *C. caryigenum* are *Fusicladium effusum* (Wint.), *Fusicladium caryigenum* (Ell. et Lang.), and *Cladosporium effusum* (Wint.) Demaree.

The fungus is in the Deuteromycetes, in the Subclass Hyphomycetidae, Order Moniliales and the Family Dematiaceae (Ellis, 1977). As such it has an imperfect reproductive state and produces spores asexually. Inoculum overwinters in stromata on the previous season's infected leaves, shucks, and woody tissues in the trees or as debris on the ground. The conidia are dispersed by wind and rain. If the spores land on a host and conditions are conducive for germination, a germ tube emerges from the spore and forms an appressorium at the host epidermis. A hyphae emerges from the pore of the appressorium and penetrates the cuticle (Latham and Rushing, 1988). Subcuticular development is characterized by enlarging, branching hyphae that extend intercellularly between upper and lower leaf epidermal cells and the middle lamella. The first observable change prior to conidiophore development is the melanization of the walls of certain hyphal cells of the subcuticular stromata (clusters of hyphal cells). The melanized cells occur in pairs, with the darker of the two swelling to form a bulbous cell. As the bulbous cells swell, they rupture the cuticle and the conidiophore arises from the distal end, producing conidia (Rushing and Latham, 1991). The conidiophores produce extensive catenulate, dendric conidial chains and multidenticulate conidiogenous ramnoconidia (Gottwald, 1982).

Conidial spores are produced in the lesions of this polycyclic pathogen. Symptoms caused by pecan scab are irregular olive-brown to black lesions that expand on susceptible tissues of the leaves, shucks and current season's shoot growth. Severe infection of young expanding leaves can result in early leaf loss and reduced photosynthetic ability that stresses the tree. Leaves become resistant to scab as they end the expansion stage and reach maturity. Infected fruits may result in small nuts at harvest with lower quality kernels. Scab infection that girdles the fruit pedicel will cause premature fruit drop. Early defoliation due to high levels of disease may also prevent the accumulation of photosynthates required for flower induction for next season's crop. Severe scab infection of the current season's shoot growth can cause shoot dieback.

Methods of Controlling Pecan Scab.

Control of pecan scab during the growing season is important to prevent tree stress and potential crop loss. Three methods of disease control are generally instituted simultaneously in pecan production to obtain the greatest amount of scab control.

Cultural control is a non-chemical method of disease control that is continued throughout the year as needed regardless of whether the trees are actively growing or not. Cultural methods include improving drainage systems for movement of water away from the trees after heavy rains, pruning the lower branches to improve air flow among the trees, removing trees to eliminate crowding or trees that scab heavily, and keeping groundcover mowed or grazed. Another cultural control that is sometimes used is removal and destruction of downed branches and other debris that may be sources of inoculum. These cultural methods are labor and time intensive, but scheduling for these tasks is highly flexible over the course of the year.

Using resistant pecan cultivars is an increasingly popular method of disease control in pecans. Many cultivars have been developed that allow a grower to choose the pecan cultivar that is best suited for their area. Although many attributes of a cultivar may be chosen to improve salability of the crop, choosing a scab resistant cultivar might be the wisest choice in areas where pecan scab is a severe problem. However, growers that purchase an older, established orchard may have trees that were once considered resistant, but now are susceptible to scab. A disadvantage to scab resistant cultivars is that they require long term planning when establishing a pecan orchard that may take 7 to 10 years to reach bearing age. Also, they are frequently expensive to purchase, and large plantings of a single cultivar may lead to a loss of resistance. Continuous monocultures of genetically similar trees can increase selection pressure for a race of pathogen for which the cultivar no longer has resistance (Fry, 1982). Because of the long time period required for a pecan tree to reach maturity, when a cultivar develops susceptibility to a new race of *C. caryigenum* chemical methods are often employed to control the scab.

Chemical control for pecan scab is in the form of fungicide applications. In areas where scab is a continual problem, fungicides are applied on a schedule. Scheduling may be set up on a calendar basis where the chemicals are applied at selected time intervals or as a phenological schedule where the developmental stages of the pecan are used to determine fungicide application intervals. Several studies have been conducted that schedule fungicide applications based on accumulations of weather related time intervals (Cooper *et al.*, 1983; Hunter *et al.*, 1978; Gazaway and McVay, 1980; Latham, 1982; McVay and Gazaway, 1980).

In the United States only a limited number of chemicals have been approved for application on pecans. These fungicides are mostly in different classes. The triphenyltin hydroxides are non-systemic foliar protectants. These fungicides have grazing restrictions and require closed tractor cabs and protective equipment for application. Propiconazole is a systemic foliar protectant fungicide with curative properties that is approved for use on pecans. However, in a trial in Alabama on pecans (Latham, 1983), little translocation of the chemical was observed at the rate used (270mg/l). Benomyl (a benzimidazole compound) is a systemic foliar fungicide with protective and curative activity. Its mode of action is the interference of nuclear division by its byproduct (methyl benzimidazole carbamate). Some resistance has been reported with benomyl in a trial in Georgia (Littrell, 1980) and Oklahoma (Marenco, 1994). Fenbuconazole is a systemic fungicide with protective, curative and eradicant properties. This fungicide is a sterol inhibiting compound that disrupts the production of ergosterol in the membranes. Azoyxstrobin is the newest fungicide approved for use on pecans. Unlike the other fungicides, it is a modified analog of a biological compound derived from another fungus. It is a systemic fungicide with protective, curative, and eradicant properties. This compound is approved for grazing and does not require a closed cab for application. It's mode of action is that it interrupts the flow of electrons in the inner mitochondrial membrane and stops production of adenosine triphosphate (ATP).

Development of a Forecast Model for Fungicide Applications.

Fungicides are only one part of the strategy for controlling pecan scab. Although all the control methods described above should be used together to provide a comprehensive program for limiting the effects of pecan scab, only through timely fungicide applications can conditions be manipulated to provide optimal control of the disease when the other methods fail. Due to the limited number of fungicides available, they should be used only as needed and rotated to prevent resistance from occurring in those that provide effective control against scab.

Determining the optimal time to apply fungicides is an area that may hold the most promise for increasing the efficacy of fungicide applications. To be able to predict the proper time to apply fungicides, the relationship of the pathogen with it's host must be understood as well as any environmental conditions that contribute to the ability of the pathogen to be able to cause the disease (Zadoks and Schein, 1979). This study of a disease in a host population is termed epidemiology (Van Der Plank, 1963). Epidemiological studies of the pathogen that result in being able to predict disease require multiple observations of the disease, weather, and/or other factors for two or more years or sites (Madden and Ellis, 1988). Accumulation of this data provides the information needed to develop a model to forecast the onset of a plant disease. Modeling of data may take many forms, but for the purpose of forecasting a disease, a quantitative model based on statistical evaluation of the data describes the relationship between two or more variables (Campbell and Madden, 1990). Van Der Plank (1963) first proposed the use of regression analysis and correlations in epidemiological studies. Although many variables must be analyzed to determine their relationship with a single component of the disease, most accurate, usable forecasting models are basically simple.

Development of a Pecan Scab Forecasting Model.

In the development of a forecast model for predicting pecan scab in Oklahoma, it is assumed that the inoculum is always present in the pecan growing areas of the study. This is supported by previous untreated studies (Marenco, 1994) that showed high disease levels without the need to apply inoculum. Based on this assumption, the correlations conducted with the epidemiological studies and weather variables for model development used lesion appearance on pecan leaves and fruits as an indication of the disease progress and inoculum source. This assumption is supported by forecasting techniques for polycyclic diseases that use secondary inoculum and weather variables to predict fungicide applications (Campbell and Madden, 1990). One means of controlling polycyclic diseases is to limit potentially rapid disease increase rates (Fry, 1982). Therefore, applying fungicides in a timely manner at the approved application rates provides an opportunity to control pecan scab at levels not detrimental to the crop.

Objectives of the Study.

The initial objective of this research was to continue to accumulate epidemiological and weather data at Oklahoma pecan sites that was begun by Alina Marenco (1994). These studies were expanded to two other sites to obtain data that represented the pecan-growing regions of the state. This data was then analyzed and trials conducted to determine if a correlation could be derived from the data to provide a usable forecasting model. Data was analyzed empirically and statistically. Two different sources of weather data were also be compared. Lastly, the model was programmed on an Internet home page to determine feasibility of providing an interactive source of forecasting for fungicide applications to control pecan scab.

CHAPTER 2

EPIDEMIOLOGICAL STUDIES OF PECAN SCAB AND COLLECTION OF WEATHER DATA IN THREE OKLAHOMA ORCHARDS

Introduction

The effect pecan scab may have on pecan production is highly variable with locale, weather patterns, and tree susceptibility. Of concern in this study is the variation of weather conditions within the pecan producing regions of Oklahoma and how these relate to pecan scab on the leaves and fruits in the field.

The complexity of environmental conditions that require many different cultivar recommendations in Oklahoma as illustrated in Pecans, a Grower's Perspective (Rice, 1994) is caused by geographical and climatic interactions (Fig. 2.1). Oklahoma has an annual rainfall gradient that varies from about 381mm in the northwest to more than 1270 mm in the southeast corner of the state. In addition to the wide range of moisture variation, Oklahoma's topography is also highly variable. The state has dry mesas in the northwest, dry plains in the western half of the state, rolling hills and low mountains in the eastern half, and swamp lands in the southeast corner (Murray, 1996). Oklahoma's vegetation varies from mixed short grass prairie in the west, tall grass prairie and mixed hardwood forests in the northeast quarter of the state to pine forests and wetland plants in the southeast quarter of the state. Because Oklahoma is in the central plains of the U.S., fluctuations of the jet stream and the occasional, upward flows of warm, moist air from the Gulf of Mexico add to the complexities of the state's regional weather differences. The resulting wide variation of growing conditions in Oklahoma creates a complexity of environments that must be taken into account to allow disease treatment recommendations to be made to the pecan grower. For this reason an epidemiological study was initiated to begin to understand the zonal requirements for the progression of pecan scab in the state.

Materials and Methods

Epidemiological Studies.

Pecan orchards were chosen to represent the full range of conditions throughout the pecan-growing regions of Oklahoma and both native pecans and susceptible cultivars. The field sites chosen for studies in 1994 and 1995 were Red River in the south-central part of the state, Sparks in the central part of the state, and Vinita in the northeastern corner of the state (Fig. 2.2). At all sites, pecan scab inoculum (*Cladosporium carigenum* (Ell. et Lang.) Gottwald) was naturally sufficient to provide strong disease symptoms when conditions were within the range required for disease initiation.

Red River Site. This site was located at the Noble Foundation Research Farm 5-km southeast of Burneyville in Love County on the north lower flood plain of the Red River. The soil on this trial site was of the Miller-Yahola Association (Maxwell and Reasoner, 1966). This association is characterized as deep, clayey and loamy soils; however, the Yahola soil predominated at the research site and is characterized as reddish loamy or sandy surface layer with loamy subsoil. The site was located on the inside of a river bend, and occasional flooding occurs. The orchard was characterized as crowded. Scab disease pressure was heavy due to site location and for want of pruning of lower branches and orchard thinning. Ground cover was a mix of Bermuda grass, native grasses, white clover, and native forbes. The orchard floor was typically maintained in the early part of the growing season by grazing stocker cattle and occasional mowing. In mid-season the farm was seldom mowed with the ground cover being mowed and downed branches raked just prior to fall pecan harvest. Fungicide spray programs are typically limited due to the presence of cattle and the lack of fungicides that are approved for use with cattle grazing. If applied, fungicide sprays generally are combined with insecticides and zinc foliar applications. Fertilization is on a regular schedule to maintain trees and ground cover. The 'Burkett' cultivars were located in even rows in the northeast part of the orchard and were about 40 years old. The native pecans were located in random order in a naturally occurring grove on the southwest side of the farm and were about 60 years old.

Sparks Site. This site was located at the Oklahoma State University Pecan Research Farm 12.5-km southeast of Chandler in Lincoln County. The trial site was bounded on the north by the Quapaw Creek and on the east by State Highway 81B. The site of the trial was located on bottomland adjacent to the creek and is subject to occasional flooding. The soil is of the Port-Pulaski Association (Williams and Bartolina, 1970). It is characterized as deep, level, and nearly level, loamy soils on flood plains. The Pulaski soil predominates at this site and is described as a 40.6 cm thick, fine sandy loam surface layer with a loamy fine sand underlay. Water is frequently within 0.6 m of the surface. The highly scab susceptible 'San Saba Improved' used for evaluation were located in even rows in the extreme northeast corner of the orchard. Some native trees were randomly distributed immediately west of the pecans, bounded on both the west and north by Quapaw Creek. The 'San Saba Improved' was about 44 years old with the native trees at least 10 to 20 years older. Scab pressure was heavy at the trial site and possibly exacerbated by the thick trees and brush bordering the encircling creek. Trees were somewhat crowded, although they were well pruned of lower branches and the orchard floor was mowed on an irregular schedule.

Vinita Site. This site was a privately owned orchard located 1.7 km east of Vinita in Craig County. The orchard was bordered on the north by U.S. 66 and bounded on the east by Little Cabin Creek. The soil for this trial was of the Verdigris-Radley-Lightning Association (Newland, 1973). These soils are described as deep, nearly level, loamy soils that are loamy throughout or have a clayey subsoil on flood plains. They are characterized by a moderately to poorly drained dark grayish-brown topsoil about 50.8 cm thick. This bottomland orchard seldom floods and was well maintained by pruning, thinning, mowing, and a weed-free area around the trees. Many cultivars were represented in these 35 year-old pecans which were planted in even, well-spaced rows. Scab pressure was light to moderate in most years. The 'Schley' cultivar and natives included in the trials were located in the southwest corner of the orchard near a section-line road that bordered the orchard on the west and about 0.4 km south of the highway.

Data loggers used for the collection of temperature (T), relative humidity (RH), leaf wetness and rainfall were either the solar-powered or the battery powered Campbell CR-10. For all data loggers the weather parameters were monitored at one-minute intervals and summarized hourly. Sensors and monitoring equipment were located onsite adjacent to the trial. The temperature and relative humidity sensors were combined in a single unit, Model number 207. The precipitation-measuring device was a Campbell Model TE525. The leaf wetness sensor was Model number 237. For the Campbell CR-10 Units, the solar collection unit was a Model MSX10. The D-battery powered Campbell CR-10 used the same sensor units, but no solar power supply. Data was downloaded for the solar-powered CR-10 unit onto a SM192 storage module. Data for the battery-powered unit was downloaded to cassette tapes.

Calibration of datalogger sensors. All sensors were initially calibrated in the lab and verified in the field with further testing after initial installation and at mid-season. For lab testing, each unit was completely connected and programmed. Units were allowed to equilibrate for about one hour prior to calibration. Temperature sensors were calibrated with a certified centigrade thermometer and tested after each modification of the program multiplier for that parameter. Relative humidity was calibrated with a water mister sprayed on the housing of the sensor unit. After adjustment of the parameter multiplier, the RH was verified with a sling psycrometer several times. Leaf wetness sensors were tested with a spray mister and calibrated to 100 percent using the parameter multiplier. Rainfall tipping bucket was tested for free swing and the multiplier was preset according to manufacturer's multiplier. After installation and programming of each unit in the field, each sensor was tested several times as described above.

Field installation of dataloggers. Installation of all units was on-site and within 0.5 m of the trees of the trial. All equipment and sensors were installed at least 1 m above the ground level to isolate the units from flooding conditions. The CR-10 units installed at the Red River and Vinita sites were mounted on 2.6 m galvanized fence posts that were placed in the ground to a depth of 0.7 m for stability. The main computer unit was mounted near the top of this pole with the provided brackets. Copper wire and lightening rods were installed on the main units to protect microcircuitry from static electricity or nearby lightening discharges. Solar panels were attached to the same pole in a position commiserate with the path of the sun. The temperature and relative humidity sensors were placed opposite and about 1 m above the ground on the pole with the monitoring unit. Both sensors were housed a single unit provided with the equipment. The rainfall-measuring unit was located on a separate pole 1.3 m above the ground beyond the drip line of the tree. The two leaf wetness sensors were located in the tree as far apart as possible on the branches above the main. Leaf wetness sensors were oriented horizontally and at an angle to simulate leaves. Sensor cables that were exposed or free swinging were supported by plastic coated, braided cable for strength. The program required the sensors to measure the ambient conditions each minute and to average them for hourly readings. Data was downloaded to disk using Campbell software, Catalog number, PC208, and converted from Ascii to spreadsheet for further analysis.

<u>Experimental design of epidemiological trials</u>. Epidemiological trials were set up similarly for each site in each year. For the Red River and Sparks sites, 10 pecan trees of the susceptible cultivars 'Burkett' and 'San Saba Improved', respectively and ten native pecan trees were chosen for the trials. On each tree two sites were marked with numbered aluminum tags to identify the leaves and fruits to be assessed for the duration of the experiment (four tags per tree). At the Little Cabin site, three trees of a susceptible cultivar 'Schley' and three native pecans were chosen. Fourteen tags on each tree identified each of the seven leaf or fruit sites. For the trees in all trials, the tagged second, third, and fourth bipinnately compound leaves were used in the ratings. The first leaf was not used due to the tendency of pecan trees to exhibit an inconsistency in leaflet numbers in the primary leaf. In all trials, each fruit tag was associated with a cluster of

three to five developing fruits. Leaf and fruit clusters were located at the southwest and northeast compass points in the trees when possible at a distance of 1.3 to 4.9 m above the orchard floor. Tagged leaves and fruits at a height greater than 2.3 m were accessed by the use of a sectional aluminum ladder which was attached to the rear bumper of the truck by sliding the legs of the ladder into the slots of a heavy, steel bracket. Disease on the tagged leaves and fruits were rated weekly at all sites and weather data from the onsite data-loggers was downloaded on these visits. Fungicide applications were not applied during the course of the epidemiological trials. Normal fertilization and insecticide application schedules were maintained.

Collection and summary of pecan scab disease ratings. All sites for all years used the same method of epidemiological measurement and similar equipment for weather data collection. For the epidemiological measurements, all pecan leaves and fruits were rated from '1' to '8' for pecan scab disease with the modified Horsfall-Barratt rating scale (Horsfall and Barratt, 1945; Hunter and Roberts, 1977) for leaf (Figs. 2.3) and fruit (Fig. 2.4) disease ratings. A rating of '1' indicated no disease and a rating of '8' indicated scab coverage of 98 to 100%. The scale requires that all leaflets be averaged for a single reading for each leaf. A single rating was then recorded for the number corresponding to the tagged leaves. While at that site, the tagged fruit clusters were also rated for disease. As the number of fruits per cluster varied, a single rating was obtained which represented the overall disease level for that cluster. The corresponding morphological structure at each tag on all trees at each site was rated at every visit. Pecan scab disease ratings and downloading of weather data were conducted weekly for each site, with rare exceptions due to flooding, extenuating circumstances that prevented visitation or the final season ratings. Means for the disease rating raw data for separate leaf and fruit ratings for each visit were calculated.

For all years and at all sites, weather data from the data logger was downloaded into a Campbell SM192 storage module or cassette tapes in the field and converted to spreadsheets and graphs. The data was analyzed and examined for trends that appeared to be relevant to the progression of scab disease observed in the field.

Results

Epidemiolgical Studies.

Red River Site. In both 1994 and 1995 conditions were conducive for the development of scab at the Red River site. For the susceptible cultivar 'Burkett' in 1994, scab was present on the leaves by the second week of May. The scab on the leaves was at a rating of '2.5' by July 5 and past a rating of '5' by August 9 (Fig. 2.5). Disease on the leaves achieved a final rating of '7' by the end of the trial on September 14. The leaves of the native pecans at the Red River in 1994 did not begin to show symptoms of scab until the third week of May and by the end of the trial on Sept. 14 the rating was slightly above '3'. The 'Burkett' fruits did not begin to show the presence of disease until the first of June with a rating of three by June 22 and a rating of '5' by the end of the first week of July. The 'Burkett' fruit crop was considered damaged by the middle of July and lost by the first of August. The fruit shucks of the native pecans did not begin to show scab until the first week of July but by the end of the trial the final rating was only '3'.

In 1995 at the Red River site, the leaves of the 'Burkett' were showing scab by the first week of May, a scab rating of nearly '3' by June 25 and a rating of '5' by July 12 (Fig. 2.6). By the end of July defoliation of the first growth was nearly complete with the secondary foliar growth infected. The native pecan leaves in 1995 showed scab lesions by the end of May, a rating of '3' by the end of July, and a rating of '5.5' by the end of the trial on October 12. The fruit shucks of 'Burkett' were showing scab disease by the end of May, a rating of '2' by the end of the first week of June and total fruit loss by the end of July. The native fruit shucks had scab lesions by the first week of June, a rating of rating of '3' by August 2, and a rating of '5.5' by the end of the trial.

Sparks Site. The 1994 Sparks field trial was conducted by Alina Marenco and the results shown in her Master's thesis (Marenco, 1994). In 1995 at Sparks, the susceptible cultivar 'San Saba Improved' showed scab lesions by the middle of May, a rating of '3' by the first week of July, and a rating of '5' by August 12 (Fig. 2.7). By the end of the trial in September 14, the rating was '7' and the trees were mostly defoliated. The foliage of the native trees adjacent to 'San Saba Improved' had lesions appearing by the end of May, a rating of '3' by the middle of September and a final rating of '3.5' by the end of the trial. Due to the severity of the disease on the 'San Saba Improved' in 1993 and 1994, the trees bore no crop in 1995. The native fruits did not show scab lesions until the middle of June, a rating of less than '3' by the end of July and a rating of '5' by August 17. The end of trial the disease rating on the native fruit shucks was '6'.

Vinita Site. In 1994 the moderately susceptible cultivar 'Schley' at Vinita showed very little scab damage. Scab disease in the leaves first recorded in the third week of May and a scab rating of slightly greater than '3' by the end of the trial on September 16 (Fig. 2.8). Leaves of the native pecans had disease ratings very similar to those of 'Schley'. Scab lesions were first recorded during the same time period as the 'Schley' leaves with an end of season rating of '2.5'. The fruit of the 'Schley' showed no disease until the second week of July, a rating of '3' by August 18 and a final rating at the trials end of slightly greater than '5'. On native fruits in 1994, scab was first recorded during the first week of June, a rating of '3' in the second week of August and a final rating of slightly less than '3.5' by the end of the trial.

For the 'Schley' pecan trees in 1995, the leaves showed scab lesions by the middle of May, a rating of '3' by the first of August and a final rating on the third of October of '4.5' (Fig. 2.9). The native leaves in 1995 had scab lesions detected in the third week of May, a rating of '3' by the end of September and a final rating of '3.25' by the end of the trial. The fruits of the 'Schley' in 1995 showed disease during the first week of June, a rating of '3' by July 25, and a rating of '5' in the first week of September. The final rating for the 1995 'Schley' fruits on October 3 was '6.5'. The native fruits in 1995 did not show scab until June 23, and the final rating at the trial's end of slightly less than '3'.

As previously described, the disease ratings and onsite weather were recorded at each visit with a weekly rating as the target. All raw data was entered into computer files and transformed to graphs. The goal of graphing the epidemiological data was to develop an understanding of how the disease progressed and at what time during the pecan growing season the pecan scab had it's highest rate of progression and the level of disease incidence in the leaves and fruits of the unsprayed pecans.

Discussion

The progress of pecan scab is important to pecan growers because of the impact of the disease on the crop. An understanding of the epidemiology of the disease is also essential for the prediction of timely fungicide spray applications. In a study correlating percent fruit drop to disease ratings (Hunter, 1983) it was found that infected pecans with a rating of '3' (11-25% infected) often dropped to the ground and were lost while those in disease ratings '4' (26-50%) and '5' (51-100%) were nearly a complete loss (82.4%). Hunter used the Hunter-Roberts disease rating scale (1978) which evaluated any leaf or fruit with a rating of '5' was severely diseased. In Alabama, disease ratings of '1, 2, and 3' with this scale are considered commercially acceptable control of scab (Gazaway and McVay, 1981). This was similarly shown by Diener (1962) in his rating scale that had a maximum disease rating of '4' (>50% infection). Using the modified Horsfall-Barratt scale for monitoring the disease, any rating of '5' (50-75% infected) or greater on the scale is considered damaged and indicates a loss of viability in the leaves and a loss of quality in the fruit crop. In comparison, growers can accept the presence of low disease in their orchards and still expect a marketable crop. Therefore, any ratings greater than '3' are very significant to the pecan grower concerning the salability of the pecan crop. Even if fruit drop is avoided, reduction in kernel development can occur.

Red River Site. In 1994, the susceptible 'Burkett' cultivar had severe scab infection on the fruit shucks while the fruit was in the liquid endosperm stage (late July). This high level of fruit disease, coupled with the loss of photosynthetic area of the leaves in early August resulted in the loss of the 'Burkett' crop in this year. The heavy scab disease on the leaves also reduced the ability of the trees to accumulate photosynthates for the next season's fruit production and increased the stresses on the trees. The 'Burkett' cultivar at this site in 1995 was heavily infested during leaf expansion with phylloxera and early pecan scab infections. These severe stresses were intensified when a flood occurred on June 6. The orchard floor remained flooded for about three weeks during which time the relative humidity remained near 100 %. The heavy scab pressure on the 'Burkett' trees in 1994 and the intense disease and environmental conditions in 1995 resulted in a complete crop loss early in the season. As the trees attempted to produce secondary foliar growth in late July, the heavy presence of *C. caryigenum* spores and overstressed trees resulted in complete defoliation in late August of 1995. This stand of 'Burkett' pecan trees was removed in the late fall of 1995. In contrast, the native pecans produced a crop of fruits in both 1994 and 1995. The native trees retained their leaves until frost in both years with more disease present on the leaves in 1995. Although no fruit harvest results are available, the native fruits in 1994 had less scab disease than in 1995.

Sparks Site. The 'San Saba Improved' cultivar was studied for scab disease in 1993 and 1994 by Alina Marenco (Marenco, 1995) and the results analyzed in her Master's Thesis. In 1993, Marenco reported the pecan scab on 'San Saba Improved' exceeded a rating of '5' by July 9. With her defoliation index, this translated into greater than two leaflets per leaf missing by that date and nearly total defoliation by her final rating on August 27. Scab disease in the natives remained below '3' for the entire season. Disease ratings in the 'San Saba Improved' leaves in 1994 reached nearly '4' by the end of the trial on August 22. The disease ratings in the native leaves for the same year did not exceed '2'. Scab pressure was heavier in 1993 than in 1994 with no pecans produced on the 'San Saba Improved' in 1994. In 1995 no pecans were produced in the 'San Saba Improved' due to the stresses of heavy scab pressure from the two previous years. As the foliage of the trees was eradicated in mid-September by pecan scab; the likelihood of a 1996 pecan crop was also eliminated. Another factor that could have increased stresses on the trees in 1995 was a period of flooding early in the growing season. The high humidity due to the closed site characteristics certainly enhanced the progression of disease in the 'San Saba Improved' trial.

Vinita Site. The susceptible 'Schley' cultivar was not heavily impacted by scab in 1994. Although the leaves only attained scab disease to a rating of slightly above '3', the disease on the fruits did reach a level in which a significant reduction in crop could occur. The native trees in 1994 remained at a disease level that was acceptable for the production of a pecan crop. The leaves of the 'Schley' cultivar in 1995 remained at a low level of disease similar to the previous year, but scab on the fruits reached a mean level of '6.5' which would have caused a significant reduction in fruit quality for the crop. The native trees in 1995 stayed well within the acceptable range for both leaves and fruits.

Limiting the impact of scab by genetic resistance and cultural techniques. The results of these trials depict some very definitive results. As shown by the unsprayed native pecans at each of the three sites, even with poor cultural techniques, overcrowding, high presence of inoculum, and optimum conditions for spore germination, some of the native trees had the resistance to produce a crop. In three of the five site/years studied, the unsprayed native fruits did not exceed a mean disease rating of '3.5' and none of the native fruit trials studied exceeded a mean rating of '5.7'. In contrast, none of the unsprayed cultivars had mean fruit disease ratings below '5.5'. The difference in resistance between native pecans and cultivars may be due to several reasons. Native pecans have over time developed resistance to strains of *C. caryigenum* to which they have been exposed. In addition, in any grove of native pecans the genetic resistance to the strain of pecan scab that is present is highly variable between trees. This natural resistance development is often lost for traits growers would deem more desirable, such has larger fruits or thinner shells. Early selection of cultivars that were desirable to growers often were for these and other desirable traits while scab resistance was not a high priority (Hunter and Roberts, 1977). The scab pathogen has been shown to be highly variable in it's virulence between strains as well as being able to genetically more pathogenic on pecan cultivars that were originally more resistant (Converse, 1960; Demaree and Cole, 1929; Graves, 1975). Any given cultivar has a specific level of resistance to different strains of the pathogen and may become susceptible if a strain of pathogen develops that is more virulent on that cultivar. Demaree (1924) observed infected 'Delmas' pecans growing in contiguous rows with uninfected 'Schley'. He further noted it took several years before the 'Schley' became infected. The loss of resistance of a given cultivar may be due to the continual pressure of large single cultivar plantings that provide the opportunity to form new strains due to mutations of asexual reproduction of *C. caryigenum*.

The level of susceptibility to pecan scab inoculum that a given cultivar exhibits is plainly indicative of the magnitude of pecan scab that will stress the pecan cultivar. The highly susceptible cultivars 'Burkett' and 'San Saba Improved' clearly demonstrated the high level of scab disease which can be expected when they are unsprayed. The 'Schley' cultivar on the other hand demonstrated an ability to produce a limited crop when unsprayed. Many of the early cultivars that were planted in Oklahoma during the mid-century establishment of pecan cultivation were derived from stock which was either initially resistant to scab or were from regions that scab was not the limiting factor. The northern cultivars are more resistant to cold damage, but were not as resistant to scab. Southern cultivars such 'San Saba Improved' were initially resistant but now are susceptible to scab. Many of the cultivars planted in Oklahoma in early plantings were chosen for characteristics other than scab resistance. The most common characteristics are fruit size, kernel flavor, percent kernel weight and prolificacy.

Secondly, the cultural techniques that are used in the natural pecan growing areas can help reduce the impact of scab without the use of fungicides. All of the cultural modifications will have in common either reducing the conditions required by pecan scab for spore germination or limiting the inoculum potential. Characteristics that must be addressed to limit the relative humidity required for spore germination are high water tables, potential flooding, poor drainage, and airflow through the trees. Although the first two characteristics have a limited ability to be modified; improved drainage can greatly reduce the extended presence of water on the orchard floor. Good drainage not only limits the periods of high humidity, but also reduces stress or damage to the roots caused by waterlogging. Increased airflow can also be used to reduce the high humidity required for spore germination of *C. caryigenum*. Airflow can be improved by proper tree spacing, lower branch pruning, low height of ground cover in the orchard and by clearing of perimeter obstructions which would block air flow.

As observed with the highly susceptible 'Burkett', the presence of the Red River adjacent to the trees coupled with poor thinning and moderately high ground cover clearly enhanced the scab progression in the trees. The presence of a high inoculum potential coupled with the flooding conditions in 1995 is a good example of how quickly the disease can decimate a potential crop. The loss of foliage during the critical nut fill time in both 1994 and 1995 as well as fruit loss by the end of the season attests to the impact of the disease on this susceptible cultivar. This was also true with 'San Saba Improved' at the Sparks site. This research site has a hill to the south of the susceptible 'San Saba Improved' that limits the movement of the prevailing summer winds. When this feature is combined with limited management techniques and the high water table due to the adjacent creek, the scab conditions seriously limit 'San Saba Improved' pecan production. The loss of a pecan crop for three successive years suggests that modifications of the environment must be made, a consistent fungicide program must be maintained or the trees replaced with a less susceptible cultivar if a fruit crop is to be produced at this site.

For many reasons growers may find themselves dependent on pecan scab susceptible cultivars to produce a crop. Due to the long period of time required to bring pecan trees to fruit production maturity, replacement of the trees may not be a financial reality. The many cultural techniques that may be used to modify the growing environment and a timely fungicide program can help to reduce the effect of pecan scab disease on most cultivars. The limited use of disease limiting cultural practices and the complications produced by site factors at the Red River and Sparks sites demonstrates the impact that pecan scab can have on highly susceptible cultivars when they are not well maintained. The cultural modifications made at the Vinita site demonstrate that with a moderately susceptible cultivar such as 'Schley', a limited crop may be harvested in some years, even if no fungicides are applied.

These studies bring to the forefront the question as to the most efficient time to spray and how timing of fungicide applications relate to the susceptibility of the cultivar. As previously discussed in the introduction, recommended spray times in the southern states is on a calendar basis, while in Oklahoma the spray schedule is based on the phenological development of seasonal foliar and fruit growth as well as the developmental stages of the pecan nut casebearer. The application of fungicides as well as the cost of the chemicals themselves are major expenses in pecan production. The epidemiological research and hourly weather data that were accumulated in these studies were used to gain a greater understanding of the conditions which are essential for the initiation and progression of pecan scab in orchards at Oklahoma field sites. This data forms the basis of development for a model to predict what conditions precede disease at field sites in Oklahoma. By improving predictability of disease initiation, fungicide applications can be applied in a timely manner to limit high levels of pecan scab.

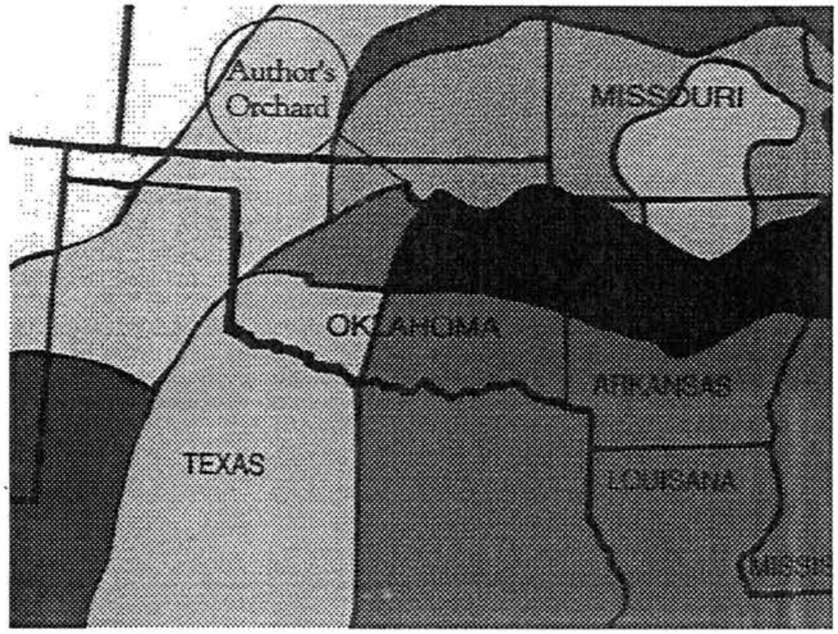


Figure 2.1 Excerpt of a map of Oklahoma, taken by authors permission from Pecans, a Grower's Perspective (Rice, 1994), that depicts the 6 regions in Oklahoma for which different pecan cultivars are recommended.

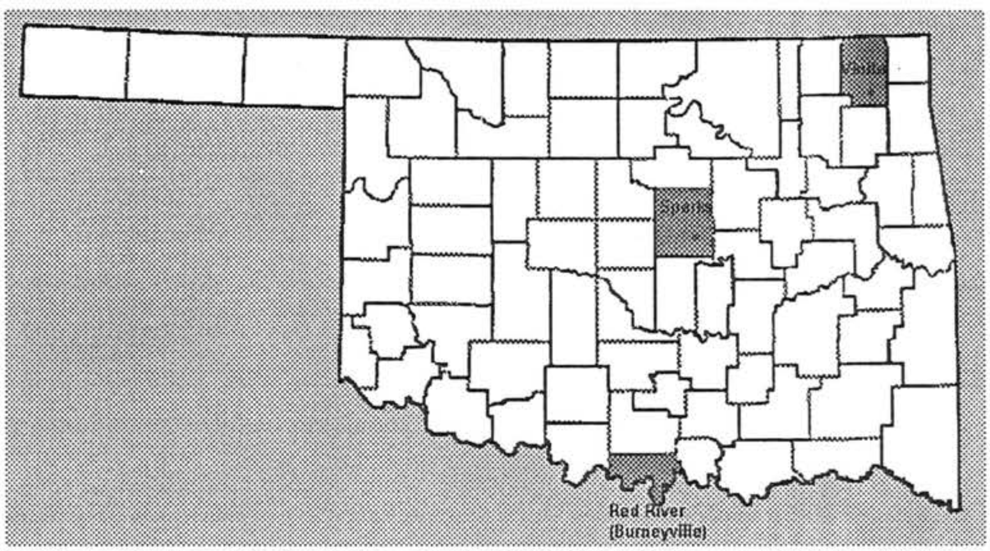


Figure 2.2 Map of Oklahoma identifying the location of the epidemiological and data logger weather data collection sites for 1994 and 1995. The center site at Sparks is an Oklahoma State University Pecan Research Station and is also the location of one 1996 empirical threshold spray trial and the 1997 statistical threshold spray trial.

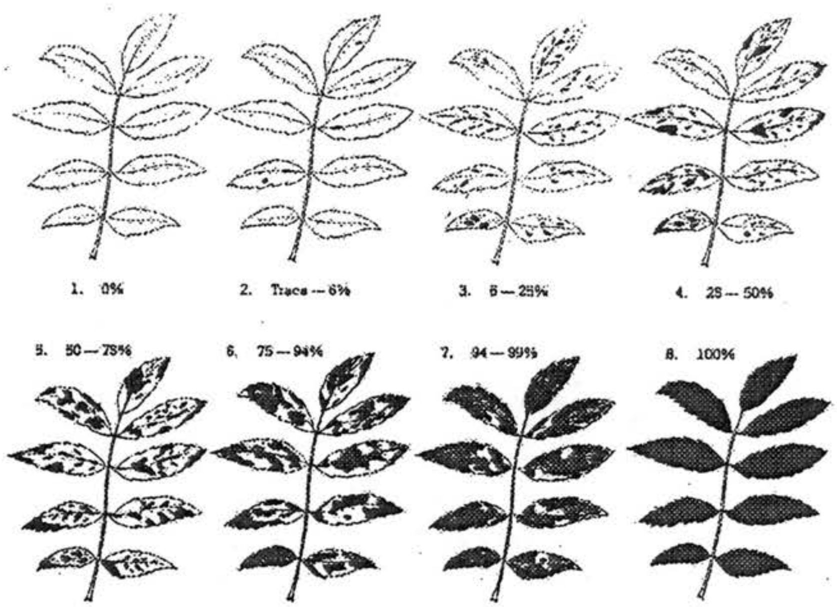


Figure 2.3 Rating scale of the modified Horsfall-Barratt system for evaluating pecan diseases on whole compound leaves (Horsfall and Barratt, 1945; Hunter and Roberts, 1978).

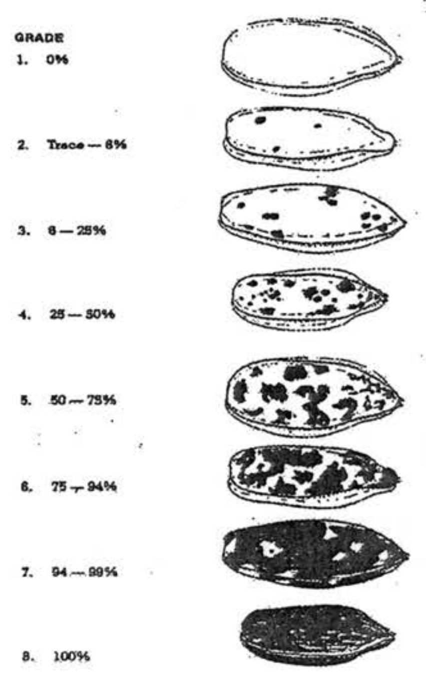


Figure 2.4 Rating scale of the modified Horsfall-Barratt system for evaluating diseases on pecan fruits (Horsfall and Barratt, 1945; Hunter and Roberts, 1978).

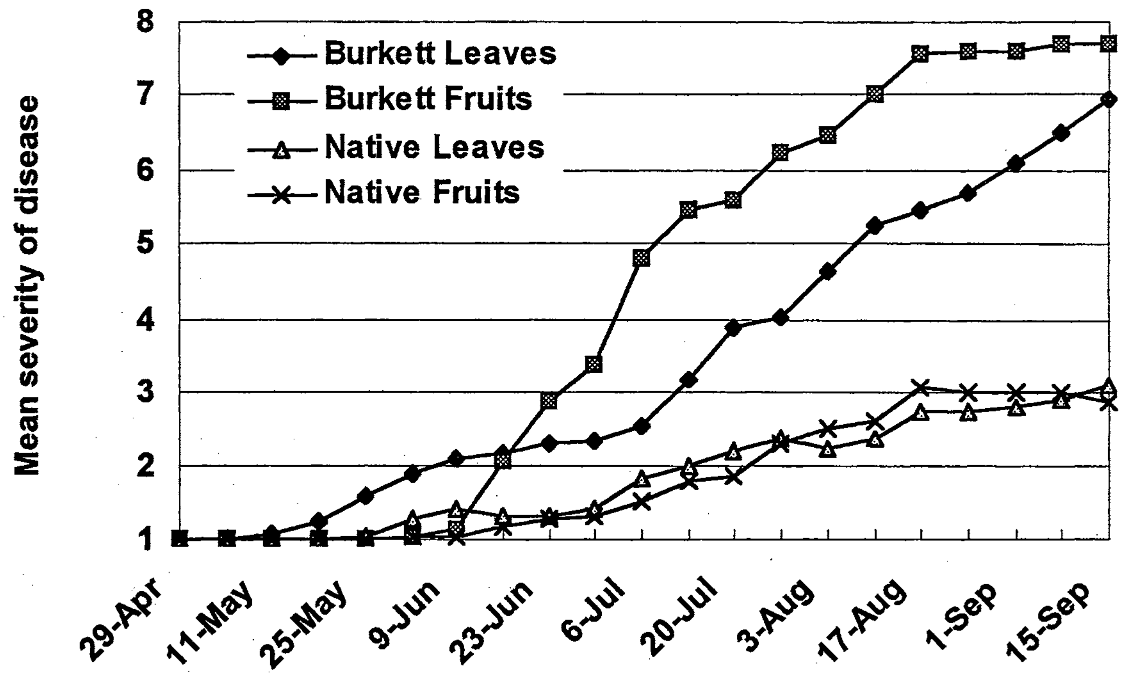


Fig. 2.5 Increase of severity of scab on leaves and fruits of 'Burkett' cultivar and native pecans near Burneyville, Oklahoma in1994. Observed values represent the mean severity of scab, assessed visually using a modified Horsfall-Barratt scale.

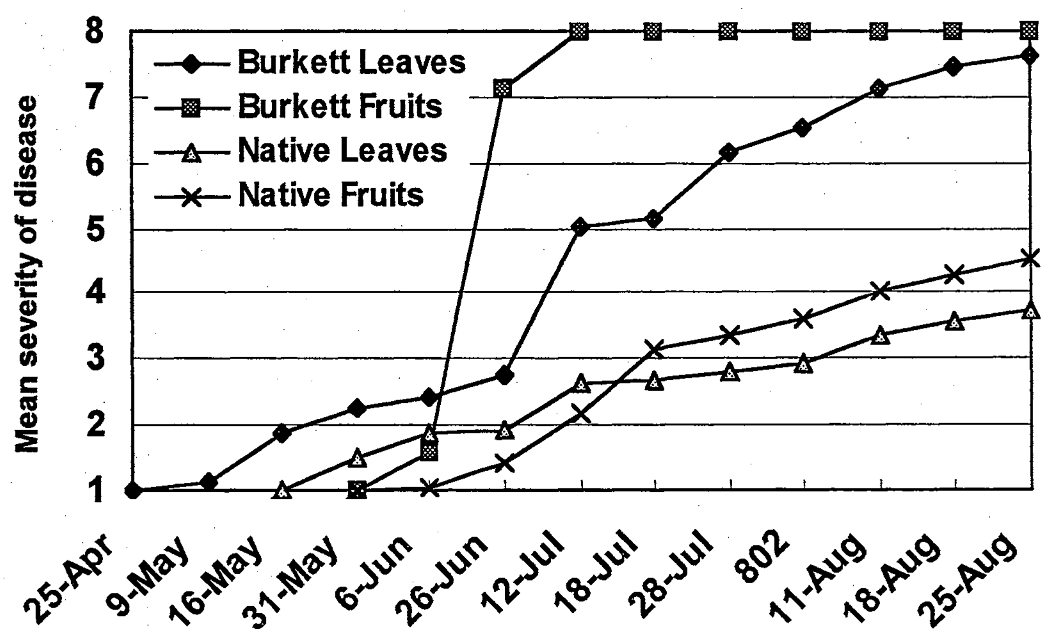


Fig. 2.6 Increase of severity of scab on leaves and fruits of 'Burkett' cultivar and native pecans near Burneyville, Oklahoma in1995. Observed values represent the mean severity of scab, assessed visually using a modified Horsfall-Barratt scale.

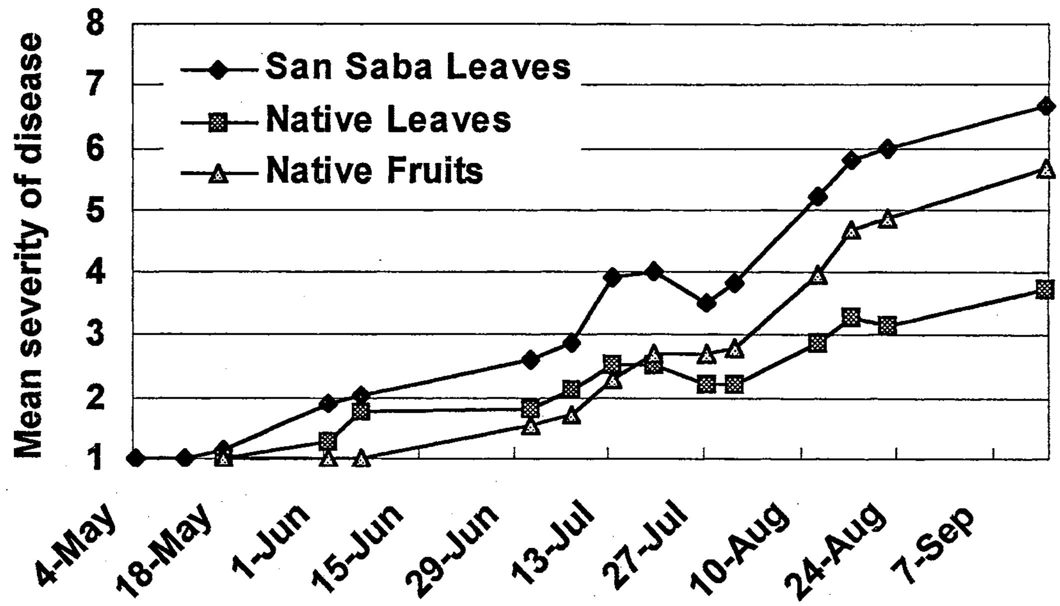


Fig. 2.7 Increase of severity of scab on leaves and fruits of 'San Saba Improved' cultivar and native pecans near Sparks, Oklahoma in 1995. Observed values represent the mean severity of scab, assessed visually using a modified Horsfall-Barratt scale.

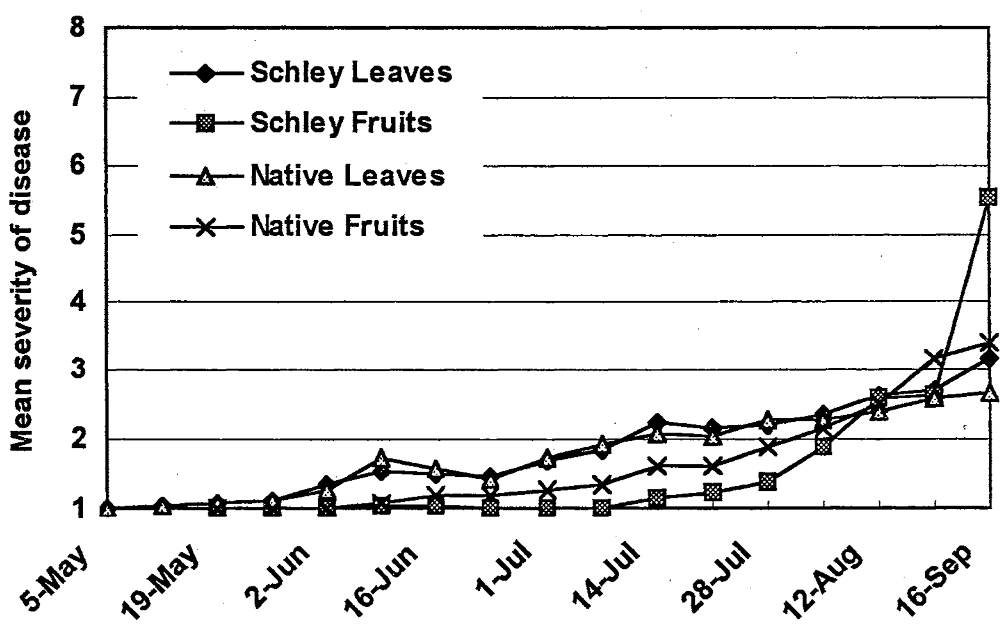


Fig. 2.8 Increase of severity of scab on leaves and fruits of 'Schley' cultivar and native pecans near Vinita, Oklahoma in1994. Observed values represent the mean severity of scab, assessed visually using a modified Horsfall-Barratt scale.

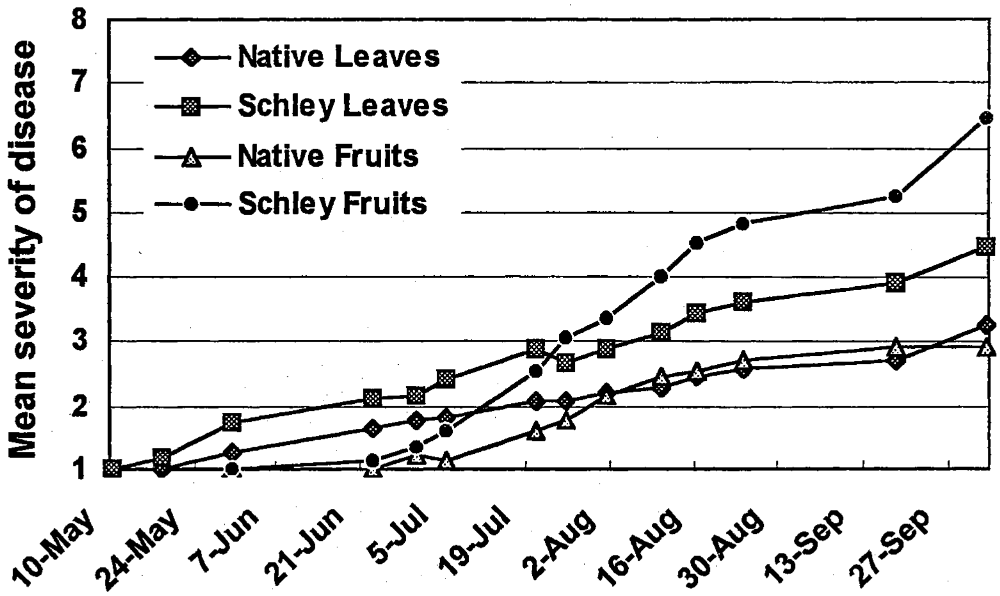


Fig. 2.9 Increase of severity of scab on leaves and fruits of 'Schley' cultivar and native pecans near Vinita, Oklahoma in1995. Observed values represent the mean severity of scab, assessed visually using a modified Horsfall-Barratt scale.

Chapter III

DEVELOPING AN EMPIRICAL THRESHOLD FORECASTING MODEL USING EPIDEMIOLOGICAL RATINGS AND WEATHER PARAMETERS

Introduction

Pecan scab is the most important disease in the pecan tree's natural range in the Mississippi River drainage and in the southeastern United States where it has been introduced. Scab disease promoted by high moisture levels and warm temperatures can cause stress of the trees and losses of fruit crops. Pecan scab is controlled by labor-intensive management techniques, resistant cultivars and the use of fungicide applications. To limit impacts on the environment and reduce costs to the pecan industry, various methods have been utilized to restrict application of fungicides to only those times when they are most effective.

Currently in Oklahoma, optimal fungicide application schedules are determined by developmental stages of the pecan tree and the infestation period of an insect pest, the pecan nut casebearer. This appears to be an improvement over the previous calendar based method used in the southeast U.S. due to fewer numbers of applications being required to control scab. Oklahoma does not have continuous periods of rainfall or relative humidity in excess of 90% as is seen in the Gulf States of the U.S. and therefore does not need a fungicide program that requires applications every two to three weeks. While the recommended phenological schedule results in fewer applications than the calendar-based schedule, it is also a blanket recommendation for the entire state. As the rainfall in Oklahoma varies in a gradient of 381 mm to 1270 mm annually across the state, it is likely that some growers may make too many or too few applications based on their location in the state. This information suggests that a adjustable usable fungicide application schedule should be developed that will provide optimal control for growers in a timely manner for all parts of the state.

Previous work in growth chambers and greenhouse studies determined that pecan scab spores may infect pecan tissues at temperatures (T) of 10 - 35 C (Valli, 1964; Hunter *et al.*, 1978; Litterell and Bertrand, 1981; Gottwald, 1984; Latham and Rushing, 1988) and relative humidity (RH)≥90% (Converse, 1956; Latham, 1982). Latham and Rushing (1988) suggested that after spore germination at 100% RH and T = 23 C, a RH > 80% could result in disease in a greenhouse at 22 -29 C.

Hunter *et al.*(1978) suggested 100 hours of leaf wetness is the threshold at which fungicides should be applied, while McVay and Gazaway (1980) concluded 120 hours (actual - 145.9 hours) of leaf wetness were needed. Cooper (*et al.*,1983) suggested that the accumulation of 100 hours in which the RH was >90% and T was 21.1 - 29.4 C should be the threshold that a fungicide should be applied. The variability of the results from these studies indicate that pecan scab may be infective through a wide range of temperatures and relative humidity.

The majority of this earlier work has taken place in the moist Gulf States of the southeastern U.S. Humidity in these areas is often very high (Demaree, 1924; Latham, 1982). As pecan scab inoculum does not appear to be a limiting factor in most pecan growing regions (Valli, 1964; Hunter *et al.*, 1978; Gottwald, 1982), only the need for optimal germinating conditions in respect to temperature and relative humidity are required for the initiation of disease. The moisture conditions which are required for germination of pecan scab conidia are readily found in the southern states, but also occur in areas of lower rainfall. With the optimal conditions such as those found in the southeastern states, a fungicide application program that provides nearly continuous coverage is essential due to the heavy scab pressure. In this region, the calendar schedule for fungicide application provides renewed protection as the disease control from the previous application of fungicide is lost. This results in a fungicide application rate of every two to three weeks when both scab pressure and relative humidity are high. However, these requirements do not appear to be applicable to Oklahoma weather conditions where RH is usually greater than 90% for shorter times during rainfall or dew events.

The climatic differences found in Oklahoma are due to the state's location in the continental U.S. Because Oklahoma is in the central plains of the U.S., fluctuations of the jet stream and the occasional, upward flows of warm, moist air from the Gulf of Mexico add to the complexities of the state's regional weather differences. This variation of Oklahoma weather conditions as well as the topographical conditions described in Chapter 2 prevents a blanket fungicide application schedule recommendation. This has prompted further analysis of the disease and weather data in an effort to provide for the varied needs of the pecan growers of Oklahoma with a more precise method of controlling pecan scab.

Late budbreak for the south and central portions of the state would begin at the middle of April and this is typically when the first early application of the calendar schedule is applied. The second application would be applied about three to three and a half weeks later (early to mid-May) at pre-pollination and the third application at casebearer time three weeks after the second application (early June). The first cover application would be applied three weeks later (late June) and the second cover application about three weeks after the first cover application in mid-July. The final (late) application would be applied three weeks after the second cover application in the first few days of August. This reduced calendar schedule attempts to protect the leaves through the developmental stage of leaf expansion and protect the fruits up through fruit expansion when the shucks were beginning to mature. The application sequence for the phenological schedule is similar to the calendar schedule except that the early and late applications are not applied.

In contrast, the threshold application schedules are based on weather conditions that are conducive to infection and therefore are dependent upon the seasonal weather patterns. At the Red River site, the early season in 1994 was dryer with lower humidity and cooler weather. If either an 80% or 90% RH threshold model had been used, the hours of T = 21.1-29.4 did not accumulate for the first application until May 28 for the 90% RH model and June 5 for the 80%

threshold model. The second applications would have occurred two and a half weeks later for the 90% and 80% thresholds on June 16 and June 20, respectively. The third applications for 90% and 80% would have been applied on July 3 and July 6, and the fourth applications would have been applied about two weeks later for both on July 20. The fifth and final application for this site would have been three and one-half weeks later on August 14 for the 90% RH threshold and three weeks later on August 10 for the 80% RH threshold.

When comparing the two standard (calendar and phenological) application schedules against either of the hypothetical threshold schedules, the threshold models at the untreated trial would have saved one application over the calendar schedule and have applied one greater than the phenological. The main advantage of the threshold schedules would have been the applications during the period of time in the later part of the season when conditions were conducive to infection and infection potential from secondary inoculum was high. In comparing the hypothetical 80% and 90% RH threshold schedules, the 90% RH fungicide application schedule would have started a few days earlier and ended a few days after the 80% RH threshold. The 80% threshold would have had a slightly more consistent spacing in the later part of the season during a time when the scab pressure was great and the fungicide protection would have been decreasing.

The purpose of this study was to determine if the empirical threshold fungicide application schedule could provide better control of pecan scab in Oklahoma than the phenological schedule. The first objective of this study was to define a relationship between the disease ratings from the 1994 and 1995 Red River and Vinita research sites and the weather data accumulated on-site during these periods. The information was then developed into an empirical threshold model. This threshold was tested on fungicide applications trials at the Sparks and Sapulpa sites in 1996. This chapter presents these studies.

Methods and Materials

Analysis of Disease Ratings and Weather Variables to Develop an Empirical Model Prototype.

Disease ratings and hourly summaries of weather data from the Red River and Vinita trial sites described in Chapter 2 were converted to spreadsheets. Leaf and fruit disease ratings of susceptible cultivars for each visit were converted to means. Combined visit means were converted to graphs as described in Chapter 2. As the native pecans for all three sites in both years showed the least amount of disease (lowest ratings), this data was not used in the analysis to construct an empirical threshold model. Each weather parameter was compared to the progression of disease with temperature and relative humidity parameters being chosen as best representing the trends observed in the disease. The leaf wetness parameter was not used due to the inconsistency of values observed during periods of high relative humidity. Leaf wetness sensors mounted in the trees were difficult to calibrate and check and were easily damaged during high winds. Rainfall parameter was not used due to the increase of disease during periods of time when no rainfall occurred. For the Red River and Vinita sites, daily accumulations of temperature (21.1 – 29.4 C) and relative humidity (≥ 90%) data were calculated as described by Cooper (1984) to compare with the current phenological fungicide application schedule and the graphed progression of scab disease.

Previous comparisons of recorded weather data had revealed that the frequency in which the hours of RH were between 80 and 90% occurred more frequently than RH ≥ 90% in the range of temperatures which were infective for *C. caryigenum.* Therefore, thresholds of 100 hours at ≥ 90% RH as described by Cooper (1983) were compared to an accumulation of 200 hours at 80% RH. Combined graphs of disease progression and accumulated hours of T and RH were constructed for the Red River, 1994 and Vinita, 1994 sites to provide a means of comparing weather values and the recommended fungicide application schedules.

Comparison of Mean Disease Ratings with Accumulated Hours of Disease Conducive Weather Conditions.

Red River Data. In an untreated trial that began on April 29th comparing the accumulation of scab hours, it was found that the leaves of the susceptible cultivar 'Burkett' became infected on May 18th after 106 hours at 80% (Fig. 3.1) versus 56 hours at 90% RH (Fig. 3.2) using the same temperature range as described above. The mean disease rating for this date on the 'Burkett' leaves was '1.25'. At this same site the fruits after development on May 4, became infected on June 2 at 153 hours at the RH of 80% while only 94 hours had accumulated at 90% RH. By the middle of June both leaves and fruits had slightly passed a disease rating of '2' using the modified Horsfall - Barratt disease rating scale. The leaves had an accumulation of 365 hours at 80% RH compared with 172 hours at 90%. The fruits had 332 hours at 80% and 162 hours at 90%. Significant scab damage (nearly a rating of '5') occurred on the fruit shucks by July 6th with the accumulation of 601 scab hours at 80% compared with 309 hours at 90% RH. Leaves were mostly damaged (rating of '5') by August 5th with ~1000 scab hours accumulated at 80% and only 450 hours accumulated at 90%.

The Red River site in southern Oklahoma in 1995 experienced heavy pressure from pecan scab as well as heavy phylloxera damage, heavy rainfall and flooding. Using 80% as the relative humidity threshold factor, the untreated plot had accumulated > 200 scab hours by May 16 (graph not shown). At this time scab in the leaves was near a rating of '2' and the fruits were not pollinated. By June 6th the susceptible 'Burkett' cultivar had leaf ratings of nearly '2.5' and fruit ratings of > '1.5' with an accumulation of 446 scab hours. Three weeks later after the flooding had occurred in the orchard, the leaf ratings were near '3' and the crop was lost with a rating of > '7'. Significant damage and defoliation of leaves occurred by July 12. Secondary growth of leaves was severely damaged by scab in the expansion stage and the 'Burkett' were defoliated by the middle of August.

Vinita Data. The moderately susceptible 'Schley' cultivar in the untreated plots showed a pecan scab infection rating of '1.3' in the leaves by June 2nd. Using 80% RH as the threshold parameter (Fig. 3.3) 107 hours had accumulated compared with 16 hours at 90% RH (Fig. 3.4). Shucks of the fruits did not exhibit scab lesions (rating '1.2' average for trial) until July 22 when the shucks were maturing. Hours accumulated at a threshold of 80% RH was 590 contrasted to 211 at 90% RH. Disease rating on leaves increased to a rating of '2.25' by July 14 with an accumulation of 80% threshold hours of 492 and 156 hours at 90% RH. Fruits attained a disease rating of '1.9' on August 4 with an 80% RH accumulation of 831 hours compared with 312 hours at the 90% RH threshold. By the end of the trial on September 16 scab ratings in the leaves remained at a tolerable level of '3.16' for tree maintenance through the growing season and the fruits attained a rating of '5.5'. The number of hours accumulated at the threshold of 80% RH was 1100 while at the 90% RH threshold it was 398. The greatest amount of scab disease occurred after foliar and shuck maturation and did not affect the crop or the production of the following seasons crop.

Based on conclusions from the above analyses, an empirical application model was developed that was used to test the ability of controlling pecan scab by predicting the increase of disease through weather monitoring. The large number of observed daily hours that were between 80 and 90% RH suggested that the threshold for the fungicide application trial should be based on the accumulation of 200 hours at 80% RH and a temperature range of 21.1-29.4C instead of 100 hours at 90% RH.

Field Trial Testing of the Empirical Threshold Model.

Field trials were conducted at the Oklahoma State University Pecan Research Station near Sparks and in a commercial pecan orchard south of Sapulpa. The Vinita and Red River sites were not chosen for this experiment due to the distance of the sites from Oklahoma State University and the difficulty inherent in getting to all the sites when applications were needed.

Other reasons for a change of sites was low disease at Vinita and the removal of the susceptible 'Burkett' cultivar from Red River.

Sparks Site. Due to the lack of fruit on the 'San Saba Improved' pecans for two consecutive years and the early defoliation in 1995, another cultivar was chosen at the Sparks site for testing of the threshold based application schedule. In the south end of the Sparks research station two groups of 45 year-old 'Western' pecans were chosen for the trial. The 'Western' were located on the east and west sides of Quapaw Creek. The eastern block was bounded on the south by the creek and on the east by State 81-B. To the north of the eastern block was the access road in to the eastern side of the station. The western block of 'Western' was bounded on the south by State 81-B and on the east by the access road into the west side of the research station. The main difference between the two blocks of trees was the presence of heavy trees and brush to the south of the eastern block of trees that limited air movement while the western block had good air movement around the trees. Both blocks of trees were in rows. The eastern block rows were oriented east-west. The western block rows were oriented north-south.

Both blocks of trees were each divided into two replications with three trees per treatment. The treatments in each of the four replications were the calendar (positive control), a phenological, a phenological with an experimental fungicide, a threshold and an untreated control (negative). The fungicides used for the calendar, the threshold, and one of the phenological treatments were a tank mix of one-half strength fenbuconazole (a.i. 0.067 kg ha^{-1}) and one-half strength (a.i. 0.34 kg ha^{-1}) triphenyltin hydroxide. The second phenological treatment was the experimental fungicide Zeneca ICIA 5504 (azoxystrobin,β-methoxyacrylate) to test against the efficacy of the tank mix. The azoxystrobin was applied at the recommended rate of a.i. 0.049 kg ha^{-1}. All fungicide applications included Latron B - 1956® at 0.22 kg ha^{-1} (surfactant/sticker).

Fungicide Application. The fungicide was applied with a 1893 liter (l) Aero-Fan air blast sprayer. Fungicide applications were mixed in quantities of 379 or 758 l, as required. The 12 nozzles delivered the prepared fungicides at the rate of 3.8 l sec^{-1}. The sprayer was pulled at the speed of 2.2 m sec^{-1}. The engine of the air blast sprayer was adjusted to highest rpm as the tractor approached each treatment and sprayer pump for the fungicide solution was engaged two to three seconds prior to contact of the air blast with the foliage allow verification of a full application pattern. Sprayer pump remained engaged until the nozzle portion of the sprayer was even with the drip line of the last tree in the treatment. Each tree received about 30.2 l of the fungicide mixture. This process was repeated for all treatments and replications to insure a uniform method of fungicide application that was reproducible.

Sapulpa Site. The Sapulpa trial site is located about 32 km southwest of Tulsa. The orchard is 13 km southwest of Sapulpa. The trial site is bounded on the south side by a county road and on the west by Polecat Creek. The trial was conducted in a large rectangular orchard of drip irrigated, 8 year-old pecans of the moderately susceptible cultivar 'Pawnee'. The well-spaced (9 m), even rowed trees of the trial consisted of five replications of the four treatments and in each replication there were eighteen trees per treatment block. The trial was laid out in a randomized complete block design, with blocks of six by three trees for each of the four treatments. Three of the four center trees of each treatment were rated in the middle of the season (July 19) and at the end of the season (September 5) for the percentage of scab on the leaves. Each tree was sampled on the north and south sides of the tree. There are a total of 360 trees in the trial. All trees in the trial received the same cultural practices, fertilization and insect control as the non-trial trees in the same orchard. The fungicide application treatments were the threshold, phenological and calendar schedules. All applications were made with a tank mix of fenbuconazole (a.i. 0.067 kg ha^{-1}) and triphenyltin hydroxide (a.i. 0.34 kg ha^{-1}) All applications included Latron B - 1956® at a.i. 0.218 kg ha^{-1} (surfactant). Controls with no fungicide application were also included.

Fungicide Application. The fungicide applications were applied with 1893 l, air blast sprayer, Model Savage 5528, supplied by Basil Savage Industries, Madill, Oklahoma. This PTO driven sprayer was pulled at a speed of about 2.2 m sec^{-1}. FloodJet® nozzles (No.1/8K-ss15) were equipped with FloodJet® tips (No.TK-SS15) for all spray orifices. Fungicide mixture was delivered at a volume of 0.2 l sec^{-1} at 40 psi. Spray activation procedure prior to application on the trees was as described for the treatments at the Sparks site. As this sprayer was a much smaller unit than the one at Sparks, the hydraulically controlled volute was utilized to obtain full coverage of these immature pecan trees. All applications were made from the up-wind side of the trees (north or south sides) with only a single pass being made for each date of fungicide application. Each tree received about 8.3 l of the fungicide mixture.

Timing for All Treatments. The calendar-based application program adapted from the Georgia pecan spray schedule (Harris *et al.*, 1976) recommends a fungicide application every two to three weeks (equaling about 8 applications per growing season). The phenological application schedule is the current fungicide application schedule recommended in Oklahoma that is based on the developmental progression of the pecan tree as well as the appearance of insect pests such as the pecan casebearer and the pecan weevil. The four center application dates for the calendar and phenological application schedules were the same with an additional date being added to the beginning and end of the phenological application schedule to cover the early and late season (calendar treatment). The threshold application schedule was entirely weather based and the decision to apply a fungicide application was dictated by the accumulation of hours that the temperature was ≥ 21.1C and the relative humidity was ≥ 90%. The accumulation of hours was monitored on both the Mesonet Weather System and the on-site datalogger.

Trial Evaluations. To prevent the effects of over-spray from adjacent fungicide treatments, only the central tree of each treatment was rated for the amount of pecan scab lesions found on the leaves and fruit shucks. Disease assessments were made in the middle of the season (July 15) and at the end of the growing season (Sept. 10). One sample per quadrant (north, south, east and west) was assessed for both rating times. Ratings used the modified Horsfall - Barratt rating system for estimating the amount of disease on the samples.

Results

Testing of Empirical Model to Control Pecan Scab with a Threshold Fungicide Applicaation Schedule.

Sparks Trial. At the end of the trial the threshold based treatment received three applications while the calendar treatments in the trial received six applications, the phenological received four applications (Table 3.1). The hours that had accumulated at each threshold based application date are included for comparison to the calendar (calendar, 6 applications) and phenological (4 applications) schedules. The final leaf and fruit disease ratings using the Horsfall-Barratt scale were significantly different ($P<0.01$) from the untreated controls in all sprayed treatments (Table 3.2). The disease rating differences of the leaves between all treatments were significant at the 5% LSD. For the fruit disease ratings, the application treatments for the calendar (tank mix), phenological (tank mix) and the phenological with the experimental fungicide were significantly different at the 5% LSD. Differences between individual application treatments were significant at the 1% LSD.

Sapulpa Trial. At the end of the trial the threshold treatments received four applications while the calendar treatments at the Sapulpa Trial received six applications, the phenological treatments received four applications (Table 3.3). Hours accumulated at the 80% RH are included for all treatments for comparison. The mid-season and final scab ratings for the treatments showed all application treatments to differ significantly from the untreated controls (Table 3.2). The mid-season showed a higher significance than the final rating. For both mid-season and final ratings, the threshold treatment did not differ from the calendar or the phenological application treatments at the 5% LSD. No disease rating data was available for the pecan fruits due to the sporadic nut production of the young trees

Discussion

The analysis of disease progression versus conducive weather conditions suggests that the threshold schedules can offer better control of pecan scab to growers under the varying conditions of the state. Although one of the goals with the threshold application schedule is the attempt to reduce the number of applications and to apply them during the period of greatest infection potential; it's greatest advantage is to provide the pecan grower with a tool in which he/she can decide if the prospective crop for a given year warrants the expenditure of additional fungicide applications.

Fungicide Application Trials to Test the Empirical Threshold Schedule.

Sparks Trial. Results of the trial show that the three applications of the threshold treatment were as effective in controlling pecan scab as the four applications of the phenological and the six applications of the calendar spray treatment (Table 3.1). At the time of the mid-season rating, the calendar treatment trees had received four applications, the phenological three applications and the threshold treatment had received one application. End of season spray applications saved one application over the phenological and three over the calendar schedule. The primary advantage that was demonstrated by the trial at this site was the shift of application times to later in the season when conditions were more conducive to scab disease development.

Disease in 'Western' was very low after a dry, early season and there were no significant differences ratings at mid-season (data not shown) between any of the five treatments for either leaves or fruits. At the final evaluation there was also no significant difference between the leaf ratings for the four fungicide treatments. This lack of difference was primarily due to low disease pressure during the early leaf expansion stage that ends in late May when the foliar tissues harden-off and are not as susceptible to disease. The final fruit disease ratings (Table 3.2) of the threshold schedule that had only three applications during the trial did show a decrease in disease control by when compared to the other fungicide schedules. This difference of '1' on the Horsfall-Barratt rating scale (Fig. 2.4) between '4' and '5' represents an increase of 25% more of the surface area of the fruit shuck being covered by scab lesions. Part of the explanation for this lack of disease control was the application date that was missed due to the inability to be in the field. The application that was applied on August 2 should have been applied July 31. In those three days, 64 hours accumulated during a time when the fungicide was no longer capable of controlling the fungus. This example illustrates the importance of applying the fungicide applications when the accumulated hours have reached the threshold limit. The level of the threshold schedule disease rating was high enough to indicate that the quality of the nuts at harvest would have been reduced compared to the other treatments. Fruit quality data was not available due to the progression of disease after the final sampling and the heavy predation by crows at this isolated site.

Sapulpa Trial. Although no fruit disease ratings were available from this trial due to the young age of the trees, the trial results on the leaf disease indicates that the threshold fungicide application schedule was as effective as the calendar or phenological schedules at both mid-season and at the end of the season. At mid-season all ratings were low, but all three fungicide treatments were significantly different from the unsprayed control treatment. Thus there was no difference between 2 (threshold), 3 (phenological) or 4 (calendar) applications by the mid-season disease rating (Table 3.3). At the end of the trial the phenological and threshold schedules both had four applications compared to the calendar schedules six applications. The threshold schedule had a rating similar to the calendar schedule and saved two applications due to the timing of the applications (Table 3.2). Both threshold and calendar application schedules had ratings significantly lower than the phenological application schedule. The final leaf disease ratings from all three fungicide treatments were significantly lower than ratings from the untreated control treatments. Although all fungicide treatments at the final rating do not differ within the 5%

LSD, the phenological has a higher disease rating because it did not receive the protection of a late season application (Aug 6) like the calendar and threshold treatments.

Summary of Discussion:

The final ratings from both sites showed that using the empirical threshold model, the scab was well controlled in the leaves. Final ratings for the fruits at the Sparks site showed that control of scab was not as good. This could partly be attributed to the difficulty in applying the second fungicide when it was scheduled to be applied. The empirical threshold model did save one application at the Sparks site. The same numbers of applications were applied at the Sapulpa site for both the phenological and threshold treatments. The empirical threshold model shifted the application dates for both trials to later in the season than the recommended phenological application schedule. For both sites the first application was applied in June as compared to late April or early May for the phenological schedule.

These trials suggest that the threshold model used to control pecan scab is able to forecast the time period when the trees need to be sprayed with fungicides to provide scab protection. They also demonstrate that timing is important in controlling the pecan scab at those periods of time when weather conditions are conducive to disease development. The trials further showed that by using the Mesonet data, the model is able calculate accumulated hours in an defined area and protect pecan trees of different levels of pecan scab susceptibility. Finally, the results of these trials indicate that the disease can be controlled and at times with a savings of spray applications. These savings will increase the profits of the growers, limit the impact of the chemical on the environment, and reduce the pressure on the fungus to mutate to resistant strains.

Further analysis and studies are needed to improve the ability of the threshold fungicide application forecasting model to control the disease development with greater accuracy. The epidemiological data used to develop this model was derived from studies on disease progression in unsprayed pecan trees and was applied as disease control program through fungicide application. As the goal of the threshold model is to limit the level of infection to an acceptable level of '3' (6 to 25% lesion coverage) on the Horsfall-Barratt scale by nut harvest, the threshold model needs to be re-evaluated. The data used to assess the potential of the empirical prototype model will be reassessed with regression analyses in an attempt to improve the threshold model.

Table 3.1 Application dates and scab hour accumulations [a] for the Sparks 1996 fungicide threshold trial comparing calendar, phenological, and threshold application scheduling to control pecan scab.

Recommended Schedules[b,c]			Threshold Schedule[d]	
Application	Date	Hrs. Accum.	Date	Hrs. Accum.
1st Early[b]	April 25	0	----	----
2nd Prepollination[b,c]	May 14	41	----	----
3rd Casebearer[b,c]	May 29	58	----	----
4th First Cover[b,c]	June 19	143	June 25	197
5th Second Cover[b,c]	July 19	321	----	----
6th Late[b]	Aug. 2	464	Aug. 2	464
----	----	----	Aug. 22	661

[a] Combined temperature (21.1-29.4°C) and relative humidity (≥ 80%), [b] Calendar schedule 6 fungicide applications) and [c] phenological (4 applications), [d] threshold applications were made when 200 hours of temperature and relative humidity as in [a] had aaaccumulated

Table 3.2 Final mean disease ratings of the 1996 fungicide application threshold trials at two sites in Oklahoma comparing the threshold schedule (200 hour accumulation of temperature 21.1-29.4°C and relative humidity ≥ 80%, calendar schedule (6 applications), and phenological (4 applications), randomized complete block.

	Sparks		Sapulpa[a]
Treatment	Leaf	Fruit	Leaf
Calen./Mix[b]	3.13	3.16	2.17
Pheno./Mix[c]	3.13	3.54	2.60
Pheno./Azoxy.[d]	3.06	3.57	nt[e]
Threshold/Mix[f]	2.88	4.54	2.30
Neg. Control[g]	4.00	7.75	3.30
5% LSD	0.70	0.63	0.42
Signif. (P<)	0.01	0.01	0.01

[a] No fruit ratings due to immaturity of trees, [b] Calen. = calendar schedule (6 fungicide applications), mix of fenbuconazole (a.i. 0.067 Kg Ha^{-1}) and triphenyltin hydroxide (a.i. 0.34 Kg Ha^{-1}), [c] Pheno. = phenological schedule with fungicide mix as in [b], [d] phenological schedule with Azoxy. = azoxystrobin (a.i. 0.049 Kg Ha^{-1}), [e] nt = not tested, [f] fungicide applications were made when 200 hours had accumulated using the fungicide miixture in [b], [g] Neg. = negative, no fungicide applications

Table 3.3 Application dates and scab hour accumulations [a] for the Sapulpa 1996 fungicide threshold trial comparing calendar, phenological, and threshold application scheduling to control pecan scab.

Recommended Schedules[b]			Threshold Schedule[c]	
Application	Date	Hrs. Accum.	Date	Hrs. Accum.
1st Early[d]	May 8	74	----	----
2nd Prepollination[d,e]	May 22	134	----	----
3rd Casebearer[d,e]	June 5	216	June 3	194
4th First Cover[d,e]	June 26	391	June 25	397
5th Second Cover[d,e]	July 19	607	July 19	607
6th Late[d]	Aug. 6	808	Aug. 6	808

[a] Combined temperature (21.1-29.4 C) and relative humidity (80%), [b] Calendar schedule (6 fungicide applications and phenological (4 applications), [c] Threshold applications based on 200 hours of temperature and relative humidity as in [a], [d] calendar applications, [e] phenological applications

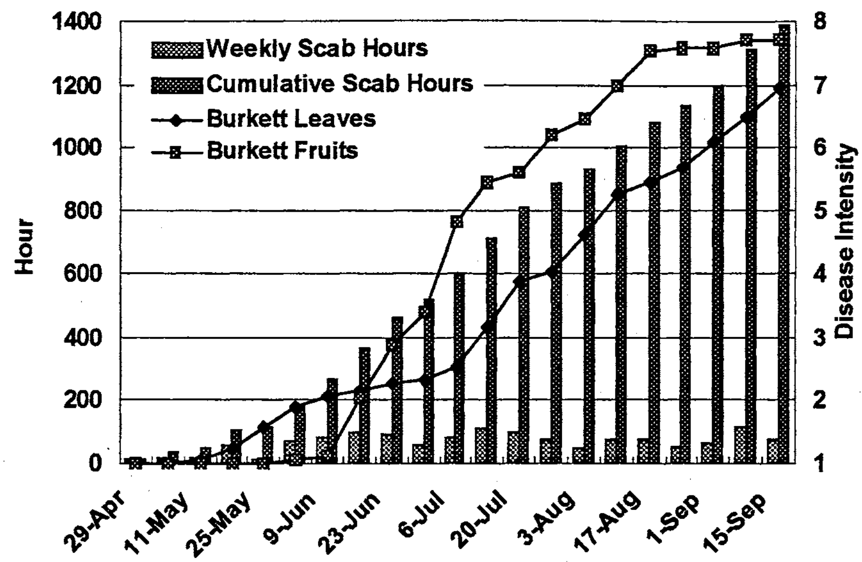


Fig. 3.1 Red River (Burneyville) 1994 weekly and cumulative hours of temperature (21.1-29.4 C) <u>and</u> relative humidity (≥ 80%) compared with leaf and fruit disease ratings. Weather data were recorded by an in-field datalogger.

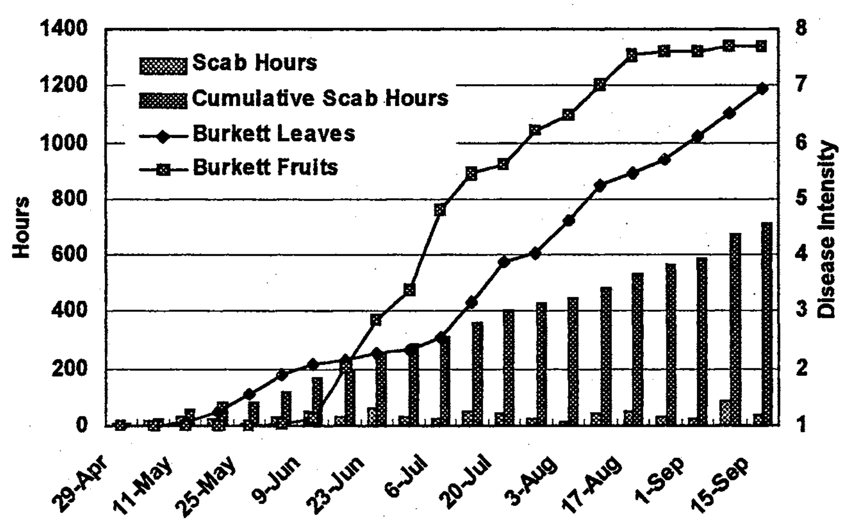


Fig. 3.2 Red River (Burneyville) 1994 weekly and cumulative hours of temperature (21.1-29.4 C) <u>and</u> relative humidity (≥ 90%) compared with leaf and fruit disease ratings. Weather data were recorded by an in-field datalogger.

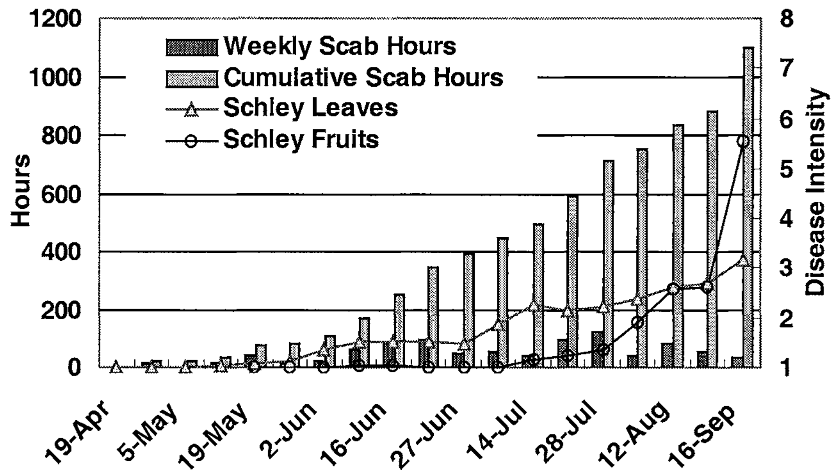


Fig. 3.3 Vinita, 1994 weekly and cumulative hours of combined temperature (21.1-29.4 C) and relative humidity (≥ 80%) compared with leaf and fruit disease ratings. Weather data were recorded by an in-field datalogger.

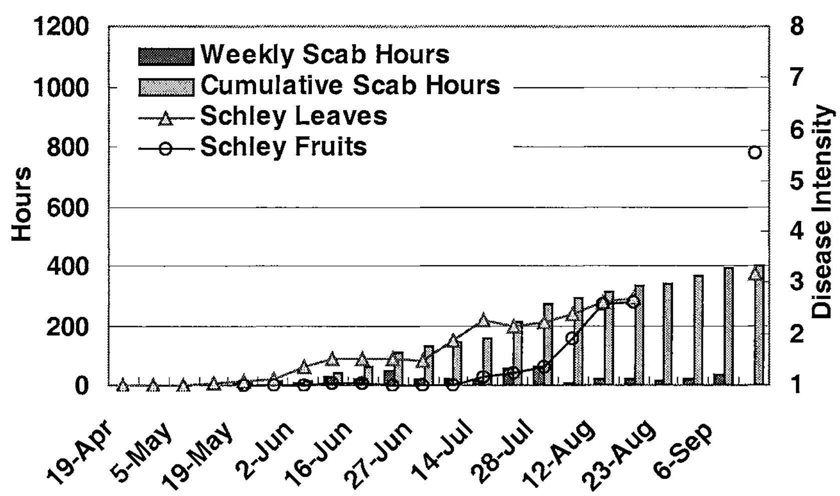


Fig. 3.4 Vinita, 1994 weekly and cumulative hours of combined temperature (21.1-29.4 C) and relative humidity (≥ 90%) compared with leaf and fruit disease ratings. Weather data were recorded by an in-field datalogger.

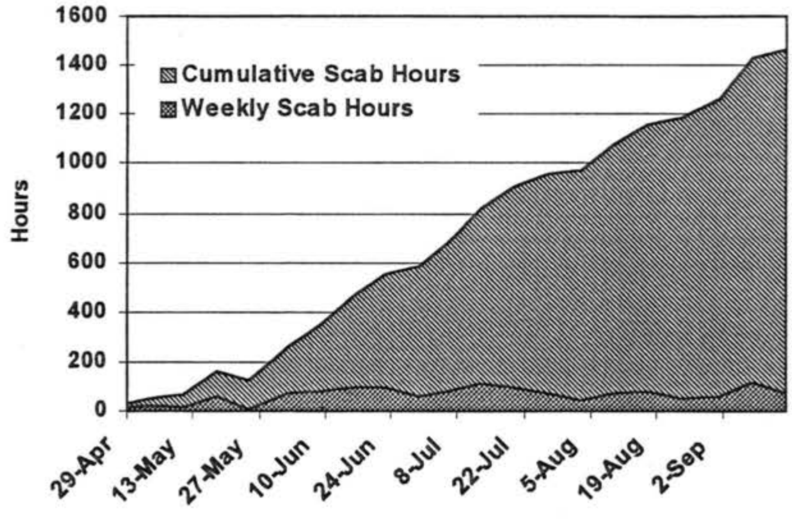


Fig. 3.5 Red River 1994, 200 hours intervals of weather conditions conducive to disease using the parameters temperature (21.1-29.4C) and relative humidity (≥ 80%). Using the threshold schedule with the described weather parameters, fungicides would be applied with each accumulation of 200 hours.

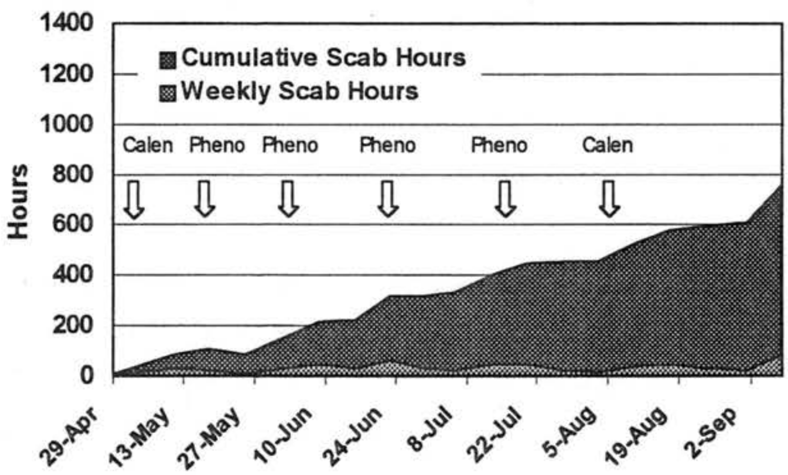


Fig. 3.6 Red River 1994, 100 hours intervals of weather conditions conducive to disease using the parameters temperature (21.1-29.4C) and relative humidity (≥ 80%). Using the threshold schedule with the described weather parameters, fungicides would be applied with each accumulation of 100 hours. The dates for the calendar (calen., (6 applications) and phenological (pheno.,4 applications) fungicide schedules are identified by the arrows. The phenological schedule would be applied on the dates of the four center arrows.

CHAPTER IV

STATISTICAL MODIFICATION OF THE THRESHOLD-BASED FUNGICIDE APPLICATION PROTOTYPE MODEL

Introduction

A review of the results from the 1996 empirical threshold trials revealed that the combination of weather variables that had been chosen did reduce the number of sprays applied to pecans and that pecan scab could be controlled by this method. The next step was to improve the predictability of the model by using statistical analysis to refine the process for calculating the accumulation of scab hours. This refinement could proceed by defining the weather variables and number of hours required for infection and disease development. The model could also be improved by identifying the "window of time" that was most highly correlated with the subsequent appearance of the disease. Further, as the fungicides approved for use on pecan scab have a 14-day protection period following application, this alteration in the disease progress curve of the unsprayed pecans (Fig.2.3) would have to be taken into account in the refinement of the model. The model would also have to be modified to limit disease development to an acceptable level, yet provide the pecan grower with a decision tool for fungicide application that was an improvement over the current fungicide application recommendation.

Early laboratory experiments (Cooper, 1956) concluded that the optimum conditions for pecan scab spore germination was 25°C at a relative humidity (RH) ≥ 90.1%. Gottwald (1984) found in his lab studies that infection took place at 10 – 35°C with the optimum range from 20 - 30°C. Green house studies (Gottwald,1985; Latham and Rushing,1988) have demonstrated that spores of *Cladosporium caryigenum* can cause infection of pecan leaves at lower levels of humidity once germination has occurred in dew chambers at 100% RH. Latham and Rushing (1988) also showed that under ideal conditions *C. caryigenum* spores may germinate in as few as 3 hours after inoculation and penetration of host cuticle may occur in 12 hours with the appearance of lesions on the foliar surfaces in as few as 144 hours (6 days). Conditions in the field are seldom ideal for long periods and therefore a more realistic determination of the number of hours under this less than ideal conditions were necessary. Valli (1964) first proposed from his observations that lesions appear 7 to 10 days after infection. Valli's proposal was supported in a field study (Latham, 1982) when lesions were reported to have become visible on the surface of leaves 7 to 9 days after a 12 hour leaf wetness period due to a rainfall event. This criterion was important in determining the period of time to analyze in the search for the optimum correlation between weather conditions and disease data accumulated at Oklahoma field sites in 1994 and 1995 (Chapter 2).

Previous research with pecans has demonstrated that weather variables may be used to forecast fungicide application schedules. For pecans the most frequently used weather variables are T, leaf wetness and RH (Hunter *et al.*, 1978; Gazaway and McVay, 1980; McVay and Gazaway, 1980; Latham, 1982; Cooper *et al*, 1983, 1984). Hunter *et al.* (1978) based an empirically derived fungicide application program in Georgia on the accumulation of 100 hours of leaf-wetness that gave improved results over the fixed spray schedule in his field studies. An empirically derived threshold of 120 hours accumulation of leaf-wetness was the trigger used by McVay and Gazaway (1980) for fungicide application in an Alabama field trial. They determined that this leaf-wetness schedule saved one application over the fixed schedule and resulted in less disease by adjusting the dates of fungicide application to periods when disease was most likely to occur. Latham (1982) disagreed with the previous leaf-wetness work and from his field-inoculated, green house-grown pecans he observed that scab lesions appeared on pecan leaves 7-9 days after a rainy day with an accumulation of only 12-16 hours of leaf-wetness. A series of Georgia field trials (Hargrove, 1991) found the empirical 16-hours of leaf wetness to be more effective than the fixed application schedules.

In an Alabama field trial, Gazaway and McVay (1981) showed that an empirically based threshold of 150 hours of RH $\geq$ 90% could be used to control pecan scab. They based their threshold on earlier studies of free moisture and pecan scab (Valli, 1964; Hunter *et al.*, 1978). Although this trial did limit the timing of fungicide applications to a threshold of 100 hours with a minimum of 10 days between applications, the threshold treatment required one more application than the commercial schedule and did not definitively determine the number of hours required to control the disease. Using a review of the earlier work as a guide, the Texas Pecan Integrated Pest Management Manual (Cooper *et al.*,1983) recommended a threshold-based fungicide application schedule based on the accumulation of 100 hours of ≥ 90% RH. However, the manual cautioned that this scheduling would not work in areas that the RH did not frequently exceed 90%. In 1984 Cooper *et al.* recommended a similar system for Texas pecan growers that was modified to include the ≥ 90% RH in the T range of 21.1 – 29.4°C with a minimum of two weeks elapsing between fungicide applications.

A number of crops now use weather variables as predictors for forecasting models. In 1966, Jensen and Boyle developed a model which predicts Cercospera Leafspot (*Cercospera arachidicola* Hori.) on peanuts (*Arachis hypogaea* L.) that was based on accumulated hours of percent RH and minimum T of ≥ 21° C for two consecutive nights. Krause *et al.* (1975) developed a model named 'Blitecast' to control potato late blight (*Phytopthora infestans* (Mont.) de Bary) in potatoes. 'Blitecast' uses two methods to predict the likelihood of infections. One formula uses combinations of T and RH (Wallin, 1962) and the other uses rainfall patterns within a range of temperatures (Hyre *et al.*, 1959. Madden *et al.* (1978) have developed a forecasting system for *Alternaria solani* on tomato (FAST) that use two empirical models to identify periods of conditions favorable for disease. The two models use maximum and minimum ambient air temperatures, hours of leaf-wetness, hours of RH > 90% and rainfall. Ellis *et al.* (1984, 1986) developed electronic disease predictors for the scheduling of fungicides in apples and grapes, respectively. Both of these models use leaf-wetness and T to predict the timing of fungicide applications.

In some cases, these forecasting models have been tested as computerized models to predict application advisories. A computerized forecasting method for peanuts (Parvin *et al.*, 1974) is based on forecasting model developed by Jensen and Boyle (1966). BLITECAST, a computerized prediction model (Krause *et al.*, 1975), was a free service offered by Pennsylvania State University in the early 1970's that was successful for a time. MacKenzie (1981) determined that the complications of sanitary practices, variability of potato cultivar resistance, and the risks of late blight epidemics prevented the wide-spread acceptance of this disease predictor. FAST (Madden *et al.,* 1978), is a computerized system developed for tomatoes (*Lycopersicon esculentum* Miller). Two models have been developed that use microcomputers to schedule fungicides for grapes (*Vitis vinifera* L.) and apples (*Malus domestica* Borkh.)(Ellis *et al.*, 1986, 1984). Perhaps the most effective example of a computer driven disease forecaster for fungicide application is Reuter-Stokes apple scab (*Venturia inaequalis* (Cooke) G. Wint.) predictor developed by Michigan State University (Jones *et al.*, 1984). This unit, in its commercialized form, is designed to be located in the field, is user friendly and predicts periods of probable disease occurrence as well as recommending fungicides. Most of these forecasting models were developed using weather patterns and their relationship with the epidemiology of the disease.

Most of the studies described above were empirically derived based on field observations as well as a review of the weather data and disease records from each site. Although knowledge of the disease, phenological development of the pecan trees and the weather data are all important facets in discovering the threshold at which to apply fungicides to control scab; an empirically derived threshold only gives a rough approximation of the true relationship between the disease and weather variables. A more definitive method in determining this relationship is to statistically correlate the weather conditions with disease incidence to derive a forecasting threshold model.

Models for predicting disease have been developed by statistically comparing change in disease with various weather variables. A disease forecasting system for controlling Pythium blight (*Pythium aphanidermatum* (Edson) Fitzp.and *P. ultimum* Trow) of turfgrasses has been developed by chi-square analysis that compared previous disease outbreaks on Pennsylvania golf courses with T and RH data (Nutter *et al.*, 1983). Another example of a statistically derived forecasting model is for predicting stripe rust (*Puccinia striiformis* Westend.) of wheat in the northwest U.S. (Coakley *et al.*,1988). This FORTRAN-based analysis looked at eleven weather variables correlated against disease records at specific plant growth stages over a seventeen-year period. The program used the Statistical Analysis System (SAS) programs of REG, RSQUARE, and STEPWISE for the calculations. These analyses resulted in one 2-variable and one 3-variable model that was predictive in forecasting disease incidence for each of the two wheat cultivars used in that region of the U.S. The 3-variable models have slightly better adjusted R^2 values than the 2-variable models, but the simpler models require less computation to predict disease. Regretfully, due to financial constraints, the analysis program used in this study to calculate these models was not obtainable for the research of others.

Although a similar analysis program could be helpful in determining those weather variables that contribute to scab disease initiation in pecans, the requirements for the disease is different as well as the crop being considered. In the stripe rust model the goal was to determine if weather conditions had occurred that promoted the development of disease to a severe level during the previous winter and spring. With pecan scab the inoculum is never a limitation and the goal is to apply the fungicide at the time when conditions are most conducive to initiation of the disease.

In Oklahoma, the leaves of susceptible cultivars of pecans are vulnerable to pecan scab only from bud break in the middle of April to the end of June when the leaves mature and are no longer expanding (Gottwald, 1985). The prevention of leaf loss is important because the loss of a majority of the leaves may cause a crop to be unmarketable due to poor fruit fill. Research by Crane *et al.* (1934) has shown that about 8 to 10 leaves is required per fruit to insure adequate fill. The shucks of the fruits are susceptible to the disease from the time of their formation at the end of May through the time the shuck matures in mid August. Due to the high level of photosynthates being routed to the fruits for kernel formation, pecan scab lesions around the pedicel may continue to cause a significant loss of the crop, even after the shuck matures.

Because there are two sensitive growth periods in the annual production of pecans, identification of the 'windows' of significance are essential to refine the threshold model.

Earlier research (Gottwald and Bertrand, 1983) has suggested that early season initiation of disease has the greatest impact on crop quality with the major effect occurring by mid-June. They also concluded in this study that while midseason infections had the greatest rate of disease increase, mid- and late season initiation of disease had no effect on fruit quality. Other research (Hunter, 1983) suggests that mid-season initiation of scab affects the late season fruit drop of pecans. While the first study applied fungicides prior to the application of inoculum for each epidemic treatment, neither study used fungicides during the trials. Therefore, these studies looked at the affect of pecan scab on untreated trees. Personal observations at the Oklahoma Sparks trial in 1996 on which fungicides were applied have shown that the loss of a crop due to scab may occur as late as the end of August or early September when fungicide applications have been terminated while the shucks are still susceptible to scab. These contrasting results suggests that further studies are needed to determine not only the optimum time to apply fungicides, but also the duration of time scab conducive conditions should be monitored to prevent the late season loss of a crop.

In the 1996 field trials in Oklahoma (Chapter 3) the empirical threshold prototype model had relied on the accumulation of 200 hours before a fungicide was applied. The hours were then monitored from the date of spray application until 200 hours had again accumulated. As the time between the accumulation of 200 hours was always greater than two weeks, the residual effect of the fungicide was depleted by the next application date. To reduce or readjust the accumulation of hours, this residual effect of the fungicide must be taken into account to prevent the overlapping of application effects. Therefore, the need to determine the number of hours in the field that the weather conditions contributed to the initiation of infection became an important aspect of modification of the threshold model.

Another important aspect of the model development was to be able to control the disease at an acceptable level that enabled the grower to produce a profitable crop. The profitability of a crop is related to the size of the fruits, the quality of the kernels, the number of fruits produced, and the input of outside resources relating to the maintenance of the trees. Research has shown that the level of scab disease can affect size and kernel quality (Gottwald and Bertrand, 1983) as well as the number of fruits produced (Gottwald and Bertrand, 1983; Hunter, 1983). These studies have also demonstrated that when the level of disease on the fruit shucks (involucre) is greater than 26% coverage, all of the above factors begin to be negatively affected. Pecan scab on the foliage and shucks of pecans at this coverage level has also been shown to reduce net photosynthetic rate and dark respiration rate (Gottwald and Wood, 1985), both of which affect the quality of the fruit crop.

These studies illustrate that in the development of any threshold model for the purpose of fungicide application to control disease, the model must be able to predict application dates in a timely manner that will prevent the increase of the disease to unacceptable levels by the time of crop harvest. For the pecans this translates into applying fungicides to prevent the level of disease from exceeding a Horsfall-Barratt rating of about '3.5'. To allow a margin of safety and control the level of disease, it is considered for this model that the level of disease that should trigger the application of fungicides should be a rating of '0.5' on the Horsfall-Barratt scale. Using this marker in a heavy disease pressure year, a total of six applications could be applied with the expectation of the disease reaching no more than a rating of '3'. This safety margin would give the grower some assurance that the model would provide a strong decision-making tool for fungicide applications in control of pecan scab. Maintaining this low level of disease is another important aspect that must be considered in the modification of the model.

The goals of the statistical modification of the empirical threshold model is to limit the disease to acceptable levels taking into account the 14-day residual protection of the currently approved fungicides. The model would also define those weather variables that offered the best means of predicting the occurrence of disease initiation as well as the "window" of time that this event was affected by the weather.

Materials and Methods

Analysis of Weather and Disease Data.

Correlation of Weather Data Sets.–To analyze the epidemiological data statistically and to reduce the efforts expended in determining the thresholds at which to apply fungicides, it was important to develop a formula that could be automated and easily obtainable by those who could have the greatest benefit of such a model. Previously, weather data from the Oklahoma Mesonet weather stations had been visually compared to weather data obtained from the on-site data loggers and were found similar. To use the Mesonet data in a statistical comparison with the epidemiological data, the two weather data monitoring methods needed to be compared statistically to verify this relationship prior to it's use in regression analysis with the epidemiological data.

As a preliminary evaluation, the weather data sets from the Red River trial site in 1994 were downloaded from an in-field data logger and a nearby Oklahoma Mesonet weather station. The preliminary analysis with a small data set for the weather included the time-period from of May 8 to May 15. The Pearson Correlation Coefficient (SAS, 1989) analysis was conducted on the May '94 data set to determine if the Mesonet system could be used to replace on-site data logger weather data in the statistical analysis of the epidemiological data. The data set from the data logger contained vertical columns of Julian date, 24-hour time scale, T in Celsius and RH as percent. This file was converted to a Circadian date, 24-hour time, T in Fahrenheit and RH as percent. As the data logger recorded summaries of weather data on hourly intervals, this did not match the Mesonet weather data that was recorded at five and fifteen minute intervals. The

Mesonet data was set up in a similar vertical file with the date as Circadian, the T as Fahrenheit, and RH as percent. The T and RH data sets in fifteen-minute intervals for each hour were averaged to single hourly values. The T and RH for these two data sets were combined into a single file with common dates and hours. Since this preliminary evaluation showed a good correlation, a second, large set of the Red River '94 data set was analyzed similarly. The second analysis was from the dates April 20 to September 10. The full season analysis was correlated with the General Linear Model (GLM) program (SAS, 1989).

Regression Analysis of Disease Data with Weather Data.

The goal in the regression analysis of the leaf and fruit ratings for susceptible pecan cultivars was to determine the span of time that certain weather conditions contributed to scab disease initiation. This span of time could be defined either as an accumulation of a specific number of hours with subsequent appropriate conditions or as an interval of time with the appropriate conditions prior to the observation of lesions on the foliage or fruits. Initially, only the epidemiological data for Red River in 1994 was analyzed to determine trends. The first step in the regression analysis of the epidemiological data was to determine which of the weather variables had the greatest significance in relation to disease as determined by the Horsfall-Barratt disease rating scales (Fig. 2.2 and 2.3). A Pearson Correlation Coefficient analysis (SAS, 1989) was set up to compare ratings and change of rating for leaves and fruits of both the susceptible 'Burkett' cultivar and the native pecans using the Red River 1994 data. Each mean disease rating for the leaves was an average of ten trees with two sites per tree and three leaves per site. Each leaf was comprised of nine to thirteen leaflets that were used as a single disease rating for each visit to the site. For the fruits, each disease rating was an average of ten trees, two sites per tree and three to five fruits per site. Data sets were further segregated into raw Horsfall-Barratt disease ratings and differences between Horsfall-Baratt weekly ratings (Fig. 2.4) to determine the best method of disease rating to compare with the weather data. The changes in the difference in disease ratings for leaves and fruits were derived by subtracting each rating from the previous rating and using this difference in the analysis.

For this preliminary analysis, the weekly leaf and fruit disease ratings were averaged separately and the mean of each visit for both disease ratings sets were tested against the weekly cumulative hours of T within 21.1–29.4°C (70-85°F), RH at ≥ 80 or ≥ 90%, and the same T range with RH at ≥ 80 or ≥ 90%. For each of these five sets of weather variables, the weather data at three time intervals was compared with raw ratings and differences between ratings for the leaves and fruits of both native pecans and the susceptible cultivar 'Burkett'. The time intervals for weather data were at 1 to 7 days (A), 8 to 14 days (B) or 1 to 14 days (AB) before each rating date. For each of the weekly mean disease ratings during the Red River '94 epidemiology trials, the correlation analysis compared the accumulated number of hours for each identified set of weather variables at the three time intervals (A, B, AB).

The 1994 Red River data sets for the 'Burketts' were further analyzed using the combined factors of T between 21.1-29.4 C and a RH of ≥ 80% or ≥ 90%. The decision to test RH of ≥ 80% was based on empirical observations of weather data that showed that in Oklahoma there are more than twice as many hours of 80% RH than 90% RH. This decision was supported by greenhouse studies (Gottwald,1985; Latham and Rushing,1988) that showed scab may develop at a lower level of humidity after germination of spores at higher levels. As the ratings taken weekly reflected disease that developed in the preceding seven days and a difference between disease ratings is the result of two week's ratings; it was considered that the time period from the second rating to the week prior to the first rating should be analyzed to determine if this period was significant. This thought process was supported by field research (Valli, 1964; Latham, 1982) that had shown disease symptoms take 7 to 10 days to develop. This series of analyses was limited to the time span 14 to 21 days prior to the rating for the comparison between of ≥ 80% or ≥ 90% RH at the T range described.

GLM analyses were expanded to determine if a minimum number of accumulated hours or a minimum number of hours that accumulated within varying number of days was important.

These analyses were conducted to help define trends that determined the best fit of weather conditions within the parameters of a minimum number hours or a period of days that characterized the best conditions for initiation of the disease. In this series of analyses, the disease data was compared with the number of accumulated hours of weather conditions in the combination of ranges described that were ≥ a minimum of 1 to 8 hours. By using groups of accumulated hours that were greater than partial or single hours, it was hoped to further identify trends which might be useful in defining the number of hours that promoted the development of pecan scab in the field. This series of analyses was conducted for leaf and fruit data separately. Based on the previous analyses of the Red River 1994 data, the fruit data was further analyzed with GLM regression analysis (SAS, 1989) in moving intervals of 2, 5, 10, and 14 -days at ≥ 90% RH in the T range described above. Beginning with the fewest number of days, each moving interval regression series was run to include a 35- 45-day span prior to each rating. Results for each series was tabulated as to the R^2 value, significance, and whether the correlation was positive or negative. R^2 values were graphed to further identify groupings of days that suggested periods of time that weather conditions were favorable for disease.

On completion of regression analyses of the Red River '94 data sets, those sets of parameters that produced the highest R^2 value and the greatest probability with a positive correlation were tested on the 1994 Vinita, 1995 Vinita, 1995 Red River, 1996 Sparks, and 1996 Sapulpa data set for fruits (See Fig. 2.1 for location of field sites). Vinita 1994/1995 and Red River 1994/1995 combined data sets were also analyzed. The rating values and difference in rating values for all epidemiological data analyzed for all sites and years were derived by the same method described for the 1994 Red River data set. Each of the disease rating data sets used in the analyses were compared to the Mesonet weather data file that was monitored by the station closest to each trial site. The epidemiological data sets were compared against the weather data sets using regression analysis with the GLM from the SAS program (1989). Results of these regressions were tabulated as for the Red River results identifying similar positive trends. Tables depicting the R^2 values with the highest significance were used to summarize the results of all epidemiological regression analyses. The linear equations with the highest R^2 values that were derived from the regression analysis were submitted to a statistical evaluation program (Table Curve, 1989,90) capable of comparing differential equations for the 'best fit' of the data. The design of the 1997 field trial was based on the results of the analyses and several 'best-fit' equations. From the disease prediction plots produced from these equations the estimated number of hours related to the change of rating was determined for the threshold treatments.

Experimental Design for the Statistical Threshold Model Field Trial.

The statistically based fungicide application threshold model was tested in a trial conducted at the Oklahoma State University Pecan Research Station at Sparks, Oklahoma. A complete randomized block design in which treatments were applied to groups of three 'Western' pecan trees similar to the 1996 trial (Chapter 3). Treatments were replicated four times. The treatments were a phenological application schedule (see Chapter 3), two 10 scab-hour application thresholds, a 30 scab-hour application threshold, and an untreated control. Each tree was marked with circles of paint on the tree to demarcate treatments as previously. A tank mix of fenbuconazole and triphenyltin hydrochloride (each at one-half the recommended rate) were applied to the phenological, one 10 hour threshold and the 30 hour threshold treatments as previously described in Chapter 3. The experimental fungicide, azoxystrobin was used for a second 10 hour threshold spray. Surfactant/sticker (Latron^R) was added at the recommended rate and was included with all fungicide applications. Fungicide applications were applied with the same equipment of the 1996 trial and with the same methods described in Chapter 3.

Based on the considerations of hourly accumulations of weather conditions within the described parameters in specific blocks of time and the residual effect of approved fungicides, the modified prototype of the threshold-based fungicide application trial was tested to determine the accuracy of the statistically derived predictions. The weather conditions were monitored through the Mesonet network that was available through Oklahoma State University's computer network. T and RH readings at fifteen-minute intervals were downloaded daily and transferred to files to increase the ease of tabulating the accumulation of hours. The decision to apply fungicides was based on the accumulation of hours that occurred on unprotected days two weeks prior to each decision. With the increase of each current day, the two-week span of time that was monitored was moved forward a day. Therefore, for the accumulation of hours for any given day encompassed only those hours conducive to scab that occurred 1 to 14 days prior to that day. Once a fungicide spray had been applied, the hours of conducive weather that promoted disease were not considered until two weeks had elapsed and then the accumulation of scab hours that induced disease were again monitored.

Trial Evaluations. The center tree of each plot (3 tree treatment unit) was evaluated at the end of the season for all four replications. Each tree was sampled from four sites on each tree and the disease rated on both leaves and fruits using the Horsfall-Barratt scales. For each treatment there were sixteen leaf and fruit samples. Results were statistically analyzed using the Duncan's multiple range test (SAS,1989).

Epidemiology Ratings of Untreated Controls. Two of the unsprayed trees in the east group of 'Westerns' were tagged at two sites for both leaf and fruit ratings. The primary purpose of this rating trial was to verify the epidemiological ratings of the previous year's trials with respect to scab progression in the untreated trees. Due to the late freeze that defoliated the trees at the time of fruit formation, additional interest was added to discern the impact of secondary foliar growth on the progression of disease.

Results

Analysis of Weather and Disease Data.

Initial Correlation of Weather Data Sets. Pearson Correlation Coefficient analysis of T and RH data from the Red River trial site data logger compared favorably with the weather data from the Oklahoma Mesonet station nearest the trial site for the time period of May 8 to May 15. Correlation analysis of the T R^2 value was 0.77 with a significance of >0.01 (Table 4.1). The R^2

value for the RH analysis was 0.91 with a significance of >0.01. Comparison of T means for Mesonet and data logger data showed less than a 4-degree difference (5.2%) between the means with similar standard deviations. The difference between the means for RH of the two weather monitoring systems is less than 6 (6.9%) with less similar standard deviations. The plots comparing the two weather collection sites at the Red River for May demonstrate a linear correlation with some occasional outlying data points. The T plot (Fig. 4.1) identifies a good correlation between the two methods of weather data collection in the T range that *C. caryigenum* is most able to cause disease. The RH plot (Fig. 4.2) of the datalogger and Mesonet weather data collection systems shows a similar trend of a correlation in the RH range that *C. caryigenum* requires for maximum disease potential.

Comparison of the two 1994 Red River weather data sets for the entire season using ANOVA analysis (SAS, 1989) demonstrated a difference between the means for T of 0.92°C (1.66° F) with a difference between standard deviations of < 0.8. The difference between the means for the RH correlation was 1.7% and a difference between standard deviations of < 2.2. T R^2 was 0.72 with a P<0.0001 (Table 4.1). RH R^2 was 0.53 with a P< 0.0001. Full season correlation plots of T (Fig. 4.1) and RH (Fig. 4.2) weather data are not as linear as the smaller May data plots (not shown), but do demonstrate the relationship between the two weather data sets. These analyses support the supposition that the Mesonet weather data can replace data logger weather data in further correlation analyses for comparison with the epidemiological data in the statistical revision of the threshold-based fungicide application model.

<u>Regression Analysis of Disease and Weather Data</u>.

<u>Initial Correlation of Disease and Weather Data</u>. Using the Pearson Correlation Analysis, definite trends were observed in comparing the accumulated hours for the five combinations of weather variables for each of the three time series. Only those weather variables that had a positive R^2 value higher than 0.45 and a significance greater than 0.03 against the disease ratings were considered as possible accumulations of hours that contributed to the

disease ratings in the eight leaf or nut rating categories (Table 4.2) tested. With the 'Burkett' mean leaf disease ratings, the weather variables with the highest R^2 for the time interval A (1-7 days before the leaf rating) were the T (A T), the combination of T/ RH at 80% (A T/RH 80%), and the combination of T/ RH at 90% (A T/RH 90%). For the time interval B (8-14 days before the rating date) with the 'Burkett' mean leaf disease ratings the significant weather variables were the T (B T), the combination of T/ RH at 80% (B T/RH 80%), and the combination of T/ RH at 90% (B T/RH 90%). For the time interval AB (1-14 days before the rating), the 'Burkett' mean leaf disease ratings with significant weather variables were the T (AB T), the combination of T/ RH at 80% (AB T/RH 80%), and the combination of T/ RH at 90% (AB T/RH 90%). For the 'Burkett' mean fruit ratings, significant R^2 values were: A T/RH 80%, B T, B T/RH 80%, B T/RH 90%, AB T, AB T/RH 80%, and AB T/RH 90%.

The differences between the mean disease ratings for the 'Burkett leaf data did not show any significance in any of the fifteen weather parameter/weekly categories tested. The difference between mean disease ratings for the 'Burkett' fruits had significant R^2 values with: B T/RH 80%, B T/RH 90%, and AB T/RH 80%.

Native leaf disease ratings had significant R^2 values with: A T, A T/RH 80%, A T/RH 90%, B T, B T/RH 80%, B T/RH 90%, AB T, AB T/RH 80%, and AB T/RH 90%. Native fruit disease ratings had significant R^2 values with: AB T/RH 80% and AB T/RH 90%. None of the categories tested for the difference between disease ratings for native leaves and fruits demonstrated any significance.

Overall, the highest R^2 value was 0.62 with a $P< 0.003$ for the combined two weeks accumulation of hours using the T of 21.1 to 29.4° C and an RH of ≥ 90%. This significant value was calculated for 'Burkett' leaf and fruit disease ratings and the native leaf disease rating. A significant R^2 of 0.60 was also calculated for a 'Burkett' fruit disease rating. All other R^2 values

($P < 0.01$) were between 0.45 and 0.584 for those categories that showed a significant correlation with the weather data.

In these preliminary correlation analyses of epidemiological disease data with weather variables, only the Red River 1994 disease data was tested. For each of the disease rating categories with significant R^2 values, a trend was demonstrated toward combinations of T and RH. Because both ≥ 80% and 90% RH showed significance and due to the large number of daily hours in Oklahoma that the RH is ≥ 80%; testing with this range of RH was continued. No further analysis was conducted with the disease data from the native pecans because of their variability of resistance to pecan scab. Since cultivars exhibit a uniform response to susceptibility of pecan scab, all correlation analyses were restricted to those cultivars that had a low to moderate resistance to pecan scab.

Comparison of Four Combinations of Temperature and Relative Humidity Limits.

Results of the further analyses using GLM with the time period of 14 to 21 days before the rating on the Red River '94 data showed that the difference between mean ratings for the fruit disease data (Table 4.3) provides a better R^2 value than the Horsfall-Barratt mean ratings for the fruit disease data, the leaf disease rating data, or the difference between ratings for the leaf disease data (data not shown). No significance was obtained with either type of leaf disease data while the lowest GLM results of the difference between ratings for the fruit disease data gave an R^2 of 0.43 at a $P < 0.01$. GLM analyses of fruit disease ratings compared at 80% to 90% RH with and without upper T limits revealed that the highest R^2 was obtained using RH ≥ 90% without the upper T limit (Table 4.3). The upper T limit had been previously suggested (Hunter *et al.*, 1978; Latham and Rushing, 1988) as the maximum T that *C. caryigenum* spores would germinate. Review of the weather data revealed that for Oklahoma conditions the RH drops off rapidly as T increases above 29.4 C. Therefore, the need to place an upper limit during the calculation of scab hours was unnecessary for the development of the model. GLM analysis of the difference between mean leaf disease rating data using the rating periods limited to early leaf expansion (first 5 or 9 visits) yielded a greater R^2 but not a greater significance over the full season's ratings (17 visits) (not shown). The highest value for the difference between ratings for the leaves had an R^2 of 0.18 with no significance as compared to an R^2 of 0.50 with a significance of 0.003 for the difference between disease ratings for the fruit data. Limiting the number of accumulated hours to a minimum of 1 to 8 in the difference between leaf disease ratings did not improve the R^2 values. A small R^2 improvement (2.5%) was seen in the Red River '94 differences between fruit disease rating data when the number of accumulated hours was limited to ≥ 2 compared to ≥ 1 in the GLM analyses (Table 4.4).

Initial correlations of the various variables of the Red River 1994 weather and disease data has shown that using the combined weather variables of RH ≥ 90% and T ≥ 21.1°C (70°F) with no upper limit produces the highest, significant R^2 with this data. Analyses of the leaf and fruit disease ratings both as means of raw ratings and the difference between a rating and the previous rating has demonstrated that highest, significant R^2 values are obtained when the weather data using the variables above are correlated with the difference between ratings for the fruit data. Although using a minimum limit of scab hours of ≥ 2 gave a slightly higher R^2 value than scab hours of ≥ 1, the decision was made to use the minimum accumulation of scab hours of ≥ 1 in future calculations. For simplification of describing the accumulation of hours with the combined characteristics of RH ≥ 90.0 and T ≥ 21.1°C for all analyses, each hour that accumulates within these parameters will be referred to as a 'scab hour'.

Regression Analyses of Red River 1994 Disease Data and the Accumulation of Hours of Disease conducive Weather in Moving Intervals of Days. GLM regression analysis of the Red River '94 fruit data (difference between ratings) with moving intervals of 2, 5, 7, 10 and 14 days revealed differential results with the weather variables of RH ≥ 90% and T ≥ 21.1°C with cumulative hours ≥ 1. The 2–day moving average had its highest significant R^2 value of 0.99 (P<0.0001) at 19–21 days prior to the rating date. The 5-day moving average had its highest R^2 value of 0.53 at 18-23 days prior to the rating, but the results were not significant (P= 0.1). The 7-day moving analyses series revealed a significant (P<0.001) R^2 value of 0.54 at 15-22. The 10-day moving average of the nut data analyses did not reveal any positive R^2 value, but had a significantly (P<0.01) negative R^2 of 0.90 at 8-18 and 9-19 days prior to the rating events. By removing the first three weeks in which the fruits did not demonstrate the presence of scabbing from the analyses, a positive R^2 of 0.96 was obtained but not with significance (P = 0.13). The 14-day moving intervals of scab hours revealed the most positive R^2 values (0.49 to 0.50) with significance (P<0.002-0.003) between 13 to 27 days and 15 to 29 days (Fig. 4.3).

With these results of the Red River '94 data set as a guide, analyses of the other data sets were conducted. GLM regression analysis was used to determine if other leaf disease data sets would produce significant correlations within the combined variables of T≥ 21.1 °C and RH ≥ 90%. Difference in disease ratings for the fruit data was also analyzed to determine the variation of R^2 values based on moving intervals of accumulated scab hours of the combined weather variables.

<u>Regression Analyses of Red River 1995 Disease Data and the Accumulation of Hours of Disease conducive Weather in Moving Intervals of Days</u>. The GLM regression analysis of Red River '95 difference between leaf disease rating data did not reveal any significance in comparing the accumulation of weather related hours with the change in ratings. Red River '95 difference between fruit disease rating data for the susceptible cultivar 'Burkett' was analyzed for hourly accumulations of weather for 2, 5, 7, 10, 14 day intervals that could be positively correlated to the change of disease rating of scab on the fruits (data not shown). These intervals covered the periods from 10 to 46 days prior to the dates of ratings. For each interval of days, moving averages were conducted with GLM analysis. Positive correlations of the data were found from 30 to 46 days prior to the disease rating (data not shown). As the literature does not agree with

these predicted time periods for germination prior to observance of lesions, it was concluded that this data set was aberrant due to the additional disease stresses and flooding that were described in Chapter 2 for this site in 1995.

Summary of Correlations for Disease Data and Weather Variables. Differences between ratings for the fruit disease data were analyzed with GLM regression with moving intervals of 7 and 14 day for all sites and years except Vinita '95. Figures 4.3 through 4.5 represent examples of these analyses. The highest, positive R^2 values, significance and the date range that they occurred for all sites and years are summarized in Table 4.5. If the aberrant Red River '95 data is excluded from the calculations for the 14-day moving averages, the results suggest that the period of time in which the weather affects the infection process occurs between 10 and 29 days prior to the occurrence of the lesions. The R^2 values range significantly from 0.33 to 0.84 within these dates for the nut data sets analyzed. The results of the 7-day moving intervals (Table 4.5) suggest that the period of time that the weather was conducive to the scab infection occurred 15 to 31 days prior to the observance of lesions. R^2 values range significantly from .54 to .86 within this range of dates.

In an effort to increase the sample size of the data sets in the analyses, the fruit disease rating data for the Vinita 1994 and 1995 sites were combined in a GLM analysis series and correlated with the weather data for the two years. Each disease data set was compared with the appropriate weather data and the resulting analyses combined into a single correlation. The GLM analyses of the combined fruit disease data for 1994 and 1995 from the Red River site did not reveal an significant periods of weather conducive to infection using the 14-day moving averages (data not shown). Using the weather variables of RH $\geq$ 90% and a T of $\geq$ 21.1 C, the moving average analyses were tested for the accumulation of hours from $\geq$ 1 through $\geq$ 5.

Analyses of Combined 1994 and 1995 Vinita Disease Data and Weather Data. Vinita was the only site that gave data from both 1994 and 1995 with no apparent complications that would preclude correlation analysis of the two data sets. In both years, however, disease severity was low and correlations with indicative periods of accumulated weather variables were expected to be low. The 1994 and 1995 Vinita fruit disease data sets were combined and compared with the weather data for those two years. Differences in ratings with moving intervals of 7, 14 and 21 days were analyzed with GLM. Rate differences with 7 day moving intervals indicated that 17 to 24 days was the period when weather affected the ratings (not shown). The R^2 values for this period was 0.28 with a $P<0.01$. Fourteen day moving intervals for differences in rating indicated that the days that weather affected the disease ratings was from 11 to 25 through 13 to 27 days (not shown). The R^2 values for these time periods was 0.16 - 0.17 with a $P< 0.1$. The 21-day moving interval series identified 7 to 28 and 8 to 29 as the time periods that the disease ratings were affected by the weather (data not shown). The significant R^2 values for these time periods was 0.31 and 0.27 ($P< 0.006$ and 0.01).

Determining the Threshold Model Equation. Based on the results of all GLM correlation analyses, the dates relating to the highest significant R^2 values was reviewed (Table 4.5) and excluding the Red River 1995 correlation for the differences between the fruit disease rating results suggested that the time that was most closely related to the development of the disease was from 10 to 29 days using the 14-day moving averages and from 15 to 28 days using the 7-day moving averages. The conclusion was reached from this review that the Red River 1994 R^2 value was in the middle of this range. The linear equation, $y = 0.09607 + 0.01387X$, derived from this correlation was compared to results from a differential equation program using the Red River 1994 difference between disease ratings data and the Mesonet weather data.

Comparison of Linear Equations with a Differential Equation Program. The statistical evaluation package, Table Curve by AISN Software (1989,90) identified a number of equations for both the Red River '94 data based on the best R^2 value with a fourteen-day moving average of hours at 15 to 29 days before the rating date. Although many types of equations were recognized as valid with varying levels of complexity; the decision was made to compare only those equations that used the data of the original data set and were simple.

The difference in rating for the Red River data set identified a simple linear equation (y=35.71 + 47.87xwith the dependent variable being the difference between ratings. The R^2 for this equation was 0.496 and a DF adjusted R^2 of 0.418. Dropping the one outlying wild point from the data and recalculating y=a+bx the R^2 value was increased to 0.589 with a DF adjusted R^2 of 0.521. A second linear equation identified was $y^{0.5}=a+bx^{0.5}$ with a and b values of 5.65 and 3.70. R^2 for this equation was 0.562 and a DF adjusted R^2 of 0.495.

The GLM regression derived equation plots were compared with the differential equation program plot with similar data sets. The purpose of this comparison was to determine if the differential equation programs would predict a similar number of scab hours that would accumulate based on a disease rating of '0.5' from the Horsfall-Barratt scale. The predicted number of scab hours based on perusal of all data was from 0 to 40. Due to the variability of the y-intercept values and the large errors associated with the y-intercept it was decided to use 10 hours and 30 hours as the thresholds to be tested. This decision was supported by the equation from the Red River 1994 fruit disease data that predicted an accumulation of 30 scab hours would produce a disease rating of '0.51'.

<u>Field Trial Tests of the Statistically Derived Threshold Model</u>. The two, low (10 scab-hour) threshold treatments received three spray applications on the 20th of June, the 16th of July, and the 6th of August. The phenological received one more on the 30 of May. The 30-hour threshold received one spray on the 16th of July. The negative control received no sprays through the course of the trial. Failure to discern differences between the phenological treatment and the two low threshold treatments is most likely due to the disruption of the phenological spray schedule caused by the April freeze and as well as the failure to apply two of the phenological fungicide sprays on a different schedule from the low threshold sprays due to complications in scheduling.

The ANOVA procedure revealed significant differences between treatments for both the leaf and fruit analysis of the Sparks '97 Threshold trial. R^2 for the leaves was 0.62 with a P< 0.0001 and for the fruits the R^2 was 0.87 with a P< 0.0001 (Table 4.6). Using Treatment (Tmt) X Replication (Rep) as the error term for the leaves, the ANOVA procedure suggests that there was a difference between Tmt and Rep with a P< 0.05. Using the same error term for the nut analysis, there was a significant difference between Tmt at P< 0.0001, but no significant difference between replications. For the leaf and fruit analyses, there was no significant difference between the samples types.

All treatments except the high threshold and negative control gave significantly better control of disease for both leaves and fruits (Table 4.6). The Duncan multiple range test (SAS, 1989) showed a difference between the control and both low threshold treatments as well as the phenological treatment. There was also a significant difference between the low threshold treatment with azoxystrobin and both the high and low threshold treatments using the tank mix of fungicides. The Duncan test also showed that for the leaf analysis, there was no significant difference between the unsprayed control and the high (30-hour) threshold treatment (HT, tank-mix) or between the high threshold, the low threshold and the phenological treatments (all tank-mix fungicide applications) or between the low threshold with Abound and the phenological treatment.

In the fruit analysis, there were significant differences between the unsprayed control and the high threshold (tank-mix); as well as differences between the high threshold treatment and both low threshold treatments and the phenological treatment. There was no difference between either of the low threshold treatments and between these and the phenological treatment.

Epidemiological Ratings. Phenological development of pecan trees was severely set back after a late freeze on April 14. Secondary foliar growth was still emerging on May 27 with second and third leaves still emerging. Fruits were regenerating during the end of the pollination phase and no pollinated fruit observed on this date. On June 20 scab was beginning to infect the leaves but no lesions were observed on the young fruits. Single lesions were observed on trial fruits on June 27 with the disease on the leaves continuing to progress. Leaf disease ratings on July 16 remained low with a rating of '2' and '3.5' on the fruits (Fig. 4.6). The leaves had a narrow range of variation, but the fruit ratings varied from a low '2' to '8' with the majority of the ratings in the '2' to '3' range. On August 6 the leaf ratings remained the same as for the July 16 rating, while the fruit rating had progressed to '5.7'. The range of ratings for the fruits varied from '3' to '8' on this date with the majority of the ratings in the '6' to '8' range. Final leaf ratings on August 28 had an average of '2.5' and a final rating of '7.4' for the fruits.

Discussion

Analyses of Weather and Disease Data.

Correlation of Weather Data Sets. The correlation analysis for this one site suggests that the 113 Mesonet weather data collection systems located around the state can be used as decision sources for predicting when to apply fungicides. Most of the Mesonet systems are located in areas much different from sites at airports where previous weather monitoring has been conducted. The advantage of the Mesonet weather monitoring stations is that they are located at remote sites in rural areas and therefore have a greater capability of reflecting the actual weather conditions found in agricultural regions of the state. Although the two data collections systems studied at the Red River site are approximately a mile from each other and are in different environments, the Mesonet site on the hill is able to reflect the weather conditions found at the data logger at the tree-covered river-bottom. This was especially true for the results for the May RH plot (data not shown) revealed a high degree of similarity between the two sources of data collection. These results would suggest that although differences may occur, in general the weather conditions found at the two sites are similar. The random data points on both the May T and May RH plots that did not agree with the general trend of the plots can most likely be explained by the differences in the two sites. The rapid temperature increase during the day and the loss of RH at the exposed Mesonet site would differ from the slower dew evaporation and gradual temperature increase found under the trees. Conversely, as the sun sets, the bottomland site of the datalogger location would retain heat longer due to the higher water table and larger biomass. The exposed Mesonet site would lose heat more rapidly resulting in a quicker attainment of dewpoint.

The full season plots of T (Fig. 4.1) and RH (Fig. 4.2) demonstrate the wider variation of conditions that may prevail between the two weather monitoring sites. Visual comparisons of the 3400+ hourly summaries for T and RH of the two weather collection systems support the premise of site variability. Overall, the differences are limited as shown by comparison of means and standard deviations of the full season data discussed in the Results section (Table 4.1).

Graphed results of the differences between the two weather collection systems for both T (Fig. 4.7) and RH (Fig. 4.8) readily show the fluctuation of conditions that occur on a day to day basis. All graphs were constructed by subtracting the Mesonet hourly value from the data logger hourly value for each parameter (T and RH). All positive values depict an hour when either T or RH from the data logger site was greater than the Mesonet site. All negative values depict the condition of the Mesonet parameter is greater than the data logger value. The results of these graphs indicate the variance between the sites on an hourly, daily and seasonal levels. As can be seen, the variation is due to the daily weather fluctuations as well as the site differences.

The correlations from which the model was derived is based on the Mesonet weather data, therefore, the functional model has been designed to accommodate these differences between sites. These differences also indicate that the data logger data would have produced higher correlation coefficients when compared with the epidemiological disease data.

<u>Correlation of Weather and Disease Data</u>. Results from the Pearson Correlation clearly demonstrates a trend toward using the combined data sets of T and RH for predicting optimal

weather conditions for disease development in the field. Each rating set that identified any weather factors also included several combination weather groups as well. This would suggest that the combination of T and RH is a stronger predictor of the disease conditions than single weather factors of T or RH alone. The 'Burkett' leaves had the largest number of correlations with the weather variables tested. These included weather factors prior to the ratings from the first, second, and first and second weeks combined. While numerous significant correlations were not observed for the 'Burkett' rate change for the fruits, the fruit ratings as well as the differences between the ratings for the fruits showed similar trends in correlations using the combined T and RH as a predictor for disease. Native leaf and nut ratings also showed similar correlations in the combinations of T and RH. The results of the Pearson Coefficient Correlation identified the blocks of time to analyze with the GLM regression. These blocks of time are supported by the limits identified by Valli (1964).

Analyses of Red River '94 Leaf and Fruit Disease Ratings. Analysis of the fruit data with various combinations of T and RH suggest that the best range of weather combinations for this method of forecasting in Oklahoma is a threshold prediction that uses a T of 21.1 C or greater and a RH of 90% or greater. These weather variables are similar to those proposed by Hunter *et al.* (1978) but without the upper range limit. Analyses that compared accumulated hours of weather using these conditions against disease ratings and the difference between ratings showed that the difference between ratings yielded the highest R^2 values. Comparing the combination of weather variables with a series of analyses of a minimum number of hours revealed that by limiting the minimum number of hours to two the highest R^2 value could be attained in the analysis. However, limiting the hours to a minimum of one decreased the R^2 value only slightly with no decrease in significance, therefore, a minimum of one was used in the completion of the GLM analyses.

Leaf Disease Data. Using the $T \geq 21.1$ C and $RH \geq 90.0$ as the weather parameter combination; the Red River '94 difference in rating of leaf data was analyzed with GLM in three ways. The disease data was compared against the weather variables in a series of minimum hours (1 - 8), difference between ratings was compared to the raw disease ratings, and the leaf data was limited to periods of phenological development. The phenological development in the analysis was first analyzed for the entire season and then tested with the disease ratings from the first five and the first nine visits. As none of the calculations for any of the series of analyses showed any significant R^2 values; it was concluded that with the weather variables tested, the leaf ratings were not a good indicator in the threshold model. However, these results were in contradiction to the earlier Pearson Coefficient analyses that were conducted in the initial phase of the statistical analysis. The earlier results with the same data set clearly demonstrated that the 'Burkett' leaves had a high correlation with the weather data. However, the earlier analysis was limited to the first fourteen days prior to the rating while this later analysis was limited to the third and fourth weeks prior to the rating dates.

Fruit Disease Data. Moving averages for different sites and years of unsprayed nut data sets for 1994 through 1996 (Table 4.5), suggests that the optimum time for the combination of weather conditions to affect the ratings at the sites studied varies with the span of time analyzed. The results of the seven-day moving averages suggest that 16 to 31 days is the time that the weather affects the initiation of disease. Results from the fourteen-day moving averages suggest that the time period from fifteen to twenty-nine days is the period in which the weather conditions could have positive influences upon the initiation of disease. Both periods are nearly two weeks prior to the rating dates and closely support the suggestions in the literature that the period of time required for infection and symptom development of *C. caryigenum* is 10 days to two weeks prior to observation of lesions. The results of these analyses would appear to indicate that at least two weeks before the siting of disease the weather must be monitored to determine if conditions are right for initiation of disease.

Combined 1994 and 1995 Vinita Disease Data. GLM analysis of the combined Vinita nut disease data sets did not support the previous results as closely as would have predicted.

Although the 7-day moving averages did suggest that the hours accumulated in the time period 17 to 24 days prior to observation of lesions, this was not supported by moving averages of 14 and 21 day analyses. The fourteen-day moving averages identified 12 to 27 days prior to the rating and the 21 day moving averages identified 7 to 28 days prior to date of rating. All R^2 values were low and the 14-day moving average series was not significant ($P<0.05$). The wide variation of results for these three data sets is indicative of other factors than those addressed in the preliminary GLM regression analyses of the Red River '94 data sets. One obvious consideration is the low R^2 values of the data sets when analyzed separately. The Vinita data sets had R^2 values of 0.55 ($P<0.006$) for the 7-day moving averages and 0.33 ($P<0.03$) for the Vinita '94 14-day moving averages. The purpose of using regression analysis on each epidemiological data set with it's own weather set and combining the results had been an effort to increase the sample size and thereby improve the R^2 value in hopes of providing a stronger definition of the time period which affects the disease initiation. The complexity of many interacting factors affected the results of the regression analyses. Although the same trees were used in the epidemiological trials for both years, factors such as winter stresses, energy depletion from the previous year's crop, and general health of individual trees, all of which influence an individual tree's ability to resist disease, cannot be assessed or calculated.

GLM analyses was also conducted on the '94/'95 Red River nut data, but the results were not significant. The main conclusion for the lack of significance is attributed to the '95 data set and the confounding factors in the field for this year. Although the data was evaluated in the same manner as for all other sites and years, the heavy phylloxera infestation that affected the trees during early leaf expansion heavily stressed the trees at Red River in 1995. Immediately after this infestation, a heavy influx of inoculum was promoted by near 100% humidity when the orchard floor was flooded for nearly three weeks. By the time the orchard floor was drying out, the higher Ts of early summer caused to secondary inoculum to proliferate with the results that the secondary foliage which emerged at the end of June was decimated during early expansion. The trees were bare of all foliage and fruit by the end of July. The management at this research station decided at this time to remove the highly susceptible 'Burketts' from the farm because the heavy stress would have prevented the overcrowded trees from producing a crop for one to two years.

Conclusions of Model Development.

Comparison of the plots of accumulated hours vs. the difference in ratings for the different equations produced a question of how much pecan scab could be allowed to develop prior to the application of a fungicide. The answer to this decision was based on two premises. First, since the grower would prefer to have scab free pecans, the scab progression through the course of the growing season must be kept as low as possible. As the maximum amount of scab tolerable to prevent damage to the crop is a rating of '3'; each fungicide application must be applied in a manner to prevent this level of disease by the end of the growing season. Since no more that five sprays would normally be applied in a heavy scab year, the trees would have to be sprayed each time the lesion coverage increased no more than one-half of a rating. If the scab increased by a half of a rating prior to each spray application, the disease would accumulate to a rating of '2.5' by nut harvest.

In the attempt to translate the correlation of the number of scab hours which could accumulate at a given rating the predicted slope was considered. The slope from the GLM analysis of the Red River'94 nut data was significant (Pr > 0.004), the intercept value was not and the estimate of standard error was large. This suggests the Y intercept at X=0 may be quite variable. This results in the inability to discern the fewest number of scab hours that will affect the difference in ratings. Because the Horsfall-Barratt scale is exponential from it's higher and lower ends, a rating of '0.5' translates into a 3% disease coverage of surface area when considering the lower end of the rating scale. As pecan scab is a polycyclic disease, it is important to maintain it at lower levels to prevent an exponential increase. This translates into controlling the disease when it is in it's linear (lag portion) of the disease progress curve thereby preventing production of secondary spores during the growing season.

Based on the graphs generated with the analysis, this translated into an accumulation of no more than 30 hours prior to the application of a fungicide. However, given the poor estimate of the intercept value, this conclusion could be subject to a wide variation. The decision was made to test the 30-hour threshold and a second threshold of 10 hours to test the variability of the model as well as limiting the progress of disease to zero.

The second premise is based on the characteristics of the fungicides. In the past , most fungicides used on pecans, such as triphenyltin hydroxide have had a two-week protectant characteristic with no curative action. Recently fungicides have been approved for use on pecans that do provide protectant as well as curative action. The benomyl and azoxystrobin used in the 1996 trials and that will be used in the 1997 trial have these characteristics. Beonmyl is from the sterol inhibiting class of fungicides while the azoxystrobin interrupts electron transport in the mitochondrial membranes. As scab fungicides have approximately two weeks of residual action, the assumption was made that the accumulation of hours conducive to disease that accumulate during these periods of coverage do not need to be considered.

The decision as to when to apply fungicides to pecan trees was based on three requirements. The number of hours that must accumulate with the prescribed combination of weather conditions, the period of time which must be monitored to accumulate those hours and the efficacy of the fungicides that are approved for application on pecans. For the first spray of the season, fungicide efficacy is not a consideration. However, once a fungicide has been applied, two weeks may elapse prior to beginning to monitor the accumulation of hours that are conducive to scab. As described above, the number of hours to accumulate prior to fungicide application for the 1997 field trial at Sparks would be tested at 10 and 30 hours. Based on the statistical analyses of the 1994 to 1996 field data, the period of time that the weather conditions influenced the disease was two weeks prior to the siting of the scab lesions.

Summary of Discussion.

The results of the field trial revealed that the model can be successfully applied to control scab and at the same time limit the number of fungicides applications in normal years. For the 1997 trial, the 10-hour threshold predictor demonstrated that the model can provide as good a level of scab control as the recommended phenological schedule. However, it also suggested that the model can be improved upon to be a better predictor of disease conditions.

The other consideration for the model is the failure of the statistical analyses to identify variables that would predict control of scab in the leaves. Although the argument may be made for the current model that if the scab is controlled in the nuts the leaves will be protected, the results of the GLM analyses of the leaves provides evidence that a parameter needs to be identified to promote better control of scab prediction. Part of the complication is the short span of time in the early part of the growing season that the leaves are susceptible to infection. As the leaves mature and the tissues harden, the leaves are more resistant to infection. The positive side of the current prototype of this model is the ability to control scab on the shucks of the nuts during the longer portion of the growing season when the shucks are susceptible to scab.

Testing a working model in the field is difficult due to the lack of control over a multitude of factors. Part of the difficulty lies in the fact that a pecan field trial to test a model may be conducted once a year. This may provide some time for evaluation of data and modification of a model, but if an error is made in model preparation, months must elapse before a new trial may be conducted. Although obviously the annual weather patterns cannot be controlled, other factors affect the outcome of any field research. Among these factors are the actual numbers of infective spores present in any given year, the impact from races of the disease pathogen which may appear, the topography of the terrain in which the trial takes place, the condition of the pecan trees in the trial that vary from year to year due to stresses, and the susceptibility of any given pecan cultivar. These trials have assumed that an infective level of *C. caryigenum* spores are not a limiting factor and the trees are maintained on a preventive schedule of normal fertilization, insect control and cultural maintenance. Testing of the model on pecan cultivars of differing susceptibility would be useful in determining the number of hours that could accumulate and the level of control that could be obtained. Future trials should be conducted with this model as it is modified through further analysis and with trees of differing susceptibilities and under differing site conditions to test the efficacy of the model as a decision tool.

Clearly, to improve the model a different approach may be needed to improve its predictability. Both the cumulative 200 hour model of 1996 and the 10 hour accumulation of hours in the two weeks prior to spray application model of 1997 demonstrated that the disease could be controlled as well or better with a fewer number of sprays than the recommended phenological spray schedule. However, both models also demonstrated that there was room for improvement and that the vast amount of data that has been accumulated needs to be approached in a different manner.

Some of the ways that the data may be analyzed differently are to 1) limit the data sets to only those periods of time that disease actually occurred, 2) convert the weather data to dewpoint calculations, 3) convert the rating data to percentages from which the original rating scale was derived, or 4) do a logit conversion on the rating data. Finally, a stronger analysis of the data should be conducted using the many variable s available through the Mesonet weather data gathering system. Coakley *et al.* (1988) used a Fortran-based program called WINDOWS that simultaneously tested a large number of weather variables against disease data that was recorded a different phenological stages of wheat. This program not only analyzed the data using a moving average regression, but also compared each shift with a differing number of days. While this method was modified to test weather variables for this model, only a limited number of variables and moving averages could be conducted without access to a program that can calculated all variables simultaneously due to the immensity of the data sets and the number of sites for which data was recorded.

Table 4.1 The correlation between temperature and relative humidity data collected at the Noble Foundation Research Farm pecan orchard near the Red River in Love County, Oklahoma with temperature and relative humidity data collected at Burneyville by the Oklahoma Mesonet Weather System. The Mesonet site is about 3 km north of the orchard. Data were collected hourly from April 20 - September 10, 1994.

	Temperature		Relative Humidity	
Site	° C	σ[a]	%	σ[a]
Orchard	24.5	±10	81	±15
Burneyville[b]	25.6	±11	79	±17
R^2	0.72		0.53	
Signif. (*P*<)	0.001		0.001	

[a] σ = standard deviation, [b] site of Mesonet Weather Station

Table 4.2 Pearson Coefficient Correlation (r) comparing Temperature between the ranges of 21.1-29.4C and Relative Humiditys Of ≥ 80 and 90% against Leaf Ratings, Fruit Ratings and the Difference Between Leaf Ratings and Fruit Ratings Of both the 'Burkett' Cultivar and Native Pecans. Source of Disease Rating Data is Red River, 1994 Field Site.

	A TEMP	A RH80	A TRH80	A RH90	A TRH90	AB TEMP	AB RH80	AB TR80	AB RH90	AB TR90	B TEMP	B RH80	B TRH80	B RH90	B TRH90
BLFRATE r	0.54	0.02	0.48	-0.05	0.50	0.58	0.09	0.55	-0.03	0.62	0.53	0.10	0.50	-0.03	0.47
significance	0.01	0.95	0.03	0.83	0.02	0.01	0.69	0.01	0.88	0.00	0.01	0.67	0.02	0.90	0.03
BLFRCHG r	0.44	0.09	0.31	0.03	0.27	0.38	0.04	0.29	-0.11	0.19	0.26	-0.04	0.21	-0.21	0.03
significance	0.05	0.69	0.17	0.90	0.24	0.09	0.86	0.21	0.64	0.41	0.26	0.86	0.36	0.35	0.89
BNTRATE r	0.47	-0.10	0.49	-0.22	0.45	0.55	-0.01	0.60	-0.21	0.62	0.53	0.05	0.58	-0.13	0.52
significance	0.03	0.66	0.02	0.33	0.04	0.01	0.97	0.00	0.37	0.00	0.01	0.83	0.01	0.58	0.01
BNTRCHG r	0.21	-0.24	0.36	-0.52	0.05	0.36	0.02	0.50	-0.24	0.35	0.43	0.21	0.53	0.09	0.50
significance	0.35	0.29	0.11	0.02	0.84	0.11	0.95	0.02	0.29	0.12	0.05	0.37	0.01	0.68	0.02
NLFRATE r	0.52	-0.02	0.49	-0.11	0.48	0.57	0.05	0.56	-0.09	0.62	0.53	0.07	0.51	-0.06	0.49
significance	0.02	0.94	0.02	0.63	0.03	0.01	0.82	0.01	0.69	0.00	0.01	0.77	0.02	0.80	0.02
NLFRCHG r	0.19	-0.03	0.15	-0.07	0.09	0.21	-0.04	0.15	-0.03	0.18	0.20	-0.05	0.11	0.00	0.18
significance	0.42	0.91	0.50	0.78	0.68	0.35	0.87	0.52	0.89	0.44	0.39	0.84	0.62	0.99	0.44
NNTRATE r	0.42	-0.06	0.39	-0.11	0.41	0.47	0.02	0.47	-0.10	0.53	0.45	0.05	0.46	-0.07	0.43
significance	0.06	0.81	0.08	0.62	0.07	0.03	0.94	0.03	0.65	0.01	0.04	0.81	0.04	0.76	0.05

Legend:
Week A= 1-7 days prior to week of rating, Week B=8-14 days prior to week of rating, Week AB=1-14 days prior to week of rating, B= 'Burkett' cultivar, N= native pecans, LF=leaf disease ratings, NT= fruit (nut) disease ratings, Temp= temperature between 21.1-29.4C

BLFRATE= Burkett Leaf Rating
BLFRCHG= Difference Between Leaf Ratings
BNTRATE= Burkett Fruit Ratings
BNTCHG= Diff. Between Ratings in Fruits
NLFRATE= Native Leaf Rating
NLFRCHG= Diff. Between Leaf Ratings
NNTRATE= Fruit ratings in natives
NNTRCHG= Diff Between ratings in fruits

A TEMP= Cumulative Hours of Temperature in week A
A RH80= Cumulative Hrs of RH≥80% in week A
A TRH80=Cum. Hrs of Temp and RH≥80% in week A
A RH90= Cum Hrs of RH≥90% in week A
A TRH90= Cum Hrs of Temp and RH≥90% in week A
AB TEMP= Cum Hrs of Temp in both weeks
AB RH80= Cum Hrs of RH≥80% in both weeks
AB TR80= Cum Hrs of Temp and RH≥80% in both weeks

AB RH90= Cumulative Hours of RH ≥90% in both weeks
AB TR90= Cumulative Hrs of Temp and RH≥90% in weeks AB
B TEMP= Cum. Hrs of Temp in week B
B RH80= Cum Hrs of RH≥80% in week B
BTRH80= Cum Hrs of Temp and RH ≥80% in week B
B RH90= Cum Hrs of RH≥90% in week B
B TRH90= Cum Hrs of Temp and RH≥90% in week B

Table 4.3 Correlations between four combinations of temperature and relative humidity and the differences between weekly fruit disease rating means (*n* = 16)[a] for the 1994 Red River site (April 20 - Sept. 10). Correlation for each *n* is 14 to 21 days before the subtrahend rating date.

Temp. C	RH %	R^2	P<
21.1-29.4	≥ 80.0	0.425	0.008
≥ 21.1	≥ 80.0	0.423	0.009
21.1-29.4	≥ 90.0	0.503	0.003
≥ 21.1	≥ 90.0	1.498	0.003

[a] General Linear Models, SAS, 1989

Table 4.4 Correlations between the accumulation of hours of weather with temperature ≥21.1°C and relative humidity ≥ 90 and the differences between successive, weekly mean disease ratings of the Red River 1994 **fruit** data. Accumulation of scab hours for each correlation has a minimum of 1 - 8 hours at 14 to 21 days before the subtrahend rating date. Leaf data with moving interval correlations was not significant (P<0.2).

Scab Hours ≥	R^2	P<
1	0.50	0.003
2	0.51	0.003
3	0.46	0.006
4	0.45	0.007
5	0.33	0.026
6	0.29	0.039
7	0.28	0.043
8	0.25	0.057

Table 4.5 Summary of General Linear Models correlation analyses with 7 and 14 day moving groups of scab hour accumulations (temperature ≥ 21.1°C and relative humidity ≥ 90%) prior to the rating date and the differences between successive, weekly fruit disease rating means. Summary identifies groups of days with the most significant R^2 value.

a. Seven day moving accumulations of scab hours

Site	Days	R^2	P<
Red River 1994	15 - 22	0.54	0.001
Red River 1995	36 - 43	0.99	0.006
Vinita 1994	16 - 23	0.55	0.002
Vinita 1995	24 - 31	0.55	0.006
Sparks 1996	21 - 28	0.86	0.007

b. Fourteen day moving accumulations of scab hours

Site	Days	R^2	P<
Red River 1994	13 - 27/15 - 29	0.49/0.50	0.002/0.003
Red River 1995	30 - 44	0.94	0.03
Vinita 1994	15 - 29	0.33	0.03
Vinita 1995	22 - 36	0.16	0.20
Sparks 1996	10 - 24	0.84	0.01
Sapulpa 1996	12 - 26	0.75	0.01

Table 4.6 Scab ratings for the Sparks 1997 threshold trial comparing thresholds of 10 and 30 accumulation of scab hours (temperature ≥ 21.1 °C and relative humidity ≥ 90%), the recommended fungicide application schedule for Oklahoma and an untreated control. Treatments were significantly different for leaves (P<0.05) and fruits (P<0.0001).

		Scab Rating[a]	
Application Schedule	Fungicide	Leaf	Fruit
Control	None Applied	2.5a	7.4a
Phenological	Fenbucon./Triphenyltin[b]	1.9c	3.2c
30 Hour Threshold	Fenbucon./Triphenyltin[b]	2.2ab	5.5b
10 Hour Threshold	Fenbucon./Triphenyltin[b]	2.0b	3.3c
10 Hour Threshold	Azoxystrobin[c]	1.5c	3.0c
R^2		0.62	0.87
P<F		0.0001	0.0001

[a]Mean separation within columns by Duncan,s Multiple Range Test, 5% level.
[b]Fenbuconazole (a.i. 0.067 kg ha^{-1}) and triphenyltin hydroxide (a.i. 0.34 kg ha^{-1})
[c] a.i. 0.049 kg ha^{-1}

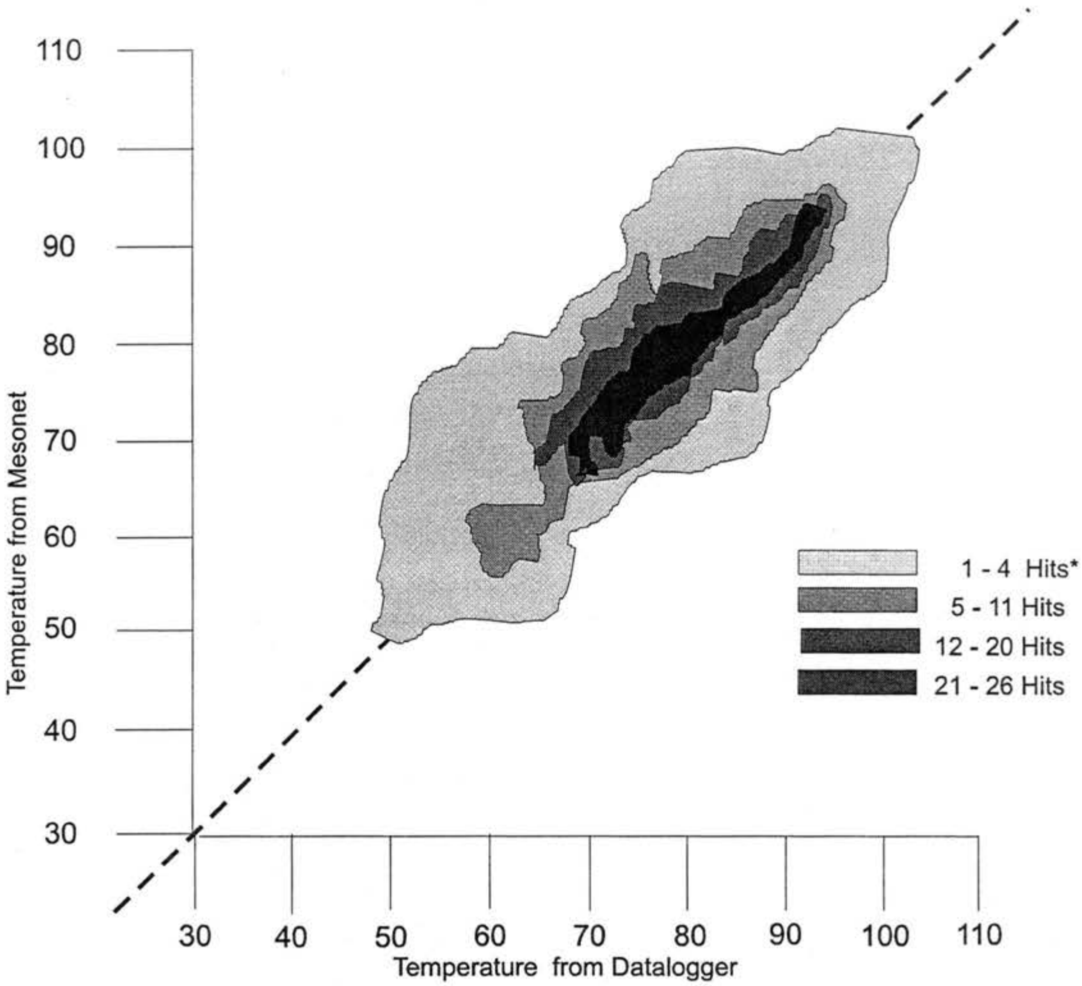


Fig. 4.1 Correlation of 3400+ hourly comparisons of 1994 temperature data from the Oklahoma Mesonet Weather System at Burneyville, OK, and the Red River datalogger data at the Noble Foundation Research Farm 3 Km South of Burneyville. Data collected from April 20 to Sept. 10. * Hits = the number of data correlations that occur at each XY location.

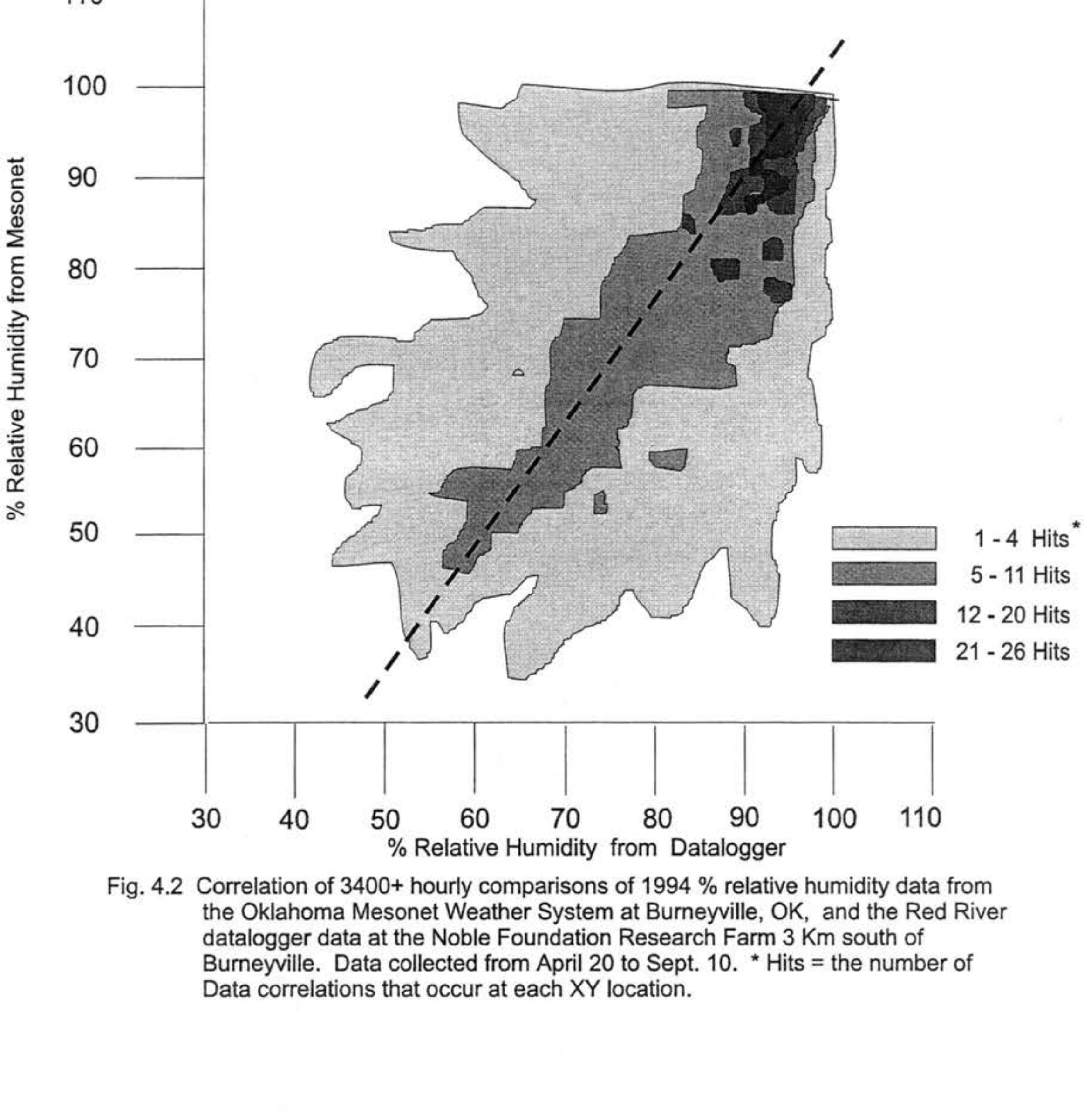
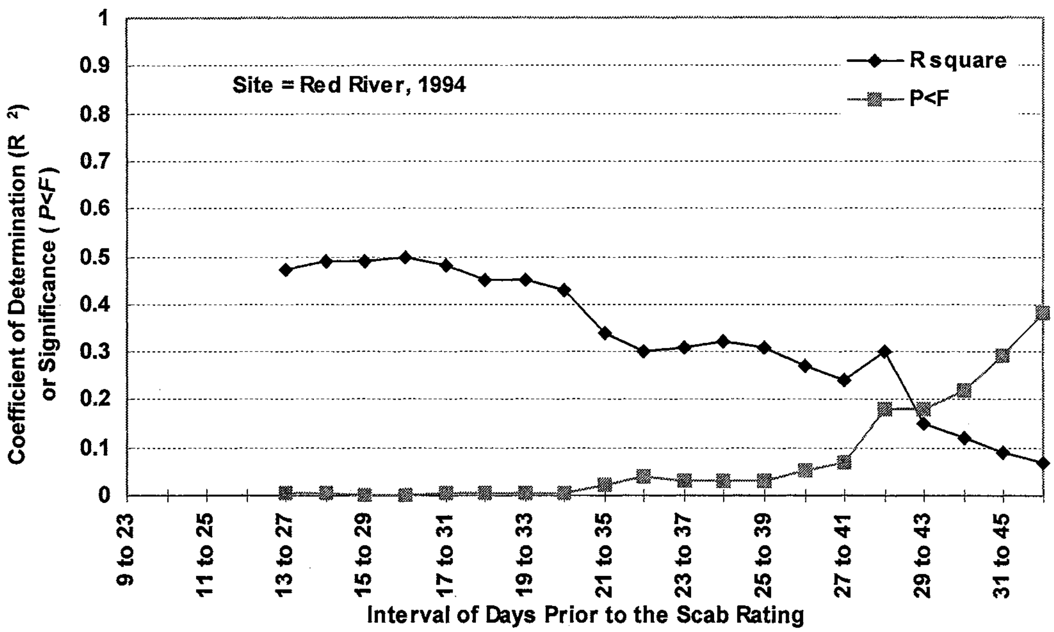


Fig. 4.2 Correlation of 3400+ hourly comparisons of 1994 % relative humidity data from the Oklahoma Mesonet Weather System at Burneyville, OK, and the Red River datalogger data at the Noble Foundation Research Farm 3 Km south of Burneyville. Data collected from April 20 to Sept. 10. * Hits = the number of Data correlations that occur at each XY location.



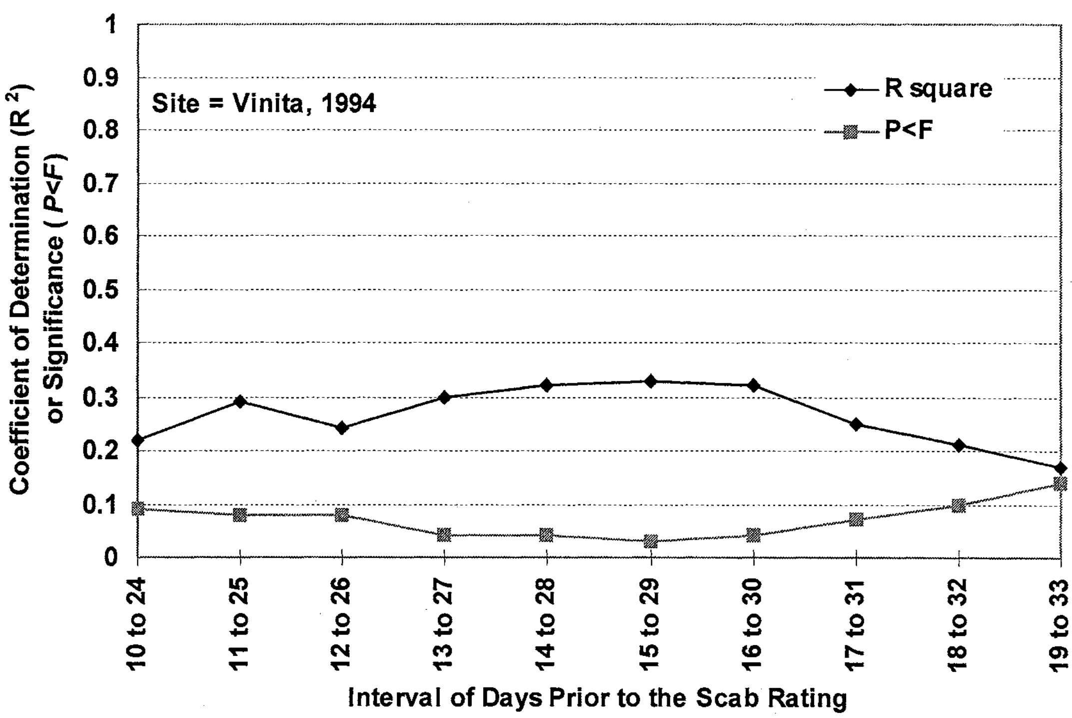


Fig. 4.3 Correlation* of the difference between mean fruit disease ratings at Oklahoma sites with hourly accumulations of temperature (≥ 21.1 C) <u>and</u> relative humidity (≥ 90%) within 14 day moving intervals.
* General Linear Models, SAS, 1989

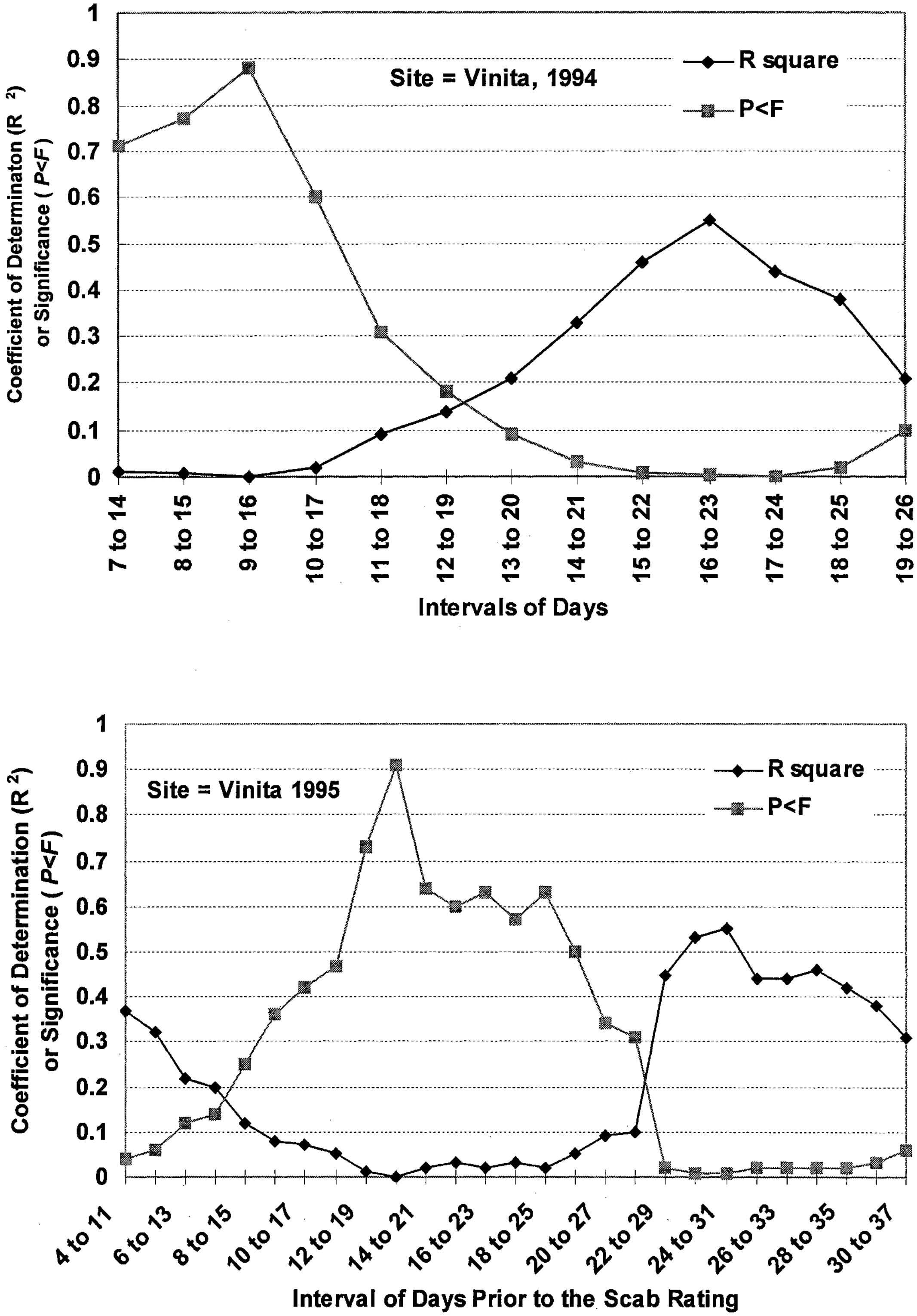
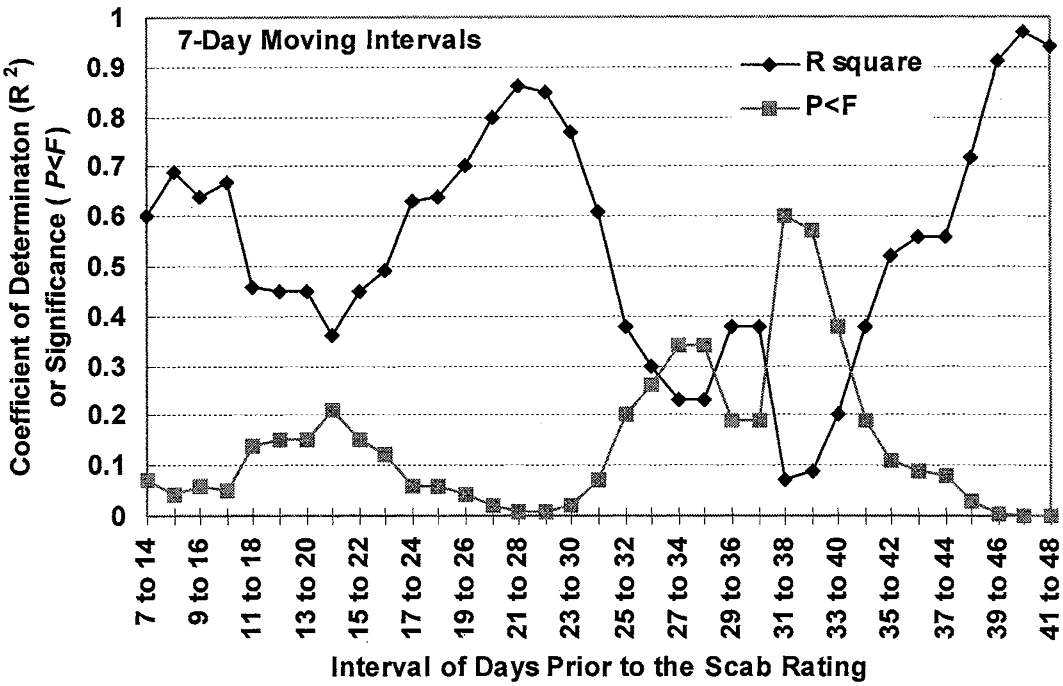


Fig. 4.4 Correlation* of the difference between mean fruit disease ratings with hourly accumulations of temperature (≥ 21.1 C) and relative humidity (≥ 90%) within 7-day moving intervals of data from Vinita, Oklahoma in 1994 and 1995.
* General Linear Models, SAS, 1989



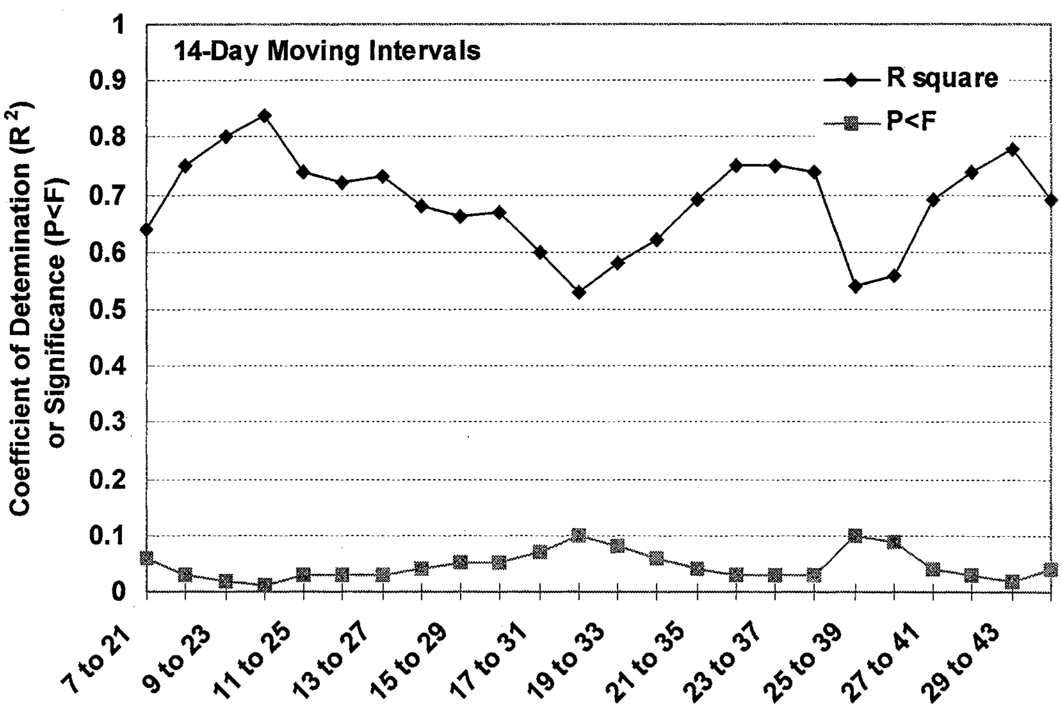


Fig. 4.5 Sparks Site, 1996: Correlation* of the difference between mean fruit disease ratings with hourly accumulations of temperature (≥ 21.1 C) and relative humidity (≥ 90%) within 7-day and 14 day moving intervals.

* General Linear Models, SAS, 1989

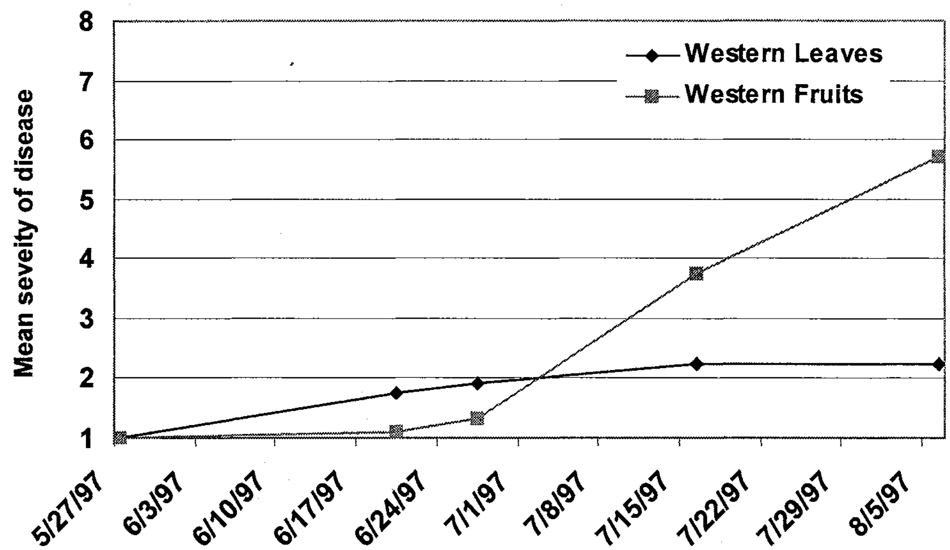
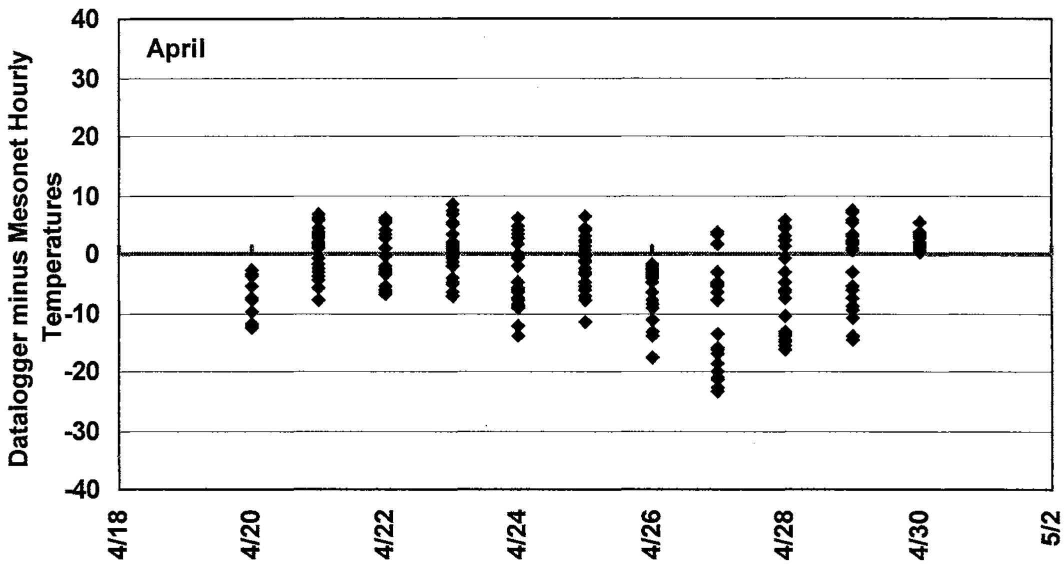


Fig. 4.6 Sparks Site, 1997: Increase in severity on 'Western' pecan cultivar leaves and fruits. No fungicides were applied during the growing season. Observed values represent the mean severity of scab, assessed visually using the modified Horsfall-Barratt scale.



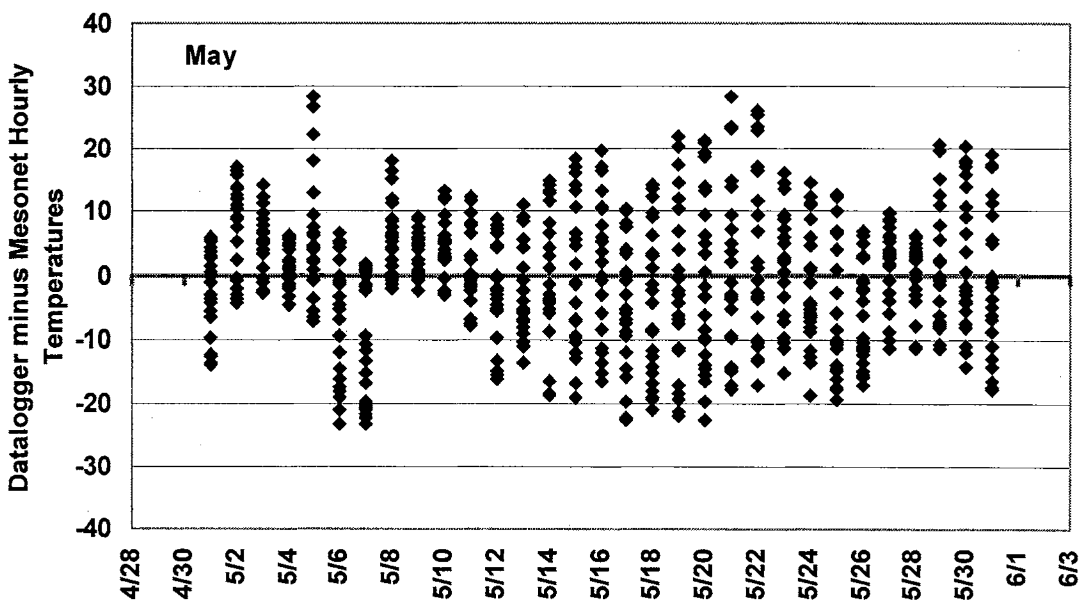
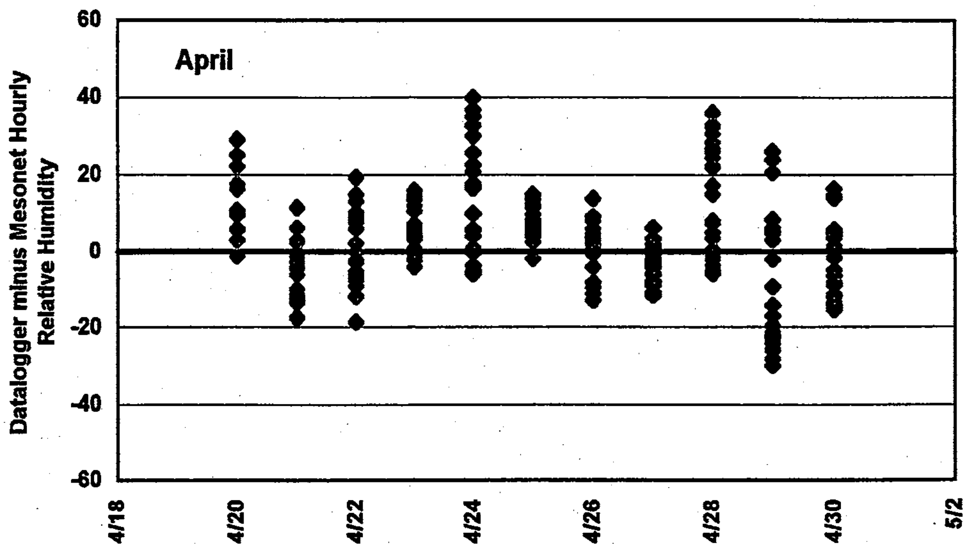


Fig. 4.7 Red River Site, 1994: Hourly comparison of temperatures of the datalogger data minus the mesonet data. Datalogger data collected at the Noble Foundation Research Pecan Orchard, in Love County, Oklahoma and the Mesonet data collected from the Oklahoma Mesonet Weather System located about 3 km north of the datalogger.



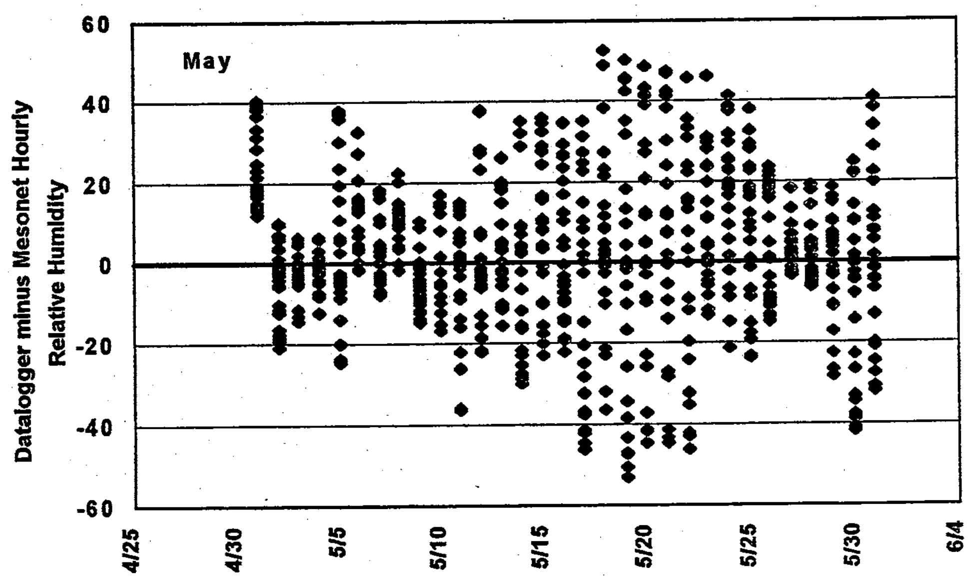


Fig. 4.8 Red River Site, 1994: Hourly comparison of relative humidity from the datalogger data minus the Mesonet data. Datalogger data collected at the Noble Foundation Research Pecan Orchard, in Love County, Oklahoma and the Mesonet data collected from the Oklahoma Mesonet Weather System located about 3 km north of the datalogger.

CHAPTER V

APPLICATION OF THE THRESHOLD MODEL AS AN FUNGICIDE APPLICATION DECISION TOOL USING THE INTERNET

Introduction

As is true with the production of most food crops, the ability to produce pecans as a financially successful business depends on good crop management practices that limit costs associated with production, including costs of disease management. Preventative management techniques are the first line of defense against disease and may take the form of efficient cultivation and sanitation practices or the use of disease resistant crops. However, once disease is present, the grower must make decisions about applying chemicals to control disease.

The threshold model developed for determining when to apply fungicides to control pecan scab (Chapter 4) addresses this important aspect of disease management. The threshold model is a decision tool that can inform growers when weather conditions are conducive to the initiation of disease and can help with decisions about fungicide application. The benefits of using the threshold model as a fungicide application decision tool are a more effective control of pecan scab and a potential reduction in the frequency and amount of fungicides that would have to be applied. The threshold model identifies those periods when the weather conditions are optimum for disease. The potential for reducing the number of applications required to control the disease could result in a financial savings for the grower in purchase of chemicals, reduced wear and tear on machinery, and lower labor costs. Other benefits would be less chemicals applied to the environment and a less intense pressure for resistance development by *Cladosporium caryigenum* to fungicides.

The primary question is how to enable the grower to have ready access to the threshold model for evaluation in a form that is easy to understand and use. Previous models have been presented as technological advances have provided different means of communication. Early efforts to predict infection for fungicide application used paper-based models. Examples are predictions of apple scab (*Venturia inaequalis* (Cooke) G. Wint.) by a graph (Mills,1944) and later with a table (Mills and LaPlante, 1951). With the development of field-based weather monitoring devices such as hygrothermographs and dataloggers, fungicide applications based on weather data and forecasting models have been tested. Using a hygrothermograph to measure temperatures and relative humidity and a dew meter to measure leaf wetness, a computerized forecasting system has been developed that uses these weather variables to predict *Alternaria solani* Sorauer on tomato (*Lycopersicon esculentum* Miller (Madden *et al*,, 1978). An adaptation of this forecasting model, TOM-CAST (Pitblado; 1988, 1992) has been tested in Canada (Brammall, 1993) and the U.S. (MacNab and Gardner, 1993; Sikora *et al.*, 1994). Pythium blight (*Pythium aphanidermatum* (Edson) Fitzp.) has also been successfully controlled with the use of hygrothermograph-based weather monitoring and a computerized forecasting program (Nutter *et al.*, 1983). Parvin *et al.* (1974) evaluated a computerized forecasting method of a model developed by Jensen and Boyle (1966) to predict Cercospera Leafspot (*Cercospora arachidicola* S. Hori) in peanuts. Daily advisories with this system were sent out by teletype and broadcast by radio and television stations in Georgia.

In 1990 – 1992, Damicone *et al.* (1994) tested a modification of the Parvin, Smith and Crosby (PSC) forecasting program (Baily *et al.*, 1994) with limited success on Oklahoma peanut (*Arachis hypogaea* L.) production systems using hygrothermographs and dataloggers as weather sources. Using a datalogger as a weather data source at the Oklahoma State University Agronomy Research Station in Perkins, the modified PSC program was tested against the Virginia (Alderman *et al.*, 1987) and AU-Pnuts (Jacobi *et al.*, 1995) threshold programs (Wu *et al.*, 1996). For Oklahoma conditions, the Virginia and AU Pnuts programs were found to provide more control of *C. arachidicola* than the modified PSC program. The Blightcast forecasting program (MacKenzie, 1981) for control of Potato Late Blight (*Phytophthora infestans* (Mont.) de Bary) utilized telephone calls initiated by growers to access computer operators that processed weather data provided by the participating grower.

With the advent of small, dependable microprocessors, disease prediction systems have moved to the field. Michigan State University, in cooperation with Reuter-Stokes, Inc., has devised an apple scab predictor (Jones *et al.*, 1984) that combines microprocessor computing with data logger weather collection. This in-field unit processes weather data to provide the grower with easy-to-understand predictions and fungicide recommendations. A similar microprocessing unit has been programmed with prediction models to forecast diseases in grapes (Ellis *et al.*, 1986) and the system is adaptable to other disease prediction models. The main drawbacks to the system are that the grower must purchase and install the system on his property and are willing to monitor and maintain the unit.

In Oklahoma, we have the advantage of a statewide-automated weather monitoring system that can be adapted to a variety of needs. This system, known as the Oklahoma Mesonet, currently consists of 114 stations located throughout the state that records a variety of weather data. The stations have an average spacing of 30 km, resulting in a dense weather observation grid. The weather data is currently used to monitor growing degree-days for a variety of crops, create spray advisories for pest management, provide assistance in irrigation scheduling, assess fire danger, and show current and recent weather maps for use in prescribed burning. An example of a forecasting model that is currently being tested in Oklahoma that uses the Mesonet weather data to forecast disease is the Watermelon (*Citrullus lanatus* (Thunb.) Matsum. & Nakai) Anthracnose (*Colletotrichum orbiculare* (Berk. & Mont.) Arx) Empirical Model (Duthie, 1995).

For this project, the Oklahoma Mesonet was utilized as a source of weather data that could be transformed to schedule fungicide applications for pecans. An Internet website was developed that pecan growers could access to assist them in decisions for fungicide applications to control pecan scab. This information source provides growers with local weather conditions in an interactive format that allows them to make their own decisions about fungicide applications.

This chapter describes how the epidemiologically derived threshold model was prepared to allow Internet access and use by the agricultural community.

Materials and Methods

Operated jointly by Oklahoma State University (OSU) and the University of Oklahoma, the Oklahoma Mesonet continuously monitors a number of important weather and soil variables (Elliot *et al.*, 1994). Every 15 minutes, data observed over three 5-minute intervals are relayed from each remote Mesonet station to the nearest facility of the Oklahoma Law Enforcement Telecommunications System (OLETS) via radio telemetry. From the OLETS site, the data is sent over their communications network to their central site in Oklahoma City, and from there to the Mesonet "base station" computer in Norman. This computer checks the data quality, manages data storage, and creates the data files and value-added products for dissemination to users. From Norman the data is sent every 15 minutes to a computer operated by Computing and Information Services at OSU. With respect to the pecan scab model, this computer runs the model and serves as a web server for user access.

The Oklahoma Pecan Scab Model is coded in C language. During the appropriate months, the model is run every day around 10 a.m. Central Daylight Time (CDT) using Mesonet weather data from the past 24-hour period. The program first inspects all the 5-minute data files (called D05 files) for missing data. Missing or flagged air temperatures are first estimated by interpolating valid temperatures from surrounding sites to the missing site using a Barnes Interpolation scheme (Koch *et al.*, 1983). For purposes of estimating missing or flagged relative humidity data, the valid relative humidities at surrounding sites are first converted to dew point temperature; the dew point temperatures are then interpolated for the missing site; finally, the interpolated dew point is then converted back to relative humidity using the temperature value at the missing site. This methodology is used because dew point temperatures is less variable in space than relative humidity. If data is missing for all stations in a specific time, then no spatial interpolation can be made and that block of missing data is ignored in the Pecan Scab Model calculations.

For each Mesonet site, the Pecan Scab Model program inspects the time series of temperature (T) and relative humidity (RH) to calculate the amount of time accumulated under the following weather conditions: $T \geq 21.1°$ C and $RH \geq 90\%$. The program uses every third 5-minute reading to calculate the accumulation of disease promoting weather. If the program detects 3 out of 4 or 4 out of 4 combinations of T and RH to be within the parameters described then 1-hour has accumulated. For the purposes of the model, this hour is designated a "scab hour". The Pecan Scab Model builds two types of files with the CIS computer for all reporting Mesonet stations. The first file includes all Mesonet stations and lists the number of "scab hours" (SH) for the "day" just completed and the daily accumulated hours since April 1st of the year. The program builds a second type of file for each Mesonet station that lists the scab hours on that date and the total accumulated scab hours from April 1 to that date.

When an Internet user accesses the Oklahoma Pecan Scab Model web page at www.okstate.edu/~mesonet/scab/, they are first introduced to the model, shown an Oklahoma map of Mesonet stations, and asked to click on the Mesonet station that is closest to their location. At that point a second web page appears and asks the user to enter the last spray date in "mm/dd/yy" format and to hit the return key. If no date is input or no sprays have yet been applied, then the default date is taken as April 1. At this point CGI scripts take the user input date and utilize the pecan scab model data files to calculate for that station. The number of hours, which have accumulated, for that part of the unprotected period that lies in the last 14 days is presented in a table. Also on this third web page is an explanation of scab hours, a listing of threshold hours for fungicide applications for pecans of differing susceptibility and a hypertext link for information on acceptable fungicides. Below this is a table listing the last 28 days, the daily scab hours, and the accumulated hours since April 1. If the user is at the beginning of the season, the daily and accumulated hours are listed for those days going back to April 1.

Results

Output of Pecan Scab Model in Response to User Request.

The information displayed at the Oklahoma Pecan Scab Model website is in the prototype stage and although the model has been statistically verified and two years of field testing have been completed, this model is a supplementary decision-making tool that is meant only to be a guide for the pecan growers throughout the state. This model takes into account the high degree of differences in weather patterns found throughout the state of Oklahoma by using the data from the Oklahoma Mesonet for each specific site to calculate the accumulation of scab hours that can be conducive to the initiation of pecan scab for that local area. The model does not replace good cultural management practices or the need to use scab resistant cultivars. It is, however, intended to be a powerful tool in controlling pecan scab during those times when conditions are optimum for disease by limiting the number of fungicide sprays to only those which are needed to control the scab.

Based on the residual action of today's fungicides, the model takes into account this action and calculates scab hours only for those days that are unprotected. For instance, if a grower has not sprayed since the beginning of the season, and the date entered is by default April 1 (Fig. 5.1a), the model would then only show those scab hours that had accumulated between the date the user accesses the page and April 1. If the date accessed is more than 14 days from April 1st (for instance April 28), only the 14 days accumulation of scab hours from the date the page is accessed (Fig. 5.1b) would be shown (in this example the accumulation of hours from April 15 to April 28). If the user enters the model, the 14 protected days following the spray are disregarded and only those days between the access date and the end of the protected spray period are considered (Fig. 5.1c). If more than 14 days have elapsed since the end of the unprotected period, than only the 14 days prior to the access date are considered in the scab hour calculations (Fig. 5.1d).

Threshold Recommendations for Fungicide Spray Applications Based on Model.

The third page of the Pecan Scab Model web site presents the number of accumulated scab hours in response to defined user input. Once the number of accumulated scab hours has been presented as a flashing number in the scab hour accumulation box, the user can review the threshold recommendations for moderately and highly susceptible pecans to determine the number of accumulated scab hours at which to apply fungicides. The threshold for moderately susceptible pecans is 30 hours and the threshold for highly susceptible pecans is 10 hours. If the value given in the box exceeds the threshold, a fungicide should be applied.

The web site also contains links to important supplemental information for making decisions using the model. Clicking on the scab susceptibility hypertext will give the web user a list of the Oklahoma pecan varieties and their susceptibility relating to the threshold level. The user will also receive information regarding recommended fungicides and their appropriate rates.

Other Uses for the Pecan Scab Model Output Data.

Web site users can use the station output data for the last 28 days as shown in the table on the third web page to monitor the progression of scab conducive weather. This enables them to plan their management activities more efficiently. Monitoring the progress of hours in the table also helps the pecan grower to recognize the weather patterns that contribute to the progression of the disease. Another use of the Pecan Scab Model web site is the ability of the grower to monitor the scab hour accumulations at surrounding Mesonet stations to understand the general trend of scab hour accumulations. This information allows the grower to make fungicide application decisions, particularly at the end of the season when the value of the pecan crop can be more closely ascertained or when insecticides are required and combining pesticide sprays may save time.

Discussion

As discussed in the introduction, there is a trend to develop models that can predict the initiation and progress of disease. This trend is due to the increasing costs associated with the production of food crops, the increasing concern for limiting pesticides to protect the environment and food quality, and the ability of technology to more easily provide a means of forecasting and accessibility to information. The Oklahoma State University Pecan Scab Model provides easy accessibility to weather data in regard to conditions that are conducive to pecan scab. The model allows growers to review local scab-supporting weather conditions for the previous 28 days through the interactive map and by entering the last date fungicides were applied provides recommendations based on current weather conditions. The Oklahoma Pecan Scab Model is delivered through the Internet and is designed for easy modification. As the model is further field tested, the model parameters can be adjusted to refine the model's ability to predict pecan scab.

The Oklahoma Pecan Scab Model web site is another example of a value-added product that can have positive impacts not only for the pecan growers, but also for their surrounding communities and the entire state. This web page illustrates how differing technologies can be combined to enhance a grower's efficient use of chemicals by controlling the scab through improved timing. Although the use of fungicides is important for the control of pecan scab, their limited use to efficiently control the disease is a benefit for everyone. The Pecan Scab Model has demonstrated that disease forecasting decision tools can easily be made accessible for the pecan growers through the use of today's computer technology and the Internet system.

Fig. 5.1a

No Fungicide Application

First Date of Yearly Model Activation
April 1

User Access Date
April 9

If the Internet user accesses the Pecan Scab Home Page on April 9, the scab model program will show 8 days accumulation of scab hours. No fungicide application* will be required if the scab hour accumulation is less than a threshold of 30 hours for moderately susceptible cultivars and 10 hours for highly susceptible cultivars.

*Those periods when the Pecan Scab Model calculates the scab hours accumulated, the parameters are temperature $\geq$ 21.1C and relative humidity $\geq$ 90%

Fig. 5.1b

No Fungicide Application

April 1 April 15 April 28

If the user accesses the home page on April 28, the model will show the scab hour accumulation for the last 14 days. If the scab hour accumulation is less than the recommended threshold, no fungicide application is required.

Fig. 5.1c

Fungicide Applied

May 1 May 15 May 28

14 Days Protection 14 Days of Scab Hours Displayed

If the user access the home page on May 28 and enters a fungicide application date of May 1, there is a 14 day residual protection period for the fungicide and the scab model program will not begin to calculate scab ours until after the 14th day. For May 28 entry the program will calculate scab hours for the previous 14 days.

Fig. 5.1d

Fungicide Applied

May 1 May 15 May 28 June 10

14 Days Protection 14 Days of Scab Hours Displayed

If the user accesses the home page on June 10 and enters a fungicide application date of May 1, the model will calculate the scab hours for the previous 14 days. Any days between the fourteen days of fungicide protection period and the 14 days for which the model calculates scab hours are not considered.

CHAPTER VI

SIGNIFICANCE OF RESEARCH

Epidemiological Field Studies.

The studies of pecan scab in Oklahoma represent the first in depth published reports of epidemiology of this disease in the field with native pecans and two cultivars of differing susceptibilities to pecan scab for multiple sites and years. The studies were begun at the Oklahoma State University Pecan Research Station near Sparks in 1993 (Marenco, 1994). She continued the study at the site in 1994 and this present study expanded those epidemiological studies to include two other sites that represented the pecan growing region of the state. The current study continued the epidemiological research at all three sites in 1995. Epidemiolgical studies were continued using smaller plots at the threshold trial sites in 1996 and 1997. In addition, weather parameters were monitored at all sites with both data loggers and the Oklahoma Mesonet Weather System. These combined studies provide an extensive set of disease and weather data relating to pecan scab for a five year period at multiple sites.

Weather-Based Fungicide Application Schedule for Control of Pecan Scab.

From this information, a useful method was developed that provides Oklahoma growers with knowledge to make informed decisions on when to apply fungicides to control pecan scab. The fungicide application decisions are based on identifying those weather conditions that contribute to the development of the disease prior to the time the fungicides need to be applied. This gives pecan growers the opportunity to monitor the potential development of the disease and to plan their schedules in a manner that the scab may be controlled without interrupting their planning. The Pecan Scab Threshold Model has shown that this schedule can control scab as well as the recommended phenological schedule in Oklahoma with the potential of fewer sprays applied.

Oklahoma State University Pecan Scab Model Home Page.

The threshold model for predicting fungicide applications to control pecan scab has been programmed to a web page to allow easier access for the pecan grower. The computer program uses the Oklahoma Mesonet Weather System to provide daily updates of the weather parameters required for the prediction process. The 114 mesonet stations distributed throughout the state provide the program with weather data that gives complete coverage of the state's weather. This gives the grower site specific information in regard to the weather conditions that are conducive to pecan scab development. The program that drives the pecan scab model on the web page processes the weather data required for the model and calculates the scab hour accumulations for the 114 sites daily.

The daily hours of pecan scab accumulation for the previous 28 days as well as the threshold model disease prediction of scab hours for the last 14 days are available for all sites on an interactive web page, allowing the Internet user to identify the site nearest their pecan production site and determine whether a fungicide application is required. This gives the grower useful information with which to make informed decisions. In addition, the web page provides links to fact sheets regarding approved fungicides for control of pecan scab, usage rates, and information regarding cultivars and their susceptibility to pecan scab.

Although Internet access is required to be able to use the web page, many growers do have computers to help them with their day to day planning and financial records. The Oklahoma State University Pecan Scab Model is another computer driven tool that will enable the grower to control scab while reducing costs associated with pecan production. Those growers that do not have Internet access can contact their county extension agent to obtain daily information during those times when the likelihood of pecan scab is high. Regardless of the method of access to the information, the threshold schedule derived from the Oklahoma State University Pecan Scab Model can provide the grower with useful information to make informed decisions to control pecan scab with fungicide applications.

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