ABSTRACT

VIRGINIE MARIE ARIS. Use of Weather-based Modeling for Disease Management of Early Leaf Spot of Peanut and Glume Blotch of Wheat (under the direction of Jack Bailey and Steven Leath)

Weather based models help time fungicide applications to the periods when the diseases are most likely to occur. The first objective of this work was to compare and adapt weather-based advisories developed for the control of *Cercospora arachidicola* on peanuts for resistant cultivars. It was achieved by comparing the disease progress curves of the 1997-1999 growing seasons in Lewiston NC, to spray schedules simulated by the Virginia Advisory, the Parvin, Smith and Crosby Advisory (PSC), NC Advisory, and AU-Pnuts Advisory and their adaptations for resistance. Field trials were conducted in 1997, 1998 and 1999 to test adaptations for resistant genotypes based on the NC Advisory. In all three years the leaf spot epidemics started late in the season (September). There was no yield difference due to leaf spot control except in 1999 in Lewiston for the susceptible genotypes (NC 7 and NC 11). All the advisories had a tendency to overspray at the beginning of the season, this might be due to a lack of inoculum at this time. The resistant genotype used for the study, GP-NC 343, did not lose any yield due to leaf spot in any of the tests and therefore did not need to be sprayed. The model that had the best fit to the disease progress curve of the susceptible genotypes was the AU-Pnuts 12/4. The AU-Pnuts advisory 7/3, currently used in the Southeastern US, started spraying to early in the season for NC. The Virginia advisories also

oversprayed. The NC advisory and the PSC were considered almost equivalent, and the adaptations for the PSC did not differ from the PSC itself.

The second objective was to develop a simulation model to predict epidemics of *Stagonospora nodorum* on winter wheat. The CERES-Wheat model was used to simulated leaf area indexes (LAI) for the wheat plant throughout the season. The disease model developed in this work simulated the spread of spores onto the plant leaves and heads, infection, the latent period and, lesion extension. The model equations were inferred from the literature and were calibrated with disease assessments made on Coker 9904 during the spring of 1998 in Plymouth NC. For 1998 and 1999, disease increase in the lower leaves took place 20 days after the disease increase was simulated by the model both years. The most effective spray timing corresponded to a period when disease was first observed in the lower leaves, no disease was seen on the flag leaf, and simulated onset of disease on the flag leaf had occurred. A sharp simulated disease increase in the flag leaf compartment may be a very good indicator for a spray recommendation. Combining a disease model to an already existing crop growth model facilitated modeling disease progress. Further work will be needed to fully validate both the CERES-wheat and the *S. nodorum* models in North Carolina Coastal Plains.

USE OF WEATHER-BASED MODELING FOR DISEASE MANAGEMENT OF EARLY LEAF SPOT OF PEANUT AND GLUME BLOTCH OF WHEAT

By

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DEDICATION

I would like to dedicate this thesis to my parents, Henri and Viviane Aris, my grand parents, Raymon and Amelie Aris, Rene and Florentine Carriere, and my brother, Emmanuel Aris, who have always been great examples for me.

BIOGRAPHY

Virginie Marie Renee Aris was born in Montpellier France on October 31st 1974. She attended kindergarten and preschool at Le Petit Bar school. She went on to the “College Las Cazes”, then to the “Lycee Mass de Tesse” in Montpellier, and graduated from high school in 1992 with honors. She then went to the University of Sciences of Montpellier where she graduated with a general degree in Chemistry and Biochemistry in 1994 without having destroyed any expensive lab equipment. Not having fulfilled her desires to spend her weekends studying, in 1994 she passed the competitive entrance exam for the “Ecole Nationale Superieure d’Agronomie et des Industries Alimentaires” in Nancy France, and spent two and a half years there. She graduated from this school in 1997 with an engineering degree in agronomy, having spent every Saturday night watching “The X-files”. She then decided to travel and work abroad, and fulfill her desire of visiting every lake in Minnesota. Despite the handicap of being French she was accepted in the Plant Pathology Department at North Carolina State University where she worked on this Masters Degree. During her free time, Virginie has practiced the martial art of tae kwon do, which she feels has prepared her for living in cities such as Newark, NJ.

Brian George

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Chapter I: Adapting Peanut Leaf Spot Advisories to Resistant Genotypes

I.1. Introduction

The origin of the peanut

Peanut, *Arachis hypogaea* L., is a legume grown in warm climates throughout the world. Peanut remains dating from 1500 to 1200 BC have been recovered from ancient archaeological sites on the northern coast of Peru. The peanut was probably first domesticated in the valley of the Parguay and Parana rivers in the Chaco region of South America. Early Portuguese explorers and traders probably found peanuts in the New World and carried them to Europe, Asia, Africa and the Pacific Islands. Much later, they were carried to the eastern seaboard colonies of North America (Coffelt and Simpson, 1984).

Peanut production and uses around the world

Peanuts are produced on 19.5 million hectares each year worldwide, resulting in 26 million metric tons of harvest. They are grown in the warm climates of Asia, Africa, Australia, and North and South America (Owens, 1999). China and India are the largest producers. The United States has about 3% of the world acreage of peanuts, but grows nearly 10% of the world's crop because of high yields. Seven states (Georgia, Alabama, North Carolina, Texas, Virginia, Oklahoma, and Florida) account for 98% of the US production. Peanut is also grown in New Mexico, South Carolina, and Mississippi. North Carolina produces approximately 8 to 9% of the nation's peanuts. The average production is 180,000 metric tons valued at about 94 million dollars annually on a total of 51,000 hectares (NCDA&CS Agricultural Statistics Service, 1999).

Immature to fully ripe peanut seeds are eaten raw or cooked. They are high in calories, and are composed (depending on the genotype) of 50% fat, 25% carbohydrates and 25% protein. They may be boiled, broiled, roasted, fried, ground into peanut butter, or crushed for oil. Peanut oil is of high quality and contains unsaturated fat such as oleic and linoleic acids. After extraction of the oil, the meat is used for animal feed. Edible peanut oil is the main commodity made from peanuts in the world, whereas in the United States approximately 65% of the production is sold as shelled kernels, and processed products such as peanut butter, salted peanuts, and candies (Porter, 1997 and Owens, 1999).

Botany

The peanut plant is a self-pollinating, annual, herbaceous legume. Plants from the genus *Arachis* are all indigenous to the area east of the Andes, lying between the Amazon and La Plata Rivers. The cultivated peanut plant (*A. hypogaea*) is tetraploid, erect or prostrate, sparsely hairy, and averages between 15 cm and 60 cm tall. The inflorescences are borne on the axils of the leaves. Self pollination occurs in the closed keel of the flower. Within 1 wk after fertilization, a pointed, black needle-like structure (the capophore), commonly called the "peg", develops and elongates quickly. The fertilized ovaries are located behind the tip of the peg. The cells at the tip of the ovary become lignified, serving as a protective cap as the peg grows towards and penetrates the soil surface, to form the geocarpic fruit. The peg, which is positively geotropic but not negatively photropic, grows into the soil to a depth of 2-7 cm. Once positioned, the ovary enlarges rapidly, and pod growth begins. One to five seeds are produced per pod. They have two large cotyledons, an epicotyl with three meristems, the hypocotyl, a primary root, and weigh at maturity between 0.2g and 2g (Porter, 1997).

Cultural practices

Peanuts are adapted to well-drained, light-colored, sandy loam soils common in eastern North Carolina. Previous crop residues are typically shredded and/or buried, but increasingly peanuts are planted into residue using minimum tillage techniques (Bailey, personal communication 1999). Seeding a cover crop in the fall preceding planting can be done to reduce water and wind erosion. For conventional tillage, fields are plowed and harrowed in the spring, and prepared several weeks in advance to allow for soil warming and uniform moisture distribution within the bed. This raised bed technique provides conditions that allow faster germination, earlier maturation, good drainage, and may reduce pod losses during digging. Rotation with non-host crops (such as cotton and corn) is highly recommended to decrease nematode populations and the likelihood of diseases caused by soil-borne and foliar pathogens. Because the peanut is a legume, there is little need for nitrogen fertilization. If phosphorus and potassium fertilization is needed, it is usually applied to the previous crop. Lime is often applied to rotational crops to keep the naturally acidic soils of eastern North Carolina in the range of pH 5.8 to 6.2 which is required to produce healthy peanuts. Calcium is the most critical element applied in the production of peanuts, promoting good pod development and reducing pod rots. In North Carolina, gypsum (calcium sulfate) is routinely added to the surface of the soil regardless of the type of soil or soil calcium levels (Jordan, 1999).

Foliar diseases

Leaf spots caused by *Cercospora arachidicola* S. Hori, and *Cercosporidium personatum* (Berk and M. A. Curtis) Deighton are the most widely distributed foliar diseases on peanut. Rust caused by *Puccina arachidis* Speg. and web blotch (*Phoma arachidicola*

Marasas, G. D. Pauer, and Boerema) are important in some areas of the world (Smith and Littrell, 1980). Web blotch can be important in North Carolina; it is found every year and can be destructive in some fields, although fungicides used to control leaf spot usually inhibit web blotch epidemics.

Epidemics of early and late leaf spot on susceptible genotypes can cause nearly complete defoliation, which drastically reduces the yield. Foliar fungicides effectively control leaf spots but they represent 16% of the cost of peanut production in North Carolina, excluding application expenses and environmental impacts (Shew et al., 1995).

Early leaf spot

Cercospora arachidicola Hori (F.P.: *Mycosphaerella arachidis* Deighton) survives between crops in the residue. The primary source of inoculum in fields is asexually produced conidia. The telomorph, *Mycosphaerella arachidis,* is rarely observed; consequently, ascospores are not an important source of inoculum. Germination and penetration in leaves occurs during periods of high relative humidity. First visible lesions appear 10 to 14 days after infection if the air temperature is above 21^{o}C. Lesions are brown and sometimes circled with a yellow halo. The conidiophores are pale golden brown and are produced in dense fasicles (20-50x3-5 μ) of five to many. They are darker brown at the base, unbranched and septate. The conidia (35-110x4-5 μ) are subhyaline, olivaceous in color, sometimes curved, with up to 12 septa, and have a truncated base and a subacute tip (Ellis, 1976). Symptoms first appear on the upper surface of the lower leaves. Time of disease occurrence depends on the weather conditions and the field cropping history. Sporulation occurs primarily on the upper surface of the leaf. *Cercospora archidicola* does not produce haustoria in the plant cell. The spores are mainly released when the dew dries and at the onset of rainfall. Dispersal of the spores is effected by the wind, splashing rain, irrigation water and insects. (Shokes and Culbreath, 1997).

Spray advisories have been used to control both *C. arachidicola* and *C. personatum*, although environmental requirements and epidemiology are somewhat different. Conidia of *C. personatum* germinate and grow at a lower temperatures than those of *C. arachidicola* (Wadia and Butler, 1994, Shew et al., 1988). *Cercosporidium personatum* is usually more of a problem at the end of the growing season, and is usually not a problem in North Carolina (Bailey, 1999, personal communication).

<u>Resistance to leaf spot</u>

In field experiments, the area under the disease progress curve (AUDPC) has been found to be the best criterion for evaluating cultivar resistance (Johnson et al., 1986). Leaf spot resistance in the field is well correlated with a longer latent period, percent of lesions sporulating, spore production, and the time to defoliation of the leaflets (Johnson et al., 1986 and Ricker et al., 1985). The time necessary for successful infection can also increase with resistant genotypes (Wu et al. 1993). Most of those resistance components are intercorrelated except defoliation and lesion number (Johnson et al., 1986 and Ricker et al., 1985). The peanut genotype NC-GP 343 is partially resistant; its resistance can be characterized by a reduction of the number of lesions per leaf, fewer sporulating lesions, a longer latent period and a smaller percentage of lesions sporulating (MPLS), but not the time to defoliation (Ricker et al., 1985). The agronomic quality of the genotype NC-GP 343 was not high enough to justify release as a cultivar. This line was conserved as a parent line for breeding (Shew et al., 1995). While resistance to early leaf spot may be sensitive to temperature, GP-NC 343 resistance was ranked moderate at all temperature regimes tested (Waliyar et al., 1994).

History of weather based-advisory on peanuts for the control of *Cercospora arachidicola*.

Peanut early leaf spot caused by *C. arachidicola* is a very important foliar disease wherever peanuts are grown. In North Carolina, fungicide sprays are often applied every 2 weeks to control the disease (Bailey *et al*., 1994, Smith and Littrel, 1980). Infection by *C. arachidicola*, and its subsequent development, is greatly influenced by environmental conditions. Jensen and Boyle (1965, 1966) determined that hours of relative humidity (RH) >95% and the minimum temperature (T) during the high humidity period could be used to forecast leaf spot secondary spread in the field. Parvin et al. (Parvin et al., 1974) formalized an algorithm (PSC advisory) using this information, created a computer program, and made leaf spot advisories available to farmers. The PSC advisory was validated for Virginia-type cultivars in Virginia (Phipps and Powell, 1984) where it was used for recommending fungicide sprays from 1981 to 1988.

A new advisory was released in Virginia to replace the PSC advisory in 1989 (Cu. et al., 1993). This new model was based on the effect of temperature and relative humidity on sporulation, conidial germination, infection, and symptom expression (Alderman et al., 1986, 1987a, 1987b).

In North Carolina, the PSC advisory was simplified to make it easier to use and was deployed from 1983 to the mid 1990's (Bailey et al., 1994). Over 75% of the North Carolina peanut farmers use the advisory to time fungicides applications at least some of the time (Bailey et al., 1994). Yield generally does not differ between spray programs scheduled with the PSC advisory, and a 14-day spray program, but leaf spot incidence is usually higher in the former (Phipps and Powell, 1984).

Description of the models:

Jesen and Boyle Advisory (1966)

Jensen and Boyle (Jensen and Boyle, 1965 and 1966) derived their temperature-relative humidity-time criteria for predicting secondary infection of peanut leaf spot from a correlation analysis on data collected in 1963 and 1964. Results were plotted using the hours of humidity for each 24-hr period on the x-axis, and minimum temperature during this period on the y-axis. Three curves were plotted, delimiting zones of little, slow, moderate and rapid disease progress. Moderate and rapid infection increase reflected environmental conditions favorable to extremely favorable, to disease progress in the field. From experience, they inferred that a single day of those conditions would not warrant a fungicide application. Favorable conditions for 2 to 3 consecutive days would, however, result in easily detectable disease increase 10 to 14 days later. This correlation was probably reflective of secondary infection and not disease onset. The authors also noticed that the latent period was quite variable.

These observations were used by the National Weather Service to issue a disease warning (advisory) in Georgia starting in 1968 (Parvin et al., 1974). During the growing season, daily advisories were issued on a Teletype network and then transmitted to growers by radio or television. The Georgia Extension Service did not promote the use of this method of timing fungicide applications because preventative calendar-based sprays were believed to be safer and more effective (Bailey, 1999, personal communication).

Experiments in controlled conditions (Alderman and Beute, 1987) supported the Jensen and Boyle model as periods of 4 hr of RH≥95% at a minimum temperature ≥16°C resulted in low conidia formation.

Parvin, Smith and Crosby Advisory (1974).

Parvin, Smith and Crosby (1974) formalized the logic of the Jensen and Boyle model into an algorithm which they computerized. Each day was given an index based on the number of hours the relative humidity was above 95% and the minimum temperature during that period. A set of rules was used to determine if sprays were needed. If the sum of the last 2 days index was ≥4.5 then a spray recommendation was issued, if it was ≥4 the preceding days where evaluated too: if their average index was >1, then a spray recommendation was issued; otherwise no sprays were necessary (Fig. I. 1). The PSC nomogram was refined and the rules simplified by Matyac and Bailey (1988).

Virginia Advisory (Cu and Phipps, 1993)

The Virginia advisory approached field infection in a sequential manner, including the information gathered on sporulation, germination, lethal conditions, infection, and disease incidence. The model incorporated results of Alderman and Beute (1986, 1987) under controlled condition experiments. It accumulated hours with favorable conditions for infection (TDV_i) and after a certain threshold was reached, called for fungicide applications. The 48 TDV_i threshold is currently used in Virginia, and the model will be referred to as 48-ADV in this manuscript.

AU-Peanut (Jacobi and Backman, 1995a)

The Au-Pnuts advisory was developed in Alabama, and was based on a correlation analysis which showed a strong positive relationship between rainfall and the development of early and late leaf spot (Davis et al., 1993). It was later improved by including the National Oceanographic and Atmospheric Administration (NOAA) precipitation probabilities (Jacobi et al., 1995a). AU-Pnuts is currently used in Alabama and Georgia. Various combinations of rain (≥0.25 cm), fog (≥ 10 h.), and rain probabilities were used to predict disease onset and trigger the need for fungicide sprays.

NC Advisory (Bailey et al., 1994)

The model used in North Carolina was a simplified version of the PSC, and used the same weather parameters; RH and temperature. Every hour was categorized as a function of the weather parameters. Hourly index values were summed for each day. If the sum was ≥10 then the day was favorable for disease increase. A spray recommendation was issued when 2 days in a row were favorable for disease increase.

Simulation model (Knudsen et al in 1987)

Another model was developed in NC (Knudsen et al, 1987). It simulated *Cercosprora* leaf spot epidemics, but has only been used for research purposes. The model is mechanistic and one of its later versions (Knudsen et al. 1988) included a fungicide module to explore different fungicide strategies for the control of leaf spot.

<u>Adapting the advisories for resistance.</u>

In 1978 Fry (Fry, 1978) suggested that the Blitecast Advisory for potato late blight could be adapted to resistant potato cultivars. The effect of fungicide was considered similar to that of general resistance. General resistance was then estimated in terms of fungicide equivalents by altering fungicide amounts per weekly application or by altering the interval between applications of a constant amount of fungicide (Fry, 1978). In 1983 Blitecast was successfully modified to account for resistance on potatoes with the method described above. (Fry et al., 1983).

Matyac and Bailey (1988) adapted the Parvin, Smith and Crosby advisory to partially resistant peanut genotypes by multiplying the daily index values by 0.85 or 0.70, reducing then the spray recommendations to only highly favorable conditions for disease development. Cu and Phipps (1993) noted that changing the TDV_i spray threshold might be a good way to adapt the Virginia Advisory for resistant cultivars as the accumulation of the TDV_i index correlated well with the disease progress curve. Jacobi and Backman (1995b), adapted the Au-Pnuts leaf spot advisory (Jacobi and Backman, 1995a) to partially resistant runner cultivars by increasing the number of rain events required to attain the spray threshold.

Most of these models were compared in Oklahoma in studies conducted by Wu et al. (1996) from 1991 to 1993. Except for the AU-Pnuts, advisory programs had been implemented mainly for virginia-type cultivars. Their study was designed to see if those models would control leaf spot on two spanish cultivars, which are more susceptible to leaf spot. The PSC advisory did not provide the best leaf spot control for either cultivar. The authors commented that it might have been due to the placement of the relative humidity and temperature sensors 1.2 m above ground as opposed to canopy height which was used for model development. The AU-Pnuts advisory provided adequate control, but called for more sprays than the Virginia Advisory. The best threshold for the Virginia advisory was 36 for the spanish cultivar “Spanco” and 48 for the runner cultivar “Florunner”.

Objective

The objective of this work was to, a) determine which of the currently used weather-based peanut leaf spot advisories is most appropriate for use with Virginia-type cultivars in North Carolina, and b) adjust the North Carolina leaf spot advisory for use with resistant cultivars.

I. 2. Materials and methods

Field experiment design

Three peanut lines (NC 7, NC 11, Gp-NC 343) were planted on 8, 7 and 5 May in 1997, 1998 and 1999 respectively, at the Peanut Belt Research Station, Lewiston, NC, and 23 and 25 May in 1998 and 1999 respectively, at the Upper Coastal Plain Research Station in Rocky Mount, NC. The field design was a complete randomized block design with four replications. Peanuts were planted in a 3-year rotation with cotton or corn at both locations. Each plot consisted of two 15 m (50-ft) rows that were separated by two border rows planted with NC 7. Cultural practices used, except for leaf spot control, were as recommended by the North Carolina Peanut Production Guide (Jordan D. L, 1999). Control of leaf spot was performed with a mix of propinconazole (Tilt 3.6 EC, Novartis) and chlorotalonil (Bravo 6F, Zeneca) at the rates of 0.022 and 0.83 kg a.i./ha, respectively, using a tractor mounted CO_2-pressurized sprayer (at 124 kPa) equipped with three hollow cone nozzles per row. The sprays were effected within 4 days (or as soon as the conditions in the field permitted the entry of the tractor) after spray thresholds were met.

Percent infected leaflets in each plot was estimated every 5 to 8 days by examining the foliage within a 1.5 m section in the center of the plots on each of the 2 rows. Areas under the disease progress curves (AUDPCs) were calculated from the equation (Shaner and Finney, 1977):

$$AUDPC = \Sigma\ [(Y_{i+1} + Y_i)/2]*(X_{i+1} - X_i)$$

in which Y_i = the percent infection (square root) at the *i*th observation, and X_i = the date of the *i*th assessment in days after planting. Differences in AUDPCs among genotypes and schedules were examined by using an ANOVA analysis with SAS (SAS Institute, Cary, Inc).

Weather data

Weather data were collected from an onsite weather station (AMS weather station, Middlesex, N. C.) which monitored air temperature, dew point, rain and relative humidity every 15 min and stored the data on a personal computer. The sensors were positioned 20 cm from the ground. In 1999, in Lewiston, missing data from 1 July to 20 July, were replaced by data collected with an identical weather station located 15 miles away in Windsor, NC (Bertie Co.).

The NC model

A C++ program ("Advise") analyzed data from the weather station and generated the advisory report. For every hour, if the relative humidity was ≥ 95%, the index for the hour took a coefficient value given by the mean temperature (rounded to the nearest integer) for that hour. In 1997 the coefficients were 0 below 15.5^{o}C (60^{o}F), 0.5 at 18.3^{o}C (65^{o}F), 1 from 21.1^{o}C (70^{o}F) to 32.2^{o}C (90^{o}F), 0.8 for 35^{o}C (95^{o}F), and 0.25 above 37.7^{o}C (100^{o}F). Index values between those temperatures were inferred by interpolation (Fig. I.2 and I.3). All of the hourly indices were added to give a daily index, which was then compared to the spray threshold. The standard recommendations for 1997 was a daily index ≥10 for 2 days in a row.

Different treatments were created by changing the daily index required to constitute favorable days for disease increase in 1997. In 1998, the temperature adjustment to allow for advisories at cooler temperatures was also changed. The index for 12.7^{o}C became 0.5 and for 15.5^{o}C became 1. Indices between, 10 and 12.7, 12.7 and 15.5 were inferred by interpolation. The later advisory was referred to as a low temperature advisory in comparison to the former one. The daily index thresholds were also modified (increased) for the low advisory to give rise to different models.

Development of the different NC model thresholds

The models used in 1997 were developed using weather data from 1996 at the same location leading to different schedule treatments. In the 1996 season, which was very conducive for leaf spot, the different advisories with a daily index of 8,10,12,14,16,and 18 would have called for 7, 6, 5, 4, 2, and 1 fungicide sprays, respectively.

The 1997 treatments were composed of an untreated control, the standard 14-day spray schedule and the North Carolina advisory with an 8, 10, 12, 14, 16, or 18 daily index attained 2 days in a row. Those treatments were referred to as 2d8hr, 2d10hr, 2d12hr, 2d14hr, 2d16hr and 2d18hr.

In 1998 the treatments consisted of: the untreated control, a 14-day spray schedule, the NC regular advisory with a daily index of 10 and 14 attained for 2 consecutive days, the low temperature advisory with a 10, 12 and 14 daily index attained for 2 consecutive days, and the low advisory with a 10 and 14 daily index attained for 4 consecutive days. Those treatments were named 2d10hr, 2d14hr, 2d10hl, 2d12hl, 2d14hl, 4d10h, and 4d14hl respectively.

In 1999 five treatments were retained: the untreated control, the 14-day spray schedule, and the low advisory with daily index thresholds of 10, 12 and 14 attained for 2 consecutive days (2d10hl, 2d12hl, and 2d14hl).

Model simulations and comparisons

The performance of the NC advisories were evaluated by comparison to the PSC advisory (Parvin Smith and Crosby, 1974), the Virginia Leafspot Advisory (Cu and Phipps, 1993), and the AU-Pnuts 7/3 advisory (Jacobi and Backman, 1995a). All the advisory computations started in July except for the AU-Pnuts advisory, which started computing rain events from plant emergence. Also modifications of those advisories found in the literature were used in our comparison; the 0.85*PSC and 0.7*PSC (Matyac and Bailey, 1988), the 72-ADV and 96-ADV (Cu and Phipps, 1993), and the AU-Pnuts 9/4 and AU-Pnuts 12/4 (Jacobi and Backman, 1995b) which may adapt to partially resistant genotypes.

Descriptions of the simulated models

PSC (Parvin, Smith and Crosby, 1974)

Each day was given an index based on the number of hours the relative humidity was ≥95% and the minimum temperature during that period (Fig. I. 1). The index for the last 2 days was added. If the sum was ≥4.5, then a spray advisory was issued and conditions were considered to be favorable for disease increase. If the result was ≤3, then the advisory indicated no fungicide sprays were needed. If the index sum was 4 (from a 1.5+ 2.5 or a 2.5+1.5), and the average of the preceding days was >1, then a spray recommendation was issued. In the other cases no sprays were necessary. To adapt for resistance, the index was then multiplied by 0.85 or by 0.7 (Matyac and Bailey, 1988), therefore reducing spray recommendations to periods highly favorable for disease increase.

Virginia Advisory (Cu, R. M., and P. M. Phipps, 1993)

At the beginning of the season the model required at least 10 hr of RH>90% and temperatures between 16 and 32^{o}C, to estimate when old lesions would sporulate on crop residue. Once this threshold was attained, it was assumed that infectious spores were present throughout the season. Spore germination conditions were rated from 1 to 3 depending on the environment. For each hour when RH was >95%, an index value was given to that hour as follows: 1 if the temperature was >28 and ≤32^{o}C, 2 if >25 and ≤28^{o}C, and 3 if ≥16 to ≤25^{o}C. Those hourly index values were then accumulated into a variable called time duration value (TDV). The TDV for germination (TDV_g) gave a disease index indicating a decreased tolerance for delays in fungicide application. The TDV for infection (TDV_i) was characterized by the total number of hours of conditions conducive to infection (RH≥95% and temperature 16-32^{o}C). Accumulated values were used to time fungicide applications after they reached a threshold of 48 TDV_i. Also lethal conditions were taken into account: if for 5 consecutive hours the ambient temperature was above 37 ^{o}C or for 8 consecutive hours and the RH<40%, then all accumulated values were reset to 0 (Table I.1).

When a fungicide spray was effected, the TDV_i and TDV_g values were reset to 0 and began to accumulate again 10 days after the fungicide treatment. The adaptation for resistance was made by increasing the TDV_i spray threshold from 48 to 72 and 96.

AU-Pnuts (Jacobi and Backman, 1995a and 1995b)

For the AU-Pnuts 7/3 advisory, the first number referred to the first spray onset after 7 rain event and the second number, 3, for the number of rain event needed for subsequent sprays. We simulated fungicide applications starting on the 7th rain event (≥2.5mm of rain or irrigation in a 24 hr period, or when ground fog occurred the previous evening before 8 p.m.) following the emergence of the peanut plants. Plants were considered protected for 10 days after fungicide treatment. Following applications were simulated if no days with rain were recorded but the 5-day average precipitation probability was ≥60%; or if 1 day with rain was recorded and the average precipitation probability was ≥40%; or if 2 days of precipitation were recorded and the 5-day average probability was ≥20%; or if 3 days of precipitation had occurred. The Au-Pnuts advisory was adapted for resistance by increasing the first spray threshold from 7 to 9 and 12 and the subsequent spray thresholds from 3 to 4, leading to 2 new advisories: the 9/4 and 12/4. The 5-day average rain probability threshold was changed accordingly with a recommendation for sprays if the average was ≥60% with one rain event, or ≥40% with two rain events, or ≥20% with three rain event. The forecast weather data for the 5-day precipitation probability was obtained from a generated AgForecast product obtained from Meso Inc. (Troy, NY).

None of the adaptations for resistance of the different models were calibrated for the GP-NC 343 nor were the adaptations equivalent among models.

I. 3. Results and discussion

Field results

Untreated controls through positive inter-plot interference provided higher disease pressure on the spray treatments, than would be anticipated in sprayed farmer's fields. They were nevertheless necessary to be able to compare the genetic resistance of the three genotypes used (low, NC11, medium, NC7, high, GP-NC343), and to evaluate differences in disease conduciveness among years and locations. Almost no early leaf spot was present in Rocky Mount both in 1998 and 1999, model treatment comparisons were not conducted at this site because we think that the absence of disease might be due to low levels of inoculum in the area (low peanut production). In 1998 the level of disease at the end of the season in Lewiston, was half that observed in 1997, and the disease level at the end of September for 1999 was similar to 1997 observations (Fig. I.4, I.5 and I.6). Fungicide treatments were applied on the dates presented in Table I. 2, I. 3, and I. 4. In both 1997 and 1998, there was no difference in yield due to leaf spot control ($P>F = 0.07$ for 1998 and 0.5 for 1997) for all genotypes and across locations. However there was significant yield reduction on the untreated plots of the NC 7 and NC 11 lines in 1999 in Lewiston (Table I.11 and I.12), but no yield reduction was observed for the GP-NC 343 line ($P>F = 0.46$). The difference between the treatments with 4 fungicide applications for NC 7 is unlikely to be the result of a significant biological effect as those treatments were applied at the same time (Table I.11). The treatments effectively reduced the AUDPC; the higher the number of fungicide sprays, the lower the AUDPC for all three years (Table I.5, I.7, and I.9).

In all the years the genotype GP-NC 343 showed a significantly lower AUDPC than the two other genotypes (Tables I.6, I.8 and I.10). In 1997 only, when the disease pressure was higher than in 1998 and 1999, was NC 7 found to have a significantly lower AUDPC when compared with NC 11 (Tables I.6, I.8 and I.10). GP-NC 343 had a yield higher when compared with the two other genotypes at Lewiston in 1997, 1998 and 1999, but not in Rocky Mount in 1998 and was significantly lower than the other lines in 1999 in Rocky Mount (Table I.13).

<u>Model simulation and spray timing:</u>

In 1997, 1998 and 1999, simulated spray timing was computed for all the different models for the Lewiston location and compared with the disease progress on the untreated checks for the three genotypes (Table I.2, I.3, I.4 and). In figures I.7, I.8, and I.9, the beginning of the bar represents the simulated date when the fungicide sprays would have been applied. The length of the bar represents the theoretical protection provided by the fungicide spray. Thus the end of the bar represents when new weather data are computed for the next advisory. The North Carolina advisory and the Parvin Smith and Crosby (PSC) advisory both have a 14-day period after a fungicide spray before the computation of the advisory restarts. The AU-Pnuts and Virginia advisory have a 10-day period.

In 1997 there was a slight disease increase in mid-August on untreated plots followed by a significant increase begining the second week of September. All the models called for a spray very early in the season except for the AU-Pnuts 12/4. All models overestimated the disease in July. By increasing the daily threshold index for the North Carolina advisory, we reduced the number of sprays: the 2d8hr was sprayed four times, the 2d10hr three, and the 2d12hr and 2d14hr were sprayed once. However, the spray reductions were more focused toward the end of the season, which was when fungicide protection was needed the most. The 2d16hr and 2d18hr NC model did not call for a spray in 1997. The Parvin Smith and Crosby model called for four sprays. The PSC*0.85 adaptation for resistant genotypes did not differ from the regular PSC advisory and the PSC*0.7 called for three sprays by omitting the end of season spray of the PSC. The Virginia advisory (48-ADV) called for six sprays and its resistant adapted versions (72-ADV and 96-ADV) for five and four, respectively. The AU-Pnuts model called for five sprays, whereas its adaptations 9/4 and 12/4, called for three sprays. The AU-Pnuts models 9/4 and 12/4 tended to follow the disease progress curve and seemed to be the ones the most appropriate to time fungicide applications in 1997 on the susceptible and resistant genotypes. Most models oversprayed, especially at the beginning of the season when there was no disease in the field.

In 1998, the leaf spot epidemic started at the beginning of September. The 1998 growing season had less leaf spot compared to 1997 (the disease levels at the end of the season were half of that in 1997), however, the weather was judged more conducive for disease by all the models. Fungicide applications were made throughout the season using the 14-day schedule. The NC advisories did not separate very well and were analyzed in two groups; group 1 (2d10hl, 2d10hr, 2d12hl and 4d10hl) called for six sprays, and group 2 (2d14hl and 2d14hr) called for three sprays. The 4d14hl did not call for a spray that year. The PSC advisories and its adaptation called for five sprays, and differed only slightly (the non-resistance-adapted advisory called for a spray a day earlier at the beginning of the season). The Virginia advisory called for six sprays and the 72-DV and 96-ADV for five each. The Au-Pnuts advisory 7/3 called for a spray very early in the season: 20 June. The AU-Pnuts 7/3, 9/4 and 12/4 called for six, five and four sprays respectively.

The end of the season 1999 was excessively wet. The amount of rain that fell from two hurricanes, Dennis (on September 4 through 6) and Floyd (on September 14 through the 16), was 84 and 247 mm respectively. After Dennis it was impossible to get into the fields and spray. However, disease assessment was still possible and we continued simulating the models. In 1999, as in 1998, the AU-Pnuts 7/3 started calling for sprays early in June (16 June) and the AU-Pnuts 9/4 on 18 June. The Au-Pnut 7/3 and 9/4 called for an excessive number of sprays, seven and six. The 12/4 version performed better and called for five sprays with most of them at the end of the season. The PSC and its adaptations for resistant genotypes did not differ in number of sprays and only slightly for the spray timing; they called for five sprays total. The Virginia advisory 48-ADV and 72-ADV called for six sprays each. The 96-ADV called for four sprays grouped in the middle of the season.

Conclusion

Only the Au-Pnuts advisory uses forecast weather, making it theoretically possible to predict infection. The other approaches describe when conditions have been conducive for particular phases of the disease process or when disease increase is likely. All systems are designed to reduce the number of unnecessary fungicide applications. The 10 day interval between fungicide sprays seemed too short for North Carolina, especially with the Virginia advisory. The latter model appeared to call for sprays too often. If this model is to be used in North Carolina, might need to be calibrated. The Virginia advisory never reached a lethal threshold in Lewiston for the years tested. Even in years with low rainfall, almost all of the advisories called for more sprays than appeared necessary. The use of the 7/3 Au-Pnuts model had a tendency to start spray programs too early and to overspray. The tendency to reduce sprays at the end of the season for resistance adapted models was only observed with the North Carolina model and the PSC during the 1997 season. This observation lead to the development of a low (temperature) advisory in 1998 because it was suspected that the lower night temperatures were high enough for disease development (Alderman and Beute, 1986 and 1987). In both years (1997 and 1998) there was no yield reduction associated with leaf spot control; therefore it seems that the model which sprayed least, before and during the disease increase in our studies, was most useful in reducing unnecessary sprays. Additional information is needed to adjust for location with a history of low disease pressure as was experienced at the Rocky Mount site.

The partially resistant genotype (GP-NC 343) did not require any sprays during the 3 years. All of the models and their resistance adaptations oversprayed GP-NC 343; the resistance models used were too conservative for this level of resistance. This genotype may be resistant enough so that it could be scouted for disease symptoms and be sprayed according to an advisory after disease onset. Effective systemic fungicides may aid in adopting this approach. Another way to adapt for resistance could have been to increase the period between sprays, such as Fry (1978) did with the Blitecast. This way of adapting for resistance has not been used previously for peanuts; most of the work concentrated on increasing periods of conducive weather to constitute the spray thresholds. As we saw each year (Fig. I.4, I.5 and I.6), the onset of the epidemic was the same for both the resistant and susceptible genotypes. The resistance observed in the fields could be characterized as rate reducing. This is supported by the fact that infection did not take place at a different time for resistant compared to susceptible genotypes. Considering resistance as a fungicide equivalent such as Fry (1978) would be appropriate, and the adaptation for resistance would be better obtained by either reducing fungicide doses or increasing the spray intervals using the same advisories as for the susceptible genotypes. This approach has been used on a schedule by Culbreath et al. (1992) and Johnson and Beute (1986). However, this approach may increase the rate of resistance development to certain fungicides by increasing the exposure to sub-lethal doses.

Based on our study, the Au-Pnuts 12/4 model was best adapted for North Carolina for currently grown genotypes. One advantage of the AU-Pnuts model is its use of precipitation probability forecasts, allowing growers to apply a fungicide prior to infection. This approach combined with improved rain forecasts for specific sites could represent an important improvement in our ability to time fungicide application for leaf spot on peanuts.

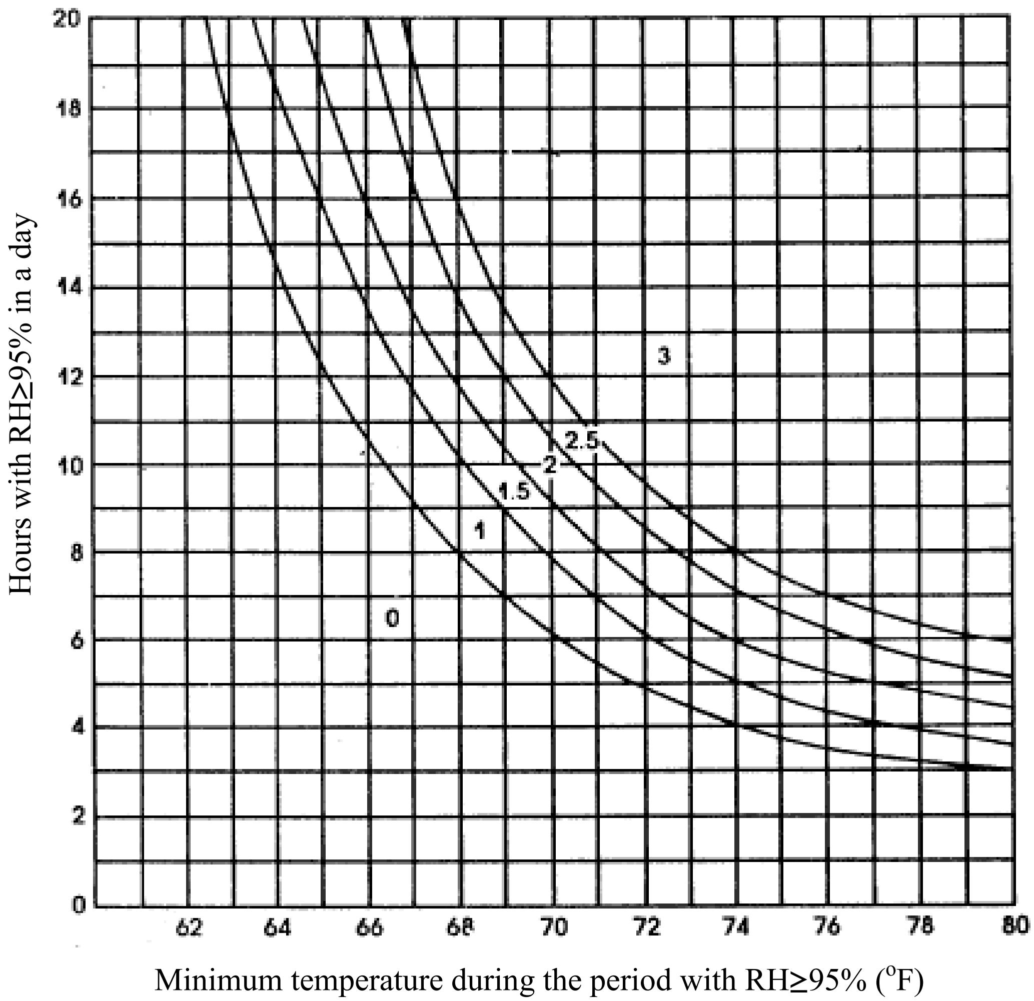


Figure I.1: Nomogram after Parvin, Smith and Crosby (1974) and Bailey, et al. (1994). This figure represents how favorable weather conditions have been for disease progress in a day (0= not favorable, 3= very favorable). If the sum of the last 2 days index was ≥4.5 then a spray recommendation was issued, if it was ≥4 the preceding days where evaluated too: if their average index was >1, then a spray recommendation was issued; otherwise no sprays were necessary.

Meteorological parameters	Time duration value (TDV)[a]			
	TDV_s	TDV_g	TDV_i	TDV_{lc}
RH>90%				
Temperature >16≤32°C	1	0	0	0
RH≥95%				
Temperature >28≤32°C	1	1	1	0
Temperature >25≤28°C	1	2	1	0
Temperature ≥16≤25°C	1	3	1	0
RH<40%	0	0	0	1
Temperature ≥37°C	0	0	0	1
TDV threshold[b]	10	48	96	5-8[c]

[a]TDV is the time-duration value assigned to each hour of specific conditions (TDV_s = sporulation, TDV_g = germination, TDV_i = infection, TDV_{lc} = lethal conditions).
[b]Threshold values reflect the estimated cumulative TDV for completion of a specific event.
[c]Lethal conditions occurred after five consecutive hours of ambient temperature ≥37 C or eight consecutive hours of RH <40%.

Table I.1: Virginia advisory resume table of the time duration values assigned to each specific meteorological condition for sporulation, germination, infection and lethal conditions (Cu and Phipps, 1993).

For 1 hour → If RH >= 95%

↓

Multiply by a Temperature Scaling Factor

↓

Mean Hourly Temperature (°C)	≤10	12.7	15.5	18.3	21.1≤T<32.2	35	≥37.7
Regular Coeff.	0	0	0	0.5	1	0.8	0.25
Low Coeff.	0	0.5	1	1	1	0.8	0.25

Coefficient values in between those categories were interpolated.

↓

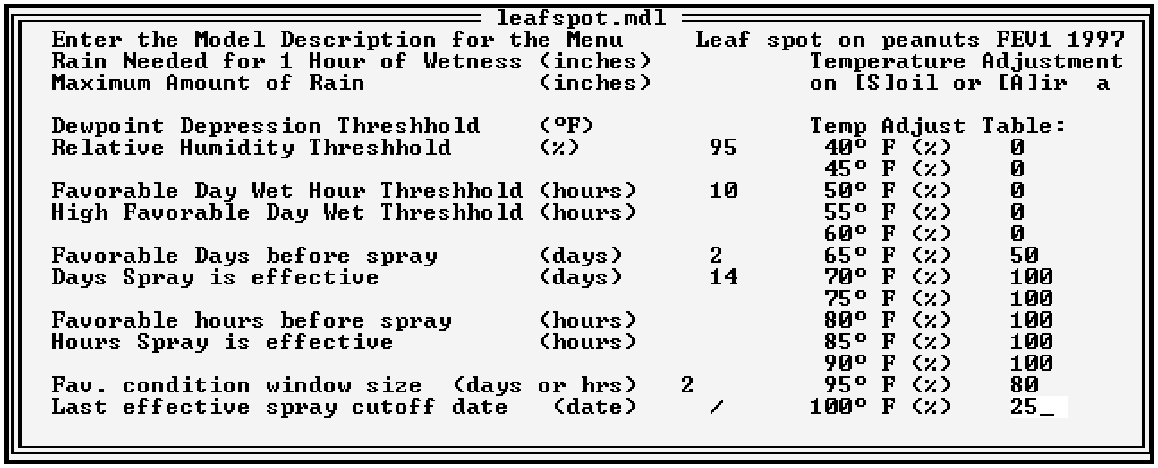
Total for 1 Day

↓

Spray Thresholds

Hour Threshold / Day	Day Threshold
In 1997:	
8, 10, 12, 14, 16 and 18 Regular	2 days in a row
In 1998:	
10, 12, 14 Low and Regular	2 days in a row
10, 12, 14 Low	4 days in a row
In 1999:	
10, 12 and 14 Low	2 days in a row

Figure I.2: North Carolina Advisory algorithm, with the different adaptations for leaf spot resistance. For every hour, if the relative humidity was ≥ 95%, the index for the hour takes a coefficient value given by the mean temperature (rounded to the nearest integer) for this hour. The NC regular model coefficients were 0 below 15.5°C, 0.5 at 18.3°C, 1 from 21.1°C to 32.2°C, 0.8 for 35°C, and 0.25 above 37.7°C. The NC low model coefficients were 0 below 10°C, 0.5 at 12.7°C, 1 from 15.5°C to 32.2°C, 0.8 for 35°C, and 0.25 above 37.7°C. Index values between those temperatures were inferred by interpolation. The index are summed at the noon (a day is a 24 hour period that starts at noon) and the daily index are compared to the thresholds. The spray recommendations were made according to the spray threshold table.


```
leafspot.mdl
Enter the Model Description for the Menu      Leaf spot on peanuts FEV1 1997
Rain Needed for 1 Hour of Wetness (inches)            Temperature Adjustment
Maximum Amount of Rain            (inches)            on [S]oil or [A]ir  a

Dewpoint Depression Threshhold    (ºF)                Temp Adjust Table:
Relative Humidity Threshhold      (%)         95        40º F (%)    0
                                                        45º F (%)    0
Favorable Day Wet Hour Threshhold (hours)     10        50º F (%)    0
High Favorable Day Wet Threshhold (hours)               55º F (%)    0
                                                        60º F (%)    0
Favorable Days before spray       (days)      2         65º F (%)    50
Days Spray is effective           (days)      14        70º F (%)    100
                                                        75º F (%)    100
Favorable hours before spray      (hours)               80º F (%)    100
Hours Spray is effective          (hours)               85º F (%)    100
                                                        90º F (%)    100
Fav. condition window size  (days or hrs)   2           95º F (%)    80
Last effective spray cutoff date   (date)     /       100º F (%)    25_
```

Figure I.3: Computer screen representing the template of the 10-hour model used as the standard advisory in North Carolina (J. E. Bailey, 1997).

Lewiston, 1997

Spray schedule and advisories	No. sprays	Actual Spray Date
14-day schedule	6	3 July, 21 July, 5 August, 19 August, 8 September, 22 September
2d8hr	4	3 July, 21 July, 8 September, 22 September
2d10hr	3	11 July, 28 July, 22 September
2d12hr	1	21 July
2d14hr	1	28 July
2d16hr and 2d18hr	0	No sprays

Advisories	No. sprays	Simulated Spray Date
PSC	4	7 July, 24 July, 16 August, 20 September
0.8*PSC	4	7 July, 24 July, 16 August, 20 September
0.75*PSC	3	7 July, 24 July, 16 August
48 ADV	6	6 July, 21 July, 7 August, 27 August, 12 September, 29 September
72 ADV	5	9 July, 25 July, 14 August, 3 September, 19 September
96 ADV	4	11 July, 28 July, 22 August, 13 September
AUP-nut 7/3	5	11 July, 23 July, 21 August, 4 September, 24 September
AUP-nut 9/4	3	23 July, 7 September, 25 September
AUP-nut 12/4	3	20 August, 9 September, 25 September

Table I.2: Spray schedules (actual and simulated) according to the different models for 1997 in Lewiston NC. The actual spray dates correspond to treatments that were effected in fields tests, the simulated spray dates corresponds to dates where the different advisories would have called for a spray. 2d8hr, 2d10hr, 2d12hr, 2d14hr, 2d14hr, 2d16hr, 2d18hr= a daily index of 8, 10, 12, 14, 16, 18, respectively, for the NC regular model attained in 2 days in a row.

Lewiston, 1998 Spray schedule and advisories	No. sprays	Spray date
14-day schedule	7	1 July, 15 July, 29 July, 12 August, 26 August, 9 September, 28 September
2d12hl 4d10hl 2d10hl 2d10hr	6	1 July, 20 July, 4 August, 19 August, 4 September, 28 September
2d14hl 2d14hr	3	20 July, 31 August, 28 September
4d14hl	0	No sprays

Advisories	No. sprays	Simulated spray date
PSC	5	9 July, 25 July, 8 August, 28 August, 19 September,
0.8*PSC 0.75*PSC	5	10 July, 25 July, 8 August, 28 August, 19 September,
48 ADV	6	7 July, 20 July, 6 August, 24 August, 6 September, 19 September
72 ADV	5	9 July, 27 July, 11 August, 31 August, 19 September
96 ADV	5	11 July, 31 July, 17 August, 3 September, 20 September
AUP-nut 7/3	6	20 June, 11 July, 26 July, 8 August, 28 August, 19 September
AUP-nut 9/4	5	5 July, 18 July, 8 August, 28 August, 19 September
AUP-nut 12/4	3	18 July, 28 August, 19 September

Table I.3: Spray schedules (actual and simulated) according to the different models for 1998 in Lewiston NC. The actual spray dates correspond to treatments that were effected in fields tests, the simulated spray dates corresponds to dates where the different advisories would have called for a spray. 2d10hr and 2d14hr= a daily index of 10 and 14 respectively, for the NC regular model attained in 2 days in a row, 2d10hl, 2d12hl and 2d14hr= a daily index of 10, 12 and 14 respectively, for the NC low model attained in 2 days in a row, 4d10hl and 4d14hl= a daily index of 10 and 14 respectively, for the NC regular model attained in 4 days in a row. The horizontal bars symbolize the treatments that called for the same spray timing.

Lewiston, 1999

Spray schedule and advisories	No. sprays	Spray date
14-day schedule	4	3 July, 21 July, 6 August, 23 August
2d10hl	4	3 July, 21 July, 6 August, 23 August
2d12hl	4	3 July, 21 July, 6 August, 23 August
2d14hl	3	3 July, 6 August, 23 August

Advisories	No. sprays	Simulated spray date
2d10hl	6	3 July, 21 July, 6 August, 23 August, 8 September, 28 September
2d12hl	6	3 July, 21 July, 6 August, 23 August, 8 September, 28 September
2d14hl	5	3 July, 6 August, 23 August, 8 September, 28 September
PSC	5	4 July, 20 July, 8 August, 27 August, 16 September
0.8*PSC	5	4 July, 20 July, 10 August, 27 August, 16 September
0.75*PSC	5	5 July, 21 July, 10 August, 27 August, 16 September
48 ADV	6	9 July, 23 July, 6 August, 20 August, 4 September, 26 September
72 ADV	6	12 July, 27 July, 11 August, 27 August, 10 September, 30 September
96 ADV	4	13 July, 30 July, 17 August, 5 September,
AUP-nut 7/3	7	16 June, 12 July, 6 August, 25 August, 5 September, 16 September, 28 September.
AUP-nut 9/4	6	18 June, 14 July, 10 August, 26 August, 6 September, 27 September
AUP-nut 12/4	5	14 July, 10 August, 26 August, 6 September, 27 September

Table I.4: Spray schedules (actual and simulated) according to the different models for 1999 season in Lewiston NC. The actual spray dates correspond to treatments that were effected in fields tests, the simulated spray dates corresponds to dates where the different advisories would have called for a spray. 2d10hl, 2d12hl, 2d14hl = a daily index of 10, 12 and 14 respectively for the NC low model 2 days in a row.

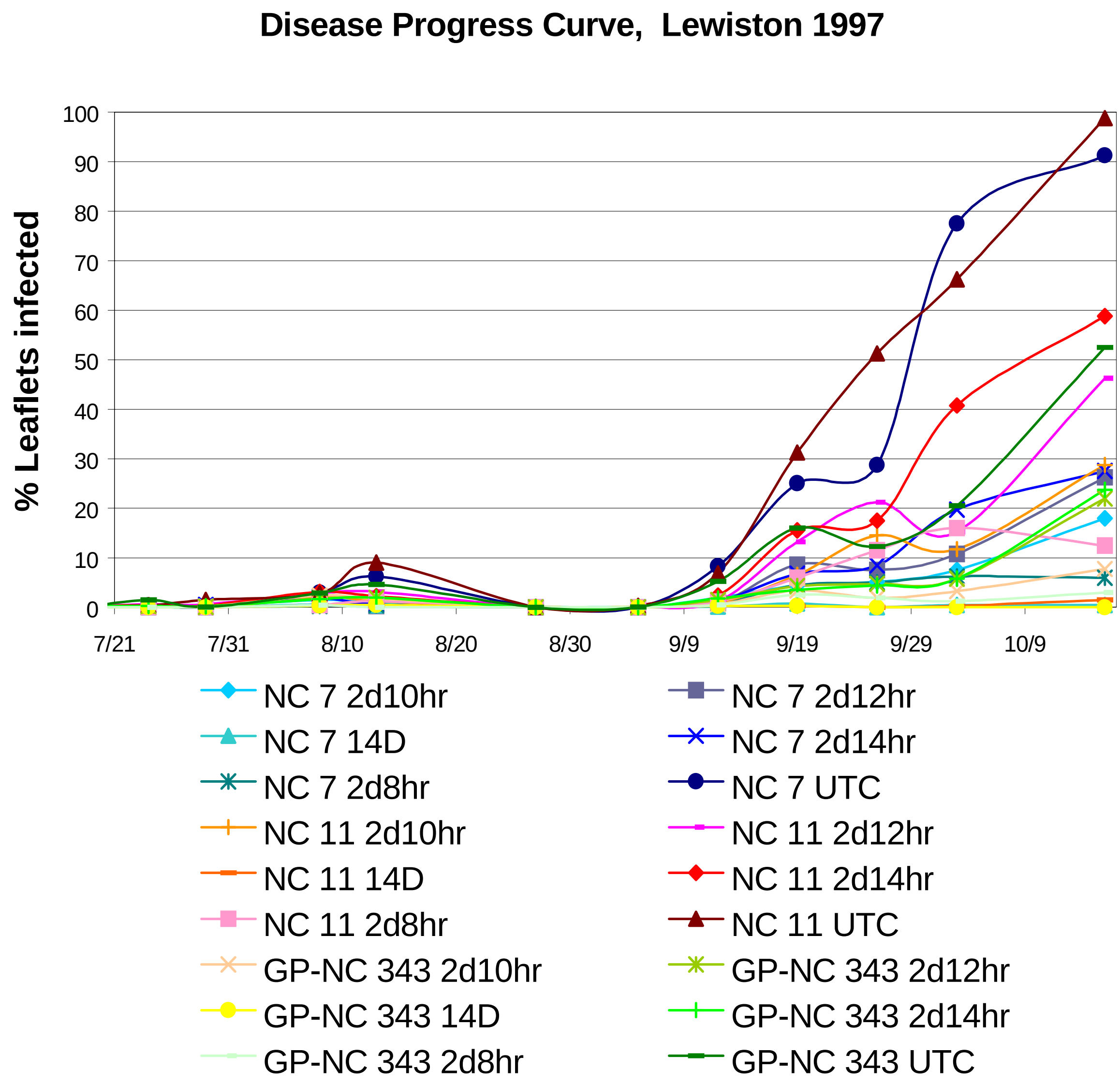


Fig. I.4: Early leaf spot disease progress curves for the North Carolina models for the genotypes NC 7, NC 11 and GP-NC 343, in 1997 at Lewiston. NC. 14D= 14-day spray schedule, UTC= untreated control, 2d8hr, 2d10hr, 2d12hr, 2d14hr, 2d14hr, 2d16hr, 2d18hr = a daily index of 8, 10, 12, 14, 16, 18, respectively, for the NC regular model attained in 2 days in a row.

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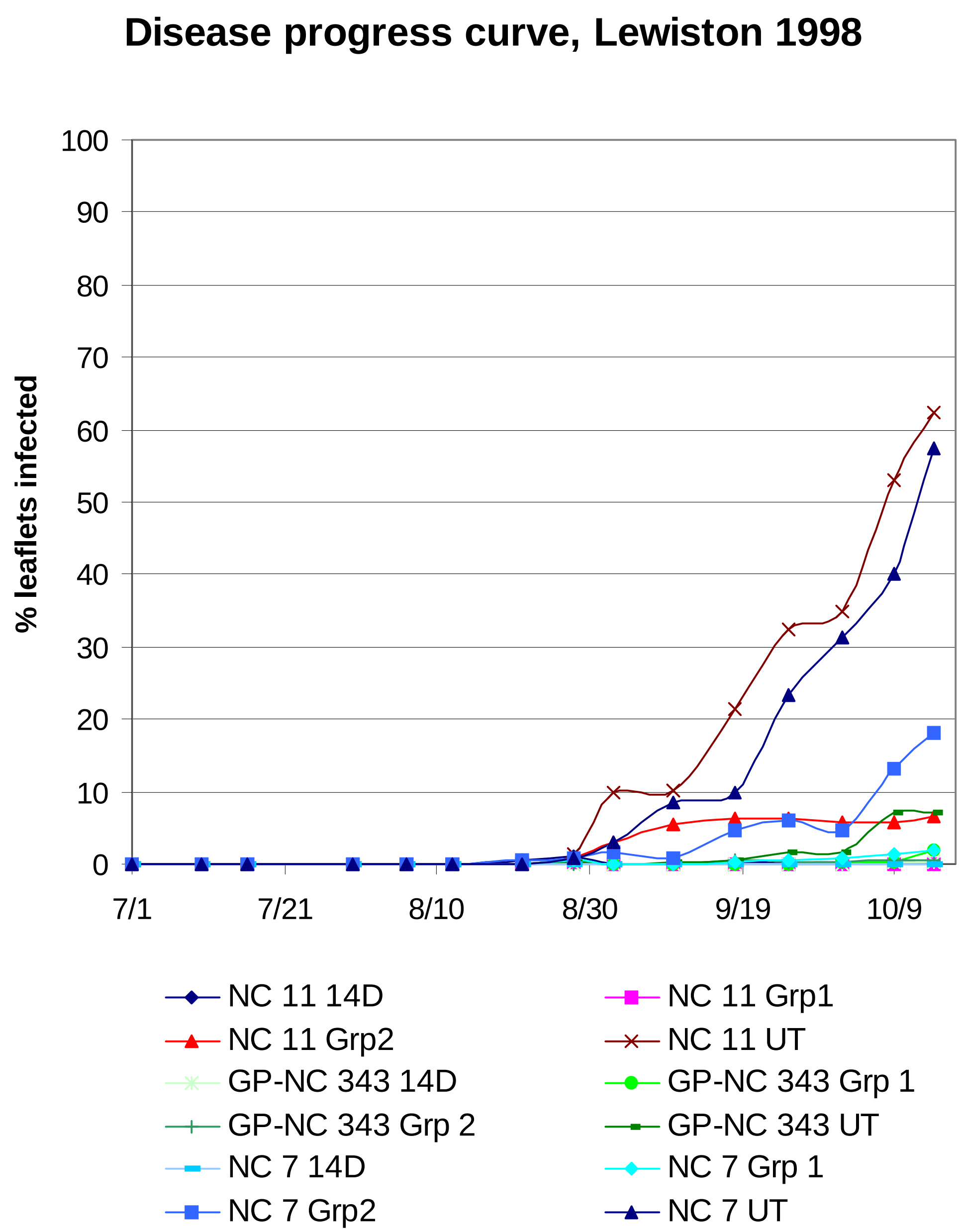

Fig. I.5: Early leaf spot disease progress curves for the North Carolina models for the genotypes NC 7, NC 11 and GP-NC 343, in 1998 at Lewiston. Grp 1 = 2d12hl, 2d10hl, 2d10hr and 4d10hl, Grp 2= 2d14hr and 2d14hl, UTC= Untreated control, 4d14hl. 2d10hr and 2d14hr = a daily index of 10 and 14 respectively, for the NC regular model attained in 2 days in a row, 2d10hl, 2d12hl and 2d14hr= a daily index of 10, 12 and 14 for the NC low model attained in 2 days in a row, 4d10hl and 4d14hl= a daily index of 10 and 14 for the NC regular model attained in 4 days in a row.

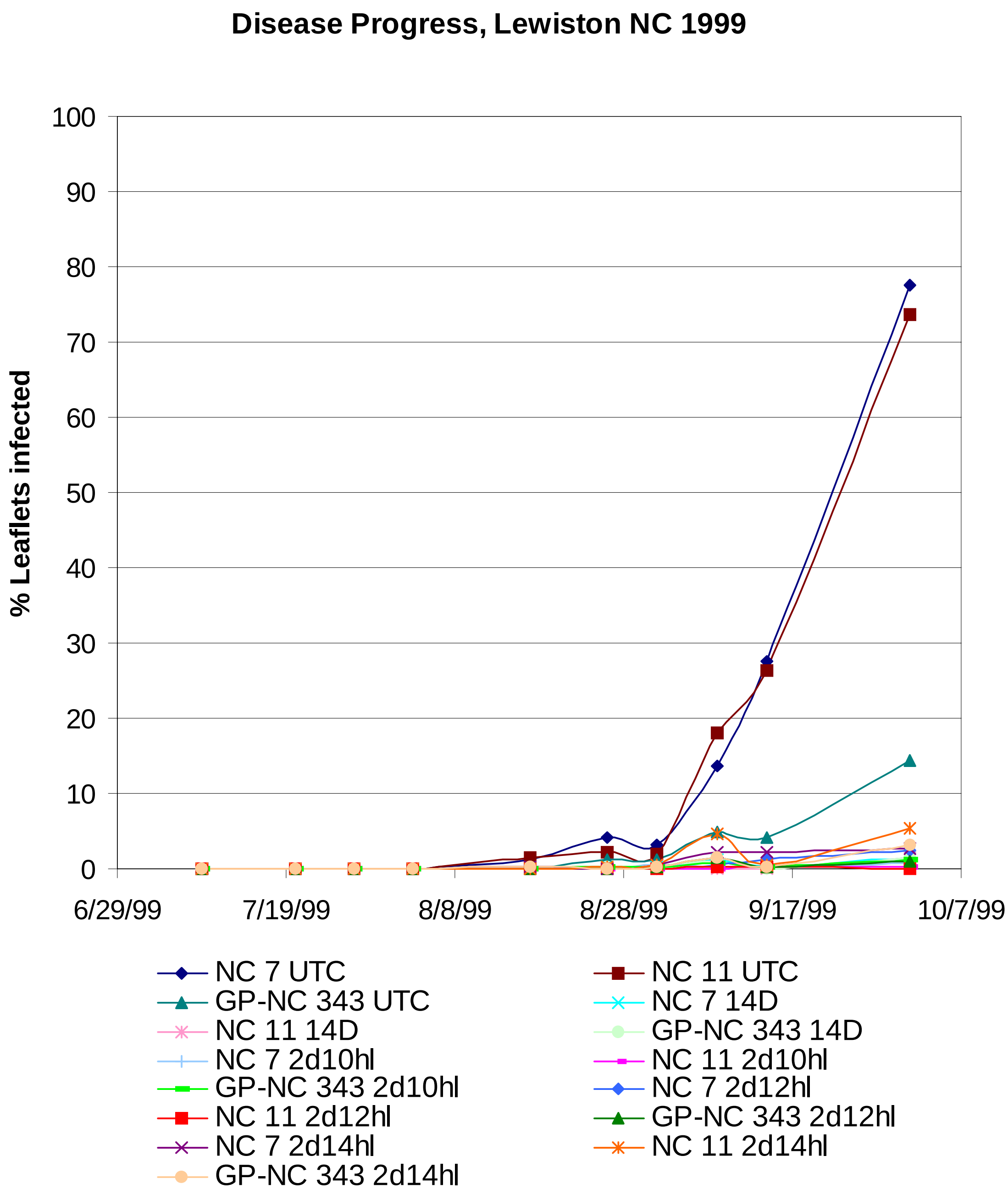

Fig. I.6: Early leaf spot disease progress curves for the North Carolina models for the genotypes NC 7, NC 11 and GP-NC 343, in 1999 at Lewiston. NC. 14D= 14-day spray schedule, UTC= untreated control, 2d10hl, 2d12hl, 2d14hl = a daily index of 10, 12 and 14 respectively for the NC low model 2 days in a row.

Treatments	Mean tAUDPC	Number of sprays	Waller Grouping
UTC	3.17	0	A
2d16hr	3.11	0	A
2d18hr	2.99	0	A
2d14hr	2.73	1	B
2d12hr	2.63	1	B
2d10hr	2.43	3	C
2d8hr	2.11	4	D
14D	1.06	6	E

Table I.5: Separation of 1997 treatments effects in Lewiston, on the log transformed AUDPC (tAUDPC= log[AUDPC+1]) with the Waller-Duncan K-ratio t-Test (F Value = 90.28, Minimum Significant Difference 0.1817, and Critical Value of t = 1.763). Means with the same letter are not significantly different ($P \leq 0.05$). UTC= untreated control, 14D= 14 day schedule, 2d8hr, 2d10hr, 2d12hr, 2d14hr, 2d14hr, 2d16hr, 2d18hr= a daily index of 8, 10, 12, 14, 16, 18, respectively, for the regular model attained in 2 days for the NC model.

Genotype	Mean AUDPC	Waller grouping
NC 11	983	A
NC 7	631	B
GP-NC 343	380	C

Table I.6: Separation of genotype effects in Lewiston, on the AUDPC in 1997 with the Waller-Duncan K-ratio t-Test (F Value 26.44, Minimum Significant Difference = 143.5, and Critical Value of t=1.785). Means with the same letter are not significantly different ($P \leq 0.05$).

Treatments	Mean tAUPDC	Number of sprays	Waller Grouping
4d14hl	2.75	0	A
UTC	2.33	0	A
2d14hr	1.68	3	B
2d14hl	1.65	3	B
2d12hl	0.72	6	C
2d10hr	0.62	6	C
2d10hl	0.57	6	C
4d10hl	0.5	6	C
14D	0.38	7	C

Table I.7: Separation of 1998 treatments effects in Lewiston, on the log transformed AUDPC (tAUDPC= log[AUDPC+1]) with the Waller-Duncan K-ratio t-Test (F Value = 22.91, Minimum Significant Difference = 0.466, and Critical Value of t = 1.79). Means with the same letter are not significantly different (P≤0.05). 14D= 14-day spray schedule, UTC = untreated control, 4d14hl. 2d10hr and 2d14hr = a daily index of 10 and 14 respectively, for the NC regular model attained in 2 days in a row, 2d10hl, 2d12hl and 2d14hr= a daily index of 10, 12 and 14 for the NC low model attained in 2 days in a row, 4d10hl and 4d14hl= a daily index of 10 and 14 for the NC regular model attained in 4 days in a row.

Genotype	Mean AUDPC	Waller Grouping
NC 11	339	A
NC 7	287	A
NC 343	30	B

Table I.8: Separation of genotype effects in Lewiston, on the AUDPC in 1998 with the Waller-Duncan K-ratio t-Test (F Value = 5.36, Minimum Significant Difference = 197.75, and Critical Value of t = 1.963). Means with the same letter are not significantly different (P≤0.05).

Treatments	Mean tAUDPC	Number of sprays [a]	Waller Grouping
UTC	2.8	0	A
2d14hl	1.79	3	B
2d12hl	1.25	4	C
14D	1.1	4	C
2d10hl	0.97	4	C

[a] The spray treatments ended in at the end of August in 1999 because of the Hurricanes.

Table I.9: Separation of 1999 treatments effects in Lewiston, on the log transformed AUDPC (tAUDPC= log[AUDPC+1]) with the Waller-Duncan K-ratio t-Test (F Value = 34.94, Minimum Significant Difference = 0.32, and Critical Value of t = 1.8). Means with the same letter are not significantly different ($P \leq 0.05$). UTC = Untreated Control, 14D = 14 day schedule, 2d10hl, 2d12hl, 2d14hl = a daily index of 10, 12 and 14 respectively for the NC low model 2 days in a row.

Genotype	Mean AUDPC	Waller Grouping
NC 7	267	A
NC 11	251	A
NC 343	70	B

Table I.10: Separation of genotype effects in Lewiston, on the AUDPC in 1998 with the Waller-Duncan K-ratio t-Test (F Value = 4.29, Minimum Significant Difference = 153.56, and Critical Value of t = 2.052). Means with the same letter are not significantly different ($P \leq 0.05$).

Treatments NC 7	Mean Yield	Number of sprays [a]	Waller Grouping
UTC	2900	0	A
2d14hl	3535	3	B
2d12hl	3655	4	B
14D	3895	4	BC
2d10hl	4092	4	C

Table I.11: Yield comparison table for the 1999 treatments on NC 7 in Lewiston, with the Waller-Duncan K-ratio t-Test (F Value = 11.30, Minimum Significant Difference = 403, and Critical Value of t = 2.1). Means with the same letter are not significantly different ($P \leq 0.05$). UTC = Untreated Control, 14D = 14 day schedule, 2d10hl, 2d12hl, 2d14hl = a daily index of 10, 12 and 14 respectively for the NC low model 2 days in a row. Yields are expressed in kg/ha and standardized to 9% moisture.

Treatments NC 11	Mean Yield	Number of sprays [a]	Waller Grouping
UTC	3314	0	A
2d14hl	3838	3	B
14D	4001	4	B
2d12hl	4018	4	B
2d10hl	4172	4	B

Table I.12: Yield comparison table for the 1999 treatments on NC 11 in Lewiston, with the Waller-Duncan K-ratio t-Test (F Value = 6.47, Minimum Significant Difference = 408, and Critical Value of t = 2.21). Means with the same letter are not significantly different ($P \leq 0.05$). UTC = Untreated Control, 14D = 14 day schedule, 2d10hl, 2d12hl, 2d14hl = a daily index of 10, 12 and 14 respectively for the NC low model 2 days in a row. Yields are expressed in kg/ha and standardized to 9% moisture.

Year/Location	NC 11	NC 7	GP-NC 343
1997/Lewiston	3640	3103[a]	3997[b]
1998/Lewiston	3954	3590[a]	4548[b]
1998/Rocky Mount	3845	3726	3857
1999/Lewiston	3869	3616[a]	4387[b]
1999/Rocky Mount	4924[b]	4304	3910[a]

[a] Significantly lower yield than the two other genotypes for that year/location ($P \leq 0.05$).
[b] Significantly higher yield than the two other genotypes for that year/location ($P \leq 0.05$).

Table I.13: Yield comparison table. Yields are expressed in kg/ha and standardized to 9% moisture. Numbers represent the mean values across all spray treatments.

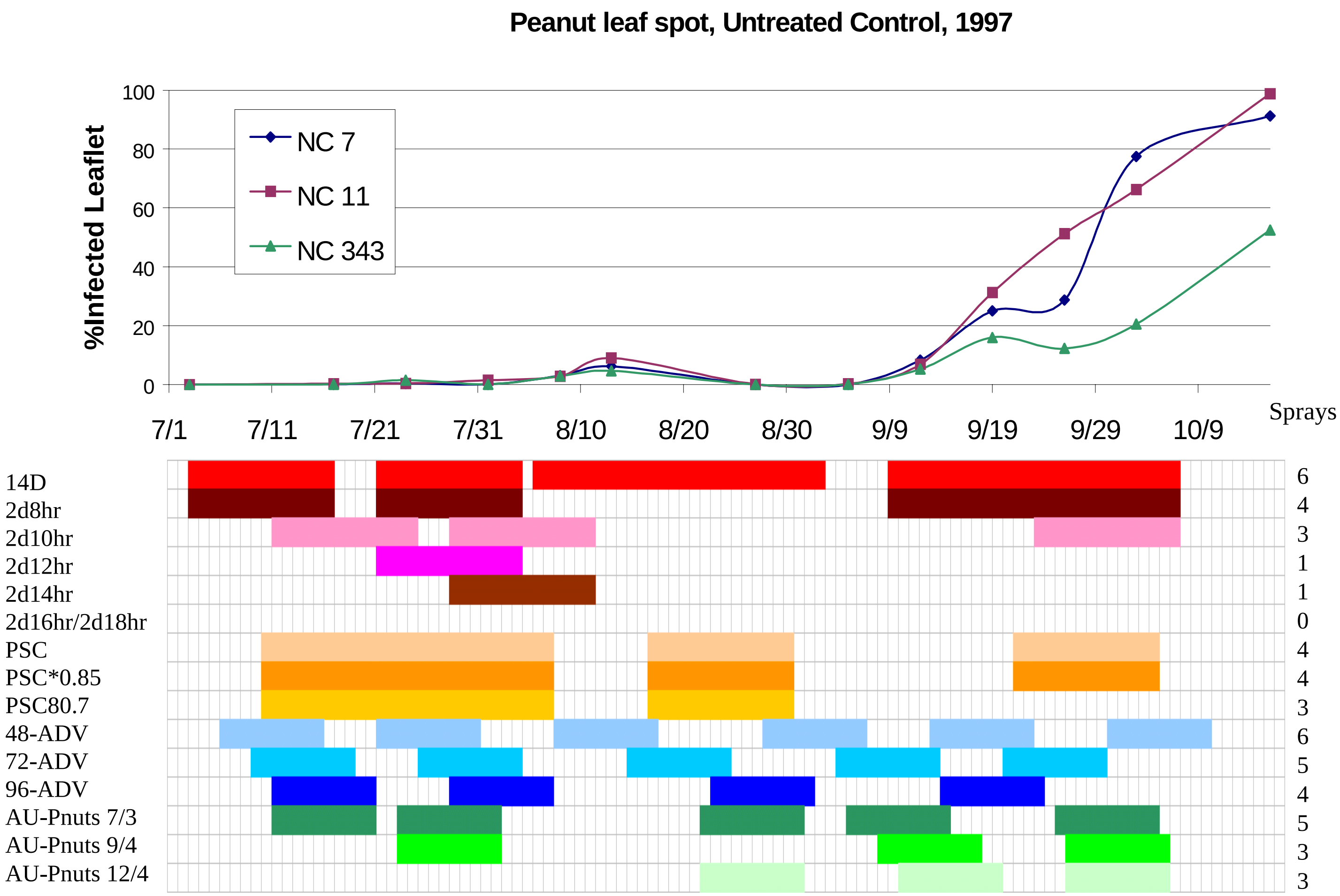

Fig. I.7: Comparative graph of the different fungicide spray schedules (1997): the bar represent the theoretical protection of the plants by the fungicides (14 days for the NC and PSC models and 10 days for the Virginia and AU-Pnuts models) before the advisory resume computation of favorable conditions to trigger sprays. 14D= 14 day schedule, 2d8hr, 2d10hr, 2d12hr, 2d14hr, 2d14hr, 2d16hr, 2d18hr = a daily index of 8, 10, 12, 14, 16, 18, respectively, for the NC regular model attained in 2 days in a row. The simulated advisories were: the Parvin Smith and Crosby PSC and its adaptation for resistance: PSC*0.85 and PSC*0.7, the Virginia advisory with a TDVi threshold of 48, 72 and 96, and the AU-Pnuts 7/3, 9/4 and 12/4 advisories.

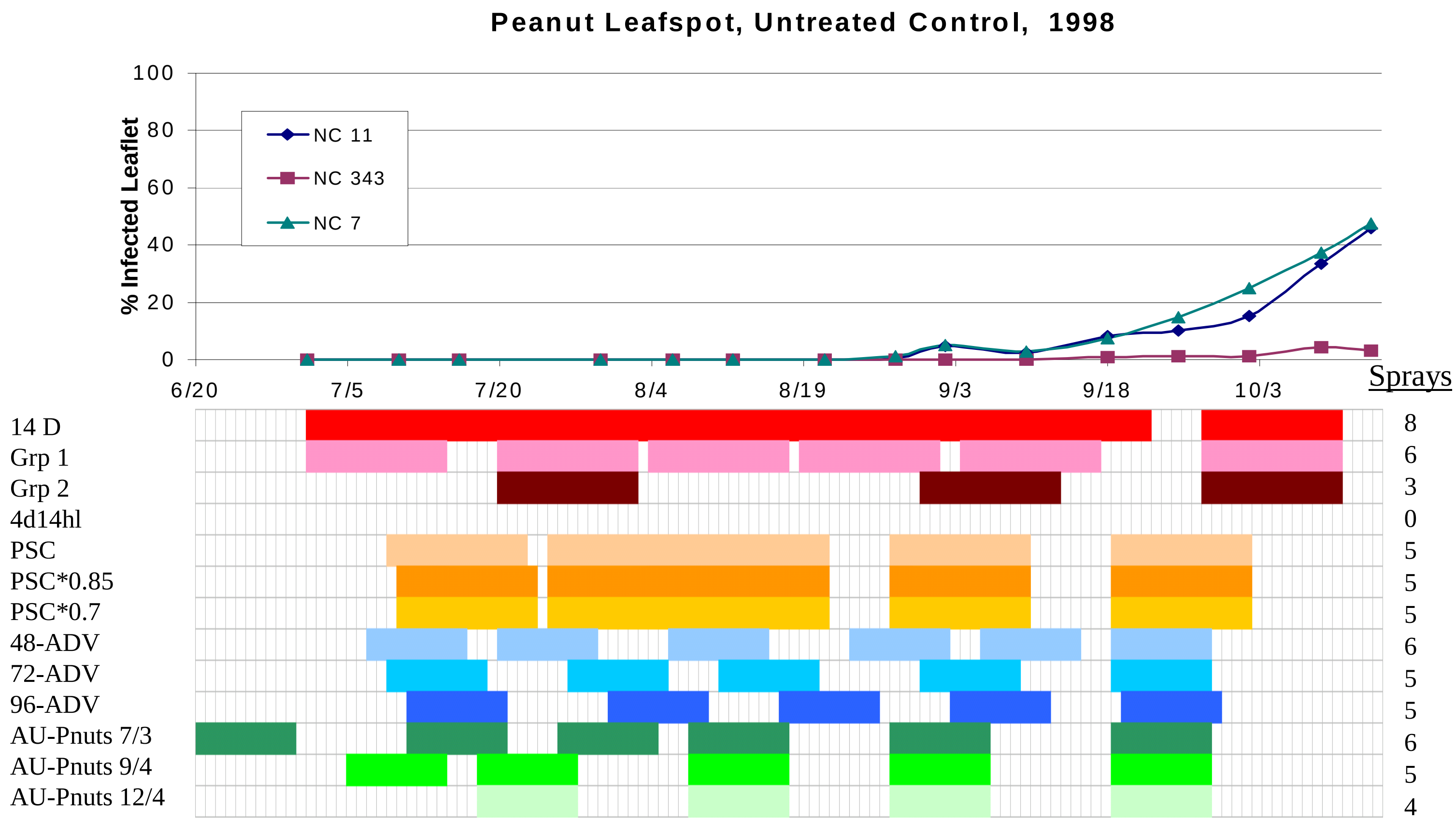

Fig. I.8: Comparative graph of the different fungicide spray schedules (1998): the bar represent the theoretical protection of the plants by the fungicides (14 days for the NC and PSC models and 10 days for the Virginia and AU-Pnuts models) before the advisory resume computation of favorable conditions to trigger sprays. 14D= 14-day spray schedule, Grp 1 = 2d12hl, 2d10hl, 2d10hr and 4d10hl, Grp 2= 2d14hr and 2d14hl, and UTC= Untreated control, 2d10hr and 2d14hr = a daily index of 10 and 14 respectively, for the NC regular model attained in 2 days in a row, 2d10hl, 2d12hl and 2d14hr= a daily index of 10, 12 and 14 respectively, for the NC low model attained in 2 days in a row, 4d10hl and 4d14hl= a daily index of 10 and 14 respectively, for the NC regular model attained in 4 days in a row. The simulated advisories were: the Parvin Smith and Crosby PSC and its adaptation for resistance: PSC*0.85 and PSC*0.7, the Virginia advisory with a TDVi threshold of 48, 72 and 96, and the AU-Pnuts 7/3, 9/4 and 12/4 advisories.

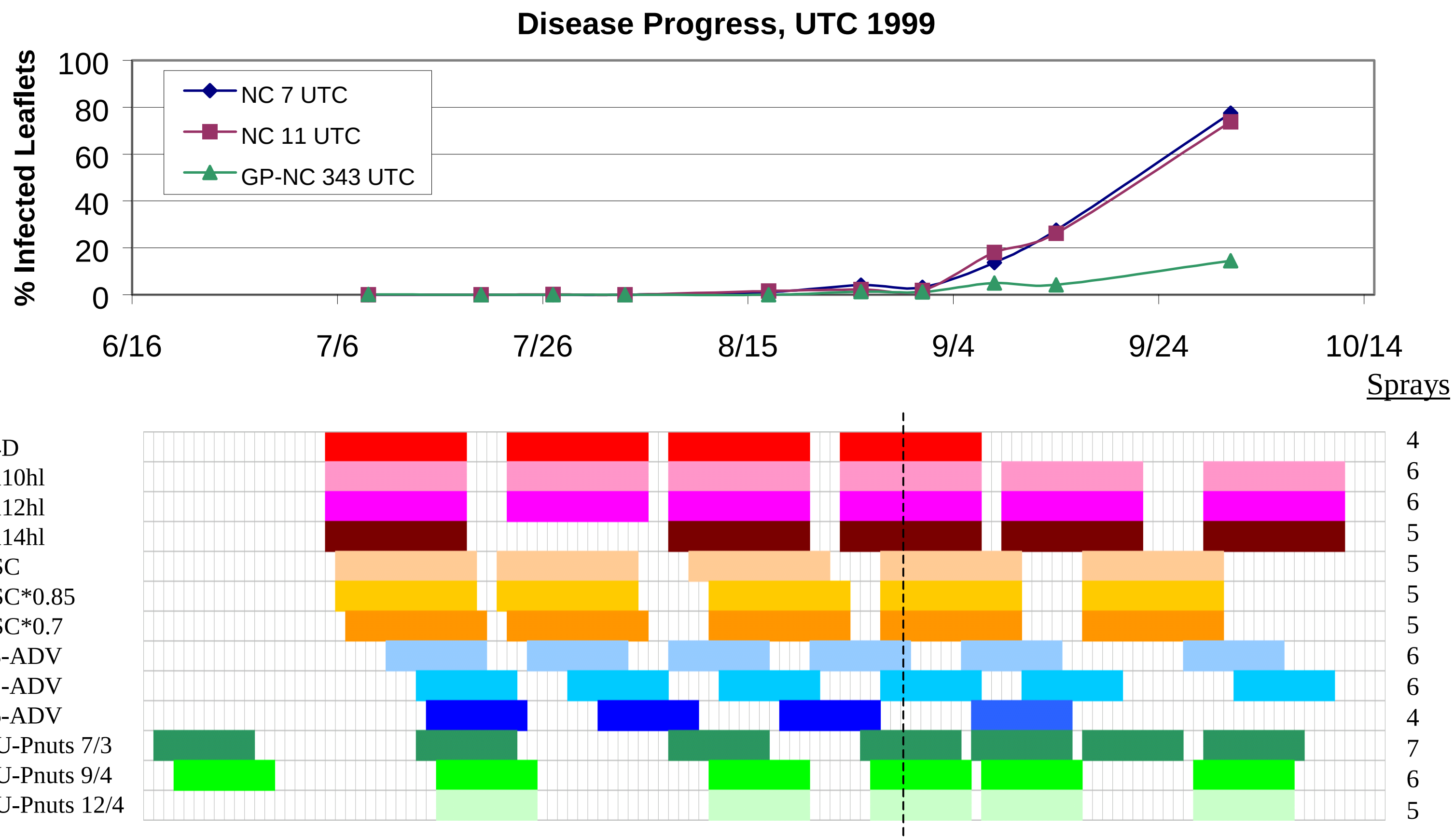

Fig. I.9: Comparative graph of the different fungicide spray schedules (1999): the bar represent the theoretical protection of the plants by the fungicides (14 days for the NC and PSC models and 10 days for the Virginia and AU-Pnuts models) before the advisory resume computation of favorable conditions to trigger sprays. 14D= 14-day spray schedule, 2d10hl, 2d12hl, and 2d14hl = a daily index of 10, 12 and 14 respectively for the NC low model 2 days in a row. The simulated advisories were: the Parvin Smith and Crosby PSC and its adaptation for resistance: PSC*0.85 and PSC*0.7, the Virginia advisory with a TDVi threshold of 48, 72 and 96, and the AU-Pnuts 7/3, 9/4 and 12/4 advisories. The dashed line represent the cut off date after which no fungicide application could have been made because of the water logged fields.

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Chapter II: Modeling the Vertical Spread of *Stagonospora nodorum* Epidemics on Winter Wheat

II. 1. Introduction

The Wheat Plant

Wheat is a staple food for nearly 40% of the world's population; it provides 20% of the world's food calories, and is a very important commodity in worldwide trade. Wheat is grown on approximately 20% of the cultivated land, mainly in the Northern Hemisphere, as a food crop and for animal alimentation (Wiese, 1987).

The center of origin for this crop is the Fertile Crescent in the Middle East. It is an annual grass and is very well adapted to well-drained clay-loamy soil and to arid/semi arid environments found in the Temperate Zone. The roots are fibrous and the height of the cultivated plants reach 1 m.

Wheat belongs to the genus *Triticum* L. in the grass family Gramineae. Modern *Triticum* spp. fall into groups based on their chromosome number: diploids (n=7), tetraploids (n=14), and hexaploids (n=21). Different ancestral parents contribute each group of seven chromosome pairs. The agronomically important wheats are: *Triticum aestivum* (hexaploid) and *T. durum* (diploid). The Soft Red winter wheat, a type of *T. aestivum* grown in Eastern USA, is sown in the fall, overwinters in a vegetative state, and resumes growth in the spring. Its flour is used primarily for cakes, cookies, pastries and crackers. Two hundred and thirty five thousand hectares of winter wheat are grown in North Carolina (National Agricultural Statistics Service, 1999).

Stagonospora nodorum (F.P.: *Phaeosphaeria nodorum* Muller)

Septoria glume blotch is caused by an ascomycete: *Phaeosphaeria nodorum* (E. Muller) Hedjaroude = *Leptosphaeria nodorum* E. Muller (anamorph *Stagonospora nodorum* (Berk.) Castellani & E. G. Germano = *Septoria nodorum* Berk.). Ascocarps (150-200μm) are immersed, globose, and mid-brown to black. Asci (47.5-65x8-10μm) are bitunicate, and cylindrical or curved. Ascospores (19.5-22.5x4μm) are fusoid, and subhyaline to pale brown, with three septae. Pycnidia are immersed, globose, honey-brown, becoming darker with age, and are 140-200 μm in diameter. Conidia (22-30x2.5-3μm) are hyaline, cylindrical, straight to sometimes irregularly curved with three septae, and obtuse at the base and apex (Sutton B. C. and J. M. Waterston, 1966). The pathogen is found in Africa, Asia, Australia, Europe, North America, and South America (Sutton, and Waterston, 1966).

Primary infections by *S. nodorum* occur in the fall. The fungus remains dormant in the leaves during the winter. Disease development resumes when temperature favors plant growth in the spring. Susceptible wheat cultivars may suffer 30-50% yield loss (Eyal, 1981). Lesions are lens shaped, initially appear water soaked, becoming dry, yellow, and finally red-brown. Necrosis extends well beyond the colonized cells because of the release of phytotoxins (Bousquet, et al. 1977). Infection of the flag leaf and the head result in greatest loss to the maturing plant as it reduces photosynthates for grain fill (Scharen, and Krupinsky, 1969, Scharen, and Taylor, 1968). Components of resistance to *S. nodorum* were classified by Jeger (Jeger, 1980) as resistance or tolerance of the plant to the fungal toxin, and reduction in fungal reproduction, growth, and establishment.

Ascospores often are airborne for long distances and are usually are most prevalent during late summer and autumn. These spores can serve as a primary sources of inoculum; however, mycelium and pycnidiospores in crop residue, seeds (Shah and Bergstrom, 1993, Shah, et al. 1995, Milus, and Chalkley, 1997), and overwinthering volunteer wheat are believed to play a more important role in primary infection (Babadoost and Herbert, 1984a, 1984b). Pycnidiospores remain viable for months (Scharen, A. L. 1964). Spores are exuded from pycnidia in a muscillaginous gel which protects them from radiation and desiccation (Scharen, 1966, Wiese, 1987). This muscillaginous material can delay germination at a high concentration or promote it at a low concentration (Rapilly and Skajennikoff, 1974). The speed and rate of germination depends on many factors. Requirements are: temperatures $\geq 5^oC$, relative humidity (RH)$\geq$98% and the muscillaginous gel concentration must be diluted in water. Conidia, produced in the pycnidia during wet periods, are disseminated by splashing rain onto other plant leaves, where they initiate new infections. In 1981, Jeger et al. found that conidia were mostly dispersed with rain. They also found that the minimum requirements for infection were RH at the time of inoculation $\geq$63%, a minimum temperature $\geq 6^oC$ the following 24 h, at least 4 h with RH $\geq$90%, and no more than 4 h with RH <60%. Infection required 6 to 16 h of wetness depending on wheat genotypes. Symptom severity and disease expression was highly dependent on environmental conditions; a prolonged wetness period enhanced both (Eyal, et al., 1977). Secondary spores (conidia emerging from the primary lesions) are produced 10 to 20 days after infection. Septoria glume blotch develops best between 20 and 27^oC. Weather conditions are a key factor in the development of *S. nodorum* epidemics. Wet windy weather favors epidemics; dry periods not only prevent infection but also halt the development of lesions and pycnidia (Wiese, 1987). Severe epidemics can develop in spite of an initially low inoculum density under highly favorable conditions (Shah et al. 1995).

In a 7-yr survey, Gilbert et al. (1998) determined that the severity of *S. nodorum* varied with years and rainfall. Within a year, prevalence *of S. nodorum* correlated positively with both rain and daily temperature, therefore, confirming results from previous studies (Leath et al. in 1993, and Djurle et al. in 1996). In a world-wide survey, *S. nodorum* was more prevalent in areas with a rainy, moist spring and more damaging when those conditions persisted until the heading stage (Leath et al 1993). Increased numbers of periods of leaf wetness events and their duration, estimated with rain events and intensity, were correlated with disease increase (Djurle et al. 1996).

Peters et al. (Peters et al., 1996) demonstrated the importance of the physiology of the crop (wheat) on the epidemiology of glume blotch; the number of leaves and rate of leaf emergence can greatly influence an epidemic in some years. As a general rule, early planted wheat plants were more likely to become more infected in the fall and sustain significantly more damage at the end of the season than late planted ones. However, in some years, the formation of an additional leaf, before the flag leaf, can compensate for the increased infection in the fall by delaying the emergence of the flag leaf until weather is warmer and drier in the spring. Thus, the flag leaf may escape infection and spread of the pathogen is prevented.

Disease management practices include sanitation (plowing or tillage) and rotation, but these methods provide only limited control. Fungicides currently used to control this disease are: azoxystrobin, mancozeb and propiconazole (Stromberg, 1999). Fungicide applications can be better timed after scouting. The time from spike emergence to harvest is usually the main period that disease increases in the upper four leaves of the culm (Shaner and Buechley, 1995). Although fungicide applications should be timed to protect the upper leaves and the head from *S. nodorum* (Eyal, 1981), no fungicides currently are labeled for use at heading. A biological decision model based on the average number of pycnidia on leaves was implemented in Germany by Verreet and Hoffmann in 1990. Treatment with fungicides was recommended to prevent yield reduction if the average number of pycnidia per leaf was ≥5 (Verreet and Hoffmann, 1990).

<u>Disease simulation models:</u>

Shearer and Zadocks (1972, 1974) conducted a series of experiments on *S. nodorum* to understand the relationship between latent period and temperature and humidity. They observed that an increase in temperature from 5 to 25^{o}C and an increase in the length of the period with high relative humidity resulted in a decrease in the latent period. They confirmed the results obtained in environment-controlled chambers (Shearer and Zadocks, 1972) in field experiments (Shearer and Zadocks, 1974). Equations were derived from these results that could eventually be used in a disease simulation model. EPISEPT is a simulation model conceived by Rapilly and Jolivet in 1976. EPISEPT is a detailed mechanistic model of dispersal (splashing), germination, incubation, and sporualtion. A crop growth model was not included, but a measurement of the crop canopy was made with a light meter and transformed into the Leaf Area Index (LAI) to give a value of the area susceptible to infection (Rapilly and Jolivet, 1976, Rapilly, 1979 and Jolivet, 1981)

Coupled plant growth and disease models have the advantage of allowing the investigators to infer a yield prediction and simulate economic benefits of disease control (Rouse, 1988). In 1991 Djurle and Yuen (Djurle and Yuen, 1991)published a simulation model for *S. nodorum* in winter wheat much like the disease module in the EPISEPT model. With more simplifying assumptions, it was then possible to use the model with standard daily weather data (rain, max, mean and min temperature, total solar radiation). The model structure includes a module for disease development (lesion development, lesion growth, spore production and dispersal), a module for crop growth and an interaction module. For example, leaf area influenced disease development and the disease module influenced the yield through the modeling of the necrotic area. However, validation this type of model is cumbersome.

<u>Objective</u>

Attempts to model glume blotch must account for crop growth, since infections on the upper leaves and the head has the greatest impact on yield. Mechanistic models encountered in the literature were developed in Europe climates (Djurle and Yuen, 1991, Rapilly and Jolivet, 1976). They require an array of weather inputs, which are not always available. It would be preferable to use a minimal data set, available at numerous sites, for the deployment of a model in NC. Another problem with these models is that they developed on different wheat cultivars and different climates (Djurle and Yuen, 1991, Rapilly and Jolivet, 1976). The empirical model developed by Verreet and Hoffmann

(Verreet and Hoffmann, 1990) is also probelmatic because it requires multiple scouting throughout the state every season. The aim of this work was to create a simulation model adapted for the climate of North Carolina Coastal Plains using only standard daily weather data (i.e. averages of temperature, rain, solar radiation), that, after validation, could be easily deployed over this region. The approach taken was to add a disease model to an existing crop growth model: the CERES-wheat model. Our model was validated by comparing its output data to those of field experiments. Its utility in determining the optimal spray timing was assessed by trying to find a relationship between the model output and the time of fungicide application which resulted in the best reduction in the area under the disease progress curve.

II. 1. 2. Materials and Methods/ Model design

Field experiment

Two genotypes, Saluda and Coker 9904 in the 1997-98 season, and Saluda and FFR555 in the 1998-99 season, were sown on 13 November 1997 and on 4 November 1998 at the Vernon James Research Station at Plymouth, NC. Plots (2x5m) were bordered with barley which is a non-host. The treatments were applied as a randomized complete block design with four replications in both years. Propiconazole (Tilt , Novartis Corp. Protection, Greensboro, NC) was applied at a rate of 48 g ai/ha with a CO_2 assisted spray boom mounted on a four-wheeler at 207 kPa with 8003 flat fan nozzles in 1998, and with a back pack sprayer at 172 kPa in 1999. Treatments were effected by spraying the plots at different dates throughout the growth of the plant in order to be able to determine the optimum treatment timing. For each fungicide-timing treatment the disease level and plant growth stage were recorded. In 1998, five fungicide treatments were applied, i) untreated control; ii) on 2 April (leaf sheaths lengthen), and on 29 April (flowering); iii) on 13 April (leaf sheaths strongly erected); iv) on 2 April (leaf sheaths lengthen); and v) on 29 April (flowering).

In 1999, eight different fungicide-timing treatments were applied: i) untreated control; ii) on 22 March (tillering), 12 April (first node visible), and 4 May (flowering); iii) on 22 March (tillering); iv) on 5 April (tillering); v) on 12 April (first node visible); vi) on 19 April (in boot); vii) on 27 April (flowering); and viii) on 4 May (flowering).

Disease Assessment

Disease assessments were made weekly in the middle of a 0.5m length of each plot (2x5 m) using the Saari and Prescott scale (1975). Assessments started on 2 April in 1998 and on 22 March in 1999 and continued until 2 weeks before harvest. The untransformed assessments were used for computing the Area Under the Disease Progress Curve (AUDPC; Shaner and Finney, 1977).

The simulation outputs were in percent area infected for each compartment of the model. As the Saari-Prescott scale is designed for assessing the severity on the highest infected leaves of the plant, comparisons were made using the higher infected compartment of the model only. To do so, the Saari-Prescott scale was transformed to the same disease scale as the model. The first digit of the Saari-Prescott scale, 0-3, was set equivalent to leaves of compartment 1, 4-7 were equivalent to compartment 2, 8 to the flag leaf compartment, and 9 to the head compartment. The transformation was then effected with the scale shown on Fig. II.1. Simulated results with a percent area infected <1% were treated as non-infected areas, because they would have not been observed by the average scout. Statistical analysis was performed using PROC GLM analysis with SAS (SAS Institute, Cary, Inc). A sensitivity analysis was conducted by varying each parameter with + or – 5% of their value and recording the change in the total disease for each compartment. The validation was effected with the genotype Coker 9904 in 1998 and FFR 555 in 1999 at Plymouth, NC by comparison of the model output to the field data.

The CERES-wheat model

The CERES-wheat model was used in this study to simulate wheat growth. It is a mechanistic model including the genetic potential of the plant, maturity requirements, nitrogen dynamics, and weather conditions (rain, temperature, and solar radiation). The output given can be daily leaf area index (LAI), or the different stages of the plant and yield (grain weight, total yield) (Ritchie and Godwin, 1999).

General model design

Our model was programmed in Matlab (the Mathwork Inc., Natick MA). Wheat leaf area was estimated by the CERES-wheat model (DSSAT v3.5 program, © IBSNAT, Honolulu). It was then separated into four compartments: the overwintering leaves, the two leaves below the flag leaf, the flag leaf, and the head. Compartment leaf areas and weather data were input into the disease model. The infected area was then accrued on a daily basis by the prediction of the upward infection (from one compartment to the compartment above), the downward infection (from one compartment to the compartment below) and the self-infection (from one compartment to itself) (Fig. II.1.).

Wheat growth/leaf area estimation

The CERES-wheat output simulated leaf emergence time as a function of the simulated wheat growth stage. A value for the area per leaf was obtained by regressing the number of leaves on the leaf area accumulated from the beginning of plant growth until the end of March. In the 1997-98 growing season the equation obtained was:

$$y = 0.2253x - 0.473 \ (R^2 = 0.9316) \qquad (1)$$

and in 1998-99 it was:

$$y = 0.3466x - 0.6938 \ (R^2 = 0.9143) \qquad (2)$$

were x is the number of leaves and y the estimated Leaf Area Index (LAI).

Compartment delimitation

Wheat growth was separated in four compartments for simplification. The first compartment included all the leaves emerged in the fall which overwintered, the second compartment included the two leaves below the flag leaf, the third compartment included only the flag leaf, and the fourth compartment included only the head (beginning of the growth stage 3 of the CERES-wheat model). Head density and its LAI area equivalent were assumed to be constant for both years and estimated at 0.0162.

Assumptions

The assumptions made for this model were that spores were only spread through rain-splash, the humidity necessary for sporulation was not limiting, lesions are not depreciated of spores during rain, spores are not washed off, spore release is proportional to the amount of rain falling, and spores can only be splashed to the same leaf level, the leaf level above and the level below.

Process Model

The infection processes modeled were: dispersal of the inoculum by splashing of rain onto sporulating lesions, infection of a non-diseased area, latent period, and lesion extension (Fig. II.2).

Equations

Splashing

Splashing represented the upward, downward, or lateral movement of a splashed droplet of water containing conidia. Infection probability was derived from the probability of a rain drop falling on a sporulating lesion, then splashing on healthy leaf area. Splash dispersal was considered to be a function of the infected sporulating leaf area, the healthy leaf area, and the amount of rain:

The equations used were:

$$IU(n)= [\ (a \times IS(n-1) + b \times IS(n) + c \times IS(n+1)) \times Splash \times NIS(n) \times C] \qquad (3)$$

And

$$Splash = (35.514 \times \ln(Rain)+3.0161) \times 10^4 \qquad (4)$$

With IU(n) equal to the Infectious Units for the leaf level n, IS(n) is the Infected Surface for the level n, NIS is the Non-infected Surface for the level n, and C is a correction factor.

The parameters a, b, c, and C were assigned the values 1/31, 1/3, 1-a-b, and C=0.000005, respectively, based on calibration. Calibration was effected by manually changing the value of the most sensitive parameters in 1998. Other values were inferred from the splashing rain studies of Rapilly and Jolivet (1976).

Infection

The model assumes that for a successful infection, relative humidity must be above 98% for 10 h within 5 days following the dispersal of spores (Rapilly and Jolivet, 1976).

Latent period

The latent period was inferred by a logarithmic regression on a data summary in Djurle and Yuen (1991).

The latent period ends when the cumulated <u>Lat</u> index reaches 5, with Lat equal to:

$$Lat=1/(-2.739*\ln(Temp)+9.7048) \quad \text{if} \quad 4^{o}C \leq Temp \leq 24^{o}C \qquad (5)$$

and

$$Lat = -1*(2.739*\ln(Temp)-9.7048) \quad \text{if} \quad 24^{o}C < Temp \leq 30^{o}C \qquad (6)$$

Otherwise the Lat index for the day is set to 0. Temp is the daily average air temperature.

Lesion Extension (m/day)

The lesion extension (m/day) was also inferred from summary data collected by Djurle and Yuen (1991). Between 4.7 and 20°C the lesion grows at a rate of:

$$B = \text{Lesion Growth} = (0.0401 * \text{Temp} - 0.1879) * 10^{-3} \quad (7)$$

And between 20 and 29.5°C (20°C included) at a rate of:

$$B = \text{Lesion Growth} = (-0.679 * \text{Temp} + 22.0064) * 10^{-3} \quad (8)$$

Above 29.5°C and below 4.7 and 20°C lesions do not grow.

II. 1. 3. Results and Discussion

Field Experiment

Less rain in the spring of 1999 made conditions less favorable for glume blotch than in 1998. There was a leaf rust (*Puccinia recondita* f. sp. *tritici*) epidemic in 1998 and 1999. In 1999 rust was so severe on Saluda that disease assessments for *S. nodorum* couldn't be made accurately at the end of the season. Due to the rust epidemics, we felt that any yield decrease associated with *S. nodorum* was confounded with that of rust; consequently yield is not discussed further (Appendix II.1).

In 1998. only two treatments controlled glume blotch: treatment ii (2 and 29 April) and treatment iii (13 April) on both cultivars. These treatments had a significantly lower AUDPC than the untreated control (Table II.2a). In 1999, on FFR 555, fungicide treatments, which differed significantly from the untreated check, included treatment ii (22 March, 12 April and 4 May), treatment iii (22 March), treatment iv (5 April), treatment v (12 April), and treatment vi (19 April) (Table: II.2b). Treatments ii and v had a lower area under the disease progress curve than the others (F Value = 5.31 and t critical = 2.12891). Treatment vii (27 April, flowering), and treatment viii (4 May, flowering) did not reduce the area under the disease progress curve compared to the untreated checks.

Wheat growth model

The CERES-wheat model was run on each season's weather data. For the 1999 season it predicted a maximum leaf area of 6.17 compared to 4.03 for 1998. The regression estimation for leaf area in each compartment resulted in a total areas of 4.65 for 1999 and

2.68 for 1998 at the end of the growing season (Table II.3 and II.4). In 1999 the wheat growth model also predicted one more leaf formed underneath the flag leaf (16 leaves total instead of 15). The CERES-wheat model was developed in the Midwest. Adjustments to the code may be necessary in order to use it in North Carolina as the model may have assumed that leaf development would occur over a longer period of time, resulting in more leaf area than actually developed in our tests. Another possibility is that the effect of late spring freezes might be different in North Carolina than accounted for by the model (Ronnie W. Heiniger, 1999 personal communication).

Sensitivity analysis

The sensitivity analysis on the disease model showed that lesion growth, first lesion size, and downward infection parameters, had very little influence on the simulation output both years (Table II.5). The other parameters, which were related to rain spread of spores (upward, same level infection, and splash parameters) or the latent period, had a large influence (from 5 to 25 %) on the head compartment total model output. This influence was greater in the flag leaf and head compartment than with all the compartments summed together (Table II.5). This occured because the model predicts that the lower leaves become rapidly infected at the end of the winter. Most of the difference is explained by the upward spread of the disease.

Simulation results

The disease model was calibrated with the disease assessment data collected on Coker 9904 (its AUDPC was significantly higher than Saluda's but the disease progress curve followed very closely). The results of the prediction were then compared to the disease data from Saluda (Fig. II.3). The model over-predicted the occurence of the disease on the plant lower compartments (1, 2 and 3) until the end of May, perhaps because the lesions on the plant stayed dormant longer than expected. The same result was observed in 1999 (Fig. II.4) when a disease increase was first simulated at the end of March throughout the middle of April and then in May. The observed disease increased slowly from April to mid-May when the rate markedly increased.

We were not able to establish relationships between AUDPC and yield because of the rust problem encountered both years. This relationship should be investigated as the Saari-Prescott scale tends to emphasize infection on the upper parts of the plant, therefore inducing a bias in the analysis. For example, the higher up the plant the disease is present the higher the first digit of the assessment is: if the disease is present, in the middle of the plant, then the digit would be 5, if it is present on the head of the plant it would then be 9. The second digit in the scale indicates the severity of the disease at the level observed and has less influence on the AUDPC compared to the first digit.

The most effective spray timing to reduce the AUDPC was 13 April in 1998 and 12 April in 1999. This timing corresponded to a period when disease was first observed in the lower leaves, no disease was seen on the flag leaf, and simulated onset of disease on the flag leaf had occurred. This disease increase in the lower leaves took place 20 days after the disease increase was simulated by the model both years. A sharp simulated disease increase in the flag leaf compartment may be a very good indicator for a spray recommendation.

Combining a disease model to an already existing crop growth model facilitated modeling disease progress. Further work will be needed to fully validate both the CERES-wheat and the *S. nodorum* models in North Carolina.

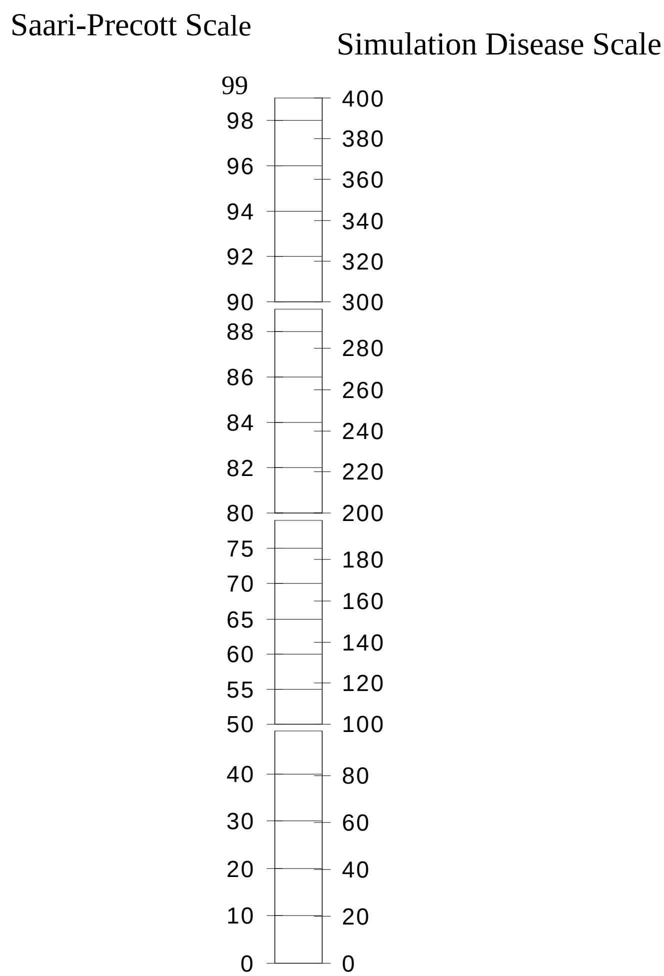

Table II.1: Conversion from the Saari-Prescott scale to the simulation disease scale. On the left the Saari-Prescott indexes are plotted and on the right the corresponding simulated disease scale is plotted. For the simulation disease scale, infection between 0 and 100 represents infection of the first leaf compartment, between 100 and 200 of the 2 leaves right below the flag leaf, between 200 and 300 of the flag leaf and between 300 and 400 of the head.

Treatments [a]	Treatment number	Plant growth stage	Mean [b] AUDPC	Waller Grouping [c]
untreated control	i		1859	A
29-April	v	flowering	1738	A
2-April	iv	leaf sheaths lengthen	1737	AB
13-April	iii	leaf sheaths strongly erected	1686	B
2 and 29 April	ii	leaf sheaths lengthen, flowering	1617	B

[a] Dates in which the fungicide treatment with Tilt was applied.
[b] Mean AUDPC across the repetitions
[c] Waller Duncan K-ratio separation for the fungicide treatments in 1998 (F= 4.36, critical value of T= 2.056, P≤0.05).

Table II.2a: Effect of fungicide timing on the AUDPC for 1998.

Treatments[a]	Treatment number	Plant growth stage	Mean [b] AUDPC	Waller grouping [c]
untreated control	i		1353	A
22-March	iii	tillering	1269	AB
4-May	viii	flowering	1268	AB
27-April	vii	flowering	1246	B
5-April	iv	tillering	1209	BC
19-April	vi	in boot	1176	BC
12-April	v	first node visible	1144	C
22 March, 12 April, 4 May	ii	tillering, first node visible, flowering	1110	C

[a] Dates in which the fungicide treatment with Tilt was applied.
[b] Mean AUDPC across the repetitions
[c] Waller Duncan K-ratio separation for the fungicide treatments in 1998 (F= 4.36, critical value of T= 2.056, P≤0.05).

Table II.2b: Effect of fungicide timing on the AUDPC for 1999

Date	Number of leaves on the plant (simulated)	Regressed total leaf area index (LAI)	Compartment separation
6-Nov-97	2	0.356	Leaf level 1
27-Nov-97	4	0.712	Leaf level1
21-Dec-97	6	1.068	Leaf level 1
11-Jan-98	8	1.424	Leaf level 1
4-Feb-98	10	1.78	Leaf level 1
25-Feb-98	12	2.136	Leaf level 1
3-Mar-89	13	2.314	Leaf level 2
15-Mar-98	14	2.492	Leaf level 2
24-Mar-98	15	2.67	Flag Leaf

Table II.3: Regression estimated leaf area, number of leaves and compartment separation for the simulated growth of winter wheat in Plymouth NC during the 1997-98 season (CERES-wheat). The Leaf level 1 represents the lower leaves on the plant, the leaf level 2 represents the 2 leaves right below the flag leaf, and then the flag leaf level represent the flag leaf.

Date	Number of leaves on the plant (simulated)	Regressed total leaf area index (LAI)	Compartment separation
17-Nov-98	2	0.5797	Leaf level 1
2-Dec-98	4	1.1594	Leaf level1
17-Dec-98	6	1.7391	Leaf level 1
16-Jan-99	8	2.3188	Leaf level 1
31-Jan-99	10	2.8985	Leaf level 1
18-Feb-99	12	3.4782	Leaf level 1
14-Mar-99	14	4.0579	Leaf level 2
1-Apr-99	16	4.6376	Flag Leaf

Table II.4: Regression estimated leaf area, number of leaves, and the compartment separation for the simulated growth of winter wheat in Plymouth NC during the 1998-99 season (CERES-wheat). The Leaf level 1 represents the lower leaves on the plant, the leaf level 2 represents the 2 leaves right below the flag leaf, and then the flag leaf level represent the flag leaf.

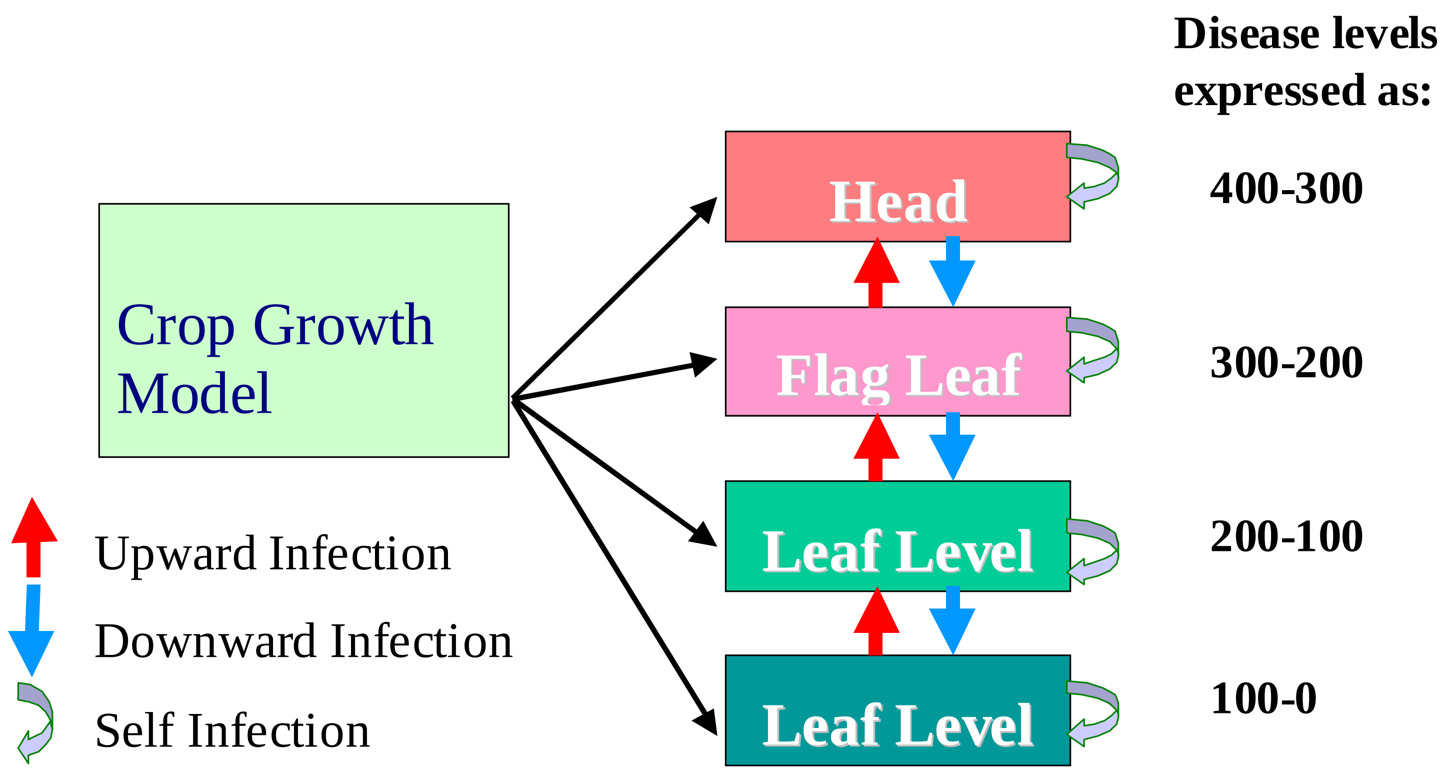

Figure II. 1: Disease Process modeled with disease scale for the simulated output on the right. The crop growth model simulates the different compartment areas, then the disease model simulate the spread of spores between the different leaf compartments. For the simulated disease scale infection between 0 and 100 represent infection in the first leaf compartment, between 100 and 200 of the 2 leaves right below the flag leaf, between 200 and 300 of the flag leaf and between 300 and 400 of the head.

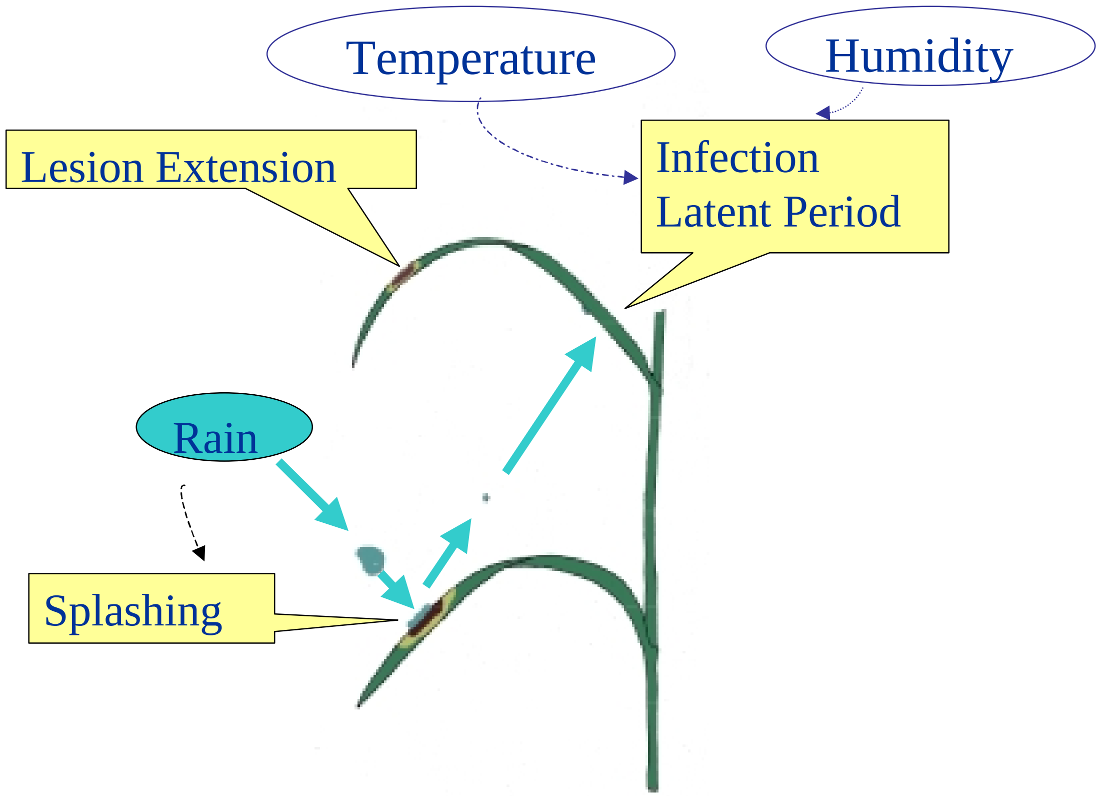

Figure II.2: Infection Processes modeled; rain splashes infectious droplets on healthy tissue that then becomes infected (if the weather conditions are favorable) and after the latent period become itself infectious. The increase in size of the lesions is also modeled. Rain, temperature and humidity are very important for the requirements of those different infection processes.

Parameters	1998						1999					
	Total		Flag leaf		Head		Total		Flag leaf		Head	
	+5%	-5%	+5%	-5%	+5%	-5%	+5%	-5%	+5%	-5%	+5%	-5%
Lat	2.64	-1.86	8.50	-11.67	20.25	-25.23	2.65	-7.13	4.45	-10.41	10.38	-26.01
B	0.03	-0.03	0.24	-0.24	0.31	-0.31	0.03	-0.03	0.12	-0.12	0.29	-0.31
e	1.01	-1.46	4.24	-4.46	5.83	-6.17	2.11	-2.00	4.05	-3.81	8.45	-7.96
First lesion size	0.41	-0.42	1.37	-1.39	2.45	-2.34	0.72	-0.72	1.20	-1.21	2.61	-2.65
h	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
g	0.61	-0.66	5.89	-5.95	12.77	-11.81	0.94	-0.93	3.59	-3.54	12.53	-11.72
Splash	1.66	-2.11	10.46	-10.19	19.29	-17.52	3.14	-2.84	7.96	-7.05	22.16	-18.59
Latent period threshold (5 days)	-1.53	2.64	-11.57	8.50	-25.19	20.25	-7.13	2.65	-10.41	4.45	-26.01	10.38

Table II.5: Sensitivity analysis results for 1998 and 1999. The different parameters used in the model were varied by ± 5% of their value. The result given is in percent of the simulated AUDPC for the the total infected area, the flag-leaf compartment and the head compartment. Lat: Latent value index, B (Lesion growth, m/day), e (same level infection), First lesion size (0.0005 m/m^2), h (Downward infection coefficient) g (Upward infection), Latent period threshold (normal value of 5 days), Splash (number of splash droplet per mm of rain).

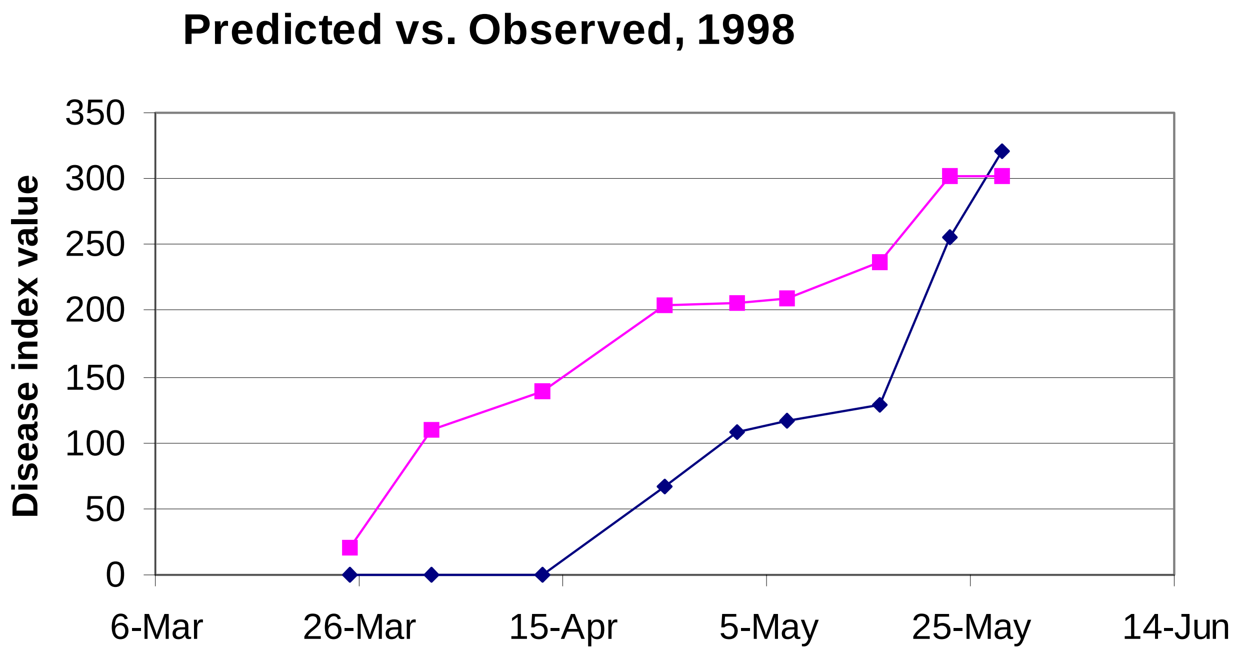

Figure II.3: Simulated disease (predicted –■–) compared to field assessments (–◆–) in 1998, Plymouth, NC.

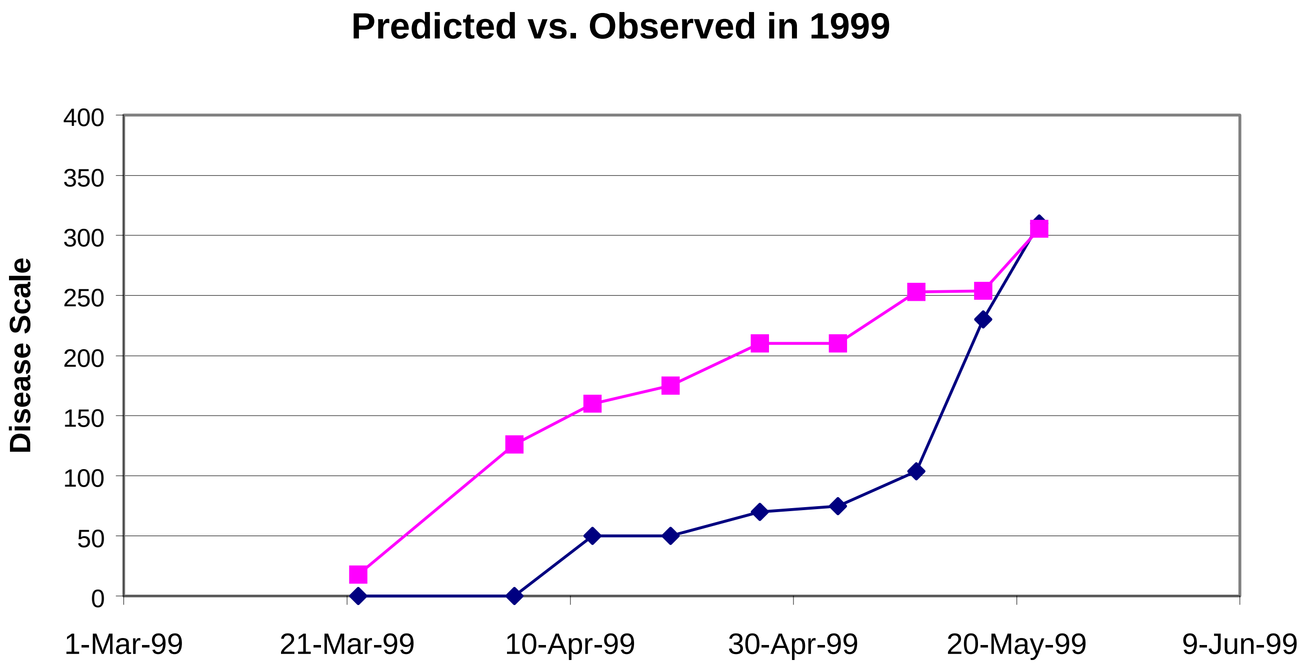

Figure II.4: Simulated disease (predicted –■–) compared to field assessments (–◆–) in 1999, Plymouth, NC.

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Appendices

Peanut yields, kg/ ha in Lewiston 1997.

Block	Treatment	NC 7	NC 11	GP-NC 343
1	10h	2675	3894	4578
1	12h	2378	3805	3805
1	14d	2735	3538	4638
1	14h	2943	3775	4251
1	16h	2824	3389	4013
1	18h	2735	3627	4043
1	8h	2586	4162	3746
1	u	.	3835	4697
2	10h	3894	3532	4162
2	12h	2646	4132	4013
2	14d	3716	4221	4102
2	14h	2735	3716	4756
2	16h	2824	3894	4310
2	18h	3835	3567	4132
2	8h	4400	4638	4132
2	u	3181	3448	5054
3	10h	3062	4043	3775
3	12h	3270	3716	3686
3	14d	3002	4340	4310
3	14h	3448	3478	4162
3	16h	3062	3211	4102
3	18h	2854	2943	4281
3	8h	4132	4073	3567
3	u	3448	4073	4756
4	10h	2616	3092	3508
4	12h	2794	3151	4459
4	14d	2913	3181	3597
4	14h	3627	2646	3401
4	16h	2884	2467	3686
4	18h	3151	3300	3329
4	8h	2943	2973	4578
4	u	2557	2557	2973

Appendix I.1: Peanut yields (adjusted for 9% moisture) for 1997 in Lewiston (kg/ha); u = untreated control, 10h, 12h, 14h, 16h, 18h, and 8h are the different thresholds models of the North Carolina advisory, and 14d is the 14 day schedule.

Peanut yields, kg/ ha in Lewiston 1998.

Rep	Treatment	NC 11	NC 343	NC 7
1	14D	4238	4970	4026
1	2d10hl	4036	5033	4026
1	2d10hr	4137	4561	3139
1	2d12hl	3767	4498	3651
1	2d14hl	3430	4027	3719
1	2d14hr	3767	4813	3412
1	4d10hl	4574	4404	3207
1	4d14hl	2489	4404	3173
1	UTC	4708	4656	4367
2	14D	4137	4907	3753
2	2d10hl	4708	4656	3685
2	2d10hr	4204	4845	3548
2	2d12hl	4574	5411	3992
2	2d14hl	4103	4090	2695
2	2d14hr	4137	4090	3412
2	4d10hl	5381	5474	3617
2	4d14hl	2825	4373	3276
2	UTC	3834	5285	3003
3	14D	3834	4058	4777
3	2d10hl	3195	5159	4606
3	2d10hr	3733	3901	4299
3	2d12hl	4170	4624	3003
3	2d14hl	4238	4404	3548
3	2d14hr	3430	4467	4094
3	4d10hl	4574	4467	3378
3	4d14hl	4507	5159	4094
3	UTC	4238	4152	3139
4	14D	3767	3901	3480
4	2d10hl	4305	4876	2764
4	2d10hr	3565	5159	4367
4	2d12hl	2960	4845	2388
4	2d14hl	4103	4404	2730
4	2d14hr	4439	3460	3548
4	4d10hl	4305	3775	4026
4	4d14hl	2892	4907	3890
4	UTC	3061	3523	3412

Appendix I.2: Peanut yields (adjusted for 9% moisture) for Lewiston 1998 in kg/ha. UTC = untreated control, 2d or 4d represent the number of consecutive days the index thresholds have to be met for a spray advisory to be issued, 10h, 12h, 14h, represent the threshold for the daily index, r and l represent the regular or low advisory NC advisory, and 14D is the 14 day schedule.

Peanut yields, kg/ ha in Rocky Mount 1998.

Block	treatment	NC 11	NC 7	GP-NC 343
1	UTC	3269	2648	4643
1	14D	3484	3521	4505
1	2d10hr	4776	5118	4190
1	2d10hl	3578	3985	3574
1	4d10hl	4655	3003	3876
1	2d12hl	4372	4640	3511
1	2d14hr	5031	2852	4593
1	2d14hl	4682	5487	4882
1	4d14hl	4049	3508	3674
2	UTC	3350	3125	3712
2	14D	4399	3453	4203
2	2d10hr	3471	3562	3423
2	2d10hl	3834	4654	3712
2	4d10hl	4413	3849	3599
2	2d12hl	4036	3876	3007
2	2d14hr	4063	4163	4417
2	2d14hl	3336	3671	3750
2	4d14hl	3592	4613	3876
3	UTC	3673	3357	3687
3	14D	4184	2812	3561
3	2d10hr	3498	4395	3548
3	2d10hl	3323	3235	3976
3	4d10hl	3700	3289	3838
3	2d12hl	3901	3262	3385
3	2d14hr	3605	3016	3838
3	2d14hl	3363	3658	3209
3	4d14hl	3753	4190	3674
4	UTC	3350	3044	3725
4	14D	3686	4258	4215
4	2d10hr	3457	4436	3775
4	2d10hl	4251	3125	4341
4	4d10hl	4466	3467	3397
4	2d12hl	3161	3071	3762
4	2d14hr	3753	4245	3146
4	2d14hl	3834	3426	4933
4	4d14hl	3094	4149	3712

Appendix I.3: Peanut yields (adjusted for 9% moisture) for Rocky Mount 1998 in kg/ha. UTC = untreated control, 2d or 4d represent the number of consecutive days the index thresholds have to be met for a spray advisory to be issued, 10h, 12h, 14h, represent the threshold for the daily index, r and l represent the regular or low advisory NC advisory, and 14D is the 14 day schedule.

Peanut yields, kg/ ha in Rocky Mount 1999.

Repetition	Treatment	NC 7	NC 11	GP-NC 343
1	14D	4501	5073	4268
1	2d10hl	4795	5176	4488
1	2d12hl	4305	4936	3552
1	2d14hl	3881	4868	3800
1	UTC	4632	5382	3992
2	14D	3686	4730	3882
2	2d10hl	3979	4216	3166
2	2d12hl	4142	4868	4213
2	2d14hl	4175	3599	3084
2	UTC	3620	4319	3937
3	14D	4305	4765	4102
3	2d10hl	4827	5622	4571
3	2d12hl	4990	5210	3717
3	2d14hl	4436	5622	3965
3	UTC	4305	4696	3910
4	14D	4110	5073	4378
4	2d10hl	4012	5073	3579
4	2d12hl	4762	5210	3882
4	2d14hl	4762	5005	4185
4	UTC	3849	5039	3524

Appendix I.4: Peanut yields (adjusted for 9% moisture) for Rocky Mount 1999 in kg/ha. UTC = untreated control, 14D = 14 day schedule, the index thresholds has to be met 2 consecutive days for a spray advisory to be issued, 10h, 12h, 14h, represent the threshold for the daily index for the low NC advisory.

Peanut yields, kg/ ha in Lewiston 1999.

Repetition	Treatment	NC 7	NC 11	GP-NC 343
1	14D	3775	3709	4534
1	2d10hl	4393	4396	4858
1	2d12hl	3535	3846	4534
1	2d14hl	3226	3434	3984
1	UTC	2608	3434	4567
2	14D	3775	3984	4923
2	2d10hl	4153	4361	4275
2	2d12hl	3878	4396	4437
2	2d14hl	3501	4190	4534
2	UTC	3089	3366	4243
3	14D	3981	4327	4437
3	2d10hl	4256	4396	4470
3	2d12hl	4050	4258	4340
3	2d14hl	3981	4361	4243
3	UTC	2917	3297	4340
4	14D	4050	3984	3887
4	2d10hl	3569	3537	4502
4	2d12hl	3157	3572	4146
4	2d14hl	3432	3366	4243
4	UTC	2986	3159	4243

Appendix I.5: Peanut yields (adjusted for 9% moisture) for Lewiston in 1999 in kg/ha. UTC = untreated control, 14D = 14 day schedule, the index thresholds has to be met 2 consecutive days for a spray advisory to be issued, 10h, 12h, 14h, represent the threshold for the daily index for the low NC advisory.

Genotype Coker 9904

Plot #	Treat	Yields Kg/ha
8	A	2085
29	A	3049
34	A	3058
51	A	2891
1	B	3058
27	B	2937
41	B	3655
63	B	3570
7	C	3840
18	C	3970
40	C	3257
64	C	3794
3	D	2871
23	D	3248
45	D	3723
60	D	3394
5	E	3573
25	E	1625
36	E	3598
56	E	3625
14	F	3849
22	F	3147
46	F	2935
50	F	3081
2	G	3362
31	G	2539
44	G	3925
54	G	3577
13	H	3714
28	H	2960
39	H	2992
62	H	2955

Genotype Saluda

Plot #	Treat	Yields Kg/ha
6	A	2974
26	A	3122
48	A	2800
55	A	2606
10	B	3856
17	B	2763
33	B	3753
59	B	4366
15	C	4443
19	C	3913
35	C	4142
58	C	3719
16	D	4153
24	D	3287
42	D	4151
49	D	3685
12	E	4201
21	E	4581
61	E	4208
9	F	3077
30	F	2866
47	F	4281
57	F	3607
11	G	3831
32	G	3317
37	G	4432
52	G	5614
4	H	3904
20	H	4533
43	H	4135
53	H	4192

Appendix II.1: Yield results in Kg/ha from the 1997-1998 wheat experiment. Treatment A= untreated control, treatment H was sprayed on 29 April (flowering), treatment E was sprayed on 2 April (leaf sheaths lengthen), treatments B and C were sprayed on 2 April (leaf sheaths lengthen) and 29 April (flowering), and treatments D, F and G were sprayed on 13 April (leaf sheaths .strongly erected)

Genotype FFR555

Plot #	Treament	Yield Kg/ha
12	A	6345
17	A	4987
45	A	5669
56	A	5519
9	B	5555
22	B	5117
46	B	7141
55	B	6868
1	C	5239
25	C	4314
42	C	4642
63	C	5285
13	D	6844
19	D	6291
35	D	6299
49	D	6868
10	E	6994
23	E	5947
34	E	6734
59	E	5772
30	F	3772
36	F	6904
51	F	5432
5	G	7044
28	G	6007
48	G	5773
50	G	6121
6	H	4413
29	H	5705
44	H	6548
60	H	5513

Genotype Saluda

Plot #	Treament	Yield Kg/ha
15	A	3375
26	A	3101
47	A	3122
52	A	3273
2	B	6364
18	B	5582
43	B	5526
57	B	5125
3	C	4058
24	C	3618
37	C	4650
64	C	4240
16	D	5275
27	D	3731
41	D	4311
58	D	3769
11	E	4196
32	E	4024
38	E	4088
53	E	4293
7	F	4562
31	F	4482
40	F	4776
61	F	4819
4	G	4632
20	G	5408
39	G	4367
62	G	8764
14	H	5576
21	H	4378
33	H	4314
54	H	4322

Appendix II.2: Yield results in Kg/ha from the 1998-1999 wheat experiment in Plymouth NC. Treatment A= untreated control, B= fungicide spray on 22 March (tillering), 12 April (first node visible), and 4 May (flowering), C= spray on 22 March (tillering), D= spray on 12 April (first node visible), E= spray on 4 May (flowering), F= spray on 5 April (tillering), G= spray on 19 April (in boot), H= spray on 27 April (flowering).

Appendix II. 3: Weather data for 1998.

Year	Julian days	Mean Temp. (^oC)	Min. Temp. (^oC)	Max. Temp. (^oC)	Hours of RH≥98%	Rain (mm)
98	1	0	5.56	-5.56	0	0
98	2	5.83	14.44	-2.78	0	0
98	3	10	20	0	8	0
98	4	11.67	21.67	1.67	14	0
98	5	13.06	22.78	3.33	13	0
98	6	19.17	23.89	14.44	10	0
98	7	19.72	24.44	15	8	0.51
98	8	20	22.78	17.22	1	11.43
98	9	17.22	20	14.44	4	0
98	10	8.89	15	2.78	3	0
98	11	7.5	15	0	14	0
98	12	9.44	15.56	3.33	5	0
98	13	12.22	16.67	7.78	3	3.81
98	14	9.17	15.56	2.78	0	0
98	15	8.89	15.56	2.22	16	20.83
98	16	10.28	13.33	7.22	23	20.57
98	17	6.11	7.78	4.44	2	2.79
98	18	6.11	9.44	2.78	4	0.76
98	19	3.61	7.22	0	15	35.31
98	20	4.44	7.78	1.11	3	6.35
98	21	1.67	7.78	-4.44	0	0
98	22	4.44	9.44	-0.56	8	0
98	23	11.11	16.11	6.11	18	37.08
98	24	12.5	16.11	8.89	23	2.79
98	25	5	9.44	0.56	6	1.78
98	26	3.89	10.56	-2.78	10	0
98	27	8.61	13.33	3.89	9	5.84
98	28	9.72	14.44	5	7	26.92
98	29	10.56	15.56	5.56	0	0.76
98	30	8.89	15.56	2.22	7	0
98	31	5.28	11.11	-0.56	0	0
98	32	3.61	11.11	-3.89	0	0
98	33	6.67	15.56	-2.22	9	0
98	34	9.44	12.22	6.67	1	5.08
98	35	12.22	15	9.44	23	59.69
98	36	8.61	11.11	6.11	2	9.65
98	37	5	6.11	3.89	3	1.27
98	38	5.83	8.33	3.33	8	2.79

Year	Julian days	Mean Temp. (°C)	Min. Temp. (°C)	Max. Temp. (°C)	Hours of RH≥98%	Rain (mm)
98	39	5.28	6.11	4.44	0	3.81
98	40	6.67	11.11	2.22	0	0
98	41	7.22	14.44	0	3	0
98	42	12.22	18.33	6.11	2	0
98	43	15	17.78	12.22	0	13.97
98	44	8.89	16.11	1.67	0	0
98	45	5.28	8.33	2.22	0	0.76
98	46	5	9.44	0.56	0	0
98	47	6.67	11.67	1.67	5	1.27
98	48	15	18.89	11.11	6	45.72
98	49	14.44	20	8.89	0	0
98	50	13.89	19.44	8.33	1	0
98	51	11.39	17.22	5.56	9	2.03
98	52	10.56	15	6.11	0	0
98	53	8.33	16.11	0.56	2	0
98	54	11.67	17.22	6.11	4	8.89
98	55	9.72	14.44	5	0	2.54
98	56	12.5	17.22	7.78	0	0
98	57	10.56	18.33	2.78	0	0
98	58	11.67	20.56	2.78	9	0
98	59	18.06	22.78	13.33	18	3.05
98	60	16.11	23.33	8.89	13	0
98	61	15.56	22.78	8.33	9	0
98	62	9.17	15	3.33	0	0.51
98	63	6.39	11.67	1.11	0	0
98	64	7.22	15.56	-1.11	5	0
98	65	6.11	12.78	-0.56	6	0
98	66	13.06	18.33	7.78	2	1.27
98	67	16.11	19.44	12.78	14	16.51
98	68	20.83	23.33	18.33	0	21.59
98	69	15	22.78	7.22	0	0
98	70	3.89	9.44	-1.67	0	0
98	71	1.11	5.56	-3.33	0	0
98	72	1.94	10.56	-6.67	0	0
98	73	9.17	20	-1.67	0	0
98	74	11.11	19.44	2.78	0	0
98	75	5.83	12.22	-0.56	0	1.78
98	76	5	6.67	3.33	3	0
98	77	13.89	22.22	5.56	9	26.67
98	78	18.06	22.22	13.89	13	37.08
98	79	15	18.89	11.11	14	0.76
98	80	13.61	17.78	9.44	6	6.6

Year	Julian days	Mean Temp. (^oC)	Min. Temp. (^oC)	Max. Temp. (^oC)	Hours of RH≥98%	Rain (mm)
98	81	9.44	13.33	5.56	0	0.51
98	82	9.17	14.44	3.89	4	0
98	83	8.33	13.33	3.33	15	0
98	84	8.89	15	2.78	3	0
98	85	14.72	25.56	3.89	8	0
98	86	19.17	27.22	11.11	5	0
98	87	19.17	26.11	12.22	6	0
98	88	22.5	30	15	7	0
98	89	21.67	30	13.33	5	0
98	90	21.94	28.33	15.56	6	0
98	91	20.83	25	16.67	16	11.43
98	92	21.94	27.78	16.11	6	5.59
98	93	19.72	26.11	13.33	0	0
98	94	12.78	16.67	8.89	7	18.03
98	95	10.28	14.44	6.11	5	0
98	96	10.56	19.44	1.67	11	0
98	97	15.28	26.11	4.44	7	0
98	98	21.94	29.44	14.44	1	0
98	99	21.94	27.22	16.67	11	16.26
98	100	17.78	26.67	8.89	5	5.59
98	101	10.83	17.22	4.44	10	0
98	102	10.83	18.89	2.78	10	0
98	103	11.39	21.11	1.67	5	0
98	104	14.17	20	8.33	1	2.54
98	105	20.28	27.22	13.33	3	0
98	106	20.83	28.33	13.33	7	0
98	107	23.61	28.89	18.33	4	1.52
98	108	19.72	26.11	13.33	3	0
98	109	19.72	27.22	12.22	12	0
98	110	18.33	24.44	12.22	6	0
98	111	14.44	21.67	7.22	3	0
98	112	12.78	17.22	8.33	4	5.33
98	113	14.17	18.33	10	2	0
98	114	15.28	23.33	7.22	7	0
98	115	18.89	27.22	10.56	0	0
98	116	19.17	26.67	11.67	0	0
98	117	19.17	26.67	11.67	3	0
98	118	11.94	19.44	4.44	9	1.02
98	119	13.61	22.22	5	6	0
98	120	17.22	25.56	8.89	4	0
98	121	20.56	24.44	16.67	14	13.97
98	122	19.17	24.44	13.89	8	0

Year	Julian days	Mean Temp. (^{o}C)	Min. Temp. (^{o}C)	Max. Temp. (^{o}C)	Hours of RH≥98%	Rain (mm)
98	123	20.28	28.89	11.67	6	0
98	124	21.39	28.89	13.89	15	1.27
98	125	19.44	25	13.89	11	40.39
98	126	19.44	26.67	12.22	12	0
98	127	20.28	27.22	13.33	8	0
98	128	21.94	28.33	15.56	12	23.88
98	129	17.22	20.56	13.89	8	0.76
98	130	18.61	23.33	13.89	7	0
98	131	18.33	23.33	13.33	6	0
98	132	14.44	17.22	11.67	5	1.02
98	133	13.06	15	11.11	13	2.03
98	134	16.11	22.22	10	6	0.51
98	135	16.94	26.67	7.22	10	0
98	136	22.5	32.78	12.22	2	0
98	137	21.67	24.44	18.89	8	21.59
98	138	23.06	27.78	18.33	13	0
98	139	24.72	32.78	16.67	7	0
98	140	25.83	32.22	19.44	5	0
98	141	24.72	31.67	17.78	7	0
98	142	24.44	31.11	17.78	0	0
98	143	21.67	26.67	16.67	18	21.59
98	144	18.06	23.33	12.78	10	1.27
98	145	25.28	31.67	18.89	10	0
98	146	25.83	30.56	21.11	7	0
98	147	25.28	30.56	20	12	3.56
98	148	23.33	26.67	20	11	0
98	149	23.61	31.11	16.11	11	0
98	150	26.39	33.33	19.44	9	0
98	151	25.83	32.22	19.44	8	0
98	152	27.22	31.67	22.78	4	0
98	153	23.61	30.56	16.67	9	0
98	154	26.11	35.56	16.67	5	0
98	155	26.39	35.56	17.22	8	23.11
98	156	23.33	26.67	20	13	1.27
98	157	20.83	23.89	17.78	17	12.19
98	158	18.33	23.33	13.33	8	0
98	159	17.78	25.56	10	9	0
98	160	20.83	25.56	16.11	8	0
98	161	23.61	29.44	17.78	13	5.59
98	162	24.17	28.89	19.44	13	0
98	163	27.78	33.89	21.67	12	5.59
98	164	27.22	32.78	21.67	12	2.03

Year	Julian days	Mean Temp. (^{o}C)	Min. Temp. (^{o}C)	Max. Temp. (^{o}C)	Hours of RH≥98%	Rain (mm)
98	165	25	32.78	17.22	6	14.22
98	166	26.94	32.78	21.11	10	8.13
98	167	28.61	33.33	23.89	2	1.27
98	168	27.78	33.33	22.22	7	0
98	169	26.11	32.22	20	9	0

Appendix II. 4: Weather data for 1999.

Year	Julian days	Mean Temp. (^oC)	Min. Temp. (^oC)	Max. Temp. (^oC)	Hours of RH≥98%	Rain (mm)
99	1	2.78	8.33	-2.78	8	0
99	2	1.39	8.33	-5.56	0	0
99	3	12.78	19.44	6.11	7	16.26
99	4	3.61	8.33	-1.11	3	0
99	5	-2.5	1.67	-6.67	2	0
99	6	-2.5	4.44	-9.44	8	0
99	7	6.39	13.33	-0.56	6	0
99	8	6.94	12.78	1.11	17	0
99	9	14.17	20.56	7.78	13	0
99	10	6.94	16.11	-2.22	6	4.06
99	11	3.33	10.56	-3.89	3	0
99	12	7.78	17.22	-1.67	3	0
99	13	11.39	20	2.78	9	0
99	14	11.94	17.22	6.67	19	1.02
99	15	12.78	16.11	9.44	7	19.56
99	16	5.83	13.89	-2.22	13	0
99	17	8.89	17.78	0	13	0
99	18	14.44	21.11	7.78	17	8.38
99	19	11.39	20	2.78	11	8.89
99	20	10.28	18.89	1.67	12	0
99	21	13.06	21.67	4.44	14	0
99	22	14.17	23.89	4.44	18	0
99	23	18.33	23.89	12.78	17	0.25
99	24	16.67	20	13.33	23	28.96
99	25	12.22	17.22	7.22	7	1.27
99	26	9.72	15	4.44	6	0
99	27	10.28	20.56	0	14	0
99	28	17.5	23.33	11.67	0	0
99	29	15	20	10	1	0
99	30	7.78	12.78	2.78	5	0
99	31	7.22	12.78	1.67	0	0
99	32	8.06	13.89	2.22	5	0
99	33	15.28	20	10.56	20	9.4
99	34	11.67	18.89	4.44	13	0
99	35	12.5	17.22	7.78	13	10.41
99	36	8.06	14.44	1.67	6	0
99	37	10	19.44	0.56	9	0
99	38	12.22	18.89	5.56	2	0
99	39	14.44	18.33	10.56	5	0

Year	Julian days	Mean Temp. (^oC)	Min. Temp. (^oC)	Max. Temp. (^oC)	Hours of RH≥98%	Rain (mm)
99	40	7.78	17.22	-1.67	15	0
99	41	15.28	21.11	9.44	10	0
99	42	10	21.11	-1.11	15	0
99	43	16.11	21.67	10.56	12	0
99	44	10.28	20.56	0	0	7.62
99	45	1.67	6.67	-3.33	4	0
99	46	4.17	13.89	-5.56	11	0
99	47	9.17	19.44	-1.11	4	0
99	48	13.33	22.22	4.44	11	0
99	49	13.06	17.78	8.33	23	17.78
99	50	8.61	11.67	5.56	4	0
99	51	6.39	10.56	2.22	8	3.05
99	52	4.17	8.33	0	0	0
99	53	0.56	3.89	-2.78	0	0
99	54	-0.28	3.89	-4.44	3	0
99	55	3.61	8.33	-1.11	1	0
99	56	4.44	8.89	0	8	0
99	57	5.56	11.11	0	12	0
99	58	7.78	18.33	-2.78	8	0
99	59	14.44	19.44	9.44	12	10.67
99	60	8.89	12.78	5	0	0
99	61	8.33	18.33	-1.67	8	0
99	62	13.61	23.89	3.33	10	0
99	63	11.67	20.56	2.78	0	6.1
99	64	5	11.11	-1.11	0	0
99	65	11.67	21.67	1.67	6	0
99	66	10.28	16.67	3.89	0	0
99	67	6.94	16.67	-2.78	4	0
99	68	0.83	6.11	-4.44	13	0.76
99	69	3.61	5.56	1.67	9	5.08
99	70	4.44	10.56	-1.67	0	0
99	71	5	11.67	-1.67	0	0
99	72	6.11	11.67	0.56	0	0
99	73	7.5	11.11	3.89	19	4.32
99	74	10.83	17.78	3.89	18	16
99	75	7.78	16.67	-1.11	3	0
99	76	14.17	25.56	2.78	4	0
99	77	17.78	26.67	8.89	0	0
99	78	15.28	25.56	5	3	0
99	79	9.72	16.67	2.78	4	0
99	80	10.83	17.22	4.44	14	6.86
99	81	10.83	16.11	5.56	8	7.87

Year	Julian days	Mean Temp. (^oC)	Min. Temp. (^oC)	Max. Temp. (^oC)	Hours of RH≥98%	Rain (mm)
99	82	9.72	19.44	0	10	0
99	83	16.94	25	8.89	10	0
99	84	16.11	22.22	10	7	0
99	85	8.89	13.33	4.44	12	18.03
99	86	5.56	8.89	2.22	5	10.67
99	87	11.94	19.44	4.44	2	0.51
99	88	12.78	22.78	2.78	8	0
99	89	12.5	20.56	4.44	2	0
99	90	11.11	21.11	1.11	11	0
99	91	18.06	25.56	10.56	16	2.54
99	92	20.56	24.44	16.67	13	0
99	93	17.22	23.89	10.56	13	0
99	94	21.11	30	12.22	11	0
99	95	19.44	27.78	11.11	4	1.78
99	96	12.5	21.67	3.33	7	0
99	97	16.11	28.89	3.33	1	0
99	98	23.61	30.56	16.67	8	0
99	99	23.33	30	16.67	10	0
99	100	20.83	28.89	12.78	10	10.67
99	101	15.28	22.22	8.33	19	10.92
99	102	16.39	22.22	10.56	6	0
99	103	11.39	18.33	4.44	5	0
99	104	11.67	21.67	1.67	6	0
99	105	16.11	22.22	10	1	0
99	106	18.61	24.44	12.78	4	0
99	107	15.83	23.33	8.33	0	0
99	108	11.11	18.89	3.33	4	0
99	109	11.67	21.11	2.22	10	0
99	110	16.67	25.56	7.78	5	0
99	111	14.72	24.44	5	9	0
99	112	23.06	32.78	13.33	6	0
99	113	25.28	31.67	18.89	0	0
99	114	21.39	30.56	12.22	3	0
99	115	11.39	21.11	1.67	8	0
99	116	15	22.78	7.22	13	0
99	117	19.17	22.22	16.11	6	3.56
99	118	13.89	17.78	10	10	5.33
99	119	11.11	13.33	8.89	8	5.84
99	120	11.94	14.44	9.44	0	1.52
99	121	11.67	13.89	9.44	3	1.02
99	122	11.39	12.78	10	16	7.11
99	123	15.28	20	10.56	7	4.57

Year	Julian days	Mean Temp. (°C)	Min. Temp. (°C)	Max. Temp. (°C)	Hours of RH≥98%	Rain (mm)
99	124	18.33	23.89	12.78	13	0
99	125	20.28	30	10.56	9	0
99	126	22.5	27.78	17.22	13	0.51
99	127	24.17	31.11	17.22	8	0
99	128	26.11	31.11	21.11	9	0
99	129	20.83	29.44	12.22	9	0
99	130	21.39	30	12.78	8	0
99	131	18.33	26.67	10	10	0
99	132	19.44	26.67	12.22	12	0
99	133	21.67	26.67	16.67	13	12.19
99	134	18.89	22.78	15	21	6.1
99	135	13.61	15	12.22	24	30.48
99	136	15.28	17.78	12.78	17	2.54
99	137	20	25	15	11	2.29
99	138	20.28	25.56	15	13	0
99	139	20	26.67	13.33	12	0
99	140	20	26.67	13.33	5	3.56
99	141	19.17	27.78	10.56	11	0
99	142	20.56	30.56	10.56	6	0
99	143	24.44	30.56	18.33	5	0
99	144	24.72	30.56	18.89	8	10.92
99	145	19.72	27.78	11.67	8	0
99	146	19.72	27.78	11.67	9	0
99	147	19.72	27.78	11.67	7	0
99	148	19.17	28.89	9.44	11	0
99	149	22.22	31.67	12.78	6	0
99	150	23.33	32.22	14.44	6	0
99	151	22.22	30.56	13.89	7	0

Appendix II. 5: Simulated leaf area for 1998.

Julian Days	Compartment 1	Compartment 2	Flag leaf	Head
1	1.068	0	0	0
2	1.246	0	0	0
3	1.246	0	0	0
4	1.246	0	0	0
5	1.246	0	0	0
6	1.246	0	0	0
7	1.246	0	0	0
8	1.246	0	0	0
9	1.246	0	0	0
10	1.246	0	0	0
11	1.424	0	0	0
12	1.424	0	0	0
13	1.424	0	0	0
14	1.424	0	0	0
15	1.424	0	0	0
16	1.424	0	0	0
17	1.424	0	0	0
18	1.424	0	0	0
19	1.424	0	0	0
20	1.424	0	0	0
21	1.424	0	0	0
22	1.424	0	0	0
23	1.602	0	0	0
24	1.602	0	0	0
25	1.602	0	0	0
26	1.602	0	0	0
27	1.602	0	0	0
28	1.602	0	0	0
29	1.602	0	0	0
30	1.602	0	0	0
31	1.602	0	0	0
32	1.602	0	0	0
33	1.602	0	0	0
34	1.602	0	0	0
35	1.78	0	0	0
36	1.78	0	0	0
37	1.78	0	0	0
38	1.78	0	0	0
39	1.78	0	0	0
40	1.78	0	0	0
41	1.78	0	0	0

Julian Days	Compartment 1	Compartment 2	Flag leaf	Head
42	1.78	0	0	0
43	1.78	0	0	0
44	1.78	0	0	0
45	1.78	0	0	0
46	1.78	0	0	0
47	1.958	0	0	0
48	1.958	0	0	0
49	1.958	0	0	0
50	1.958	0	0	0
51	1.958	0	0	0
52	1.958	0	0	0
53	1.958	0	0	0
54	1.958	0	0	0
55	1.958	0	0	0
56	2.136	0	0	0
57	2.136	0	0	0
58	2.136	0	0	0
59	2.136	0	0	0
60	2.136	0	0	0
61	2.136	0	0	0
62	2.136	0.178	0	0
63	2.136	0.178	0	0
64	2.136	0.178	0	0
65	2.136	0.178	0	0
66	2.136	0.178	0	0
67	2.136	0.178	0	0
68	2.136	0.178	0	0
69	2.136	0.178	0	0
70	2.136	0.178	0	0
71	2.136	0.178	0	0
72	2.136	0.178	0	0
73	2.136	0.178	0	0
74	2.136	0.356	0	0
75	2.136	0.356	0	0
76	2.136	0.356	0	0
77	2.136	0.356	0	0
78	2.136	0.356	0	0
79	2.136	0.356	0	0
80	2.136	0.356	0	0
81	2.136	0.356	0	0
82	2.136	0.356	0	0
83	2.136	0.356	0.178	0
84	2.136	0.356	0.178	0

Julian Days	Compartment 1	Compartment 2	Flag leaf	Head
85	2.136	0.356	0.178	0
86	2.136	0.356	0.178	0
87	2.136	0.356	0.178	0
88	2.136	0.356	0.178	0
89	2.136	0.356	0.178	0.0162
90	2.136	0.356	0.178	0.0162
91	2.136	0.356	0.178	0.0162
92	2.136	0.356	0.178	0.0162
93	2.136	0.356	0.178	0.0162
94	2.136	0.356	0.178	0.0162
95	2.136	0.356	0.178	0.0162
96	2.136	0.356	0.178	0.0162
97	2.136	0.356	0.178	0.0162
98	2.136	0.356	0.178	0.0162
99	2.136	0.356	0.178	0.0162
100	2.136	0.356	0.178	0.0162
101	2.136	0.356	0.178	0.0162
102	2.136	0.356	0.178	0.0162
103	2.136	0.356	0.178	0.0162
104	2.136	0.356	0.178	0.0162
105	2.136	0.356	0.178	0.0162
106	2.136	0.356	0.178	0.0162
107	2.136	0.356	0.178	0.0162
108	2.136	0.356	0.178	0.0162
109	2.136	0.356	0.178	0.0162
110	2.136	0.356	0.178	0.0162
111	2.136	0.356	0.178	0.0162
112	2.136	0.356	0.178	0.0162
113	2.136	0.356	0.178	0.0162
114	2.136	0.356	0.178	0.0162
115	2.136	0.356	0.178	0.0162
116	2.136	0.356	0.178	0.0162
117	2.136	0.356	0.178	0.0162
118	2.136	0.356	0.178	0.0162
119	2.136	0.356	0.178	0.0162
120	2.136	0.356	0.178	0.0162
121	2.136	0.356	0.178	0.0162
122	2.136	0.356	0.178	0.0162
123	2.136	0.356	0.178	0.0162
124	2.136	0.356	0.178	0.0162
125	2.136	0.356	0.178	0.0162
126	2.136	0.356	0.178	0.0162
127	2.136	0.356	0.178	0.0162

Julian Days	Compartment 1	Compartment 2	Flag leaf	Head
128	2.136	0.356	0.178	0.0162
129	2.136	0.356	0.178	0.0162
130	2.136	0.356	0.178	0.0162
131	2.136	0.356	0.178	0.0162
132	2.136	0.356	0.178	0.0162
133	2.136	0.356	0.178	0.0162
134	2.136	0.356	0.178	0.0162
135	2.136	0.356	0.178	0.0162
136	2.136	0.356	0.178	0.0162
137	2.136	0.356	0.178	0.0162
138	2.136	0.356	0.178	0.0162
139	2.136	0.356	0.178	0.0162
140	2.136	0.356	0.178	0.0162
141	2.136	0.356	0.178	0.0162
142	2.136	0.356	0.178	0.0162
143	2.136	0.356	0.178	0.0162
144	2.136	0.356	0.178	0.0162
145	2.136	0.356	0.178	0.0162
146	2.136	0.356	0.178	0.0162
147	2.136	0.356	0.178	0.0162
148	2.136	0.356	0.178	0.0162

Appendix II.6: Leaf area simulation for 1999.

Julian Days	Compartment 1	Compartment 2	Flag leaf	Head
1	2.02895	0	0	0
2	2.02895	0	0	0
3	2.02895	0	0	0
4	2.02895	0	0	0
5	2.02895	0	0	0
6	2.02895	0	0	0
7	2.02895	0	0	0
8	2.02895	0	0	0
9	2.02895	0	0	0
10	2.02895	0	0	0
11	2.02895	0	0	0
12	2.02895	0	0	0
13	2.02895	0	0	0
14	2.02895	0	0	0
15	2.02895	0	0	0
16	2.3188	0	0	0
17	2.3188	0	0	0
18	2.3188	0	0	0
19	2.3188	0	0	0
20	2.3188	0	0	0
21	2.3188	0	0	0
22	2.3188	0	0	0
23	2.3188	0	0	0
24	2.3188	0	0	0
25	2.60865	0	0	0
26	2.60865	0	0	0
27	2.60865	0	0	0
28	2.60865	0	0	0
29	2.60865	0	0	0
30	2.60865	0	0	0
31	2.8985	0	0	0
32	2.8985	0	0	0
33	2.8985	0	0	0
34	2.8985	0	0	0
35	2.8985	0	0	0
36	2.8985	0	0	0
37	2.8985	0	0	0
38	2.8985	0	0	0
39	2.8985	0	0	0
40	3.18835	0	0	0

Julian Days	Compartment 1	Compartment 2	Flag leaf	Head
41	3.18835	0	0	0
42	3.18835	0	0	0
43	3.18835	0	0	0
44	3.18835	0	0	0
45	3.18835	0	0	0
46	3.18835	0	0	0
47	3.18835	0	0	0
48	3.18835	0	0	0
49	3.4782	0	0	0
50	3.4782	0	0	0
51	3.4782	0	0	0
52	3.4782	0	0	0
53	3.4782	0	0	0
54	3.4782	0	0	0
55	3.4782	0	0	0
56	3.4782	0	0	0
57	3.4782	0	0	0
58	3.4782	0	0	0
59	3.4782	0	0	0
60	3.4782	0	0	0
61	3.76805	0	0	0
62	3.76805	0	0	0
63	3.76805	0	0	0
64	3.76805	0	0	0
65	3.76805	0	0	0
66	3.76805	0	0	0
67	3.76805	0	0	0
68	3.76805	0	0	0
69	3.76805	0	0	0
70	3.76805	0	0	0
71	3.76805	0	0	0
72	3.76805	0	0	0
73	3.76805	0.28985	0	0
74	3.76805	0.28985	0	0
75	3.76805	0.28985	0	0
76	3.76805	0.28985	0	0
77	3.76805	0.28985	0	0
78	3.76805	0.28985	0	0
79	3.76805	0.28985	0	0
80	3.76805	0.28985	0	0
81	3.76805	0.28985	0	0
82	3.76805	0.5797	0	0
83	3.76805	0.5797	0	0

Julian Days	Compartment 1	Compartment 2	Flag leaf	Head
84	3.76805	0.5797	0	0
85	3.76805	0.5797	0	0
86	3.76805	0.5797	0	0
87	3.76805	0.5797	0	0
88	3.76805	0.5797	0	0
89	3.76805	0.5797	0	0
90	3.76805	0.5797	0	0
91	3.76805	0.5797	0.28985	0
92	3.76805	0.5797	0.28985	0
93	3.76805	0.5797	0.28985	0
94	3.76805	0.5797	0.28985	0
95	3.76805	0.5797	0.28985	0
96	3.76805	0.5797	0.28985	0
97	3.76805	0.5797	0.28985	0
98	3.76805	0.5797	0.28985	0
99	3.76805	0.5797	0.28985	0
100	3.76805	0.5797	0.28985	0.0162
101	3.76805	0.5797	0.28985	0.0162
102	3.76805	0.5797	0.28985	0.0162
103	3.76805	0.5797	0.28985	0.0162
104	3.76805	0.5797	0.28985	0.0162
105	3.76805	0.5797	0.28985	0.0162
106	3.76805	0.5797	0.28985	0.0162
107	3.76805	0.5797	0.28985	0.0162
108	3.76805	0.5797	0.28985	0.0162
109	3.76805	0.5797	0.28985	0.0162
110	3.76805	0.5797	0.28985	0.0162
111	3.76805	0.5797	0.28985	0.0162
112	3.76805	0.5797	0.28985	0.0162
113	3.76805	0.5797	0.28985	0.0162
114	3.76805	0.5797	0.28985	0.0162
115	3.76805	0.5797	0.28985	0.0162
116	3.76805	0.5797	0.28985	0.0162
117	3.76805	0.5797	0.28985	0.0162
118	3.76805	0.5797	0.28985	0.0162
119	3.76805	0.5797	0.28985	0.0162
120	3.76805	0.5797	0.28985	0.0162
121	3.76805	0.5797	0.28985	0.0162
122	3.76805	0.5797	0.28985	0.0162
123	3.76805	0.5797	0.28985	0.0162
124	3.76805	0.5797	0.28985	0.0162
125	3.76805	0.5797	0.28985	0.0162
126	3.76805	0.5797	0.28985	0.0162

Julian Days	Compartment 1	Compartment 2	Flag leaf	Head
127	3.76805	0.5797	0.28985	0.0162
128	3.76805	0.5797	0.28985	0.0162
129	3.76805	0.5797	0.28985	0.0162
130	3.76805	0.5797	0.28985	0.0162
131	3.76805	0.5797	0.28985	0.0162
132	3.76805	0.5797	0.28985	0.0162
133	3.76805	0.5797	0.28985	0.0162
134	3.76805	0.5797	0.28985	0.0162
135	3.76805	0.5797	0.28985	0.0162
136	3.76805	0.5797	0.28985	0.0162
137	3.76805	0.5797	0.28985	0.0162
138	3.76805	0.5797	0.28985	0.0162
139	3.76805	0.5797	0.28985	0.0162
140	3.76805	0.5797	0.28985	0.0162
141	3.76805	0.5797	0.28985	0.0162
142	3.76805	0.5797	0.28985	0.0162
143	3.76805	0.5797	0.28985	0.0162
144	3.76805	0.5797	0.28985	0.0162
145	3.76805	0.5797	0.28985	0.0162
146	3.76805	0.5797	0.28985	0.0162
147	3.76805	0.5797	0.28985	0.0162
148	3.76805	0.5797	0.28985	0.0162
149	3.76805	0.5797	0.28985	0.0162
150	3.76805	0.5797	0.28985	0.0162
151	3.76805	0.5797	0.28985	0.0162
152	3.76805	0.5797	0.28985	0.0162
153	3.76805	0.5797	0.28985	0.0162
154	3.76805	0.5797	0.28985	0.0162

Appendix II.7: *Stagonospora* (*Septoria*) simulation model.

```
%%%%%%%%%%%%%%%%%%%%%%%%%%
%%                      %%
%%    Septoria Model    %%
%%                      %%
%%%%%%%%%%%%%%%%%%%%%%%%%%


%Open Weather and crop growth file.

fid = fopen('weat99.dat','rt'); %Read from data file.
data = fscanf(fid, '%f %f %f %f %f %f %f ', [7, 151])';
fclose(fid);

year=data(:,1);
t= data(:,2);
Temp= data(:,3);
Tmax = data (:,4);
Tmin = data (:,5);
RH=data(:,6);
Rain=data(:,7);

fid = fopen('leaf99.dat','rt'); %Read from data file.
data2 = fscanf(fid, '%f %f %f %f %f ', [5, 151])';
fclose(fid);

t=data2(:,1);
LAI1= data2(:,2);
LAI2= data2(:,3);
LAI3= data2(:,4);
LAI4= data2(:,5);

Dis1= zeros(151,1);
Dis2= zeros(151,1);
Dis3= zeros(151,1);
Dis4= zeros(151,1);

SI1= zeros(151,3); SI1(:,2)=t;
SI2= zeros(151,3); SI2(:,2)=t;
SI3= zeros(151,3); SI3(:,2)=t;
SI4= zeros(151,3); SI4(:,2)=t;

OldLL1= zeros(151,1);
OldLL1(7)=0.0005;
OldLL2= zeros(151,1);
OldLL3= zeros(151,1);
OldLL4= zeros(151,1);

New1= zeros(1,151);
```

```
New2= zeros(1,151);
New3= zeros(1,151);
New4= zeros(1,151);

NewL1= zeros(1,151);
NewL2= zeros(1,151);
NewL3= zeros(1,151);
NewL4= zeros(1,151);

LogOL1= zeros(1,151);
LogOL2= zeros(1,151);
LogOL3= zeros(1,151);
LogOL4= zeros(1,151);

IU1= zeros (151,3);
IU2= zeros (151,3);
IU3= zeros (151,3);
IU4= zeros (151,3);

B=zeros (151,1);
a=zeros (151,1);

%Latent growth rate depending on T, can make it differential for the
different leaf level
e=1/3;
g=1/31;
h=1-(1/3)-(1/31);
C=0.000005;
%Latent period threshold
Lat = 5;


for t =8:151 ;

%%%%%%%%% Estimate B in function of the temperature %%%%%%%%%%%%%%%


if ((Temp(t)>=4.7)&(Temp(t)<20))
 B(t)=(0.0401*Temp(t)-0.1879)*10^(-3);
 elseif ((Temp(t)>=20)&(Temp(t)<=29.5))
 B(t)=(-0.679*Temp(t)+22.0064)*10^(-3);
 else  B(t)=0;
 end;


%%%%%%%%%%% Estimate Rain Splashing factor %%%%%%%%%%%%%%%%%%%%%

if Rain(t)>0
%Splash= (6.19*Rain(t))*10^4;
Splash= (35.514*log(Rain(t))+3.0161)*10^4 ;
% Splash= 0.36*Splash;
```

```
else Splash=0;
end;


%%% Estimate a (latent period delay) in function of the temperature %%%

if ((Temp(t)>=4)&(Temp(t)<=24))
 a(t)=1/(-2.739*log(Temp(t))+9.7048);
 elseif ((Temp(t)>24)&(Temp(t)<=30))
 a(t)=(2.739*log(Temp(t))-9.7048)*(-1);
 else a(t)=0;
 end;

%%%%%%% Infectious Unit Dispersal (Dissemination) %%%%%%%%%%%%%%%%%


IU1(t,1)= (e* Dis1(t-1)*LAI1(t-1) +h* Dis2(t-1)*LAI2(t-1)) * Splash
*(LAI1(t-1)-Dis1(t-1)*LAI1(t-1))*C;
IU2(t,1)= (g* Dis1(t-1)*LAI1(t-1) +e* Dis2(t-1)*LAI2(t-1)+ h *
Dis3(t-1)*LAI3(t-1))* Splash * (LAI2(t-1)-Dis2(t-1)*LAI2(t-1))*C;
IU3(t,1)= (g* Dis2(t-1)*LAI2(t-1) +e* Dis3(t-1)*LAI3(t-1)+ h
*Dis4(t-1)*LAI4(t-1))* Splash *(LAI3(t-1)-Dis3(t-1)*LAI3(t-1)) *C;
IU4(t,1)= (g* Dis3(t-1)*LAI3(t-1) +e* Dis4(t-1)*LAI4(t-1))* Splash
*(LAI4(t-1)-Dis4(t-1)*LAI4(t-1))*C;


% Total pollution for a leaf level = Pollution from level below +
Pollution from above + pollution from same level
% Total Infectious Droplets for L1 = (1/3 * %Leaf area L * %Disease
below * %leaf area below * Splash * Rain (mm))
%       +(1/3 * %Leaf area L * %Disease L * %leaf area L * Splash *
Rain (mm))
%       +(1/3 * %Leaf area L * %Disease L+1 * %leaf area L+1 * Splash *
Rain (mm))
%      = IUL1 {n} (1)


%%%%%%%%%%%%% Infection %%%%%%%%%%%%%%%%%%%%%%%%%%%%%

%  Accumulation of hours of RH >=98%

for d= (t-5):t;


 if ((25>=Temp(t))& (Temp(t)>= 4))


IU1(d,3)= IU1(d,3)+ RH(t);
IU2(d,3)= IU2(d,3)+ RH(t);
IU3(d,3)= IU3(d,3)+ RH(t);
IU4(d,3)= IU4(d,3)+ RH(t);
```

```
 end;


IU1(d,2)= IU1(d,2)+ 1;
IU2(d,2)= IU2(d,2)+ 1;
IU3(d,2)= IU3(d,2)+ 1;
IU4(d,2)= IU4(d,2)+ 1;


%%%%%%%%%%%% Successful Infections %%%%%%%%%%%%%%%%

% The infection is successful if RH>=98% for 10 hours

if ((IU1(d,3) >= 10) & (IU1(d,1) >0))
SI1(t,1)= SI1(t,1)+ IU1(d,1);
end;

if ((IU2(d,3) >= 10) & (IU2(d,1) >0))
SI2(t,1)= SI2(t,1)+ IU2(d,1);
end;

if ((IU3(d,3) >= 10) & (IU3(d,1) >0))
SI3(t,1)= SI3(t,1)+ IU3(d,1);
end;

if ((IU4(d,3) >= 10) & (IU4(d,1) >0))
SI4(t,1)= SI4(t,1)+IU4(d,1);
end;

end;


%%%%%%Incubation/ Latent period is function of temperature %%%%%%%%%%%


for c= (t-t+1): t;

 if (SI1(c,1)>0)
 SI1(c,3)= SI1(c,3)+a(t);
 end;

 if (SI2(c,1)>0)
 SI2(c,3)= SI2(c,3)+a(t);
 end;

 if (SI3(c,1)>0)
 SI3(c,3)= SI3(c,3)+a(t);
 end;

 if (SI4(c,1)>0)
```

```
 SI4(c,3)= SI4(c,3)+a(t);
 end;

 if (SI1(c,3)>= Lat)
  New1(1,c)= SI1(c,1);
 end;

 if (SI2(c,3)>= Lat)
  New2(1,c)= SI2(c,1);
 end;

 if (SI3(c,3)>= Lat)
  New3(1,c)= SI3(c,1);
 end;

 if (SI4(c,3)>= Lat)
  New4(1,c)= SI4(c,1);
 end;

NewL1(1,t)= sum(New1(1,:));
NewL2(1,t)= sum(New2(1,:));
NewL3(1,t)= sum(New3(1,:));
NewL4(1,t)= sum(New4(1,:));

end;


% IncuL1{n}=[ SIL1 (1), days since infection , Accrued Temperature]
% for each hour add a number function of temperature
% if Accrued Temp is above 7
% then NewLesionL1{n}= 0.000005 * IncuL1{n} (1)
% and IncuL1{n}(1)=0
% unit=cm


%%%%%%% Disease Progression %%%%%%%%%%%%%%%%%%%%%%%%%%%


if Dis1(t-1)<1
 OldLL1(t)= OldLL1(t-1)*(1+B(t))+ NewL1(1,t);
 else OldLL1(t)= OldLL1(t-1);
end;
if Dis2(t-1)<1
 OldLL2(t)= OldLL2(t-1)*(1+B(t))+ NewL2(1,t);
 else OldLL2(t)= OldLL2(t-1);
end;
if Dis3(t-1)<1
 OldLL3(t)= OldLL3(t-1)*(1+B(t))+ NewL3(1,t);
 else OldLL3(t)= OldLL3(t-1);
end;
if Dis4(t-1)<1
```

```
 OldLL4(t)= OldLL4(t-1)*(1+B(t))+ NewL4(1,t);
 else OldLL4(t)= OldLL4(t-1);
end;

 if (LAI1(t)>0)
 if OldLL1(t)< LAI1(t)
 Dis1(t)= (OldLL1(t)/LAI1(t));
 else Dis1(t)=1;
 end;
 end;

 if (LAI2(t)>0)
 if OldLL2(t)< LAI2(t)
 Dis2(t)= (OldLL2(t)/LAI2(t));
 else Dis2(t)=1;
 end;
 end;
 if (LAI3(t)>0)
 if OldLL3(t)< LAI3(t)
 Dis3(t)= (OldLL3(t)/LAI3(t));
 else Dis3(t)=1;
 end;
 end;
 if (LAI4(t)>0)
 if OldLL4(t)< LAI4(t)
 Dis4(t)= (OldLL4(t)/LAI4(t));
 else Dis4(t)=1;
 end;
 end;

if OldLL1(t)>0
LogOL1(t)= log10(OldLL1(t));
end;

if OldLL2(t)>0
LogOL2(t)= log10(OldLL2(t));
end;

if OldLL3(t)>0
LogOL3(t)= log10(OldLL3(t));
end;

if OldLL4(t)>0
LogOL4(t)= log10(OldLL4(t));
end;


% erase the record in the potential infection if the infection was successful
% erase record if infection did not occur within 5 days

for d=(t-5):t;
```

```
 if ((IU1(d,3)>=10) | (IU1(d,2)>5))
IU1(d,:)= [ 0 0 0];
else IU1 (d,:)=IU1 (d,:);
end;

if ((IU2(d,3)>=10 ) | (IU2(d,2)>5))
IU2(d,:)= [ 0 0 0];
else IU2 (d,:)=IU2 (d,:);
end;

 if ((IU3(d,3)>=10) | (IU3(d,2)>5))
IU3(d,:)= [ 0 0 0];
else IU3 (d,:)=IU3 (d,:);
end;

 if ((IU4(d,3)>=10) | (IU4(d,2)>5))
IU4(d,:)= [ 0 0 0];
else IU4 (d,:)=IU4 (d,:);
end;

end;

%reset SI records to 0 if the Lat threshold has been reached

for c=(t-t+1): t;

if (SI1(c,3)>= Lat)
 SI1(c,:)=[0 0 0];
end;
if (SI2(c,3)>= Lat)
 SI2(c,:)=[0 0 0];
end;
if (SI3(c,3)>= Lat)
 SI3(c,:)= [0 0 0];
end;
if (SI4(c,3)>= Lat)
 SI4(c,:)= [0 0 0];
end;
end;

% reset New to 0

New1(1,:)= zeros(1,151);
New2(1,:)= zeros(1,151);
New3(1,:)= zeros(1,151);
New4(1,:)= zeros(1,151);

 end;
```