THE USE OF GENETICS AND CULTURAL PRACTICES TO SUPPRESS FOLIAR DISEASES OF PEANUT AND REDUCE FUNGICIDE REQUIREMENTS

by

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(Under the Direction of Albert K. Culbreath)

ABSTRACT

Peanut is affected by a number of plant pathogens that degrade the health of foliage, including *Cercospora arachidicola*, the cause of early leaf spot. The standard peanut production system in Georgia (the cultivar Georgia Green, conventionally tilled field, 14-day interval fungicide schedule) is relatively expensive and may be less profitable under the new market loan system than the previous quota program. Studies were conducted to characterize the effects of enhanced host resistance and strip-tillage on foliar disease epidemics of peanut and to utilize combinations of those factors with optimal applications of fungicides for integrated management of those diseases.

The onset of early leaf spot epidemics was delayed by approximately 12 days in strip-tilled plots compared to conventionally tilled plots as evidenced by fewer initial infections. The onset delay appears to be the result of fewer initial inocula, rather than the facilitation of a less favorable microclimate or induction of enhanced resistance. Less than half of disease suppression observed with strip-tillage could be attributed to the maintenance of surface residue,

while little to no effect was observed for pre-plant applications of glyphosate. Suppression of early leaf spot by strip-tillage was not consistently observed in fields planted to peanut in sequential years. Severity of a new leaf spot, Florida leaf spot (FLS), peaked around 50 DAP and decreased as the season progressed. This study provided no evidence that FLS is caused by a fungal or bacterial pathogen.

Components of resistance to *C. arachidicola*, monitored using inoculated detached leaves of Georgia Green, DP-1 and C-11-2-39, corroborated the ranking of resistance by these genotypes in the field. DP-1 and C-11-2-39 had lower infection frequencies, smaller lesion diameters and longer latent periods than Georgia Green. Integrated management of early leaf spot was comparable with 2 or 3 fewer fungicide applications to the standard system. In most cases, yields and net returns were comparable with 4, 5, or 7 applications of chlorothalonil. From these results, the integrated management of foliar diseases with enhanced host resistance and/or strip-tillage is feasible for reducing fungicide inputs, with minimal economic risk due to early leaf spot.

INDEX WORDS: Early leaf spot, Cercospora arachidicola, Tomato spotted wilt virus, Florida leaf spot, late leaf spot, Cercosporidium personatum, Epidemiology, Tillage, Host resistance, Integrated management

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CHAPTER 1

INTRODUCTION

Peanut is an extremely important crop in Georgia, with over 40% of domestic production occurring in the state. The industry contributes an estimated $1 billion to Georgia's economy each year, and supports over 250 companies dedicated to the industry, and an excess of 150,000 Georgians (Perdue, 2003). In 2004, peanut was planted to more than 600,000 acres across the state, with production exceeding 2 billion pounds of in-shell peanuts (Anonymous, 2004).

Peanut production in the U.S. changed from a supply management quota program to a market loan system with implementation of the 2002 Farm Bill (Smith, 2002). The new system established a minimum price for in-shell peanut with a price increase based on market demand. Two goals of this change were to enhance producer control over peanut marketing and to make U.S. peanuts more competitive with imported peanuts in the domestic market (Smith, 2002). However, economic risks for growers are often greater when supply and prices are not fixed. Since the economic shift, peanut acreage in Georgia has increased by 25%, while prices have decreased by 13.5% (Anonymous, 2004; Williams-Woodward, 2002; 2004). An economic review of standard peanut production practices employed during the quota system era is needed for the new market system since, depending on the peanut market price, production may not be profitable.

One of the single greatest production costs of peanut in Georgia is the use of fungicides to manage fungal pathogens (Williams-Woodward, 1999). Peanut is plagued by a number of fungal plant pathogens that can limit pod yields. These include *Cercospora arachidicola* S. Hori

and *Cercosporidium personatum* (Berk. & M. A. Curtis) Deighton, the cause of early and late leaf spot, respectively, *Sclerotium rolfsii* Sacc., the cause of stem rot, and *Rhizoctonia solani* (Kuhn), the cause of Rhizoctonia limb rot. Most of the fungicide use is for control of early and late leaf spot, with approximately $26 million spent solely on leaf spot management in 2003 (Williams-Woodward, 2004). Stem rot and limb rot are also managed with applications of fungicide, although the cost is typically not as great as that for leaf spot (Williams-Woodward, 2004). Two to four seasonal sprays are recommended for the combined management of stem rot and limb rot, while 6 to 8 sprays are common for leaf spot control (Kemerait et al., 2005). Fungicides applied for control of stem rot and limb rot must also provide control of leaf spot or be applied with fungicides that do.

Because of the significant cost of fungicide-based-management, it is evident that fewer fungicide applications per season could benefit many growers under the new market loan system. Ten years ago reduced spray programs were not feasible without risk to yield. However, they may be today. Epidemics of early leaf spot have been found to be less severe in fields prepared using strip-tillage, a conservation tillage system, than conventional deep-plow tillage (Monfort et al., 2004; Porter and Wright, 1991). The mechanism of disease suppression by strip-tillage is not understood; however, a 2-year field study demonstrated that 3 fewer applications of fungicides resulted in comparable management of early leaf spot in strip-tilled fields as 7 applications in conventionally tilled fields (Monfort et al., 2004). In addition, planting peanut cultivars with enhanced resistance to leaf spot has also been shown to require fewer applications of fungicide per season than susceptible cultivars (Culbreath et al., 1992c; Culbreath et al., 1992d; Gorbet et al., 1982; Gorbet et al., 1990; Smith et al., 1994).

Recently, several commercially available cultivars have been released with enhanced resistance to one or both leaf spot pathogens, as well as, enhanced resistance to spotted wilt caused by the tospovirus *Tomato spotted wilt virus* (TSWV) (Gorbet, 2003). Spotted wilt is one of the most important diseases of peanut in the southeastern U.S., with estimated losses exceeding $43 million in 1997 in Georgia alone (Bertrand, 1998). Strip-tillage also provides some suppression of spotted wilt. The integration of strip-tillage and enhanced resistance to early leaf spot and spotted wilt could provide enough natural disease suppression to allow use of reduced fungicide programs with minimal economic risk due to early leaf spot.

The overall objective of this dissertation research was to characterize the effects of enhanced host resistance and strip-tillage on foliar disease epidemics of peanut and to utilize combinations of those factors with optimal applications of fungicides for integrated management of those diseases. The following five sub-objectives were identified to meet this goal: (i) to characterize the nature and primary target of early leaf spot suppression by strip-tillage, (ii) to quantitatively measure the effects of cover crop residue and pre-plant herbicide use, two aspects common to strip-tillage, on the development of early leaf spot epidemics, (iii) to describe disease progression over time of Florida leaf spot (FLS), a new leaf spot of unknown etiology, and study the effects of tillage, genotype and pesticide chemistry on the severity of FLS; (iv) to examine the effect of enhanced host resistance on epidemic progression of early leaf spot over time in the field, and characterize components of resistance to *C. arachidicola* and *C. personatum* of current runner-type genotypes, and (v) to evaluate the economic implications of leaf spot and spotted wilt management with combinations of enhanced genetic resistance, strip-tillage and reduced fungicide programs.

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CHAPTER 2

LITERATURE REVIEW

Epidemiology and plant disease management. Plant disease development requires the presence of a virulent pathogen, a susceptible host and an environment conducive for infection. The variability and interaction of these three factors explains the amount of disease in a plant population and is modeled as the disease triangle (Agrios, 1997). The area within the triangle represents the amount of disease in a population of host plants. If a disease factor is altered, the corresponding triangle leg will change accordingly. For example, if leaf wetness favors disease development and the irrigation practice of a field is changed from overhead to soil-level drip, the environmental condition becomes less favorable for disease development and the environment leg is shortened.

Agronomic practices often affect one or more of the three components of the disease triangle. The factors altered by some practices are obvious, such as a decrease in initial inoculum due to crop rotation, decrease in host susceptibility by growing cultivars with disease resistance, or reducing pathogen viability with fungicide use. Effects of other practices are not always clear. For example, conventional tillage with a moldboard plow, once considered to be essential for reducing initial inoculum of soil inhabiting pathogens by burying crop debris, has been shown to have variable effects on disease epidemics (Bailey, 1996; Bockus and Shroyer, 1998; Everts, 2002).

Epidemics can be suppressed by a delay in onset of disease, a reduction in the rate of disease increase or a reduction in the duration of the epidemic. A delayed onset of disease is

most often associated with fewer initial infections that typically leads to a delay of the entire epidemic, while reduced epidemic rates are due to fewer secondary infections (Campbell and Madden, 1990). Epidemic variables derived using mathematical models that describe progress of disease over time can provide particular insight to help explain disease dynamics. For example, the rate of disease progression can be approximated by the rate parameter of models and time of disease onset can be estimated by solving for time when a low level of disease is set for the model. Studies designed to compare the effects of agronomic practices on epidemic variables, as well as host, pathogen, and environmental variables, can provide critical insights to predict or explain disease development within a production system, and enhance our biological understanding of pathosystems (Kranz, 2003).

Leaf spot of peanut. Early leaf spot, caused by *Cercospora arachidicola* S. Hori, (teleomorph = *Mycosphaerella arachidis* Deighton) and late leaf spot, caused by *Cercosporidium personatum* (Berk. & M. A. Curtis) Deighton, (teleomorph = *Mycosphaerella berkeleyi* Jenk.) are the most important foliar diseases affecting peanut (*Arachis hypogaea* L.) throughout the world (Shokes and Culbreath, 1997). The diseases are often found together or one disease may be more predominant in a given location or year. Predominance may vary over time within a location. In Georgia, late leaf spot was more common in the 1980s and early 1990s, while early leaf spot became the predominant leaf spot in much of Georgia during the late 1990s. However, late leaf spot has not disappeared from the southeastern United States. Late leaf spot is still predominant in Florida, and lately has increased in prevalence in Georgia. For this reason it is critical to evaluate the resistance of runner-type peanut genotypes, the type most widely grown throughout Georgia, Alabama, and Florida, to both early and late leaf spot pathogens. The term

leaf spot is used when early and late leaf spot are referred to as a single disease complex (Shokes and Culbreath, 1997).

Both leaf spot diseases begin as chlorotic specks that develop into circular lesions between 1 and 10 mm in diameter. Infections most often occur on leaves but can also appear on petioles, stipules, stems and pegs. Early leaf spot is distinguishable from late leaf spot by the color of the lesion on the abaxial surface and sporulation habit. On the underside of the leaf, early leaf spot lesions are lighter brown than late leaf spot, which are dark brown to black. Sporulation occurs on the adaxial side of early leaf spot lesions, and on the abaxial surface of late leaf spot lesions. Sporulation is often more profuse for late leaf spot. In cases where identification of the disease is questionable, the pathogens can be distinguished by microscopic examination of the shape of the conidia produced from sporulating lesions. Conidia of both species are olivaceous and obclavate, but conidia of *C. arachidicola* tend to be long (35 to110 μm), thin (3 to 6 μm), and most often curved, while those if *C. personatum* are typically shorter (20 to 70 μm), wider (4 to 9 μm), and most often straight (Shokes and Culbreath, 1997).

No alternative hosts have been documented for *C. arachidicola* or *C. personatum*. *Cercospora arachidicola* is considered a hemibiotroph of peanut because it induces cell death prior to cellular invasion, but cannot survive without peanut (Woodroof, 1933). *Cercosporidium personatum* is a biotrophic pathogen of peanut, utilizing haustoria to absorb nutrients from plant cells (Woodroof, 1933). Both fungi overwinter as stroma or mycelium on crop residue in the soil, which is often attributed as the primary source of initial inoculum. Primary infections usually occur on the adaxial surface of lower leaves, after a period of rain or continual leaf wetness (Smith and Littrell, 1980). Incubation and latent periods vary by peanut cultivar and environment, but may be as short as 10 and 18 days, respectively. Secondary inoculum is

produced on mature lesions after periods of extended leaf wetness, and temperatures above 19°C (Shokes and Culbreath, 1997). Alderman et al. (1987) reported a 3-day average RH > 90% as the best predictor for sporulation. Spores are released from lesions after rain, irrigation, or heavy morning dews, in greatest densities between sunrise and early afternoon (Alderman et al., 1987). Spore dispersal agents include water evaporation, rain splash, wind and insects (Shokes and Culbreath, 1997). Epidemics typically begin after plants begin to bloom, around 30 days after planting (DAP), since peanut shows some resistance to leaf spot during the vegetative phase (Miller et al., 1990). As epidemics progress, leaf spot symptoms typically appear in the upper canopy, and earlier infected leaflets abscise. Complete defoliation of susceptible cultivars is common when fungicides are not used and conditions are favorable for leaf spot development.

Most yield loss due to leaf spot is correlated with defoliation, likely in response to weakened geocarpophores, or pegs, which lead to detached pods at digging (Knauft et al., 1988). Peanut can tolerate some defoliation by leaf spot without significant reductions to yield. Tolerance thresholds near 35 to 40% defoliation were reported for the susceptible cultivar Florunner (Nutter and Shokes, 1995; Shokes and Culbreath, 1997). Pod losses of up to 50% are common where diseases are not controlled with fungicides (Smith and Littrell, 1980), and can be greater (Nutter and Shokes, 1995). For this reason, managing leaf spot is a top priority for growers.

Management of leaf spot. Most management practices for leaf spot target pathogen abundance or viability. Crop rotation reduces the amount of initial inoculum from overwintering debris, and applications of fungicide reduce the viability of inoculum prior to infection or eradicate the pathogen shortly after infection (Shokes and Culbreath, 1997). Until recently, deep tillage was recommended to reduce initial inoculum under the assumption that extensive tillage

separates infested debris from susceptible host tissues and encourages quicker degradation of plant debris. However, in fields rotated away from peanut for at least 1 year, deep tillage has been found to result in more severe early leaf spot epidemics than use of conservation tillage (Monfort et al., 2004; Porter and Wright, 1991).

Fungicide applications are used in most commercial production fields of peanut in the southeastern U.S for control of leaf spots and other foliar and soilborne peanut diseases. Over the past few decades, fungicides such as sulfur, copper fungicides, benomyl, fentin hydroxide, chlorothalonil, maneb, mancozeb (Smith and Littrell, 1980), propiconazole (Culbreath et al., 1995), tebuconazole (Bowen et al., 1997), azoxystrobin and pyraclostrobin (Culbreath et al., 2002) have been used for leaf spot control. These fungicides vary in their efficacy against leaf spot, cost, and potential for pathogen resistance. Chlorothalonil, a broad-spectrum fungicide, has been, and continues to be, one of the most widely used fungicides for leaf spot control. The current calendar-based program recommended by the University of Georgia Extension Service is to begin fungicide applications 30 to 40 days after planting (DAP), and to make subsequent applications at 14-day intervals until no later than 2 weeks before digging (Kemerait et al., 2004). This regime typically results in 6 to 8 applications of fungicides throughout the season.

There are fewer management options that target the susceptibility of the host or conduciveness of the environment. Resistant cultivars with good yield potential have been available since the release of the cultivar Southern Runner in 1986 (Gorbet et al., 1987), but has yet to be utilized on a large scale. Induced resistance of peanut to leaf spot by plant growth-promoting rhizobacteria (PGPR) or chemical elicitors, such as salicylic acid, acibenzolar S-methyl (Actigard), and DL-β-amino-n-butyric acid (BABA) has been inconsistent (Zhang et al., 2001), and does not appear to be an avenue of great potential. Management of environmental

favorability for disease development is limited. Overhead irrigation wets peanut leaves, which creates a more favorable environment for infection; but alternatives also have problems. Surface drip-irrigation is expensive and at risk of damage by digging equipment. Dry-land fields, without irrigation, often produce lower pod yields and have a greater risk for aflatoxin contamination of pods by *Aspergillus flavus* (Dorner et al., 1989).

Economics of peanut production and leaf spot control. Peanut production in the United States changed from a supply management quota program to a market loan system with implementation of the 2002 Farm Bill (Smith, 2002). The new system established a floor price for in-shell peanut with a price increase based on market demand. Two goals of this change were to enhance producer control over peanut marketing and to make peanuts produced in the United States more competitive with imported peanuts in the domestic market (Smith, 2002). However, economic risks for growers are often greater when supply and prices are not fixed. Since the economic shift, peanut acreage in Georgia has increased by 25%, while prices have decreased by 13.5% (Anonymous, 2004; Williams-Woodward, 2002; 2004). An economic review of standard peanut production practices employed during the quota system era is needed for the new market system since, depending on the peanut market price, production may not be profitable.

Fungicides for disease control represent one of the greatest single production costs for peanuts in Georgia. Nearly $40 million was spent on fungicides, over 10% of the crop value, in Georgia in 2003 (Williams-Woodward, 2004). Approximately 60% of the fungicide expense is solely used for leaf spot management (Williams-Woodward, 2004). Other diseases, such as stem rot, caused by *Sclerotium rolfsii* Sacc., and limb rot, caused by *Rhizoctonia solani* (Kuhn), are also managed with fungicide applications, although the cost is typically not as great as that for

leaf spot (Williams-Woodward, 2004). Two to four seasonal sprays are recommended for management of stem rot and limb rot combined, while 6 to 8 sprays are common for leaf spot management (Kemerait et al., 2004). In most cases, fungicide use for management of stem rot and limb rot also provide control of leaf spot diseases.

Because of the significant cost of fungicide-based-management, being able to provide good yields with fewer fungicide applications per season would benefit many growers, especially under the new market loan system. The estimated savings of each tractor-mounted fungicide application that can be eliminated is $5.80/ha in addition to the cost of the chemical (Smith, 2003b). Ten years ago, with the prevalent cultivars at that time, reduced fungicide programs would not have been feasible without yield loss. However, today they may. Early leaf spot epidemics have been shown to be less severe in fields prepared using strip-tillage, a conservation tillage practice, than fields prepared with conventional tillage (Monfort et al., 2004; Porter and Wright, 1991), and several commercially available cultivars have been released recently with enhanced resistance to one or both leaf spot pathogens (Gorbet, 2003). The integration of resistance with strip-tillage and suitable crop rotation could provide enough natural leaf spot suppression to allow use of reduced fungicide programs without increasing the risk of losses to leaf spot diseases.

Conservation tillage of peanut. The use of conservation tillage systems like strip-tillage for peanut production has increased over the past decade in reaction to lower crop prices, increased energy costs, and a reduced labor force (Johnson et al., 2001). A conventionally tilled field is worked multiple times using implements such as disk harrows, moldboard plows, rotor tillers, and bedders, to form a clean field and bed for planting. In a strip-tilled system, the winter cover crop is killed with an herbicide, such as glyphosate, and typically left as stubble in the

field. Thin strips, approximately 20 to 25 cm wide, are tilled with a subsoil shank for seedbed preparation. The estimated average variable cost (fuel, labor and machinery repairs and maintenance) of conventional deep plow tillage is $89/ha compared to $47/ha with strip-tillage (Smith, 2003b). In addition, savings of fixed costs associated with the purchase of equipment may be as high as $73/ha/yr for strip-tillage (Smith, 2003b).

Pod yields of peanuts grown under conservation tillage have been reported to be higher (Cheshire et al., 1985) or as high (Johnson et al., 2001) as yields from conventionally grown plants. However, inconsistencies in yields (Hartzog and Adams, 1989; Monfort et al., 2004; Sholar et al., 1993), or reduced yields (Grichar and Boswell, 1987; Grichar, 1998; Porter and Wright, 1991; Wright and Porter, 1995) have been noted by others. Yield losses are common for many crops planted to fields in their first few years of reduced tillage, and it is possible that the inconsistency in peanut yield response is similar. A 6-year study of peanuts grown in plots under continuous conventional or strip-tillage, demonstrated that the variability of yield in strip-tilled plots in Georgia, decreased as time into conservation tillage increased (Truman, 2004).

Tillage effects on leaf spot. As previously mentioned, early leaf spot epidemics have been shown to be less severe under strip-tillage than conventional tillage, at least for fields rotated away from peanut for at least 1 year (Monfort et al., 2004). It is not known whether this tillage effect occurs in fields under continuous peanut production. The response of late leaf spot to minimal tillage has not been experimentally tested; however, preliminary observations suggest that late leaf spot may also be suppressed by strip-tillage (Culbreath, personal communication).

Porter & Wright (1991) were the first to report less early leaf spot in peanuts grown under reduced tillage. Their study, conducted across 4 growing seasons in Virginia, demonstrated that leaf spot incidence, lesions per leaflet and percent defoliation were lower in band and in-row-

tilled plots than conventionally tilled plots. Monfort et al. (2004) corroborated these findings for peanut in strip-tilled plots in Georgia. Monfort found that throughout most of the season, early leaf spot was less severe in the strip-tilled plots than the conventionally tilled plots. However, by the end of the season, disease severity for those plots that were not treated with fungicide were statistically similar in both tillage treatments (Monfort, 2002).

Mechanism of leaf spot suppression by strip-tillage. The mechanism of early leaf spot suppression by strip-tillage is not known. Strip-tillage may create a less favorable environment for spore production or infection, enhance host resistance by increasing plant health or inducing resistance, or reduce pathogen abundance, dispersal or virulence. Visual comparisons of disease progress curves reported by Monfort (2002), based on Florida 1 to 10 scale ratings over time, appeared to delay epidemic development in strip-tilled plots, shift the curve to the right, rather than reduce the rate of epidemic progression. However, the Florida scale may not be appropriate for epidemic modeling since ratings are extremely subjective when disease levels are low, and the scale is not proportional to disease incidence or severity (Chiteka et al., 1988a).

Two standard practices associated with strip-tillage that typically are not employed in conventional tillage are pre-plant applications of the herbicide glyphosate to kill the cover crop and maintenance of cover crop residue at the soil surface. Both glyphosate and cover crop residues have been implicated as mechanisms of disease suppression for other pathosystems (Berner et al., 1991; Everts, 2002; Ristaino et al., 1997). Fungicidal activity of glyphosate have been documented for a wide range of fungi, including *Pyrenophora tritici-repentis* and *Stagonospora nodorum*, pathogens of wheat (Harris and Grossbard, 1979; Sharma et al., 1989), *Drechslera teres* of barley (Toubia-Rahme et al., 1995), and *Calonectria ilicicola* of soybean (Berner et al., 1991). Berner et al. (1991) demonstrated that pre-plant applications of low rates

of glyphosate suppressed red crown rot in soybean fields that relied on naturally occurring inoculum of *C. ilicicola* from microsclerotia in infested soils. Although there are no reports of glyphosate toxicity to *C. arachidicola*, negative effects on the germination of *C. arachidicola* conidia were reported for post-emergence application rates of lactofen, 2,4-DB, and acifluorfen herbicides, and sporulation of early leaf spot lesions was reduced on plants treated with lactofen and acifluorfen 1 week prior to inoculation with *C. arachidicola* conidia (Baysinger et al., 1999). Associations of cover crop residue and disease suppression has been shown for a number of pathosystems, including Phytophthora blight of bell pepper, caused by *Phytophthora capsici* (Ristaino et al., 1997), and two diseases of pumpkin, Plectosporium blight, caused by *Plectosporium tabacinum*, and black rot, caused by *Didymella bryoniae* (Everts, 2002). The mechanism of disease suppression by surface residue is thought for some pathosystems to be related to reduced rain splash dispersal of inoculum (Madden and Ellis, 1990; Madden, 1992, 1997; Ristaino et al., 1997). Addition of straw mulch to bare soil plots resulted in decreased rain splash dispersal of spores of *Colletotrichum acutatum*, the cause of anthracnose fruit rot of strawberry, and *Phytophthora cactorum*, the cause of strawberry leather rot, from inoculum sources placed at the soil surface, and decreased foliar disease severities in the field (Madden and Ellis, 1990; Madden, 1992). The same effect on splash dispersal and disease was found for *C. acutatum* in plots with a living sudangrass mulch (Ntahimpera et al., 1998) and for *P. capsici* by a herbicide-treated wheat cover crop (Ristaino et al., 1997).

Preliminary observations in the field do not rule out or implicate either glyphosate or cover crop residue as a mechanism of disease suppression by strip-tillage. Early leaf spot suppression by reduced tillage was observed for plots where the cover crop in both conservational tillage and conventional tillage was treated with glyphosate (Porter and Wright,

1991). However, conventional tillage following application of glyphosate may result in additional inoculum available for dispersal that was not exposed to glyphosate. In addition, suppression was observed for plots with low cover crop density due to cattle grazing (Monfort, 2002).

Resistance of peanut to leaf spot. There has been no complete or single-gene resistance to *C. arachidicola* or *C. personatum* reported in cultivated peanut. Instead, resistance is partial and rate-reducing (Abdou et al., 1974). Partial resistance is typically a function of multiple components of resistance that contribute additively to a reduction in the rate of epidemic progress (Parlevliet, 1979). Characterization of the components of resistance to early leaf spot (Foster et al., 1980; Green and Wynne, 1986; Melouk and Banks, 1984; Ricker et al., 1985) and/or late leaf spot (Chiteka et al., 1988a; Cook, 1981; Subrahmanyam et al., 1982; Walls et al., 1985; Watson et al., 1998) was described for many peanut genotypes under field and greenhouse conditions in the 1980s. However, relatively little work has been published for peanut cultivars and breeding lines developed within the past 20 years (Anderson et al., 1993; Aquino et al., 1995; Chiteka et al., 1997; Chiyembekeza et al., 1993), despite significant advances in breeding for leaf spot resistance during this time. Even less work has been conducted to investigate the resistance of genotypes to both leaf spot pathogens (Walls et al., 1985), even though the inheritance of resistance to each pathogen appears to be independent (Wynne et al., 1991).

Nearly all resistance components that have been investigated for early and late leaf spot are affected by genetic variation. These include infection frequency, incubation period (time from inoculation to symptom appearance), latent period (time from inoculation to first sporulating lesion), lesion size, percent necrotic leaf area, percent lesions with sporulation, spore production, and time to defoliation. Latent period, lesion size and spore production are the

components that have most commonly been associated with genetic resistance (Chiteka et al., 1988a; Chiteka et al., 1988b; Chiyembekeza et al., 1993; Walls et al., 1985). Infection frequency is highly dependent upon temperature and relative humidity (Shew et al., 1988; Waliyar et al., 1994), and has been suggested to be an unreliable measure of resistance for this reason (Ricker et al., 1985; Waliyar et al., 1993). Examination of multiple resistance components within resistance genotypes have shown that components are often correlated. For example, Jogloy, et al. (1987) and Chiteka, et al. (1988b) reported a positive genetic relationship between the size of late leaf spot lesions and the quantity of secondary spores produced, both of which were negatively correlated with latent period. However, no single component has been identified as a primary or consistent predictor of resistance in the field. The stability of resistance components to CA can vary across growing regions (Chiteka et al., 1997; Waliyar et al., 1993) due to environmental interactions (Shew et al., 1988; Waliyar et al., 1994), pathogen populations (Waliyar et al., 1993) or both (Chiteka et al., 1997). However, Shew et al. (1989) reported stable response of peanut genotypes to isolates of CP from the United States and Thailand.

History of runner-type cultivar resistance to leaf spot. Florunner, the industry standard runner-type cultivar from 1970 into the 1990s, was very susceptible to both leaf spot pathogens. Cultivars with partial resistance to leaf spot were not available to growers before the mid-1980s because components of resistance to leaf spot were often linked to late or indeterminate maturity and low pod yield (Gorbet et al., 1990). During this period, many breeding programs concentrated on combining commercially acceptable characteristics with resistance to leaf spot pathogens. The first runner-type cultivar with moderate resistance to CP was Southern Runner, released in 1986 by D.W. Gorbet at the University of Florida (Gorbet et al., 1987). Southern Runner had high yield potential, but matured approximately 2 weeks later

than Florunner and was not accepted by peanut shellers and processors (Smith et al., 1994). For these reasons, Southern Runner was not grown widely.

Genetic variation in the tolerance to defoliation by leaf spot has also been noted (Smith et al., 1994). Georgia Runner, a cultivar released by W.D. Branch at the University of Georgia (Branch, 1991), was shown to produce high yields despite high levels of leaf spot. Under an extended 28-day interval fungicide schedule, the mean leaf spot rating for Georgia Runner was 7.16 on the Florida 1 to 10 scale (77% defoliation), with a mean yield of 5453 kg/ha. Florunner had a similar mean leaf spot rating, 7.59 (83% defoliation), but yielded only 4056 kg/ha, while Southern Runner had less leaf spot, 6.69 rating (67% defoliation), and intermediate yield, 4673 kg/ha (Smith et al., 1994). The same leaf spot and yield trends for these cultivars were also observed in non-treated and 14-day interval fungicide treatments. Although Smith and his colleagues did not consider Georgia Runner a leaf spot resistant cultivar, they suggested that the ability of Georgia Runner to yield well despite significant leaf spot disease could help manage losses in heavy pressure years, or when fungicide applications were missed or activity failed.

In the late 1980s, tomato spotted wilt of peanut, caused by the tospovirus *Tomato spotted wilt virus* (TSWV), was observed in Georgia and quickly became one of the most potentially devastating diseases in the state (Culbreath et al., 2003). Florunner was very susceptible to TSWV (Culbreath et al., 1992b), and spotted wilt concerns eliminated Florunner as a viable peanut cultivar for production in Georgia. Georgia Runner was also susceptible to TSWV (Culbreath et al., 1996a), while Southern Runner was shown to be moderately resistant (Culbreath et al., 1992a). In breeding programs, cultivars and breeding lines were screened for resistance to TSWV, and various runner-type cultivars with levels of TSWV resistance similar to or better than Southern Runner were released. Georgia Green, developed by W.D. Branch at the

University of Georgia (Branch, 1996), had desirable agronomic characteristics and was among the genotypes with the best resistance to TSWV. In just a few years, Georgia Green replaced Florunner as the standard runner-type cultivar grown in the southeastern U.S. An estimated 85% of the acreage in Georgia was planted to Georgia Green in 2003 (Smith, 2003a).

The leaf spot resistance of Georgia Green is slightly better than that of Florunner (Culbreath, unpublished data). Since the release of Georgia Green, a number of cultivars have been released with equal or better resistance to TSWV and better resistance to one or both leaf spot pathogens, and often *S. rolfsii* or *R. solani*. These include Florida MDR-98 and C-99R, released in 1998 and 1999, respectively, with better resistance to CA (Cantonwine et al., 2002; Monfort et al., 2004) , CP (Gorbet and Shokes, 2002a, 2002b), TSWV (Culbreath et al., 1997a; Culbreath et al., 1997b; Culbreath et al., 1999; Culbreath et al., 2000; Gorbet, 1998; Wells et al., 2002), and *S. rolfisii* (Gorbet and Shokes, 2002a, 2002b) than Southern Runner or Georgia Green. The "high oleic" cultivar Hull has similar resistance levels to CP, TSWV and *S. rolfsii* as C-99R (Gorbet, 2003), and the cultivar DP-1 reportedly has levels of resistance to CP, TSWV and *S. rolfsii* that are among the best of any cultivar currently available in the U.S. (Gorbet, 2003). Hull and DP-1 have also been shown to have moderate resistance to CA (Culbreath, unpublished data). GA-01R, released in 2001, has moderate resistance to CA and TSWV (Culbreath, unpublished data).

Peanut breeders continue to develop and evaluate genotypes for enhanced resistance and tolerance to various pathogens. The breeding lines C-11-2-39, C-28-305, and C-34-24 developed by C.C. Holbrook with USDA/ARS, have better resistance to CA and TSWV than C-99R (Cantonwine et al., 2002).

Integrated disease management of peanut. Goals of integrated disease management (IDM) typically include the management of multiple diseases of a cropping system, employment of multiple management strategies, and efficient use of pesticides. The management of spotted wilt in peanut has become a model example of successful IDM for a single disease. No single management tool alone can provide adequate control of spotted wilt. However, there are various genetic, chemical and cultural practices that can be used in combination to minimize disease severity. These include cultivar selection, planting date, established plant population density, in-furrow insecticides, row pattern, tillage practices, and herbicide usage (Culbreath et al., 2003).

Over the last 10 years, nearly all growers in Georgia have altered their production practices to help manage spotted wilt. The most notable changes to peanut production have been planting cultivars with enhanced resistance to TSWV, planting later, in May instead of April, and planting at a higher seeding rate, 4 to 6 seed per foot instead of 2 to 3 (Smith, 2003a). The shift from Florunner to Georgia Green did not enhance the susceptibility of peanut to other pathogens, but later planting dates and higher seeding rates can exacerbate other peanut diseases. Planting in May instead of April provides a longer window for leaf spot epidemics to develop, since initial infections typically begin in June or July regardless of plating date. Shokes and Gorbet (1982) observed two and six times more leaf spot lesions on peanuts planted during early and late May, respectively, compared with peanuts planted during late April. Planting at higher seeding rates was found to increase stem rot (Sconyers, 2003). As the distance among plants decreased, vegetative spread of *S. rolfsii* from infected to uninfected plants increased. It is important to note that the potential benefits of these strategies for spotted wilt management often outweigh the negative impact to other diseases, especially since there are post-plant options, such as fungicides, that can be used to manage diseases caused by fungi.

In general, intensity of peanut diseases is similar or lower in strip-tilled fields compared to conventionally tilled fields. Strip-tillage has been shown to suppress the severity of spotted wilt by as much as 42% (Johnson et al., 2001). The mechanism of spotted wilt suppression in strip-tillage may be related to lower populations of thrips, the vector for TSWV. Mechanisms affecting population dynamics of thrips in strip-tillage are unclear; however, it has been proposed that herbicide-treated plant debris at the soil surface in strip-tilled fields interferes with the ability of thrips to find peanut plants (Culbreath et al., 2003).

Stem rot severity is not influenced by tillage (Brenneman et al., 1999; Johnson et al., 2001; Monfort et al., 2004). Rhizoctonia limb rot caused less damage in minimally tilled than conventionally tilled plots (Minton et al., 1991), but others have speculated that limb rot epidemics are likely to be more severe in reduced tillage because *R. solani* can survive saprophytically on plant debris and sclerotia are stimulated to germinate by organic matter in soils (Brenneman, 1997).

There is a relatively new disease symptom of peanut, that has been referred to as Florida leaf spot (FLS), funky leaf spot or irregular leaf spot that may be more severe in strip-tilled than conventionally tilled fields (Culbreath, unpublished data). The FLS symptom is a non-sporulating leaf spot that typically appears on the lower leaves of plants prior to the reproductive growth stages and often leads to premature defoliation. The cause of FLS is unknown. Furthermore, little is known about its epidemic progression over time, response to fungicides or effect on pod yield. FLS is an example of a minor 'disease' that should be monitored in studies investigating IDM strategies for leaf spot to insure it does not become a major concern in response to production shifts.

Potential of reducing fungicide inputs for leaf spot control with IDM of peanut. In severe years with a susceptible cultivar, the standard 14-day interval program of chlorothalonil may not prevent yield losses to leaf spot. However, a number of studies have demonstrated that the frequency of fungicide applications can be reduced without impacting yield when a cultivar with moderate leaf spot resistance is grown (Culbreath et al., 1992c; Culbreath et al., 1992d; Gorbet et al., 1982; Gorbet et al., 1990; Smith et al., 1994). Gorbet and colleagues investigated the response of cultivars with various levels of late leaf spot resistance, including Florunner and Southern Runner, to spray schedules of chlorothalonil at 14 and 20-day intervals in 1982, and 14 and 21-day intervals in 1990. They found that Southern Runner could be grown under a 20 or 21-day interval schedule with comparable leaf spot ratings and yield as Florunner under a 14-day interval schedule (Gorbet et al., 1982; Gorbet et al., 1990). A study in Georgia corroborated these results for Southern Runner under moderate and heavy late leaf spot pressures (Culbreath et al., 1992d).

Cultivars that have moderate resistance to one leaf spot pathogen but not the other, such as Southern Runner, may not be sufficient to control leaf spot with reduced fungicide inputs in fields infested with both pathogens. Gricher et al. (1998) investigated the leaf spot and yield response of Florunner, Southern Runner, and other cultivars grown in Texas, to 14, 21 and 28-day interval schedules using chlorothalonil and tebuconazole. The leaf spot pressure was high, and included both early and late leaf spot. Under these conditions, the final leaf spot severity was significantly greater with the extended interval programs compared to the 14-day interval program for all cultivars.

A more recent study, using some of the breeding lines and cultivars with enhanced resistance to leaf spot described in the cultivar history section, was conducted in 2000 and 2001,

under heavy early leaf spot pressures (Cantonwine et al., 2002). The leaf spot levels observed in Georgia Green plots under a 14-day interval chlorothalonil based program were similar to those of Florida MDR-98, C-99R and breeding line C-28-305 under a 21-day interval regime, and breeding line C-11-2-39 under a 28-day interval regime.

Only one study has previously investigated the integration of host resistance, strip-tillage and reduced fungicide inputs for management of early leaf spot of peanut. Monfort et al. (2004) compared the disease response of Georgia Green, C-99R or Florida MDR-98, grown under conventional or strip-tillage, with a 4-spray extended (21-28-21-28 day) interval program, or 7-spray (14-day) interval program utilizing chlorothalonil alone, an alteration of chlorothalonil and tebuconazole, or chlorothalonil and azoxystrobin. They found that all genotypes had early leaf spot disease in strip-tilled plots with the 4-spray program that was comparable to conventionally tilled plots with the 7-spray program regardless of fungicide. Less disease was observed in plots planted to C-99R and Florida MDR-98 than Georgia Green; however, the amount of resistance by these cultivars did not appear to be additive to suppression by strip-tillage and fungicide use. The incorporation of genotypes with even more resistance than Florida MDR-98 or C-99R to leaf spot pathogens may provide additional disease suppression for leaf spot management with strip-tillage and extended interval fungicide programs.

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CHAPTER 3

CHARACTERIZATION OF EARLY LEAF SPOT SUPPRESSION BY STRIP-TILLAGE IN PEANUT[1]

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Characterization of early leaf spot suppression by strip-tillage in peanut

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ABSTRACT

Epidemics of early leaf spot, caused by *Cercospora arachidicola*, are suppressed by strip-tillage in fields under crop rotation. Experiments were carried out to characterize the effect of strip-tillage and to identify the primary target of disease suppression using a comparative epidemiology approach. Peanut was planted to conventionally and strip-tilled plots in 2002 to 2004 and disease intensity was assessed weekly as percent incidence or with the Florida 1 to 10 severity scale. The logistic model was fit to estimate time of disease onset (TDO) and the epidemic rate. Environmental conditions, spore concentrations in the air, early infection patterns, and components of host resistance of field leaves were also monitored. The estimated TDO in strip-tilled plots was 12 to 13 days later than in conventionally tilled plots. The epidemic rate was lower in strip-tillage according to models of incidence, but was similar between tillage systems for models based on severity. Mean relative humidity and the frequencies of environmental records favorable for infection and spore dispersal were lower in strip-tillage at the top of peanut canopies in 2002, but these differences were not observed in 2003 or 2004. Tillage did not affect host response to infection, but infections were detected earlier and at higher frequencies with detached leaves from conventionally tilled plots. These data suggest that strip-tillage delays the onset of early leaf spot epidemics due to fewer initial

infections; most likely a result of fewer initial inocula dispersed to peanut leaves from overwintering stroma in the soil.

INTRODUCTION

Disease development requires the presence of a virulent pathogen, a susceptible host and an environment conducive for infection. The variability and interaction of these factors explain the amount of disease in a population, and is modeled by the disease triangle (Agrios, 1997). Agronomic practices can affect all three components of the disease triangle. The targeted components of some practices are obvious, such as reducing host susceptibility by planting a resistant cultivar; however, impacts of other practices are not always clear. Conventional tillage with a moldboard plow, once considered essential for managing soilborne pathogens, has been shown to have variable effects on disease epidemics (Bailey, 1996; Bockus and Shroyer, 1998; Everts, 2002; Porter and Wright, 1991).

Epidemics can be suppressed by delaying the onset of disease, reducing the rate of disease increase, or by reducing the duration of the epidemic. Delayed onset is most often associated with a reduction in the number of initial infections, while reduced epidemic rates are typically due to fewer secondary infections (Campbell and Madden, 1990). Comparisons of epidemic model parameters can help assess whether disease suppression is the result of a delay in the onset of the epidemic and/or a reduction to the epidemic rate of increase (Kranz, 2003).

Early leaf spot of peanut (*Arachis hypogaea* L.) is caused by *Cercospora arachidicola* S. Hori, (teleomorph = *Mycosphaerella arachidis* Deighton). Infections of *C. arachidicola* cause lesions on leaves, petioles and stems, which often lead to premature defoliation, loss of integrity of the geocarpophore, or peg, and yield loss. *C. arachidicola* is a hemibiotrophic pathogen of

peanut with no known alternative host (Woodroof, 1933). The fungus overwinters as stroma or mycelium on crop residue in the soil, to which initial inoculum is most often attributed (Shokes and Culbreath, 1997). Primary infections usually occur on the adaxial surface of lower leaves, after a period of rain or continuous leaf wetness (Smith and Littrell, 1980). Incubation and latent periods vary by peanut cultivar and environment, and can be as short as 9 and 18 days, respectively (Aquino et al., 1995; Johnson et al., 1986; Shew et al., 1988). Secondary inoculum is produced on mature lesions after periods of extended leaf wetness and temperatures above 19°C (Shokes and Culbreath, 1997). Spores are released from lesions after rain, irrigation, or heavy morning dews, in greatest densities between sunrise and early afternoon (Alderman et al., 1987). Spore dispersal agents include water evaporation, rain splash, wind and insects (Shokes and Culbreath, 1997). Initial infections typically begin after plants begin to bloom, around 30 days after planting (DAP), since peanut shows some resistance to leaf spot during the vegetative phase (Miller et al., 1990). Symptoms typically appear first in the lower canopy and then in the upper canopy as the epidemic progresses (Chiteka et al., 1988a; Plaut and Berger, 1980). Complete defoliation of susceptible cultivars is common when fungicides are not used.

When crop rotation is used, epidemics of early leaf spot have been reported to be more severe in conventionally tilled than strip-tilled fields (Monfort et al., 2004; Porter and Wright, 1991), with suppression worth 3 to 5 sprays of chlorothalonil (Monfort et al., 2004). The mechanism of suppression by strip-tillage is not known; it could provide a less favorable environment for spore production or infection, enhance host resistance by improving plant health, or reduce pathogen abundance, dispersal or virulence. Visual comparisons of disease progress curves based on Florida 1 to 10 scale ratings (Chiteka et al., 1988a), suggest that strip-tillage causes a delay in the onset of disease rather than a reduction to the rate of epidemic

progression (Monfort et al., 2004). Unfortunately the Florida scale may not be appropriate for model comparisons since ratings are extremely subjective when disease levels are low, and the scale is not proportional to disease incidence or severity (Chiteka et al., 1988a). However, models based on disease incidence alone are often not sufficient for description of the entire epidemic since incidence can reach 100% well before the growing season is complete. The objectives of this study were to characterize disease suppression by strip-tillage and to identify the primary target of suppression using a comparative epidemiology approach.

METHODS

Experimental design. Field studies were conducted at the University of Georgia Coastal Plain Experiment Station, Tifton GA in 2002 to 2004. Soil type was a Tifton loamy sand. Fields were planted to cotton (*Gossypium hirsutum* L.) the previous year, and peanut two years prior, each under conventional tillage. Winter wheat (*Triticum aestivum*) was planted as a cover crop the previous fall. Conventional and strip-tillage treatments were randomized over 3 plots (replications) at the Rigdon Farm in 2002 and 2003, 4 replications at the Blackshank Farm in 2003, and 4 replications at Rigdon and Blackshank Farms in 2004. Plots were planted to the susceptible cultivar Georgia Green and no fungicides were applied, unless otherwise stated.

Conventional tillage plots were mowed and disked twice before the soil was deep turned with a switch plow, 20 to 25 cm deep, and bedded with a disk bedder. Ethalfluralin (Sonolan HFP 3.0, Dow AgroScience LLC, Indianapolis, IN) 0.95 kg a.i/ha and S-metoalochlor (Dual Magnum 8E, Syngenta Crop Protection, Greensboro, NC) 1.68 kg a.i./ha were incorporated into the tilled beds. In the strip-tillage plots, the cover crop was killed with glyphosate (Roundup 4 EC, Monsanto, Kansas City, MO) at 1.2 kg a.i./ha. A subsoil shank attached to a strip-till

implement (Kelley Manufacturing Co., Tifton, GA), loosened the plow pan 33 cm beneath the row, while the implement tilled strips approximately 20 to 25 cm wide. Tillage plot sizes varied for each test but exceeded 10.8 x 39.9 m in all cases. Treatment plot size was 1.8 x 6.0 to 7.5 m. Planting dates were 17 May 2002, 20 May at the Rigdon Farm and 15 May at the Blackshank Farm in 2003, and 25 May at the Ridgon Farm and 26 May at the Blackshank Farm in 2004.

Disease assessments. Early leaf spot incidence was assessed weekly as the number of leaves with 1 or more lesions or defoliated leaflets divided by the total number of leaves x 100, beginning when disease was first noticed. Percent incidence was assessed on leaves from 80 lateral branches evenly sampled from plots of 8 genotypes with varied levels of resistance to *C. arachidicola* at the Ridgon Farm in 2002 and 2003. For other fields, percent incidence was estimated from 10 lateral branches arbitrarily collected from each plot. Collections began at 74 DAP in 2002, and between 55 and 59 DAP in 2003 and 2004. Leaf spot severity per plot was estimated using the Florida 1-10 scale rating system, where 1 = no leaf spot; 2 = very few lesions on the leaves, none on the upper canopy; 3 = few lesions on the leaves, very few on the upper canopy; 4 = some lesions with more on the upper canopy, 5% defoliation; 5 = lesions noticeable even on upper canopy, 20% defoliation; 6 = lesions numerous and very evident on upper canopy, 50% defoliation; 7 = lesions numerous on upper canopy, 75% defoliation; 8 = upper canopy covered with lesions, 90% defoliation; 9 = very few leaves remaining and those covered with lesions, 98% defoliation; and 10 = plants completely defoliated and killed by leaf spot (Chiteka et al., 1988a). Severity assessments were made at 7 to 22 day intervals 5 times beginning 89 DAP in 2002, 9 times beginning 59 to 63 DAP in 2003, and 6 times beginning 56 DAP in 2004. Mean disease incidence and severity was plotted by assessment date and treatment averaged over replications for each field and year.

Disease assessments were analyzed separately. For each plot, area under the disease progress curve (AUDPC) was computed (Shaner and Finney, 1977). Disease assessments were converted to proportions [proportion of incidence = percent incidence / 100; proportion of severity assessment = (Florida rating - 1) / 9], and linearized forms of the Gompertz [-ln(-ln y)], logistic [ln(y/1-y)] and monomolecular [ln(1/1-y)] models were fit using linear regression of transformed disease intensity proportions on time (DAP). The model that significantly ($P <$ 0.05) fit all of the curves within each experiment was selected. If more than one model fit all of the curves within an experiment, that model with the highest recalculated R^2 after back transformation was selected. If none of the models fit a majority of the curves satisfactorily, models were fit to data with replications combined after the replication effect was removed and the mean replication estimate was added back to residuals, or the data was excluded from analysis. Time of disease onset (TDO) was estimated by calculating the time (DAP) when the model predicted 5% incidence or 1.5 on the Florida scale. The model rate parameter was used as an estimate of the epidemic rate (Campbell and Madden, 1990). Effects of tillage on AUDPC, TDO and epidemic rate were determined using the Proc MIXED procedure (v 8.3; SAS Institute, Inc. Cary, NC) with year and field within year as random effects.

Environmental monitoring. In all plots at the Rigdon Farm, air temperature (AT) and relative humidity (RH) were measured every 30 minutes at the top of the peanut canopy, in all three years, and within the canopy in 2003 and 2004 using HOBO dataloggers (H8 Pro Series, Onset Computer Corporation, Bourne, MA). Dataloggers were also used to measure soil temperature (ST) every 30 minutes at 5 cm below the soil surface. Environmental variables were monitored from 29 May to 15 September in 2002, 16 June to 14 September in 2003, and 17 June to 15 September in 2004. Every 30 min reading was classified as favorable or unfavorable for

infection based on parameters reported by Alderman et al. (1987) as favorable for infection being RH ≥ 95% and AT ≥ 19°C. Likewise, every 30 min reading was classified as favorable or unfavorable for spore dispersal based on parameters of RH ≥ 90% and 20 ≤ AT ≤ 24°C, reported as favorable for spore dispersal (Alderman et al., 1987). Effects of tillage on environmental variables were examined by year using the Proc MIXED procedure of SAS with satterthwaite in the option statement and rep, rep*tillage, and date (rep tillage) as random effects. Effects of tillage on the frequencies of environmental records that were favorable for infection and spore dispersal were conducted separately with Chi square analysis of SAS (Proc FREQ).

Monitoring initial infections and secondary inoculum. Asymptomatic leaves were collected from plots at the Rigdon and Blackshank Farms in 2003 and 2004, to estimate the occurrence and frequency of primary infections. Five leaves per plot (trap leaves) were arbitrarily collected from the first or second newly expanded leaf of lateral branches in conventional and strip-tillage plots. Leaves were collected weekly from the field beginning 47 DAP in 2003 and 36 DAP in 2004, until disease was observed in leaves from all plots. Detached leaf methods were modified from those described by Melouk, et al. (1978) and Waliyar, et al. (1995). Leaves were excised at the base of the petiole using a razor blade. The cut ends were immediately dipped in a dry formulation of napthaleneacetamide and thiram (Rootone, Security Products Co., Atlanta, GA) and set in sterile saturated sand in 100 ml beakers or test tubes filled with sterile water covered with Parafilm. Leaves were transported to the laboratory and incubated in a mist chamber at room temperature (20 to 23ºC) and 12 h photoperiod. After 48 h, misting was discontinued. Water was added to beakers and test tubes as needed. The mean number of lesions per leaf and percent incidence of leaves with lesions was recorded after 2 weeks. Tillage effects on the mean number of lesions per leaf and percent incidence from the

final collection dates for each field (47 DAP at the Blackshank Farm and 73 DAP at the Rigdon Farm in 2003, and 57 DAP at both Farms in 2004) were tested using the Proc MIXED procedure of SAS with year and field within year as random effects.

The density of *C. arachidicola* conidia per cubic meter of air was estimated for conventional and strip-tillage plots using Rotorod samplers (Model 20, Multidata, Inc., Minnetonka, MN). Samplers were placed 15 cm above the peanut canopy at the center of replicated plots. Air was sampled from 11:00am to 1:00pm. Sample location and time were chosen to maximize spore capture per sample period since Alderman et al. (1987) found that secondary spore dispersal of *C. arachidicola* at 42 cm above the soil peaked near noon. Air was sampled at the Rigdon Farm 7 times between 58 and 101 DAP for 1 replication in 2002, 9 times between 49 and 106 DAP for 1 to 3 replications in 2003, and between 85 and 92 DAP for 2 replications in 2004. Rods were incubated at room temperature and high RH for 24 to 48 h. Incubation promoted germination of conidia to help distinguish conidia from similarly shaped debris or conidia of *Fusarium* sp., which tended to have a longer germ-tube than *C. arachidicola*. After incubation, the rods were stained with cotton blue in lactophenol and covered with a 22-mm cover slip. Conidia of *C. arachidicola* were counted using a light microscope at 400x magnification. Spore densities were analyzed across sampling time with the Proc MIXED procedure of SAS with year and rep within year as random effects. Linear regression analysis was conducted across replications to determine the quantitative relationship between the tillage ratio (strip-till / conventional till) of spore concentrations in the air from strip-tillage plots on the tillage ratio of disease severity and incidence in the same plots during the same week. Common dates for Rotorod sampling and disease incidence assessments were 73, 80, 87, 94 and 101 DAP in 2002, 65, 71, 88, and 91 DAP in 2003, and 92 DAP in 2004. Common dates for Rotorod

sampling and disease severity assessments were 87 and 101 DAP in 2002, 65, 71, 88, 91, 101 and 106 DAP in 2003, and 92 DAP in 2004.

Host susceptibility assessment. Field host susceptibility to infection by *C. arachidicola* conidia was monitored for leaves from conventional and strip-tillage plots at the Rigdon Farm in 2003 and Rigdon and Blackshank Farms in 2004 using the detached leaf sand beaker method described above. Ten first or second fully expanded leaves per plot were arbitrarily collected after plants were flowering and before evidence of disease onset, 42 DAP in 2003, and 29 DAP in 2004. Five leaves per plot were inoculated with conidia of *C. arachidicola* and 5 were used as controls.

Conidia for inoculations were acquired from cultures begun from single *C. arachidicola* conidia obtained the previous growing season using a technique modified from Lu, et al. (2003). Sporulating early leaf spot lesions were excised from leaves of Georgia Green and swiped across water agar. After 24 h at room temperature, single germinated conidia were transferred to potato dextrose agar (PDA). Fungal colonies grown for 4 to 8 months (0.5 to 1.0 cm diameter) were ground in 1 ml of sterile 0.005% Tween 20 using a homogenizer (TissueMiser, 115V, Fisher Scientific, Pittsburgh, PA). Aliquots of the homogenate (0.25 ml) were spread evenly across 4 clarified V8 juice agar plates with a glass rod. Plates were left without Parafilm until agar was near dry, then wrapped with Parafilm and incubated under light at room temperature for 7 to 14 days. Spores were rinsed from cultures with 10 ml of 0.0005% Tween 20. Spore concentrations were adjusted to 5000 conidia ml^{-1} using a hemacytometer.

Leaves were uniformly inoculated for 1 sec with the conidial suspension or with 0.005% Tween 20 as a control using an aerosol spray bottle. Leaves were randomly positioned on trays and placed within a transparent enclosure (1.3 x 0.7 x 0.6 m) in a growth chamber set at 24˚C,

90% RH, and 12-h photoperiod. The enclosure was constructed using 2.54-cm PVC pipe with clear plastic sides and a glass top. The enclosure did not affect air temperature. Relative humidity was supplemented by maintaining standing water in trays and with two humidifiers (PersonalMist ultrasonic humidifier, Kaz, Inc, Hudson, NY) evenly spaced within the enclosure. Humidifiers functioned constantly for the first 48 h, and were then programmed to turn off and on for alternating 30-min periods while the lights were on, and to turn off with the lights, to maintain continuous leaf wetness without runoff. Water was added to beakers and trays as needed.

After 28 days, number of lesions per leaf, lesion diameter, percent lesions with sporulation and number of leaflets defoliated were recorded. The Proc MIXED procedure was used to determine effects of tillage on untransformed and square root transformed response variables listed above.

RESULTS

Disease progress curves of early leaf spot incidence in conventionally tilled and strip-tilled plots at each field and year are shown in Fig. 3.1. The increase in disease incidence over time was best described by the logistic model for each plot at the Rigdon Farm each year and at the Blackshank Farm in 2004, and for combined plots at the Blackshank Farm in 2003. Disease progress curves of Florida scale severity ratings in conventionally tilled and strip-tilled plots at each field and year are shown in Fig. 3.2. The logistic model best described the increase in disease severity over time for plots in each field and year. Parameter estimates and regression statistics for the selected models are presented in Table 3.1.

Early leaf spot epidemics, as measured by AUDPC based on incidence and severity, were less severe in strip-tilled than conventionally tilled plots (Table 3.2). It took 13 days longer to reach 5% incidence and 12 days longer to reach 1.5 severity in the strip-tilled plots than the conventionally tilled plots (Table 3.2). The epidemic rate was slightly lower in strip-tilled than conventionally tilled plots for models based on incidence, and comparable between tillage treatments for models based on severity (Table 3.2).

The influence of tillage treatment on environmental variables was determined separately by year to reduce model complexity for timely analysis of the large data set (Tables 3.3-3.4). The tillage treatments did not affect mean air temperatures measured at the top of the peanut canopy ($P \geq 0.48$) or within the canopy ($P \geq 0.53$), or mean soil temperatures ($P \geq 0.14$) (Table 3.3). In 2002, the mean RH at the top of the canopy was lower in strip-tilled plots than conventionally tilled plots by nearly 2% ($P < 0.01$), but no tillage effects on mean RH were observed in 2002 or 2003 ($P \geq 0.49$) (Table 3.3). Soil temperature tended to be slightly higher during June and July and lower in August and September in strip-tilled plots than conventionally tilled plots (Fig. 3.3).

In 2002, the frequency of environmental records favorable for infection and spore dispersal was lower in strip-tilled plots than conventionally-tilled plots at the top of the peanut canopy (Table 3.4). These differences were not detected between tillage treatments in 2003 or 2004, with the exception of a lower frequency of environmental records favorable for spore dispersal within the canopy in 2003 for strip-tilled plots than conventionally tilled plots. In 2002, the mean cumulative period of time when RH > 95% at the top of the canopy was about 30 and 90 min shorter in strip-tilled plots after sunrise and sunset than conventionally tilled plots, respectively; while in 2003 and 2004 the tillage difference was less than 15 min combined (Fig. 3.4). The mean cumulative period where RH > 90% in 2002 was 30 min shorter in strip-tilled

plots than conventionally tilled plots after sunrise and sunset, and similar between tillage treatments in 2003 and 2004.

Estimations of initial infections and secondary inoculum densities in the air differed between tillage treatments. The mean number of initial infections per trap leaf and the percent of trap leaves with infections was less in strip-tilled plots than conventionally tilled plots ($P < 0.01$) (Table 3.5). The mean concentration of spores in the air above strip-tilled plots was lower that that above conventionally tilled plots ($P < 0.01$) (Table 3.5). Across years, the tillage ratio (strip-till / conventional till) of spore concentration in the air was positively correlated to the tillage ratio of disease severity ($P = 0.02$), but was not correlated to the ratio of disease incidence ($P = 0.49$) (Fig. 3.5).

No measure of host susceptibility was affected by tillage ($P > 0.35$). The overall means combined over tillage treatments were 36.3 lesions per leaf, 1.5 mm lesion diameter, 35% lesions with sporulation, and 33% leaflets defoliated.

DISCUSSION

Results of our 3-year field study provide evidence that the primary manner of early leaf spot suppression by strip-tillage is to reduce the amount of initial infections, which result in a delay of the epidemic. Both disease assessment techniques, incidence and severity, were useful to demonstrate early leaf spot suppression by strip-tillage and to detect tillage differences in TDO. The TDO was 12 to 13 days later in the strip-tilled compared to conventionally tilled plots. The effect of tillage on the epidemic rate, although statistically different based on incidence, was nearly negligible in comparison to the large differences observed for TDO.

The cause of fewer initial infections in strip-tillage is most likely due to fewer or less viable spores dispersed to peanut leaves from overwintering stroma on debris in the soil. Under a controlled environment, early infection was significantly lower on detached trap leaves from strip-tilled plots than conventionally tilled plots, yet host resistance of detached leaves did not differ between the tillage systems. Peanut resistance to leaf spot does not appear to be easily induced. In greenhouse and field studies, Zhang et al. (2001) failed to detect consistent induction of systemic resistance in peanut to late leaf spot disease by strains of plant growth-promoting rhizobacteria (PGPR) that elicited systemic disease control in cucumber, tomato or tobacco, or by chemical elicitors, including salicylic acid, sodium salicylate, isonicotinic acid, acibenzolar-S-methyl (Actigard), or DL-β-amino-n-butyric acid (BABA). Since induced resistance was observed in 1 or 2 trials for 7 of 19 PGPR strains and BABA, Zhang concluded that peanut is not systemically inducible by PGPR and chemical elicitors in the same manner as other crops. The environmental parameters measured in this study, although different in some cases, were not consistently different across years. Soil moisture was not measured in this study, but the increase of soil water retention in response to reduced tillage practices, at least for Tifton loamy sand soils, appears to require more time than a single season of reduced tillage, as in this study. In a long term tillage study in Tifton, GA, where plots were maintained under continuous conventional tillage or strip-tillage, the water infiltration rates of soils in the tillage treatment plots were comparable during the first growing season; infiltration rates were found to higher in the strip-tilled than conventionally tilled plots after 4 years (Truman, 2004). It is important to point out that strip-tillage and cover crop residue do not appear to enhance RH around peanut plants, which was previously assumed (Johnson et al., 2001). Forest litter and mulch can act as

an open sponge, absorbing and holding water (Holmgren, 2002), and it is possible that cover crop residue may act similarly, especially when conditions are dry, as in 2002.

Although the detached trap leaf method did not provide a direct measure of initial inoculum, similar methods that employ trap plants are standard procedures used to estimate early season inoculum levels within a uniform environment (Campbell and Madden, 1990). In this study, detached trap leaves were preferable over container trap plants because they provided a more natural setting for spore capture, and allowed for investigation of larger sample sizes since space in the mist chamber was limited. Initially, Vaseline-coated slides were placed near the soil surface prior to disease onset to quantify initial inoculum. However, slides were not useful due to soil contamination, especially in conventional tillage plots where soil contamination was heavy. Rotorod samplers were not useful to monitor initial inoculum densities since no conidia were detected with samplers prior to the observation of secondary inoculum on lesions within the peanut canopy. Rotorod samplers were useful for detecting differences in airborne inoculum densities, but quantification of secondary inoculum concentrations in the air was time consuming and challenged by the capture of various structures with a similar color and shape to *C. arachidicola* conidia (Fig. 3.5). Although airborne inoculum densities of *C. arachidicola* are highly affected by weather (Alderman et al., 1987), the positive relationship between the tillage ratios (strip-till / conventional till) of disease severity and airborne inoculum densities suggest that estimates of disease severity may be a reasonable indicator of the relative density potential of secondary inoculum in the air above plots. The failure to find a correlation between the tillage ratio of airborne inoculum density and disease incidence was likely due to lower levels of disease for the incidence rating dates than severity dates, which may have lead to insufficient numbers of spores sampled to detect tillage differences.

The cause of fewer early infections, and possibly fewer initial inocula, is likely related to differences of the tillage systems. Strip-tillage differs from conventional tillage in a number of ways, including the use of the herbicide glyphosate to kill the winter cover crop and the presence of cover crop residue at the soil surface. The use of glyphosate may inhibit spore production of overwintering stroma in the soil. Glyphosate has been shown to have fungicidal activities against *Pyrenophora tritici-repentis* and *Septoria nodorum* of wheat (Harris and Grossbard, 1979; Sharma et al., 1989), *Drechslera teres* of barley (Toubia-Rahme et al., 1995), and *Calonectria crotalariae* of soybean (Berner et al., 1991). Berner et al. (1991) demonstrated that pre-plant applications of low rates of glyphosate suppressed red crown rot in soybean fields that relied on naturally occurring inoculum of *C. crotalariae* from microsclerotia in infested soils. Although there are no reports that have directly investigated glyphosate toxicity to *C. arachidicola*, negative effects on the germination of *C. arachidicola* conidia were reported for post-emergence application rates of lactofen, 2,4-DB, and acifluorfen herbicides, and the degree of sporulation of early leaf spot lesions was reduced on plants treated with lactofen and acifluorfen 1 week prior to inoculation with *C. arachidicola* conidia (Baysinger et al., 1999). The maintenance of cover crop residues at the soil surface could also be involved in disease suppression. Straw mulch and cover crop residue has been found to decrease spore dispersal from inoculum sources at the soil surface by rain splash (Madden and Ellis, 1990; Madden, 1992; Ntahimpera et al., 1998) and to decrease foliar disease severities in the field (Everts, 2002; Madden, 1992; Mills et al., 2002; Ristaino et al., 1997). Suppression of spore dispersal by surface mulch may be related to its effect on increasing surface roughness, which has been shown to reduce rain splash velocities and alter the angle of splash trajectories (Madden, 1992; Yang and Madden, 1993). In peanut, a rain simulation study of plots under strip-tillage and

conventional tillage in Tifton, GA, indicated that raindrop impact velocities and soil displacement by rain are measurably less in strip-tilled plots (Truman, personal communication). More research is needed to explore the specific factors responsible for the observed reduction in initial infections of early leaf spot of peanuts grown under strip-tillage cultivation.

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Table 3.1. Parameter estimates and regression statistics for the logistic model selected to describe early leaf spot disease progression over time for each peanut treatment plot at the Rigdon and Blackshank Farms, 2002-2004.

		Incidence[a]				Severity[b]			
Year/Farm/Treatment	Rep	Y-intercept	Rate	*P*-value	Recalc. R2[c]	Y-intercept	Rate	*P*-value	Recalc. R2[c]
2002, Rigdon Farm									
Conventional tillage	1	-18.82	0.190	< 0.01	0.82	-10.05	0.080	< 0.01	0.72
	2	-17.81	0.175	< 0.01	0.82	-9.85	0.078	< 0.01	0.72
	3	-18.06	0.170	< 0.01	0.87	-11.11	0.085	< 0.01	0.80
Strip-tillage	1	-17.60	0.161	< 0.01	0.90	-10.81	0.080	< 0.01	0.76
	2	-15.42	0.135	< 0.01	0.85	-10.82	0.077	< 0.01	0.76
	3	-19.75	0.179	< 0.01	0.89	-9.71	0.070	< 0.01	0.87
2003, Rigdon Farm									
Conventional tillage	1	-8.48	0.102	< 0.01	0.83	-6.50	0.057	< 0.01	0.89
	2	-9.02	0.101	< 0.01	0.74	-6.74	0.058	< 0.01	0.86
	3	-9.32	0.110	< 0.01	0.84	-6.99	0.060	< 0.01	0.89
Strip-tillage	1	-8.54	0.080	< 0.01	0.63	-7.75	0.062	< 0.01	0.93
	2	-10.69	0.099	< 0.01	0.47	-8.02	0.064	< 0.01	0.90
	3	-8.55	0.083	< 0.01	0.75	-8.06	0.067	< 0.01	0.94
2003, Blackshank Farm									
Conventional tillage	1	-3.33	0.059	0.02	0.23	-5.68	0.062	< 0.01	0.96
	2	*[d]	*	*	*	-5.19	0.061	< 0.01	0.99
	3	*	*	*	*	-5.44	0.064	< 0.01	0.96
	4	*	*	*	*	-4.49	0.055	< 0.01	0.92
Strip-tillage	1	-3.83	0.057	0.02	0.31	-8.03	0.077	< 0.01	0.96
	2	*	*	*	*	-7.73	0.076	< 0.01	0.98
	3	*	*	*	*	-6.69	0.068	< 0.01	0.98
	4	*	*	*	*	-5.49	0.055	< 0.01	0.97

Table 3.1 continued

2004, Rigdon Farm									
Conventional tillage	1	-7.35	0.111	0.05	0.67	-5.61	0.073	< 0.01	0.99
	2	-8.52	0.121	< 0.01	0.97	-5.41	0.070	< 0.01	0.99
	3	-7.28	0.108	< 0.01	0.86	-4.25	0.056	< 0.01	0.99
	4	-6.96	0.106	0.03	0.72	-4.75	0.059	< 0.01	0.99
Strip-tillage	1	-9.76	0.126	< 0.01	0.95	-4.33	0.045	< 0.01	0.93
	2	-7.53	0.096	0.02	0.81	-5.09	0.053	< 0.01	0.92
	3	-10.01	0.126	< 0.01	0.95	-4.40	0.045	< 0.01	0.96
	4	-11.48	0.140	< 0.01	0.89	-5.36	0.053	< 0.01	0.94
2004, Blackshank Farm									
Conventional tillage	1	-6.23	0.081	0.04	0.97	-5.33	0.063	< 0.01	0.99
	2	-8.89	0.115	< 0.01	0.96	-4.16	0.043	< 0.01	0.94
	3	-6.76	0.087	< 0.01	0.75	-6.03	0.064	< 0.01	0.97
	4	-7.54	0.102	0.02	0.89	-5.28	0.063	< 0.01	0.97
Strip-tillage	1	-7.24	0.069	< 0.01	0.70	-5.94	0.053	< 0.01	0.97
	2	-5.12	0.048	0.03	0.52	-5.07	0.046	< 0.01	0.98
	3	-6.54	0.070	< 0.01	0.81	-7.21	0.073	< 0.01	0.97
	4	-8.02	0.091	0.01	0.84	-5.24	0.053	< 0.01	0.99

[a] Number of leaves with 1 or more early leaf spot lesion or defoliated leaflet / total number of leaves from 10-80 lateral branches sampled from tillage plots.

[b] Based on Florida 1-10 scale ratings.

[c] Recalculated R^2 from regression of back-transformed predicted values against untransformed data.

[d] An asterisk represents data of replication (Rep) plots that were combined with data of the first replication plot of an experiment to achieve a significant ($P < 0.05$) fit of the model.

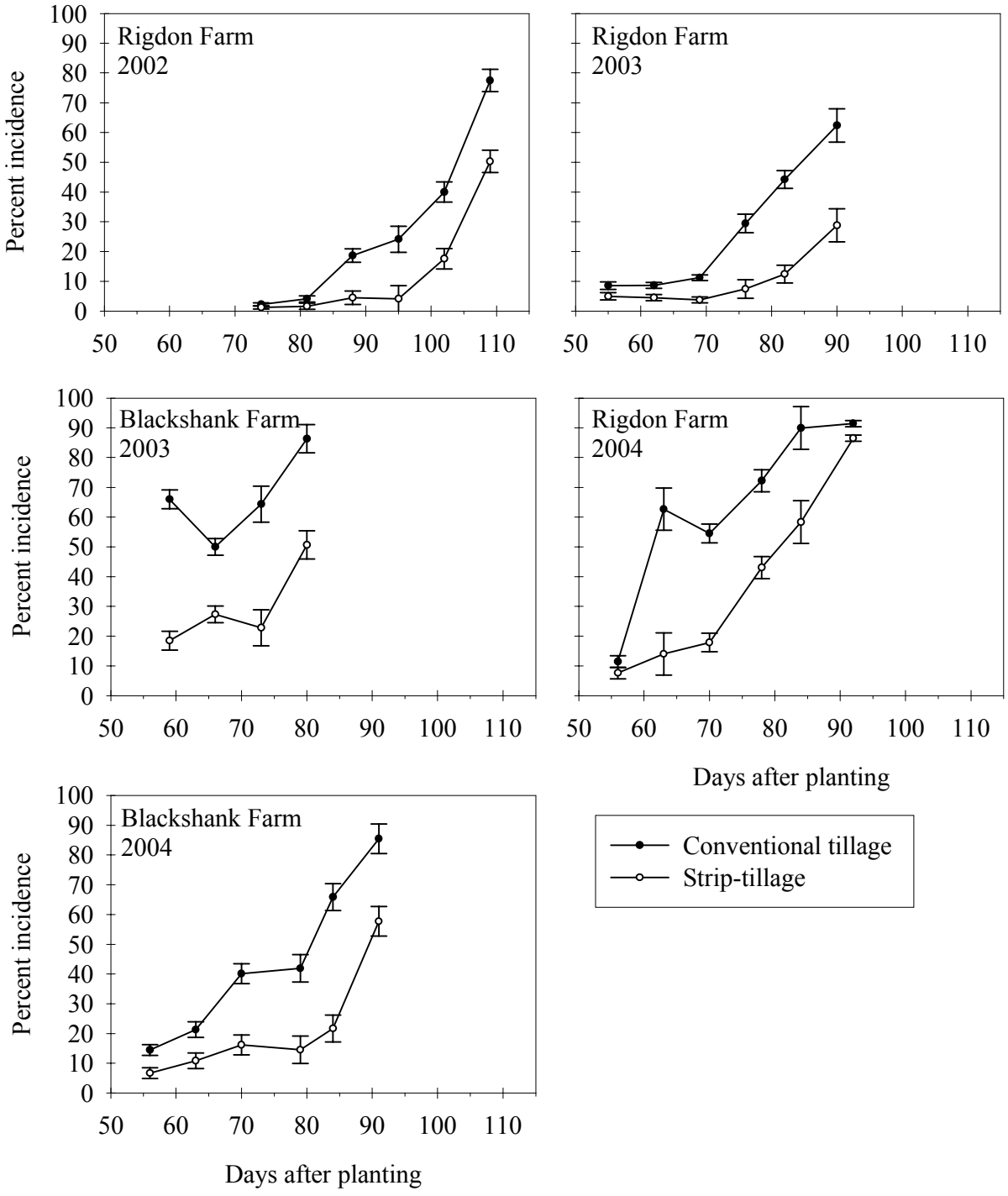

Fig. 3.1. Progress of early leaf spot severity over time for peanut plots in conventional tillage and strip-tillage at two locations 2002 -2004. Standard error bars are presented for each assessment date and treatment averaged over replications.

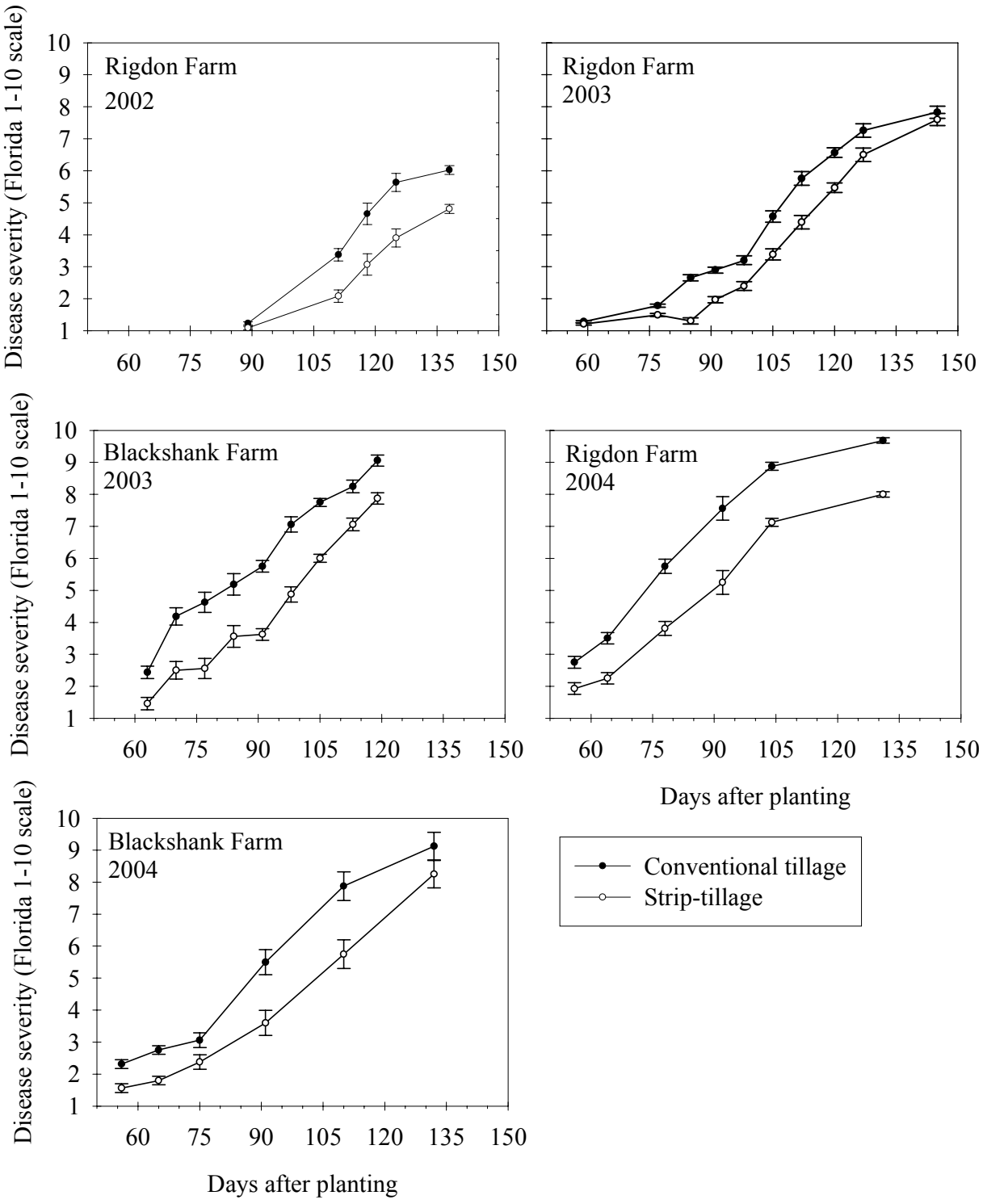

Fig. 3.2. Progress of early leaf spot severity over time for peanut plots in conventional tillage and strip-tillage at two locations, 2002 -2004. Standard error bars are presented for each assessment date and treatment averaged over replications.

Table 3.2. Effect of tillage treatments on AUDPC, time of disease onset (TDO) and apparent infection rate of early leaf spot epidemics of peanut, 2002 - 2004.

Tillage	Incidence[a]			Severity[b]		
	AUDPC[c]	TDO[d]	Epidemic rate[e]	AUDPC[c]	TDO[f]	Epidemic rate[e]
Conventional tillage	1309 b	55 a	0.117 b	496 b	59 a	0.067 a
Strip-tillage	699 a	68 b	0.107 a	365 a	71 b	0.065 a
P-value	< 0.01	< 0.01	0.04	< 0.01	< 0.01	0.47

[a] Number of leaves with 1 or more early leaf spot lesions or defoliated leaflets / total number of leaves from 10-80 lateral branches sampled from tillage plots across field and year.
[b] Rating based on the Florida scale for tillage plots across field and year.
[c] Least square means from Proc MIXED of area under the disease progress curve. Means within a column with the same letter do not differ at the 5% level, (LSD = 86, df = 114).
[d] Estimated as days after planting when percent incidence = 5%, (LSD = 3, df = 29).
[e] Rate parameter from logit transformation. Incidence LSD = 0.0096, df = 30; severity LSD = 0.0056, df = 30.
[f] Estimated as days after planting when Florida scale rating = 1.5, (LSD = 5, df = 30).

Table 3.3. Effects of tillage treatments on air and soil temperatures and relative humidity (RH) of peanut plots, 2002-2004.

Year/ Tillage	Top of Canopy[a]						Within Canopy[b]						Soil (5 cm depth)		
	Temperature (°C)			RH (%)			Temperature (°C)			RH (%)			Temperature (°C)		
	Mean[c]	Min	Max	Mean[c]	Min	Max	Mean[c]	Min	Max	Mean[c]	Min	Max	Mean[c]	Min	Max
2002[d]															
Conv[e]	26.3 a	14.3	44.0	86.0 b	19.1	100	-	-	-	-	-	-	27.1 a	20.5	40.2
Strip[f]	26.4 a	14.2	43.8	84.0 a	17.9	100	-	-	-	-	-	-	27.3 a	20.9	43.1
F, df	0.51, 562			6.88, 573									2.14, 613		
2003[g]															
Conv[e]	25.5 a	13.9	39.1	89.4 a	37.1	100	25.9 a	14.4	42.9	93.9 a	34.7	100	26.6 a	16.9	40.7
Strip[f]	25.5 a	14.0	38.5	90.0 a	36.3	100	25.7 a	15.2	38.9	93.6 a	37.2	100	26.7 a	20.0	38.4
F, df	0.00, 460			0.74, 1.8			0.51, 2.7			0.05, 1.6			0.14, 1.7		
2004[h]															
Conv[e]	26.0 a	17.4	40.9	90.3 a	30.9	100	26.1 a	18.0	40.3	93.4 a	37.1	100	26.7 a	22.6	39.0
Strip[f]	25.9 a	17.1	39.1	90.5 a	32.8	100	26.0 a	18.2	39.8	93.3 a	38.3	100	26.8 a	22.5	37.8
F, df	0.04, 633			0.07, 6.1			0.25, 5.5			0.04, 6.3			1.22, 4.6		

[a] Hobo data logger sensors placed within the top 1 cm of the peanut canopy.
[b] Hobo data logger sensors were 2-5 cm above the soil surface within the peanut canopy.
[c] Least square means from Proc MIXED with satterthwaite in option. Means within a column for the same year with the same letter do not differ at the 5% level.
[d] Three sensors per tillage treatment recorded variables every 30 minutes from 29 May to 15 September.
[e] Conventionally tilled plots.
[f] Strip-tilled plots.
[g] Three sensors per tillage treatment recorded every 30 minutes from 16 June to 14 September.
[h] Four sensors per tillage treatment recorded every 30 minutes from 17 June to 15 September.

Table 3.4. Effect of tillage on the frequency of environmental records favorable for infection or spore dispersal in peanut plots, 2002-2004.

	Top of canopy[a]			Within canopy[b]		
Year[f] / Tillage	Number of records per season (N)[c]	Records favorable for infection [n(%)][d]	Records favorable for spore dispersal [n(%)][e]	Number of records per season (N)[c]	Records favorable for infection [n(%)][d]	Records favorable for spore dispersal [n(%)][e]
2002						
Conv[g]	14645	7058 (48.2) b	5688 (38.8) b	-	-	-
Strip[h]	12317	5285 (42.9) a	4467 (36.3) a	-	-	-
2003						
Conv[g]	9062	4667 (51.5) a	3994 (44.1) a	12873	8346 (64.8) b	5176 (40.2) a
Strip[h]	13593	7178 (52.8) a	5965 (43.9) a	10740	6802 (63.3) a	4271 (39.8) a
2004						
Conv[g]	15630	8802 (56.3) a	7035 (45.0) a	17268	10692 (61.9) a	7284 (42.2) a
Strip[h]	14044	7885 (56.1) a	6211 (44.2) a	14635	9054 (61.9) a	6135 (41.9) a

[a] Hobo data logger sensors placed within the top 2 cm of peanut canopy.
[b] Sensors placed at least 2 cm above soil surface within peanut canopy.
[c] Total number of 30 minute records of air temperature and relative humidity utilized per year.
[d] Frequency favorable for infection, RH $\geq$ 95% and AT $\geq$ 19°C as reported by Alderman et al. (1987).
[e] Frequency favorable for spore dispersal, RH $\geq$ 90% and 20 $\leq$ AT $\leq$ 24°C as reported by Alderman et al. (1987).
[f] Recorded every 30 minutes from 29 May to 15 September, 2002; 16 June to 14 September, 2003; 17 June to 15 September, 2004.
[g] Conventionally tilled plots.
[h] Strip-tilled plots.
Chi square 1 degree of freedom 5% critical value is 3.84.

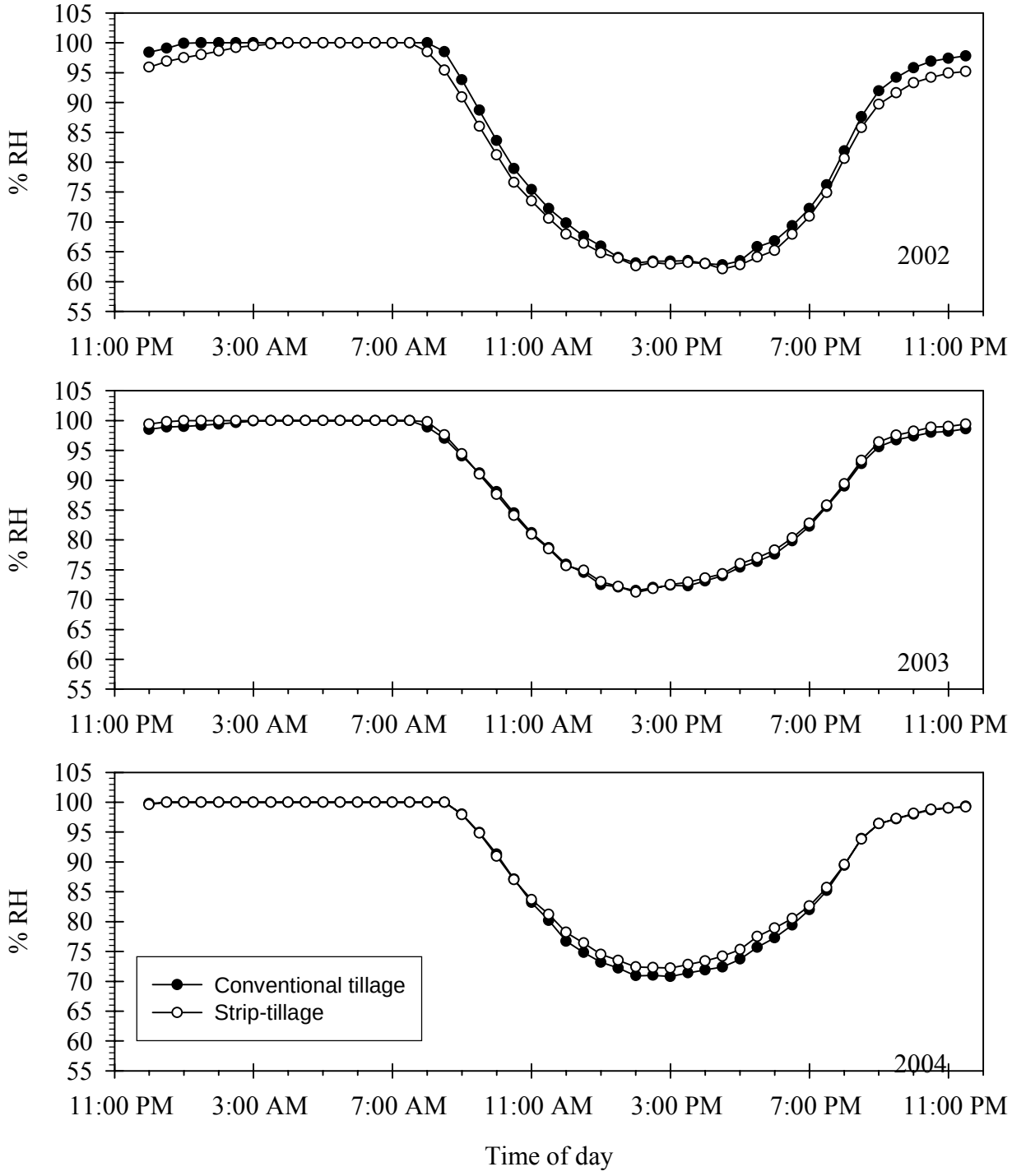

Fig. 3.3. Mean percent relative humidity (RH) by time of day at the top of peanut canopies in conventionally tilled and strip-tilled plots at the Rigdon Farm, 2002-2004, averaged over replications and season.

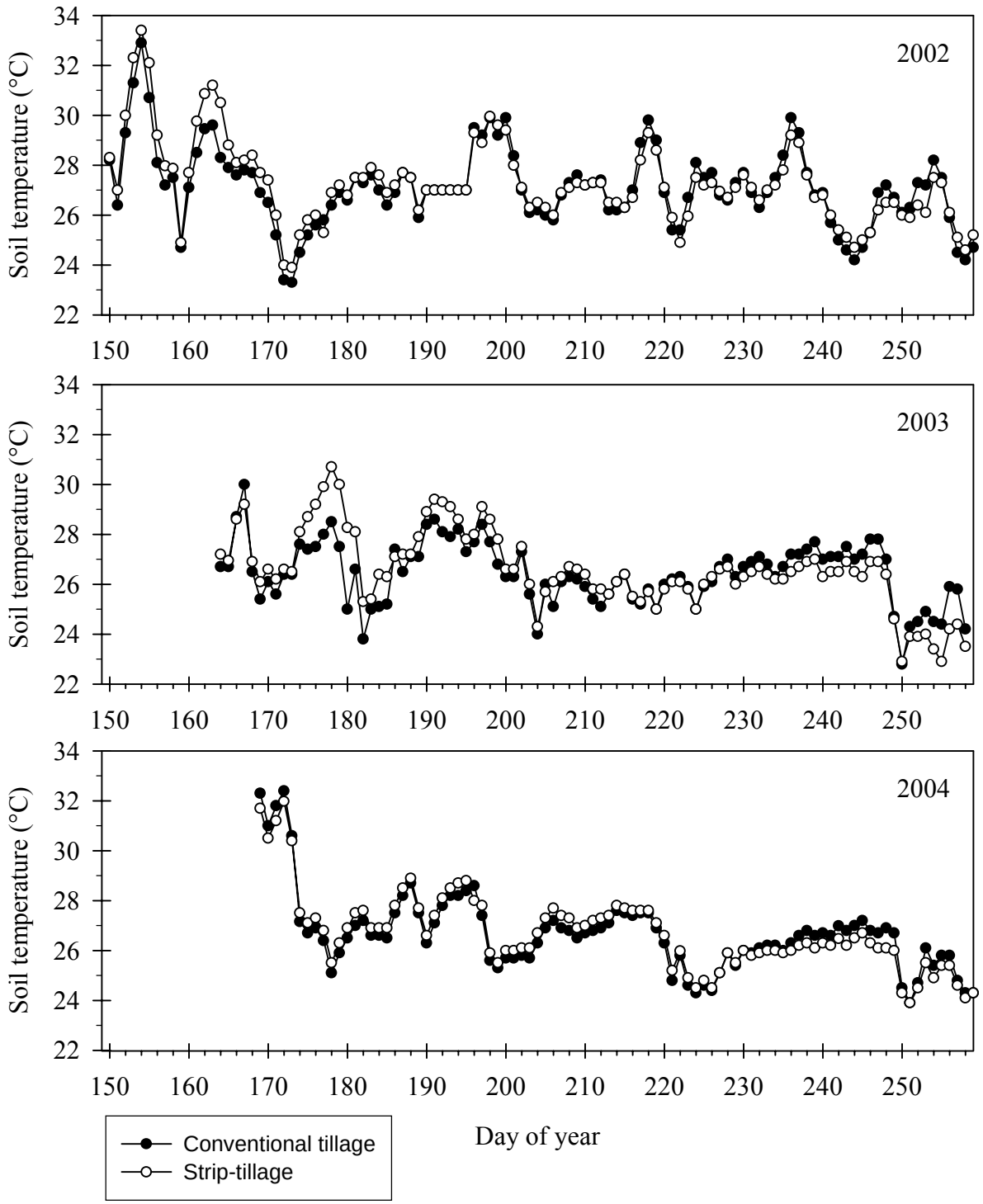

Fig. 3.4. Daily mean soil temperature 5 cm below the soil surface in conventionally tilled and strip-tilled peanut plots at the Rigdon Farm, 2002-2004, averaged over replications and 30 minute readings each day.

Table 3.5. Effect of tillage on initial early leaf spot infection patterns, 2003-2004, and concentration of *Cercospora arachidicola* conidia in air above peanut plots, 2002-2004.

Tillage	Initial infections[a]		Secondary inoculum[b]
	Number of lesions per leaf	Percent incidence[c]	Concentration in air (condia / m^3 air)
Conventional tillage	5.5 b	64 b	16.4 b
Strip-tillage	0.4 a	28 a	9.8 a
SE	1.37	4.2	1.0

[a] Monitored for 5 detached leaves per tillage plot 47 DAP at the Blackshank Farm and 73 DAP at the Rigdon Farm in 2003, and 57 DAP at both Farms in 2004.
[b] Least square means across year and sample date from Proc MIXED of sampled air using Rotorod samplers 15 cm above the peanut canopy from 11:00am to 1:00pm. Means within a column with the same letter do not differ at the 5% level.
[c] Number of leaves with 1 or more early leaf spot lesion / total number of leaves * 100.

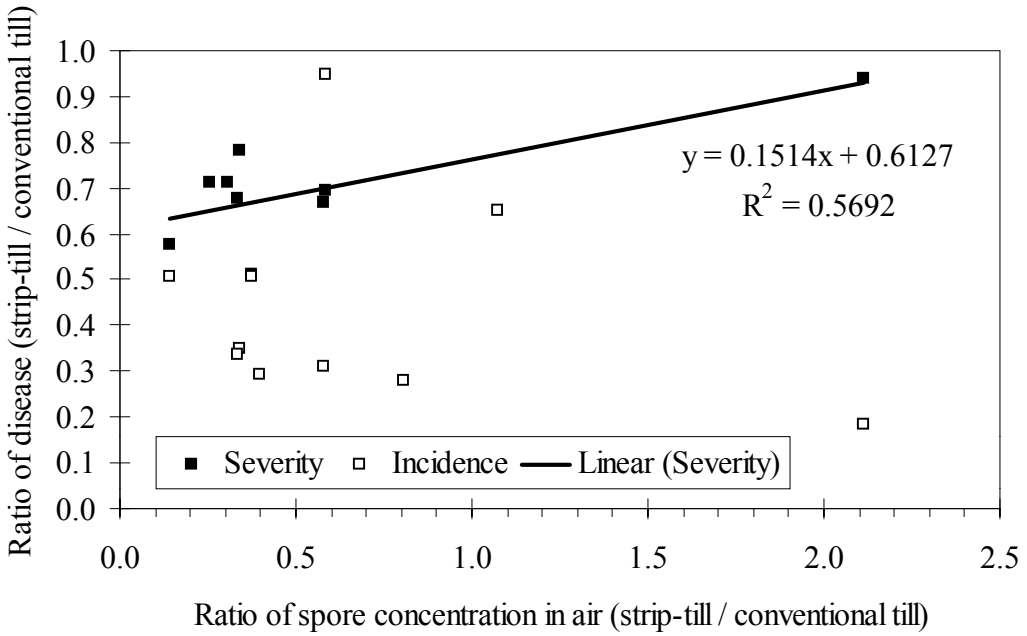

Fig. 3.5. Relationship between the tillage ratios (strip-till / conventional till) of early leaf spot disease severity and incidence and the tillage ratio of spore concentration in air above plots within the same collection week. The linear relationship was significant ($P = 0.02$) between ratios of disease severity and spore concentration, but the relationship was not significant ($P = 0.49$) between ratios of incidence and spore concentration.

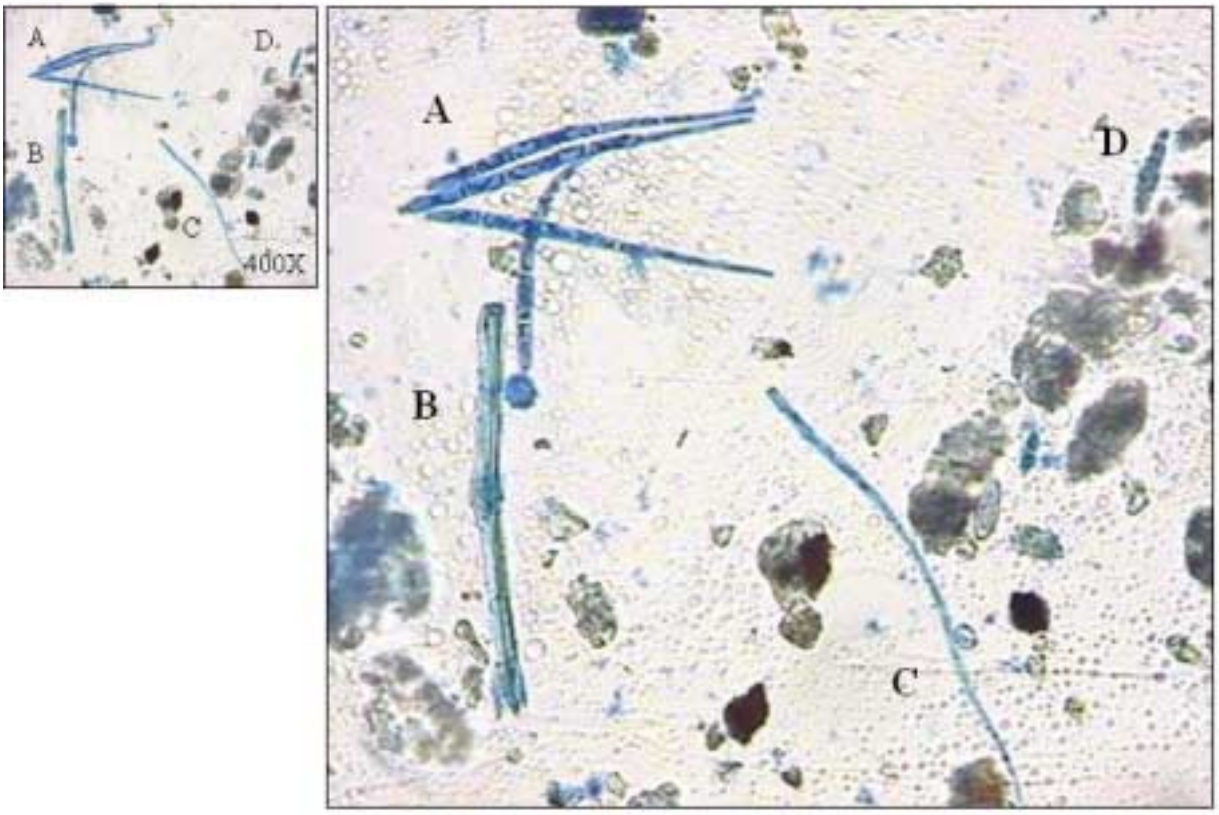

Fig. 3.6. Photograph of four stained *Cercospora arachidicola* conidia (A), and various structures (B-D) with similar appearances, captured using Rotorod samplers. The picture at the top left is an approximation of the magnification that was used for spore counts. The small beak at the wide end of *C. arachidicola* conidia was the characteristic found to be most useful for diagnosis.

CHAPTER 4

EFFECTS OF COVER CROP RESIDUE AND PRE-PLANT HERBICIDE ON EARLY LEAF SPOT OF PEANUT[1]

[1]Cantonwine, E.G., and A.K. Culbreath. 2005. To be submitted to *Plant Disease*.

Effects of cover crop residue and pre-plant herbicide on early leaf spot of peanut

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ABSTRACT

Time of disease onset (TDO) of early leaf spot of peanut is delayed in strip-tilled fields compared to conventionally tilled fields but the mechanism is unknown. Two factors of strip-tillage uncommon to conventional tillage are application of glyphosate to kill the cover crop, and the presence of cover crop residue on the soil surface after planting. Pre-plant herbicide (no herbicide, glyphosate and paraquat), reciprocal residue (plus residue in conventional tillage and minus residue in strip-tillage), and added straw mulch treatments were employed to determine effects on disease intensity and TDO. Additional experiments were carried out to study the effect of straw mulch quality (wheat or oat) and quantity (high or low), characterize the effect of mulch using straw, fumigated straw and plastic straw (textraw) mulch treatments, and study the disease response to tillage in non-rotated peanut fields. Early leaf spot epidemics were suppressed in strip-tillage treatments. Most of the disease variables assessed were not affected by glyphosate or paraquat. The reciprocal residue and conventionally tilled plus straw treatments resulted in intermediate levels of disease and TDO relative to conventional and strip-tillage standards. Suppression was greater when straw was added to strip-tilled plots. Wheat straw and high mulch treatments had slightly less disease than the oat straw and low mulch treatments. Addition of textraw mulch suppressed disease compared to the bare soil control, but not as much as straw and fumigated straw mulch. Disease was not consistently suppressed in strip-tilled plots

in non-rotated fields. These results indicate that the presence of cover crop residue provides some of the suppression observed in strip-tilled fields, but does not appear to be the only suppressive factor.

INTRODUCTION

Under crop rotation, epidemics of early leaf spot, caused by *Cercospora arachidicola* S. Hori, (teleomorph = *Mycosphaerella arachidis* Deighton) of peanut (*Arachis hypogaea* L.) have been shown to be less severe in strip-tilled fields than conventionally tilled fields (Monfort et al., 2004; Porter and Wright, 1991), with suppression worth as much as 3 to 5 applications of chlorothalonil (Monfort et al., 2004). We recently demonstrated that time of disease onset (TDO) is delayed in strip-tilled plots as evidenced by fewer initial infections in strip-tilled than conventionally tilled plots (Chapter 3). One likely cause for fewer infections is a reduction in the numbers of initial inocula dispersed to plant tissues from overwintering stroma in the soil. Initial inocula of *C. arachidicola* are thought to be transmitted to leaves primarily by rain splash, wind and insects (Shokes and Culbreath, 1997).

Two standard practices associated with strip-tillage that typically are not employed in conventional tillage are pre-plant applications of the herbicide glyphosate to kill the cover crop and maintenance of cover crop residue at the soil surface. Both glyphosate and cover crop residues have been implicated as mechanisms of disease suppression for other pathosystems (Berner et al., 1991; Everts, 2002; Ristaino et al., 1997). Fungicidal activity of glyphosate have been documented for a wide range of fungi, including *Pyrenophora tritici-repentis* and *Stagonospora nodorum*, pathogens of wheat (Harris and Grossbard, 1979; Sharma et al., 1989), *Drechslera teres* of barley (Toubia-Rahme et al., 1995), and *Calonectria ilicicola* of soybean

(Berner et al., 1991). Berner et al. (1991) demonstrated that pre-plant applications of low rates of glyphosate suppressed red crown rot in soybean fields that relied on naturally occurring inoculum of *C. ilicicola* from microsclerotia in infested soils. Although there are no reports of glyphosate toxicity to *C. arachidicola*, negative effects on the germination of *C. arachidicola* conidia were reported for post-emergence application rates of lactofen, 2,4-DB, and acifluorfen herbicides, and sporulation of early leaf spot lesions was reduced on plants treated with lactofen and acifluorfen 1 week prior to inoculation with *C. arachidicola* conidia (Baysinger et al., 1999). Associations of cover crop residue and disease suppression have been shown for a number of pathosystems, including Phytophthora blight of bell pepper, caused by *Phytophthora capsici* (Ristaino et al., 1997), and two diseases of pumpkin, Plectosporium blight, caused by *Plectosporium tabacinum*, and black rot, caused by *Didymella bryoniae* (Everts, 2002). The mechanism of disease suppression by surface residue is thought for some pathosystems to be related to reduced rain splash dispersal of inoculum (Madden and Ellis, 1990; Madden, 1992, 1997; Ristaino et al., 1997). Addition of straw mulch to bare soil plots resulted in decreased rain splash dispersal of spores of *Colletotrichum acutatum*, the cause of anthracnose fruit rot of strawberry, and *Phytophthora cactorum*, the cause of strawberry leather rot, from inoculum sources placed at the soil surface, and decreased foliar disease severities in the field (Madden and Ellis, 1990; Madden, 1992). The same effect on splash dispersal and disease was found for *C. acutatum* in plots with a living sudangrass mulch (Ntahimpera et al., 1998) and for *P. capsici* by a herbicide-treated wheat cover crop (Ristaino et al., 1997).

Preliminary observations in the field do not rule out or implicate either glyphosate or cover crop residue as a mechanism of disease suppression by strip-tillage. Early leaf spot suppression by reduced tillage was observed for plots where the cover crop in both

conservational tillage and conventional tillage was treated with glyphosate (Porter and Wright, 1991). However, conventional tillage following application of glyphosate may result in additional inoculum available for dispersal that was not exposed to glyphosate. In addition, suppression was observed for plots with low cover crop density due to cattle grazing (Monfort, 2002). The objective of this study was to quantitatively measure the effects of cover crop residue and pre-plant herbicide use on the TDO and subsequent development of early leaf spot epidemics. In addition, the effect of strip-tillage on early leaf spot epidemics in fields that were planted to peanut in successive years was included to determine whether disease suppression occurs in fields that are not under crop rotation.

METHODS

Effects of cover crop residue and pre-plant herbicides. Field studies were carried out at the University of Georgia Coastal Plain Experiment Station Rigdon Farm in 2002 and 2004, and Blackshank Farm in 2003 and 2004, in Tifton, GA. Soil type was a Tifton loamy sand. Fields were planted to cotton (*Gossypium hirsutum* L.) the previous year, and peanut 2 years prior, each grown using conventional tillage. Winter wheat (*Triticum aestivum*) was planted as a cover crop the previous fall.

The experiment was a randomized complete block design and treatments associated with conventional tillage were randomly assigned to 5 contiguous plots and those associated with strip-tillage were assigned to the remaining plots. Treatment plot sizes were 1.8 x 6.0 m separated by 2.4 m alleys in 2002, and 7.2 x 7.5 m separated by 3.0 m alleys in 2003 and 2004. The susceptible cultivar Georgia Green was planted to 91 cm spaced single rows in all plots. Tillage treatments were replicated 3 times in 2002, 4 times in 2003 and 4 times in each of 2

fields in 2004. Pre-plant herbicide treatments were: (i) glyphosate (Roundup 4 EC, Monsanto, Kansas City, MO) at 1.2 kg a.i./ha; (ii) paraquat (Starfire 1.5, Syngenta Crop Protection, Greensboro, NC) at 0.1 kg/ha; and (iii) no herbicide. Paraquat was selected as a pre-plant herbicide of different chemistry since glyphosate was found to have more fungicidal activity than paraquat against *Septoria nodorum* of wheat (Harris and Grossbard, 1979) and *Drechslera teres* in barley straw (Toubia-Rahme et al. 1995). Residue treatments included removal of cover crop residue in strip-tillage and addition of residue from the corresponding strip-tillage plot in conventional tillage (reciprocal residue treatments) (Figs. 4A.1-2). Treatments also included the addition of 1 bale of wheat straw mulch to plots in each of conventional and strip-tillage. Residue was removed from strip-tillage plots by cutting near the soil with a string trimmer and raking with minimal disturbance of the soil. Pre-plant herbicide treatments were tested in 2002 and 2003, added straw mulch in 2003 and 2004 and reciprocal residue treatments all 3 years.

Herbicide treatments were applied to plots prior to tillage in strip-tilled plots, and after tillage in conventionally tilled plots. For the no herbicide treatment, the cover crop residue was killed by mowing and deep turning in conventional tillage, and in response to increasing daily mean temperatures in strip-tillage. Weeds in strip-tilled plots not treated with herbicide were removed manually. In conventionally tilled plots, the cover crop was mowed and disked twice prior to deep turning (20 to 25 cm deep) with a switch plow, and bedded with a disk bedder. In strip-tillage plots, a subsoil shank attached to a two-row strip-till implement (Kelley Manufacturing Co., Tifton, GA) was used to loosen the plow pan 33 cm beneath the row, while the implement tilled strips approximately 20 to 25 cm wide. Cover crop residue and straw mulch treatments were applied 12 to 14 days after planting (DAP) in all years.

Early leaf spot incidence was assessed weekly as the number of leaves with 1 or more lesions or defoliated leaflets divided by the total number of leaves x 100, beginning when disease was first noticed. Percent incidence was estimated from 10 lateral branches arbitrarily collected from each plot, beginning 78 DAP in 2002, 59 DAP in 2003, and 56 DAP in 2004. Disease severity was monitored over the season using the Florida 1 to 10 scale (Chiteka et al., 1988a), described in Chapter 3. Severity was assessed weekly for 4 weeks beginning 98 DAP in 2002 and 9 weeks beginning 63 DAP in 2003. In 2004, severity assessments were made at 7- to 22-day intervals 6 times beginning 56 DAP. Final percent defoliation was estimated from the last severity assessment, 127 DAP in 2002, 119 DAP in 2003, 131 DAP at the Rigdon Farm and 132 DAP at the Blackshank Farm in 2004. Mean disease incidence and severity of the conventional tillage control, strip-tillage control and reciprocal residue treatments were plotted against assessment date for each field and year.

For each plot, area under the disease progress curve (AUDPC) was computed for percent incidence and severity separately (Shaner and Finney, 1977). Disease assessments were converted to proportions [proportion of incidence = percent incidence / 100; proportion of severity assessment = (Florida rating - 1) / 9], and linearized forms of the Gompertz [-ln(-ln y)], logistic [ln(y/1-y)] and monomolecular [ln(1/1-y)] models were fit using linear regression of transformed disease intensity proportions on time (DAP). The model that significantly ($P < 0.05$) fit all of the curves within each experiment was selected. If more than one model fit all of the curves within an experiment, that model with the highest recalculated R^2 after back transformation was selected. If none of the models fit a majority of the curves satisfactorily, models were fit to data with replications combined after the replication effect was removed and the mean replication estimate was added back to residuals, or the data was excluded from

analysis. TDO was estimated by calculating the time (DAP) when the model predicted 5% incidence or 1.5 on the Florida scale.

Spotted wilt disease, caused by the *Tomato spotted wilt virus* (TSWV), was not the primary disease of interest in this study, but spotted wilt intensity was assessed after noticing differences among treatments. Spotted wilt intensity was determined in each plot between 100 and 116 DAP each year using a disease intensity rating that represents a combination of incidence and severity as described by Culbreath et al. (1997b). The number of 0.3-m portions of row containing severely stunted, chlorotic, wilted or dead plants was counted for each plot and converted to a percentage of row length for comparison of treatments.

Treatment means were determined across field and year using the Proc MIXED procedure of SAS (v 8.3; SAS Institute, Inc. Cary, NC). Standard errors were corrected due to the fact that not all treatments appeared in every year. Comparisons of interest were used to test for treatment effects on AUDPC, TDO, and defoliation. Treatment effects on spotted wilt were examined using the Proc MIXED procedure with year, location within year and replication as random effects.

Effects of straw mulch quality and quantity. Field studies were conducted in conventionally tilled plots in 2003 and 2004 at the University of Georgia Southwest Georgia Branch Experiment Station Plains, Plains, GA, and in 2004 at the Rigdon Farm. Five treatments, consisting of surface application of low and high levels of wheat straw mulch (½ and 1 bale, respectively), oat (*Avena sativa*) straw mulch ($^1/_3$ and $^2/_3$ bale, respectively), and a bare-soil control, were replicated 4 times. The mean weights of straw bales were 10.0 kg for wheat and 14.5 kg for oat. Plots were 5.4 x 7.6 m with 3.0-m alleys. Early leaf spot severity was assessed mid-season at 74 DAP in 2003 and 79 DAP in 2004 for each plot. The effects of mulch quality

and quantity factors were tested using the Proc MIXED procedure with year, location within year and replication as random effects after determination that all straw mulch treatments differed from the control using treatment as the main effect in the Proc MIXED model.

Characterization of disease suppression by straw mulch. Experimental plots, 3.6 x 7.5 m with 3.0-m alleys, were established in conventionally tilled fields in 2003 and 2004 at the Rigdon Farm. Four treatments, consisting of surface application of 1 bale of wheat straw mulch, fumigated wheat straw mulch, or plastic pine straw mulch (textraw) (Textraw Synthetic Pine Straw, Thomasville, GA), and bare soil control, were replicated 5 times. Fumigated straw bales were treated with 67% methyl bromide and 33% chloropicrin at 0.48 to 0.54 kg m^{-3} under plastic for 3 to 4 days. These rates were well above the recommended rate, 0.024 to 0.064 kg m^{-3}, due to the volume fumigated, 0.87 to 1.48 m^3, being smaller than the potential volume of fumigation of the smallest chemical canister available. The fumigated bales were removed from the plastic immediately before placement in the field. The mean weights of bales were 10.0 kg for fumigated wheat straw in 2003, and non-fumigated wheat straw in 2003 and 2004, 18.1 kg for fumigated straw (wheat, corn mix) in 2004, and 13.6 kg for textraw both years. Treatments were applied 7 DAP in 2003 and 15 DAP in 2004.

Disease severity was assessed 6 times throughout the season using the Florida 1 to 10 scale. For each plot, AUDPC was computed. Data were adjusted to proportions and linearized forms of simple models fit, as described above. Estimates of TDO were calculated for the time (DAP) when the model predicted 1.5 on the Florida scale. Treatment effects on AUDPC and TDO were tested using the Proc MIXED procedure with year and replication as random effects.

A detached leaf experiment (Melouk and Banks, 1978; Waliyar et al., 1995) was carried out to estimate the occurrence and frequency of primary infections in control and textraw plots.

Five asymptomatic leaves per plot (trap leaves) were arbitrarily collected from the first or second newly expanded leaf of lateral branches in conventional and strip-tillage plots. Leaves were collected weekly from the field beginning 47 DAP in 2003 and 36 DAP in 2004, until disease was observed in leaves from all plots. Leaves were excised at the base of the petiole using a razor blade. The cut ends were immediately dipped in a dry formulation of napthaleneacetamide and thiram (Rootone, Security Products Co., Atlanta, GA) and set in sterile saturated sand in 100 ml beakers or test tubes filled with sterile water covered with Parafilm. Leaves were transported to the laboratory and incubated in a mist chamber at room temperature (20 to 23°C) and a 12-h photoperiod. After 48 h, misting was discontinued. Water was added to beakers and test tubes as needed. The number of lesions per leaf and percent incidence of leaves with lesions were recorded after 2 weeks. Mean number of lesions per leaf and percent incidence from the final collection dates for each field (73 DAP in 2003, and 57 DAP in 2004) were analyzed using the Proc MIXED procedure.

Effects of tillage treatments in fields without crop rotation. A field study was carried out at the University of Georgia Coastal Plain Experiment Station Lang Farm, Tifton, GA during the 2002 to 2004 growing seasons. Fields were planted to peanut the previous year in 2003 and 2004, and two years prior in 2002. The winter cover crop, planted the previous fall, was winter wheat in 2002, and oat in 2003 and 2004.

Conventional tillage and strip-tillage treatments were conducted as described above with the exception of pre-plant herbicides. No pre-plant herbicide was used in conventionally tilled plots and glyphosate, 1.2 kg a.i./ha, was applied to all strip-tilled plots. Treatments were conventional and strip-tillage in 2002. In 2003 and 2004, the reciprocal cover crop residue treatments (minus residue in strip-tillage and plus residue in conventional tillage), as described

previously, were included. Treatments were replicated 4 times each year and plot sizes were 1.8 x 7.5 m in 2002, 5.4 x 12.1 m in 2003, and 5.4 x 7.5 m in 2004. In 2002, 6 additional treatment plots included in the experimental design were treated with 4 to 7 applications of chlorothalonil (Bravo Weatherstik 720 F, Syngenta Crop Protection, Inc, Greensboro, NC), 1.26 kg a.i./ha; these treatments were not repeated in 2003 or 2004. No fungicides were employed in the field in 2003, while peanuts immediately surrounding plots were sprayed with chlorothalonil in 2004.

Percent incidence of early leaf spot, as described above, was assessed weekly for 5 weeks beginning 69 DAP in 2002, and 6 weeks beginning 57 DAP in 2004. Leaf spot severity was assessed using the Florida 1 to 10 scale 6 times beginning 100 DAP in 2002, 5 times beginning 44 DAP in 2003, and 6 times beginning 57 DAP in 2004. For each plot, AUDPC was computed for percent incidence and severity separately. Treatment effects on AUDPC values were tested using the PROC MIXED procedure of SAS with year and replication as random effects.

RESULTS

Effects of cover crop residue and pre-plant herbicide. Disease progress curves for early leaf spot incidence in the conventional tillage no herbicide, strip-tillage glyphosate, and reciprocal residue treatments are shown in Fig. 4.1. The increase in disease incidence over time in each plot in 2002 and 2004 and for combined plots in 2003 was best described by the logistic model, except for 2 replications in the strip-tillage plus straw treatment at the Blackshank Farm in 2004, which were excluded from analysis because none of the models provided an adequate fit. Disease progress curves for Florida scale severity ratings in the conventional tillage no herbicide, strip-tillage glyphosate, and reciprocal residue treatments are shown in Fig. 4.2. The increase in disease severity over time for plots in each field and year was best described by the

logistic model. Parameter estimates (y-intercept and rate) and regression statistics for the selected models are presented in Table 4A.1.

Treatment means and standard errors of early leaf spot AUDPC based on incidence (AUDPC-I) and severity (AUDPC-S), TDO based on incidence (TDO-I) and severity (TDO-S), and final percent defoliation were computed across field and year (Table 4.1). Across pre-plant herbicides, disease was lower and TDO was delayed in strip-tilled than conventionally tilled plots (Table 4.2). There was a reduction in AUDPC-S with the use of glyphosate compared to no herbicide treatment, but the effect was small compared to the overall effect of strip-tillage treatments and no glyphosate effect was apparent for AUDPC-I or defoliation. Treatment with paraquat resulted in earlier TDO-I than no herbicide or glyphosate treatments (Table 4.2). Adding cover crop residue to conventionally tilled plots decreased AUDPC values and defoliation, and significantly delayed TDO-I by 4.9 days; TDO-S was numerically delayed by 5.8 days (Tables 4.1 and 4.2). Removing residue from strip-tillage plots increased AUDPC-I compared to the strip-tillage glyphosate control, but AUDPC-S, TDO and defoliation did not significantly differ between these treatments (Table 4.2). Adding straw to strip-tillage provided additional suppression to AUDPC values compared to the strip-tillage glyphosate control treatment and delayed TDO-I by an additional 7.3 days (Tables 4.1 and 4.2). Addition of cover crop residue to conventionally tilled plots did not suppress disease as much as strip-tilled plots with or without residue; however, TDO estimates of this treatment were comparable to TDO estimates for the strip-tilled treatment where cover crop residue was removed (Table 4.2). Addition of straw mulch to conventionally tilled plots resulted in a comparable AUDPC-I and TDO-S as the strip-tilled treatment plot where cover crop residue was removed. Final percent defoliation and AUDPC-S was greater in the conventionally tilled plots where straw mulch was

added than the strip-tilled plots where cover crop residue was removed (Table 4.2). Although straw and cover crop residue effects on disease were not directly compared, disease assessments were similar or lower and estimates of TDO were similar or later for the added straw treatment than the cover crop residue treatment in conventional tillage (Table 4.1).

Across years, the addition of cover crop residue to the soil surface of conventionally tilled plots resulted in comparable levels of spotted wilt suppression as strip-tillage. However, removing cover crop residue from strip-tilled plots did not affect spotted wilt suppression (Fig. 4A.3).

Effects of straw mulch quality and quantity. All mulch treatments suppressed leaf spot epidemics compared to the bare soil control, which had a severity rating of 4.7 ($P < 0.01$). There were small differences between the severity ratings of the high and low mulch treatments, 3.6 and 3.9, respectively ($P < 0.01$), and the wheat and oat mulch treatments, 3.6 and 3.8, respectively ($P = 0.05$).

Characterization of disease suppression by straw mulch. All mulch treatments had lower AUDPC values than the bare soil control (AUDPC = 254) ($P < 0.01$). The straw and fumigated straw mulch treatments had similar AUDPC values, 222 and 224, respectively, and lower values than the textraw treatment, 238 ($P < 0.01$) (LSD = 8, df = 27).

The increase in disease severity over time was best described by the monomolecular model in 2003 ($P < 0.01$) and the logistic model in 2004 ($P < 0.02$). Parameter estimates and regression statistics for the selected models are presented in Table 4A.2. TDO occurred later in the straw and fumigated straw mulch treatments (60 and 61 DAP, respectively) than in the control (53 DAP) and textraw (56 DAP) treatments ($P < 0.01$); TDO for the later two treatments did not differ ($P = 0.10$). Trap leaves from control and textraw plots indicated a lower incidence

of initial infections in the textraw than control treatment, 0.46 and 0.88% incidence respectively, ($P < 0.01$) and fewer initial infections, 2.0 and 6.6 lesions per leaf respectively ($P < 0.01$).

Effects of tillage treatments in fields without crop rotation. In 2002, neither AUDPC based on disease incidence or severity was significantly different in conventional or strip-tillage ($P \geq 0.17$) (Table 4.3). Likewise, no difference in AUDPC was detected among tillage-residue treatments in 2003 ($P = 0.99$). In 2004, AUDPC-I was lower in the strip-tilled plots and the conventional tillage plus residue plots than the conventional tillage control plots ($P \leq 0.02$), while AUDPC-S was lower in the strip-tilled plots than the conventionally tilled plots ($P < 0.01$) (Table 4.3).

DISCUSSION

Based on our results, pre-plant application of herbicide does not appear to be the cause of early leaf spot suppression in strip-tillage. Most of the disease variables assessed were not affected by either glyphosate or paraquat treatments. The lack of consistent leaf spot suppression in the continuous peanut tests also provides evidence that glyphosate was not the primary factor in leaf spot suppression since all strip tillage treatments in those tests included use of glyphosate.

The presence of cover crop residue at the soil surface does appear to be involved in disease suppression. The reciprocal cover crop residue treatments (removal of residue in strip tillage and addition of residue in conventional tillage) and the conventional till straw mulch treatment had intermediate levels of disease and TDO estimates relative to the tillage standards, while even greater suppression and delayed disease onset when straw was added to strip-tilled plots. In most cases, the disease suppression and TDO delay with added cover crop residue or straw to conventionally tilled plots was not as great as the disease suppression and TDO delay in

strip-tilled plots, with or without cover crop residue. This suggests that the presence of cover crop residue at the soil surface is not the only disease suppressive factor of strip-tillage, and that tillage differences that were not explored in these experiments may also affect disease. For example, the density of overwintering *C. arachidicola* stroma at the soil surface may be less in strip-tilled fields than conventionally tilled fields. This may be particularly true for fields under a 2-year rotation, as for most of these field studies, since infested peanut debris may be tilled under the first year following peanut and returned to the surface the second year. It is also possible that more soil erosion in conventionally tilled fields increases the overall surface area of infested soil exposed to plants throughout the season. In a similar study in Tifton, GA, Truman (2004) found that nearly twice as much soil was lost from peanut plots under conventional tillage than those in their first year of strip-tillage. Soil displacement was observably higher in the conventionally tilled plots than strip-tilled plots after rain events in our fields, but was not measured. Differences in the microbial communities within the soils of conventionally tilled and strip-tilled fields may also impact initial inoculum potential by affecting the competition or antagonism of organisms with *C. arachidicola* stroma or conidia. Comparisons of the microbial communities within soils of Georgia peanut fields under conventional and strip-tillage have not been studied in great detail. However, the communities may not differ greatly for fields in their first year of strip-tillage. Organic carbon, a predictor of soil community diversity, and microbial biomass were not detectably different for peanut plots in their first year of strip-tillage compared to conventionally-tilled plots (Truman, 2004). After 6 years of continuous strip-tillage, organic carbon increased in the strip-tilled plots by 75% in the top 1.3 cm soil and microbial biomass increased by 200 to 600% in the top 7.6 cm (Truman, 2004). More work is needed to assess the

effects of conservation tillage on early leaf spot epidemics under continuous conservation tillage practices, and across various rotation patterns.

Cover crop densities in strip-till plots were not measured in these studies, but they varied from relatively low to medium densities. In most cases, the straw treatments provided more surface coverage in plots than cover crop residue. The only exception was at the Blackshank Farm in 2004, where the amount of cover crop residue removed from strip-tillage plots appeared to be comparable to 1 bale of straw for 2 of 4 replications. This observation along with the finding that the high straw mulch treatments suppressed disease slightly more than the low mulch treatments suggests that placement of baled straw at the soil surface in conventionally tilled plots had a similar effect on disease as cover crop residue in these plots. Although suppression of early leaf spot has been observed in fields with relatively low cover crop densities (Monfort, 2002) and with wheat, rye and oat cover crops, residue mass and cover crop species may also affect suppression potential of strip-tillage. More research is needed to explore the effects of cover crop quality and density on disease suppression under strip-tillage.

Early leaf spot suppression and TDO were similar in plots with added straw and fumigated straw mulch. Since the fumigation of straw did not affect disease suppression, it appears that microorganisms associated with wheat straw are not critical for suppression. However, this does not rule out a biological component of suppression since fumigated straw can be colonized and degraded by microorganisms. Disease suppression was also observed for textraw mulch plots compared to bare soil plots, although not to the degree of the straw mulch treatments. However, disease suppression and the observation of fewer initial infections on detached trap leaves in the textraw mulch plots than the bare soil plots indicates that the physical

presence of mulch is responsible for at least part of the suppression and TDO delay observed for the straw mulch, cover crop residue and strip-tillage treatments.

The mechanism of early leaf spot suppression by mulch may be similar to that reported for leather rot and anthracnose fruit rot of strawberry, where the horizontal dispersal of spores by rain splash had a steeper gradient for plots with straw mulch at the soil surface than plots with bare soil (Madden and Ellis, 1990; Madden, 1992, 1997). A rain simulation study in peanut plots under strip-tillage and conventional tillage indicated that rain drop impact velocities were measurably less in the strip-tilled plots (Truman, personal communication). Suppression of spore dispersal by surface mulch has been suggested to be related to its effect on increasing surface roughness, which has been shown to reduce rain splash velocities and alter the angle of splash trajectories (Madden, 1992, 1997; Yang and Madden, 1993). The observation that organic mulch enhanced disease suppression better than the inorganic textraw mulch suggests that the organic nature of the mulch provides additional suppression. Splash dispersal of *C. acutatum* conidia was found to be greater in plots with plastic sheet mulch than bare soil or straw mulch (Yang et al., 1990), and it is possible that the plastic nature of the textraw mulch, although providing similar complexity to surface roughness as the organic mulches, did not reduce rain splash dynamics as well as the organic mulch. It is also possible that the organic mulches enhanced microorganism composition near the soil surface or released chemical toxins that interfered with inoculum production of stroma.

Without crop rotation of at least a year, growers should not rely on strip-tillage to help manage early leaf spot since no suppression was observed with strip-tillage 2 of the 3 years tested in fields planted to peanut the previous summer. Overall, the presence or absence of cover crop residue did not appear to have a strong effect either year tested. However, in 2004 disease

development in the residue treatments showed numerical trends that corresponded with those seen in the cover crop residue study. It was surprising that early leaf spot epidemics were not more severe in strip-tilled plots than conventionally tilled plots without rotation; a number of volunteer peanut plants were present in strip-tilled plots shortly after planting each year and we expected infested peanut debris from the previous season to be nearer to the soil surface in the strip-tilled plots than the conventionally tilled plots. It is possible that much of the infested peanut debris was buried in strip-tilled plots by the previous year's digging or while planting the cover crop the previous fall; which may have resulted in similar amounts of debris with and without extensive tillage. It is also possible that the inoculum load near the soil surface was greater in the strip-tilled plots than conventionally tilled plots, but the suppressive effect of strip-tillage resulted in comparable disease levels between the tillage systems 2 of 3 years tested.

The addition of cover crop residue from strip-tilled plots to the soil surface of conventionally tilled plots resulted in comparable levels of spotted wilt suppression as strip-tillage. However, removing cover crop residue from strip-tillage did not cause a reversal of spotted wilt suppression. One hypothesis addressing the mechanism of spotted wilt suppression by strip-tillage is that thrips, the vector of TSWV, have a harder time finding peanut plants in strip-tilled fields than conventionally tilled fields, which leads to less feeding and fewer infections(Culbreath et al., 2003). Interplot interference of treatment plots in the strip-tillage may have failed to distinguish the cover crop residue treatments from the perspective of thrips.

In conclusion, application of a pre-tillage herbicide is not the cause of leaf spot suppression by strip-tillage, while the maintenance of cover crop residue at the soil surface appears to explain part of the suppression. Cover crop residue interferes with the number of initial inocula that are dispersed from stroma in the soil to the plant tissues. The density and

quality of cover crop may influence the suppression potential of strip-tillage; however, more research is needed to characterize these relationships. Without crop rotation of at least a year, growers should not rely on strip-tillage to help manage early leaf spot epidemics. Additional research is needed to identify the mechanism of initial inoculum suppression by surface mulch, and to identify other factors of strip-tillage involved in early leaf spot suppression of peanut.

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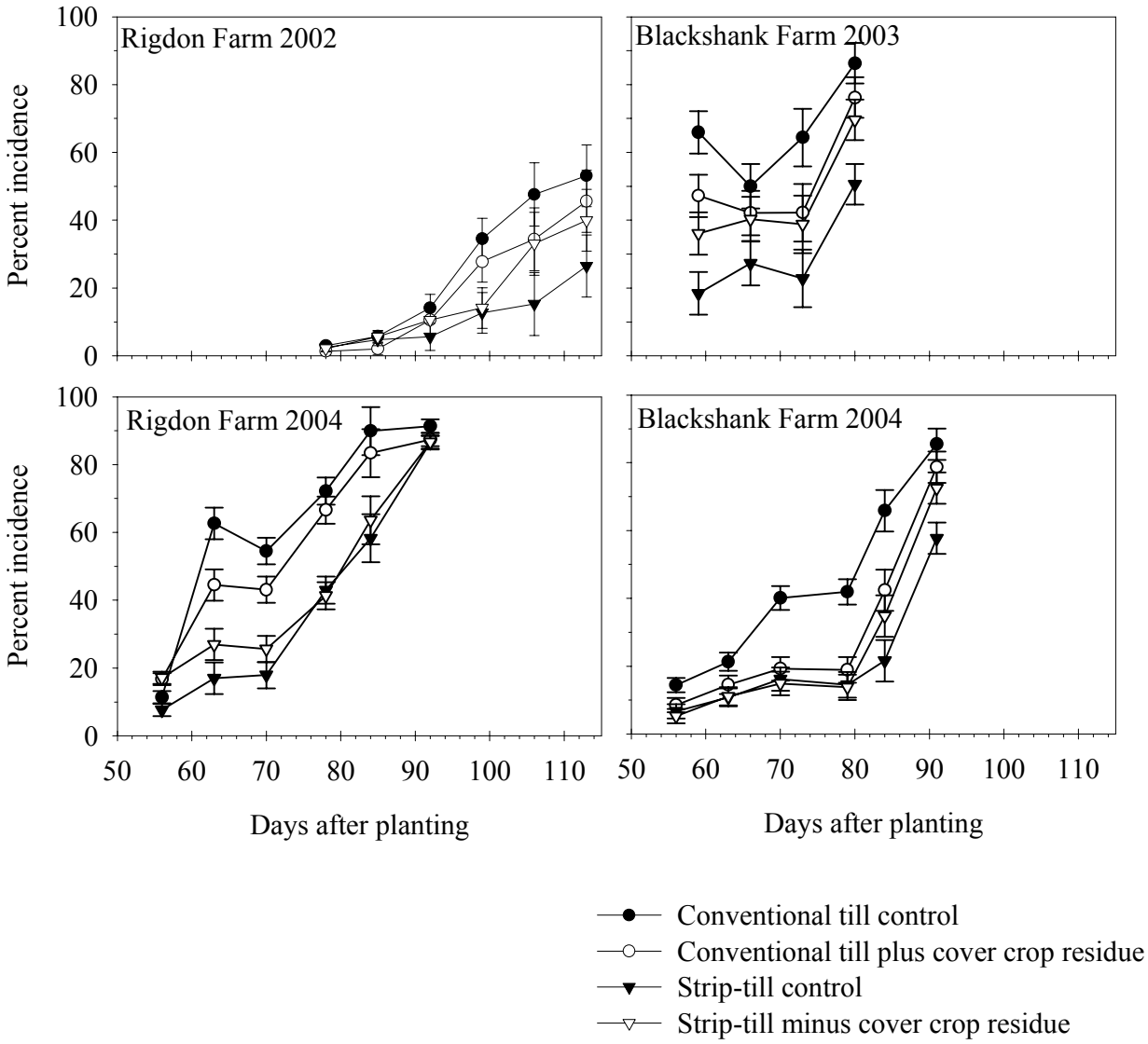

Fig. 4.1. Progress of early leaf spot incidence over time in peanuts planted in conventionally and strip-tilled plots with or without cover crop residue. Data points are least square means of 3 replications for the Rigdon Farm in 2002 and 4 replications for the Blackshank Farm in 2003 and 2004 and Rigdon Farm in 2004.

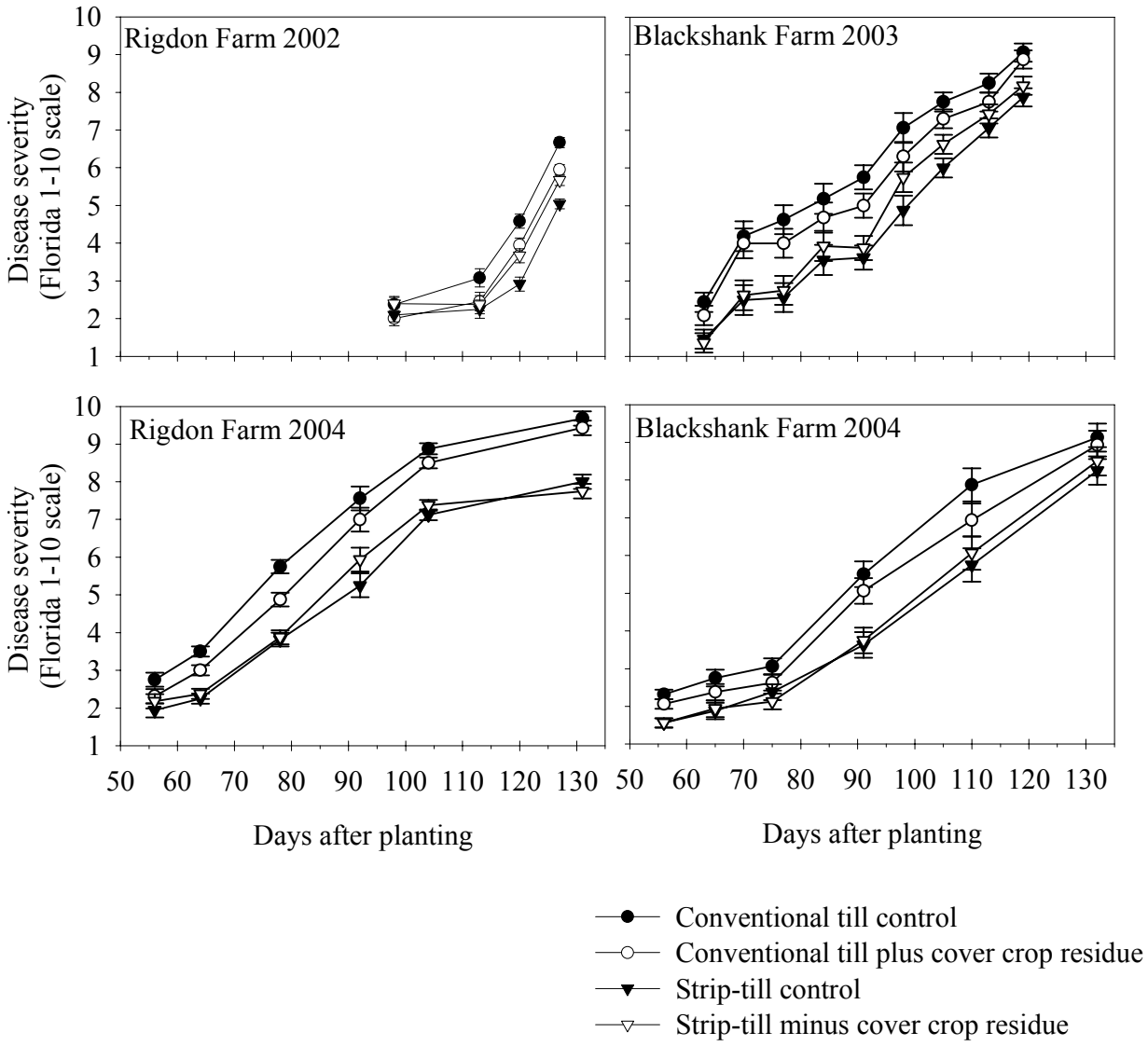

Fig. 4.2. Progress of early leaf spot severity over time in peanuts planted in conventionally and strip-tilled plots with or without cover crop residue. Data points are least square means of 3 replications for the Rigdon Farm in 2002 and 4 replications for the Blackshank Farm in 2003 and 2004 and Rigdon Farm in 2004.

Table 4.1. Effect of pre-plant herbicide and cover crop residue treatment on area under the disease progress curve (AUDPC) and time of early leaf spot disease onset (TDO) of peanut combined across the Rigdon Farm, 2002 and 2003, and Blackshank Farm, 2003 and 2004.

Treatment	% Incidence[a]				Severity[b]				Final %	
	AUDPC		TDO (DAP)[c]		AUDPC		TDO (DAP)[d]		Defoliation[e]	
	Mean[f]	SE[g]	Mean[f]	SE[g]	Mean[f]	SE[g]	Mean[f]	SE[g]	Mean[f]	SE[g]
Conventional tillage no herbicide	1539	57.8	45.4	1.83	313	6.3	52.4	2.22	93.1	1.30
Conventional tillage glyphosate	1444	77.5	48.6	2.67	299	8.4	53.3	3.26	95.7	1.73
Conventional tillage paraquat	1512	77.5	37.4	2.67	295	8.4	53.4	3.26	94.1	1.74
Conventional tillage plus cover crop residue	1174	59.5	51.3	1.83	284	6.3	58.6	2.22	90.2	1.32
Strip-tillage no herbicide	784	77.5	66.5	2.67	244	8.4	64.6	3.26	77.0	1.70
Strip-tillage glyphosate	759	59.5	60.0	1.83	229	6.3	64.4	2.22	75.3	1.26
Strip-tillage paraquat	812	84.9	56.1	2.67	237	8.4	66.7	3.26	76.7	1.70
Strip-tillage minus cover crop residue	978	57.8	56.2	1.83	242	6.3	62.1	2.22	79.4	1.28
Conventional tillage plus straw	960	70.8	64.6	2.04	279	7.7	61.7	2.49	91.4	1.61
Strip-tillage plus straw	519	70.8	69.9	2.04	198	7.7	69.7	2.49	78.0	1.56

[a] Assessed as the number of leaves with at least 1 early leaf spot lesion or 1 defoliated leaflet / total number of leaves of 10 lateral branches * 100.
[b] Based on the Florida 1-10 rating scale.
[c] Estimated from logistic models based on incidence when disease = 5% incidence.
[d] Estimated from logistic models based on severity when Florida 1-10 rating = 1.5.
[e] Based on the last Florida 1-10 rating per season, 127 DAP in 2002, 119 DAP in 2003, 131-132 DAP in 2004.
[f] Least square means from Proc MIXED combined across field and year.
[g] Standard errors correctly determined from analysis since not all treatments appeared all years.

Table 4.2. Comparisons of interest *t*-values for pre-plant herbicide and cover crop residue treatments across the Rigdon Farm 2002 and 2004, and Blackshank Farm 2003 and 2004.

Treatment	% Incidence[ad]		Severity[bd]		Final %
	AUDPC	TDO (DAP)[e]	AUDPC	TDO (DAP)[f]	Defoliation[cd]
Strip-tillage vs. Conventional tillage [g]	-11.95 **	8.62 **	-10.34 **	5.06 **	-12.23 **
Glyphosate vs. No herbicide [h]	-0.87	-0.72	-1.99 *	0.13	0.76
Paraquat vs. No herbicide [h]	0.01	-3.70 **	-1.59	0.50	0.34
Glyphosate vs. Paraquat [h]	-0.79	3.03 **	-0.27	-0.38	0.37
Conventional tillage no herbicide vs. Conventional tillage plus cover crop residue	4.40 **	-2.28 *	3.26 **	-1.94	2.23 *
Strip-tillage glyphosate vs. Strip-tillage minus cover crop residue	-2.64 **	1.47	-1.46	0.75	-1.63
Conventional tillage no herbicide vs. Conventional tillage plus straw	6.35 **	-7.02 **	3.46 **	-2.77 **	1.13
Strip-tillage glyphosate vs. Strip-tillage plus straw	2.60 *	-3.61 **	3.07 **	-1.58	-0.97
Conventional tillage plus cover crop residue vs. Strip-tillage minus cover crop residue	2.36 *	-1.89	4.79 **	-1.11	4.40 **
Strip-tillage minus cover crop residue vs. Conventional tillage plus straw	0.19	-2.92 **	-3.41 **	0.10	-4.38 **

Means and standard errors used to compute *t*-values are shown in Table 4.1.
[a] Assessed as the number of leaves with at least 1 early leaf spot lesion or 1 defoliated leaflet / total number of leaves of 10 lateral branches * 100.
[b] Based on the Florida 1-10 rating scale.
[c] Based on the last Florida 1-10 rating of season, 127 DAP in 2002, 119 DAP in 2003, 131-132 DAP in 2004.
[d] Single asterisk (*)indicates significance at 5% level, and double asterisk (**) indicates significance at 1% level, df=98.
[e] Estimated from models based on incidence when disease = 5% incidence.
[f] Estimated from models based on severity when Florida 1-10 rating = 1.5.
[g] Across pre-plant herbicide.
[h] Across tillage.

Table 4.3. Effects of tillage and reciprocal cover crop residue treatments on area under the disease progress curve (AUDPC) for early leaf spot in continuous peanut fields, 2002-2004.

Treatment	2002		2003 [a]		2004 [a]	
	Incidence AUDPC[a]	Severity AUDPC[b]	Incidence AUDPC[a]	Severity AUDPC[b]	Incidence AUDPC[a]	Severity AUDPC[b]
Conventional tillage	371 a	207 a	-	233 a	1658 b	277 b
Conventional tillage plus cover crop residue	-	-	-	232 a	1281 a	253 b
Strip-tillage	897 b	241 a	-	233 a	999 a	208 a
Strip-tillage minus cover crop residue	-	-	-	233 a	1246 a	215 a
Standard error	174.0	20.0	-	5.9	85.8	7.9

[a] Least square means from Proc MIXED of area under the disease progress curve using the number of leaves with at least 1 early leaf spot lesion or 1 defoliated leaflet / total number of leaves of 10 lateral branches x 100. Letters in a column that are the same do not differ at the 5% level.
[b] Based on Florida 1-10 scale.

APPENDIX TO CHAPTER 4

Fig. 4A.1. Strip-tilled plot with cover crop residue removed.

Fig. 4A.2. Conventionally tilled plot with cover crop residue from a strip-tilled plot added to the soil surface.

Table 4A.1. Parameter estimates and regression statistics for the logistic model selected to describe early leaf spot disease progression over time for each peanut treatment plot at the Rigdon Farm in 2002 and 2004, and Blackshank Farm in 2003 and 2004.

		Incidence[a]				Severity[b]			
Year/Farm/Treatment	Rep	Y-intercept	Rate	*P*-value	Recalc. R2[c]	Y-intercept	Rate	*P*-value	Recalc. R2[c]
2002, Rigdon Farm									
Conventional tillage	1	-13.32	0.133	< 0.01	0.92	-8.87	0.073	< 0.01	0.91
no herbicide	2	-11.74	0.105	< 0.01	0.48	-9.70	0.078	< 0.01	0.86
	3	-12.11	0.103	< 0.01	0.85	-9.92	0.079	< 0.01	0.90
Conventional tillage	1	-15.57	0.154	< 0.01	0.92	-9.32	0.079	< 0.01	0.93
glyphosate	2	-13.92	0.130	< 0.01	0.67	-8.93	0.073	< 0.01	0.78
	3	-10.93	0.097	< 0.01	0.84	-8.63	0.069	< 0.01	0.87
Conventional tillage	1	-14.72	0.151	< 0.01	0.97	-8.05	0.067	< 0.01	0.86
paraquat	2	-13.75	0.129	< 0.01	0.81	-8.54	0.069	< 0.01	0.81
	3	-11.42	0.102	< 0.01	0.77	-10.03	0.080	< 0.01	0.84
Conventional tillage	1	-14.02	0.134	< 0.01	0.90	-9.69	0.076	< 0.01	0.92
plus cover crop residue	2	-11.75	0.103	< 0.01	0.77	-10.45	0.082	< 0.01	0.87
	3	-12.47	0.104	< 0.01	0.68	-9.81	0.075	< 0.01	0.87
Strip-tillage	1	-11.25	0.094	< 0.01	0.84	-8.31	0.061	< 0.01	0.83
no herbicide	2	-9.60	0.074	< 0.01	0.82	-7.11	0.051	0.02	0.72
	3	-8.19	0.060	< 0.01	0.83	-8.27	0.060	0.05	0.76
Strip-tillage	1	-9.79	0.077	< 0.01	0.89	-6.00	0.043	< 0.01	0.61
glyphosate	2	-9.62	0.077	< 0.01	0.66	-7.80	0.056	< 0.01	0.79
	3	-8.25	0.060	< 0.01	0.74	-11.40	0.086	0.01	0.88
Strip-tillage	1	-7.50	0.059	< 0.01	0.57	-9.93	0.073	< 0.01	0.83
paraquat	2	-8.19	0.060	< 0.01	0.68	-8.70	0.065	< 0.01	0.86
	3	-8.47	0.062	< 0.01	0.68	-9.33	0.070	< 0.01	0.84

Table 4A.1 continued

Strip-tillage	1	-11.32	0.102	< 0.01	0.77	-6.15	0.046	0.05	0.61
minus cover crop residue	2	-11.91	0.103	< 0.01	0.93	-7.70	0.058	< 0.01	0.81
	3	-9.13	0.071	< 0.01	0.83	-9.88	0.075	< 0.01	0.89
2003, Blackshank Farm									
Conventional tillage	1	-3.33	0.059	0.02	0.23	-5.68	0.062	< 0.01	0.96
no herbicide	2	*[c]	*	*	*	-5.19	0.061	< 0.01	0.99
	3	*	*	*	*	-5.44	0.064	< 0.01	0.96
	4	*	*	*	*	-4.49	0.055	< 0.01	0.92
Conventional tillage	1	-4.41	0.073	< 0.01	0.37	-5.86	0.063	< 0.01	0.97
glyphosate	2	*	*	*	*	-5.52	0.065	< 0.01	0.97
	3	*	*	*	*	-5.13	0.060	< 0.01	0.93
	4	*	*	*	*	-6.02	0.073	< 0.01	0.91
Conventional tillage	1	-3.03	0.054	< 0.01	0.29	-8.20	0.083	< 0.01	0.95
paraquat	2	*	*	*	*	-5.01	0.059	< 0.01	0.99
	3	*	*	*	*	-4.76	0.055	< 0.01	0.91
	4	*	*	*	*	-5.01	0.063	< 0.01	0.94
Conventional tillage	1	-3.83	0.057	0.02	0.31	-7.87	0.079	< 0.01	0.94
plus cover crop residue	2	*	*	*	*	-5.92	0.065	< 0.01	0.98
	3	*	*	*	*	-5.64	0.064	< 0.01	0.93
	4	*	*	*	*	-4.08	0.051	< 0.01	0.90
Strip-tillage	1	-7.19	0.090	< 0.01	0.58	-8.59	0.084	< 0.01	0.98
no herbicide	2	*	*	*	*	-7.87	0.077	< 0.01	0.99
	3	*	*	*	*	-6.13	0.064	< 0.01	0.92
	4	*	*	*	*	-5.76	0.060	< 0.01	0.96
Strip-tillage	1	-5.27	0.062	< 0.01	0.61	-8.03	0.077	< 0.01	0.96
glyphosate	2	*	*	*	*	-7.73	0.076	< 0.01	0.98
	3	*	*	*	*	-6.69	0.068	< 0.01	0.98
	4	*	*	*	*	-5.49	0.055	< 0.01	0.97

Table 4A.1 continued

Strip-tillage	1	-4.81	0.058	0.02	0.42	-5.98	0.056	< 0.01	0.92
paraquat	2	*	*	*	*	-7.75	0.075	< 0.01	0.98
	3	*	*	*	*	-8.20	0.084	< 0.01	0.97
	4	*	*	*	*	-5.49	0.055	< 0.01	0.95
Strip-tillage	1	-4.85	0.067	< 0.01	0.42	-8.39	0.086	< 0.01	0.94
minus cover crop residue	2	*	*	*	*	-8.71	0.084	< 0.01	0.98
	3	*	*	*	*	-6.78	0.070	< 0.01	0.97
	4	*	*	*	*	-6.02	0.063	< 0.01	0.95
Conventional tillage	1	-7.92	0.109	< 0.01	0.60	-7.26	0.073	< 0.01	0.94
plus straw	2	*	*	*	*	-7.14	0.076	< 0.01	0.98
	3	*	*	*	*	-5.82	0.064	< 0.01	0.95
	4	*	*	*	*	-4.60	0.054	< 0.01	0.96
Strip-tillage	1	-8.08	0.101	< 0.01	0.67	-8.05	0.075	< 0.01	0.97
plus straw	2	*	*	*	*	-8.94	0.088	< 0.01	0.99
	3	*	*	*	*	-7.22	0.073	< 0.01	0.96
	4	*	*	*	*	-5.66	0.058	< 0.01	0.96
2004, Rigdon Farm									
Conventional tillage	1	-7.35	0.111	0.05	0.67	-5.61	0.073	< 0.01	0.99
no herbicide	2	-8.52	0.121	< 0.01	0.97	-5.41	0.070	< 0.01	0.99
	3	-7.28	0.108	< 0.01	0.86	-4.25	0.056	< 0.01	0.99
	4	-6.96	0.106	0.03	0.72	-4.75	0.059	< 0.01	0.99
Conventional tillage	1	-6.97	0.101	0.01	0.90	-5.24	0.063	< 0.01	0.99
plus cover crop residue	2	-6.99	0.096	< 0.01	0.86	-5.65	0.070	< 0.01	0.99
	3	-6.85	0.098	< 0.01	0.96	-5.07	0.063	< 0.01	0.99
	4	-6.89	0.101	0.01	0.91	-4.90	0.056	< 0.01	0.98
Strip-tillage	1	-9.76	0.126	< 0.01	2395	-4.33	0.045	< 0.01	0.93
glyphosate	2	-7.53	0.096	0.02	0.81	-5.09	0.053	< 0.01	0.92
	3	-10.01	0.126	< 0.01	0.95	-4.40	0.045	< 0.01	0.96
	4	-11.48	0.140	< 0.01	0.89	-5.36	0.053	< 0.01	0.94

Table 4A.1 continued

Strip-tillage	1	-7.44	0.097	< 0.01	0.93	-4.33	0.045	< 0.01	0.93
minus cover crop residue	2	-7.58	0.102	0.01	0.88	-4.04	0.044	0.02	0.83
	3	-6.86	0.084	< 0.01	0.90	-3.55	0.036	< 0.01	0.87
	4	-8.29	0.109	< 0.01	0.86	-5.57	0.058	< 0.01	0.97
Conventional tillage	1	-11.91	0.159	< 0.01	0.98	-5.70	0.068	< 0.01	0.99
plus straw	2	-8.51	0.104	< 0.01	0.94	-5.76	0.066	< 0.01	0.99
	3	-8.97	0.119	< 0.01	0.90	-6.42	0.076	< 0.01	0.99
	4	-10.00	0.134	< 0.01	0.99	-6.43	0.072	< 0.01	0.99
Strip-tillage	1	-8.11	0.094	0.02	0.86	-5.85	0.058	< 0.01	0.96
plus straw	2	-9.45	0.108	0.02	0.88	-6.17	0.061	< 0.01	0.96
	3	-10.48	0.119	< 0.01	0.89	-4.10	0.039	< 0.01	0.97
	4	-9.59	0.107	0.03	0.86	-5.90	0.058	< 0.01	0.99
2004, Blackshank Farm									
Conventional tillage	1	-6.23	0.081	< 0.01	0.97	-5.53	0.063	< 0.01	0.99
no herbicide	2	-8.89	0.115	< 0.01	0.96	-4.16	0.073	< 0.01	0.94
	3	-6.76	0.087	0.02	0.75	-6.03	0.064	< 0.01	0.97
	4	-8.89	0.115	< 0.01	0.89	-5.28	0.063	< 0.01	0.97
Conventional tillage	1	-8.75	0.098	< 0.01	0.84	-6.26	0.067	< 0.01	0.96
plus cover crop residue	2	-8.56	0.096	0.02	0.91	-4.40	0.042	< 0.01	0.95
	3	-8.86	0.106	0.03	0.75	-6.29	0.065	< 0.01	0.97
	4	-8.56	0.096	0.02	0.77	-5.24	0.058	< 0.01	0.98
Strip-tillage	1	-7.24	0.069	0.03	0.70	-5.94	0.053	< 0.01	0.97
glyphosate	2	-5.12	0.048	0.11	0.52	-5.07	0.046	< 0.01	0.98
	3	-6.54	0.070	0.02	0.81	-7.21	0.073	< 0.01	0.97
	4	-8.02	0.091	0.01	0.84	-5.52	0.053	< 0.01	0.99
Strip-tillage	1	-9.63	0.110	< 0.01	0.93	-6.27	0.058	< 0.01	0.99
minus cover crop residue	2	-7.67	0.087	0.02	0.84	-5.53	0.054	< 0.01	0.99
	3	-10.97	0.126	0.02	0.77	-7.14	0.072	< 0.01	0.97
	4	-7.67	0.087	0.02	0.77	-5.67	0.052	< 0.01	0.99

Table 4A.1 continued

Conventional tillage	1	-8.66	0.095	0.01	0.87	-6.13	0.061	< 0.01	0.95
plus straw	2	-8.05	0.093	0.02	0.85	-5.14	0.051	< 0.01	0.97
	3	-8.37	0.091	0.02	0.78	-5.72	0.058	< 0.01	0.99
	4	-8.05	0.093	0.02	0.96	-4.97	0.054	< 0.01	0.97
Strip-tillage	1	-9.32	0.098	< 0.01	0.87	-6.28	0.054	< 0.01	0.93
plus straw	2	- [d]	-	0.44	-	-5.67	0.052	< 0.01	0.98
	3	-	-	0.30	-	-6.33	0.061	< 0.01	0.98
	4	-9.90	0.113	< 0.01	0.88	-5.29	0.050	< 0.01	0.99

[a] Number of leaves with 1 or more early leaf spot lesion or defoliated leaflet / total number of leaves from 10 lateral branches sampled from each treatment plots.
[b] Based on Florida 1-10 scale ratings.
[c] An asterisk represents data of replication (rep) plots that were combined with data of the first replication plot of an experiment to achieve a significant ($P < 0.05$) fit of the model.
[d] A dash represents a replication plot where no model significantly fit the curve.

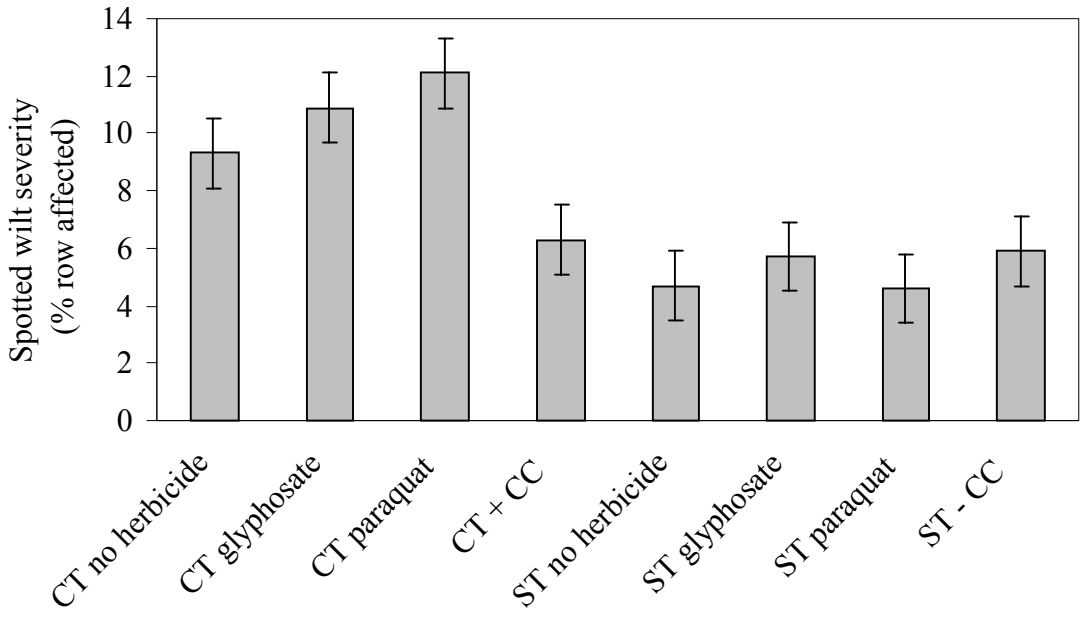

Fig. 4A.3. Effect of reciprocal cover crop residue treatments, plus cover crop residue (+ CC) and minus cover crop residue (- CC), and pre-plant herbicide treatments, no herbicide, glyphosate and paraquat, in conventionally tilled (CT) and strip-tilled (ST) plots on spotted wilt of peanut across field studies at the Rigdon Farm in 2002 and 2004, and Blackshank Farm in 2003 and 2004. Least square means and standard errors from Proc MIXED procedure of SAS.

Table 4A.2. Parameter estimates and regression statistics for the monomolecular model 2003 and logistic model and 2004selected to describe the progression of early leaf spot severity over time for each peanut mulch treatment plot.

		2003				2004			
Year/Farm/Treatment	Rep	Y-intercept	Rate	*P*-value	Recalc. $R2^c$	Y-intercept	Rate	*P*-value	Recalc. $R2^c$
Bare-soil	1	-2.49	0.051	< 0.01	0.96	-7.53	0.086	< 0.01	0.98
	2	-2.55	0.045	< 0.01	0.97	-6.74	0.079	< 0.01	0.97
	3	-3.13	0.053	< 0.01	0.99	-5.44	0.065	< 0.01	0.99
	4	-3.01	0.051	< 0.01	0.98	-4.98	0.059	< 0.01	0.98
	5	-3.13	0.054	< 0.01	0.98	-5.50	0.065	< 0.01	0.99
Textraw	1	-3.09	0.052	< 0.01	0.99	-6.46	0.075	< 0.01	0.99
	2	-2.84	0.048	< 0.01	0.97	-8.23	0.092	0.02	0.93
	3	-2.53	0.045	< 0.01	0.97	-5.91	0.070	< 0.01	0.97
	4	-2.54	0.043	< 0.01	0.96	-5.79	0.067	< 0.01	0.97
	5	-2.68	0.046	< 0.01	0.99	-5.64	0.064	< 0.01	0.99
Wheat mulch	1	-3.12	0.051	< 0.01	0.99	-7.54	0.085	< 0.01	0.98
	2	-2.59	0.044	< 0.01	0.97	-7.99	0.087	0.03	0.95
	3	-2.33	0.039	< 0.01	0.98	-6.02	0.069	< 0.01	0.98
	4	-2.28	0.038	< 0.01	0.98	-7.33	0.080	0.02	0.97
	5	-2.64	0.046	< 0.01	0.99	-8.46	0.094	0.02	0.96
Fumigated wheat mulch	1	-3.03	0.051	< 0.01	0.97	-7.30	0.081	< 0.01	0.96
	2	-2.61	0.044	< 0.01	0.97	-7.44	0.079	0.02	0.90
	3	-2.49	0.042	< 0.01	0.98	-6.94	0.080	< 0.01	0.99
	4	-2.47	0.042	< 0.01	0.97	-7.74	0.084	< 0.01	0.93
	5	-4.04	0.065	< 0.01	0.98	-7.81	0.085	0.01	0.94

CHAPTER 5

CHARACTERIZATION AND MANAGEMENT OF A NEW PEANUT LEAF SPOT OF UNKNOWN ETIOLOGY[1]

[1]Cantonwine, E.G., A.K. Culbreath, and R.C. Kemerait, 2005. To be submitted to *Plant Health Progress.*

Characterization and management of a new peanut leaf spot of unknown etiology

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ABSTRACT

Florida leaf spot (FLS), a new peanut leaf spot first noticed in Florida during the late 1990s, was apparent throughout much of the southeastern peanut growing regions by 2000. Experiments were conducted to characterize FLS epidemics over time, to evaluate the effect of pesticide chemistries with fungicidal or bactericidal activities on management of FLS, and to attempt to identify the cause of the FLS symptom. Severity of FLS, assessed with a 1 to 7 scale, was relatively high near the first assessment period, 33 to 42 DAP each year, and in decline by 56 DAP. Incidence of FLS was greater in the lower canopy than the upper canopy. In most cases, FLS incidence and AUDPC severity were greater in strip-tilled plots than conventionally tilled plots and for the peanut breeding line UF 99325 than the cultivar Georgia Green. No fungicide or bactericide treatment consistently suppressed FLS intensity. Severity of FLS was slightly lower in strip-tilled plots when cover crop residue was removed than in the strip-tilled control plots, but was not statistically greater in conventionally tilled plots when residue was added than in the conventionally tilled control plots. No apparently pathogenic fungi or bacteria were isolated from FLS lesions. Most attempts to transfer symptoms from diseased to healthy tissues failed; however, necrosis was observed when diseased tissue was attached to healthy tissue with a staple for 6 of 12 FLS lesions and 12 of 12 early leaf spot lesions. This transfer test

should be conducted using FLS lesions prior to early leaf spot disease onset to confirm infectivity of FLS tissues.

INTRODUCTION

Symptoms of a new leaf spot, first noticed during the late 1990s on leaves of peanut (*Arachis hypogaea* L.) plants grown in parts of Florida, consists of foliar lesions that are similar to those of early leaf spot, caused by *Cercospora arachidicola* S. Hori. Similar to early leaf spot, the new lesions are brown, often with a yellow halo, first observed in the lower peanut canopy, and often lead to premature defoliation. However, the new lesions tend to appear on plants well before the typical onset of early leaf spot, tend to be larger and have more irregular margins than early leaf spot, and most importantly, lack signs of fungal sporulation, common in the necrotic center of mature early leaf spot lesions. By the year 2000, the new leaf spot, called Florida leaf spot (FLS), funky leaf spot, or irregular leaf spot, was affecting peanut fields throughout northern Florida and had been reported in Georgia, South Carolina and in the southern counties of North Carolina (Rood, 2004).

The FLS symptom became a significant concern to growers in Georgia in 2001, primarily because it was often mistaken as an early onset of early leaf spot. Early leaf spot epidemics can increase extremely rapidly if not controlled, and have the potential to cause as much as 70% pod loss (Nutter and Shokes, 1995). Many growers began fungicide programs early or applied extra fungicide applications in attempts to control FLS. However, neither fungicide strategy appeared to affect disease intensity, which led to concerns of fungicide failure for early leaf spot management. Concerns subsided as the season progressed without an overwhelming early leaf spot epidemic in most fields (Kemerait, personal communication).

The cause of FLS is unknown and relatively little is known about how FLS epidemics progress over time. Observations by researchers at the University of Florida and the University of Georgia suggest there is variation of FLS intensity among peanut genotypes (Gorbet, personal communication), and peanut production systems. FLS intensity appeared to be more severe in strip-tilled than conventionally tilled plots (Culbreath, unpublished results). Others have noticed a positive correlation between the incidence of FLS and the incidence of pepper spot and/or leaf scorch, two diseases caused by *Leptosphaerulina crassiasca* (Young, personal communication). One hypothesis is that FLS is a third (non-sporulating) symptom caused by *L. crassiasca*. Other hypotheses suggest that FLS as a non-sporulating or delayed sporulating early leaf spot or a resistanct reaction to infection by *Tomato spotted wilt virus* (TSWV), which is common in peanut in Georgia and Florida. The lack of information about the cause, epidemic progression and management of FLS prompted the development of the present study. Objectives of this study were to characterize FLS epidemics over time in strip-tilled and conventionally tilled plots, to evaluate the effects of genotype and pesticide chemistries with fungicidal or bactericidal activities on management of FLS, and to identify the cause of the FLS symptom.

METHODS

Disease progress and treatment effects. A field experiment was conducted at the University of Georgia, Coastal Plain Experiment Station, Rigdon Farm, Tifton, GA during the 2002 to 2004 growing seasons to monitor FLS intensity over time and to assess the effects of peanut genotype, tillage system and pesticide chemistry on the intensity of FLS. Soil type was a Tifton loamy sand. Fields were planted to cotton (*Gossypium hirsutum* L.) the previous year,

and peanut 2 years prior, each grown using conventional tillage. Winter wheat (*Triticum aestivum*) was planted as a cover crop the previous fall.

In 2002 and 2003, the experiment was laid out in a randomized split-split plot design with 3 replications. Treatments consisted of combinations of 2 tillage treatments (main plots), 2 peanut genotypes (subplots), and 6 or 8 pesticide treatments (sub-subplots). In 2004, the experiment was a split-plot design with 4 replications with tillage treatements as whole plots and genotype as sub-plot treatments. Tillage treatments included conventional and strip-tillage. Conventionally tilled plots were mowed and disked twice before the soil was deep turned with a switch plow, 20 to 25 cm deep, and bedded with a disk bedder. Ethalfluralin (Sonolan HFP 3.0, Dow AgroScience LLC, Indianapolis, IN) 0.95 kg a.i/ha and S-metoalochlor (Dual Magnum 8E, Syngenta Crop Protection, Inc., Greensboro, NC) 1.68 kg a.i./ha were incorporated into the tilled beds. In the strip-tilled plots, the cover crop was treated with glyphosate (Roundup 4 EC, Monsanto, Kansas City, MO) at 1.2 kg a.i./ha. A subsoil shank attached to a strip-till implement (Kelly Manufacturing Co., Tifton, GA), loosened the plow pan 33 cm beneath the row, while the implement tilled strips approximately 20 to 25 cm wide, as described by Monfort et al. (2004). Treatment plots were 6.0 m long, separated by 2.4-m alleys. The peanut genotypes included the cultivar Georgia Green, and breeding line UF-99325. UF-99325 had been observed to have greater levels of a leaf spot thought to be FLS. Peanut seed was planted to 91-cm spaced single rows on 20 May 2002, 26 May 2003, and 27 May 2004. No in-furrow insecticide was applied at planting. In 2002, pesticide treatments consisted of a non-sprayed control and 5 fungicide programs where the first 2 applications were: (i) 1.26 kg a.i./ha chlorothalonil (Bravo Weatherstik 720 F, Syngenta Crop Protection, Inc, Greensboro, NC); (ii) 0.22kg a.i./ha tebuconazole (Folicur 3.6 F, Bayer CropSciences, Research Triangle Park, NC); (iii) 0.28 kg

a.i./ha thiophanate-methyl (Topsin M 70 WP, Cerexagri, Inc., King of Prussia, PA); (iv) 0.064 kg a.i./ha trifloxystrobin + 0.064 kg a.i./ha propiconazole (Stratego, Bayer CropSciences, Research Triangle Park, NC); and (v) 0.11 kg a.i./ha pyraclostrobin (Headline, BASF, Research Triangle Park, NC). In 2003, the same fungicide treatments were employed, plus 2 additional programs with bactericidal activity; where the first 2 applications were: (vi) 1.2 kg a.i./ha copper hydroxide (Kocide 2000, DuPont Crop Protection, Wilmington, DE); and (vii) 0.38 kg a.i./ha streptomycin sulfate (Agri-mycin, Syngenta Crop Protection, Inc, Greensboro, NC). All pesticide programs were calendar-based; the first application was applied 24 DAP and consecutive applications at 14-day intervals. Applications of tebuconazole were used in all programs treated with pesticide following the second application (applications 3 to 7). Fungicides were applied with a tractor-propelled boom sprayer under 345 kPa pressure in 115 liters of water/ha. Post-emergence herbicides and insecticides were applied to treatment plots based on recommendations by the University of Georgia Extension Service.

Incidence of FLS was evaluated for 26 arbitrarily sampled leaves from the upper half of the peanut canopy and 26 leaves from the lower half of the peanut canopy, 45 DAP in 2002, 35 DAP in 2003, and 33 DAP in 2004. In 2002, leaflets with FLS lesions, pepper spot, leaf scorch, or that were defoliated were recorded together as diseased. In 2003 and 2004, only leaflets with FLS lesions or that were defoliated were recorded as diseased. Diseased leaflets were considered affected by FLS, and percent incidence determined for upper and lower canopy leaves separately.

Severity of FLS per plot was estimated using a 1 to 7 scale (FLS scale) where 1 = no FLS symptoms; 2 = very few FLS lesions on the leaves on the lower canopy; 3 = few FLS lesions on the leaves on the lower canopy, very few on the upper canopy; 4 = more FLS lesions on the

leaves on the upper canopy, and 5% defoliation; 5 = FLS lesions evident on upper canopy, and 20% defoliation; 6 = FLS lesions evident, and 50% defoliation; and 7 = FLS lesions evident and > 50% defoliation. Ratings 1 to 6 of the FLS scale are directly comparable to 1 to 6 on the Florida 1 to10 scale for early and late leaf spot (Chiteka et al., 1988a). Since no plots in this study exceeded 50% defoliation in response to FLS, all defoliation levels greater than 50% were combined into the final rating level. Evaluations of FLS severity began 42 DAP in 2002 and 35 DAP in 2003, and continued at 7-day intervals until early leaf spot severity began to interfere with assessments (77 DAP in 2002, 78 DAP in 2003). Mean disease severity by assessment date was plotted for the tillage-genotype treatments across fungicide treatments and replications. Severity of FLS was assessed only once in 2004, 34 DAP.

To evaluate the correlation of FLS severity to other peanut diseases, as possible causes or effects of FLS, intensity was assessed in selected plots for other diseases present in the field. In 2002, early leaf spot severity for the non-sprayed treatment plots was estimated with the Florida 1 to 10 scale just prior to digging. Tomato spotted wilt was evaluated 64 DAP in 2002 and 60 DAP in 2003 using a disease intensity rating where the number of 0.3-m portions of row containing severely stunted, chlorotic, wilted or dead plants was counted for each plot and converted to linear row length affected by spotted wilt (Culbreath et al., 1997b). Spotted wilt was not evaluated in 2004 because there were too few symptomatic plants to rate. Stem rot, caused by *Sclerotium rolfsii*, was evaluated immediately after digging as the percent of 0.3-m portions of linear row with stem rot symptoms or signs of the pathogen.

Pod yield was evaluated for plots in 2002. All plots were dug near the reported time to maturity of the genotypes, 133 DAP for Georgia Green and 139 DAP for UF 99325. Peanuts

were harvested mechanically 7 to 10 days after digging and pod yields were determined by weighing harvested pods after they were dried and adjusted to 10% wt/wt moisture.

A second field experiment was conducted at the Coastal Plain Experiment Station Rigdon Farm and Blackshank Farm, Tifton, GA, in 2004 to study the effects of surface mulch on FLS severity in an attempt to characterize the mechanism driving the tillage effect. Conventionally tilled and strip-tilled plots were implemented in fields under the same rotation regime and cover crop residue situations as described above. All plots were planted to the peanut cultivar Georgia Green and no fungicide was applied. The experiment was designed as a randomized complete block; treatments associated with conventional tillage were assigned to 3 contiguous plots at random and those associated with strip-tillage were assigned to the remaining plots. Each tillage treatment was replicated 4 times at each farm. Treatments included conventional tillage and strip-tillage controls, removal of cover crop residue in strip-tillage and addition of residue from the corresponding strip-tillage plot in conventional tillage (reciprocal residue treatments), and addition of 1 bale (10 kg) of wheat straw mulch in conventional and strip-tillage. Residue removed from strip-tillage plots was cut near the soil with a string trimmer and raked with minimal disturbance of the soil. Cover crop residue and straw mulch treatments were applied 14 days after planting (DAP). Treatment plot sizes were 7.2 x 7.5 m separated by 3.0-m alleys. Florida leaf spot severity was assessed 43 DAP using the FLS 1 to 7 scale.

Effects of tillage, genotype and pesticide treatment were examined using the Proc MIXED procedure with ddfm = satterth option on the model statement (SAS v.8.3, SAS Institute, Cary, NC). Fisher's LSD values were computed using standard error and t-values of adjusted degrees of freedom. When an interaction was significant, the above Fisher's LSD was further adjusted to reflect use of the interaction term as a source of error if the F-test for the main

effect using the appropriate interaction showed the main effect to be significant; otherwise, only the interaction means were presented.

Etiology of FLS. Peanut leaves with FLS symptoms from non-sprayed plots were periodically examined with a hand-lens (20X), dissecting microscope, or compound light microscope (100 to 400x) to look for fungal fruiting structures, fungal spores or bacterial streaming. Detached leaves with FLS lesions were placed in moist chambers for 24 to 48-h to encourage sporulation.

Attempts were made to isolate fungi and bacteria from leaf tissue with FLS symptoms. Fungal isolation attempts were conducted in 2002, 2003 and 2004 using leaves with FLS symptoms from non-sprayed plots. Isolations were conducted as early as 24 DAP and as late as 100 DAP, from FLS lesions 0.1 to 1.0 cm diameter. Green tissues were cut along the necrotic edge of FLS lesions using a razor blade. Tissue samples were surface sterilized in 0.6% sodium hypochlorite with or without 0.005% Tween 20 for 0.25 to 10 minutes, rinsed in sterile water or not rinsed and placed on water agar. After 1 to 14 days, fungal mycelia were transferred to potato dextrose agar (PDA), PDA amended with 5 ppm chlorothalonil, mycrophylla agar, or V8 juice agar. Petri dishes were wrapped with Parafilm and stored in the lab at room temperature (20 to 23ºC) for up to 12 months. Colonies were periodically examined microscopically for spore production. Fungal colonies that were most frequently isolated were identified to genus.

Isolation of bacteria associated with FLS was conducted in August, 2002 and June, 2003, with the aid of R.D. Gitaitis. Green leaf tissue along the edge of FLS lesions was submerged in approximately 1 ml phosphate buffer and saline (PBS) in a sterile petri dish, finely macerated with a razor blade, and allowed to sit for 10 min. The sample solution was streaked onto nutrient

agar and King's medium B agar and incubated for 36 to 48 h at 28°C. Bacterial colonies were examined and described morphologically.

Pathogenicity tests were conducted with isolated fungi to fulfill Koch's postulates. Peanut plants or detached peanut leaves in saturated sand beakers (as described in Chapters 3 and 4) of UF-99325 plants grown in the greenhouse for 8 or more weeks were inoculated with the fungal cultures that were most frequently isolated from symptomatic tissue. Inoculations of fungi were attempted by: (i) mist inoculating plants with a 0.005% Tween 20 solution that included mycelia and/or spores from each selected colony, prepared by scraping agar plates with the Tween 20 solution and a scalpel; (ii) placing mycelia onto the upper side of detached leaves using a scalpel; and (iii) attaching a 5-mm^2 section of mycelia, cut from agar plates, mycelia side down onto the upper surface of detached leaves with a straightened staple, so that the staple punctured the mycelia section and the peanut leaf. Between 3 and 5 replications of each inoculation attempt were maintained for at least 48 h in a mist chamber. Inoculated plants and leaves were examined for FLS symptoms daily for 3 or more weeks.

Wheat residue in strip-tilled plots was found to be infested with conidia of *Leptosphaerulina* sp. (the species was not determined) and was explored as a possible inoculum source for FLS. Leaves of 8 week-old UF 99325 peanut plants grown in the greenhouse were inoculated with a conidial suspension prepared by agitating wheat glumes in 50 ml 0.005% Tween 20 and adjusted to $1.0*10^4$ conidia per ml^{-1} with a hemacytometer. The conidial suspension or a 0.005% Tween 20 control was rubbed onto marked leaves within the upper and lower canopies. Test plants were incubated at room temperature (20 to 23ºC) in a mist chamber for 48 h or placed in the greenhouse at ambient temperature and relative humidity (RH). After

incubation, all plants were maintained in the greenhouse and monitored daily for FLS symptom development for 4 weeks.

Transmissibility and infectivity experiments. Whole plants or detached leaves of UF-99325 peanut plants grown in the greenhouse for 8 or more weeks were exposed to FLS symptomatic tissues to determine if an infectious, transmissible agent was associated with FLS lesions. Lesions of FLS or healthy tissue were excised from symptomatic or healthy leaves collected from non-sprayed plots in July, 2003 and June, 2004. Approximately 20 FLS lesions were cut from symptomatic peanut leaves and ground with a tissue homogenizer (TissueMiser, 115V, Fisher Scientific, Pittsburgh, PA) in 1ml 0.005% Tween 20. A similar area of healthy tissue was also ground for a control homogenate solution. The homogenate solutions were rubbed onto marked leaves within the upper and lower canopy of greenhouse plants. Plants were incubated at room temperature (20 to 23ºC) in a mist chamber for 48 h or placed in the greenhouse at ambient temperature and RH. After incubation, all plants were maintained in the greenhouse and monitored daily for FLS symptom development for 4 weeks.

Lesions of FLS or healthy tissue were excised from symptomatic or healthy leaves collected from non-sprayed plots in August, 2004. Tissue samples were randomly attached to one of four leaflets of a detached UF 99325 leaf with a straightened staple, so that the staple punctured the sample and detached leaf tissues. Staples were inserted at the margin of FLS lesions. A staple without a tissue sample was placed through a separate leaflet. Treated leaves (n = 3) were covered with clear plastic, to enhance RH, and placed in a light box. After 2 weeks, leaflets were examined for necrosis. The experiment was repeated in September, 2004 for 12 leaves. Early leaf spot lesions and surface sterilization of tissues (30 seconds in sodium hypochlorite diluted to 0.6% with 0.005% Tween 20) were added as treatments.

RESULTS

Disease progress and treatment effects. Severity of FLS was relatively high at the first assessment date, 33 to 42 DAP, each year. Except for the strip-tilled plots in 2003, which had a positive slope between 42 and 56 DAP, there was a slight negative slope for most plots after 49 DAP in 2002 and 35 DAP in 2003 (Fig. 5.1).

Statistical analyses of FLS incidence and AUDPC were done by year due to significant interactions of year with one or more main effects. Incidence of FLS was not affected by fungicide treatment in the upper ($P > 0.30$) or lower canopies ($P > 0.40$), and there were no significant interactions with fungicide ($P > 0.17$). Fungicide treatment did affect AUDPC in 2002 ($P = 0.04$); trifloxystrobin + propiconazole and the pyraclostrobin treatments resulted in lower AUDPC values than the non-sprayed control (Fig. 5.2). However, this effect was not observed in 2003 ($P = 0.98$) (Fig. 5.2). Analysis of FLS severity at each assessment date did not distinguish fungicide treatments from the non-sprayed control ($P \geq 0.19$) except for the 63 DAP evaluation in 2002; FLS severity was lower in plots treated with trifloxystrobin + propiconazole or pyraclostrobin compared to the control ($P \leq 0.01$) (Table 5A.1).

For all tillage and genotype treatment combinations, FLS incidence was higher in the lower peanut canopy than the upper canopy (Table 5.1). Incidence of FLS in both canopy layers was numerically or statistically higher in strip-tilled than conventionally tilled plots and higher for UF 99325 than Georgia Green (Table 5.1). There was a significant tillage by genotype interaction for lower canopy incidence in 2002 ($F = 5.67$, $P = 0.02$), but it was not great enough to produce non-significant F-tests of the main effects. In all cases, AUDPC was lower in conventionally tilled than strip-tilled plots and lower for Georgia Green than UF 99325. Tillage by genotype interactions were significant for AUDPC in 2002 ($F = 184$, $P < 0.01$) and 2003 ($F =$

8.78, $P < 0.01$), but they were not great enough to produce non-significant F-tests of the main effects.

A relative comparison of early leaf spot and FLS severity for each non-treated tillage and genotype treatment combination in 2002 is shown in Fig. 5.3. Early leaf spot severity was greater in conventionally tilled than strip-tilled plots and greater for Georgia Green than UF 99325. In 2002, spotted wilt severity was lower ($F = 13.8$, $P < 0.01$) in strip-tilled plots (7.2%) than conventionally tilled plots (10.3%), and was lower ($F = 10.9$, $P < 0.01$) for UF 99325 (7.3%) than Georgia Green (10.1%). In 2003, spotted wilt was less than 1% in all treatments. There was a significant interaction between tillage and genotype for stem rot incidence ($F = 19.5$, $P < 0.01$), but no interaction with pesticide treatment ($F = 0.6$, $P = 0.68$). Across pesticide treatments, stem rot incidence did not differ ($P = 0.36$) for Georgia Green in conventionally tilled (4.6%) or strip-tilled plots (3.3%), but was greater ($P < 0.01$) for UF 99325 plots in conventionally tilled (8.8%) than strip-tilled plots (2.7%).

For pod yields, there were no interactions between fungicide treatment and tillage or genotype factors ($F < 1.1$, $P > 0.38$); however, there was a significant interaction between tillage and genotype ($F = 4.1$, $P < 0.05$). Across fungicide treatments, pod yields were comparable ($P > 0.32$) for the strip-tilled Georgia Green plots (2330 kg/ha), strip-tilled UF 99325 plots (2421 kg/ha), and conventionally tilled Georgia Green plots (2277 kg/ha), and higher ($P < 0.02$) for the conventionally tilled UF 99325 plots (2777 kg/ha).

FLS was less severe in the conventionally tilled plots than the strip-tilled plots (Fig. 5.4). Severity was suppressed in strip-tilled plots when cover crop residue was removed, compared to the strip-tilled control plots ($P = 0.04$). No difference in FLS severity was apparent between the

strip-tilled control plots and the strip-tilled plots with added wheat straw ($P = 0.46$). All conventionally tilled plots had comparable levels of FLS severity ($P \geq 0.27$).

After careful examination of FLS lesions, no evidence of sporulation was observed, except for *Cercospora arachidicola* sporulation on less than 10% of FLS lesions observed after 30 July 2002, or the first week of July in 2003 and 2004. Incubation of leaves in moist chambers did not induce sporulation of non-sporulating lesions. No bacterial streaming was observed from FLS lesions.

Fungi in the genus *Alternaria* were most frequently isolated from surface-sterilized FLS tissues. Other fungi that were isolated was a *Cochliobolis* sp., *Lophotrichus* sp., and *Bipolaris* sp. The *Alternaria* spp. that were isolated sporulated poorly on PDA and V8 agar medium and conidia that were produced had short beaks. No fungi were isolated from surface-sterilized healthy leaf tissue controls. Relatively few bacteria were isolated from FLS lesions. Those that were isolated grew slowly. For these reasons the isolated bacteria were not believed to have a pathogenic nature (Gitaitis, personal communication) and were not included in pathogenicity tests.

Inoculations with fungi from FLS isolations or *Leptosphaerulina* conidia from wheat residues failed to produce necrosis or typical symptoms of FLS. Experiments to determine transmission or infectivity using homogenated tissue did not result in necrosis of treated leaflets. However, some necrosis developed on detached leaves to which diseased tissue was attached. In the first trial, necrosis was observed at the site of attachment for 2 of 3 leaves. No necrosis was observed for the healthy tissue and staple controls. In the second trial, necrosis developed at the site of attachment for all 12 early leaf spot tissues, 6 FLS tissues, and 2 healthy tissues, one of

which had observable fungal mycelium growth; this was the only case where mycelium growth was evident. Surface sterilization did not affect results.

DISCUSSION

The shape of FLS progress curves suggests that FLS epidemics are not polycyclic in nature. Instead, the epidemic appears to be caused by a single stressful event, or by a stressor that is limited in number or opportunity as the season continues. Although new FLS symptoms were observed on young, newly expanded leaves as late as September each year, additional defoliation in response to FLS symptoms was not noticeable for plants after 60 DAP.

In most cases, FLS epidemics were not affected by applications of fungicide or bactericide. Furthermore, the suppression of AUDPC in 2002 by the trifloxystrobin + propiconazole and the pyraclostrobin treatments, was relatively small compared to the effects of genotype and tillage treatments. The fungicide effect was most likely due to a suppressive effect on early leaf spot, which was present at low levels during the later assessment dates (63 and 70 DAP). Strobilurins have been reported to have curative activity against early leaf spot (Culbreath and Brenneman, 2002), which may explain why the trifloxystrobin + propiconazole and the pyraclostrobin treatments showed a slight response while the other treatments did not. It is possible that initial infections of FLS may have occurred prior to the first pesticide application 24 DAP; but unless symptoms can spread systemically, there should have been a greater response to one or more of the pesticide treatments than was observed since the chemistries employed in this study have a wide range of antagonistic activity to fungi and bacteria. For this reason, there was not sufficient response to these pesticides to suggest that FLS is caused by a fungus or bacterium. The failure to isolate pathogenic fungi or bacteria from FLS lesions,

likewise, provides no evidence that FLS is caused by a fungus or bacterium. Preliminary tests, using ELISA plates (Agdia, Elkhart, IN) and culture media (Chang and Walker, 1998), were conducted by C.J. Chang in 2003 to detect the presence of *Xylella fastidiosa*, a xylem-limited fastidious prokaryote, in FLS tissues. Results of both procedures were negative (Chang, unpublished data).

Incidence of FLS was greater in the lower canopy than the upper canopy, and greater in strip-tilled plots than conventionally tilled plots. Severity of FLS was slightly less in strip-tilled plots where the cover crop residue was removed compared to the strip-tillage control plots, but the effect was not great enough (and no effect was observed in the reciprocal residue treatment in conventional tillage) to conclude that cover crop residue plays a role in FLS symptom expression. However, since the residue and straw mulch treatments were implemented 14 DAP, an effect cannot be ruled out.

There also appears to be a significant amount of genetic variation in FLS symptom expression, as indicated by the differences between Georgia Green and UF-99325. Based on results from this study, the optimum time to assess the effects of genotype or cultural practices on FLS is between 33 and 56 DAP. Lower canopy incidence and/or defoliation are good measures of FLS intensity.

It seems unlikely that FLS is a non-sporulating symptom of early leaf spot since there was a negative correlation between the severity of early leaf spot and FLS across the tillage-genotype treatments. The suppression of early leaf by genetic resistance and strip-tillage was not associated with development of non-sporulating early leaf spot lesions (Chapter 3 and Chapter 6). Sporulation of *C. arachidicola* was occasionally observed in association with FLS lesions after the onset of early leaf spot in the field, approximately 10% of lesions examined, but no

sporulation was apparent for FLS lesions prior to early leaf spot onset. In Florida, *C. arachidicola* sporulation was observedon FLS lesions that were tagged and monitored throughout the season (T. Kucharek, personal communication). In our observations, sporulation of *C. arachidicola* may have been due to misidentification of FLS, which was done based on lesion shape after the onset of early leaf spot. The method used by Kucharek reduces the chance of lesion misidentification since FLS lesions were identified early in the season, prior to onset of early leaf spot. Since *C. arachidicola* kills cells prior to invasion (Abdou et al., 1974; Woodroof, 1933), it may be possible that *C. arachidicola* conidia can infest the necrotic tissues of FLS lesions and produce secondary inoculum from these lesions if the cells in the lesion are not completely killed by FLS.

There was a positive correlation between spotted wilt severity and FLS severity across the tillage-genotype treatments in 2002. However, the hypothesis that FLS is a local resistance symptom to TSWV infection is unlikely since spotted wilt severity in the test plots was high in 2002 and low in 2003 and 2004, yet FLS severities were relatively similar across these years.

Most of the transmissibility trials from symptomatic leaf tissues to healthy tissues did not produce necrotic symptoms. However, it is important to point out that an abrasive (e.g. carborundum or celite) was not used during the inoculation procedure, and all test plants were 8 weeks old or older. Carborundum has been shown to enhance the transfer of infectious viral agents (Hull, 2002), and is commonly used to facilitate mechanical virus inoculations. Future research should include inoculation of younger plants (between 30 and 40 days old), in case there is some ontogenetic resistance to FLS with maturity, and the use of an abrasive material during inoculation. When staples were used to puncture and attach FLS and healthy tissues, necrosis did develop in the healthy tissues. However, the same response was observed when early leaf

spot lesions were tested. Because this trial was conducted late in the season, and because FLS can look so similar to early leaf spot, it is possible that the diseased tissues that produced necrosis were actually early leaf spot lesions misidentified as FLS. This experiment should be conducted earlier in the season to reduce the chance of early leaf spot contamination of the FLS treatment.

Although we were unable to control FLS in the field to assess its potential impact on pod yield, the results from 2002 suggest that the effect, if any, is minimal. Stem rot incidence in 2002 was relatively low. However, the results suggest that FLS may enhance stem rot incidence in conventional tillage. There was no stem rot difference detected among genotypes in the strip-tilled plots, which suggests that the difference observed in conventionally tilled plots was likely not due to differences of stem rot susceptibility of the genotypes tested. Peanut leaf debris on the soil surface may increase stem rot severity by creating a more conducive microenvironment for infection by *S. rolfsii* (Punja, 1985), as well as provide a food source for increased vegetative growth of the pathogen (Brenneman, personal communication). It is possible that in the conventionally tilled plots, where defoliation was significantly greater for UF 99325 than Georgia Green, the number of stem rot infections increased in response to defoliation by FLS. The fact that the same trend was not observed in strip-tilled plots, despite a significant difference in defoliation between these genotypes, suggests that the effect of premature defoliation on stem rot incidence may be less important in strip-tilled than conventionally tilled plots.

In conclusion, the cause of FLS is still unclear; however, we found no evidence that it is the result of an interaction with a pathogenic fungal or bacterial species. Experiments to provide evidence of transmission of an infectious agent from FLS affected tissues to healthy peanut leaf tissues should be repeated using FLS lesions collected prior to the onset of early leaf spot to

confirm infectivity of FLS tissues. This follow-up work is critical for the direction of future investigations into the etiology of FLS symptoms since infectivity of disease tissues would imply a pathogenic relationship, while lack of infectivity would imply a physiological response. The presence of cover crop residue may be involved in the expression of FLS symptoms. Pod yield does not appear to be affected to a great degree by FLS, but early season defoliation by FLS may enhance the incidence or severity of stem rot in conventionally tilled fields. No pesticides tested in this study consistently suppressed FLS incidence or severity. Based on this work, growers are currently being advised to follow recommended disease management programs, as long as early season FLS lesions do not have obvious signs of fungal sporulation.

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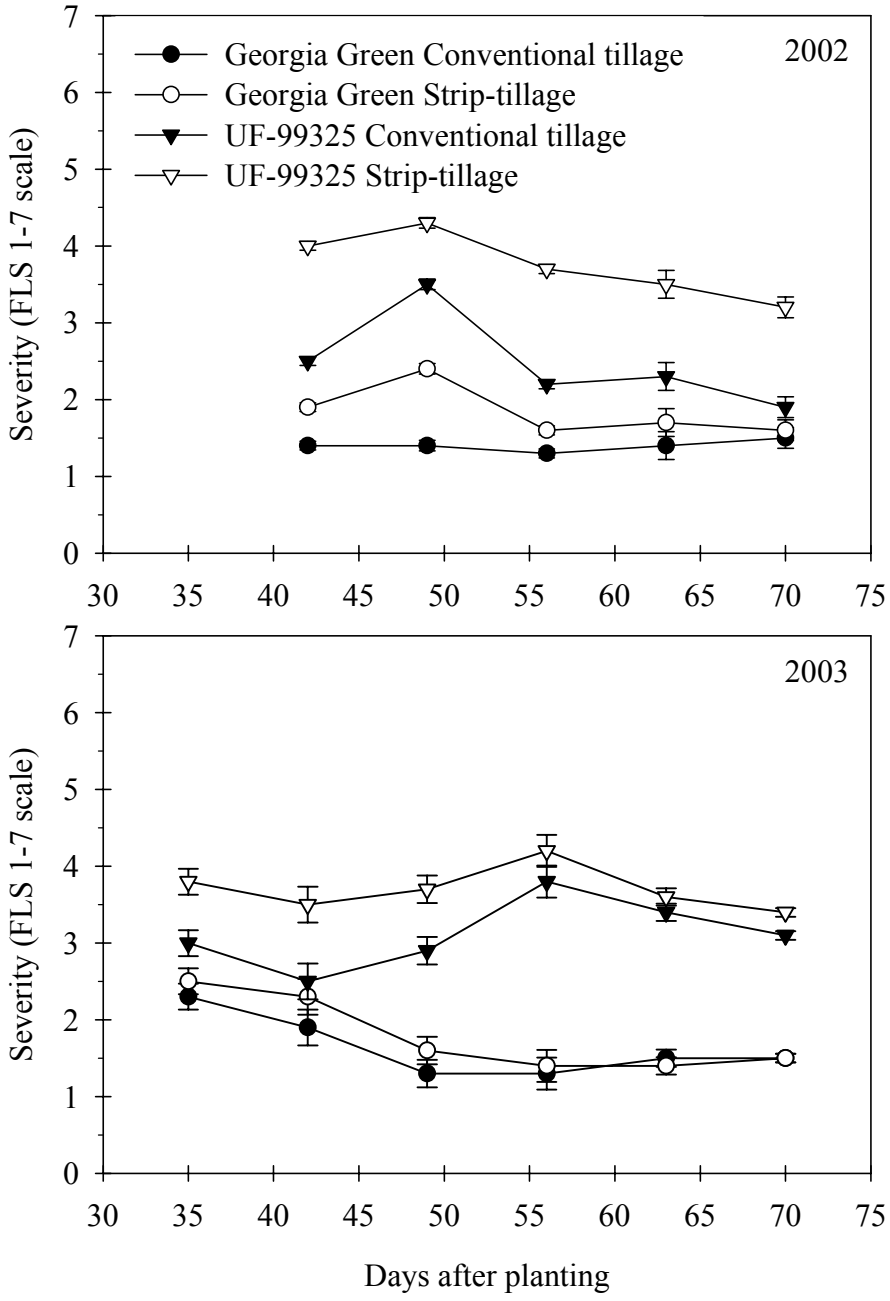

Fig. 5.1. Florida leaf spot (FLS) severity ratings over time for Georgia Green and UF-99325 in conventional tillage and in strip-tillage in 2002 and 2003. Ratings at each date are pooled across fungicide treatment and replication.

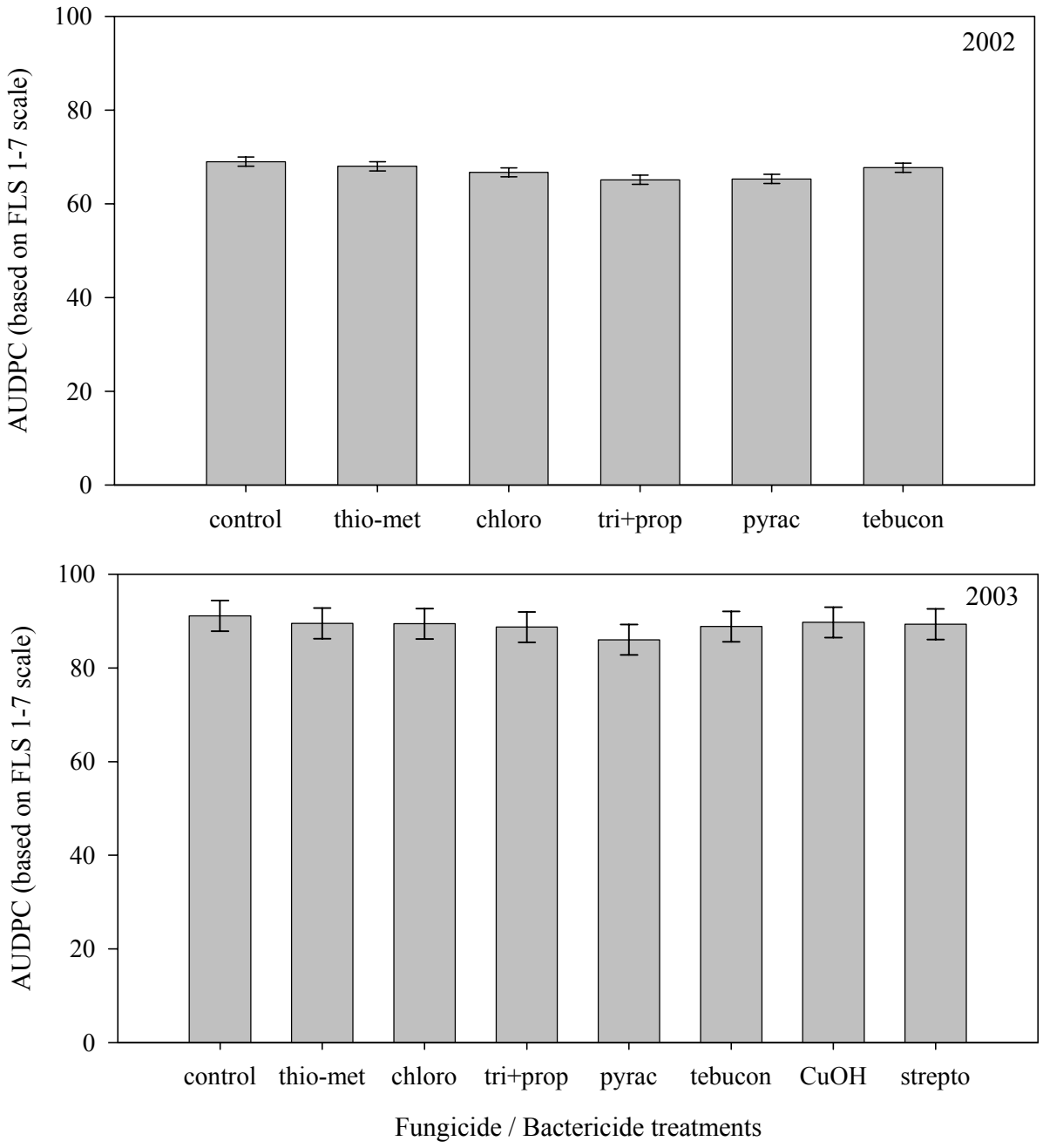

Fig. 5.2. Effect of fungicide treatments, non-treated control (control), thiophanate-methyl (thio-met), chlorothalonil (chloro), trifloxystrobin + propiconazole (tri+prop), pyraclostrobin (pyrac), and tebuconazole (tebucon), and bactericide treatments, copper hydroxide (CuOH) and streptomycin sulfate (strepto), on AUDPC of Florida leaf spot severity ratings in 2002 and 2003. Least square means from Proc MIXED across genotype and tillage treatments.

Table 5.1. Effect of peanut genotype and tillage on Florida leaf spot disease assessments in 2002 - 2004.

Year/Factor/Level	Upper canopy incidence[a]	Lower canopy incidence[b]	AUDPC[c]
2002[d]			
Genotype			
Georgia Green	17.3	16.2	45.3
UF-99325	28.6	54.8	88.6
	$F = 10.9$, $P < 0.01$	$F = 231$, $P < 0.01$	$F = 2963$, $P < 0.01$
Tillage			
Conventional till	13.0	23.7	54.7
Strip-till	33.0	47.2	79.2
	$F = 5.7$, $P = 0.08$	$F = 85.6$, $P < 0.01$	$F = 940$, $P < 0.01$
2003[e]			
Genotype			
Georgia Green	1.7	15.8	59.2
UF-99325	2.5	37.6	118.9
	$F = 1.7$, $P = 0.19$	$F = 24.4$, $P < 0.01$	$F = 674$, $P < 0.01$
Tillage			
Conventional till	1	22.6	81.4
Strip-till	3.2	30.9	96.8
	$F = 12.0$, $P < 0.01$	$F = 3.6$, $P = 0.06$	$F = 44.9$, $P < 0.01$
2004[f]			
Genotype			
Georgia Green	8.9	22.4	-
UF-99325	11.1	43.6	-
	$F = 2.0$, $P = 0.20$	$F = 30.1$, $P < 0.01$	
Tillage			
Conventional till	2.3	17.6	-
Strip-till	18.8	48.4	-
	$F = 67.8$, $P < 0.01$	$F = 63.08$, $P < 0.01$	

Estimate of the standard error = $(F\text{-value}/2)^{1/2}$.

[a] Least square means, F-values and P-values from Proc MIXED of FLS incidence from 26 leaves collected from the upper half of the peanut canopy.

[b] Least square means, F-values and P-values of FLS incidence from 26 leaves collected from the lower half of the peanut canopy.

[c] Least square means, F-values and P-values of area under the disease progress curve using the Florida 1-10 scale adjusted for FLS.

[d] Percent incidence of leaflets affected by FLS, pepper spot, leaf scorch, or defoliated 45 DAP. FLS scale ratings were recorded 42 to 70 DAP at a 7-day interval in 2002.

[e] Percent incidence of leaflets affected by FLS or defoliated 35 DAP. FLS scale ratings were recorded 35 to 70 DAP at a 7-day interval in 2003.

[f] Percent incidence of leaflets affected by FLS or defoliated 33 DAP. Florida 1-10 ratings were recorded only once in 2004; therefore, AUDPC was not computed.

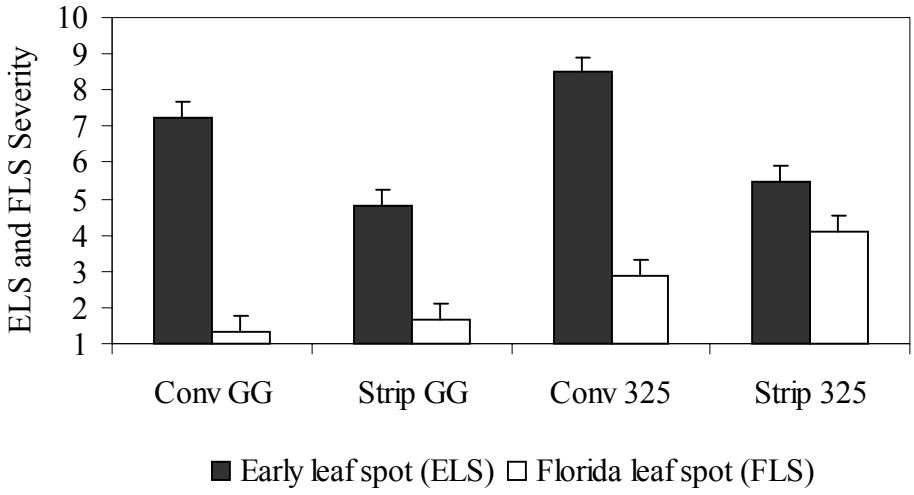

Fig. 5.3. Relative field resistance of peanut cultivar Georgia Green (GG) and breeding line UF 99325 (325) in conventionally tilled (Conv) and strip-tilled (Strip) plots to early leaf spot assessed just before peanuts were dug (133 DAP for GG and 139 DAP for 325), and Florida leaf spot assessed 42 DAP, in non-sprayed plots, 2002. The rating scales for ELS and FLS are comparable between 1 and 6. Both scales are based on the frequency and location of lesions within the peanut canopy for ratings 1 to 3, and level of defoliation above rating 3.

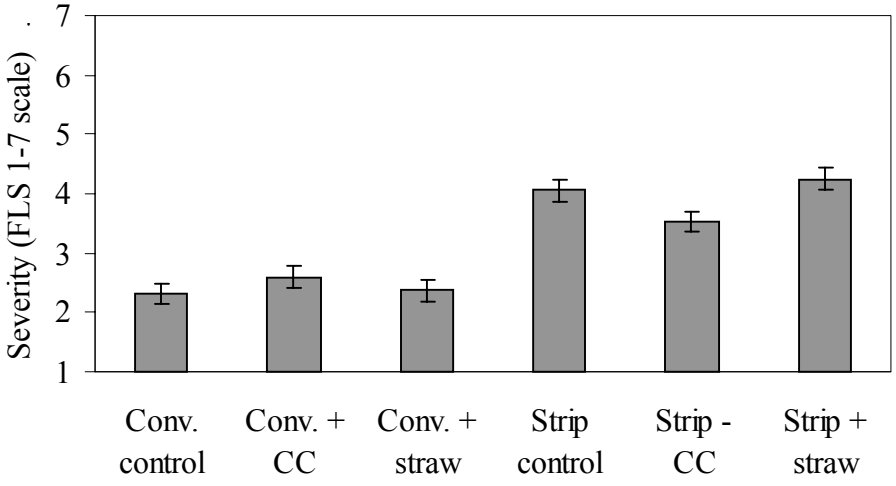

Fig. 5.4. Severity of Florida leaf spot in conventionally tilled (Conv.) and strip-tilled (Strip) peanuts. Treatments included the addition of cover crop residue (+ CC) or straw (+ straw) to the soil surface, or the removal of cover crop residue (- CC) from the soil surface. Disease was assessed 43 DAP at the Rigdon Farm and Blackshank Farm in Tifton, GA in 2004.

APPENDIX TO CHAPTER 5

Table 5A.1. Severity of Florida leaf spot (FLS 1-7 scale) at each assessment date for fungicide and bactericide treatments across tillage and peanut genotype in 2002 and 2003.

Year/Treatment	Assessment date				
2002	42 DAP	49 DAP	56 DAP	63 DAP	70 DAP
non-treated control	2.5	3.0	2.2	2.4	2.2
thiophanate-methyl	2.5	2.9	2.3	2.3	2.0
chlorothalonil	2.3	2.8	2.2	2.3	2.1
trifloxystrobin + propiconazole	2.5	2.9	2.1	2.0	2.0
pyraclostrobin	2.4	2.9	2.1	2.1	1.9
tebuconazole	2.4	2.9	2.2	2.3	2.1
copper hydroxide	-	-	-	-	-
streptomycin sulfate	-	-	-	-	-
Standard error	0.07	0.06	0.06	0.06	0.07
P-value	0.47	0.81	0.19	< 0.01	0.19

2003	35 DAP	42 DAP	49 DAP	56 DAP	63 DAP	71 DAP
non-treated control	2.9	2.5	2.4	2.9	2.5	2.4
thiophanate-methyl	3.0	2.5	2.4	2.7	2.5	2.4
chlorothalonil	3.0	2.6	2.4	2.4	2.6	2.4
trifloxystrobin + propiconazole	2.8	2.5	2.4	2.7	2.5	2.3
pyraclostrobin	2.8	2.5	2.3	2.6	2.4	2.4
tebuconazole	2.9	2.5	2.4	2.7	2.5	2.3
copper hydroxide	2.9	2.4	2.4	2.8	2.5	2.4
streptomycin sulfate	2.9	2.6	2.3	2.7	2.5	2.3
Standard error	0.11	0.13	0.09	0.14	0.07	0.06
P-value	0.85	0.99	0.94	0.46	0.27	0.94

Least square means from Proc MIXED.

CHAPTER 6

DISEASE PROGRESS OF EARLY LEAF SPOT AND COMPONENTS OF RESISTANCE TO CERCOSPORA ARACHIDICOLA AND CERCOSPORIDIUM PERSONATUM IN RUNNER-TYPE PEANUT GENOTYPES[1]

[1]Cantonwine, E.G., A.K. Culbreath, C.C. Holbrook, and D.W. Gorbet, 2005. To be submitted to *Crop Protection.*

Disease progress of early leaf spot and components of resistance to *Cercospora arachidicola* and *Cercosporidium personatum* in runner-type peanut genotypes

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ABSTRACT

A field study was carried out to monitor the progression of leaf spot incidence and severity in peanut genotypes Georgia Green, C-11-2-39, and DP-1. Time of disease onset (TDO) and temporal epidemic rate (rate) was estimated for incidence with the logistic model, and for severity with the linear model. Early leaf spot, caused by *Cercospora arachidicola* (CA) was the predominant disease in the field. Estimates of TDO were 9 days later for DP-1 than Georgia Green based on incidence models, and 5 and 6.5 days later for C-11-2-39 and DP-1 than Georgia Green, respectively, based on severity models. The rate of incidence progression was highest for C-11-2-39 in 2002 and lower for DP-1 and C-11-2-39 than Georgia Green in 2003, while the rate of severity progression was lowest for DP-1 and highest for Georgia Green across years. A detached leaf assay was used to determine components of resistance of these genotypes to infections by CA and *Cercosporidium personatum* (CP), the cause of late leaf spot. For both pathogens, infection frequency 30 days after inoculation, lesion diameter and percent necrotic area was greatest for Georgia Green. Besides a 2-day longer latent period of resistant genotypes,

no differences of CA reproduction were detected. For CP, latent period was shorter for C-11-2-39 than DP-1, and sporulation per unit lesion area was greatest for C-11-2-39. A smaller percent of CA spores germinated on the surface of leaves of DP-1, than Georgia Green or C-11-2-39, while no differences were detected for germination of CP spores. These results suggest that the enhanced field resistance to early and late leaf spot by DP-1 and early leaf spot by C-11-2-39 is in part due to lower infection frequencies, smaller lesions, and longer latent periods.

INTRODUCTION

Early leaf spot, caused by *Cercospora arachidicola* S. Hori, (teleomorph = *Mycosphaerella arachidis* Deighton) and late leaf spot, caused by *Cercosporidium personatum* (Berk. & M. A. Curtis) Deighton, (teleomorph = *Mycosphaerella berkeleyi* Jenk.) are the most important foliar diseases affecting peanut (*Arachis hypogaea* L.) throughout the world (Shokes and Culbreath, 1997). The diseases are often found together or one disease may be more predominant in a given location or year. Predominance may vary over time within a location. In Georgia, late leaf spot was more common in the 1980s and early 1990s, while early leaf spot became the predominant leaf spot in much of Georgia during the late 1990s. However, late leaf spot has not disappeared from the southeastern United States. Late leaf spot is still predominant in Florida, and lately has again increased in prevalence in Georgia. For this reason it is critical to evaluate the resistance of runner-type peanut genotypes, the type most widely grown throughout Georgia, Alabama, and Florida, to both early and late leaf spot pathogens. Fields tests can be used for evaluation of resistance to the prevalent pathogen, but greenhouse or growth chamber evaluations should be utilized when field evaluations to both pathogens are not feasible.

There has been no complete or single-gene resistance to *C. arachidicola* or *C. personatum* reported in cultivated peanut. Instead, resistance is partial and rate-reducing (Abdou et al., 1974). Partial resistance is typically a function of multiple components of resistance that contribute additively to a reduction in the rate of epidemic progress (Parlevliet, 1979). Characterization of the components of resistance to early leaf spot (Foster et al., 1980; Green and Wynne, 1986; Melouk and Banks, 1984; Ricker et al., 1985) and/or late leaf spot (Chiteka et al., 1988a; Cook, 1981; Subrahmanyam et al., 1982; Walls et al., 1985; Watson et al., 1998) was described for many peanut genotypes under field and greenhouse conditions in the 1980s. However, relatively little work has been published for peanut cultivars and breeding lines developed within the past 20 years (Anderson et al., 1993; Aquino et al., 1995; Chiteka et al., 1997; Chiyembekeza et al., 1993), despite significant advances in breeding for leaf spot resistance during this time. Even less work has been conducted to investigate the resistance of genotypes to both leaf spot pathogens (Walls et al., 1985), even though the inheritance of resistance to each pathogen appears to be independent (Wynne et al., 1991).

Nearly all resistance components that have been investigated for early and late leaf spot are affected by genetic variation. These include infection frequency, incubation period (time from inoculation to symptom appearance), latent period (time from inoculation to first sporulating lesion), lesion size, percent necrotic leaf area, percent lesions with sporulation, spore production, and time to defoliation. Latent period, lesion size and spore production are the components that have most commonly been associated with genetic resistance (Chiteka et al., 1988a; Chiteka et al., 1988b; Chiyembekeza et al., 1993; Walls et al., 1985). Infection frequency is highly dependent upon temperature and relative humidity (Shew et al., 1988;

Waliyar et al., 1994), and has been suggested to be an unreliable measure of resistance (Ricker et al., 1985; Waliyar et al., 1993). Examinations of multiple resistance components within resistance genotypes have shown that components are often correlated. For example, Jogloy, et al. (1987) and Chiteka, et al. (1988b) reported a positive genetic relationship between the size of late leaf spot lesions and the quantity of secondary spores produced, both of which were negatively correlated with latent period. However, no single component has been identified as a primary or consistent predictor of resistance in the field. The stability of resistance components to CA can vary across growing regions (Chiteka et al., 1997; Waliyar et al., 1993) due to environmental interactions (Shew et al., 1988; Waliyar et al., 1994), pathogen populations (Waliyar et al., 1993) or both (Chiteka et al., 1997). However, Shew et al. (1989) reported stable response of peanut genotypes to isolates of CP from the U.S. and Thailand.

The cultivar Georgia Green is currently the predominant runner-type cultivar grown in the southeastern U.S. (Smith, 2003a). The leaf spot resistance of Georgia Green is slightly better than that of Florunner (Culbreath, unpublished data), which was used as a susceptible check in studies of components of resistance of runner-type genotypes conducted in the 1980's (Aquino et al., 1995; Chiteka et al., 1988a). In a recent field study, the field resistance to early leaf spot was assessed for Georgia Green and 7 newly released cultivars or advanced breeding lines (C-99R, Hull, DP-1, GA-01R, C-11-2-39, C-28-305 and C-34-24). These were all developed for resistance to leaf spot or spotted wilt, caused by *Tomato spotted wilt virus*. The cultivar DP-1, originating from the University of Florida peanut breeding program, had the best field resistance to early leaf spot of the genotypes tested (Chapter 1), and reportedly has better resistance to late leaf spot than any cultivar currently available in

the U.S. (Gorbet, 2003). The breeding line C-11-2-39, developed by USDA/ARS, Tifton, GA, had an intermediate level of resistance relative to Georgia Green and DP-1 (Chapter 1), and has been shown to have good field resistance to late leaf spot (Holbrook, personal communication). This study was conducted to evaluate the progression of leaf spot intensity in the field, and some of the components of host resistance to CA and CP expressed in peanut cultivars Georgia Green and DP-1 and the C-11-2-39 breeding line.

METHODS

Evaluation of leaf spot epidemic progress in the field. A field experiment was carried out in 2002 and 2003 at the Coastal Plain Experiment Station Ridgon Farm in Tifton, GA to monitor temporal progress of naturally occurring leaf spot epidemics in plots planted to Georgia Green, DP-1 and C-11-2-39 peanuts. Five additional genotypes, C-99R, Hull, GA-01R, C-34-24, and C-28-305, were also grown, but data concerning these later genotypes will only be presented in the Appendix. The soil was a Tifton loamy sand and fields were irrigated as needed with overhead irrigation. Fields were planted to cotton (*Gossypium hirsutum* L.) the previous year, and peanut 2 years prior. The experimental design was a randomized complete block with 3 replications of each genotype per year. Peanut seed were planted in 91-cm spaced single rows in conventionally tilled plots (1.8 x 6 m) on 17 May 2002 and 20 May 2003. No fungicides were applied. Herbicides, insecticides and fertilizers were applied following recommendations of the University of Georgia Extension Service.

Early leaf spot incidence was assessed weekly as the number of leaves with 1 or more lesions or defoliated leaflets divided by the total number of leaves x 100, beginning when disease was first noticed. Percent incidence was estimated from 10 lateral branches arbitrarily collected

from each plot, beginning 78 DAP in 2002, 59 DAP in 2003, and 56 DAP in 2004. Disease severity was monitored over the season using the Florida 1 to 10 scale (Chiteka et al., 1988a), described in Chapter 3. Severity assessments were made at 7 to 22 day intervals 4 to 5 times beginning 89 DAP in 2002, and 9 to 10 times beginning 59 DAP in 2003. One less severity assessment was taken for Georgia Green plots because Georgia Green matures earlier than DP-1 and C-11-2-39, and the plants in these plots were inverted 11 to 13 days earlier than DP-1 and C-11-2-39 plots. Means of disease incidence and severity for each year, assessment date and genotype were plotted against assessment date for each year.

For each plot, area under the disease progress curve (AUDPC) was computed for percent incidence and severity separately (Shaner and Finney, 1977). Disease assessments were converted to proportions [proportion of incidence = percent incidence / 100; proportion of severity assessment = (Florida rating - 1) / 9], and linearized forms of the Gompertz [-ln(-ln y)], logistic [ln(y/1-y)] and monomolecular [ln(1/1-y)] models were fit using linear regression of transformed disease intensity proportions on time (DAP). The model that significantly ($P < 0.05$) fit all of the curves within each experiment was selected. If more than one model fit all of the curves within an experiment, that model with the highest recalculated R^2 after back transformation was selected. Time of disease onset (TDO) was estimated by calculating the time (DAP) when the model predicted 5% incidence or 1.5 on the Florida scale. Effects of genotype on AUDPC, TDO and the epidemic rate parameter estimates were determined using the Proc MIXED procedure (v 8.3; SAS Institute, Inc. Cary, NC). Differences among genotype levels were determined using Fisher's LSD values using standard error and t-values of adjusted degrees of freedom when the main effect was significant ($P < 0.05$).

Disease incidence and severity assessments were also recorded for the 5 additional genotypes, C-99R, Hull, GA-01R, C-34-24, and C-28-305, grown in neighboring plots within the experimental design. Linear regression of untransformed or transformed disease intensity proportions on time (DAP) was conducted for these genotype across replications each year.

Evaluation of components of resistance to leaf spot pathogens. A growth chamber experiment was carried out to assess various components of resistance of Georgia Green, DP-1 and C-11-2-39 peanut genotypes to infection by CA and CP under a controlled environment. The Experimental design was a randomized complete block, with 12 replications of each of 3 genotype treatments. The experiment was conducted twice beginning November 29, 2003 and April 21 2004.

Plants were grown in 15-cm pots with Promix potting soil and maintained in a greenhouse for 9 weeks. Three youngest first or second fully expanded leaves were cut at the base of the petiole from lateral branches on each of 12 plants of each genotype. The cut ends were dipped in a dry formulation of napthaleneacetamide and thiram (Rootone, Security Products Co., Atlanta, GA) and placed individually in sterile saturated sand in 100-ml beakers (Waliyar et al., 1995).

For inoculations, conidia of CP were acquired by agitating leaf discs of sporulating late leaf spot lesions from Georgia Green leaves that were collected in Tifton, GA and stored at 10°C for 3 to 9 months in a solution of 0.005% Tween 20. Conidia of CA were acquired by rinsing conidia from single-conidium cultures isolated from infected Georgia Green peanut leaves collected in Tifton, GA the previous growing season using a technique modified from Lu, et al. (2003) and described in Chapter 3 using a 0.005% Tween 20 rinse. Conidial suspensions were standardized to a concentration of 1.0×10^4 conidia ml^{-1} using a hemacytometer. Each leaf was inoculated by spraying for 1 second with an aerosol spray bottle. A solution of 0.005% Tween

20 without conidia was used as a control. Viability of conidia from inoculation suspensions was verified by measuring spore germination on 2% water agar plates after 24 h incubation at 22°C under incandescent light.

Leaves in beakers were randomly positioned on trays and placed within a transparent enclosure in a growth chamber set at 24˚C, 90% RH, and a 12-h photoperiod to provide optimal conditions for CA germination and infection (Waliyar et al., 1995). The enclosure (1.3 x 0.7 x 0.6 m) was constructed using 2.54-cm diameter PVC pipe with clear plastic sides and a glass top. The enclosure did not affect air temperature. Relative humidity was supplemented by maintaining standing water in trays and with two humidifiers (PersonalMist ultrasonic humidifier, Kaz, Inc, Hudson, NY) evenly spaced within the enclosure. Humidifiers functioned constantly for the first 48 h, and were then programmed to turn off and on for alternating 30-min periods while the lights were on, and to turn off with the lights, to maintain continuous leaf wetness without runoff. Water was added to beakers and trays as needed. Severely wilted leaves were excluded from measurements.

The number of lesions per leaf was counted at 17 and 30 days after inoculation (DAI). The percent incubation period 17 DAI was computed by dividing the number of lesions from the 17 DAI count by the 30 DAI count and multiplying by 100. Latent period, defined as DAI until 1 lesion presented sporulation, was determined by inspecting spots daily with a 20X magnification lens beginning 17 DAI. After sporulation was observed on one lesion per leaf, or at 30 DAI if no sporulation was apparent, leaves were removed from the growth chamber and placed in a light box at 100% RH chamber for 72 h, after which the percentage of spots with sporulation was determined. Latent period was not recorded for leaves if no sporulation was apparent 33 DAI. Leaflets were removed from petioles, placed sporulation side up (adaxial side

for CA and abaxial side for CP) next to a reference object against a blue background, and covered with a clear sheet of plexiglass to flatten leaves for digital photography. Leaf area was measured using the leaf area option in the image analysis software ASSESS (American Phytopathological Society, St. Paul, MN). Infection frequency at 17 and 30 DAI was determined by dividing the number of lesions at each DAI by leaf area. Three sporulating lesions per leaf were randomly selected, excised with a razor blade and placed in a 1-ml tube with 0.1 ml of 0.005% Tween 20 for spore quantification. Areas of the selected lesions were measured using the freehand option in ASSESS. The number of spores per lesion was estimated using a hemacytometer and spores per unit sporulating lesion area, and spores per unit leaf area were determined. In cases where no sporulation occurred, the number of lesions with stroma and the number of stroma per leasion were counted. Diameters (d) of non-sporulating lesions with stroma were measured. Stroma per unit lesion area was determined by dividing the number of stroma per lesion by the corresponding lesion area estimated as: $[\pi(d / 2)^2]$. Number of stroma per unit leaf area was also calculated. Percent necrotic area per leaf was estimated using the following equation: [(lesion number 30-DAI * $\pi(d / 2)^2$) / leaf area], where d was measured for a sub-sample of 10 to 50 randomly selected lesions per leaf. ASSESS was not useful for this measurement because the program did not adequately distinguish necrotic from healthy tissues.

In a separate experiment, percent spore germination on leaf surfaces was determined for each genotype, and for the 5 additional genotypes included in the field experiment. Experimental design was a randomized complete block and included 5 replications of each genotype. The experiment was carried out once, beginning November 2002. Detached leaves were collected from 8-week-old greenhouse-grown plants and inoculated with suspensions of $1.5*10^4$ conidia ml^{-1} of CA, CP or 0.005% Tween 20 control solution, as described above.

Inoculum suspensions of CA and CP were prepared by rinsing leaf discs of sporulating early or late leaf spot lesions on leaves collected from field-grown Georgia Green peanut plants in Tifton, GA and stored at 10°C for less than 2 months, with a solution of 0.005% Tween 20. Viability of CA and CP conidia in the inoculum suspensions was not verified in this experiment. Leaves were maintained in a growth chamber under the same conditions as above. After 72 h, percent conidia germinated was determined using the technique reported by Waliyar et al. (1995). Leaflets were removed from the petiole and transparent cellophane tape (Scotch Magic Tape; 3M Corp., St. Paul, MN) was pressed against the adaxial inoculated surface of leaflets. The tape was carefully removed and placed sticky side down over 1 drop of cotton blue in lactophenol stain on a microscope slide. At least 100 conidia per leaf slide were counted and classified as germinated or not germinated to determine percent germination.

Effects of genotype on resistance variables and square root transformations of variables were tested using the Proc MIXED procedure (Version 8.3, SAS Institute, Cary, NC). Due to unbalanced data, whenever the standard errors were reasonably similar, the largest standard error was used for means comparisons rather than computing a weighted standard error. Fisher's LSD values were computed using standard errors and t-values of adjusted degrees of freedom when the main effect was significant ($P < 0.05$). Comparisons of untransformed means of transformed variables were determined based on analysis of transformed variables, since variances cannot be transformed (Steel and Torrie, 1980).

RESULTS

Evaluation of leaf spot epidemic progress in the field. Early leaf spot was the predominant disease in the field study, although late leaf spot occurred late in the season (>100

DAP) both years. Disease progress curves for early leaf spot incidence in plots of each genotype and year are shown in Fig. 6.1. The increase in disease incidence over time in each plot was best described by the logistic model ($P \leq 0.03$). Disease progress curves for Florida scale severity ratings in plots of each genotype and year are shown in Fig. 6.2. The increase in disease severity over time in each plot was best described by the linear model ($P \leq 0.01$). Parameter estimates for the selected models are presented in Table 6A.1 for all reps combined, along with parameter estimates for the 5 additional peanut genotypes grown in neighboring plots within the experimental design.

Across years, early leaf spot epidemics, measured by AUDPC based on incidence (AUDPC-I) and severity (AUDPC-S), were more severe for Georgia Green, than DP-1 and C-11-2-39 (Table 6.1). AUDPC-I was comparable between the resistant genotypes, while AUDPC-S was significantly lower for DP-1 than C-11-2-39. There was a significant interaction between year and genotype for incidence based estimates of TDO (TDO-I) and epidemic rate (rate-I). Estimates of TDO-I were 9 days later for DP-1 than Georgia Green both years, but this difference was only statistically significant in 2002 (Table 6.1). In 2002, TDO-I of C-11-2-39 was more similar to TDO-I of DP-1 than Georgia Green, while in 2003, TDO-I of C-11-2-39 was more similar to TDO-I of Georgia Green than DP-1. Severity based estimates of TDO were statistically later for DP-1 and C-11-2-39 than Georgia Green. No differences to rate-I were detected among genotypes in 2002, but DP-1 and C-11-2-39 had lower rate-I estimates than Georgia Green in 2003. Severity based epidemic rates were highest for Georgia Green and lowest for DP-1 (Table 6.1).

Evaluation of components of resistance to leaf spot pathogens. In the growth chamber experiment, leaf spot symptoms were observed on all inoculated leaves and none were observed

on control leaves. Germination of CA and CP conidia in the inoculum suspensions was approximately 87% and 65%, respectively, in both trials. Across trials and pathogen exposures, 5 to 7 leaves of each genotype were excluded from analyses due to severe wilting that appeared to impede lesion development. The pattern of wilting was random and the cause was not evident. Infection frequency of CA did not differ among genotypes 17 DAI, but was higher for Georgia Green 30 DAI (Table 6.2). Percent incubation period 17 DAI did not differ among genotypes (Table 6.2). Lesion diameter was approximately 20% greater for Georgia Green than the other genotypes, while percent necrotic area was 47 and 60% greater for Georgia Green than DP-1 and C-11-2-39 respectively (Table 6.2). The latent period was 2 days longer for DP-1 and C-11-2-39 compared to Georgia Green, but no other differences in early leaf spot reproductive patterns were detected among genotypes (Table 6.3).

Infection frequency of CP was lower on DP-1 17 DAI, and DP-1 and C-11-2-39 30 DAI compared to the other genotypes (Table 6.4). Percent incubation period 17 DAI was lower for DP-1 than C-11-2-39 (Table 6.4). Lesion diameter for Georgia Green was 11% greater than C-11-2-39 and 15% greater than DP-1, while percent necrotic area was approximately 46% greater for Georgia Green than the other genotypes (Table 6.4). The latent period was more than 2 days shorter and percent sporulating lesions was greater for C-11-2-39 than DP-1 (Table 6.5). Spores per sporulating lesion area were significantly higher for C-11-2-39 than the other genotypes, but spores per leaf area were comparable for all genotypes (Table 6.5).

The percent of CA spores that germinated on the surface of leaves of DP-1 (62%) was significantly lower than Georgia Green (83%), or C-11-2-39 (76%) ($P \leq 0.01$). Percent germination of CA spores did not differ between Georgia Green and C-11-2-39 ($P = 0.13$). No differences among genotypes were detected for the percent germination of CP conidia (mean =

79% across all genotypes) ($P = 0.91$). Percent germination of CA and CP conidia on leaves of greenhouse-grown plants of the 5 additional genotypes included in the field study is shown in Table 6A.2.

DISCUSSION

The field study provided a suitable setting to characterize field resistance of Georgia Green, DP-1 and C-11-2-39 to CA but not to CP, since early leaf spot was the predominant disease both years. Genotype ranking of field resistance to early leaf spot indicated Georgia Green as the most susceptible, C-11-2-39 as moderately resistant, and DP-1 as the most resistant. These results corroborate those observed in previous field trials (Culbreath, unpublished data). The observed delay of TDO for DP-1 and C-11-2-39 compared to Georgia Green was not always consistent, but it suggests that fewer initial infections may have occurred for these genotypes. Although it is likely that the TDO differences detected for the selected disease intensities (5% incidence and 1.5 on Florida scale) were confounded by differences in the rate of disease increase, data from the growth chamber studies suggest there might be a true delay in TDO for DP-1 and C-11-2-39 since infection frequency was shown to be reduced by these genotypes and CA germination rates by DP-1.

Reduced infection frequencies likely also contributed to the reduced rates of epidemic progress that were observed for C-11-2-39 and DP-1. Genotype ranking by the epidemic rate parameter estimate corresponded more closely to the ranking observed by AUDPC of incidence and severity than did the ranking by disease onset. This is not surprising since the length of time that resistance factors affect disease intensity is greater for measures of rate of increase and

AUDPC than disease onset. However, it supports the concept that partial resistance primarily suppresses epidemics by causing a reduction to the rate of disease increase (Parlevliet, 1979).

Infection frequency, reported as an unreliable resistance component for CA (Ricker et al., 1985; Waliyar et al., 1993), appeared to be an important component of resistance for comparison of genotypes in this study. It is possible that the environmental conditions selected for the growth chamber study, 24˚C and high RH, were more suitable to measure differences of infection frequency than a more variable greenhouse environment, or different regime. The frequency and variation of conidial germination rates and infections was found to be greater for CA under 24/24˚C and 26/20˚C day / night regimes, than 32/26, 38/26, and 38/32 ˚C regimes (Waliyar et al., 1994; Waliyar et al., 1995), and for CP at 20, 24 and 28˚C, compared to 32˚C (Shew et al., 1988). In addition to lower infection frequencies, components of resistance to CA measured for DP-1 and C-11-2-39 were smaller lesion diameters, reduced percent necrotic areas, and prolonged latent periods. Inconsistencies in measurement techniques throughout the literature and lack of a consistent reference cultivar make comparisons of these results to others difficult. However, the general trend of our results appears to corroborate those reported previously. The mean size of early leaf spot lesions in this study was similar to the range of diameters of CA lesions plus necrotic areas surrounding lesions (halo) (approximately 1.7 to 1.8 mm) for the most resistant Virginia-type peanut genotypes observed by Waliyar, et al. (1994) under the same temperature regime. The means of early leaf spot latent period for DP-1 and C-11-2-39 were equal to the T_2 latent period (days until two CA lesions sporulated) observed for NC 3033, the Virginia-type genotype with the longest T_2 latent period of the genotypes investigated by Ricker, et al. (1985). In this study, it was common to find 2 or more lesions with sporulation per leaf on the first day that sporulation was noticed. Measurements of components

affecting secondary reproduction of CA did not differ among genotypes. However, various obstacles to the collection of these data may have inhibited our ability to detect differences for these variables. Sporulation did not occur in trial 1. Instead lesions with stroma and total number of stroma per lesion were counted. Stroma formation is a precursor to sporulation of CA and CP lesions (Abdou et al., 1974). Abdou et al. (1974) noticed less defined stroma development within lesions from moderately susceptible *Arachis* species than highly susceptible species. Estimates of stroma per leaf area did not differ among genotypes ($P = 0.27$), even though the means were 50 and 33% greater for Georgia Green than DP-1 and C-11-2-39, respectively. In trial 2, sporulation was common for early leaf spots, but spore concentrations were not measured due to contamination of spore quantification vials that resulted in degradation of spores.

Although not assessed in this study, C-11-2-39 and DP-1 have been shown to have more field resistance to late leaf spot than Georgia Green (Culbreath, unpublished data). The growth chamber study suggests their resistance is due in part to reduced infection frequency, smaller lesion size and less % necrotic area (Table 5.4). The mean CP lesion size for all genotypes in this study was smaller than for the most resistant genotypes reported by Chiteka, et al. (1988a) or Aquino et al. (1995). Since neither of these earlier studies included Georgia Green, it is unclear whether genetic variation is responsible for the lesion diameter discrepancy observed between the genotypes tested in our study and those tested by Chiteka et al. (1988a) and Aquino et al. (1995), since factors other than genetics have been shown to influence lesion size. Temperature does not appear to be the cause of the lesion discrepancy since the temperatures in Chiteka's greenhouse trials (between 19.8 to 30.8°C in one trial, and mean daily temperatures ranged from 27 to 34°C in the second trial) may have been less favorable for lesion expansion than the

temperature (24°C) in this study (Shew et al., 1988). It is possible that the high mean number of CP lesions per leaf in this study, which ranged from 55.5 to 101.2 per leaf, limited the expansion potential of CP lesions, as observed for CA (Johnson et al., 1986). The mean number of CP lesions per leaf in Chiteka's study ranged from 8.6 to 13.0, but was not reported by Aquino et al. (1995). The latent periods for the genotypes in this study fell within the range observed by Chiteka et al. (1988a), 16.2 to 35.0 DAI, and Aquino et al. (1995), 21.8 to 30.8 DAI. Ricker et al. (1985) reported that percent sporulating lesions was a component of resistance for CA, but that it did not appear to be a resistance component for CP. We found the opposite trend with the genotypes in our study, but it is important to point out that CA sporulation data were only recorded for trial 2, and therefore was not repeated.

Overall, C-11-2-39 suppressed reproduction if CP the least of the genotypes tested. Although CP spore production per unit leaf area was not statistically different among genotypes ($P = 0.07$), they were more similar for C-11-2-39 and Georgia Green than for DP-1 (Table 5.5). Typically, as lesion size decreases in response to host genetics, spore production decreases and latent period increases (Chiteka et al., 1988a; Jogloy et al., 1987). This trend was observed for all genotypes for CA, and for Georgia Green and DP-1 for CP, but C-11-2-39 presented relatively small CP lesions, more CP sporulation and short CP latent periods. It is possible that the temperature regime chosen in this study was more conducive for sporulation of CP on C-11-2-39 than the other genotypes. Interactions between genotype and temperature have been observed with early leaf spot for incubation period, infection frequency, lesion diameter and latent period (Shew et al., 1988; Waliyar et al., 1994), although no genotype and temperature interactions were observed in the cited studies for spore production. These results suggest that the relative field resistance of C-11-2-39 to late leaf spot compared to Georgia Green or DP-1

may interact with time of disease onset (time available for secondary infection cycles). Information on timing and quantification of secondary inoculum production under field conditions could help assess the precision of the results observed in the growth chamber study, and their effect in the field.

Results from this study suggest that reduced germination of CA spores on the leaf surface may be a component of resistance for DP-1. Waliyar et al. (1995) also found fewer germinated CA conidia on the leaf surface of resistant compared to susceptible peanut genotypes. However, other mechanisms beyond inhibition of germination appear to be involved in the resistance to infection by CA and CP that was exhibited these genotypes; reduced conidial germination was not evident between Georgia Green and C-11-2-39 for CA, or among all genotypes tested for CP. On highly susceptible peanut leaves, Abdou et al. (1974) observed that germtubes of CA and CP showed directional elongation towards open stomata, while on moderately susceptible *Arachis* species the direction of germtube elongation was more variable and often failed to penetrate. Cook, (1981) reported that the number of stomatal penetrations by CP germtubes did not differ among genotypes despite differences in infection frequencies, and suggested that differences in infection frequencies among genotypes were due to factors that limited pathogen growth within the leaf. Abdou et al. (1974) also observed differences in post infection development of CA and CP between highly and moderately susceptible *Arachis* species. Early stages of infection and disease development were similar, but in the moderately susceptible group, mycelial colonization of host cells, numbers of host cells completely destroyed, and stroma formation were less than for the highly susceptible group.

In conclusion, results from the growth chamber study indicate that DP-1 has greater resistance to CA and CP than C-11-2-39 and Georgia Green. Multiple components of resistance

to CA provided similar ranking of the genotypes as measured by AUDPC based on incidence and severity for early leaf spot epidemics in the field. Although not directly comparable, most of the resistance components measured in this study were within the ranges reported for the most resistant peanut genotypes previously reported. This suggests that similar resistance components observed by previous authors are applicable for these current peanut genotypes with enhanced resistance to CA and CP.

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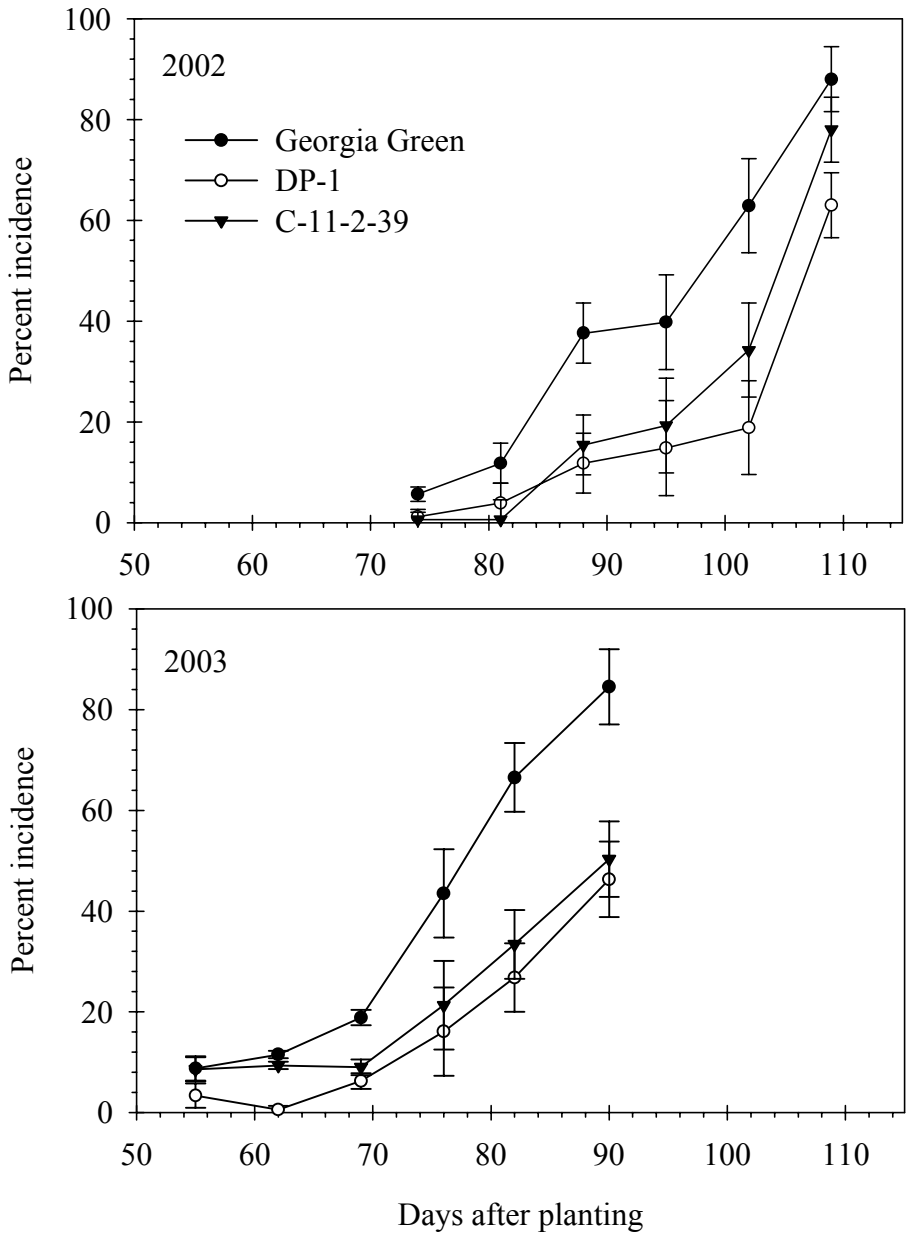

Fig. 6.1. Percent incidence of early leaf spot (diseased leaves of 10 lateral branches) in plots planted to three peanut genotypes at each assessment date averaged over replications in 2002 and 2003.

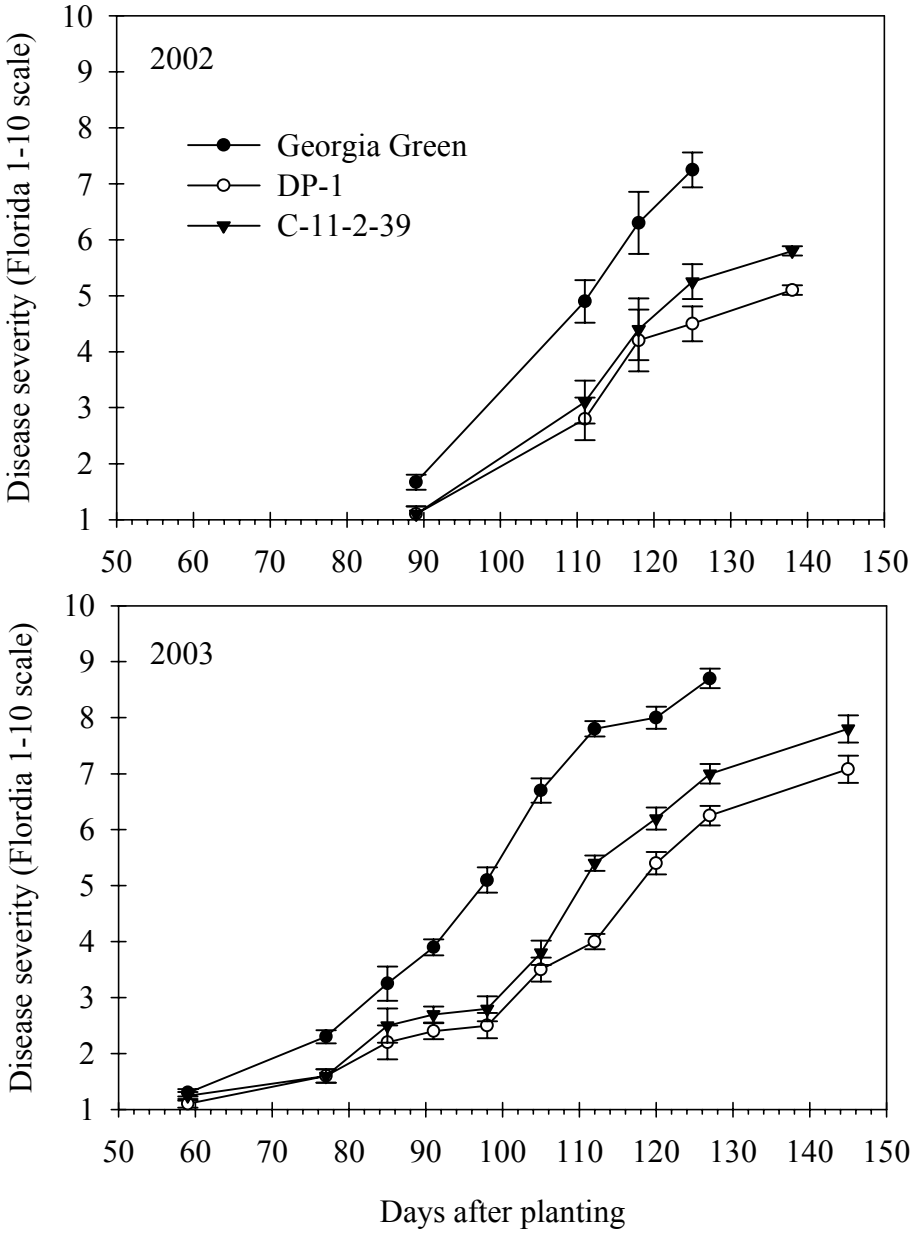

Fig. 6.2. Early leaf spot severity based on Florida 1 to 10 ratings at each assessment date for three peanut genotypes across replications in 2002 and 2003.

Table 6.1. Effect of peanut genotype on early leaf spot disease progress variable assessed as incidence or severity, 2002 to 2003.

	Incidence[a] (%)					Severity[b]		
	Across years	2002		2003		Across years		
Genotype	AUDPC[c]	TDO[d]	Rate[d]	TDO[d]	Rate[d]	AUDPC[e]	TDO[f]	Rate[f]
Georgia Green	1361 A	77 A	0.158 A	54 A	0.129 A	4.6 A	77 A	0.016 A
DP-1	554 B	86 A	0.137 A	63 B	0.095 B	3.5 C	84 B	0.009 C
C-11-2-39	746 B	89 A	0.214 B	52 A	0.079 B	3.9 B	83 B	0.011 B
Standard error	64.2	13.2	0.1063	8.8	0.0257	0.06	2.5	0.0004
P-value	< 0.01	0.13	< 0.01	0.05	0.01	< 0.01	< 0.01	< 0.01

[a] Number of leaves with leaf spot symptoms per total number of leaves averaged from 10 lateral branches arbitrarily sampled per plot.
[b] Florida 1 to 10 leaf spot intensity scale.
[c] Least square means from Proc MIXED of area under the disease progress curve (AUDPC) assessed at a 7-day interval 74 to 109 days after planting (DAP) in 2002, and 55 to 90 DAP in 2003. Means within a column with the same letter do not differ at the 5% level.
[d] Estimated using linear regression of logit transformed data over time.
[e] Area under the disease progress curve standardized by dividing by the number of days from the first to last rating assessed at a 7-day interval 89 to 138 days after planting (DAP) in 2002, and 59 to 145 DAP in 2003.
[g] Estimated using linear regression of Florida 1-10 severity over time.

Table 6.2. Components of symptom expression for detached peanut leaves inoculated with conidia of *Cercospora arachidicola*.

Genotype	Infection frequency 17-d[a]	Infection frequency 30-d[b]	Percent incubation 17-d[c]	Lesion diameter (mm) [d]	Percent necrotic leaf area[e]
Georgia Green	1.4 A	2.9 A	46.2 A	1.9 A	8.3 A
DP-1	1.2 A	2.1 B	58.1 A	1.6 B	4.4 B
C-11-2-39	1.0 A	1.9 B	50.1 A	1.5 B	3.3 B
Standard error	0.22	0.33	6.97	0.10	1.03
P-value	0.24[f]	0.02[f]	0.47[g]	0.01[g]	< 0.01[g]

[a] Least square means from Proc MIXED of number of lesions per leaf area (cm^2), 17 days after inoculation (dai). Means within a column with the same letter do not differ at the 5% level.
[b] Number of lesions per leaf area (cm^2), 30 dai.
[c] Percent of lesions 30 dai apparent 17 dai.
[d] Based on sub-sample of 10 to 50 randomly selected lesions per leaf.
[e] Estimated as [(lesion number 30-DAI * $\pi(d / 2)^2$) / leaf area].
[f] From analysis of square root transformed data. Standard error shown is from the untransformed data and may not reflect the transformed analysis.
[g] From analysis of untransformed data.

Table 6.3. Components of reproductive patterns for early leaf spot lesions on detached peanut leaves.

Genotype	Latent period (days)[a]	Percent spots with sporulation[b]	Percent spots with stroma[b]	Stroma per lesion area (cm^2)[b]	Stroma per leaf area (cm^2)[b]
Georgia Green	22.1 B	48.1 A	34.5 A	1120 A	6.2 A
DP-1	24.4 A	32.6 A	40.4 A	980 A	3.0 A
C-11-2-39	24.4 A	30.2 A	31.5 A	1120 A	4.1 A
Standard error	0.42	6.57	8.58	225	1.41
P-value[c]	< 0.01	0.14	0.76	0.87	0.27

[a] Least square means from Proc MIXED of days after inoculation until first lesion sporulating. Means within a column with the same letter do not differ at the 5% level based on Fisher's LSD values.
[b] Data from one trial.
[c] From analysis of untransformed data.

Table 6.4. Components of symptom expression for detached peanut leaves inoculated with conidia of *Cercosporidium personatum*.

Genotype	Infection frequency 17-d[a]	Infection frequency 30-d[b]	Percent incubation 17-d[c]	Lesion diameter (mm)[d]	Percent necrotic leaf area[e]
Georgia Green	2.5 A	5.4 A	43.5 AB	1.3 A	7.1 A
DP-1	1.3 B	3.9 B	35.0 B	1.1 B	3.7 B
C-11-2-39	2.6 A	3.8 B	52.1 A	1.1 B	3.9 B
Standard error	0.16	0.47	3.65	0.38	0.60
P-value	0.05[f]	< 0.01[f]	< 0.01[g]	< 0.01[g]	< 0.01[g]

[a] Least square means from Proc MIXED of number of lesions per leaf area (cm^2), 17 days after inoculation (dai). Means within a column with the same letter do not differ at the 5% level based on Fisher's LSD values.
[b] Number of lesions per leaf area (cm^2), 30 dai.
[c] Percent of lesions 30 dai apparent 17 dai.
[d] Based on sub-sample of 10 to 50 randomly selected lesions per leaf.
[e] Estimated as [(lesion number 30-DAI * $\pi(d / 2)^2$) / leaf area].
[f] From analysis of square root transformed data. Standard error shown is from the untransformed data and may not reflect the transformed analysis.
[g] From analysis of untransformed data.

Table 6.5. Components of reproductive patterns for late leaf spot lesions on detached peanut leaves.

Genotype	Latent period (days)[a]	Percent spots sporulating	Spores per sporulating lesion area (cm^2)[b]	Spores per leaf area (cm^2)[b]
Georgia Green	24.7 BC	24.4 AB	18400 B	330 A
DP-1	26.0 AB	19.4 B	23700 B	190 A
C-11-2-39	23.4 C	32.7 A	50300 A	570 A
Standard error	0.56	4.09	7250	115
P-value	< 0.01[c]	0.04[d]	< 0.01[c]	0.08[c]

[a] Least square means from Proc MIXED of days after inoculation until first lesion sporulating. Means within a column with the same letter do not differ at the 5% level based on Fisher's LSD values.
[b] Spore quantification estimated from 3 randomly selected sporulating lesions.
[c] From analysis of untransformed data.
[d] From analysis of square root transformed data. Standard error shown is from the untransformed data and may not reflect the transformed analysis.

APPENDIX TO CHAPTER 6

Table 6A.1. Parameters of models across replications that best described the progression of early leaf spot epidemics over time in the field for 8 peanut genotypes in 2002 and 2003.

Year/Genotype	Incidence (logistic model)					Severity (linear model)				
	Intercept	SE	Slope	SE	Recalc. R^2	Intercept	SE	Slope	SE	R^2
2002										
Georgia Green	-15.19	2.74	0.158	0.030	0.76	-1.48	0.17	0.017	0.002	0.93
C-99R	-18.09	2.72	0.177	0.030	0.81	-1.03	0.12	0.012	0.001	0.91
Hull	-17.23	2.44	0.169	0.026	0.88	-1.13	0.20	0.013	0.001	0.81
DP-1	-14.70	1.56	0.137	0.017	0.84	-0.83	0.10	0.010	$8*10^{-4}$	0.90
C-11-2-39	-21.98	2.37	0.214	0.026	0.89	-0.99	0.14	0.011	0.001	0.87
C-28-305	-20.64	2.27	0.196	0.025	0.87	-1.04	0.10	0.012	$9*10^{-4}$	0.94
C-34-24	-16.60	1.78	0.166	0.019	0.91	-1.14	0.15	0.013	0.001	0.89
GA-01R	-21.42	2.22	0.214	0.024	0.92	-0.96	0.11	0.011	0.001	0.91
2003										
Georgia Green	-9.94	0.90	0.129	0.012	0.90	-0.84	0.06	0.014	$6*10^{-4}$	0.95
C-99R	-7.34	0.83	0.086	0.011	0.87	-0.65	0.06	0.010	$5*10^{-4}$	0.93
Hull	-9.59	0.75	0.115	0.010	0.95	-0.61	0.06	0.010	$5*10^{-4}$	0.92
DP-1	-12.06	1.96	0.132	0.027	0.81	-0.59	0.06	0.009	$5*10^{-4}$	0.91
C-11-2-39	-6.85	0.89	0.073	0.012	0.79	-0.66	0.06	0.010	$5*10^{-4}$	0.92
C-28-305	-5.20	0.69	0.057	0.009	0.79	-0.66	0.07	0.010	$6*10^{-4}$	0.90
C-34-24	-11.12	1.54	0.133	0.021	0.89	-0.74	0.08	0.011	$7*10^{-4}$	0.89
GA-01R	-9.39	1.26	0.109	0.172	0.87	-0.63	0.05	0.010	$5*10^{-4}$	0.92

All models significantly fit curves ($P < 0.01$).

Table 6A.2. Germination of *Cercospora arachidicola* and *Cercosporidium personatum* conidia on the surface of peanut leaves of 8 genotypes with varied levels of host resistance.

Genotype	*Cercospora arachidicola*	*Cercosporidium personatum*
	Germination (%)[a]	Germination (%)[a]
Georgia Green	82.6	80.4
C-99R	81.2	77.2
Hull	73.2	76.2
DP-1	61.8	80.2
C-11-2-39	75.6	78.4
C-28-305	71.0	78.8
C-34-24	66.4	66.8
GA-01R	72.6	78.6
Standard error	4.28	4.92

[a] Least square means from Proc MIXED, df = 28.

CHAPTER 7

ECONOMIC EVALUATION OF HOST RESISTANCE, CONSERVATION TILLAGE, AND REDUCED FUNGICIDE PROGRAMS FOR INTEGRATED MANAGEMENT OF LEAF SPOT AND SPOTTED WILT OF PEANUT[1]

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Economic evaluation of host resistance, conservation tillage, and reduced fungicide programs for integrated management of leaf spot and spotted wilt of peanut

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ABSTRACT

Field experiments were carried out to evaluate leaf spot and spotted wilt disease intensity, pod yields and economic return of integrated management of peanut using host resistance, conservation tillage and reduced fungicide programs. Spotted wilt and leaf spot epidemics were suppressed in strip-tilled plots compared to conventionally tilled plots. Breeding lines C-11-2-39 and C-34-24 demonstrated the best field resistance to TSWV, while the cultivars DP-1, GA-01R and line C-28-305 were among the genotypes with the best leaf spot resistance. Leaf spot intensity decreased as the number of fungicide applications increased; however, the response to fungicide decreased with enhanced resistance and use of strip-tillage. Yields and net economic returns were lower in strip-tillage than conventional tillage in 2003, and were affected by genotype both years. The genotypes with the greatest yields and net returns were C-11-2-39, C-99R and GA-01R. Net returns were comparable among the 4, 5, and 7 spray programs both years, despite differences in yield. The standard production system, Georgia Green in conventional tillage with 7 sprays, resulted in lower returns than half the integrated systems tested in 2002, but had as high or higher returns than nearly all the integrated systems in 2003. When significant, yields and net returns were correlated with spotted wilt intensity to a greater

degree than leaf spot intensity. The cost savings incurred by strip-tillage were not great enough to exceed the return potential of conventional tillage in 2002, or to compensate for losses of yield in strip-tilled plots in 2003.

INTRODUCTION

Peanut production in the U.S. changed from a supply management quota program to a market loan system with implementation of the 2002 Farm Bill (Smith, 2002). The new system established a floor price for in-shell peanut of $391/metric ton loan rate with a price increase based on market demand. Two goals of this change were to enhance producer control over peanut marketing and to make U.S. peanuts more competitive with imported peanuts in the domestic market (Smith, 2002). However, economic risks for growers are often greater when supply and prices are not fixed. Since the economic shift, peanut acreage in Georgia has increased by 25%, while prices have decreased by 13.5% (Anonymous, 2004; Williams-Woodward, 2002; 2004). An economic review of standard peanut production practices employed during the quota system era is needed for the new market system since, depending on the peanut market price, production may not be profitable.

In the southeastern United States, the most important foliar diseases of peanut (*Arachis hypogaea* L.) are spotted wilt, caused by *Tomato spotted wilt virus* (TSWV), early leaf spot, caused by *Cercospora arachidicola* S. Hori, (teleomorph = *Mycosphaerella arachidis* Deighton), and late leaf spot, caused by *Cercosporidium personatum* (Berk. & M. A. Curtis) Deighton, (teleomorph = *Mycosphaerella berkeleyi* Jenk.). These diseases occur every year in Georgia, although severity fluctuates by year and location. Disease control of leaf spot is a priority for

growers since pod losses of up to 50% are common without control, (Smith and Littrell, 1980) and can be greater.

No single management tool provides adequate control of spotted wilt; however, genetic, chemical and cultural practices, such as cultivar selection, planting date, plant population, row pattern, tillage practice and in-furrow insecticide, can reduce disease risk (Brown et al., 2003; Culbreath et al., 2003). Frequent fungicide applications are common for leaf spot management. The standard fungicide program for Georgia includes an initial application at 30 days after planting (DAP), followed by additional sprays at 14-day intervals, resulting in 7 or more applications per season (Kemerait et al., 2004).

Two inexpensive practices that provide some suppression of spotted wilt and leaf spot diseases are planting cultivars with host resistance and preparing fields using strip-tillage, a conservation tillage practice that consists of 15 to 20 cm tilled strips. Host resistance to TSWV, *C. arachidicola* and *C. personatum* is partial in peanut, resulting in a reduction of epidemic severity rather than immunity to disease (Chiteka, 1987; Chiyembekeza, 1992; Culbreath et al., 2003). In the past, lower yield potential often was associated with resistant cultivars; however, cultivars and breeding lines with moderate disease resistance and high yield potential are now available (Gorbet et al., 1982). The cultivar Georgia Green, estimated as planted to over 85% of the acreage in Georgia during 2003 (Smith, 2003a), has good yield potential and field resistance to TSWV (Culbreath et al., 1996b), but is susceptible to *C. arachidicola* and *C. personatum* (Branch, 1996).

Strip-tillage has been shown to suppress spotted wilt severity by as much as 42% (Johnson et al., 2001) and when combined with 4 fungicide applications provided a level of leaf spot control that was comparable to that of conventionally tilled fields that received 7 fungicide

applications (Monfort et al., 2004). Pod yields were comparable in conventional and strip-tillage plots over a 5-year study (Johnson et al., 2001), but have been inconsistent in other tests (Hartzog and Adams, 1989; Monfort et al., 2004). The benefits of strip-tillage for peanut production are not limited to disease management. Strip-tillage and other conservation tillage practices build soil, increase soil fertility, reduce erosion, improve water infiltration, and save fuel, time and labor. Use of conservation tillage for peanut production increased over the past decade primarily due to depressed crop prices, increased energy costs, and a reduced labor force (Johnson et al., 2001).

Production decisions regarding tillage and chemical inputs can significantly affect costs. The estimated variable cost (fuel, labor and machinery repairs and maintenance) of conventional deep plow tillage is $89/ha compared to $47/ha with strip-tillage (Smith, 2003b). In addition, savings of fixed costs associated with the purchase of equipment for tillage may be as high as $73/ha/yr with strip-tillage (Smith, 2003b). The variable cost of each tractor-mounted fungicide application is $5.80/ha in addition to the cost of the chemical. The potential reduction in variable costs with strip-tillage and no fungicide applications can be as much as $180/ha (Smith, 2003b), or 60% of the of the average crop value per ha in Georgia in 2001 (Williams-Woodward, 2004).

Monetary savings of strip-tillage and fewer fungicide inputs may compensate for the economic impact of reduced yields in strip-tilled fields when they occur, and provide an opportunity for greater returns when yields are not affected. This study was carried out to compare disease management, pod yields and grades, and economics of peanut cultivars and advanced breeding lines, grown under conventional and strip-tillage, with standard, reduced or no fungicide programs. An economic comparison of these integrated disease management

systems with the standard production system, consisting of cultivar Georgia Green, conventional tillage and 7 application fungicide program for leaf spot control, was also conducted.

METHODS

Experimental design. A field experiment was carried out at the University of Georgia Coastal Plain Experiment Station, Rigdon Farm, Tifton GA in 2002 and 2003. Soil type was a Tifton loamy sand. Fields were planted to cotton (*Gossypium hirsutum* L.) the previous year, and peanut 2 years prior, both grown with conventional tillage. Winter wheat (*Triticum aestivum*) was planted as a cover crop the previous fall.

The experiment was laid out in a randomized split-split plot design with 3 replications. Treatments consisted of combinations of 2 tillage treatments (main plots), 4 fungicide programs (subplots) and 8 genotypes (sub-subplots). Tillage treatments included conventional and strip-tillage. Conventionally tilled plots were mowed and disked twice before the soil was deep turned with a switch plow, 20-25 cm deep, and bedded with a disk bedder. Ethalfluralin (Sonolan HFP 3.0, Dow AgroScience LLC, Indianapolis, IN) 0.95 kg a.i/ha and S-metoalochlor (Dual Magnum 8E, Syngenta Crop Protection, Inc., Greensboro, NC) 1.68 kg a.i./ha were incorporated into the tilled beds. In the strip-tillage plots, the cover crop was treated with glyphosate (Roundup 4 EC, Monsanto, Kansas City, MO) at 1.2 kg a.i./ha. A subsoil shank attached to a strip-till implement (Kelley Manufacturing Co., Tifton, GA), loosened the plow pan 33 cm beneath the row, while the implement tilled strips approximately 20 to 25 cm wide, as described by Monfort *et al*. (2004). Genotype plots were 6.0 m long, separated by 2.4 m alleys. The genotypes included the cultivars Georgia Green, C-99R, Hull, GA-01R, and DP-1 and breeding lines C-11-2-39, C-28-305, and C-34-24. Peanut seed was planted to 91 cm spaced single rows at a rate of 24 seed m^{-1}

of row on 17 May 2002 and 30 seed m^{-1} of row 20 May 2003 using a cone planter. Stand counts were recorded after peanut emergence and additional seed were hand planted in empty spaces greater than 20 cm in 2002 and 15 cm in 2003. Fungicide programs consisted of calendar-based applications of chlorothalonil (Bravo Weatherstik 720 F, Syngenta Crop Protection, Inc, Greensboro, NC) at 1.26 kg/ha. The first spray was applied at approximately 30 DAP, followed by sprays at 14, 21 or 28-day intervals, resulting in totals of 7, 5 and 4 applications, respectively. A non-treated control, or 0-spray program, was also included. References to fungicide programs are by the number of sprays applied. Fungicides were applied with a tractor-propelled boom sprayer under 345 kPa pressure in 115 liters of water/ha. In 2002, chlorothalonil was applied at 32, 46, 59, 73, 87, 101 and 115 DAP for the 7-spray program; 32, 53, 73, 91 and 115 DAP for the 5-spray program; and 32, 59, 87 and 115 DAP for the 4-spray program. In 2003, spray dates were 30, 43, 57, 71, 84, 96 (reapplied at 103 due to wash off by rain), and 113 DAP for the 7-spray program; 30, 50, 71, 91 and 113 DAP for the 5-spray program; and 30, 57, 84 and 113 DAP for the 4-spray program. Acephate (Orthene 75W, Valent U.S.A. Corporation, Walnut Creek, CA) 0.84 kg a.i./ha was applied 13 DAP both years for early season control of tobacco thrips (*Frankliniella fusca* Hinds). Acephate at the same rate was applied 106 DAP in 2003 and at 0.42 kg a.i./ha with 0.07 kg a.i. of diflubenzuron (Dimilin 2L, Crompton Chemical, Middlebury, CT) at 108 DAP in 2002 for late season control of foliage feeding insects. No post-planting herbicide applications were necessary for conventional tillage plots, but in the strip-tillage plots, 0.84 kg a.i./ha of bentazon (Basagran 4 EC, BASF Corporation, Research Triangle Park, NC) and petroleum oil (Agri-Oil, ChemNut, Albany, GA) surfactant was applied 21 DAP, and a mixture of 0.84 kg a.i./ha of bentazon, 0.25 kg a.i./ha of 2,4-DB (Butyrac 175, Bayer CropScience, Research Triangle Park, NC) and petroleum oil was applied 43 DAP in 2002. In

2003, a mixture of 0.14 kg a.i./ha of clethodim (Select 2 EC, Valent U.S.A. Corporation, Walnut Creek, CA), 0.62 kg a.i./ha of bentazon and petroleum oil was applied to the strip-till plots 15 DAP. Calcium sulfate was applied to all plots as gypsum, 1120 kg/ha 52 DAP in 2002 and 672 and 560 kg/ha 55 and 71 DAP, respectively, in 2003.

Disease assessment. Tomato spotted wilt was evaluated 101 DAP in 2002 and 107 DAP in 2003. Spotted wilt intensity was determined in each plot using a disease intensity rating that represents a combination of incidence and severity as described by Culbreath et al. (1997b). The number of 0.3-m portions of row containing severely stunted, chlorotic, wilted or dead plants was counted for each plot and converted to a percentage of row length for comparison of treatments.

Leaf spot severity per plot was estimated using the Florida 1-10 scale rating system, where 1 = no leaf spot; 2 = very few lesions on the leaves, none on the upper canopy; 3 = few lesions on the leaves, very few on the upper canopy; 4 = some lesions with more on the upper canopy, 5% defoliation; 5 = lesions noticeable even on upper canopy, 20% defoliation; 6 = lesions numerous and very evident on upper canopy, 50% defoliation; 7 = lesions numerous on upper canopy, 75% defoliation; 8 = upper canopy covered with lesions, 90% defoliation; 9 = very few leaves remaining and those covered with lesions, 98% defoliation; and 10 = plants completely defoliated and killed by leaf spot (Chiteka et al., 1988a). Leaf spot severity was assessed when symptoms first appeared (89 DAP in 2002, 59 DAP in 2003) continued at 7 to 22-day intervals until harvest. Final percentage defoliation was estimated from the Florida scale rating taken just before peanuts were dug. Area under the disease progress curve (AUDPC) was computed for each plot using leaf spot intensity ratings, and standardized by dividing AUDPC by the number of days from the first to last rating (Campbell and Madden, 1990).

Severity of Florida leaf spot (FLS), cause unknown, was assessed 56 DAP in 2002 using the FLS 1 to 7 scale described in Chapter 5. Severity of stem rot, a soilborne disease caused by *Sclerotium rolfsii*, was assessed immediately before digging in 2002 and immediately after digging in 2003. The number of 0.3-m portions of row with stem rot signs or symptoms was counted to compute percent linear row affected by stem rot.

Pod yield and grade. Peanuts were harvested based on maturity. Georgia Green plants were dug and inverted 129 DAP and 132 DAP in 2002 and 2003, respectively. All other genotypes were dug and inverted 140 DAP in 2002 and 145 DAP in 2003. Peanuts were harvested mechanically 7 to 11 days after digging and pod yields were determined by weighing harvested pods after they were dried and adjusted to 10% (wt/wt) moisture. One 1000-g sample of harvested pods per plot was cleaned, and non-pod materials were weighed. The percent of kernels that was immature, damaged, and sound was determined from one 500-g sample of cleaned pods using commercial grading equipment according to official Federal-State Inspection Service methods.

Economic returns. Crop value was determined for each plot using the following formula from the 2003 pod price schedule: dollars per metric ton = [(% TSMK * $5.37) + (% immature * $1.54)] – [(% foreign material – 4) * $1.10] – (% damaged deduction) (Anonymous, 2003a, 2003b). There was no deduction for damaged kernels below 2% damaged kernels. The damaged kernel deduction was $3.75 per metric ton if $2 \leq$ % damaged < 3, and $7.70 if $3 \leq$ % damaged < 4 (Anonymous, 2003b) .

Variable costs were calculated for each combination of tillage, fungicide, and genotype treatment using cost estimates for treatment and production practices described in the experimental design section, modified from Smith (2003b) (Table 7.1). Seed costs were

computed using the following equation: Seed cost = [seed price ($/kg) * seed/kg * seed/ha]. Seed per ha were based on seeding rate and were 143,500 in 2002 and 179,400 in 2003. Seed price was determined using 2004 cultivar distribution price, or an average price for genotypes not available for purchase. Seed prices were $1.19/kg for Georgia Green, $1.26/kg for C-99R and $1.23/kg for the other genotypes. The mean number of seed per kg was 1819 for Georgia Green, 1488 for C-99R, Hull, and GA-01R; 1653 for DP-1 (Beasley, personal communication), and 1764 for the 3 breeding lines (Holbrook, personal communication). Fuel costs were set at $0.30/liter and labor at $9.25/h. Net returns were determined by subtracting variable production costs from crop value estimates.

Statistical analysis. Data were analyzed using Proc MIXED with ddfm = satterth option on the model statement with SAS (SAS v.8.3, SAS Institute, Cary, NC), unless otherwise stated. Fisher's LSD values were computed using standard error and t-values of adjusted degrees of freedom. If an interaction was significant, the above Fisher's LSD was further adjusted to reflect use of the interaction term as a source of error if the F-test for the main effect using the appropriate interaction showed the main effect to be significant; otherwise, only the interaction means were presented.

The rate of decrease in disease with increasing numbers of fungicide sprays was estimated using linear regression (SPSS Graduate Pack v.9.0 for Windows, SPSS, Inc., Chicago, IL) of AUDPC on number of fungicide applications for each tillage-genotype treatment. Net returns of integrated systems were compared to the standard system, Georgia Green with 7 applications under conventional tillage, by setting the three-way interaction (tillage*fungicide*genotype) as the only effect in the model.

RESULTS

Disease assessment. Spotted wilt was more severe in 2002 than 2003 (Table 7.2). Despite a significant interaction between tillage and genotype in 2002 ($P < 0.01$), spotted wilt incidence was less for C-11-2-39 than any other genotype except C-34-24, and Georgia Green and C-28-305 were among the genotypes with the highest spotted wilt levels (Table 7.2). Spotted wilt was numerically lower in strip-tillage than conventional tillage in 2002 with 8.5 and 12.8% row length severely affected, respectively ($P = 0.06$), and significantly lower in 2003 with 4.0 and 6.1%, respectively ($P < 0.01$). The genotype main effect explained 53% of the variation observed for spotted wilt in 2002 and 60% in 2003, while tillage explained 15% and 36% these years, respectively. Fungicide did not affect spotted wilt (Table 7A.1).

Early leaf spot was the predominant leaf spot disease in the study (>90%), although some late leaf spot was observed both years. Leaf spot epidemics were more severe in 2003 than 2002 (Table 7.3). Tillage, fungicide and genotype main effects for % defoliation and AUDPC were significant both years. In most cases, there was a significant interaction between tillage and genotype. Under conventional tillage or across tillage, Georgia Green, C-99R and C-34-24 were among the genotypes with the highest disease levels, while DP-1, GA-01R and C-28-305 were among the genotypes with the lowest levels of leaf spot (% defoliation and AUDPC) (Table 7.3). Although disease response to genotype was less consistent across years under strip-tillage, Georgia Green and C-34-24 continued to be among the genotypes with highest levels of leaf spot, while DP-1 had the lowest % defoliation and AUDPC (Table 7.3).

Fungicide had the greatest impact on leaf spot severity, explaining 45 and 40% of the variation in % defoliation and AUDPC, respectively, in 2002, and 61 and 62%, respectively, in 2003. Tillage had a greater impact on leaf spot severity than genotype, with tillage explaining

between 26 and 34% of the variation observed for % defoliation and AUDPC, while genotype explained 1 to 7%. In general, leaf spot severity decreased as the number of fungicide applications increased; however, in 2002, there was no difference in % defoliation in strip-tilled plots among the 4, 5 and 7-spray programs, or in AUDPC in the 4 and 5-spray programs (Table 7.4). Defoliation and AUDPC values were numerically lower or similar in strip-tilled plots with 0 sprays than in conventionally tilled plots that received 5 or 4 sprays in 2002, and similar in strip-tilled plots that received 5 sprays and conventional tilled plots that received 7 sprays both years (Table 7.4).

There was a negative linear relationship between AUDPC and the number of fungicide applications for all genotype and tillage treatment combinations ($P < 0.01$) (Table 7.5). Fungicide response rate, the slope parameter estimate from the regression, differed among genotypes ($P < 0.01$), and was more negative for conventional than strip-tillage for most genotypes (Table 7.5). Response rates were negatively correlated with disease potential (AUDPC of the 0-spray treatment) in 2002 ($y = -0.10x + 0.12$, $R^2 = 0.93$), and in 2003 ($y = -0.07x + 0.07$, $R^2 = 0.58$) (Fig. 7.1). When the effect of disease potential was removed (residuals from Fig. 7.1), response rates did not differ among genotypes ($P = 0.10$) or between tillage systems ($P = 0.23$).

Stem rot severity was not affected by tillage ($P > 0.07$) or fungicide program ($P > 0.15$) either year; however the genotype effect was significant both years ($P < 0.01$). DP-1 and C-11-2-39 had less stem rot than Georgia Green in 2002, and all genotypes had less stem rot than Georgia Green in 2003 (Table 7A.2).

Pod yield and grade. Pod yields of all genotypes were higher in 2003 than 2002. Yield was affected by genotype in 2002 and 2003 ($P < 0.01$), and tillage in 2003 ($P = 0.03$), but was

not affected by tillage in 2002 (P = 0.14). Despite significant tillage*genotype interactions both years, Georgia Green and C-28-305 were consistently among the lowest yielding genotypes, while C-11-2-39 and C-99R were among the highest (Table 7.6). Yields of GA-01R were relatively high under both tillage systems in 2002 and in strip-tilled plots in 2003. Yields of DP-1 and C-34-24 were relatively high in 2002, but were among the lowest in 2003. Fungicide affected yield both years (P < 0.01), but there were no differences among the 4, 5 and 7-spray programs in 2002 or between the 5 and 7-spray programs in 2003 when the fungicide*genotype interaction was considered (Table 7.7).

Georgia Green, DP-1 and C-28-305 had the lowest grades, while C-11-2-39, C-34-24 and C-99R were among the genotypes with the highest grades (Table 7.8). Use of conventional tillage resulted in higher grades than those in strip-tillage in 2002 (SMK = 72.9 and 70.9 respectively; *P* = 0.01) and numerically higher grades in 2003 (SMK = 74.5, 73.8; *P* = 0.08). Fungicide did not affect grades in 2003 (*P* = 0.54) but did in 2002 (*P* = 0.01); however there was no difference between the 0 and 7-spray program (Table 7A.3). Average % damaged kernels and % foreign material for all plots was below the respective 1.4 and 4% deduction thresholds, with few exceptions that resulted in less than $1.32 loss per metric ton of kernels (Table 7A.4-7A.7). Average % immature kernels ranged from 2.6 to 11.4%. Despite a significant 3-way interaction both years, Georgia Green and DP-1 tended to have higher % immature kernels than the other genotypes in the study (Table 7A.4).

Economic returns. Estimated total variable costs for each tillage and fungicide treatment are shown in Table 7A.8. The cost difference between conventional and strip-tillage was less in the 0-spray program than in the other programs due to differences in the number of non-fungicide pesticide applications that could not be tank-mixed with fungicide applications.

The cost of each fungicide spray was estimated at $23.09/ha, which included labor, fuel, machinery repair and chemical costs. Seed costs ranged from $93.94/ha for Georgia Green in 2002 to $151.49/ha for C-99R in 2003, but were never more than $34.07/ha different among genotypes each year (Table 7A.9).

Net returns were higher in 2003 than 2002. Genotype affected returns both years ($P < 0.01$) despite a 3-way interaction with tillage and fungicide in 2002 ($P < 0.05$) and 2-way interaction with tillage in 2003 ($P < 0.05$). C-11-2-39, C-99R and GA-01R showed consistently high returns, while Georgia Green was among the genotypes with the lowest returns (Table 7.6). The 0-spray fungicide program resulted in lower returns than all other fungicide treatments in 2003, and the 7-spray regime in 2002, but returns were similar among the 4, 5, and 7-spray programs both years (Table 7.7). Tillage did not affect net returns in 2002, with $613.68/ha in conventional tillage and $522.05/ha in strip-tillage ($P = 0.19$), but did in 2003, with $1038.77/ha in conventional tillage and $792.90/ha in strip tillage ($P = 0.03$).

In 2002, 33 of the 63 integrated treatment combinations resulted in greater returns than the standard Gerogia Green, conventional tillage, 7 spray system: 6 from the 0-spray program, 8 from the 4-spray program, 8 from the 5-spray program and 11 from the 7-spray program (Fig. 7.2). In 2002, net returns from treatment combinations that included C-11-2-39, DP-1, GA-01R and C-34-24 exceeded those of the standard system more often than other genotypes. None of the treatment combinations resulted in lower returns than the standard system in 2002. In 2003, only C-11-2-39 in conventional tillage with 5 sprays resulted in greater returns than the standard system, while 9 systems, 4 with Georgia Green, 2 with DP-1 and C-28-305, and 1 with Hull, all from strip-tillage, had lower returns (Fig. 7.2).

Spotted wilt severity was negatively correlated with yield and economic returns in 2002, but not in 2003 (Table 7.9). Leaf spot AUDPC values were not correlated with yield or economic returns either year, but final % defoliation levels were negatively correlated with yield and net returns both years.

DISCUSSION

Spotted wilt and leaf spot epidemics in the experimental fields were different each year, and reflected disease pressure throughout much of South Georgia these years. Disease loss estimates for fields under a standard fungicide program were 1.5% for leaf spot and 4.5% for spotted wilt in 2002, and 1.5% for leaf spot and 1% for spotted wilt in 2003 (Williams-Woodward, 2003; 2004). In the 4 years prior to this study, yield loss estimates for leaf spot were between 1 and 3% and spotted wilt between 1.5 and 4.5% (Williams-Woodward, 1999; 2000; 2001; 2002). Leaf spot severity is highly dependent upon weather, especially rainfall. Tifton, GA received nearly 60% less rainfall during the growing season in 2002 than in 2003 (Georgia Automated Environmental Monitoring Network). Little is known about the causes of variation in severity of spotted wilt epidemics, which are notoriously difficult to predict.

In most cases, epidemics of spotted wilt and leaf spot were suppressed in the strip-tilled plots compared to conventionally tilled plots. Exceptions typically occurred when disease was low in conventional tillage, due to naturally low disease pressure, enhanced host resistance and/or fungicide use. Others have reported similar interactions of tillage and other factors that affect severity of spotted wilt and leaf spot (Monfort et al., 2004).

The cause of spotted wilt suppression in strip-tillage may be related to lower population numbers of thrips, the vector for TSWV. Mechanisms affecting population dynamics of thrips in

strip-tillage are unclear; however, it has been proposed that killed plant debris at the soil surface in strip-tilled fields interfere with the ability of thrips to find peanut plants (Culbreath et al., 2003). The cause of leaf spot epidemic suppression by strip-tillage is less clear. Visual comparisons of disease progress curves from this study (not shown) and those reported by Monfort et al. (2004) suggest that disease onset occurs later in strip-tillage than in conventional tillage, and that the rate of disease progression is similar. However, these disease progress curves used the Florida 1 to 10 scale to estimate leaf spot severity, which may not accurately describe early epidemic development since low disease assessments are extremely subjective and incremental differences of the scale are not linear with disease severity. Disease progress curves based on incidence of early leaf spot would allow a more detailed description of disease progression, especially during the early portion of the epidemic, and provide more accurate comparisons of epidemic parameters from disease models. Incidence data were recorded for the 0-spray treatment plots in this test and are used, along with data from other field studies, to describe the tillage effects on leaf spot epidemics in Chapter 3. It is important to point out that all of the reports of leaf spot suppression by strip-tillage have been for epidemics dominated by early leaf spot (Monfort et al., 2004; Porter and Wright, 1991). More research is necessary to establish the effect of tillage on late leaf spot epidemics.

Leaf spot severity in strip-tilled plots that received 4 or 5 sprays in 2002 and 5 sprays in 2003 was comparable to that in conventionally tilled plots that received 7 sprays. These results corroborate reports by Monfort (2004), that leaf spot control with a 4-spray 21-28-21-28-day interval program in strip-tillage was similar to a 7-spray 14-day interval program in conventional tillage. The fungicide equivalence of strip-tillage for leaf spot control as it compared to conventional tillage with 0 sprays was 5 sprays in 2002 and 4 sprays in 2003.

Georgia Green and C-99R were among the genotypes tested with the least field resistance to leaf spot and spotted wilt, while C-11-2-39 and C-34-24 had the best field resistance to spotted wilt, and DP-1, GA-01R and C-28-305 were among the genotypes with the best leaf spot resistance. The genotypes with the best combined disease resistance were DP-1, GA-01R and C-11-2-39. Genotype choice appears to be a more important factor for spotted wilt management than leaf spot management, since genotype explained over 50% of the variation observed for spotted wilt and less than 9% for leaf spot. This result is in part due to the greater amount of resistance to spotted wilt represented by the genotypes in this study. C-11-2-39 has a high level of resistance to systemic viral movement (Mandal et al., 2002), while DP-1 reduces rates of leaf spot epidemic progression. In a growth chamber experiment, DP-1 had 28% fewer infections, 17% smaller lesion diameters, and 2 day longer latent period than Georgia Green (Chapter 6). The genotypes included in this test have the best resistance to TSWV, *C. arachidicola* and *C. personatum* currently available in runner-type peanuts.

Fungicide did not affect spotted wilt but was the most important factor affecting leaf spot severity. In all cases, leaf spot severity decreased as the number of fungicide applications increased; however, differences were not always statistically significant. Disease response to increasing numbers of fungicide applications was negatively related to the disease potential of specific tillage-genotype combinations. Furthermore, fungicide response rates were not affected by genotype or tillage when differences in disease potential were ignored. This suggests that differences in disease potential may explain the observed genotype and tillage interactions with fungicide, rather than differences in fungicide deposition on peanut foliage due to differences in canopy architecture or physical obstruction by standing cover crop residue in strip-tilled fields, as was seen in peanut fields with broad leaf weeds (Royal et al., 1997). As far as these authors

are aware, no studies have compared fungicide efficacy in strip-tilled fields with a standing cover crop residue and conventional tilled fields without residue for any cropping system. Our results indicate that the additive effects of tillage system, peanut genotype and fungicide program on leaf spot severity are dependent upon disease potential.

Spotted wilt management was an important consideration to optimize yields and net returns in 2002, when spotted wilt pressure was high, but not in 2003. Severity of leaf spot epidemics, as assessed by AUDPC, was not correlated with yields or net returns, but the amount of defoliation was a good predictor of both yield and net returns. The relationship between defoliation and yield loss is documented for susceptible cultivars (Shokes and Culbreath, 1997), and is most likely due to lost pods at digging because pegs weaken as defoliation levels increase (Knauft et al., 1988). Yield loss induced by defoliation is not linear. Florunner, the industry standard runner-type cultivar from 1970 into the 1990's, tolerated as much as 40% defoliation before yield loss occurred (Shokes and Culbreath, 1997). In this study, the absence of yield loss observed in response to different levels of defoliation suggests that the peanut genotypes included in this study also tolerate some amount of defoliation before incurring pod losses. More research is needed to determine the potential of tolerance to help reduce yield losses from leaf spot.

Of the factors investigated in this study, genotype had the greatest impact on yield and net returns. Although some of this effect can be attributed to disease resistance or tolerance, it is likely that variations in overall yield potential also play a role. C-11-2-39 appears to be the most promising of the genotypes compared in this study with regard to consistent profits despite disease pressure. However, this breeding line is not suitable for large-scale commercial production because it produces a seed with a red testa that is not acceptable to shellers. C-99R

does not have as much field resistance to TSWV as many of the other genotypes, but it does have great yield potential when spotted wilt severity is relatively low, as seen in 2003. C-34-24, released as Tifrunner for the 2005 season, was similar to Georgia Green in resistance to leaf spot, but has much better field resistance to TSWV and equal or better yield potential. Tifrunner and C-11-2-39 have the same parentage, but the seed testa color of Tifrunner is tan, like Georgia Green, and may be a viable alternative to Georgia Green when additional resistance to TSWV is needed. The yield and net returns for DP-1 and GA-01R were high, relative to the other genotypes, in 2002, and relatively low in 2003. Germination was low for these lines in 2003, and although seed were replanted, it is likely that there were some losses due to poor germination. DP-1 and some other lines from the University of Florida breeding program, such as Southern Runner, have a history of poor germination (Gorbet, personal communication). Since yield and net returns were more highly correlated with spotted wilt severity than leaf spot intensity, when correlations were significant, growers would be well advised to base cultivar selection on spotted wilt resistance rather than leaf spot resistance, especially since other options are available for leaf spot management. However, some of the breeding lines and cultivars offer improved resistance to both TSWV and leaf spot pathogens, and should work well in an integrated program where management of multiple diseases must be considered.

The savings incurred by strip-tillage were not great enough to exceed the return potential of conventional tillage in 2002, or to compensate for losses to yield in strip-tilled fields in 2003. However, it is important to point out that these fields were in their first year of strip-tillage, and it is common to see reduced yields during the first year of conservation tillage. A 6-year field study of peanut plots in Georgia that were continuously prepared using conventional or strip-tillage with a peanut-cotton-corn rotation, also found lower pod yields in the strip-tilled plots

than conventionally tilled plots during the first year; however, the tillage differences to peanut yields were reduced with increased years under the continuous tillage treatments (Truman, personal communication). More research is necessary to assess disease suppression under continuous conservation tillage systems. Increases in fuel costs could also make conservation tillage economically more favorable even if yield differential observed in this study was consistent over time.

In general, the standard program consisting of Georgia Green, 7 fungicide applications, and conventional tillage did not maximize net returns. The savings in labor (time spent) and fixed costs were not included in the results and add to the value of strip-tillage. In addition, economic incentives for conservation tillage practices by cost share programs, such as the Conservation Reserve and Conservation Reserve Enhancement Programs, increase the economic potential of strip-tillage.

Stem rot and limb rot, caused by *Sclerotium rolfsii* and *Rhizoctonia solani*, respectively, were not present at high levels in this study; however, their management is of critical importance in Georgia peanut fields (Williams-Woodward, 2004). The genotype entries in this study showed equal or better field resistance to stem rot than Georgia Green. The 2005 Peanut Disease Risk Index (Brown et al., 2005), an index that rates the risk to peanut diseases due to genetic, cultural and chemical practices, ranks DP-1, GA-01R and C-99R as more resistant to white mold than Georgia Green or Tifrunner, and Georgia Green and GA-01R as more resistant to limb rot than DP-1 or C-99R. Stem rot severity was not affected by tillage in this study, and has not been previously reported to be influenced by tillage (Brenneman et al., 1999; Johnson et al., 2001; Monfort et al., 2004); however, strip-tillage may aggravate limb rot severity since *R. solani* can survive saprophytically on plant debris and sclerotia are stimulated to germinate by organic

matter in soils (Brenneman, 1997). Chlorothalonil has no activity against *S. rolfsii* or *R. solani,* but other fungicides are available that have multipathogen activity and provide comparable or better leaf spot control. Studies are underway to evaluate the relative levels of resistance of these genotypes to soilborne pathogens, and to explore impacts of reduced application programs with various fungicides on disease development and economic returns.

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Table 7.1. Estimated cost analysis of conventional tillage and strip-tillage peanut production.

		Conventional tillage			Strip-tillage		
VARIABLE COSTS:	Unit	No. Units	$ Cost /Unit	$ Cost /ha	No. Units	$ Cost /Unit	$ Cost /ha
Seed	Varied by year and genotype						
Lime/Gypsum	Ton	0.50	23.00	28.42	0.50	23.00	28.42
Inoculant	Lb.	0.00	1.00	0.00	0.00	1.00	0.00
Fertilizer:							
Phosphate (P2 O5)	Lb.	20.00	0.25	12.36	20.00	0.25	12.36
Potash (K2O)	Lb.	40.00	0.15	14.83	40.00	0.15	14.83
Boron	Lb.	0.50	2.50	3.09	0.50	2.50	3.09
Herbicides	Acre	1.00	45.26	111.81	1.00	48.29	119.32
Fungicides	Varied by fungicide treatment						
Insecticides	Acre	1.00	23.00	56.83	1.00	23.00	56.83
Nematicide	Acre	0.00	60.00	0.00	0.00	60.00	0.00
Machinery: Preharvest							
Fuel	Gal.	6.60	1.15	18.75	1.09	1.15	5.40
Repairs and Maint.	Acre	1.00	15.16	37.46	1.00	11.73	28.98
Machinery: Harvest							
Fuel	Gal.	6.30	1.15	17.90	6.30	1.15	17.90
Repairs and Maint.	Acre	1.00	26.25	64.86	1.00	26.25	64.86
Labor	Hour	4.12	9.25	94.17	3.24	9.25	74.06
Crop Insurance	Dol.	1.00	15.00	37.07	1.00	15.00	37.07
Irrigation	Appl	5.00	5.25	64.86	5.00	5.25	64.86
Operating capital interest	Dol.	227.61	0.055	15.47	213.67	0.055	14.52
Cleaning	Ton	0.88	10.00	21.62	0.88	10.00	21.62
Drying	Ton	0.88	15.00	32.43	0.88	15.00	32.43
GPC & GPPA[a]	Ton	1.85	3.00	13.71	1.85	3.00	13.71
NPB[b]	Dol.	0.01	621.25	15.35	0.01	621.25	15.35
Total Variable Costs				661.00			625.61
Total Fixed Costs (details not shown)				603.20			530.52

[a] Dues and checkoff money for Georgia Peanut Commission & Georgia Peanut Producer Association.

[a] National Peanut Board checkoff.

Table 7.2. Effect of peanut genotype on spotted wilt severity by tillage in 2002 and across tillage in 2003.

	Spotted wilt severity[a]					
	2002				2003	
Genotype	Conventional tillage[b]		Strip-tillage[b]		Across tillage[c]	
Georgia Green	21.7	E	12.9	D *[d]	6.9	CD
C-99R	12.7	D	10.4	CD	4.7	B
Hull	19.4	E	10.0	CD *	4.9	BC
DP-1	8.5	BC	7.5	BC	5.7	BCD
C-11-2-39	2.9	A	2.7	A	1.8	A
C-28-305	22.7	E	11.1	CD *	6.7	BCD
C-34-24	5.4	AB	4.2	AB	2.4	A
GA-01R	9.4	C	9.2	CD	7.1	D

[a] Least square means from Proc MIXED of percent of linear plot row severely affected by spotted wilt.
[b] There was an interaction between tillage and genotype in 2002 ($P < 0.01$); therefore genotypes were compared within tillage treatments (LSD = 3.9, df = 112). Means within a column with the same letter do not differ at the 5% level.
[c] There was not an interaction between tillage and genotype in 2003 ($P > 0.05$); therefore genotypes were compared across tillage systems (LSD = 2.8, df = 154). Means within a column with the same letter do not differ at the 5% level.
[d] Asterisks indicate significant differences between conventional tillage and strip-tillage within a genotype in 2002 (LSD = 5.4, df = 17.4).

Table 7.3. Effects of tillage and peanut genotype on leaf spot intensity across fungicide treatments in 2002 and 2003.

	2002				2003			
	Defoliation[a]		AUDPC[b]		Defoliation[a]	AUDPC[b]		
Genotype	Conventional tillage[c]	Strip-tillage[c]	Conventional tillage[c]	Strip-tillage[c]	Across tillage[d]	Conventional tillage[c]	Strip-tillage[c]	
Georgia Green	43.2 E	9.6 CD *[e]	3.12 C	2.12 BC *	65.8 E	3.86 E	2.83	BC *
C-99R	32.8 D	5.4 ABC *	3.04 C	2.09 ABC *	64.4 DE	3.78 DE	3.20	E *
Hull	27.1 C	6.7 ABC *	2.81 B	2.21 C	56.8 CD	3.52 C	3.04	D *
DP-1	10.0 A	1.1 A	2.51 A	2.00 AB	39.7 A	2.93 A	2.59	A *
C-11-2-39	23.2 BC	3.8 ABC *	2.69 B	1.95 A *	59.3 CDE	3.56 C	2.86	C *
C-28-305	23.1 BC	4.7 ABC *	2.75 B	2.07 ABC *	51.8 BC	3.33 B	2.86	C *
C-34-24	35.8 D	13.8 D *	3.02 C	2.18 C *	64.8 E	3.70 D	3.02	D *
GA-01R	20.3 B	7.7 BCD	2.70 B	2.08 ABC *	47.8 B	3.32 B	2.72	AB *

[a] Least square means from Proc MIXED of percent defoliation of peanut canopy due to leaf spot at digging.

[b] Least square means of area under the disease progress curve using Florida 1-10 leaf spot intensity ratings and standardized by dividing by the number of days from the first to last rating.

[c] There was an interaction between tillage and genotype in 2002 for defoliation ($P < 0.01$) and AUDPC ($P < 0.01$), and in 2003 for AUDPC ($P < 0.01$); therefore genotypes were compared within tillage treatments in 2002 for defoliation (LSD = 6.1, df = 111) and AUDPC (LSD = 0.15, df = 112), and in 2003 for AUDPC (LSD = 0.13, df = 112). Means within a column with the same letter do not differ at the 5% level.

[d] There was not an interaction between tillage and genotype in 2003 for defoliation ($P = 0.21$); therefore genotypes were compared across tillage systems after adjusting the LSD for the significant fungicide*genotype interaction ($P < 0.01$) (LSD = 7.7, df = 29.5).

[e] Asterisks indicate significant differences between conventional tillage and strip-tillage within a genotype for defoliation (LSD = 13.9, df = 4.26) and AUDPC (LSD = 0.61, df = 2.8) in 2002, and for AUDPC (LSD = 0.21, df = 10.1) in 2003.

Table 7.4. Effect of fungicide treatments on leaf spot intensity for each tillage system across genotype entries in 2002 and 2003.

	2002				2003		
	Defoliation[a]		AUDPC[b]		Defoliation[a]	AUDPC[b]	
Fungicide program[c]	Conventional tillage[d]	Strip-tillage[d]	Conventional tillage[d]	Strip-tillage[d]	Across tillage[e]	Conventional tillage[d]	Strip-tillage[d]
0 spray	53.0 D	19.7 B *[f]	3.82 C	2.67 C *	85.9 D	4.33 D	3.57 D *
4 spray	31.4 C	5.6 A *	2.90 B	2.08 B *	66.1 C	3.66 C	3.02 C *
5 spray	21.7 B	1.1 A *	2.64 B	1.96 B *	47.9 B	3.23 B	2.73 B *
7 spray	1.7 A	0.0 A	1.96 A	1.64 A	25.2 A	2.69 A	2.23 A *

[a] Least square means from Proc MIXED of percent defoliation of peanut canopy due to leaf spot at digging.
[b] Least square means of area under the disease progress curve using Florida 1-10 leaf spot intensity ratings and standardized by dividing by the number of days from the first to last rating.
[c] Number of chlorothalonil applications applied throughout the season.
[d] There was an interaction between tillage and fungicide in 2002 for defoliation ($P < 0.01$) and AUDPC ($P < 0.01$), and in 2003 for AUDPC ($P = 0.05$); therefore fungicide programs were compared within tillage treatments in 2002 for defoliation (LSD = 9.6, df = 12) and AUDPC (LSD = 0.29, df = 12), and in 2003 for AUDPC (LSD = 0.12, df = 12). Means within a column with the same letter do not differ at the 5% level.
[e] There was not a significant interaction between tillage and fungicide in 2003 for defoliation ($P = 0.07$); therefore fungicide programs were compared across tillage systems after adjusting the LSD for the significant fungicide*genotype interaction ($P < 0.01$) (LSD = 7.7, df = 29.5).
[f] Asterisks indicate significant differences between conventional tillage and strip-tillage within a fungicide program for defoliation (LSD = 13.9, df = 6.0) and AUDPC (LSD = 0.52, df = 4.2) in 2002, and for AUDPC (LSD = 0.22, df = 10.3) in 2003.

Table 7.5. Effects of conventional and strip-tillage and peanut genotype on fungicide response rates (slope parameter estimates) from regressions of AUDPC of leaf spot epidemics on number of fungicide applications in 2002 and 2003.

	2002				2003			
	Conventional tillage		Strip-tillage		Conventional tillage		Strip-tillage	
Genotype	Fungicide response rate[a]	Average R^2	Fungicide response rate[a]	Average R^2	Fungicide response rate[a]	Average R^2	Fungicide response rate[a]	Average R^2
Georgia Green	-0.31 C	0.91	-0.17 AB *[b]	0.93	-0.29 B	0.91	-0.17 A *	0.89
C-99R	-0.30 BC	0.91	-0.12 AB *	0.90	-0.24 AB	0.99	-0.20 A	0.93
Hull	-0.22 AB	0.90	-0.17 AB	0.99	-0.21 A	0.94	-0.20 A	0.96
DP-1	-0.20 A	0.93	-0.12 AB	0.94	-0.20 A	0.96	-0.16 A	0.91
C-11-2-39	-0.25 ABC	0.96	-0.15 AB *	0.99	-0.19 A	0.79	-0.18 A	0.93
C-28-305	-0.24 ABC	0.92	-0.09 A *	0.75	-0.25 AB	0.99	-0.16 A *	0.89
C-34-24	-0.29 BC	0.93	-0.18 B *	0.93	-0.24 AB	0.90	-0.20 A	0.98
GA-01R	-0.27 ABC	0.96	-0.16 AB *	0.92	-0.24 AB	0.93	-0.22 A	0.98

[a] Mean slope parameter from linear regressions of AUDPC on number of fungicide applications with SPSS. Genotypes were compared within tillage treatments in 2002 (LSD = 0.08, df = 158) and 2003 (LSD = 0.07, df = 158) with SAS. Means within a column with the same letter do not differ at the 5% level.

[b] Asterisks indicate significant differences between conventional tillage and strip-tillage within a genotype in 2002 (LSD = 0.08, df = 158), and in 2003 (LSD = 0.07, df = 158).

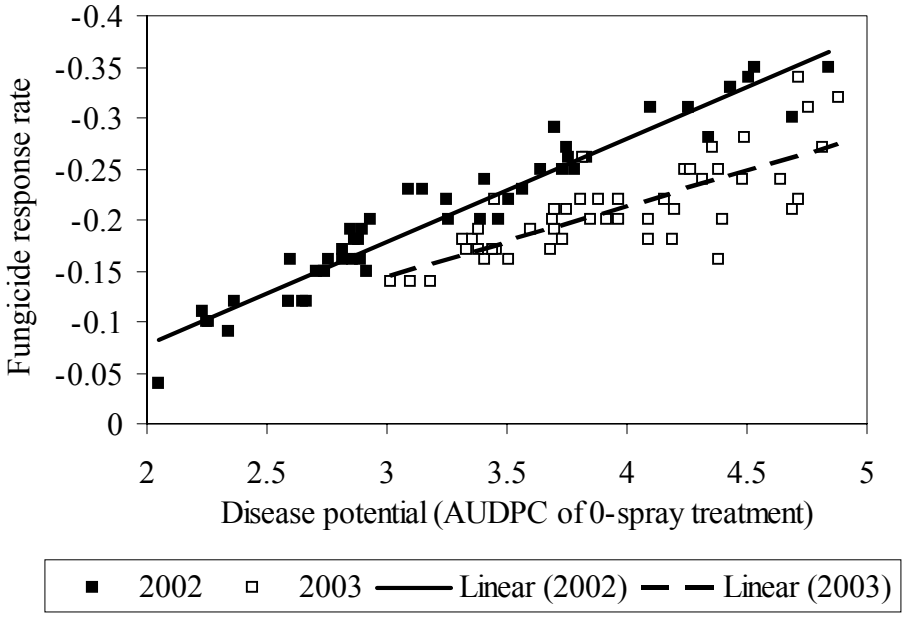

Fig. 7.1. Linear regressions of fungicide response rate (slope parameter from linear regressions of AUDPC on number of fungicide applications) on leaf spot disease potential (AUDPC for 0-spray treatment) in 2002 and in 2003.

Table 7.6. Effects of conventional and strip-tillage and peanut genotype on pod yields and net dollar returns over variable costs per hectare in 2002 and 2003.

Genotype	Pod yield (kg/ha)[a]		Net returns ($/ha)[b]	
	Conventional tillage	Strip-tillage	Conventional tillage	Strip-tillage
2002				
Georgia Green	2663 A	2873 A	189 A	286 A
C-99R	3673 CD	3503 BC	599 B	526 C
Hull	3429 BC	3408 B	495 B	496 B
DP-1	3910 D	3706 BC	678 C	600 C
C-11-2-39	4310 E	3842 C *[c]	890 D	701 C
C-28-305	3280 B	3009 A	426 B	335 AB
C-34-24	3923 D	3734 BC	733 CD	649 C
GA-01R	4310 E	3598 BC	856 CD	543 C *
2003				
Georgia Green	4340 A	3192 A *	885 A	443 A *
C-99R	5441 B	4760 E *	1333 B	1034 D *
Hull	4625 A	4164 CD	976 A	791 BC
DP-1	4313 A	3872 BC	835 A	682 BC
C-11-2-39	5316 B	4428 DE *	1279 B	950 CD *
C-28-305	4726 A	3690 B *	993 A	613 AB *
C-34-24	4523 A	4120 BCD	951 A	822 C
GA-01R	4631 A	4459 DE	999 A	956 CD

[a] Least square means from Proc MIXED of estimated weight of peanut pods per hectare after dried to 12% (w/w). There was an interaction between tillage and genotype in 2002 ($P = 0.02$) and in 2003 ($P = 0.04$); therefore genotypes were compared within tillage treatments in 2002 (LSD = 349, df = 124) and in 2003 (LSD = 463, df = 112). Means within a column with the same letter do not differ at the 5% level.

[b] Least square means of estimated crop value using the 2003 peanut pod price schedule minus variable costs to production. There was a 3-way interaction in 2002 ($P < 0.05$) and an interaction between tillage and genotype in 2003 ($P < 0.05$); therefore genotypes were compared across tillage systems in 2002, using the LSD adjusted for the 3-way interaction (LSD = 192, df = 21), and in 2003 (LSD = 188, df = 112).

[c] Asterisks indicate significant differences between conventional tillage and strip-tillage within a genotype for yield in 2002 (LSD = 390, df = 28.1), yield in 2003 (LSD = 515, df = 28.3), net return in 2002, adjusted for the 3-way interaction, (LSD = 218, df = 21), and net return in 2003 (LSD = 205, df = 33.8).

Table 7.7. Effect of number of fungicide applications on peanut pod yields and net dollar returns over variable costs in 2002 and 2003.

	2002		2003	
Fungicide program[a]	Pod yield (kg/ha)[bc]	Net Return ($/ha)[de]	Pod yield (kg/ha)[bf]	Net Return ($/ha)[df]
0 spray	3173 A	487 A	3706 A	715 A
4 spray	3605 B	581 AB	4429 B	920 B
5 spray	3625 B	571 AB	4739 C	1012 B
7 spray	3889 B	612 B	4775 C	989 B

[a] Number of chlorothalonil applications applied throughout the season.
[b] Least square means from Proc MIXED of estimated weight of peanut pods per hectare after dried to 12% (w/w).
[c] There was an interaction between fungicide and genotype for yield in 2002 ($P < 0.05$) that was not as great as the fungicide effect; therefore the LSD was adjusted for the interaction (LSD = 314, df = 21). Means within a column with the same letter do not differ at the 5% level.
[d] Least square means of estimated crop value using the 2003 peanut pod price schedule minus variable costs to production.
[e] There was a 3-way interaction for net return in 2002 ($P < 0.05$) that was not as great as the fungicide effect; therefore the LSD was adjusted for the interaction (LSD = 96, df = 21).
[f] There were no interactions with fungicide in 2003 for yield (LSD = 298, df = 21), or net return (LSD = 136, df = 12).

Table 7.8. Effect of peanut genotype on percent sound mature kernels at harvest in 2002 and 2003.

	Sound mature kernels (SMK) (%)[a]			
Genotype	2002[b]		2003[c]	
Georgia Green	69.3	A	73.9	BC
C-99R	72.8	CD	74.8	CD
Hull	72.6	CD	74.2	C
DP-1	71.0	B	73.0	AB
C-11-2-39	73.5	D	74.6	CD
C-28-305	70.8	B	72.7	A
C-34-24	73.2	D	74.5	CD
GA-01R	71.8	BC	75.4	D

[a] Least square means from Proc MIXED of percent yield weight that was sound mature kernels (SMK).
[b] There was an interaction between fungicide and genotype in 2002 ($P < 0.05$) that was not as great as the genotype effect; therefore the LSD was adjusted for the interaction (LSD = 1.1, df = 21). Means within a column with the same letter do not differ at the 5% level.
[c] There were no interactions with fungicide in 2003 (LSD = 1.1, df = 16).

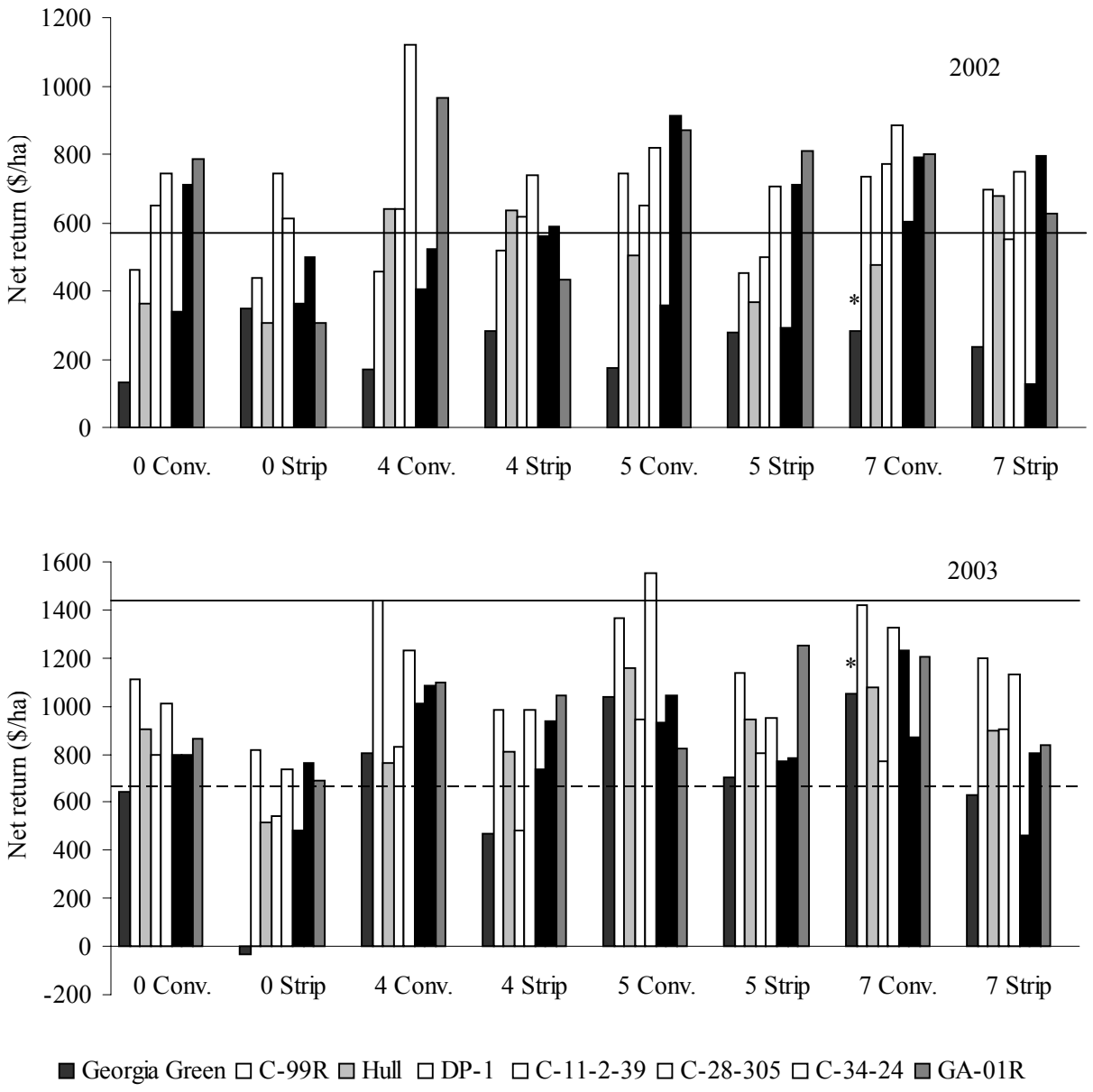

Fig. 7.2. Comparisons of net returns over variable costs ($/ha) of integrated management systems and the standard production practice (*) in 2002 and 2003. The solid line indicates the net return above which systems are significantly greater than the standard (Georgia Green, conventional tillage, 7-spray program), and the dashed line (in 2003) indicates the net return below which systems are significantly less than the standard.

Table 7.9. Correlation coefficients and probabilities for linear relationships between intensity of spotted wilt and leaf spot (defoliation and AUDPC) with peanut yields and net returns in 2002 and 2003.

	2002			2003		
	Spotted wilt [a]	Defoliation [b]	AUDPC [c]	Spotted wilt [a]	Defoliation [b]	AUDPC [c]
Yield (kg/ha) [d]	-0.5632 <0.0001	-0.2818 <0.0001	-0.0971 0.1803	-0.0515 0.4784	-0.2875 <0.0001	-0.0484 0.5053
Net Return ($/ha) [e]	-0.5897 <0.0001	-0.1479 0.0407	0.0613 0.3981	-0.0744 0.3051	-0.1662 0.0212	0.0678 0.3501

[a] Least square means from Proc MIXED of percent of linear plot row severely affected by spotted wilt.
[b] Least square means of percent defoliation of peanut canopy due to leaf spot at digging.
[c] Least square means of area under the disease progress curve using Florida 1-10 leaf spot intensity ratings and standardized by dividing by the number of days from the first to last rating.
[d] Least square means of estimated weight of peanut pods per hectare after dried to 12% (w/w).
[e] Least square means of estimated crop value using the 2003 peanut pod price schedule minus variable costs to production.

APPENDIX TO CHAPTER 7

Table 7A.1. Mean and standard error of spotted wilt severity of peanut for the fungicide application treatments each year.

	2002	2003
Fungicide program[a]	Mean[b]	Mean[b]
0 spray	11.8	4.8
4 spray	10.9	5.2
5 spray	10.2	5.2
7 spray	9.7	4.9
Standard error	0.72	0.56

[a] Number of chlorothalonil applications applied throughout the season.
[b] Least square means from Proc MIXED of percent of linear plot row severely affected by spotted wilt.

Table 7A.2. Effect of peanut genotype on stem rot severity each year.

	2002	2003
Genotype	Mean[ab]	Mean[ab]
Georgia Green	7.6 BC	7.6 C
C-99R	7.9 BC	3.9 AB
Hull	7.5 BC	4.3 B
DP-1	5.0 A	2.4 A
C-11-2-39	4.5 A	2.8 AB
C-28-305	9.3 C	3.0 AB
C-34-24	6.0 AB	3.1 AB
GA-01R	7.5 BC	4.0 AB

[a] Least square means from Proc MIXED of percent of linear plot row severely affected by stem rot.

[b] There were no interactions with genotype; therefore genotypes were compared across tillage treatments and fungicide programs in 2002 (LSD = 2.0, df = 112) and in 2003 (LSD = 1.8, df = 111). Means within a column with the same letter do not differ at the 5% level.

Table 7A.3. Mean and standard error of percent sound mature peanut kernels for the fungicide application treatments each year.

	2002	2003
Fungicide program[a]	Mean[b]	Mean[b]
0 spray	72.0	74.6
4 spray	72.0	74.1
5 spray	72.3	73.8
7 spray	71.2	74.1
Standard error	0.27	0.38

[a] Number of chlorothalonil applications applied throughout the season.
[a] Least square means from Proc MIXED of percent yield weight that was sound mature kernels.
[b] Standard error.

Table 7A.4. Mean percent damaged and immature peanut kernels for tillage*fungicide*genotype treatments each year.

Fungicide / Genotype	2002				2003			
	Damaged kernels (%)[a]		Immature kernels (%)[b]		Damaged kernels (%)[a]		Immature kernels (%)[b]	
	Conv.	Strip	Conv.	Strip	Conv.	Strip	Conv.	Strip
0 spray[c]								
GA Green	0.1	0.1	8.7	11.3	0.00	0.3	3.7	4.4
C-99R	0.8	0.6	3.8	5.1	0.1	0.1	3.1	5.1
Hull	0.6	1.1	4.1	4.1	0.1	0.	2.2	3.4
DP-1	0.2	0.5	4.9	6.2	0.0	0.2	3.5	3.4
C-11-2-39	0.8	1.2	3.6	5.1	0.1	0.1	3.8	8.6
C-28-305	1.7	0.7	5.8	5.8	0.4	0.0	3.4	3.7
C-34-24	0.7	0.8	4.0	4.5	0.2	0.2	2.9	3.4
GA-01R	0.5	0.5	4.5	6.3	0.0	0.4	3.2	4.0
4 spray[c]								
GA Green	0.1	0.1	9.0	9.6	0.2	0.0	4.2	5.3
C-99R	0.7	0.5	3.5	5.8	0.1	0.2	2.8	4.3
Hull	0.7	0.5	2.8	4.7	0.1	0.2	3.9	3.4
DP-1	0.5	0.3	4.9	5.6	0.0	0.0	4.2	5.0
C-11-2-39	0.4	0.9	3.4	3.8	0.1	0.0	3.1	2.6
C-28-305	0.7	1.1	4.2	4.5	0.2	0.2	5.2	3.5
C-34-24	0.7	0.3	3.7	5.3	0.1	0.1	3.7	3.0
GA-01R	0.7	0.5	3.5	4.8	0.4	0.3	4.2	3.6

Table 7A.4 continued

5 spray[c]								
GA Green	0.0	0.1	8.0	10.3	0.1	0.0	4.5	5.0
C-99R	0.6	0.5	3.7	4.5	0.1	0.3	2.8	3.3
Hull	0.4	0.7	4.0	4.2	0.1	0.0	3.9	3.8
DP-1	0.7	0.3	5.2	6.0	0.0	0.2	4.6	4.5
C-11-2-39	0.6	1.1	3.5	3.4	0.0	0.0	3.5	3.4
C-28-305	0.5	1.1	4.1	4.6	0.2	0.2	3.9	3.9
C-34-24	0.5	1.1	3.5	4.8	0.1	0.0	3.9	4.1
GA-01R	0.6	0.6	4.0	5.5	0.3	0.1	3.7	2.9
7 spray[c]								
GA Green	0.2	0.0	9.7	11.4	0.1	0.1	7.3	5.7
C-99R	0.6	0.8	3.7	4.6	0.1	0.0	3.2	3.7
Hull	0.7	0.9	4.6	5.1	0.2	0.4	2.9	4.2
DP-1	0.4	0.8	6.2	6.4	0.1	0.2	4.0	5.1
C-11-2-39	0.7	0.7	3.8	4.7	0.4	0.1	3.0	3.4
C-28-305	0.9	0.9	4.5	6.5	0.0	0.2	2.8	4.3
C-34-24	0.4	0.5	2.6	4.2	0.0	0.0	2.9	3.5
GA-01R	0.6	0.6	4.6	7.2	0.2	0.7	3.0	4.0
Standard error	0.19		0.42		0.14		0.77	

[a] Least square means from Proc MIXED of percent yield weight that was damaged kernels.
[b] Least square means of percent yield weight that was immature kernels.
[c] Number of chlorothalonil applications applied throughout the season.

Table 7A.5. Mean and standard error of percent foreign material of harvested pods in conventional and strip-tillage each year.

	2002	2003
Tillage system	Mean[a]	Mean[a]
Conventional tillage	2.5	2.6
Strip-tillage	2.9	2.7
Standard error	0.19	0.18

[a] Least square means from Proc MIXED of percent yield weight that was foreign material.

Table 7A.6. Mean and standard error of percent foreign material of harvested pods for peanut genotype each year.

	2002	2003
Genotype	Mean[a]	Mean[a]
Georgia Green	2.4	2.2
C-99R	3.7	2.7
Hull	2.2	2.7
DP-1	1.9	2.4
C-11-2-39	2.7	2.9
C-28-305	2.6	2.6
C-34-24	2.7	2.5
GA-01R	2.9	3.0
Standard error	0.37	0.32

[a] Least square means from Proc MIXED of percent yield weight that was foreign material.

Table 7A.7. Effects of fungicide application treatment on percent foreign material of harvested pods each year.

	2002	2003
Fungicide[a]	Mean[b]	Mean[b]
0 spray	3.2	2.5
4 spray	2.5	2.7
5 spray	2.9	2.5
7 spray	2.0	2.9
Standard error	0.26	0.24

[a] Number of chlorothalonil applications applied throughout the season.
[b] Least square means from Proc MIXED of percent yield weight that was foreign material.

Table 7A.8. Estimated total variable cost (dollar per hectare) of peanut production for each tillage and fungicide treatment across genotype in 2002 and 2003.

Year/ Fungicide program[a]	Conventional tillage			Strip-tillage		
	Mean	Min	Max	Mean	Min	Max
2002						
0 spray	315.78	310.20	321.23	303.81	298.22	309.26
4 spray	348.46	342.88	353.91	334.15	328.57	339.60
5 spray	357.80	352.22	363.25	343.49	337.91	348.94
7 spray	376.48	370.90	381.93	362.17	356.59	367.62
2003						
0 spray	326.68	319.71	333.49	314.71	307.73	321.52
4 spray	359.36	352.39	366.17	345.05	338.07	351.86
5 spray	368.70	361.73	375.51	354.39	347.41	361.20
7 spray	387.38	380.40	394.19	373.07	366.09	379.88

Table 7A.9. Seed cost per hectare for each peanut genotype and year.

Genotype	2002[a]	2003[b]
Georgia Green	93.94	117.42
C-99R	121.19	151.49
Hull	119.06	148.83
DP-1	107.16	133.95
C-11-2-39	100.46	125.58
C-28-305	100.46	125.58
C-34-24	100.46	125.58
GA-01R	119.06	148.83

[a] Least square means from Proc MIXED of dollar value of seed planted at 143,500 seed per hectare.
[b] Least square means of Dollar value of seed planted at 179,400 seed per hectare.

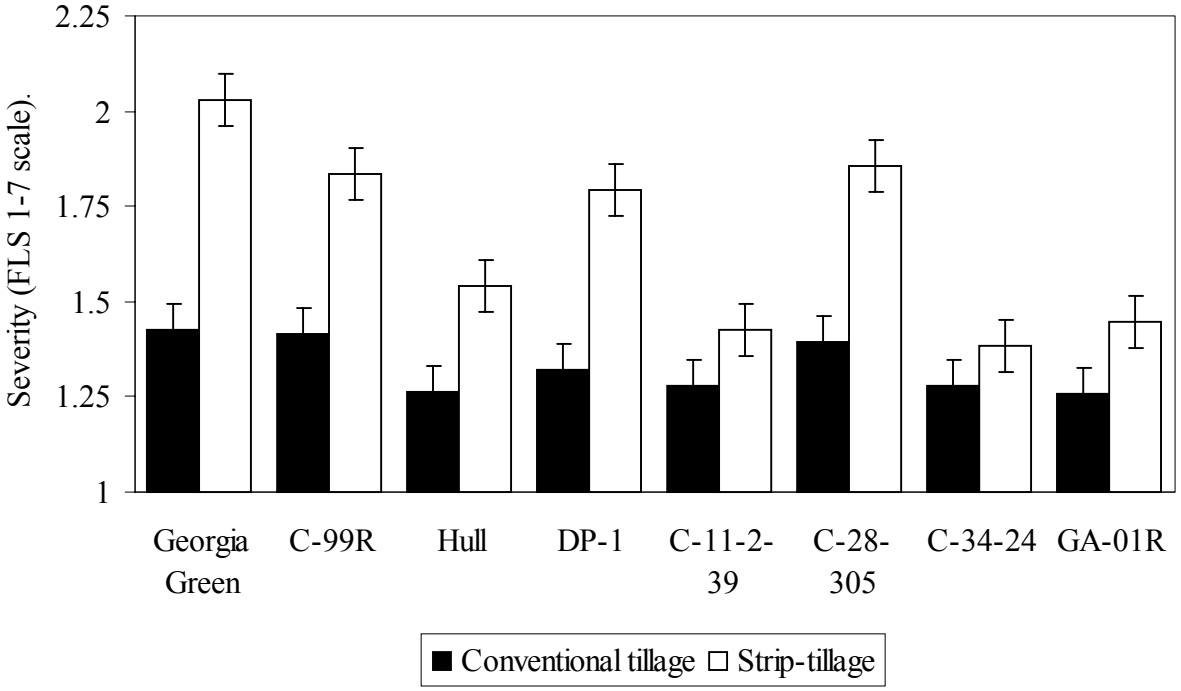

Fig. 7A.1. Severity of Florida leaf spot 56 DAP in 2002 for peanut genotypes in conventionally tilled and strip-tilled plots, where 1 = no disease and 2 = very few lesions on the leaves in the lower canopy.

CHAPTER 8

CONCLUSIONS

This research was conducted to characterize the effects of enhanced host resistance and strip-tillage on foliar disease epidemics of peanut and utilize combinations of those factors with optimal applications of fungicides for integrated management of foliar diseases. The primary disease investigated in these studies was early leaf spot, caused by *Cercospora arachidicola*. However, genetic and tillage effects were also monitored in the field for spotted wilt, caused by the tospovirus *Tomato spotted wilt virus* (TSWV), and Florida leaf spot (FLS), a symptom of unknown etiology, and genetic effects were monitored in growth chamber studies for *Cercosporidium personatum*, the causal agent of late leaf spot of peanut.

The onset of early leaf spot epidemics was delayed by approximately 12 days in strip-tilled plots compared to conventionally tilled plots as evidenced by fewer initial infections. The onset delay appears to be the result of fewer initial inocula dispersed from overwintering stroma to peanut tissues in strip-tilled soils, rather than the facilitation of a less favorable microclimate for infection or induction of enhanced resistance of peanut plants to infection. Maintenance of cover crop residue at the soil surface is involved in the suppression of initial infections; however, it is not the only suppressive factor of strip-tillage. Less than half of disease suppression observed with strip-tillage could be attributed to the maintenance of surface residue in the field. Minimization of splash dispersal dynamics, i.e. velocity and horizontal distance, by mulch residue is one possible mechanism to explain the reduced initial infections seen in strip-tillage and with added cover crop residue or straw mulch to the surface of plots. Early leaf spot

suppression by strip-tillage was not consistently observed in fields that were planted to peanut in sequential years. For this reason, crop rotation away from peanut for at least 1 year will be critical for growers interested in utilizing strip-tillage to suppress leaf spot.

Previous reports concerning the suppression of spotted wilt by strip-tillage were corroborated by this work. In addition, new information related to the role of cover crop residue in spotted wilt suppression was observed. The addition of cover crop residue from strip-tilled plots to the soil surface of conventionally tilled plots resulted in comparable levels of spotted wilt suppression as strip-tillage. However, removing cover crop residue from strip-tillage did not cause a reversal of spotted wilt suppression. One hypothesis addressing the mechanism of spotted wilt suppression by strip-tillage is that thrips, the vector of TSWV, have a harder time finding peanut plants in strip-tilled fields than conventionally tilled fields, which leads to less feeding and fewer infections. Interplot interference of treatment plots in the strip-tillage whole plots may have failed to distinguish the cover crop residue treatments from the perspective of thrips.

Strip-tillage did not suppress all foliar diseases of peanut compared to conventional tillage. Severity of Florida leaf spot (FLS) was found to be more severe in strip-tilled plots than conventionally tilled plots. Symptoms of FLS were observed as early as 33 DAP and occurred at higher frequency in the lower half of the peanut canopy than the upper half. Premature defoliation occurred in response to FLS symptom development early in the season but did not appear to be a significant response after 63 DAP. Progress of FLS epidemics over time was indicative of a monocyclic or nearly monocyclic causative agent, and did not appear to greatly impact pod yield. Although symptoms continued to be observed on young leaves throughout the season, the severity of FLS was reduced with vegetative growth of plants, and as the season

progressed. The cause of the FLS symptom was not ascertained by our attempts. This study provided no evidence that it is caused by a fungal or bacterial pathogen. Not only were we unable to isolate pathogenic fungi or bacteria from FLS lesions, but fungicides and bactericides with varying modes of action applied as early as 25 days after planting did not consistently reduce FLS severity in the field. Preliminary results indicate that the symptom may be transferable from disease to healthy peanut tissue, but more work is needed to confirm this result before confirmation of a pathogenic cause.

Resistance to early leaf spot and spotted wilt was evaluated in the field for the cultivars Georgia Green, C-99R, Hull, DP-1 and GA-01R, and breeding lines, C-11-2-39, C-28-305 and C-34-24. Field resistance to early leaf spot was best for DP-1, C-28-305, and GA-01R, while resistance to spotted wilt was best for C-11-2-39 and C-34-24. The genotypes with the best combined disease resistance were C-11-2-39, DP-1 and GA-01R. Components of resistance to *C. arachidicola*, monitored using inoculated detached peanut leaves of Georgia Green, DP-1 and C-11-2-39 in a growth chamber, corroborated the ranking of early leaf spot resistance by these genotypes in the field, with DP-1 as the most resistant, C-11-2-39 as moderately resistant, and Georgia Green as the most susceptible. The components of resistance to *C. arachidicola* measured for DP-1 and C-11-2-39 compared to Georgia Green were reduced infection frequencies, smaller lesion diameters, lower percent necrotic leaf area and 2-day longer latent periods. The same order of rank was observed for these genotypes inoculated with conidia of *C. personatum*, with the same resistance variables to *C. personatum* for DP-1. Infection frequency, lesion diameter and percent necrotic leaf area were also reduced for C-11-2-39 compared to Georgia Green; however, secondary reproduction variables, such as latent period and number of secondary spores produced per unit lesion area, were greater for C-11-2-39 than DP-1 or Georgia

Green. Although not directly measured in the field study, the relative field resistance of C-11-2-39 to late leaf spot may interact with time of disease onset (time available for secondary infection cycles). The results of this work indicates that the components of resistance observed for DP-1 and C-11-2-39 are similar in nature to those reported for Southern Runner and other partially resistant genotypes investigated in the 1980s.

Results from our applied field study indicate that 2 to 3 fewer fungicide applications are needed to comparably manage early leaf spot when host resistance and/or strip-tillage are employed, than when Georgia Green is grown under conventional tillage, in which a 7 application program is standard. Furthermore, as disease potential decreased with the use of enhanced genetic resistance and strip-tillage, the disease response to additional numbers of chlorothalonil applications per season decreased. This relationship has the potential to be used to predict the number of fungicide applications needed in a field to manage leaf spot below a predetermined threshold. In most cases when genotypes and tillage systems were pooled, peanut pod yields and net returns over variable costs were statistically comparable with 4, 5, or 7 applications of chlorothalonil. Without fungicides, yields and returns were typically less than what was observed for the standard 7-spray program, but some of the genotype-tillage systems that were not treated with fungicides had comparable net returns as the standard production system. These results indicate that the integrated management of foliar diseases with enhanced host resistance and/or strip-tillage is feasible for reducing fungicide inputs, with minimal economic risk. Additional work to stabilize pod yields of strip-tilled fields, compared to conventionally tilled fields, should enhance the over-all economic benefit of strip-tillage for peanut production.