OPTIMIZING EFFICACY AND ECONOMIC BENEFITS OF FUNGICIDES FOR PEANUT DISEASE CONTROL VIA PRE-PLANT ANALYSIS OF DISEASE RISK AND IRRIGATION TIMING

by

JASON E. WOODWARD

(Under the Direction of Timothy B. Brenneman)

ABSTRACT

Peanut (*Arachis hypogaea* L.) is susceptible to infection by numerous foliar and soilborne fungal diseases including early leaf spot (*Cercospora arachidicola* S. Hori), leaf spot (*Cercosporidium personatum* (Berk. & M. A. Curtis) Deighton), and southern stem rot (*Sclerotium rolfsii* Sacc.). Numerous fungicide applications are made each growing season to mitigate losses associated these diseases. Changes to the 2002 Farm Bill resulted in producers receiving approximately 40% less for their commodity, while input costs remain unchanged. With increasing energy costs and suppressed crop value, reductions in input costs are needed if producers are to remain economically competitive. One potential way to reduce costs associated with fungicide inputs would to use an integrated disease management approach. The overall objective of this research was to determine the benefits and feasibility of using reduced input fungicide programs in conjunction with the University of Georgia Fungal Disease Risk Index to maximize profits without compromising yield or disease control. Small and large plot experiments were conducted in fields with varying levels of disease risk. Cultivars with partial resistance to leaf spot and/or stem rot were included in

most studies. Yields and grades for these cultivars were equivalent to or greater than Georgia Green, the current commercial standard. Several standard fungicide programs were also compared to their respective reduced programs. Despite increased leaf spot intensity and stem rot incidence for the reduced programs, yields for those programs were generally equal to or greater than their respective standard program. Furthermore, the reduced programs typically provided higher crop values than the standard programs. Bioassays involving *S. rolfsii* were developed to determine examine fungicide residues peanut foliage and pods. *In vitro* trials indicated that wounding was not required for lesion development on leaflet or stem tissues. In addition, tissues obtained from the upper canopy were more susceptible to infection by *S. rolfsii* than tissues obtained from the middle and lower canopy, respectively. This method was successfully used to determine the effect of irrigation timing on the redistribution of foliar applied fungicides. Lesion development on leaflet and stem tissues was greatest when irrigation was applied immediately after the fungicides compared to later irrigation timings. When irrigation was applied after 24 h lesion size did not differ from the non-irrigated controls. Likewise, early leaf spot was more severe when irrigation was administered immediately following the application fungicides, and was significantly reduced for the 6 and 12 h irrigation timings. Maximum leaf spot control was obtained for the 24 h treatment. Conversely, the colonization of pods was lower for the earlier irrigation treatments. The percent pod colonization was similar for all irrigation timings for azoxystrobin and flutolanil; whereas, suppression was greatest for tebuconazole at earlier irrigation timings. This research demonstrates reduced input fungicide programs can be used within an integrated disease management system to adequately control foliar and soilborne

diseases, and that irrigation can be used to improve soilborne disease control, while maintaining adequate levels of leaf spot control.

INDEX WORDS: *Arachis hypogaea*, peanut leaf spot, *Cercospora arachidicola*, *Cercosporidium personatum*, stem rot, *Sclerotium rolfsii*, integrated disease management, fungal risk index, reduced inputs, economics, fungicide redistribution

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JASON E. WOODWARD

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JASON E. WOODWARD

Major Professor: Timothy B. Brenneman

Committee: Albert K. Culbreath
Robert C. Kemerait, Jr.
Nathan B. Smith
Katherine L. Stevenson

Electronic Version Approved:

Maureen Grasso
Dean of the Graduate School
The University of Georgia
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DEDICATION

To Jennifer, Jacob, and Jack.

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CHAPTER 1

INTRODUCTION AND LITERATURE REVIEW

PEANUT PRODUCTION

Peanut (*Arachis hypogaea* L.) is an important food crop grown throughout the world. Peanut seeds, which are produced below ground, are very nutritious, containing high levels of proteins, carbohydrates as well as vitamins and minerals (Moss and Rao, 1995). Various types of peanuts are grown throughout the world. Four types of peanuts are the most popular: Runner, Virginia, Spanish and Valencia. Peanut types can be distinguished by growth habit and height. The cultivated peanut has an erect or prostrate growth habit. Mature plants range from 15 to 60 cm in height (Porter, 1997) and have an optimal temperature range between 27 and 33°C (Williams and Boote, 1995). In addition, peanut plants require large amounts of rainfall, 50-75 cm, during production to optimize growth and seed maturity (Beasley et al., 1997). Peanuts are generally grown in well-drained, basic, sandy types of soil (Beasley et al., 1997). If ample water and optimum temperatures are available after planting, peanut plants will emerge within 2 weeks. These plants form self-pollinating flowers approximately 30 to 40 days after emergence and may continue to produce new flowers throughout the growing season until harvest. Fertilized flowers will then form pointed needle-like carpophores (commonly referred to as "pegs"), that grow geotropically. The tissue at the tip of the peg becomes lignified, thus protecting the fertilized ovaries located behind the tip. The peg grows into the soil to a depth of 2-7 cm (Porter, 1997). Peanut pod growth is then initiated as the tip of the peg becomes horizontally oriented. The mature pods are oblong and may contain as many as five seeds.

The genus *Arachis* is believed to have originated in the tropical and subtropical countries of South America east of the Andes Mountains (Moss and Rao 1995; Coffelt and Simpson, 1997). Peanuts were later introduced throughout the world via various trade routes

(Stalker and Simpson, 1995). Today the worlds leading peanut producing countries include India, China and the United States (USDA-NASS, 2003). According to the United States Department of Agriculture National Agricultural Statistics Service (2003), approximately 3.1 million hectares of peanuts were harvested in the US in 2003; where production is limited to three regions comprised of nine states. These regions include the southeastern region (Alabama, Florida, Georgia, and South Carolina), the southwestern region (New Mexico, Oklahoma, and Texas), and the Virginia-Carolina region (North Carolina and Virginia). The southeast is the largest production region totaling more than 2.1 million hectares with a farm value in excess of $375 million (Anonymous, 2003).

Due to recent changes in the economics of peanut production, producers must consider minimizing production costs in order to maximize farm income. Under the 2002 farm bill, the new peanut program replaces the traditional quota system with a market loan system, thus making peanut prices more responsive to the market. The peanut quota buyout and subsequent move to a marketing loan program will affect the way peanuts are produced and marketed in the southeast. According to Smith (2002), Georgia peanut producers must be willing to make major adjustments in production practices if they are to remain economically competitive.

Georgia is the largest peanut producing state in the United States utilizing approximately 275,000 hectares for peanut production annually (Anonymous, 2003). Georgia peanut production is isolated to the coastal plain region with the majority of peanuts being produced in the southwestern part of the state. The growing conditions, such as soil type, temperature and rainfall, of this region are optimal for peanut production.

Unfortunately, these environmental conditions are conducive for many pests, including weeds, insects and diseases.

PEANUT DISEASES

Peanut plants are susceptible to infection by various disease-causing organisms, the most damaging of which are fungi. Early and late leaf spot, Rhizoctonia limb rot and southern stem rot are critical yield limiting diseases in the southeastern United States, as well as other peanut production regions throughout the world. Combined economic losses due to yield reduction and the cost of disease control results in an estimated $82.7 million reduction in overall revenue for Georgia producers alone (Kemerait, 2003). An additional disease of economic importance in the southeastern United States is spotted wilt, caused by tomato spotted wilt *Tospovirus* (TSWV). Although sporadic in nature, TSWV has become an important disease within the past 10 years, resulting in annual crop reductions ranging from 4.5 to 40% (Kemerait, 2003). Peanut producers can ill afford such losses and therefore must optimize feasible disease management strategies. In order to maximize disease suppression, it is beneficial to understand the biology of the organism(s) that impact the cropping system.

Tomato Spotted Wilt. Although TSWV was first observed in the U.S. in the early 1980s it was not a widespread problem until 1989 (Culbreath et al., 1992). Currently, spotted wilt is considered one of the most destructive peanut diseases in the southeast (Sherwood and Melouk, 1995). The virus can be transmitted by several species of thrips, but only the tobacco thrips, *Frankliniella fusca* (Hinds), and the western flower thrips, *F. occidentalis* (Pergande), are capable of transmission to peanut (Culbreath et al., 1996). The introduction of spotted wilt in the southeastern United States has resulted in a regional, multi-disciplinary effort at managing the disease. Thanks to collaborative efforts from researchers in Georgia,

Florida, and Alabama, management practices that help minimize the losses incurred by spotted wilt have been identified (Sherwood and Melouk, 1995; Culbreath et al., 1996; Culbreath et al. 1999). Since there are no curative measures for TSWV, various management decisions, such as planting date, plant population, insecticide and herbicide use, row pattern, and tillage, have been incorporated in a Risk Index, designed to help minimize the effects of this disease (Culbreath et al., 1999; Brown et al., 2004; Brown et al., 2005).

***Cercospora arachidicola* and *Cercosporidium personatum*.** Early and late leaf spot are the two most economically important foliar diseases of peanut and may occur wherever peanuts are grown. Either disease may be predominant within a given area within a given year. For example, early leaf spot, caused by *Cercospora arachidicola* (Hori), (Teleomorph: *Mycosphaerella arachidis* Deighton), was predominant in the southeastern United States through the mid 1960s and 1970s. However, late leaf spot, caused by *Cercosporidium personatum* (Berk. & Curt.) Deighton, (Teloomorph: *Mycosphaerella berkeleyi* Jenk.), was most prevalent in the 1980s. Throughout the 1990s, early leaf spot has been more prevalent in Georgia, but late leaf spot is currently gaining predominance. Although *C. arachidicola* and *C. personatum* are destructive on leaves, they are also capable of causing lesions on petioles, pegs, main stems and lateral branches (Shokes and Culbreath, 1997). Leaf spot symptoms are initially seen as small necrotic flecks that appear approximately 10 days after spore deposition. Over several weeks, the lesions will enlarge from 1 to 10 mm in diameter and sporulate.

Although the physical appearance of the two diseases is similar, early leaf spot can be distinguished from late leaf spot based on lesion characteristics; the most noteworthy is the color of the lesion on the adaxial surface. Light to dark brown lesions are characteristic of *C.*

arachidicola; while *C. personatum* lesions have more of a black appearance (Smith and Littrell, 1980; Sholar et al., 1993; Shokes and Culbreath, 1997). In addition, early leaf spot lesions have a distinct yellow 'halo' surrounding the lesions, which is not associated with lesions caused by *C. personatum*. The orientation of sporulation is a more consistent way to distinguishing between the two diseases. *Cercospora arachidicola* sporulates primarily on the adaxial leaf surface; whereas *C. personatum* sporulates more frequently on the abaxial surface of the leaf. However, microscopic examination of conidia is required to properly diagnose a leaf spot pathogen. Conidiophores of *C. arachidicola* dark at the base, unbranched, and septate; giving rise to curved, subhyaline, septate conidia (15-45 × 3-6 μm). Conidia (20-70 × 4-9 μm) of *C. personatum* are typically straight, rounded at the apex and not constricted, and are produced on smooth, brown conidiaphores (Shokes and Culbreath, 1997).

Optimal environmental conditions for infection and reproduction for the two pathogens are quite similar; 16-24 °C and 20-26 °C for *C. arachidicola* and *C. personatum*, respectively, and both require long periods of relative humidity greater than 90% (Shokes and Culbreath, 1997). Primary inoculum for either pathogen originates from infected residue in the soil from previous peanut crops (Shokes and Culbreath, 1997). Both *C. arachidicola* and *C. personatum* overwinter as dormant stromata on infected residue until environmental conditions are conducive for sporulation and dispersal. Initial inoculum is responsible for the onset of leaf spot epidemics, and subsequent sporulation propitiates the disease. If not managed, yield may be reduced by 70% or more (Nutter and Shokes, 1995; Shokes and Culbreath, 1997).

Sclerotium rolfsii. In addition to leaf spot southern stem rot, caused by the soilborne fungus *Sclerotium rolfsii* Sacc., is one of the most destructive peanut diseases. *Sclerotium rolfsii* has a worldwide distribution and is capable of infecting a wide variety of row crops including crucifers, grasses and legumes (Aycock, 1966; Punja, 1985). Although the sexual stage of *S. rolfsii*, the basidiomycete *Athelia rolfsii* (Cruz) Tu & Kimbrough, has been identified, it is rarely seen under field conditions (Backman and Brenneman, 1997). *Sclerotium rolfsii* does not produce conidia and is classified as a Deuteromycete in the group 'Mycelia Sterilia' (Alexopolous et al., 1992). The fungus overwinters in the soil as hard, round, brown sclerotia (Backman and Brenneman, 1997). Mature sclerotia have a melanized outer layer, the rind, which allows the fungus to survive periods of adverse environmental conditions and remain viable for up to 3 years (Punja, 1985).

Upon germination of sclerotia, *S. rolfsii* may survive saprophytically as mycelium in organic matter in the soil or directly infect a susceptible host plant (Aycock, 1966). After an infection site is established, the fungus becomes necotrophic, meaning an external energy source is needed to breach host defenses (Punja, 1985). Initial symptoms of infection include chlorosis and/or wilting of a lateral branch; however, if main stems become infected, the entire plant may appear wilted or chlorotic (Backman and Brenneman, 1997). Infected leaves typically have a water-soaked or necrotic appearance. Symptoms can appear rather quickly if temperatures are favorable. The incubation period typically ranges from 2 to 4 days; however, wounding of plants may decrease the time required (Aycock, 1966).

Since its first report on tomato by Rolfs in 1892, *S. rolfsii* continues to cause considerable economic losses on numerous dicot row crops and several species of monocots. Also referred to as 'white mold' of peanut in Georgia, the disease caused by *S. rolfsii* is

responsible for annual crop reductions from 7 to 10%; however, losses as great as 80% have been reported in heavily infested areas in years with conducive environmental conditions (Backman and Brenneman, 1997). Over the last 2 years, *S. rolfsii* has been responsible for crop reductions in excess of $18.5 million in Georgia alone (Kemerait, 2003). Substantial reductions in peanut yield can also occur in other production regions in the United States, and worldwide (Mehan, 1994; Mehan, 1995; Rago et al., 1996; Subrahmanyam, 1997). Mehan et al. (1995) and Cillers et al. (2003) conclude that stem rot control is best accomplished through integrated approaches.

Rhizoctonia solani. An additional soilborne pathogen of peanutof economic importance is *Rhizoctonia solani* (Kühn) anastomosis group 4 (AG-4). *Rhizoctonia solani* is capable of causing seed decay, pre- and post-emergence damping-off, as well as hypocotyl and root rot; however, it is most devastating on mature plants causing a rot of pegs, pods, leaves and stems. Although variable from year to year, Rhizoctonia limb rot is considered a major disease of peanut in the southeast (Brenneman, 1997; Thompson, 1982). Annual losses associated with limb rot over the last 2 years have amounted to approximately $4.6 million (Kemerait, 2003). Development and severity of limb rot requires cool wet periods making the disease somewhat sporadic in nature (Thompson, 1982; Barnes et al., 1990). However, losses incurred by *R. solani* are not easily assessed since disease severity is evaluated after digging and may be difficult to distinguish from those caused by other soilborne diseases.

As with *S. rolfsii*, the host range of *R. solani* is quite broad and includes many crops such as cotton (*Gossypium hirsutum*), tobacco (*Nicotiana tabacum*) and vegetables that are grown throughout the southeastern United States. *Rhizoctonia solani* and its sexual stage,

Thanatephorus cucumeris (Frank) Donk, are widely distributed throughout the world and can often be isolated from soil or organic debris (Brenneman, 1997). While *T. cucumeris* is commonly recovered from soil, its role in disease development is currently unknown.

Mycelium of *R. solani* is typically white to brown in color, 4-15µm thick, septate and branches at right angles (Taber and Pettit, 1970). During infection, hyphae quickly invade the epidermis and advance intracellularly (Christou, 1962). Studies conducted by Bateman (1970), suggest that *R. solani* produces various phytotoxins and degradative enzymes to kill host tissue, resulting in the release of nutrients that promote fungal growth.

Because *R.. solani* and other *Rhizoctonia* spp. do not produce conidia and only rarely produce basidiospores, their classification is quite difficult. Prior to the 1960s, researchers classified *Rhizoctonia* spp. based on morphology in culture and/or results of extensive pathogenicity tests. In 1969, Parmeter et al. suggested the concept of hyphal anastomosis to characterize and identify *Rhizoctonia* spp. The concept implies that isolates of *Rhizoctonia* spp., which are genetically related, have the ability to recognize and fuse (anastomose) with each other; whereas isolates that do not are genetically unrelated.

Different anastomosis groups (AG) are often associated with specific crops or diseases. Some examples include AG-4, a severe seed rot pathogen, AG-1, AG-2-2, and AG-4 cause damping-off, crown and many other rots. Additional groups which are moderately pathogenic include AG-2-1, AG-3, AG-5, unidentified *R. solani* and binucleate Rhizoctonia-like fungi (Sneh et al., 1991). Several AGs are associated with peanut; however, AG-4 is considered the most destructive. In studies conducted by Brenneman and Sumner (1990), *R. solani* (AG-4) and two binucleate *Rhizoctonia* spp. like fungi (CAG-3 and CAG-2) were

isolated from diseased peanut plants; however, only AG-4 was associated with typical limb rot symptoms.

Generally limb rot symptoms are first observed on lower branches that are in contact with the soil surface. Circular lesions, yellow to dark brown in color, occur at infection sites and have distinct target spot appearance. As lesion development progresses, infected limbs become girdled and die (Franke, 1999). As nutrient sources become depleted, the fungus produces irregularly shaped sclerotia within host tissue, that serve as the primary survival structures for this fungus (Brenneman, 1997).

FACTORS THAT INFLUENCE DISEASE DEVELOPMENT

Crop rotation. Crop rotation is a planned order of different crops planted sequentially in the same field. Many positive agronomic, economic and environmental benefits can be attributed to establishing a good rotation. Studies conducted on various cropping systems suggest that crop rotations result in improved soil fertility (Dogliotti et al, 2004), improved soil structure and stability (Chan and Heenan, 1999), better soil moisture (Lindwall et al., 1995) and reduced insect (Johnson et al., 1999; Pendelton et al., 2000) and disease problems (Curl, 1963; Kucharek, 1975; Brenneman et al., 1995; Johnson et al., 1999).

Typical crop rotations range from one to four years. The Georgia Extension Service currently recommends at least a two-year rotation away from peanuts to reduce foliar and soilborne diseases and nematode related loses (Padgett, 1995). Numerous studies have been conducted to determine the effects of crop rotation and duration on peanut diseases. Kucharek (1975) reported that rotation of peanut with corn (*Zea maydis*), and soybeans (*Glicine max*) resulted in a reduction of leaf spot of peanut in subsequent years. In later

studies, Brenneman et al. (1995) evaluated the duration of bahiagrass (*Paspalum notatum*) rotations and found that the intensity of both early and late leaf spot were significantly higher in shorter rotations. In contrast to *S. rolfsii* and *R. solani*, which have extensive host ranges, *C. arachidicola* and *C. personatum* are only capable of infecting peanuts (Shokes and Culbreath, 1997). Therefore, duration of the rotation is more important than cropping sequence for management of leaf spot. However, severe leaf spot epidemics may occur in fields with long rotation, if high concentrations of spores are in the air.

Since sclerotia of *S. rolfsii* can remain viable in soil for long periods of time, Mehan et al. (1995) suggests rotations of three or more years to effectively suppress the disease. Brenneman et al. (1995) found the duration of rotation with a non-host crop is highly correlated with disease incidence. Many different non-host crops have been effectively used in rotations to reduced stem rot levels in the southeastern United States. Rotation with wheat (*Triticum* spp.) and corn has resulted in reduced stem rot levels in peanut (Garren, 1961; Johnson et al., 1999). According to several studies conducted in the southeast bahiagrass appears to be most effective at suppressing populations of *S. rolfsii* (Rodriguez-Kabana et al., 1991a; Rodriguez-Kabana et al., 1991b; Johnson et al., 1999; Brenneman et al., 1995; Timper et al., 2001). Bahiagrass is a particularly good fit for producers who also raise cattle, but it is not currently being utilized in many rotational sequences because of economic reasons (Brenneman, personal communication).

The crop most commonly rotated with peanut is cotton, but Rhizoctonia limb rot can be a significant problem in a cotton rotation. *Rhizoctonia solani* is capable of surviving in soil for long periods of time, either as sclerotia or saprophytically on organic material. Recovery of *R. solani* from peanut shells decreases following rotation with corn or

bahiagrass (Baird et al., 1993; Baird et al., 1995). Additional studies have found that limb rot incidence was less following a two year corn rotation compared to peanut monoculture (Johnson et al., 1999). In contrast, Brenneman et al. (1995) reported that limb rot levels were not affected by bahiagrass rotations; however, *R. solani* population densities were relatively low.

Tillage. Traditionally, peanut producers in the southeastern United States use conventional tillage practices, such as moldboard plowing, to turn the upper 8 to 12 cm of soil. Secondary tillage using a disk harrow or power tiller is conducted to incorporate herbicides and prepare seed beds. Deep turning of the soil reduces initial inoculum levels by burying infected plant debris (Nutter and Shokes, 1995). Deep plowing also eliminates nutrient sources required for the germination of *S. rolfsii* sclerotia (Garren et al., 1961), and leads to a reduction in the release of volatile compounds essential for sclerotial germination (Smith et al., 1976). It has been hypothesized that deep plowing increases biological antagonism (Punja and Jenkins, 1984).

Due to lower energy and labor costs associated with conservation tillage, these practices are being evaluated in peanut. Recently, corn and small-grain producers in the Midwestern United States have changed to strip-tillage, as have cotton and soybean producers in the southeast (Bockus and Shroyer, 1998). Strip-tillage requires a seed bed preparation implement equipped with sub-soil shanks and fluted coulters. Planter boxes can also be mounted on the tillage implement for direct seeding.

Until the 1990s, peanut producers have been reluctant to adopt strip-tillage due to concerns about reduced weed control, poor plant stands, reduced harvest efficiency, and the potential build-up of pathogens. However, results of recent research suggest that strip-tillage

actually suppresses TSWV (Brown et al., 2001; Johnson et al., 2001). As a result more than 20% of peanut acreage in Georgia was being cultivated using strip-tillage by 2002 (Smith, 2003). Increased soil moisture retention and soil tilth are also responsible for this transition (Bockus and Shroyer, 1998). In addition, field studies have implicated that the incidence of southern stem rot is not significantly affected by reduced tillage practices (Ferguson and Shew, 2001; Grichar and Smith, 1991; Grichar and Smith, 1992; Harzog and Adams, 1989; Minton et al., 1990; Grichar and Boswell, 1987; Johnson et al., 2001).

Limited information is available on the effects of strip-tillage on early and late leaf spot. Porter and Wright (1991) reported a reduction in leaf spot in strip-tillage compared to conventional tillage; however, other studies indicate that more leaf spot was present in strip-tillage plots compared to conventional tillage plots Sholar et al. (1993). Recent studies have shown that strip-tillage consistently reduced defoliation caused by leaf spot by approximately 20% (Monfort et al., 2004; and Cantonwine et al., 2006). Although the mechanism behind leaf spot suppression using strip-tillage is currently unknown, preliminary results suggest that increased crop residue acts as a physical barrier that disrupts spore dispersal, thus delaying the onset of epidemics (Cantonwine et al., 2006). Although not clearly understood, it appears that strip-tillage may aid in the management of peanut leaf spot.

Field history. Since initial inoculum of the aforementioned diseases generally originates from the soil, it is important to know the disease history of a field. This is somewhat of a qualitative measure and is based on grower observations and experience. It requires detailed observations of disease problems in the past and varies greatly for each pathogen. For example, stem rot and leaf spot are fairly predictable. In fields where stem rot and leaf spot have been a problem in the past, they are most likely going to be present even

despite treatment with fungicides or extended crop rotations. Limb rot may also remain a problem once established in a field; however, *R. solani* is much more sensitive to environmental conditions, such as moisture and temperature, making disease severity more variable from year to year and even location to location.

Host resistance. Due to the importance of TSWV, peanut breeding programs are only releasing cultivars with spotted wilt resistance equivalent to or better than that of Georgia Green, the current commercial standard. Although the development of a peanut cultivar resistant to all the major pathogens is unlikely, cultivars with partial resistance to one or more pathogens are currently available. The release of pathogen-resistant cultivars into the market has enabled producers to reduce losses from leaf spot and stem rot.

In addition to TSWV, breeding programs have made leaf spot resistance a major objective of their programs (Chiteka et al., 1988a,b; Pixley et al., 1990). Several genotypes, including Georgia-01R (Branch, 2002), C-99R (Gorbet and Shokes, 2002), DP-1 (Gorbet, 2003a) and Hull (Gorbet, 2003b), have increased levels of resistance to *C. arachidicola* and *C. personatum* and increased yield potential compared to Georgia Green; however they are all late-maturing. Efforts have also been made to develop a mid-maturing cultivar with increased resistance to the leaf spot pathogens (Branch and Culbreath, 1995; Branch, 1996).

According to Mehan et al. (1995) extensive efforts are being made to identify and incorporate sources of stem rot resistance into peanut germplasm; however, progress has been slow due to the non-specific mode of infection by *S. rolfsii* (Mehan et al., 1994). Currently, cultivars with increased stem rot resistance have been derived from breeding lines that exhibit other agronomic qualities or resistance to other pests. In addition to the release of cultivars resistant to leaf spot and TSWV, several cultivars such as, UF-MDR-98, C-99R,

Georgia-01R, Georgia-03, Georgia-02C, and AP-3 have improved stem rot resistance (Gorbet and Shokes, 2002a,b; Culbreath et al., 1997; Culbreath et al., 1998; Branch, 2003; Gorbet et al., 2004; Brenneman et al., 2005).

According to Holbrook et al. (1993), there is great genetic diversity in the U.S. Peanut Germplasm's 7,500 accessions; however, differences in resistance to limb rot is lacking. As of 1993, Georgia Browne was the only runner cultivar reported to have partial resistance to limb rot (Branch, 1994); however, it is not currently being grown due to industry concerns regarding its undesirable small seed size. Earlier reports suggested that Georgia Green is as susceptible to limb rot as GK-7 and Florunner (Branch and Brenneman, 1993). Later studies conducted by Franke et al. (1999) found that Georgia Green had a level of limb rot resistance equivalent to that of Georgia Browne; in addition, Georgia Green was more resistant than Georgia Browne to hypocotyl infections. Additional studies are currently being conducted to evaluate limb rot resistance in commercially available cultivars and advanced breeding lines (Brenneman, unpublished data).

Irrigation. Although peanuts have the ability to withstand early season drought, irrigation is a critical component of peanut production in the southeast. Several studies have shown large yield increases where irrigation is applied Lanier et al., 2004; Zhu et al. 2004; Branch and Brenneman, 1996; Davis et al., 1996). As of 2004, approximately 56% of Georgia's peanut acreage was under some type of irrigation (Harrison, 2005). Water requirements vary greatly from year to year, and the ability to add supplemental water minimizes the potential for yield losses associated with drought. However, the addition of irrigation is also beneficial to the pathogens causing fungal diseases.

Increased moisture on the soil surface and relative humidity in the peanut canopy following irrigation has been proven to increase disease problems (Wright et al., 1986; Rotem and Palti, 1969). In studies conducted by Lanier et al (2004), overhead irrigation systems resulted in greater leaf spot incidence when compared to subsurface drip irrigation; but peanut yield was unaffected. Irrigation also has a significant effect on stem rot incidence (Rideout, 2002; Black et al., 2001; Bowen, 2003; Brenneman; 1998; Davis et al., 1996). Branch and Brenneman (1996) reported stem rot incidence to be twice as high in irrigated as in non-irrigated plots. Davis et al. (1996) also reported increased stem rot levels in irrigated plots compared to non-irrigated plots, but it should be stressed that in fields with high inoculum levels, damaging stem rot often occurs when no irrigation is applied.

Rhizoctonia solani AG-4 is widely distributed throughout Georgia; however, limb rot of peanut did not become a significant problem until the late 1970s (Thompson, 1982). During this time irrigation in Georgia increased approximately seven-fold (Harrison, 1981). Limb rot was more severe in irrigated than non-irrigated fields (Barnes et al., 1990; Thompson, 1982). In addition, limb rot incidence was positively correlated with irrigation frequency (Barnes et al., 1990). Since *R. solani* is favored by moderate temperatures, irrigation may supply the moisture and in moderate temperatures required for optimal disease development.

Planting Date. Planting date is an important production practices that impacts the development of diseases in many crops. Planting too early increases the risk of seedling disease caused by *R. solani* and other soilborne pathogens. Brenneman and Hadden (1996) found that higher stem rot levels were associated with peanut planted in on 21 April compared to 10 May or 20 May. Additionally, stem rot levels for peanuts planted on 10 May

were higher than those planted 20 May. Results from controlled inoculations indicated that plants infected earlier in the season suffer greater yield reductions compared to those infected later, because the disease has a longer time to develop (Sconyers, 2003). On the other hand, when peanuts are planted too late, there is an even greater risk for yield losses associated with more severe leaf spot epidemics (Shokes et al. 1982). Later planting dates may also result increased limb rot associated losses, as environmental conditions are more conducive for disease development toward the end of the season (Brenneman, personal communication).

Row Pattern. Single row patterns typically consist of individual rows planted 91-97 cm apart. By comparison, twin row patterns generally have a pair of rows planted approximately 17.8 cm apart on each side of bed. Research over the past 10 years has consistently shown that peanuts planted in a twin row pattern provided yield advantages of about 330 to 440 kg per hectare over the single row pattern (Lanier el al., 2004; Jordan et al., 2001; Mozingo, 1984; Mozingo and Coffelt, 1984). The boost in yield may be due to decreased TSWV incidence in peanuts planted in twin rows. Baldwin (1997) showed that peanuts planted in a twin row pattern with adequate stands significantly reduce TSWV and result in higher yield and grade. These findings have led to an increase in acreage being planted to twin rows in Georgia. As of 1999, over 50% of the acreage in Georgia was planted in a twin row pattern at a higher seeding rate (Baldwin and Shurley, 1999).

Although the effects of row pattern on TSWV incidence is well documented, less is known about the effects of row pattern and seeding rate on the development of stem rot or limb rot. Minton and Csinos (1986) observed lower stem rot levels in peanuts planted in twin rows than in single rowa; however, no effect of seeding rate was observed. In a more

recent study, Black et al. (2001) found that a significant increase in stem rot was associated with increasing seeding rates. Preliminary studies of the effects of row pattern on disease development indicated that leaf spot was more severe in peanuts planted in a twin row pattern when compared to single rows (Sconyers, 2003); however, results from tests in subsequent years have been variable. Sconyers et al. (2005) did report that stem rot was more severe in single than in twin-row patterns, suggesting that a closer plant spacing favored disease development after canopy closure and that the increased distance between plant crowns delays plant to plant spread. Although information about the effects of row pattern on the development of Rhizoctonia limb rot is currently lacking, it is conceivable that limb rot may be more severe peanuts planted in a twin row due to changes in environment, primarily relative humidity.

CHEMICAL DISEASE CONTROL

Fungicides. Foliar applications of fungicides are required for the management of foliar and soilborne diseases of peanut in commercial peanut production in the southeastern United States. These products have traditionally been the second largest variable expense in peanut production, behind seed cost. However, with the reduced cost of seed under the new peanut program, fungicides are the single largest production expense for growers in Georgia (Smith, 2002). Multiple applications of fungicides are required to ensure control of diseases within a given year (Melouk and Backman, 1995; Shokes and Culbreath, 1997). In much of the peanut production area in the Southeast, these fungicides are applied on calendar-based spray schedules; fungicide applications are initiated approximately 30 days after planting and subsequent applications made on 14-day intervals. Due to the long growing season and high

disease pressure in the southeast, six to eight applications are typically made within a single growing season.

A wide range of fungicides is available to growers, each with different strengths and weaknesses. Protectant fungicides, such as maneb and chlorothalonil have been used to manage *C. arachidicola* and *C. personatum* over the past few decades. Chlorothalonil, a multi-site protectant fungicide, is among the most effective fungicides registered for leaf spot control and has been the standard fungicide for leaf spot management since the 1970s (Culbreath et al., 1992). Unfortunately, chlorothalonil is not effective for control of *S. rolfsii* or *R. solani* and other fungicide chemistries are required to control these soilborne pathogens. The registration of tebuconazole, flutolanil and azoxystrobin in 1994, 1995 and 1997, respectively, has supplied peanut producers with more options in managing both foliar and soilborne diseases. Tebuconazole and azoxystrobin are highly active against both foliar and soilborne diseases; however, they both have site specific modes of action, and therefore, a greater risk for resistance development (Bertrand and Padgett, 1997).

Field trials to evaluate the effects of ergosterol biosynthesis inhibiting fungicides in combination with chlorothalonil demonstrated that using reduced rates of chlorothalonil tank mixed with either propiconazole or cyproconazole improved the control of leaf spot over that of a full rate of chlorothalonil alone (Culbreath et al., 1992; Culbreath et al., 1995). However, tank-mix combinations of fungicides may result in added cost compared to alternative products. Culbreath et al. (2001) also evaluated the efficacy of various alternations and combinations of chlorothalonil and benomyl for managing benomyl-resistant *C. arachidicola* and *C. personatum* populations. Results of that study showed that full season tank mixes of the compounds provided leaf spot control comparable to the standard

chlorothalonil program, suggesting that tank-mixing is a valid resistance management tool where fungicide resistance is already a problem.

Brenneman and Culbreath (1994) studied various application schedules of chlorothalonil and tebuconazole, and found that a block of four applications of tebuconazole beginning at the third spray, reduced the severity of both foliar and soilborne diseases, and increased pod yields and kernel quality when compared to the full season chlorothalonil program. Similar trends were observed when less than four tebuconazole applications were made (Brenneman and Culbreath, 1994).

Fungicide application timing. Although fungicides are typically applied on a 14-day schedule to manage fungal diseases, the use of extended spray intervals could certainly be beneficial to producers by reducing production costs if they could maintain similar yields (Smith, 2002). In a study conducted by Brenneman and Culbreath (1994), fungicides applied on a 14-day schedule and 21-day schedule provided similar levels of leaf spot and stem rot suppression. Disease control decreased in plots treated on a 21-day interval; however, leaf spot and stem rot suppression was higher for the 21-day schedule than for the non-treated control. Similar trends were observed for yield, where yields did not differ when fungicides were applied on 14-day and 21-day intervals, but were both significantly higher than the non-treated control. Additional studies have shown that fungicides applied on 21- or 28-day intervals provide sufficient control of diseases and provide yields comparable to those achieved by the standard 14-day applications interval (Brenneman et al., 2001; Culbreath, 1993; Culbreath et al., 1992; Monfort, 2002; Phatak et al., 2002). Results of one study in particular showed that plots receiving as few as four chlorothalonil applications applied on a 28-day interval had yields as high as plots treated with seven applications made on a 14-day

interval (Culbreath et al., 1992). Chandra et al. (1998), found that one properly timed application provided adequate control of leaf spot; however, timings differed within years.

By better defining the environmental conditions that favor disease development, peanut producers can improve disease control by timely applications of fungicides. Disease forecasting models use environmental data, such as temperature, rainfall and relative humidity, to predict when conditions are favorable for pathogen and disease development (Campbell and Madden, 1990). Over the past 40 years, various forecasting models have been developed and successfully implemented for peanut diseases. Jenson and Boyle (1966) and Phipps and Powell (1984) are credited with developing some of the first forecasting models to manage peanut leaf spot. More recently, an early leaf spot spray advisory, developed in Virginia, was effective in reducing number of sprays required for satisfactory disease control and has been highly accepted by growers (Cu and Phipps, 1993; Phipps, 1993). Spray advisories for late leaf spot have been implemented in other peanut producing states, such as Georgia, Alabama, North Carolina and Oklahoma (Nutter and Brenneman, 1989; Davis et al., 1993; Bailey et al., 1994; Damicone 1994).

In Georgia, AU-Pnut is the predominant leaf spot advisory used in research; however, it is not widely used by producers. This model was developed in the late 1980s, and is based solely on precipitation (the number of precipitation events and the five-day forecasted probability of precipitation) (Davis et al., 1993). Evaluations of the AU-Pnut advisory for timing applications of fungicides aimed at soilborne fungi have shown suppression of southern stem rot, but the results have been inconsistent (Brenneman and Culbreath, 1994; Rideout, 2003).

Based on the environmental conditions that incite Sclerotinia blight (caused by *Sclerotinia minor*) in Virginia (Phipps, 1995), several spray advisories have been developed and shown to improve disease control when compared to calendar applications (Langston, 1998, Langston et al., 2002). These advisories are based on air and soil temperatures, precipitation, relative humidity, vine growth, and canopy closure. Adaptations of these models have been evaluated for timing fungicides for control of southern stem rot. Rideout (2003) demonstrated that fungicide application timing has a significant effect on stem rot control and yield. Furthermore, he concluded that the application of fungicides according to advisories based on soil temperature, precipitation and host growth provided similar or better disease control greater than the typical calendar-based programs. In addition to a better understanding of fungicides, implementation of disease forecasting models can help producers minimize disease losses.

Targeting fungicide applications. Peanut producers have more fungicide options now than ever before. Many of the products currently on the market have activity against both foliar and soilborne diseases. A major factor in the utility of these products is targeting them toward soilborne diseases. Pentachloronitrobenzene (PCNB), an organochlorine fungicide, was the first fungicide used extensively for soilborne disease control; however, high costs and inconsistent field results limited it use by producers (Csinos, 1989). PCNB was applied as a granule, the logic being that granules were needed to filter down through the canopy to the soil surface for control of soilborne diseases (Csinos, 1989).

This same strategy was applied to newer fungicides, such as the sterol biosynthesis inhibitors (SBI's) as they were evaluated on peanut. Granular formulations of diniconazole and tebuconazole were examined, but results were inconsistent (Csinos, 1987). However,

suppression of soilborne diseases was observed when these compounds were applied to foliage in leaf spot studies (Backman and Crawford, 1985; Csinos et al., 1987; Brenneman et al., 1991; Brenneman and Culbreath, 1994). By mixing dyes with the foliar-applied fungicides and applying irrigation, Csinos (1988) documented how these materials were delivered to the soil. He demonstrated that the architecture of the peanut plant served to funnel rain or irrigation water along the stems and increase deposition of fungicides at the plant crown and pegs. This redistribution is important since these structures serve as primary infection courts for stem rot infections (Melouk and Backman, 1995).

Several factors are known to affect fungicide deposition and efficacy. Differences the morphology and or chemical composition of the leaf cuticle can influence the retention of fungicides (Neely, 1970; Neely, 1971), and changes in the composition of the cuticle have been attributed to different environmental factors (Skoss, 1955). Pesticide deposition is also greatly affected by canopy density. Researchers have found that higher levels of chlorothalonil are deposited on the upper plant canopy, compared to the lower canopy (Brenneman et al. 1990; Hamm and Clough, 1999). Zhu et al. (2004), demonstrated that spray deposits in the upper and lower peanut canopy differed significantly, and that deposits in the lower canopy decreased as plants aged. The deposition and retention of chlorothalonil may differ within the peanut canopy layer and volume of water used for application (Brenneman et al., 1996). O'leary et al. (1997) found that both formulation and application method of flutolanil resulted in significant increases in chemical residues on subterranean plant parts and the lower canopy, respectively.

RESEARCH OBJECTIVES

With the restructuring of the peanut support program, it is crucial that all aspects of disease management be considered if producers are to remain economically competitive. The purpose of this research is to address what cultural practices can be implemented to adequately manage fungal diseases without jeopardizing yield, and to better define methods of controlling soilborne diseases with foliar applied fungicides. The overall focus of this research is to provide information that will aid peanut producers in adequately managing diseases while maximizing profits. The following objectives will provide this information: (i) to evaluate reduced input fungicide programs in small research plots, (ii) to demonstrate the benefits of using reduced input fungicide programs in commercial fields classified as having low or moderate leaf spot or stem rot risk, and (iii) to determine the effects of irrigation timing on the efficacy of foliar applied fungicides.

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CHAPTER 2

MANAGEMENT OF PEANUT DISEASES WITH REDUCED INPUT FUNGICIDE PROGRAMS IN FIELDS WITH VARYING LEVELS OF DISEASE RISK[1]

[1]Woodward, J.E., T.B. Brenneman, R.C. Kemerait, Jr., A.K. Culbreath, N.B. Smith, and B.G. Mullinix, 2006. To be submitted to *Plant Disease*.

Abstract

Field experiments were conducted in 2003 and 2004 to evaluate full and reduced input fungicide programs in peanut fields with varying levels of disease risk. Foliar-based programs consisted tank-mix combinations of chlorothalonil and propoconazole, while soilborne-based programs also included alternating applications of tebuconazole and azoxystrobin. Fungicides were applied on a 14-, 21-, or 28-day interval resulting in 7, 5, and 3 sprays, respectively. The intensity of peanut leaf spot (*Cercospora arachidichola* and *Cercosporidium personatum*) epidemics was similar for all programs in fields considered to be reduced risk. In high risk fields, leaf spot intensity did not differ for the 14 and 21-day interval; however, there was significantly more leaf spot in plots treated on a 28-day interval. Incidence of southern stem rot (*Sclerotium rolfsii*) was consistently lower in plots treated with soilborne-based programs than those treated with foliar-based programs. Control for the extended interval soilborne-based programs was comparable to that for the seven-spray program in all cases except the high disease risk situations where plot treated on the 28-day interval had significantly higher levels of stem rot than those treated on a 14-day interval. Pod yields were similar among application intervals for all instances. Returns were $232 and $362 per ha higher for the 28-day interval foliar and soilborne-based programs, respectively, compared to the respective 14-day interval programs in low risk fields. Based on these results, soilborne-based fungicide programs provide superior yields compared to foliar-based programs regardless of disease risk level, thus reductions in the number of applications can be made without compromising leaf spot control, stem rot control, or yield.

Keywords: *Arachis hypogaea* L., disease risk index, integrated disease management, extended interval, partial resistance, economics

INTRODUCTION

Early and late leaf spot caused by *Cercospora arachidicola* S. Hori and *Cercosporidium personatum* (Berk. & M.A. Curtis) Deighton, respectively, are the predominant foliar diseases of peanut (*Arachis hypogaea* L.) in the southeastern United States. If left unmanaged, either disease can cause complete defoliation and result in yield losses between 50 and 70% (34). Diseases caused by soilborne pathogens, such as stem rot (*Sclerotium rolfsii* Sacc.) and limb rot (*Rhizoctonia solani* Kühn, anastomosis group 4 (AG-4)), are also capable of reducing yields (31). Combined, these diseases account for annual losses in excess of $65 million in Georgia alone (29). To minimize the potential impact of these diseases, peanut producers rely heavily on the use of chemical fungicides. Multiple applications within a given year are required to ensure control of diseases within a given year (31,34). Fungicide applications are typically initiated 30 to 40 days after planting (DAP), and subsequent applications are made on 14-day intervals. As a result, six to eight applications are made within a single season.

Currently, there is a wide range of products labeled for the management of peanut diseases. Chlorothalonil, a multi-site protectant fungicide, is among the most effective products for leaf spot control and has been the standard fungicide for leaf spot management since the 1970s (16). However, tank mix combinations of other fungicides with reduced rates of chlorothalonil are also used to manage leaf spot. Culbreath et al. (17) reported that reduced rates of chlorothalonil tank-mixed with propiconazole provide superior suppression of leaf spot compared to full rates of chlorothalonil. Chlorothalonil does control stem rot or limb rot, and rates of propiconazole required for controlling soilborne diseases are cost

prohibitive (9,17). However, additional fungicides which are active against soilborne pathogens are commercially available.

The registration of tebuconazole and azoxystrobin in 1994 and 1997, respectively, has provided peanut producers with more options for managing leaf spot (6,7,32) as well as soilborne diseases (6, 8,25). Although fungicides are essential in disease management, they are also the single largest expenditure for peanut producers (38). Economic changes have greatly impacted peanut production in this region. Historically, peanuts were regulated through a quota poundage system. The 2002 farm bill replaced this system with a market loan system, which reduced crop value by approximately 40% reduction in crop value. More recently, reductions in the labor force and higher fuel costs have also impacted peanut production. Despite these changes, peanut production in Georgia has increased. This is due in part to the expansion of acreage into non-traditional production areas of the state, where production was limited under the quota system. The long-term implications of this transition are not fully understood. However, producers will need to change management practices and minimize production costs to remain competitive. One way to accomplish this goal would be to utilize integrated disease management approaches. Such approaches are currently being practiced in the management of other peanut diseases, such as spotted wilt caused by *Tomato spotted wilt tospovirus* (TSWV) (12).

Since emerging in the late 1980s, spotted wilt has become a threat to many economically important crops in the southeastern United States. Improved management of spotted wilt has been accomplished by the implementation of various cultural practices (11,18). Many of the same factors that impact the incidence and severity of spotted wilt also influence the development of leaf spot (13,32) and stem rot (26,32). Based on this

knowledge, the University of Georgia's Fungal Disease Risk Index (30) was developed to aid producers in quantitatively determining foliar and soilborne disease risk levels prior to planting based on cultural practices. Such practices include cultivar selection, crop rotation, planting date, row pattern, tillage, irrigation and the disease history of a field. This information can be used to categorize fields as having a low, moderate, or high risk for leaf spot, stem rot, and limb rot. Using information obtained from the index, fungicide programs can be designed specifically for each individual field. Those with low to moderate disease risk levels for foliar diseases might require less frequent fungicide applications. Those with low to moderate risk levels for soilborne diseases could have a similar increase in application interval, thus effectively reducing fungicide expenditures. However, such changes in disease management strategies must not compromise disease control, yield, or economic returns.

Fungicide programs utilizing extended spray intervals have been used to adequately manage both foliar (15,16,21) and soilborne (2,3,6,21) diseases in the southeastern United States. For leaf spot, Monfort et al., (32) found that the use of extended-interval fungicide programs in conjunction with strip-tillage, provided levels of control similar to that obtained by using standard programs with conventional tillage. Additional studies have shown that epidemics can be further suppressed by including cultivars with moderate levels of leaf spot resistance (10,32). Extended interval programs utilizing tebuconazole (3,24) or azoxystrobin (32) have been used to provide levels of stem rot control and yield equivalent to their respective standard schedules. However, the calendar-based schedules currently used are based on years of research, and indiscriminant reductions in the number of applications could lead to serious crop losses (3,6).

One promising way to approach this is the use of weather-based spray advisories that could potentially reduce the number of fungicide applications within a season without jeopardizing peanut yield or crop quality. Since disease development is depends upon environmental conditions, properly timed fungicide applications greatly can improve disease control. Several complex advisories have been developed for leaf spot (28,33) In 1991, Davis et al. (20), developed a simple model, referred to as AU-Pnut that uses rainfall events and future rainfall probabilities to trigger chlorothalonil applications to manage leaf spot. Modifications to this model, such as substituting tebuconazole (6) or azoxystrobin for chlorothalonil for mid-season sprays, have been made to enhance soilborne disease control. While these programs have been effective, they have not been widely used because most growers prefer to make fungicide applications on a calendar-based schedule. Therefore, extended calendar-based schedules should be more readily adopted by growers. The objectives of this research was to evaluate the effects of full and reduced input fungicide programs, and a modified AU-Pnut advisory program on i) leaf spot and stem rot control, ii) pod yield and quality, and iii) economic return in fields with varying disease risk levels. Currently used fungicide programs, reduced programs derived from them, and several new cultivars with varying levels of disease susceptibility were also included in comparisons.

MATERIALS AND METHODS

Field experiments. Field experiments were conducted at the University of Georgia Coastal Plain Experiment Station Gibbs, Black Shank and/or Rigdon research farms in Tifton, GA in 2003 and 2004. The plot area at the Gibbs farm was a Tifton loamy sand (fine-loamy sand, siliceous, thermic Plinthic Kandiudults, slope 2-5%, 2003 pH 6.0-6.2). The field had been planted to corn (*Zea mays*) the previous year, but had a long history of peanut

production and high leaf spot and stem rot pressure. The peanut cultivar Georgia Green was planted in single rows on 7 May 2003 and 11 May 2004. The soil type at the Black Shank farm was a loamy, kaolinitic, thermic Aernic Plinthic Kandiudult Fuquay sand, slope 2-5%, pH 6.0-6.5). The cultivars Georgia-01R and DP-1 were planted in alternating beds on 23 May 2003 and 17 May 2004 in fields that had been planted to tobacco (*Nicotiana tabacum* L.) the previous years. A second experiment was conducted at the Black Shank farm and repeated in 2004 at the Rigdon farm. The soil type at the Rigdon farm was a loamy, kaolinitic, thermic Aernic Plinthic Kandiudults Fuquay sand, slope 2-5%, pH 6.2. The cultivars Georgia Green and Georgia-01R were planted in alternating beds on 23 May 2003 in a field with no recent history of peanut production and 14 May 2004 following cotton (*Gossypium hirsutum* L.) the previous year.

Rye (*Secale cereale* L.) was planted as a winter cover crop at all locations. Fields were prepared by deep turning the cover crop with a moldboard plow, disk harrowing and bedding. All fields were irrigated as needed, and other management decisions, except disease control, followed Georgia Cooperative Extension Service guidelines (1). Each plot consisted of a two-row (7.6m × 1.8m) bed that was separated by 2.1-m fallow alleys. At the Gibbs farm, experiments were arranged in a randomized complete block with five replications. A split-plot design with four or five replications was used in experiments evaluating multiple cultivars. For these experiments, whole plots consisted of fungicide program and cultivars were the sub-plots. Leaf spot and stem rot risk was determined for each trial based on the aforementioned cultural practices (30).

Fungicide regimes and schedules. All experiments included seven treatments (fungicide programs): three for foliar diseases only, three for foliar and soilborne diseases,

and one spray advisory. Fungicide programs for foliar diseases consisted of tank-mixes of 0.84 kg ha^{-1} chlorothalonil (Bravo Weatherstik 720F, Syngenta Crop Protection, Greensboro, NC) and 0.06 kg ha^{-1} propiconazole (Tilt 3.6 EC, Syngenta Crop Protection). Fungicide programs for soilborne diseases consisted of tank mixes of chlorothalonil + propiconazole, and alternating applications of 0.23 kg ha^{-1} tebuconazole (Folicur 7.2F, Bayer CropScience, Research Triangle Park, NC) and 0.22 kg ha^{-1} azoxystrobin (Abound 2.08 SC, Syngenta Crop Protection). The advisory program consisted of a modified version of AU-Pnut (6), where tebuconazole and azoxystrobin were applied on an alternating schedule during the mid-season. Fungicides in the calendar-based programs were applied on 14, 21 or 28-day intervals resulting in 7, 5 or 3 applications, respectively. A detailed description of fungicide programs is given in Table 2.1. Fungicide applications were initiated 32 to 36 days after planting in 2003 and 30 to 35 days after planting in 2004. All applications were made with a CO_2 pressurized beltpack sprayer, calibrated to deliver 188 liters ha^{-1} at 310 kPa with three ConeJet TX-6 hollow cone nozzles (TeeJet Technologies, Springfield, IL) per row.

Data collection. Leaf spot intensity was assessed in each plot every 14 days after the onset of disease. Disease was assessed using the Florida 1-10 scale, where 1 = no disease; 2 = very few lesions (none on upper canopy); 3 = few lesions (very few on upper canopy); 4 = some lesions with more on upper canopy (<5% defoliation); 5 = lesions prevalent on upper canopy with noticeable (~20%) defoliation; 6 = lesions numerous and very evident on upper canopy with significant (~50%) defoliation; 7 = lesions numerous on upper canopy with much (~75%); 8 = upper canopy covered with lesions and high (~90%) defoliation; 9 = very few leaves remaining and those covered with lesions (some plants 100% defoliated); and 10 = plants completely defoliated and killed by leaf spot (14). For this scale, values 1 through 4

reflect increasing leaf spot incidence on leaflets and occurrence of spots within the lower or upper canopy, and values 4 through 10 reflect increasing levels of defoliation (14). The area under the disease progress curve (AUDPC) was calculated using leaf spot intensity ratings and time in days after planting (37). Due to differences in the maturity of the cultivars used, epidemics were standardized by dividing the AUDPC by the duration of the epidemic (stAUDPC).

Peanuts were dug and inverted based on maturity using the hull scrape method described by Williams (43). Stem rot incidence was determined immediately after plants were inverted by counting the number of disease loci, where a single locus represents a 30-cm section of row exhibiting stem rot symptoms and/or signs of *S. rolfsii* (35). The number of disease loci within a plot was converted to a percentage of total row length for comparison of treatments. When present, limb rot severity was also assessed immediately after plants were inverted by estimating the percentage of symptomatic vines per meter of row at six arbitrarily selected areas per plot. Spotted wilt intensity was assessed several weeks prior to digging based on a scale that represents a combination of incidence and severity as described by Culbreath et al. (19). Plants were allowed to cure in windrows for 4 to 9 days. Pods were mechanically harvested from each plot, and moisture content was adjusted to 10% (wt/wt). Plot yields were determined, and pod samples were graded in accordance with the Federal-State Inspection Service methods (40). Pod yields and grades were used to calculate the crop value for each plot based on the current year pricing schedule (41,42). The return to fungicide program was estimated for each plot by subtracting the estimates cost of the fungicide program including application costs from the estimated crop value (Smith, 2003).

Statistical analysis. To estimate fungicide treatment effects across all trials, a second analysis was performed using Proc MIXED (36). Trial, replication within trial, and trial × fungicide program were considered random effects, and cultivar, leaf spot risk, fungicide program, cultivar × fungicide program and leaf spot risk × fungicide program were fixed effects. It was not possible to obtain a cultivar × leaf spot risk interaction since there were only 4 degrees of freedom (df) (2 for cultivar and 2 for leaf spot risk), leaving 0 df for the interaction (confirmed by Proc MIXED). The random effect of trial was extremely large; therefore, it was decided to remove the three cultivars, as well as the three leaf spot risk levels to determine the trial effect. Reducing the random effect due to trial allowed the observation of significant fungicide program effects. This was also the case for the trial by treatment interaction. Single degree-of-freedom contrasts were constructed for fungicide comparisons. It was not possible to test for an interaction between risk level and cultivar. To construct the contrasts and to ensure that the contrasts contained risk level and cultivar, it was necessary to equate Georgia Green with high risk. For yield only, the two MIXED models were run with final leaf spot intensity or AUDPC as covariates. Values for covariates were rescaled to a mean of zero as described by Draper and Smith (22). The Satterthwaite option was used to adjust the degrees of freedom to match adjustments in the sums of squares.

RESULTS

Early leaf spot was the predominant foliar disease in 2003, and late leaf spot was prevalent in 2004. Leaf spot epidemics were more severe in 2004 than in 2003. In both years epidemics varied by location, and disease progress curves for 2003 and 2004 are shown in Figures 2.1 and 2.2, respectively. AUDPC was not significant in the linear or quadratic model therefore it will not be presented. For the final leaf spot (FLS) assessments, the linear

portion of the polynomial effect due to yield was not important, but the quadratic or curve-linear form was significant at $P \leq 0.01$ (data not shown). Both AUDPC and FLS were included in the model as covariates for yield. Significant differences in leaf spot were observed among cultivars. The partially resistant cultivars Georgia-01R and DP-1 had lower levels of leaf spot for the 21- d.i. than Georgia Green (Table 2.2). Across the three cultivars, the 14- and 21-d.i. did not differ; however, the 28-d.i. programs consistently had higher leaf spot levels than the corresponding 14-d.i. programs. When comparing the calendar-based programs to AU-Pnut, stAUDPC was greater for the foliar 14- and 21-d.i.; whereas, stAUDPC as well as the soilborne calendar programs for Georgia-01R and DP-1. In regard to the three leaf spot risk levels, differences were only significant in the high risk trials (Table 2.3). In these comparisons, leaf spot development for both the foliar and soilborne 28-d.i. programs was significantly higher than their respective 14-d.i. programs. In addition, leaf spot was significantly lower for the AU-Pnut program when compared to the other programs in the high leaf spot risk fields.

Stem rot pressure varied by trial and year and was more severe in 2004 than in 2003 (Figures 2.4 and 2.3, respectively). As expected there were no differences in stem rot incidence for any of the foliar-based programs, and stem rot intensity was significantly less for the soilborne-based programs than for the foliar-based programs across all cultivars and risk levels. No differences were observed between the 14- ad 21-d.i. soilborne-based programs across any of the cultivars or risk levels. When comparing the 14- and 28-d.i. soilborne-based programs, stem rot was significantly greater for the extended interval program for the cultivars Georgia-01R and Georgia Green, but not for DP-1 which has a

higher level of resistance to stem rot (23). This difference was also significant in the high risk leaf spot fields.

Across cultivars, peanut yields were significantly higher for the soilborne-based programs when compared to the foliar-based programs by 1244, 1191 and 1214 kg/ha for Georgia-01R, DP-1 and Georgia Green, respectively (Table 2.4). Few additional differences in yield were observed among treatments. There was a significant difference in the yield of Georgia-01R between the 14- and 28-d.i. for Georgia-01R, where yields for the standard program were 376 kg/ha greater than the extended interval program. Few differences in yield were observed when analyzed across leaf spot risk category. In the high risk fields, yields for the AU-Pnut program and the soilborne programs were significantly higher than yields of he foliar-based programs (Table 2.5). There were no differences in yield between programs in the moderate risk trial; however, yields were significantly higher for the 28-d.i. soilborne program when compared to the standard 14-d.i. program.

Overall, quality grades were higher for Georgia Green and Georgia-01R (data not shown); however, the fungicide programs did not affect peanut quality, except for the foliar and soilborne program comparisons. Across all cultivars and risk levels, grades were significantly higher for the soilborne programs by 2.53 and 2.11% for Georgia-01R and Georgia Green, respectively (Table 2.4). This trend was also significant in the high risk trials, where peanut grades were 2.90% higher for the soilborne programs.

As was the case with yield and grade, few differences in economic returns were observed between the fungicide programs. Differences between the foliar and soilborne programs were significant across all cultivars and risk levels, and the soilborne programs provided profits of 430.12, 383.48, and 425.85 $/ha for Georgia-01R, DP-1, and Georgia

Green, respectively (Table 2.4). Returns were significantly higher for the 28-d.i. foliar and soilborne programs by 232.36 and 361.70 $/ha, respectively when compared to the standard 14-d.i. programs at low risk levels, but were not significantly different at moderate or high risk levels (Table 2.5). There were no significant differences in returns for the moderate risk trial; however, returns were numerically higher for both of the 28-d.i. programs.

DISCUSSION

The environmental conditions in the southeastern United States generally favor peanut production; however, the same conditions are also conducive for leaf spot and stem rot development. In both years of this study, rainfall amounts were well above historical averages for the area (27). Disease levels were higher in 2004 than in 2003. Although, leaf spot severity and stem rot incidence varied by trial, final disease assessments were highly correlated with disease risk levels in most cases (data not shown). These results suggest that the University of Georgia Fungal Disease Risk Index (30) can be used to accurately determine disease risk pre-plant, and that changes can be made to fungicide programs which will allow producers to reduce production costs.

In these studies, leaf spot epidemics were consistently suppressed using extended interval foliar or soilborne-based program, with the 21-d.i. programs providing leaf spot control equal to or better than the respective 14-d.i. programs. The difference in cultivar response to the 21-d.i. programs can be explained by the leaf spot resistance of each cultivar. While Georgia Green has a high yield potential, it is susceptible to infection by the leaf spot pathogens. In contrast, Georgia-01R and DP-1 have some of the highest levels of leaf spot resistance currently available. These results corroborate reports that the use of leaf spot resistant cultivars can help reduce production costs by using fewer fungicides (4,13,32). The

benefits of using extended interval programs were also illustrated when considering leaf spot risk. There were no significant differences among any of the programs in the low or moderate risk trials; however, in the high-risk fields both the foliar and soilborne-based 28-d.i. had significantly more leaf spot than the standard 14-d.i. programs. In these trials, applications of fungicides using AU-Pnut advisory provided better leaf spot control when compared to the other trials, indicating that weather-based advisories can be used to improve disease control. However, due to frequent rainfall, at least seven applications were required for this regime and eight applications were made to the late maturing cultivars in 2003.

The relative stem rot incidence in plots that received soilborne and foliar-based fungicide programs demonstrates the importance of using compounds with some level of activity against soilborne pathogens. However, the need for soilborne-based programs was also evident in fields with low or moderate stem rot risk. In addition, the use of stem rot-resistant cultivars reduced losses associated with stem rot. Monfort et al (32) also reported a reduction in stem rot incidence with the use of stem rot-resistant cultivars. While disease intensity was low in those studies, the benefits of using stem rot resistant cultivars have been reported under high disease pressure (4,23). Few differences were observed in yield or grade, among any of the extended interval programs. These results corroborate reports (6) that stem rot incidence is negatively correlated with yield and grade (data not shown). Yields were significantly higher for the soilborne programs in all comparisons, and peanut quality was higher for Georgia-01R and Georgia Green, but not DP-1. Additional on-farm studies have shown that reduced input programs can be successful in fields with moderate or low leaf spot or stem rot risk (unpublished data). The majority of the trials in the current study were established in fields with a one year rotation, and were determined to be high-risk, thus

providing a more conservative evaluation of the reduced fungicide programs. These results suggest there is some margin of safety when reducing fungicide inputs in low risk fields. As few as five applications of a soilborne-based program provided levels of disease control similar to seven-spray programs even in high risk situations. Fields with no history of peanut production that were planted to Georgia-01R and Georgia Green in 2003 were considered low and moderate risk, respectively. Despite having lower risks levels, yields for both cultivars were substantially lower due to poor field conditions.

This information will be valuable in the implementation of extended interval programs for several reasons. First, azoxystrobin and tebuconazole are important components of a fungicide program because they can both be used in the control foliar and soilborne diseases. These compounds are more costly than the protectant compounds, such as chlorothalonil, used to manage leaf spot alone (Table 2.1). However, these results indicate that the benefits of using soilborne-based programs offset the additional costs. While this study indicates that fewer fungicide applications can be used to adequately manage peanut diseases, concerns over fungicide resistance management for compounds with site-specific modes of action must be addressed. Azoxystrobin and tebuconazole each target a specific enzyme in biological pathways, inhibiting mitochondrial respiration and ergosterol biosynthesis, respectively. The risk of fungicide resistance is greater for *C. arachidicola* and *C. personatum* than for soilborne pathogens. However, the potential for fungicide resistance in *S. rolfsii* should not be ignored (3,6). For azoxystrobin, a maximum of two applications per season is labeled for disease control; whereas tebuconazole is labeled for a four-block application regime. Current resistance management recommendations are to include compounds with different modes of action (3,6,17). In regard to *C. arachidicola* and *C.*

personatum, chlorothalonil is applied in alternating applications with azoxystrobin, and preceding and following tebuconazole applications. Since chlorothalonil is not effective in controlling *S. rolfsii*, fungicide resistance management options are more limited. Bowen et al. (3) suggested the number of tebuconazole applications could be reduced to avoid resistance development in *S. rolfsii*. These results indicate that alternating azoxystrobin and tebuconazole applications adequately control foliar and soilborne diseases in fields with varying levels of disease risk. Combinations of the two products can be used to manage fungicide resistance. However, additional research is needed on incorporating other compounds into extended interval programs before such recommendations are made.

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Table 2.1. Characteristics and costs of fungicide programs for disease control of foliar and soilborne diseases in peanut fields with varying risk levels (2003 and 2004).

Program, Interval	Fungicide(s)[a]	Rate (kg ha^{-1})	Application Timing[b]	Cost ($ ha^{-1})[c]
Foliar-based				
14-d.i.	Chlorothalonil	0.84		
	+ Propiconazole	0.06	1 - 7	238.52
21-d.i.	Chlorothalonil	0.84		
	+ Propiconazole	0.06	1, 2.5, 4, 5.5, 7	170.37
28-d.i.	Chlorothalonil	0.84		
	+ Propiconazole	0.06	2, 4, 6	102.22
Soilborne-based				
14-d.i.	Chlorothalonil	0.84		
	+ Propiconazole	0.06	1, 2, 7	
	Tebuconazole	0.23	3 & 5	
	Azoxystrobin	0.22	4 & 6	306.32
21.d.i.	Chlorothalonil	0.84		
	+ Propiconazole	0.06	1 & 7	
	Tebuconazole	0.23	2.5	
	Azoxystrobin	0.22	4 & 5.5	225.33
28-d.i	Chlorothalonil	0.84		
	+ Propiconazole	0.06	2	
	Tebuconazole	0.23	4	
	Azoxystrobin	0.22	6	136.12
AU-Pnuts	Chlorothalonil	0.84		
	+ Propiconazole	0.06	<50 & >110 DAP	
	Tebuconazole	0.23	alt. 50 - 110 DAP	288.51-
	Azoxystrobin	0.22	alt. 50 - 110 DAP	321.83[d]

[a] Chlorothalonil was applied as Bravo WeatherStik 720F in a tank mix with propiconazole applied as Tilt 3.6 EC. Tebuconazole and azoxystrobin were applied as Folicur 3.6F and Abound 2.08 SC, respectively.

[b] Refers to the application number in a standard seven spray schedule, where there is one week between 1 and 1.5 and two weeks between 1 and 2.

[c] Refers to the cost of the fungicide program plus the associated cost of each application estimated at $12.35 per ha.

[d] The number of applications and combinations of fungicides varied for the AU-Pnut program, the range of costs for the programs is presented for ease of presentation.

Table 2.2. Effect of full and reduced input fungicide programs on peanut leaf spot (standardized area under disease progress curve (AUDPC)) and incidence of southern stem rot in Georgia-01R, DP-1, and Georgia Green peanut cultivars

	Program	Leaf spot			Stem rot		
Cultivar	comparison[x]	stAUDPC[y]	t[z]	P[z]	(%)	t[z]	P[z]
Georgia-01R	AU-Pnut vs. others	-0.21	2.44	*	-12.19	3.90	***
	Foliar vs. soilborne	-0.21	1.78	+	20.14	4.87	***
	14- vs. 21 d.i. (Foliar)	0.21	2.74	**	-0.02	0.01	ns
	14- vs. 21 d.i. (Soilborne)	0.22	2.87	**	2.40	0.87	ns
	14- vs. 28 d.i. (Foliar)	-0.76	9.88	***	-2.37	0.86	ns
	14- vs. 28 d.i. (Soilborne)	-0.62	7.90	***	-6.79	2.46	*
DP-1	AU-Pnut vs. others	-0.30	2.68	**	-6.69	1.70	+
	Foliar vs. soilborne	-0.19	1.26	ns	17.77	3.42	***
	14- vs. 21 d.i. (Foliar)	0.13	1.33	ns	0.31	0.09	ns
	14- vs. 21 d.i. (Soilborne)	0.27	2.80	**	-0.50	0.14	ns
	14- vs. 28 d.i. (Foliar)	-0.82	8.40	***	-3.69	1.07	ns
	14- vs. 28 d.i. (Soilborne)	-0.79	8.12	***	-2.10	0.61	ns

Georgia Green	AU-Pnut vs. others	-0.53	3.87	***	-7.97	2.59	*
	Foliar vs. soilborne	-0.10	0.58	ns	29.08	7.15	***
	14- vs. 21 d.i. (Foliar)	0.01	0.11	ns	-3.33	1.23	ns
	14- vs. 21 d.i. (Soilborne)	0.05	0.43	ns	3.32	1.22	ns
	14- vs. 28 d.i. (Foliar)	-0.49	4.05	***	-1.40	0.51	ns
	14- vs. 28 d.i. (Soilborne)	-0.35	2.93	**	-6.74	2.49	*

[x] Represents the comparisons of fungicide programs from Table 2.1.

[y] Differences in least squared means from Proc MIXED for standardized area under disease progress curves using te Florida 1 to 10 scale (14).

[z] *t*-value and probability of a greater *t*-value for single degree-of-freedom contrasts of the fungicide treatment means within a cultivar treatment. n.s., +, *, **, and *** represents significance levels of $P \geq 0.10$, $P \leq 0.10$, $P \leq 0.05$, $P \leq 0.01$, and $P \leq 0.001$, respectively.

Table 2.3. Effect of full and reduced input fungicide programs on peanut leaf spot (standardized area under disease progress curve (AUDPC)) and incidence of southern stem rot in fields classified as having low, moderate, or high fungal disease risk

	Program	Leaf spot			Stem rot		
Risk level	comparison[x]	stAUDPC[y]	t[z]	P[z]	(%)	t[z]	P[z]
Low	AU-Pnut vs. others	-0.46	1.43	ns	2.79	0.41	ns
	Foliar vs. soilborne	-0.06	0.14	ns	23.44	2.59	*
	14- vs. 21 d.i. (Foliar)	-0.22	0.77	ns	-0.80	0.13	ns
	14- vs. 21 d.i. (Soilborne)	-0.13	0.46	ns	2.25	0.37	ns
	14- vs. 28 d.i. (Foliar)	0.13	0.46	ns	0.98	0.16	ns
	14- vs. 28 d.i. (Soilborne)	0.13	0.44	ns	-2.12	0.35	ns
Moderate	AU-Pnut vs. others	-0.09	0.29	ns	-4.57	0.67	ns
	Foliar vs. soilborne	-0.12	0.28	ns	19.00	2.10	*
	14- vs. 21 d.i. (Foliar)	-0.01	0.04	ns	0.17	0.03	ns
	14- vs. 21 d.i. (Soilborne)	0.06	0.20	ns	-2.50	0.41	ns
	14- vs. 28 d.i. (Foliar)	-0.10	0.36	ns	2.17	0.36	ns
	14- vs. 28 d.i. (Soilborne)	-0.17	0.59	ns	-2.00	0.33	ns

High	AU-Pnut vs. others	-0.53	3.87	***	-7.97	2.59	*
	Foliar vs. soilborne	-0.10	0.58	ns	29.08	7.15	***
	14- vs. 21 d.i. (Foliar)	0.01	0.11	ns	-3.33	1.23	ns
	14- vs. 21 d.i. (Soilborne)	0.05	0.43	ns	3.32	1.22	ns
	14- vs. 28 d.i. (Foliar)	-0.49	4.05	***	-1.40	0.51	ns
	14- vs. 28 d.i. (Soilborne)	-0.35	2.93	**	-6.74	2.49	*

[x] Represents the comparisons of fungicide programs from Table 2.1.

[y] Differences in least squared means from Proc MIXED for standardized area under disease progress curves using te Florida 1 to 10 scale (14).

[z] *t*-value and probability of a greater *t*-value for single degree-of-freedom contrasts of the fungicide treatment means within a cultivar treatment. n.s., +, *, **, and *** represents significance levels of $P \geq 0.10$, $P \leq 0.10$, $P \leq 0.05$, $P \leq 0.01$, and $P \leq 0.001$, respectively.

Table 2.4. Effect of full and reduced input fungicide programs on peanut pod yield, quality, and economic returns in Georgia-01R, DP-1, Georgia Green peanut cultivars

Cultivar	Program Comparison[y]	Yield (kg ha^{-1})	t[z]	P[z]	Grade (smk+ss)	t[z]	P[z]	Return ($ ha^{-1})	t[z]	P[z]
Georgia-01R	AU-Pnut vs. others	208	0.78	ns	0.88	1.09	ns	32.42	0.32	ns
	Foliar vs. Soilborne	-1244	3.77	***	-2.53	2.37	*	-430.12	3.26	**
	14- vs. 21 d.i. (Foliar)	-149	0.68	ns	0.85	1.20	ns	-67.16	0.76	ns
	14- vs. 21 d.i. (Soilborne)	-234	1.07	ns	0.81	1.14	ns	-90.59	1.03	ns
	14- vs. 28 d.i. (Foliar)	277	1.26	ns	-1.08	1.51	ns	103.53	1.18	ns
	14- vs. 28 d.i. (Soilborne)	376	1.71	+	-0.95	1.34	ns	99.01	1.12	ns
DP-1	AU-Pnut vs. others	-135	0.45	ns	-0.74	0.79	ns	26.32	0.22	ns
	Foliar vs. Soilborne	-1191	3.04	**	-0.48	0.39	ns	-383.48	2.45	*
	14- vs. 21 d.i. (Foliar)	-9	0.03	ns	0.00	0.00	ns	-7.70	0.07	ns
	14- vs. 21 d.i. (Soilborne)	138	0.53	ns	-0.59	0.72	ns	14.42	0.14	ns
	14- vs. 28 d.i. (Foliar)	101	0.39	ns	-0.83	1.01	ns	25.48	0.24	ns
	14- vs. 28 d.i. (Soilborne)	-243	0.92	ns	0.42	0.51	ns	-88.32	0.85	ns

Georgia Green	AU-Pnut vs. others	-382	2.00	+	-0.27	0.50	ns	126.32	1.78	+
	Foliar vs. Soilborne	-1214	5.13	***	-2.11	2.90	**	-425.85	4.53	***
	14- vs. 21 d.i. (Foliar)	245	1.54	ns	0.14	0.30	ns	80.40	1.28	ns
	14- vs. 21 d.i. (Soilborne)	-45	0.28	ns	0.52	1.08	ns	-33.78	0.54	ns
	14- vs. 28 d.i. (Foliar)	-26	0.14	ns	-0.02	0.03	ns	-3.28	0.05	ns
	14- vs. 28 d.i. (Soilborne)	180	1.01	ns	-0.07	0.15	ns	37.51	0.60	ns

[y] Represents the comparisons of fungicide programs from Table 2.1.

[z] *t*-value and probability of a greater *t*-value for single degree-of-freedom contrasts of the fungicide treatment means within a cultivar treatment. n.s., +, *, **, and *** represents significance levels of $P \geq 0.10$, $P \leq 0.10$, $P \leq 0.05$, $P \leq 0.01$, and $P \leq 0.001$, respectively.

Table 2.5. Effect of full and reduced input fungicide programs on peanut pod yield, quality, and economic returns in fields classified as having low, moderate, or high fungal disease risk

Risk Level	Program comparison[y]	Yield (kg ha^{-1})	t[z]	P[z]	Grade (smk+ss)	t[z]	P[z]	Return ($ ha^{-1})	t[z]	P[z]
Low	AU-Pnut vs. others	-251	0.64	ns	-0.92	0.76	ns	107.55	0.69	ns
	Foliar vs. Soilborne	-469	0.91	ns	-1.36	0.84	ns	-139.09	0.68	ns
	14- vs. 21 d.i. (Foliar)	318	0.92	ns	-1.02	0.95	ns	109.98	0.80	ns
	14- vs. 21 d.i. (Soilborne)	557	1.62	ns	-0.33	0.31	ns	204.43	1.49	ns
	14- vs. 28 d.i. (Foliar)	-472	1.33	ns	0.40	0.38	ns	-232.36	1.70	+
	14- vs. 28 d.i. (Soilborne)	-768	2.19	*	1.52	1.41	ns	-361.70	2.64	*
Moderate	AU-Pnut vs. others	122	0.31	ns	-0.40	0.34	ns	-110.65	0.72	ns
	Foliar vs. Soilborne	58	0.11	ns	-1.14	0.72	ns	90.10	0.45	ns
	14- vs. 21 d.i. (Foliar)	302	0.89	ns	-0.64	0.60	ns	112.87	0.84	ns
	14- vs. 21 d.i. (Soilborne)	36	0.11	ns	-0.64	0.60	ns	3.60	0.03	ns
	14- vs. 28 d.i. (Foliar)	-196	0.56	ns	1.07	1.01	ns	-121.84	0.90	ns
	14- vs. 28 d.i. (Soilborne)	-110	0.32	ns	-0.36	0.34	ns	-113.32	0.84	ns

High	AU-Pnut vs. others	-382	2.00	+	-0.27	0.50	ns	126.33	1.78	+
	Foliar vs. Soilborne	-1214	5.13	***	-2.11	2.90	**	-425.85	4.53	***
	14- vs. 21 d.i. (Foliar)	255	1.54	ns	0.14	0.30	ns	80.41	1.28	ns
	14- vs. 21 d.i. (Soilborne)	-45	0.28	ns	0.52	1.08	ns	-33.77	0.54	ns
	14- vs. 28 d.i. (Foliar)	-26	0.14	ns	-0.02	0.03	ns	-3.28	0.05	ns
	14- vs. 28 d.i. (Soilborne)	180	1.01	ns	-0.07	0.15	ns	37.51	0.60	ns

[y] Represents the comparisons of fungicide programs from Table 2.1.

[z] *t*-value and probability of a greater *t*-value for single degree-of-freedom contrasts of the fungicide treatment means within a cultivar treatment. n.s., +, *, **, and *** represents significance levels of $P \geq 0.10$, $P \leq 0.10$, $P \leq 0.05$, $P \leq 0.01$, and $P \leq 0.001$, respectively.

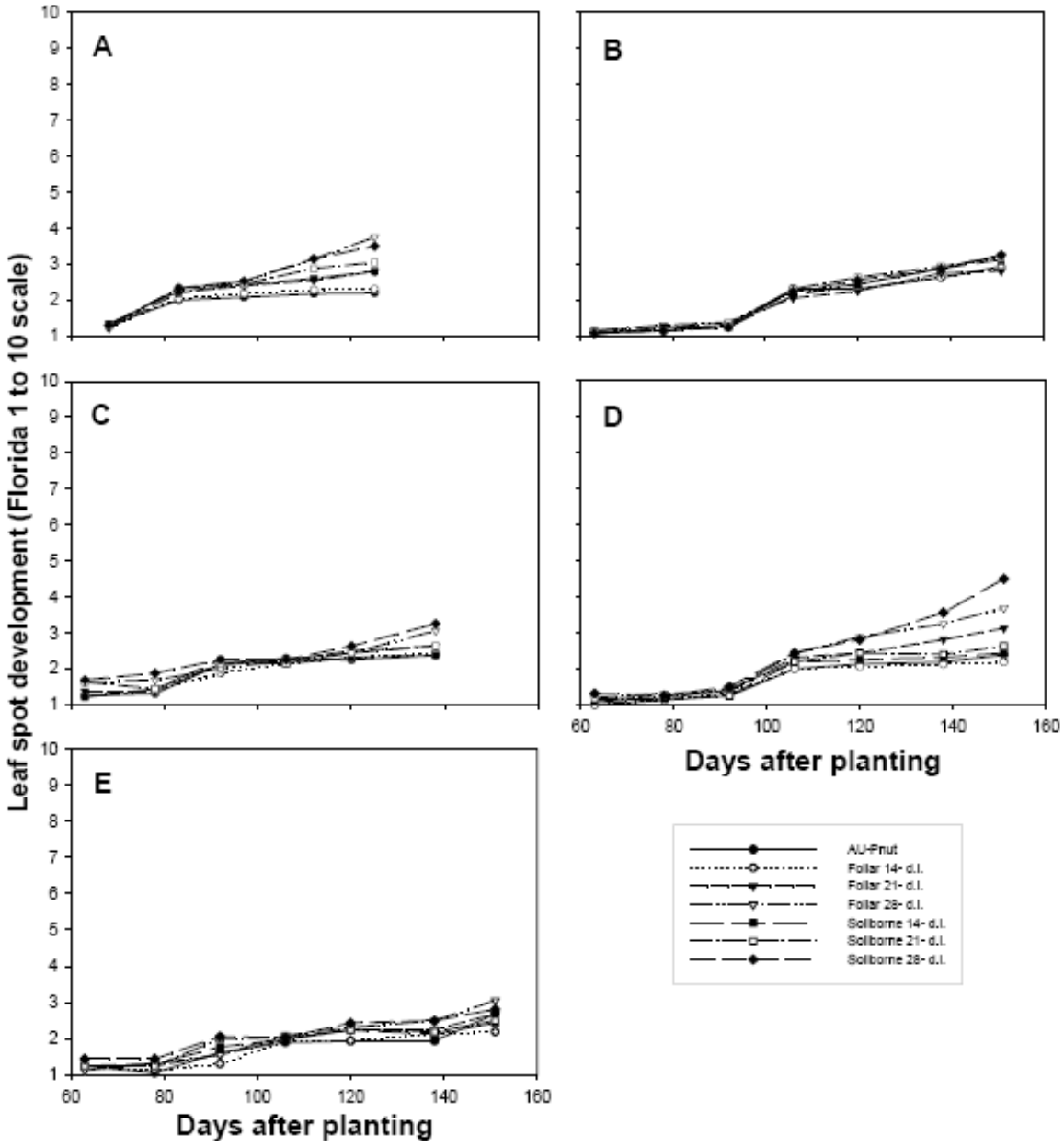

Figure 2.1. Progress of leaf spot epidemics in five trials with varying levels of leaf spot risk under foliar- or soilborne-based fungicide programs applied on 14-, 21-, or 28-day intervals in 2003. Trials A and C were planted to the cultivar Georgia Green, trials B and E to Georgia-01R and trial D to DP-1.

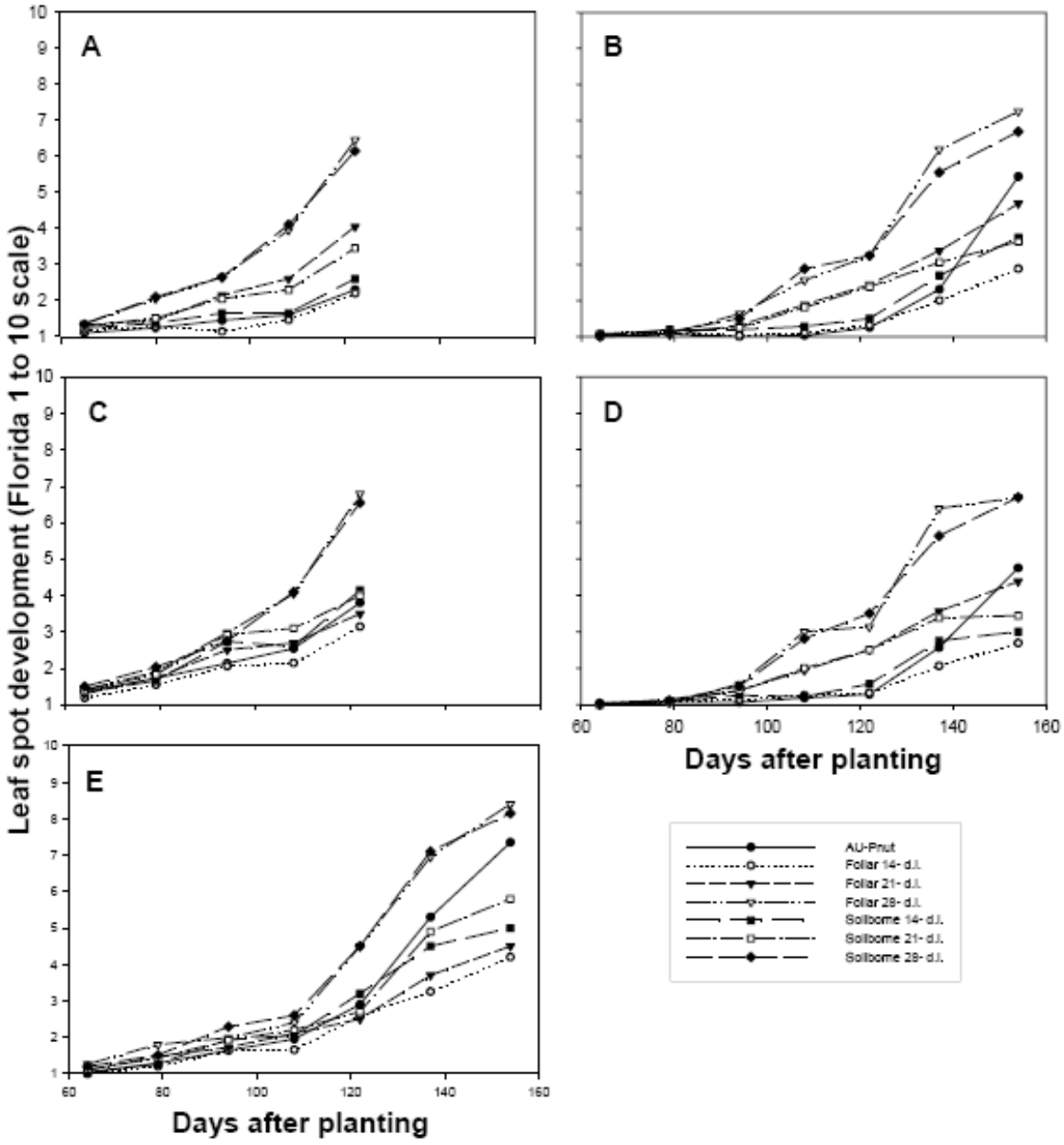

Figure 2.2. Progress of leaf spot epidemics in five trials with varying levels of leaf spot risk under foliar- or soilborne-based fungicide programs applied on 14-, 21-, or 28-day intervals in 2003. Trials A and C were planted to the cultivar Georgia Green, trials B and E to Georgia-01R and trial D to DP-1.

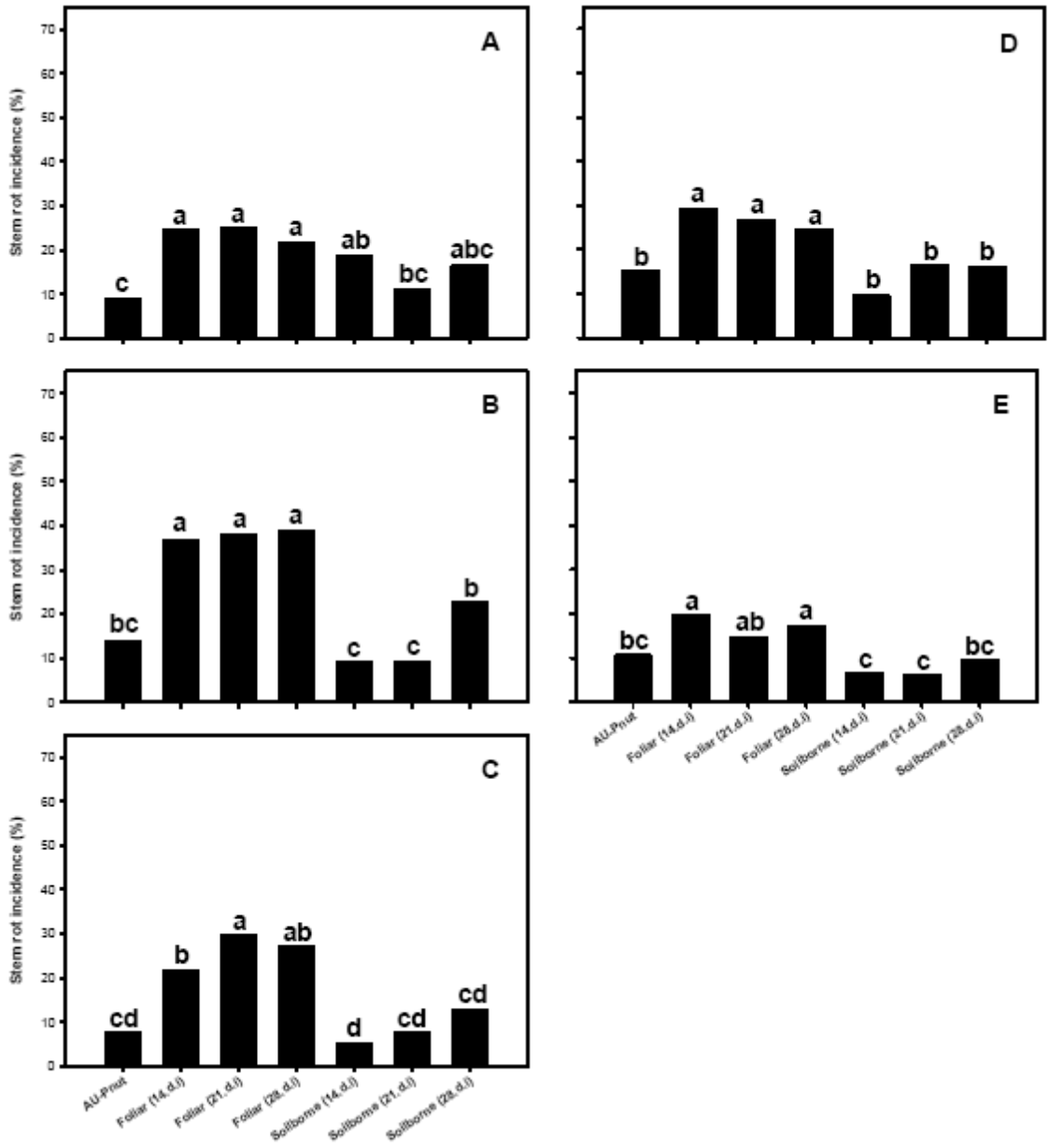

Figure 2.3. Final stem rot incidence in five trials with varying levels of leaf spot risk under foliar- or soilborne-based fungicide programs applied on 14-, 21-, or 28-day intervals in 2003. Trials A and D were planted to the cultivar Georgia Green, trials B and C to Georgia-01R and trial C to DP-1.

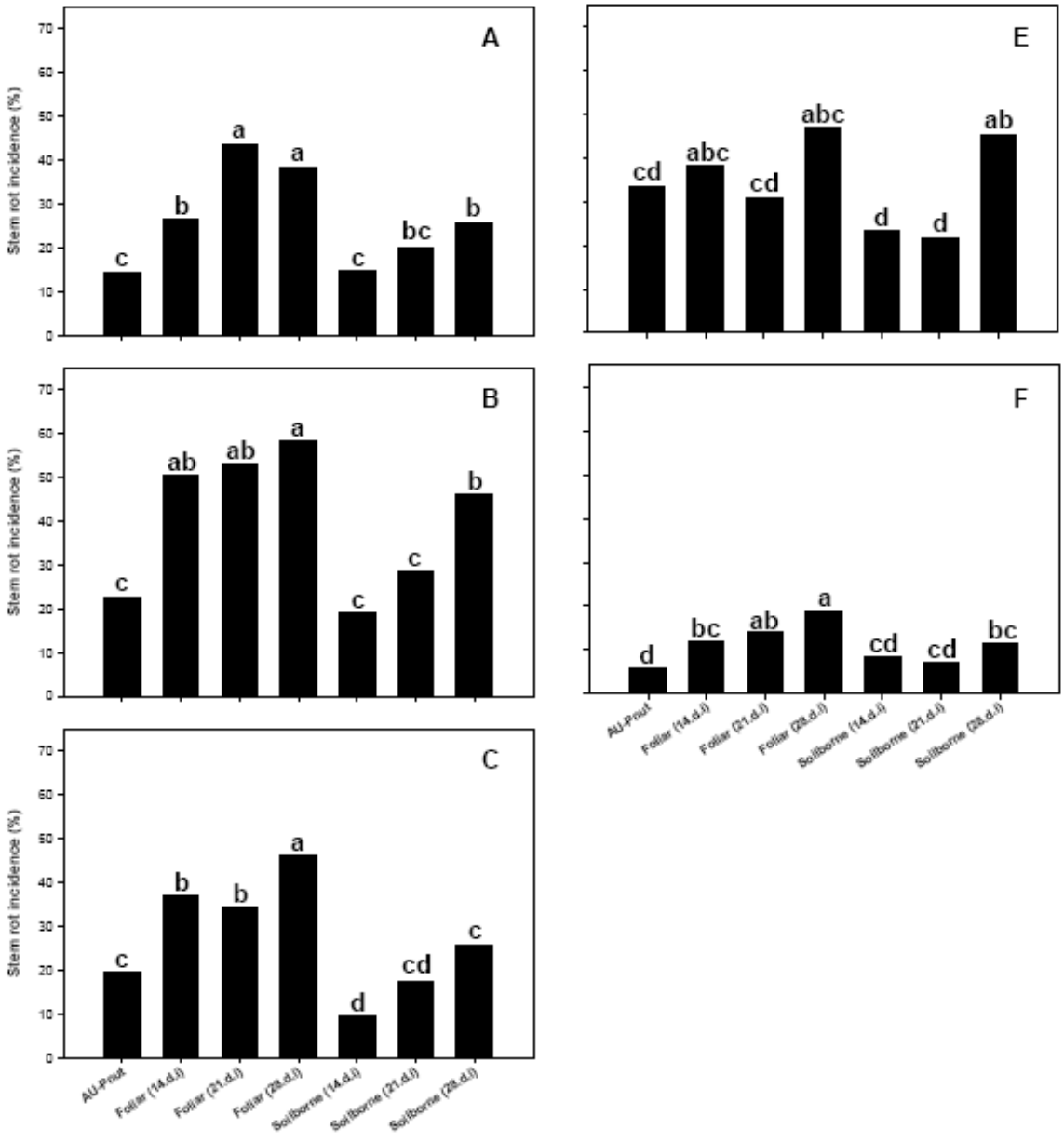

Figure 2.4. Final stem rot incidence in five trials with varying levels of leaf spot risk under foliar- or soilborne-based fungicide programs applied on 14-, 21-, or 28-day intervals in 2004. Trials A and D were planted to the cultivar Georgia Green, trials B and C to Georgia-01R and trial C to DP-1.

CHAPTER 3

USE OF DISEASE RESISTANT CULTIVARS AND REDUCED INPUT FUNGICIDE PROGRAMS TO MANAGE PEANUT DISEASES IN IRRIGATED OR NON-IRRIGATED FIELDS[1]

[1]Woodward, J. E., T. B. Brenneman, R. C. Kemerait, Jr., A. K. Culbreath, K. L. Stevenson and N. B. Smith. 2006. To be submitted to *Plant Disease.*

Abstract

Field experiments were conducted in 2004 and 2005 to evaluate the response of several peanut cultivars to standard and reduced input fungicide programs under production systems, which differed in the duration of crop rotation, disease history within a field, and irrigation. Effects on early leaf spot (*Cercospora arachidicola*), late leaf spot (*Cercosporidium personatum*), and southern stem rot (*Sclerotium rolfsii*), pod yields, and economic returns were assessed. Standard programs were similar for both sets of studies and included applications of pyraclostrobin, tebuconazole, azoxystrobin, and/or chlorothaolnil. The reduced fungicide programs consisted of two or four applications for the rotation and irrigation study, respectively. Two additional programs (a seven spray chlorothalonil, and a non-treated control) were included in the rotation study. All fungicide programs provided adequate levels of leaf spot suppression, and stem rot incidence was similar among fungicide programs within the respective management system. In the rotation study, returns were significantly lower for the reduced program compared to the respective full program and seven spray chlorothalonil program; however, they were significantly higher than the non-treated control. For the irrigation study, pod yields and returns were comparable for the two programs for earlier maturing cultivars, but were significantly lower for the reduced program on later maturing cultivars. Significant differences in leaf spot, stem rot and yield were observed among cultivars in both experiments. Overall, leaf spot intensity was lowest for the cultivars Georgia-03L and Georgia-01R, and greatest for Georgia Green and Georgia-02C. Georiga-03L, Georgia-02C, and AP-3 consistently had lower incidence of stem rot than the other cultivars. Pod yields for all cultivars were equivalent to or greater than Georgia Green in both studies. The performance of reduced fungicide programs were inconsistent;

therefore, additional studies are required to identify which management strategies can be used to aid producers in reducing the number of fungicide applications without impacting yield.

Keywords: groundnut, *Arachis hypogaea* L., fungal diseases, risk index, integrated disease management, partial resistance, economics

INTRODUCTION

Fungal diseases are responsible for economic losses throughout peanut (*Arachis hypogaea* L.) production areas of the southeastern United States. The most important foliar diseases are 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.). Stem rot caused by *Sclerotium rolfsii* Sacc. (teleomorph = *Athellia rolfsii* Tu and Kimbrough) and Rhizoctonia limb rot, caused by *Rhizoctonia solani* Kuhn (telomorph = *Thanotephorus cucumerisis*) are the most important soilborne diseases. These diseases occur annually and if not managed, pod losses can exceed 50% (29, 32, 34). Therefore, frequent fungicide applications are required for disease management.

In the southeastern United States, typical fungicide programs are initiated approximately 30 days after planting (DAP) and subsequent applications are made on a 14-day interval. As a result seven or more applications are made per season (30). The protectant fungicide chlorothalonil has been the industry standard for managing leaf spot since the 1970s (38). Because chlorothalonil is a protectant fungicide, applications must be made prior to infection in order to ensure maximum control. Systemic fungicides such as tebuconazole, an ergosterol biosynthesis inhibitor (EBI), and azoxystrobin, a quinine outside inhibitor (QoI), have some curative activity and provide levels of leaf spot equivalent to or greater than chlorothalonil (3, 5, 13, 24). In addition, these compounds are also highly efficacious against soilborne diseases. The manufacturers of tebuconazole and azoxystrobin currently recommend four and two applications, respectively. Tebuconazole programs are typically comprised of four consecutive applications made on 14-day intervals beginning 58

DAP with remaining treatments being chlorothalonil applications (30). The labeled use pattern for azoxystrobin consists of a total of two applications, which are generally applied 60 and 90 DAP. Reports have indicated that azoxystrobin provides a level of stem rot control similar to that obtained with tebuconazole (24, 25), and it is also active on leaf spot; however, five additional applications of chlorothalonil are typically required for full season leaf spot management (30). Despite the efficacy of tebuconazole and azoxystrobin, recommended programs involving either product require seven applications. Due to escalating production costs and suppressed crop value, reductions in input costs are needed if producers are to remain economically competitive.

Pyraclostrobin is a QoI fungicide that was recently registered for use on peanut. Previous reports indicated that pyraclostrobin provides levels of leaf spot control superior to chlorothalonil applied on similar schedules (13, 14), and that pyraclostrobin applied at 21-day intervals was as effective as chlorothalonil applied at 14-day intervals (14). Because of the superior activity of pyraclostrobin, efforts have been made to integrate this product into programs with reduced numbers of fungicide applications. Culbreath et al. (14) reported that delaying initial applications of pyraclostrobin as late as 60 DAP provided levels of leaf spot control equivalent to that of chlorothalonil or tebuconazole programs initiated at 30 DAP. Such results indicate that pyraclostrobin may be more suitable than chlorothalonil or tebuconazole when applications are late or delayed; however, fungicide resistance issues need to be addressed before such delays are implemented. One recommended fungicide program consists of an initial application of pyraclostrobin (0.17 kg a.i. ha^{-1}) at 45 DAP followed by a second application of a compound with a different mode of action 21 days later. All subsequent applications are made at 14-day intervals (14, 25).

An additional means of reducing the reliance of fungicides in the management of peanut diseases is the use of cultivars with increased disease resistance. The cultivar Georgia Green is the current commercial standard and is planted on approximately 85% of the acreage in Georgia (Smith, *unpublished data*). Currently, breeding programs in the southeast are focusing on developing resistance to *Tomato spotted wilt virus* (TSWV), but are also screening for resistance to leaf spot, Rhizoctonia limb rot, Cylindrocladium black rot (CBR), and stem rot. The cultivars Georgia-01R, Hull and Tifrunner have among the highest levels of leaf spot resistance available (6, 8, 21); whereas, C-99R, AP-3 and Georgia-02C have moderate levels of stem rot resistance (6, 21, 22, 33). With the availability of cultivars with partial resistance to foliar and soilborne diseases, research is needed to evaluate the economic viability of reducing production inputs.

Another factor known to influence fungicide activity and disease pressure is irrigation (16). Approximately 55% of peanut in Georgia are irrigated (Smith, unpublished) and most research is done in well-irrigated plots. There is a need for additional research on disease management and cultivar performance in irrigated versus non-irrigated fields. The first objective of these studies was to evaluate the performance of several commercially available peanut cultivars with different levels of resistance to several diseases under full and reduced fungicide programs. A second objective was to determine the effects of irrigation on disease development, cultivar performance, and fungicide efficacy.

MATERIALS AND METHODS

Rotation studies. This study was initiated in 2004 at the Rigdon Farm and repeated in 2005 at the Lang Farm, both being University of Georgia Costal Plain Experiment Station (UGA-CPES) research sites. The soil type at both locations was a Tifton sandy loam and the

soil pH ranged from 6.0 to 6.4. Both fields were non-irrigated and had a low to moderate leaf spot and stem rot risk according to the University of Georgia Fungal Disease Risk Index (28). The plot area in 2004 had been planted to cotton (*Gossypium hirsutum* L.) for more than 10 years and had no history of peanut production; whereas the field site chosen in 2005 had been part of a cotton-corn (*Zea mays* L.) rotation and had not been planted to peanut within the past 5 years. Fields were prepared for planting using a moldboard plow and a disk harrow. All production practices other than disease control were based on recommendations of the University of Georgia Cooperative Extension Service. Plots were two rows, 7.6 m long planted 0.9 m apart, and seeded at a rate of 28 seeds/m of row. Planting dates were 3 June 2004 and 12 May 2005. Eight commercially available runner type cultivars were evaluated both years of the study (Table 3.1). Cultivars were grouped by maturity (medium or late) as described by Gorbet et al. (22), and arranged in a split-plot design with five and four replications in 2004 and 2005, respectively. Whole plot treatments consisted of fungicide programs, and cultivars served as sub-plots. Broadcast applications of fungicide were made using a CO_2-pressurized backpack sprayer calibrated to deliver a total output of 188 liters ha^{-1} with three TX-6 hollow-cone nozzles (TeeJet Technologies, Springfield, IL) per row.

Four fungicide programs evaluated in these trials included i) a non-treated control, ii) seven applications of chlorothalonil (Bravo Ultrex, Syngenta Crop Protection, Greensboro, NC) at 1.26 kg a.i. ha^{-1}, iii) pyraclostrobin (Headline 2.09 EC, BASF Corp., Research Triangle Park, NC) applied at a rate of 0.16 kg a.i. ha^{-1} followed by four applications of tebuconazole (Folicur 3.6F, Bayer Corp., Kansas City, MO) at 0.23 kg a.i. ha^{-1} and concluding with a single application of chlorothalonil, and iv) pyraclostrobin at 0.22 kg a.i.

ha^{-1} and a single tebuconazole application. Details of specific timings of applications are given in Table 3.2.

Irrigation experiment. This experiment was conducted in 2004 and 2005 at the UGA-CPES Black Shank research farm in a field of Tifton loamy sand (fine-loamy, siliceous, thermic Plinthic Kandiudults, pH 6.0). The field was irrigated with solid-set riser sprinklers that were designed to provide replicated irrigated and non-irrigated blocks. Irrigation was applied as needed to maximize peanut growth, and ensure conducive environmental conditions for leaf spot development. The field site had been in continuous peanut production over the past 15 years, and was prepared and managed as described previously. Plots were two rows, 6.1 m long 0.9 m apart and planted on 25 May 2004 and 21 May 2005. Six cultivars (Georgia Green, Georgia-02C, Georgia-03L, Georgia-01R, Hull, and Tifrunner) were evaluated in this trial, and represented different maturity groups. Cultivars were grouped by maturity as described by Gorbet et al. (22). Plots were arranged in a split-split-plot design with five replications. Fungicide programs served as whole plots, irrigation as sub-plots, and cultivar as sub-sub-plots. Two fungicide programs, designated full- and reduced-input, were evaluated in this experiment. Broadcast applications were applied as described above. The application schedule for the standard program was similar to the standard pyraclostrobin-four-block-tebuconazole program listed above, except that 0.34 kg a.i. ha^{-1} of azoxystrobin (Abound 2.08SC, Syngenta, Crop Protection, Greensboro, NC) replaced the final tebuconazole application. The reduced-input program was derived from this program and consisted of four applications, pyraclostrobin applied 40 DAP, tebuconazole applications were made 61 and 82 DAP, and a single application of azoxystrobin replaced the final tebuconazole application (Table 3.2).

Disease assessment. Early and late leaf spot were assessed for each plot using the Florida 1 to 10 scale, a disease index where 1 = no disease and 10 = plants completely defoliated and killed by leaf spot (9). Values 1 through 4 on the scale reflect increasing incidence of leaf spot in the lower to upper canopy, and values 5 through 10 estimate increasing levels of defoliation (9). Disease was assessed at the onset of epidemics and subsequent assessments were made every 14 to 21 days until harvest. Leaf spot assessments were used to calculate the area under disease progress curve (AUDPC) for each plot (36). To account for differences in the duration of leaf spot epidemics between cultivars, AUDPC values were standardized (stAUDPC) by dividing by the duration of the epidemic in days. Spotted wilt intensity was evaluated once at 75 to 90 DAP as described by Culbreath et al. (10), and converted to a percentage of row length.

Plots were dug and inverted based on pod maturity using the hull scrape method described by Williams (42). Incidence of stem rot was estimated immediately after plants were inverted by determining the number of disease loci per plot (<30 cm per locus) exhibiting stem rot symptoms and/or signs of *S. rolfsii* (35). The number of disease loci within a plot was converted to a percentage of total row length for comparison of treatments.

Pod yield, quality and economic returns. Pod yields were determined for each plot by weighing harvested pods after they were dried, and adjusted to 10% moisture (wt/wt). A 500-g sub-sample of pods was collected from each plot and graded according to the 2005 Federal Inspection Service (39). The dollar values of pod yields were determined for each plot based on the percentages of foreign material (%FM), total sound mature kernels (%TSMK), damaged kernels (%DK), and other kernels (%OK) using the 2005 USDA loan price schedules (40, 41). Crop values were calculated for each plot based on the 2004 pod

price schedule where dollars/metric to = (((%TSMK × $5.02) + (%OK × $1.57)) – ((%FM – 4) × $1.12) – (%DK deduction)). Deductions of $0.00, $3.80, and $7.60/metric ton were assessed for DK percentages of ≤ 2, ≤ 3, and ≤ 4, respectively (41).

Variable costs, including machinery use, were based on University of Georgia enterprise budgets (37) and an estimated fuel price of $2.25 gal^{-1} and a labor wage of $9.05 $hour^{-1}$. Adjustments were made to account for differences in seed and fungicide costs. Seed costs were estimated as described by Cantonwine et al. (8), and the seed weight was determined for each cultivar using a 3 year average (2003-2005) of irrigated trials conducted by the University of Georgia State Wide Variety Testing Program (17-19). Fungicide costs were estimated based on prices obtained from a survey of pesticide distributors located throughout the state (Table 3.2). Additional adjustments were made to account for energy costs required to apply irrigation. The economic analysis was conducted using a budgeting technique consistent with University of Georgia Cooperative Extension cost enterprise budgets. A plot generator spreadsheet tool (developed by N.R. Martin, Auburn University) was modified to run cost and returns for each plot. Economic returns, defined as the income above variable cost (IAVC), were calculated as the difference between variable costs and the estimated crop value based on $398/metric ton and adjusted for grade according to the 2005 Crop Peanut Loan Rates (40, 41).

Statistical analysis. Data were analyzed using Proc MIXED (SAS v.9.1; SAS Institute, Cary, NC) with the ddfm=satterthwaite option in the model statement and treatment comparisons based on LSMEANS with the pdiff option. Because leaf spot intensity values were based on ordinal-categorical data, ranked analyses were used to equalize variances. For leaf spot intensity and stAUDPC data, Proc RANK was used to assign ranks using midrank

for any ties and Proc MIXED was used to analyze the rank-transformed data from the Rotation and Irrigation studies. For the Rotation study, fixed effects included Fungicide Program [FP], Cultivar [C] and FP x C interaction; while random effects included Year [Y], Replication [R(Y)], and R x FP(Y). For the Irrigation study, fixed effects included Fungicide Program [FP], Irrigation [I], Cultivar [C], FP x I, FP x C, I x C, and FP x I x C; while random effects included Year [Y], Replication [R(Y)], R x FP(Y), and R x I(Y I). Fixed effects were considered significant at the P=0.05 unless otherwise stated. Treatment means were compared using the Pdiff option in the LSMEANS statement of Proc MIXED, and least significant difference (LSD) values were calculated using the standard errors and t-values representing the adjusted degrees of freedom. When interactions were significant, the LSD for main effects was further adjusted by including the interaction in the random statement as suggested by Fisher (1990) and elaborated by Cantonwine et al. (8).

RESULTS

Rotation studies. Leaf spot epidemics were severe and late leaf spot was the predominant leaf spot disease at harvest in both years of this study. Epidemics were significantly different among cultivars and fungicide programs (Figure 3.1 and Table 3.3). Overall, stAUDPC values were lower for the late-maturing cultivars (Georgia-01R, Hull, and Tifrunner) when compared to the mid-maturing cultivars (Georgia Green, Georgia-03L, and AP-3). For each cultivar, all fungicide programs significantly reduced the stAUDPC compared to the corresponding non-treated control. There were no significant differences between the standard leaf spot program and the full-input pyraclostrobin program, but the reduced-input pyraclostrobin program had significantly higher stAUDPC values than the either of them.

Spotted wilt incidence was low in 2004, but high in 2005, and differences in cultivar response to spotted wilt were significant (Table 3.3). Spotted wilt incidence ranged from 10.8 to 34.2%. Disease incidence was greatest for Georgia Green, Hull and C-99R and lowest for AP-3, Georgia-03L and Georgia-02C. Disease incidence was intermediate for Tifrunner and Georgia-01R. There were no significant differences in spotted wilt incidence among fungicide programs.

Fungicide and cultivar main effects, as well as the fungicide × cultivar interaction, were significant for stem rot; therefore cultivars were compared within each fungicide program (Figure 3.2). Disease severity was generally lowest in plots that received the full-input program, and highest in the non-treated plots, and some general patterns of cultivar susceptibility were observed. Final incidence of stem rot was highest for Tifrunner and lowest for Georgia-03L, Georgia-02C, and AP-3. Overall, the late-maturing cultivars and Georgia Green responded better to the standard pyraclostrobin program than the reduced program; whereas, Georgia-02C, Georgia-03L and AP-3 responded similarly to the two programs. In general, stem rot incidence was lower when fungicides, including the standard leaf spot program, were applied. The mean final disease incidence across cultivars was 32.4, 19.3, 14.1 and 21.8% for the non-treated, the standard leaf spot, and the full- and reduced-input pyraclostrobin programs, respectively (Figure 3.2).

Pod yields of all other cultivars were equivalent to or greater than yields for Georgia Green, the current industry standard (Table 3.4). The cultivar AP-3 had the highest yields followed by Georgia-01R, C-99R and Georgia-03L, respectively. Yields were significantly higher in plots that received fungicide treatments, compared to the non-treated controls (Table 3.4). The standard leaf spot and full-input pyraclostrobin programs resulted in the

highest yields; whereas, pod yields for the reduced-input pyraclostrobin program were intermediate. Few differences in pod quality were observed among cultivars. AP-3 and Georgia-03L had the lowest pod quality, whereas, C-99R, Georgia Green, Georgia-02C, and Georgia-01R were among the cultivars with the highest quality (Table 3.4). There was no significant fungicide effect on pod quality. Overall, the mean percent immature kernels ranged from 9.5 to 17.6%, and the mean percent foreign material and damaged kernels were below deduction thresholds (data not shown).

Fungicide program costs were estimated to be \$0 ha^{-1}, \$135.33 ha^{-1}, \$193.09 ha^{-1} and \$81.33 ha^{-1} for the non-treated control, leaf spot, full-input, and reduced-input program, respectively. Seed costs ranged from \$125.03 ha^{-1} for Georgia Green to \$151.76 ha^{-1} for C-99R (Table 3.1). Cultivar and fungicide program had significant effects on economic returns (Table 3.4). Mean returns ranged from \$837 for AP-3 to \$493 ha^{-1} for Tifrunner. All other cultivars except Georgia-01R had returns equivalent to Tifrunner. The application of fungicides resulted in significantly greater returns compared to the non-treated control; however, returns for the reduced-input program were significantly less than the leaf spot or full-input program for all cultivars.

Irrigation studies. Stem rot epidemics were similar both years of the study and were quite severe at harvest. Disease incidence ranged from 19.8 to 68.0%. Due to a significant fungicide × cultivar interaction on stem rot incidence, stem rot data were analyzed independently. Stem rot epidemics were similar both years of the study and were quite severe at harvest. Significant differences in disease development were observed between cultivars, but not fungicide programs (Table 3.5). Incidence of stem rot was greatest for the cultivars Georgia Green and Tifrunner, lowest for the cultivars Georgia-03L and Georgia-

02C, and intermediate for Georgia-01R and Hull. Stem rot incidence was numerically greater for the reduced-input programs; however, the differences were not statistically significant.

There were no significant interaction effects between fungicide programs and cultivar on leaf spot intensity, spotted wilt incidence, pod yield, grade or economic returns; therefore, only main effects are presented in Table 3.5. Of the main effects tested, only cultivar had a significant effect on stAUDPC. Early leaf spot was the predominant foliar disease throughout each of the growing seasons; however, late leaf spot became more prevalent at harvest both years. The stAUDPC values were similar for the three mid-maturing varieties, and values for Georgia-03L did not differ from Georgia-01R, Hull, or Tifrunner. In addition, only cultivar had a significant effect on spotted wilt incidence. Spotted wilt was more severe in 2004 than in 2005; however, cultivar effects were similar both years. Disease incidence was lowest for Tifrunner, Georgia-03L and Georgia-02C, and greatest for Georgia Green, Georgia-01R and Hull. Cultivar, fungicide, and irrigation treatments had no significant effect on pod quality. The mean percentages of TSMK, immature kernels, and percent foreign material, were 72.2, 2.7, 2.8, and 0.8, respectively.

Due to a significant fungicide × cultivar interaction on economic returns, differences among cultivars and fungicide programs were evaluated separately within each level of the other factor (Table 3.7). The cost of the full-input program was \$230.60 ha^{-1} compared to \$176.57 ha^{-1} for the reduced-input program (Table 3.2). For the full-input program, returns were greatest for the cultivars Tifrunner, Georgia-03L, and Georgia-01R. Likewise returns for the reduced-input program were greatest for Georgia-03L; however, Tifrunner, Hull, and Georgia-01R did not perform as well under the reduced-input program. The number of

irrigation events varied by year. A total of five applications were made in 2004 and nine applications in 2005. Based on current energy prices, the estimated cost associated with each irrigation event was \$19.41 ha^{-1}, resulting in costs of \$97.04 ha^{-1} and \$174.67 ha^{-1} for 2004 and 2005, respectively. Therefore, a significant difference in economic returns of \$35.39 ha^{-1} was observed for non-irrigated plots compared to irrigated plots (Figure 3.3).

DISCUSSION

The availability of peanut cultivars with moderate levels of disease resistance has made it possible to manage diseases with reduced fungicide inputs (1, 5, 8, 14, 23, 33), which can potentially reduce costs and increase profits for producers. In addition, fungicide programs containing pyraclostrobin have been shown to provide levels of leaf spot control superior to that of chlorothalonil (13, 14, 25, 26), and delaying initial applications of pyraclostrobin until 44 and 58 DAP provides levels of leaf spot control similar to chlorothalonil or tebuconazole applied 30 DAP (14). The flexibility of delaying initial applications of pyraclostrobin without compromising leaf spot control allows producers to reduce the number of fungicide applications and associated costs. However; the risk of resistance to strobilurin fungicides must be considered. Current guidelines for use of QoI fungicides in peanut discourage curative applications, and limit growers to two applications per season (7). Previous problems with resistance to both benzimidazole, and sterol biosynthesis inhibitors (SBI) fungicides in peanut have already been reported (12, 14, 15).

Leaf spot levels differed between the standard- and reduced-input programs in the rotation studies, but not the irrigation studies. This was unexpected based on rotational and cropping histories of the locations. Based on the University of Georgia Fungal Disease Risk Index (28), disease risk was determined to be low to moderate for the rotation studies;

whereas, the irrigation studies were deemed as high risk. One explanation in the performance in the reduced programs in the rotation study could be attributed to SBI insensitive isolates at the locations where the rotation studies were conducted. SBI insensitive isolates of both leaf spot pathogens were recovered from the rotation study in 2005 (Stevenson unpublished data). The reduced control of leaf spot in these studies did affect yield, and as a result economic returns were impacted. However, the reduced program proved to be valuable in managing diseases, when compared to the non-treated control.

Results from these studies corroborate previous reports that the cultivars evaluated have yields that are equivalent to or greater than yields for Georgia Green (8, 17-19, 21, 22, 33). Increased yields could be attributed to the yield potential of each cultivar or increased levels of spotted wilt, leaf spot, or stem rot resistance. In both the rotation and the irrigation studies, yields were highest for the cultivars with increased stem rot resistance. Yields were similar across the two maturity groups (data not shown). Mid-maturing cultivars with the highest yield were AP-3 and Georgia-03L from rotation and irrigation studies respectively; whereas Georgia-01R had the highest yields for the late-maturing cultivars in both studies. The use of cultivars with increased disease resistance will play an important role when implementing reduced-input fungicide programs.

Although pyraclostrobin is labeled for control of stem rot, reports of the effects of pyraclostrobin use are inconclusive (14, 24). When determining which fungicides to use in a regime, considerations for stem rot control are critical. Other studies have shown that programs containing fungicides with activity against soilborne diseases provide significantly higher yields than foliar-based programs (3-5,25, 26). However, the majority of those studies were conducted using moderately susceptible cultivars in fields with high soilborne disease

pressure. Reduced-input foliar-based programs were not evaluated in these studies. Such programs would not be warranted in fields with continuous peanut and a history of disease, as was the case for the field where the irrigation studies were conducted (28), but may be appropriate in fields deemed as having reduced risk, as was the case in the rotation study. In that study, a full season chlorothalonil program was also evaluated, because of the low risk of stem rot (28). The seven-spray foliar program provided sufficient control of leaf spot and, is relatively inexpensive, compared to applications of used for soilborne disease control; therefore, the leaf spot program also provided the highest economic returns. Additional studies evaluating reduced-input chlorothalonil programs may be needed to elucidate which programs will allow producers to maximize profits when using stem rot resistant cultivars in low risk fields.

Precipitation is also an important factor in maximizing yields (16), and one would expect to have increased yields in fields receiving irrigation. However, that was not the case for the irrigation study. Economic returns were significantly higher for non-irrigated plots compared to irrigated plots. These trends are somewhat atypical, and can be explained by rainfall that were substantially higher than the 10 year average for the region (27) in 2004, and early during the 2005 season; however, drought conditions were experienced toward the latter part 2005. Despite adequate rainfall throughout most of this study, irrigation was administered to encourage disease development. Levels of leaf spot and stem rot, as well as yield, were similar in irrigated plots compared to non-irrigated plots.

The cultivars evaluated in the irrigation study performed similarly as in the rotation study with respect to disease susceptibility. No significant differences in economic returns were found between the two programs when analyzed across all cultivars; however, returns

for the reduced program for cultivars deemed as being resistant to stem rot were closer to returns obtained from using the full-input program. Returns were significantly lower for the later maturing cultivars evaluated in this study. This decrease in economic returns could be related to the duration of leaf spot and stem rot epidemics. Fungicide programs were initiated at the same time for all cultivars; however, the late-maturing cultivars remained in the field approximately four weeks without receiving any additional fungicide applications. Despite improved levels of resistance for Georgia-01R and Hull, final leaf spot and stem rot levels were substantially higher than the final assessments of the mid-maturing cultivars. This trend was most evident for Tifrunner, which is susceptible to stem rot infection (28), and studies evaluating the initiation of spray programs for later maturing cultivars are needed.

Although current recommendations do not advise producers to plant peanuts in consecutive seasons, results from this study indicate that cultivars with increased stem rot resistance can be used in conjunction with reduced-input fungicide programs to maximize profits. Results from the irrigation study in particular lend credence to the use of reduced-input fungicide programs in conjunction with disease resistant cultivars. Additional study of reduced-input fungicide programs are warranted; as is the evaluation of fungicide tank-mixes to prolong combat fungicide resistance issues; thus prolonging the use of products currently available.

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Table 3.1. Disease resistance, seed count and costs of seed of medium and late maturing peanut cultivars used in studies evaluating reduced-input fungicide programs.

Maturity group[x]	Resistance level[y]		Count	Cost
Cultivar	Leaf spot	Stem rot	(Seed kg^{-1})	($ ha^{-1})[z]
Medium				
Georgia Green	+	+	1972	124.81
Georgia-02C	+/-	-	1794	137.24
Georgia-03L	+/-	-	1628	151.23
AP-3	+	-	1767	139.33
Late				
Georgia-01R	-	+/-	1628	151.19
C-99R	+/-	+/-	1625	151.51
Hull	-	+/-	1677	146.79
Tifrunner	-	+	1727	142.57

[x] Approximate days from planting to maturity for medium and late maturity groups were 135-140 and 155-160, respectively.

[y] Disease resistance levels are based on the University of Georgia Fungal Disease Risk Index (28). Cultivars which exhibit a susceptible, resistant, or intermediate reaction to leaf spot or stem rot are denoted with a +, -, or +/-, respectively.

[z] Total seed costs were determined using methods described by Cantonwine et al. (8), using an average cost of \$1.15 kg^{-1} and seeding rates of 109, 120, 132, 122, 132, 133, 128, 125 kg ha^{-1} for Georgia Green, Georgia-02C, Georgia-03L, AP-3, Georgia-01R, C-99R, Hull, and Tifrunner, respectively.

Table 3.2. Characteristics and costs of full- and reduced-input fungicide programs for peanut disease control in two field studies

Studies	Program	Fungicide	Formulation[w]	Rate[x]	Schedule[y]	Cost ($ ha^{-1})[z]
Rotation	Control	None	. . . .	. . . .	. . . .	. . . .
	Leaf spot	Chlorothalonil	Bravo Ultrex 82.5WDG	1.26	1 - 7	135.31
	Full-input	Pyraclostrobin	Headline 2.09EC	0.16	1.5	193.11
		Tebuconazole	Folicur 3.6F	0.23	3 - 6	
		Chlorothalonil	Bravo Ultrex 82.5WDG	1.26	7	
	Reduced-input	Pyraclostrobin	Headline 2.09EC	0.22	3	81.34
		Tebuconazole	Folicur 3.6F	0.23	5	
Irrigation	Full-input	Pyraclostrobin	Headline 2.09EC	0.16	1.5	230.60
		Tebuconazole	Folicur 3.6F	0.23	3 - 5	
		Azoxystrobin	Abound 2.08F	0.34	6	
		Chlorothalonil	Bravo Ultrex 82.5WDG	1.26	7	
	Reduced-input	Pyraclostrobin	Headline 2.09EC	0.16	1.5	176.57
		Tebuconazole	Folicur 3.6F	0.23	3 & 4.5	
		Azoxystrobin	Abound 2.08F	0.34	6	

[w] Percentage of a.i. in products formulated as water dispersed granules (WDG), emulsifiable concentrates (EC), or flowables (F).

[x] Fungicide application rate in kg a.i. ha^{-1}.

[y] Represents sprays in a standard seven-spray schedule (ie. there is one week between 1 and 1.5 and two weeks between 1 and 2).

[z] Fungicide program costs were based on results from a regional survey: chlorothalonil ($19.33 ha^{-1}); tebuconazole ($34.70 ha^{-1}); azoxystrobin ($72.19 ha^{-1}); and pyraclostrobin ($34.98 and $46.64 ha^{-1}, for the 0.17 and 0.25 kg a.i. rates, respectively).

Table 3.3. Effect of peanut cultivar and fungicide program on leaf spot development and spotted wilt incidence (rotation studies).

Treatment	Leaf spot stAUDPC[x]	Spotted wilt % Incidence[y]
Cultivar		
Georgia Green	3.38 ab[z]	34.2 a
Georgia-02C	3.43 a	15.4 bc
Georgia-03L	2.58 b	11.6 c
AP-3	2.76 ab	10.8 c
Georgia-01R	2.87 ab	22.7 abc
C-99R	3.05 a	30.7 ab
Hull	2.93 ab	30.0 ab
Tifrunner	3.17 ab	17.2 abc
Fungicide program		
Non-treated control	4.26 a	19.3 a
Leaf spot	2.17 c	23.0 a
Full-input	2.56 c	21.2 a
Reduced-input	3.09 b	22.9 a

[x] Least square means from Proc MIXED of AUDPC using Florida 1-10 leaf spot intensity ratings (9). Values were standardized by dividing by the (number of days) of the epidemic.

[y] Least square means from Proc MIXED of percent of linear row affected by spotted wilt.

[z] Fishers least significant difference (LSD) values were calculated using the standard errors and t-values representing the adjusted degrees of freedom from the pairwise comparison of least square means. Means followed by the same letter are not significantly different at the P=0.05 level.

Table 3.4. Effect of peanut cultivar and fungicide program on peanut yield, quality and economic return

Treatment	Pod yield[w] (kg ha^{-1})	Pod quality[x] (%TSMK)	Return[y] ($ ha^{-1})
Cultivar			
Georgia Green	3389 b[z]	70.6 a	539 bcd
Georgia-02C	3768 ab	71.5 a	550 bcd
Georgia-03L	3817 ab	68.3 c	544 bcd
AP-3	4485 a	67.5 c	837 a
Georgia-01R	4251 ab	72.2 a	690 bc
C-99R	4027 ab	71.9 a	668 bcd
Hull	3628 ab	69.0 bc	562 bcd
Tifrunner	3742 ab	70.8 ab	493 d
Fungicide program			
Non-treated control	3132 b	70.5 a	337 c
Leaf spot	4361 a	70.2 a	821 a
Full-input	4368 a	69.8 a	785 a
Reduced-input	3694 ab	70.5 a	498 b

[w] Least square means from Proc MIXED of estimated weights of peanut pods per hectare after dried to 10% moisture (wt/wt).

[x] Least square means from Proc MIXED of percent yield weight of total sound mature kernels.

[y] Least square means from Proc MIXED of estimated crop value. Means represent the income above variable cost (IAVC) and were calculated using the 2005 peanut pod price schedule minus variable cost of production.

[z] Fishers least significant difference (LSD) values were calculated using the standard errors and t-values representing the adjusted degrees of freedom from the pairwise comparison of least square means. Means followed by the same letter are not significantly different at the P=0.05 level.

Table 3.5. Effect of peanut cultivar and fungicide program on stem rot incidence across irrigation treatments

	Stem rot incidence (%)[w,x]		
Cultivar	Full-input	Reduced-input	Cultivar means
Georgia Green	58.8 a[y] A[z]	67.4 a A	63.1 a
Georgia-02C	26.1 bc A	36.4 bc A	31.3 c
Georgia-03L	19.8 c A	27.3 c A	23.4 c
Georgia-01R	24.9 bc A	41.6 abc A	33.3 bc
Hull	37.1 abc A	57.3 ab A	47.2 abc
Tifrunner	50.9 ab A	68.0 a A	59.4 ab
Program means	36.3 A	49.6 A	

[w] Least square means from Proc MIXED of percent of 30.5-cm row segments showing signs or symptoms of *S. rolfsii* infection (35).

[x] Least significant difference (LSD) was calculated using the standard errors from the PDIFF option in Proc MIXED and t-values from the Satterthwaite adjusted degrees of freedom from the pairwise comparison of least square means (also in PDIFF option).

[y] Means followed by the same lower-case letter within a column are not significantly different at the P=0.05 level.

[z] Means followed by the same upper-case letter within a row are not significantly different at the P=0.05 level.

Table 3.6. Effect of peanut cultivar, fungicide program and irrigation on leaf spot development, spotted wilt incidence, peanut yield, and quality

Effect	Leaf spot stAUDPC[v]	Spotted wilt % Incidence[w]	Pod yield (kg ha^{-1})[x]	Pod qualit (%TSMK)[y]
Cultivar				
Georgia Green	1.97 a[z]	28.9 a	4313 bc	73.2 a
Georgia-02C	1.87 a	17.8 bc	4785 ab	72.7 a
Georgia-03L	1.61 ab	16.3 c	5197 a	71.1 a
Georgia-01R	1.43 b	24.5 abc	4661 bc	72.7 a
Hull	1.51 b	28.4 ab	3942 c	71.7 a
Tifrunner	1.71 ab	14.6 c	4549 abc	72.0 a
Fungicide program				
Full-input	1.47 a	20.9 a	4967 a	72.0 a
Reduced-input	1.90 a	22.5 a	4174 a	72.5 a
Irrigation				
Irrigated	1.81 a	23.1 a	4473 a	72.4 a
Non-irrigated	1.55 a	20.3 a	4669 a	72.1 a

[v] Least square means from Proc MIXED of AUDPC using Florida 1-10 leaf spot intensity ratings (9). Epidemics were standardized by dividing by the (number of days) of the epidemic.
[w] Least square means from Proc MIXED of percent of linear row affected by spotted wilt.
[x] Least square means from Proc MIXED of estimated weights of peanut pods per hectare after dried to 10% moisture (wt/wt).
[y] Least square means from Proc MIXED of percent yield weight of total sound mature kernels.
[z] Least significant differences (LSD) were calculated using the standard errors and t-values from the adjusted degrees of freedom from the pairwise comparison of LSMEANS. Means followed by the same letter are not significantly different at the P=0.05 level.

Table 3.7. Effect of peanut cultivar × fungicide program interaction on economic returns across irrigation treatments

	IAVC ($ ha^{-1})[w,x]		
Cultivar	Full-input	Reduced-input	Cultivar means
Georgia Green	187 bc[y] A[z]	135 bc A	161 ab
Georgia-02C	223 abc A	214 a A	221 ab
Georgia-03L	235 ab A	244 a A	240 a
Georgia-01R	240 ab A	149 b B	194 ab
Hull	174 c A	39 d B	106 b
Tifrunner	271 a A	92 cd B	182 ab
Program means	222 A	146 A	

[w] Least square means from Proc MIXED of estimated crop value. Means represent the income above variable cost (IAVC), and were calculated using the 2005 peanut pod price schedule minus variable cost of production.

[x] Least significant difference (LSD) was calculated using the standard errors from the PDIFF option in Proc MIXED, and t-values from the Satterthwaite adjusted degrees of freedom from the pairwise comparison of least square means (also in PDIFF option).

[y] Means followed by the same lower-case letter within a column are not significantly different at the P=0.05 level.

[z] Means followed by the same upper-case letter within a row are not significantly different at the P=0.05 level.

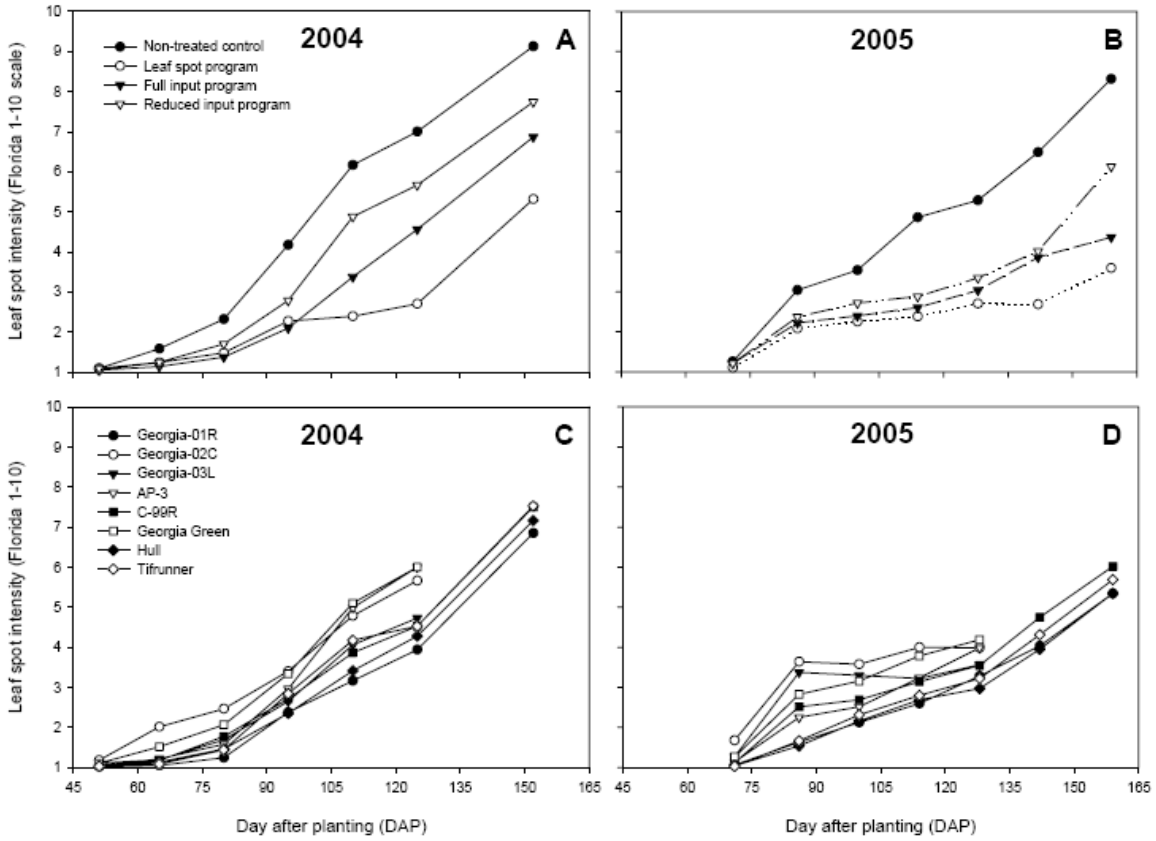

Figure 3.1. Leaf spot development over time for four fungicide programs (A and B), and eight peanut cultivars (B and C) for the 2004 and 2005 growing season in the rotation study.

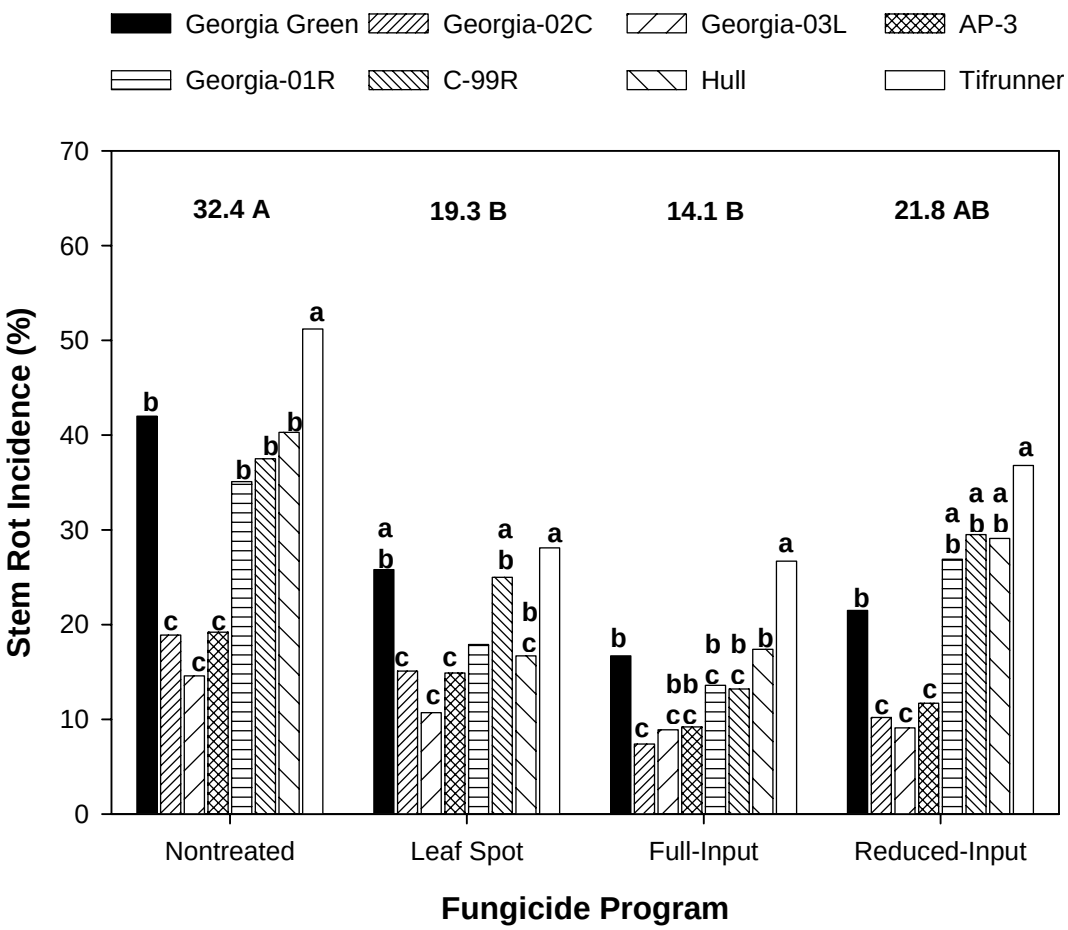

Figure 3.2. Effect of peanut cultivar and fungicide program interaction on stem rot incidence (35) across two years. Fisher's least significant difference (LSD) values were calculated using the standard errors and t-values representing the adjusted degrees of freedom from the pairwise comparison of least square means. Means represented by mars, marked with the same lower-case letter are not significantly different within a fungicide program; whereas, means at the top of the graph followed by the same upper-case letter indicate there are no significant differences between fungicide programs. References to significance are at the *P*=0.05 level. (Refer to footnote x on Table 3.7 for the determination of means separation letters shown above).

CHAPTER 4

LARGE PLOT EVALUATIONS OF REDUCED INPUT FUNGICIDE PROGRAMS IN PEANUT FIELDS WITH VARYING LEVELS OF DISEASE RISK[1]

[1] Woodward, J. E., T.B. Brenneman, R.C. Kemerait, Jr., A.K. Culbreath, K.L. Stevenson and N.B. Smith. 2006. To be submitted to *Peanut Science*.

Abstract

In 2003, 2004, and 2005 standard and reduced input fungicide programs were evaluated in fourteen trials throughout the peanut production region of Georgia for control of peanut leaf spot (*Cercospora arachidicola* and *Cercosporidium personatum*), and southern stem rot (*Sclerotium rolfsii*). Additional studies were conducted in 2004 and 2005 to evaluate the performance of eight peanut cultivars to a seven, three, and zero spray fungicide programs. Six to eight fungicide applications were made in the standard programs; whereas, the number of applications in the reduced programs ranged from three to six. Leaf spot intensity was significantly higher for the reduced programs in five of the fourteen trials; however, control levels were generally within commercial standards. Stem rot control for the reduced programs was equal to or better than that for the standard program in all trials. Pod yields for the reduced programs were equal to or greater than the standard programs in all but one trial. Returns were significantly higher for the reduced programs in seven of the fourteen trials; however, the reduced program resulted in significantly lower yields and returns in one trial in 2004. For the cultivar study, significant differences in leaf spot, stem rot, yield, and return were observed among cultivars. Leaf spot intensity was lowest for Georgia-01R and Hull and highest for AP-3 and Georgia Green. Stem rot incidence was consistently lower for Georgia-03L, Georgia-02C, and AP-3 compared to all other cultivars. Pod yields and economic returns were greatest for Georgia-03L, Georgia-01R, Georgia-02C, and C-99R. Results from these studies indicate that reduced input fungicide programs can be used to adequately manage fungal diseases of peanut without compromising yield or profitability, and that the use of cultivars with moderate levels of disease resistance will may enhance disease control.

Keywords: *Arachis hypogaea* L., extended intervals, integrated disease management, partial resistance, fungal disease risk, risk index.

INTRODUCTION

Peanut (*Arachis hypogaea* L.) is one of the most economically important crops in the southeastern United States with a farm gate value of approximately $835 million (USDA-NASS, 2005). To ensure profitable returns, producers rely heavily on fungicides to manage a variety of damaging fungal diseases that are made more severe by the warm temperatures and ample precipitation in the region. Early and late leaf spot, caused by *Cercospora arachidichola* Hori and *Cercosporidium personatum* (Burk. & Curt.) Deighton, respectively, are the primary foliar diseases, whereas stem rot and limb rot, caused by *Sclerotium rolfsii* Sacc. and *Rhizoctonia solani* Kühn AG-4, respectively, are the principal soilborne diseases. Combined, the aforementioned diseases are responsible for losses from crop reductions and cost of control that may exceed $83 million annually in Georgia (Kemerait, 2005). To reduce these losses, peanut producers apply between 5 and 8 fungicide applications per season, with total costs of control of these diseases estimated at over $50 million per year (Kemerait, 2005, Kemerait et al., 2006). Fungicides represent the single largest expenditure for many peanut producers. As growers seek to remain economically competitive, the cost of disease control programs must be addressed. Economic efficiency in production is even more important after changes in the 2002 U.S. farm bill drastically impacted peanut production by replacing the old quota system with a new marketing loan system. As a result, the in-shell loan price was reduced from $548 to $398/metric ton (Smith, 2002). In addition to lower crop prices and high fungicide expenditures, recent increases in fuel costs have also become a significant economic constraint for peanut producers. In response to these factors, less expensive disease management strategies are needed to ensure producers maintain an economically profitable crop.

Integrated disease management (IDM) involves the use of a range of disease control strategies to achieve a level of disease control that is economically acceptable to producers. An integrated approach was implemented in 1995 to manage Tomato spotted wilt caused by *Tomato spotted wilt tospovirus* (TSWV) (family: Bunyaviridae) in the southeastern U.S. The spotted wilt risk index uses factors such as cultivar selection, insecticide application, planting date, plant population, row pattern and tillage to minimize losses associated with the virus (Culbreath et al. 1999; Brown et al. 2003; Brown et al. 2005). According to Brown et al (2005), peanut yields increased approximately 10% over a 5 year period following the release of the spotted wilt risk index. Currently more than 80% of Georgia producers are using some combination of the factors included in the index (Brown et al. 2005).

Many of the factors that comprise the spotted wilt risk index also influence the development of fungal diseases (Brenneman and Hadden, 1996; Monfort et al. 2004; Sconyers et al. 2005; Cantonwine et al. 2006); therefore, a similar integrated approach should be helpful in the management of leaf spot, stem rot and limb rot. Using criteria such as cultivar, crop rotation, field history, planting date, irrigation, tillage, and irrigation a Fungal Disease Risk Index (Kemerait et al., 2004) has been developed. Since its release, this index has been combined with the spotted wilt risk index (Brown et al. 2005) to serve as an educational tool to allow producers to quantitatively measure the risk of each disease on an individual field basis.

The index is designed to be used prior to planting, where information obtained can allow producers to choose management practices that can help minimize disease related losses. Fungicide programs can then be adapted to fit specific field situations. Reduced fungicide programs for peanut disease control have been evaluated (Besler et al. 2001;

Brenneman and Culbreath, 1994; Culbreath et al. 1992; Damicone and Jackson, 1997; Grichar et al. 1998); however, few studies using integrated approaches for these diseases have been conducted. Monfort et al. (2004), compared the effects of tillage, cultivar and reduced versus full fungicide inputs on the development of early leaf spot, and found that leaf spot intensity in reduced-tillage plots treated with four fungicide applications was comparable to that in standard seven application treatments in conventional tillage. Cantonwine et al. (2006) evaluated the economic aspects of using integrated approaches to manage leaf spot and tomato spotted wilt. Despite differences in yield over the duration of these studies, economic returns were similar for the four, five and seven application programs they evaluated. Furthermore, the integrated tillage systems they evaluated typically performed as well as the standard production system. Additional studies are needed to evaluate the potential for implementing such programs in commercial production settings.

Changes to the peanut program in the 2002 Farm Bill also resulted in an expansion of peanut production in areas of Georgia that had no recent history of peanut production. These areas should have inherently lower disease pressure and provide an excellent opportunity to test the reduced fungicide inputs in lower risk situations. The objectives of this research were to i) quantify disease risk levels in commercial peanut fields based on cultural practices, ii) compare the effects of standard and reduced fungicide programs on foliar and soilborne disease development, and iii) determine the economic benefits of using reduced fungicide programs in fields with low-to-moderate levels of disease risk.

MATERIALS AND METHODS

Large-plot evaluations. Field experiments were conducted in 2003, 2004 and 2005 in the peanut growing region of southern Georgia in Dougherty, Lanier, Tift, Macon and

Berrien counties (Figure 4.1). Descriptions of cultural practices and the fungicide programs for each trial can be found in Tables 4.1 and 4.2, respectively. All production practices other than disease control were based on University of Georgia Cooperative Extension recommendations (Beasley et al., 1997).

Dougherty County trial. In 2003, an experiment was established in an irrigated field in Dougherty Co. near Albany, which had been planted to cotton (*Gossypium hirsutum* L.) the two previous years, and had a history of problems with leaf spot and stem rot. The peanut cultivar Georgia Green was planted on 5 May 2003 in twin rows, using conventional tillage. Two standard and reduced fungicide programs were evaluated at this location and have been designated trial A and B (Table 4.2). Four replications of each treatment were arranged in a randomized complete block design. Plots were 18 rows (16.5 m) wide with an average length of 675 m.

Lanier County trials. Experiments were established in 2003, 2004 and 2005 in commercial peanut fields in Lanier Co. near Lakeland. The field sites for 2003 and 2005 had no history of peanut production; whereas, the 2004 location had been planted to cotton the three previous years, and had a history of production. The cultivar Georgia Green was used in all three years of the study and planted in mid-May. Fields used in all three years were strip tilled. Peanuts were planted in twin rows in 2003 and 2005 and single rows in 2004. The standard program for trial A was identical to the Dougherty Co. trial described previously; however, the reduced program differed (Table 4.2). Likewise, the standard program for trial B was identical to the Dougherty Co. trial; however, changes were made to the reduced program (Table 4.2). In 2004, all plots received an additional chlorothalonil

application on 1 Oct, due to an extended period of rain late in the season. The experimental design for each year was a randomized complete block design with four replications.

Macon County trials. In 2004, experiment was conducted in an irrigated field, in Macon Co. near Oglethorpe. The field was in a four year rotation, and a history of problems with foliar and soilborne diseases. The experiment was repeated in 2005 in an adjacent field with similar history. The cultivar Georgia-02C was planted 5-7 May in twin rows with conventional tillage. Plots (eighteen rows (16.5 m) wide by 305 m long) were arranged in a randomized complete block design with three and four replications in 2004 and 2005, respectively. A description of the two fungicide programs evaluated in these trials can be found in Table 4.2. In 2004, all plots received an additional chlorothalonil application 102 days after application due to rain shortly after the azoxystrobin application.

Tift county trials. Trials were conducted in 2004 and 2005 in Tift County, near Omega. Cultural practices used to determine disease risk included a 4-year rotation, planting Georgia-01R in twin rows, and conventional tillage. Both fields were irrigated and had a history of problems with foliar and soilborne diseases. Peanuts were planted on 1-May in 2004 and 10-May 2005. Plots were sixteen rows wide by 350 m the length of the field and were arranged in alternating strips with four replications. Changes were made in fungicide programs between the two years, and are listed in Table 4.2.

Berrien County trials. Two locations (Berrien 1 and Berrien 2) were used in Berrien Co. in 2005. The cultural practices at Berrien 1 included a 3 year rotation with corn (*Zea mays* L.), the use of conventional tillage and single rows. The field was irrigated and had a history of soilborne disease. Georgia Green peanuts were planted on 26-May. The Berrien 2

field had been in continuous cotton production for the past 15 years. Fungicide programs for each location were the same (Table 4.2).

Cultivar study. Field experiments were conducted in 2004 and 2005 in Appling County near Baxley (Figure 4.1), to evaluate the response of eight commercially available cultivars to varying levels of fungicide inputs. The cultivars Georgia Green, Georgia-02C, Georgia-03L and AP-3 represented mid-maturity class, and Georgia-01R, Hull, Tifrunner and C-99R represented the late-maturity class. This was a non-irrigated site and had a prior history of cotton or corn production for at least 10 years. Peanuts were strip-tilled into a killed rye cover on 11-Jun 2004 and 19-May 2005. A single row pattern was used in 2004 and a twin row pattern in 2005. Plots were 1.8 m wide and 61 m long in 2004 and 1.8 m wide and 84 m long in 2005. Plots were separated by 1.5-m fallow alleys.

Three fungicide programs, a zero-spray (control), three-spray (reduced), and seven-spray (standard) program were evaluated. For the standard seven-spray program, a mixture of chlorothalonil (0.84 kg a.i./ha) and propiconazole (0.06 kg a.i./ha) were applied approximately 30, 44, and 124 DAP. Alternating applications of 0.23 kg a.i./ha tebuconazole and 0.33 kg a.i./ha of azoxystrobin were applied 58, 72, 86 and 90 DAP. The three-spray program consisted of a single application of each of the chlorothalonil-propiconazole combination, tebuconazole and azoxystrobin applied 44, 72 and 110 DAP, respectively.

Disease evaluations and harvest. Leaf spot and stem rot development were monitored throughout the season, and final assessments were made prior to or at digging. Spotted wilt assessments were based on disease intensity ratings that represent a combination of incidence and severity as described by Culbreath et al. (1997). Final leaf spot intensity was rated prior to plants being inverted. Ratings were made using the Florida 1-10 scale,

where 1 = no disease and 10 = plants completely defoliated and killed by leaf spot (Chiketa et al. 1988). Plants were inverted based on pod maturity (Williams and Drexler, 1981), and the incidence of stem rot was determined by counting the number of disease foci exhibiting symptoms of the disease or signs of *S. rolfsii* (Rodriguez-Kabana et al. 1975). When present, limb rot assessments were made by estimating the percentage of symptomatic vines at six arbitrarily selected areas (2-m-diam.) per plot. Plants were allowed to dry in windrows for 3-7 days, except at the Berrien 2 location, where plants remained in windrows for 14 days due to extended periods of rain. For all county trials, peanuts were harvested with grower-cooperator combines, and yields were determined for each plot. In the cultivar trials, peanuts were harvested with a 2-row mechanical combine and total pod weight was recorded from each plot. Pods weights were adjusted to 10% moisture (w/w) based on the moisture content of a 1-kg sample.

Pod quality and economic analysis. A 600-g sub-sample of pods was collected from each plot in 2004 and 2005 and graded according to Federal Inspection Service guidelines (USDA-AMS, 2003). Pod quality was determined by the % total sound mature kernels (%TSMK). Crop value ($ per metric ton) was determined for each plot using the 2005 pod price schedule (USDA-FSA, 2003 a,b). Fungicide costs were determined by averaging the product prices from ten pesticide dealers throughout the state and are listed in Table 4.2. Application costs including fuel and labor were based on Georgia enterprise budgets described by Smith et al. (2004). For the cultivar study, seed costs were estimated as described by Cantonwine et al. (2006). The number of seed/kg was determined using a three year average (2003-2005) of irrigated trials conducted by the University of Georgia State Wide Variety Testing Program (Day et al. 2003, 2004, 2005). Fixed costs, such as

depreciation, insurance and interest on investment were not included in the analysis. The return above fungicide cost, defined as the difference between fungicide costs and the USDA loan crop value, were calculated for each plot.

Statistical analysis. Data from the large plot evaluations for each trial and year were analyzed using Proc T-TEST of SAS (SAS v9.1, SAS Institute, Cary, NC). For the Cultivar study, planter constraints limited randomization; however, data were analyzed across cultivars as three separate (seven, three and zero-spray) trials as complete blocks using Proc ANOVA (SAS). Treatment means were separated according to Fisher's least significant difference test. Means of each of the three fungicide programs were computed for comparison. To quantify the relationship between standard and reduced fungicide programs for yield and economic returns, data from all experiments were combined, and linear regression analyses were performed using Proc REG of SAS. The data from the standard programs were considered as independent and the center of regression was moved from zero to the mean as suggested by Draper and Smith (1981). All subsequent references to statistical differences are at the 0.05 significance level, unless stated otherwise.

RESULTS

Large-plot evaluations. Differences in disease intensity were observed across years and locations. Both leaf spot and stem rot were more severe in 2004 than in any other year. Spotted wilt severity was low in 2003 and 2004 and moderate to severe in 2005 at all locations. No significant differences in spotted wilt incidence between standard and reduced fungicide programs were observed. In 2003, early leaf spot was the predominant foliar disease; whereas, late leaf spot was prevalent in the majority of trials in 2004 and 2005. Stem rot was the predominant soilborne disease at all locations, but limb rot was present in

four of the trials. There were no significant differences in limb rot control between standard and reduced programs where that disease was evaluated. Therefore, only leaf spot and stem rot data will be presented.

Dougherty county trial. This field was classified as having moderate risk levels for leaf spot, stem rot, and limb rot (Table 4.1). Leaf spot intensity was generally low and no significant differences in leaf spot control were observed for either of the two trials (Table 4.3). Stem rot intensity was moderate, and control was similar for both programs in either test (Table 4.3). There was no difference in pod yield or quality between standard or reduced programs in trial B; however, yields were significantly higher for the reduced program in trial A. Economic returns were significantly higher (P<0.10) for the reduced programs in both trials (Table 4.3).

Lanier county trials. Disease risk levels varied each year of this study. Leaf spot risk was estimated to be moderate in 2003 and 2004 and low in 2005, and stem rot risk levels were low, moderate and low for 2003, 2004, and 2005, respectively (Table 4.1). Differences in leaf spot control were significant in 2004 for trial A, and in 2004 and 2005 for trial B (Table 4.3). For trial B in 2003 and 2004, incidence of stem rot was higher for the standard program than for the reduced program (P<0.10) (Table 4.3). No other differences in stem rot were observed. Yields were similar between the standard and reduced programs in all years for trial A and B. No differences in net returns between the standard and reduced program were observed for trial A during any year of the study; however, the net returns for the reduced program were significantly higher (P<0.10) for the reduced program in 2003 and 2005 for trial B (Table 4.3).

Macon county trials. Disease risk levels for foliar and soilborne diseases were estimated to be moderate both years (Table 4.1). There were no differences in leaf spot, stem rot, yield or returns between the standard and reduced program in either year (Table 4.3). Leaf spot pressure was low both years, and stem rot was the predominant disease both years of this study.

Tift county trials. Disease risk was moderate for all diseases both years of this study (Table 4.1). Leaf spot pressure was high in 2004 and moderate in 2005. Intensity of leaf spot was lower in the standard input fungicide programs than the reduced program in both years (Table 4.3). Stem rot was moderate in both years, and incidence of stem rot was similar for the two programs (Table 4.3). Yield was higher in the standard program than in the reduced program in 2004, but was similar for the two programs in 2005 (Table 4.3). Economic returns were significantly reduced ($P<0.001$) in 2004; however, the opposite was observed in 2005 when returns were greater for the reduced program.

Berrien county trials. The Berrien 1 trial had moderate levels of disease risk for leaf spot, stem rot and limb rot, whereas, the Berrien 2 trial was classified as low risk for all three diseases (Table 4.1). Leaf spot ratings were similar for the two programs at the Berrien 1 trial; however, there was a significant ($P<0.05$) increase in leaf spot intensity at the Berrien 2 trial (Table 4.3). There were no significant ($P<0.10$) differences in stem rot control or pod yields between the two programs at either location (Table 4.3). For both locations, the reduced program had higher economic returns than the standard program (Table 4.3). Returns were $227 per ha and $72 per ha higher for the reduced program at the Berrien 1 and Berrien 2 trial, respectively.

Cultivar studies. Although inconsistent, significant ($P<0.01$) differences in leaf spot intensity were evident among the cultivars evaluated over both years of this study (Table 4.4). In most instances, leaf spot intensity was highest for AP-3, Georgia Green and Georgia-02C, and lowest for Hull, Georgia-01R and Tifrunner. Although statistical comparisons of the three fungicide programs were not possible, mean leaf spot intensity was lowest for the standard seven-spray program, greatest for the non-treated control and intermediate for the reduced three-spray program (Table 4.4). Soilborne disease intensity was low; however, there was considerably more disease in non-treated plots when compared to the seven- and three spray-programs in both years of the study (Table 4.4). In all three programs, Georgia-02C and Georgia-03L appear to have the highest levels of field resistance to stem rot (Table 4.4). Yields were similar in both years and ranged from 3873 to 5941 kg/ha in 2004 and from 2956 to 5762 kg/ha in 2005 (Table 4.4). Yields were consistently higher for Georgia-03L, Georgia-01R and Georgia-02C with mean yields of 5170, 5160 and 5155 kg/ha and 5374, 5219 and 4887 kg/ha for 2004 and 2005, respectively. Significant ($P<0.05$) differences in economic returns were observed between cultivars with the cultivars Georgia-01R, Georgia-02C, and Gerogia-03L providing the highest yields (Table 4.4).

Overall comparison of standard and reduced programs. When data from all trials were combined, pod yields ranged from 3644 to 7220 kg/ha (Tables 4.3 and 4.4). There was a significant regression of the yields where the standard program was the independent variable and reduced program was the dependent variable (Figure 4.2). Although the slope was 0.9004, this value was not different from a slope of one relationship. There was a similar linear relationship between the economic returns of the two programs (Figure 4.3). Similarly, the slope was 0.9053 and was not different from a slope of one.

DISCUSSION

Results of this research validate the University of Georgia Fungal Disease Risk Index (Kemerait et al., 2006), and indicate that reduced fungicide programs can be used in an integrated system for management of fungal diseases of peanut. Leaf spot and stem rot intensity varied by location and year, which may have been attributed to the cropping histories and different cultural practices implemented in each field, which agrees with risk levels predicted by the index. Variations in disease pressure are also caused by the highly variable environmental conditions of the region. Above average rainfall amounts probably accounted for increased levels of disease, especially leaf spot in 2004. Over the duration of these studies, average rainfall was 25, 35 and 15% above the ten-year average for 2003, 2004 and 2005, respectively (Hoogenboom et al. 2003). Differences in the level of leaf spot control between standard and reduced programs varied by location and warranted an examination of the products that comprised each program. Tebuconazole was included in each of the instances where significant differences were observed in leaf spot control between standard and reduced programs. Lower leaf spot ratings for the reduced program at the Lanier Co., a site in 2004 may have been due to better efficacy of pyraclostrobin used in the reduced program.

Tebuconazole has been highly efficacious against leaf spot in the past (Brenneman and Culbreath, 1994); however, results from trials conducted in recent years have raised concerns about the potential development of fungicide resistance to sterol demethylation inhibiting (DMI) fungicides (Culbreath et al. 2005). Recent studies have indicated that changes in tebuconazole sensitivity within *C. arachidicola* and *C. personatum* populations may be taking place (Culbreath et al. 2005; Stevenson unpublished). Current resistance

management recommendations include the use a non-DMI fungicide prior to and after applications of a DMI (Brenneman and Culbreath, 1994). Since reduced fungicide input programs provide fewer opportunities to incorporate compounds with different modes of action, this situation needs to be monitored closely to avoid the development of fungicide resistance.

Sclerotium rolfsii was present at all locations included in these studies to some degree. Disease incidence was generally highest in fields that had been planted to peanut within the past four years, reinforcing the importance of crop rotation and field history. The sclerotia of *S. rolfsii* can remain viable in the soil for up to three years, and the fungus is capable of infecting more than 500 species of plants (Punja, 1985). Results from the cultivar studies corroborate previous findings that varying levels of stem rot resistance in the cultivars grown in the southeast (Brenneman et al., 2005). Although stem rot intensity was generally higher for the late-maturity cultivars, assessments within the season indicate that, with the exception of Tifrunner, the late-maturing cultivars have levels of stem rot resistance equal to or better than that of Georgia Green (data not shown). However, because they are later maturing, the duration of stem rot epidemics resulted in higher levels of disease. Components of fungicide programs and application timing may need to be modified if producers wish to use integrated systems that include reduced fungicide programs and late-maturing cultivars. Such modifications may have in the 2004 Tift County trial. That situation was exacerbated when multiple tropical weather systems impacted the area, which help explain the high level of leaf spot in plots treated with the reduced program. Those results emphasize the importance of conducive environmental conditions for leaf spot epidemics.

These studies also support results of previous reports indicating that fungicide inputs to manage peanut diseases can be reduced without compromising yields (Cantonwine et al. 2006; Monfort et al. 2004). Cantonwine et al. (2006) evaluated the economic benefits of various integrated disease management systems and found that the standard production system consisting of Georgia Green, conventional tillage, and a 7-spray chlorothalonil program did not maximize returns. No differences were observed among the four, five or seven-spray programs of chlorothalonil evaluated in their study, indicating that by using an integrated system, as many as three applications could be excluded from the standard leaf spot management program. However, those studies focused exclusively on foliar diseases and did not consider soilborne diseases, which can be responsible for significant yield reductions. In addition, the cost of fungicides used to manage soilborne diseases is substantially greater than that of fungicides used solely for leaf spot control.

Although yields varied by location, reductions in yield and subsequently returns for the reduced fungicide program occurred only in the 2004 Tift Co. trial. Results from the regression analysis illustrate the relationship between the standard and reduced programs evaluated in these studies, suggesting that the yields of the reduced programs were not significantly different from those of the standard. Regression analysis indicated that the reduced programs were not significantly different from the respective standard programs; however, economic returns typically favored reduced programs. These results indicate that integrated disease management systems can be used to manage peanut diseases without jeopardizing yield or returns. However, additional research is needed to ensure the economic stability of utilizing reduced fungicide programs.

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Table 4.1. Description of cultural practices and disease risk levels of field sites used in the evaluation of reduced input fungicide programs

Year, Location	Cultivar[a]	Rotation	Field History[b] Leaf Spot	Stem Rot	Limb Rot	Planting Date	Row Pattern	Tillage[c]	Irrigation	Disease Risk Level[d] Leaf Spot	Stem Rot	Limb Rot
2003												
Doughtery Co.	Ga. Green	2	Yes	Yes	No	5-May	Twin	Red	Yes	Mod.	Mod	Mod
Lanier Co.	Ga. Green	10+	No	No	No	14-May	Twin	Red.	Yes	Mod.	Low	Low
2004												
Lanier Co.	Ga. Green	3	Yes	Yes	No	24-May	Single	Red.	Yes	Mod.	Mod.	Mod.
Tift Co.	Ga. -01R	4	Yes	Yes	Yes	1-May	Twin	Con.	Yes	Mod.	Mod.	Mod.
Macon Co.	Ga. -02C	4	Yes	Yes	Yes	6-May	Twin	Con.	Yes	Mod.	Mod.	Mod.
2005												
Lanier Co.	Ga. Green	10+	No	No	No	25-May	Twin	Red.	Yes	Low	Low	Low
Tift Co.	Ga. -01R	4	Yes	Yes	Yes	10-May	Twin	Red.	Yes	Mod.	Mod.	Mod.
Macon Co.	Ga. -02C	3	Yes	Yes	Yes	10-May	Twin	Con.	Yes	Mod.	Mod.	Mod.
Berrien Co. 1	Ga. Green	3	Yes	Yes	No	26-May	Single	Red.	Yes	Mod.	Mod.	Mod.
Berrien Co. 2	Ga. Green	10+	No	No	No	24-May	Single	Red.	No	Low	Low	Low

[a] Represents the cultivar used in each trial. Ga. is the abbreviation for Georgia.
[b] Yes indicates leaf spot, stem rot or limb rot were a problem when previously cropped to peanuts, despite a good fungicide program.
[c] Con. = conventional (deep-plow) tillage; whereas Red. = reduced (strip-tillage) tillage.
[d] Mod. refers to a moderate level of disease risk.

Table 4.2. Schedule of fungicide applications for on-farm evaluations of standard and reduced programs in 2003, 2004, and 2005.

Location, (Year)	Fungicide Application Schedule[a]											
Program	1.0	1.5	2.0	3.0	3.5	4.0	4.5	5.0	6.0	6.5	7.0	8.0
Dougherty (2003)												
Standard A		$Pyr_{0.16}$[b]		Teb		Teb		Teb	Teb		Chl	
Reduced A		$Pyr_{0.11}$		Teb		Teb		Teb		Chl		
Standard B	C+P[c]		C+P	$Azo_{0.34}$		Chl		$Azo_{0.34}$	Chl		Chl	
Reduced B		C+P		$Azo_{0.22}$		Teb		$Azo_{0.22}$		Chl		
Lanier (2003-2005)[d]												
Standard A		$Pyr_{0.16}$		Teb		Teb		Teb	Teb		Chl	
Reduced A		$Pyr_{0.16}$		Teb			$Pyr_{0.16}$		Teb			
Standard B	C+P		C+P	$Azo_{0.34}$		Chl		$Azo_{0.34}$	Chl		Chl	
Reduced B		C+P		Teb			$Azo_{0.22}$		$Azo_{0.22}$			
Macon (2004&2005)[e]												
Standard		$Pyr_{0.16}$		Teb		Teb		Teb	$Azo_{0.34}$		Chl	
Reduced		$Pyr_{0.16}$		Teb			Teb		$Azo_{0.34}$			
Tift (2004)												
Standard	C+P	$Pyr_{0.15}$		$Azo_{0.34}$		Teb		$Pyr_{0.15}$	$Azo_{0.34}$		Chl	Teb
Reduced		$Pyr_{0.15}$			$Azo_{0.34}$				$Azo_{0.34}$		Teb	
Tift (2005)												
Standard	C+P	$Pyr_{0.19}$		$Azo_{0.34}$		Chl		Teb	Teb		F+P	F+P
Reduced	C+P	$Pyr_{0.19}$		$Azo_{0.34}$					Teb		F+P	F+P
Berrien 1&2 (2005)												
Standard	C+P		C+P	Teb		$Azo_{0.34}$		Teb		$Azo_{0.34}$		
Reduced			C+P		Teb			Teb		$Azo_{0.34}$		

[a] Represents the standard 7-spray application schedule with the exception of the two Tift County trials. In these trials, the cultivar

used is late maturing and required an additional application toward the end of the season. Note there is one week between application 1 and 1.5 and two weeks between 1 and 2.

[b] Fungicides used included: Azo = azoxystrobin (Abound 2.08F, 0.22-0.34 kg a.i./ha), Chl = chlorothalonil (Bravo Ultrex, 1.26 kg a.i /ha), C+P = chlorothalonil + propiconazole (Bravo Weather Stik, 0.84 kg a.i./ha + Tilt, 0.06 kg a.i./ha), F+P = flutolanil + propiconazole (Artisan, 0.84 + 0.17 kg a.i./ha, respectively), Pyr = pyraclostrobin (Headline 2.09EC, 0.11-0.22 kg a.i./ha), Teb = tebuconazole (Folicur 3.6F, 0.23 kg a.i./ha). Subscripted numbers represent the fungicide rate in kg a.i., in instances were different rates were used.

[c] An additional application of chlorothalonil was applied to all plots at this location in 2004, due to an extended period of rain.

[d] All plots received an additional chlorothalonil application in 2004, due to rain shortly after the azoxystrobin application.

Table 4.3. Effects of standard and reduced fungicide programs on final leaf spot intensity, stem rot incidence, yield and net returns in multiple peanut fields throughout Georgia (2003-2005).

	Trail[a]													
	Doughtery Co.		Lanier Co. A			Lanier Co. B			Macon Co.		Tift Co.		Berrien Co.	
Program	A	B	`03	`04	`05	`03	`04	`05	`04	`05	`04	`05	1	2
	Final Leaf Spot Intensity[b]													
Standard	2.9	2.9	2.0	4.6	1.5	2.0	2.2	1.4	2.5	2.9	3.2	3.7	2.6	3.6
Reduced	2.7	2.6	2.1	2.7	1.3	2.0	4.2	2.0	2.5	3.0	6.3	4.4	2.8	4.1
$P > t$[e]	ns	ns	ns	**	ns	ns	**	**	ns	ns	***	***	ns	**
	Stem Rot Incidence[c]													
Standard	11.8	8.9	2.0	21.4	3.0	7.8	36.0	2.0	17.3	7.3	16.4	11.9	20.3	12.8
Reduced	10.6	8.4	4.3	26.5	2.3	5.0	25.8	2.0	13.0	8.8	20.0	13.5	17.8	14.0
$P > t$	ns	ns	ns	ns	ns	*	*	ns	ns	ns	ns	ns	ns	ns
	Pod Yield (kg/ha)													
Standard	3644	4100	7130	6552	6657	6751	6472	6595	6511	5785	6999	5560	3956	4866
Reduced	4099	4193	7220	6285	6550	6909	6259	6393	6396	5591	6100	5433	4201	4778
$P > t$	***	ns	ns	ns	ns	ns	ns	ns	ns	ns	***	ns	**	ns
	Return ($/ha)[d]													
Standard	1202	1329	2566	2331	2504	2368	2277	2348	2084	1923	2432	1284	1084	1360
Reduced	1432	1449	2665	2198	2472	2561	2270	2521	2173	1985	2240	1531	1311	1432
$P > t$	*	*	ns	ns	ns	*	ns	*	ns	ns	***	*	***	**

[a] Trial refers to the counties were the studies were established. There were two trials conducted in Dougherty County in 2003, Lanier county in 2003, 2004, and in Berrien County in 2005. For a detailed description of fungicide programs refer to Table 4.2.

[b] Leaf spot severity was assessed prior to peanut inversion using the Florida 1-to-10 scale, where 1 = no leaf spot and 10 = plants completely defoliated and killed by leaf spot (Chiketa et al. 1988).

[c] Final stem rot incidence was assessed immediately following peanut inversion, based on the percentage of 30.5-cm row segments

showing signs or symptoms of *S. rolfsii* infection (Rodriguez-Kabana et al. 1975).

[d] Return refers to net returns which are defined as the difference between variable costs and the estimated crop value.

[e] Probability of a greater t-value for each comparison. Probabilities of less than 0.10, 0.05 and 0.01 are indicated by a single, double and triple asterisks, respectively; ns denotes a probability greater than 0.10.

Table 4.4. Effects of seven, three and zero fungicide applications and eight peanut cultivars on final leaf spot intensity, stem rot incidence, yield and net returns in a field in Appling County, Georgia (2004 and 2005).

Year,		Final Leaf Spot Intensity[a]			Stem Rot Incidence[b]			Yield (kg/ha)			Returns ($/ha)[c]		
Cultivar[d]	N[e]	Seven	Three	Zero	Seven	Three	Zero	Seven	Three	Zero	Seven	Three	Zero
2004													
Ga. Green	6	3.7	4.3	7.7	0.7	3.7	6.3	4860	4951	4289	1430	1465	1320
AP-3	2	4.1	5.0	8.5	0.0	1.0	10.0	5636	5942	4816	1732	2037	1766
Ga. -02C	4	3.6	4.3	7.8	0.5	0.8	2.0	5139	5575	4765	1532	1784	1750
Ga. -03L	4	3.3	3.8	6.4	0.0	0.3	0.5	5382	5092	5036	1595	1663	1774
Ga. -01R	8	2.4	3.2	6.3	0.1	2.4	4.5	5586	5414	4464	1637	1684	1511
C-99R	4	2.5	3.3	6.4	0.3	1.8	2.3	5651	5744	3873	1799	1972	1117
Hull	4	2.4	3.4	6.6	0.8	1.0	7.0	4494	4165	4018	1159	1112	1202
Tifrunner	4	2.8	3.7	7.3	0.5	0.8	4.0	4978	4967	4411	1518	1594	1356
LSD[f]		0.2***	0.3***	0.6***	ns	ns	3.9***	706*	523***	663*	313*	232***	269**
Mean		3.1	4.0	7.1	0.4	1.5	4.6	5216	5231	4459	1550	1664	1475
2005													
Ga. Green	8	3.2	5.1	7.1	0.8	1.5	5.0	4618	4929	3969	1421	1703	1424
AP-3	4	2.9	5.0	7.8	0.0	0.0	3.5	4527	3886	2956	1336	1247	1003
Ga. -02C	4	2.8	4.3	7.3	0.0	0.0	1.0	4970	4645	5047	1506	1618	1874
Ga. -03L	4	2.8	4.5	6.6	0.0	0.0	1.0	5762	5113	5247	1794	1681	1879
Ga. -01R	8	2.8	4.4	6.1	4.5	8.0	11.8	5374	5225	5058	1572	1719	1752

C-99R	4	3.1	4.9	6.8	4.0	7.0	13.5	5428	4980	4640	1581	1598	1608
Hull	4	2.5	3.9	6.7	2.5	7.5	10.5	4723	4576	4148	1271	1418	1349
Tifrunner	4	2.6	4.5	7.3	6.5	14.0	17.5	4905	4492	3698	1293	1392	1223
LSD[f]		0.3***	0.4***	0.4***	2.4***	2.5***	2.7***	765 *	741*	835***	289*	279*	324**
Mean		2.8	4.6	7.0	2.3	4.8	8.0	5038	4731	4345	1472	1547	1511

[a] Leaf spot severity was assessed prior to peanut inversion using the Florida 1-to-10 scale, where 1 = no leaf spot and 10 = plants completely defoliated and killed by leaf spot (Chiketa et al. 1988).

[b] Final stem rot incidence was assessed immediately following peanut inversion, based on the percentage of 30.5-cm row segments showing signs or symptoms of *S. rolfsii* infection (Rodriguez-Kabana et al. 1975).

[c] Return refers to net returns which are defined as the difference between variable costs and the estimated crop value.

[d] Represents commercially available mid- and late-maturity class cultivars used in the southeast. Ga. is the abbreviation for Georgia.

[e] Refers to the number of observations of each cultivar. Georgia-01R and Georgia Green were the most abundant in both years, while AP-3 seed was limited in 2004.

[f] LSD = least significant difference. Significance levels of less than 0.10, 0.05 and 0.01 are indicated by a single, double and triple asterisks, respectively; ns denotes a probability greater than 0.10.

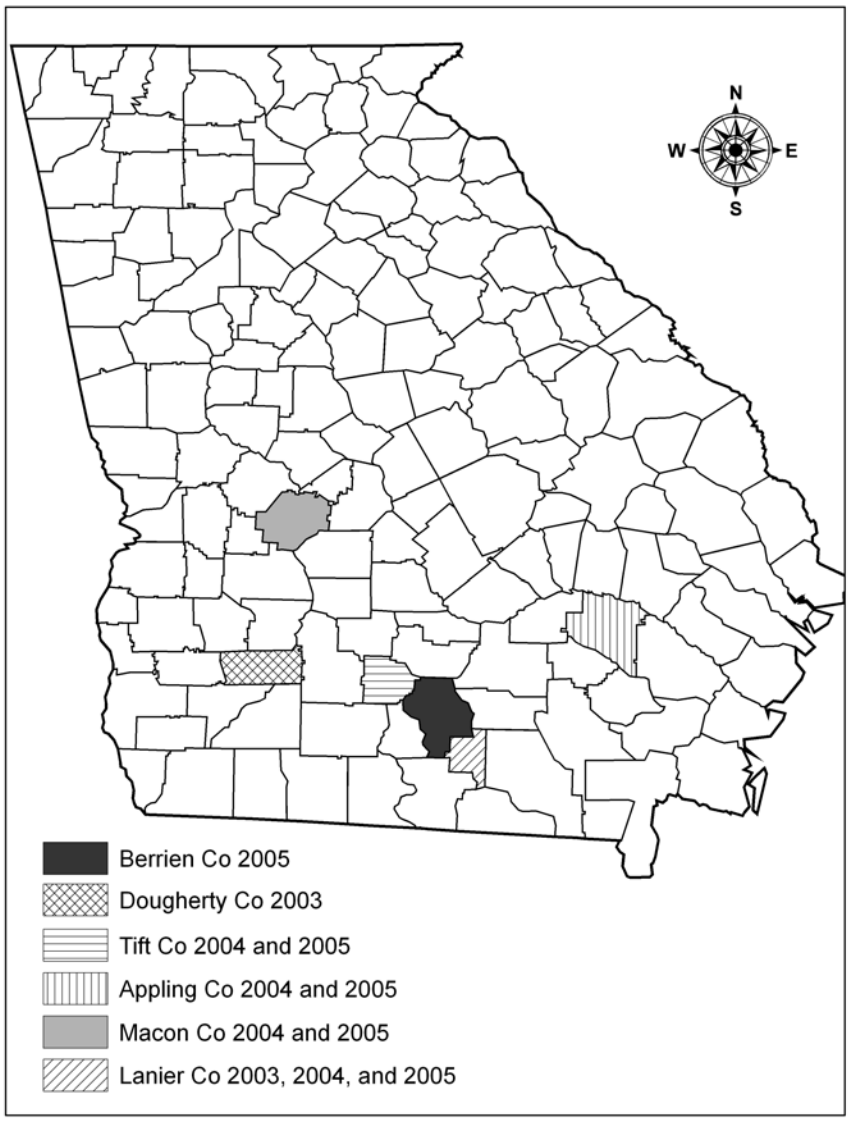

Figure 4.1. Map of Georgia counties included in the large plot evaluation of reduced input fungicide programs in 2003, 2004, and 2005.

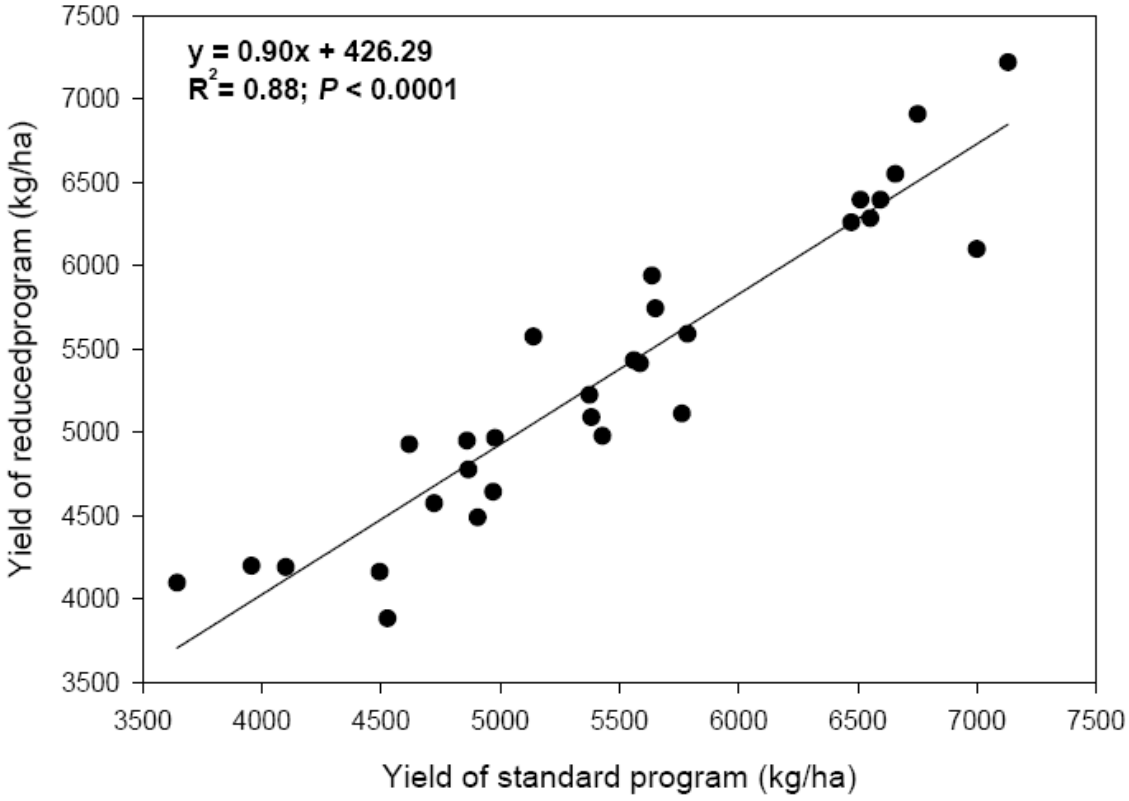

Figure 4.2. Linear relationship of pod yields between standard and reduced input fungicide programs evaluated in large plot trials (2003-2005).

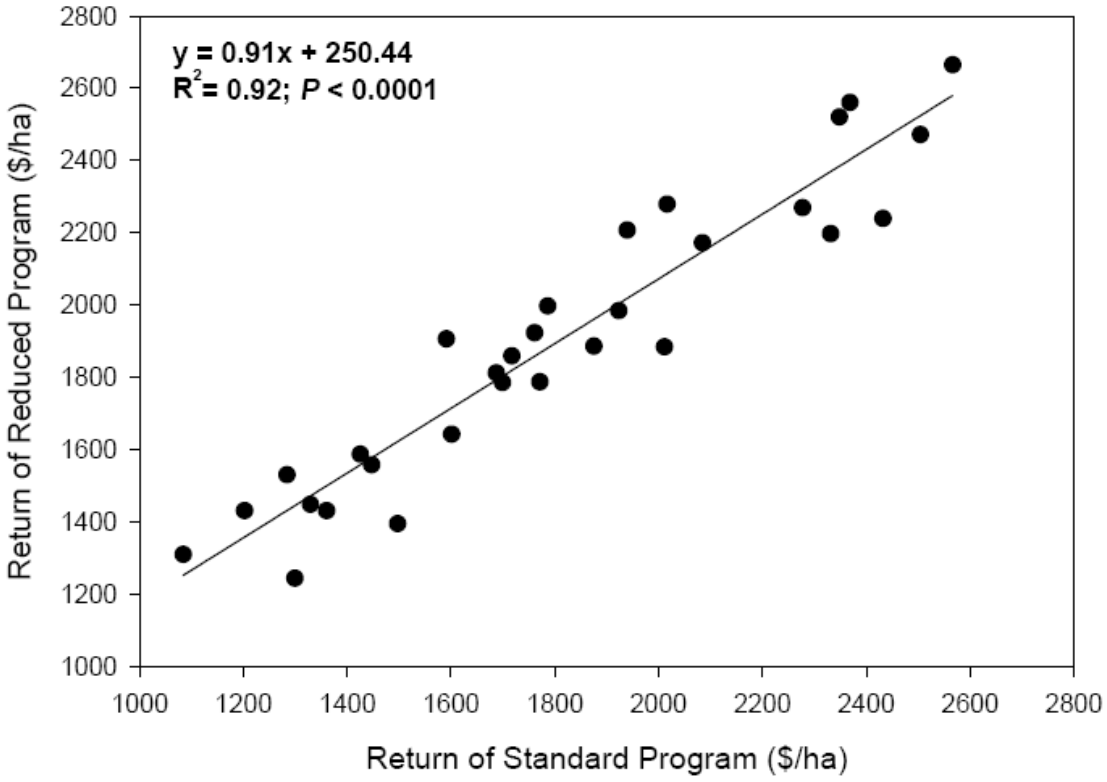

Figure 4.3. Linear relationship of economic returns between standard and reduced input fungicide programs evaluated in large plot trials (2003-2005).

CHAPTER 5

DEVELOPMENT OF A BIOASSAY TO QUANTIFY FUNGICIDE RESIDUES ON PEANUT FOLIAGE

[1]Woodward, J. E. and T. B. Brenneman. 2006. To be submitted to *Peanut Science*.

Abstract

A bioassay was developed to evaluate residues of foliar applied fungicides on peanut leaflets and stems obtained from the upper, middle, and lower canopy. Experiments were conducted to determine the effects of wounding and inoculum source on the development *Sclerotium rolfsii* lesions. Results indicated that wounding was not required for infection on either tissue, and that lesion development was less variable when ¼ strength potato dextrose agar was used as an inoculum source. Significant differences in lesion development were observed among canopy layer for leaflets and stems implicating the importance of standardizing tissue canopy. In general, tissues collected from the upper canopy were more rapidly colonized by *S. rolfsii* than tissues from the middle or lower canopy. This method was used to determine an appropriate sample size, and to evaluate the response of *S. rolfsii* to varying concentrations of azoxystrobin, flutolanil and tebuconazole. Based on differences in the sample mean, standard deviation, and coefficient of variation, a total of 8 to 10 replicates are required to obtain a reliable estimate. The application of fungicides significantly reduced the size of *S. rolfsii* lesions compared to the non-treated control. Consistent results were obtained from the leaflet and stem assays, and a lesion sized decreased linearly with increasing $\log_{10}$+1 transformed fungicide concentration. The EC_{50} values from the leaflet and stem assays were 17.2, 9.5, and 18.1 mg/L, and 18.1, 8.3, and 13.5 mg/L for azoxystrobin, tebuconazole, and flutolanil, respectively. This method is a effective way to determine differences in the residual activity of foliar applied fungicides.

Keywords: *Arachis hypogaea*, fungicide deposition, southern stem rot

INTRODUCTION

Peanut (*Arachis hypogaea* L.) is an economically important crop in the southeastern United States; however, fungal diseases are responsible for substantial yield reductions annually (Nutter and Shokes, 1995; Melouk and Backman, 1995). The primary foliar diseases in this region are early leaf spot (*Cercospora arachidicola* Hori) and late leaf spot (*Cercosporidium personatum* Berk. & Curt.) Deighton), southern stem rot (*Sclerotium rolfsii* Sacc.) and Rhizoctonia limb (*Rhizoctonia solani* Kuhn anatimosis group (AG)-4) are the most important soilborne diseases.

A recent survey of Georgia peanut producers indicated that approximately 6.2 fungicide applications are made per season for the management of the aforementioned diseases (N. Smith, *unpublished*). Chlorothalonil, a broad spectrum protectant fungicide, is an effective fungicide for the control of leaf spot, and has remained the standard since the 1970s (Smith and Luttrell, 1980). Pentachloronitrobenzene (PCNB), an organochlorine fungicide, was the first fungicide used extensively for soilborne disease control; however, high costs and inconsistent field results limited producer usage (Csinos, 1989). PCNB was applied as a granule, the logic being that granules were needed to filter down through the canopy to the soil surface for control of soilborne diseases (Csinos, 1989). This same strategy was applied to newer fungicides, such as the sterol demethylation inhibitors (DMI) as they were evaluated on peanut. Granular formulations of diniconazole and tebuconazole were examined, but results were inconsistent (Csinos, 1987). However, suppression of soilborne diseases was observed when these compounds were applied to foliage in leaf spot studies (Backman and Crawford, 1985; Csinos et al., 1987; Brenneman et al., 1991; Brenneman and Culbreath, 1994). By mixing dyes with the foliar-applied fungicides and

applying irrigation, Csinos (1986) documented how these materials were delivered to the soil. He demonstrated that the architecture of the peanut plant served to funnel rain or irrigation water along the stems and increase deposition of fungicides at the plant crown and pegs. This redistribution is important since these structures serve as primary infection courts for stem rot infections (Melouk and Backman, 1995).

In addition to tebuconazole, several other fungicides have been registered for foliar and/or soilborne disease control in peanuts. Flutolanil, a benzanilide fungicide, is highly effective against *S. rolfsii* and *R. solani* (Csinos, 1987; Hagan et al., 2004), but has little or no activity against the leaf spot pathogens. Therefore, tank-mixes with other fungicides, such as propiconazole or chlorothalonil, are required for leaf spot control (Kemerait et al., 2003). Azoxystrobin, a quinone outside inhibiting (QoI) fungicide, has been shown to be active against both foliar and soilborne diseases (Grichar, 2000; Hagan et al., 2004). The registration, utility, and efficacy of these products have dramatically improved control of soilborne diseases. As a result, these products have become widely accepted by producers. Fungicide programs utilizing tebuconazole consist of a calendar-based 4-spray block; whereas, flutolanil and azoxystrobin are generally applied 60 and 90 days after planting (Kemerait et al.,, 2003).

All fungicides currently used for management of peanut stem rot are applied as foliar sprays, and presumably redistributed with subsequent rainfall and/or irrigation as previously described. However, this process is not well defined. To better understand this phenomenon, particularly with different fungicide classes, a bioassay was needed to quantify residues of previously applied fungicides on various parts of the peanut plant. Previous researchers have used excised peanut stems to determine the residual activity of fungicides for the control of

Sclerotinia blight, caused by the soilborne fungus *Sclerotinia minor* Jagger (Brenneman et al., 1988), and southern stem rot (Rideout, 2002). Stem inoculations also proved useful for evaluating differences in susceptibility of plant parts as they aged (Rideout, 2002). Based on these previous results, the methods should be adaptable for evaluating susceptibility of various tissues in the peanut canopy to infection by *S. rolfsii*. The initial objective of this study was to develop an inoculation method to assay fungicide residues on different plant tissues. The second objective was to use this method to quantify the deposition, and redistribution of foliar applied fungicides on peanut leaves and stems. Techniques resulting from this work will also be used in subsequent experiments to determine the effects of irrigation on the redistribution of foliar-applied fungicides.

MATERIALS AND METHODS

Inoculation techniques. In 2003, main stems of 45-day-old Georgia Green peanut plants were sampled from non-fungicide treated border rows collected from a field experiment at the University of Georgia Coastal Plain Experiment Station, Gibbs farm (trial 1). The experiment was repeated with 48-day-old plants obtained from non-fungicide treated border rows of a similar experiment at the University of Georgia Coastal Plain Experiment Station, Rigdon farm (trial 2). Main stems were cut at the soil line and taken to the laboratory. One leaflet and stem section (2.5-cm long) were cut from the upper canopy (at or below the second fully expanded leaf), middle canopy (at an intermediate node), and lower canopy (above the node closest to the soil line) of each plant. In all, 48 plants were used for each trial. Excised tissues were then placed in petri dishes (100 × 15 mm) containing moistened, sterile filter paper. Wound treatments consisted of wounded or non-wounded tissues, and were assigned at random to the 48 plants. A sterile dissecting needle was used to

create shallow wound in the center of each tissue. Inoculations were made on wounded or non-wounded tissues by placing the fungus mycelial side down in the middle of the tissue. Hyphal plugs (1-cm diam.) of *Sclerotium rolfsii* isolate SR-18, were obtained from actively growing colonies on water agar (WA), potato dextrose agar (PDA), half-strength potato dextrose agar (½ PDA), or quarter-strength potato dextrose agar (¼ PDA). Treatments were arranged in a split-plot design with wounding serving as whole plots, and nutrient sources as sub-plots. There were a total of six replications per treatment. Tissue pieces in Petri dishes were transferred to a growth chamber, and incubated in the dark at 28ºC and 95% relative humidity (RH) for 96 hours. Lesion area and length were recorded at 12-hour intervals, for leaflets and stems, respectively. The area under disease progress curve (AUDPC) was calculated using methods described by Shaner and Finney (1977).

Sample size. To determine an appropriate sample size, fifty main stems of healthy Georgia Green peanut plants were randomly collected from plots in a non-fungicide treated field study in Appling County at 50 DAP during the 2004 growing season. Tissues were inoculated with ¼ PDA plugs containing *S. rolfsii* SR-18 as previously described. The excised tissues in Petri plates incubated in the dark at 28ºC and 95% RH for 72-hours at which time lesions were measured.

Evaluation of fungicides. The inoculation method described above was also used to quantify the response of *S. rolfsii* isolate SR-18 to varying concentrations of the fungicides azoxystrobin, flutolanil and tebuconazole *in planta*. Leaflet and stem tissues were collected from non-fungicide treated border rows of Georgia Green peanuts from field plots at the Rigdon farm and Appling County field trial during the 2004 field season 60 DAP. Standard formulations and field rates, applied in 188 L/ha of water, of azoxystrobin (Abound 2.08F,

0.33 kg a.i./ha, Syngenta Crop Protection, Greensboro, NC), tebuconazole (Folicur 3.6F, 0.23 kg a.i./ha, Kansas City, MO), and flutolanil (Moncut 70DF, 1.0 kg a.i./ha, Gowan Co., Yuma, AZ) were used to prepare ten-fold serial dilutions. Water containing no fungicide served as controls. A surfactant (30 µl of Tween 20 per 100 ml) was added to each solution including controls to ensure a relatively uniform distribution of fungicides on the tissue surface. Excised tissues were randomly assigned a fungicide concentration, and tissues were immersed in fungicide suspensions for 30 sec, and allowed to dry at room temperature overnight prior to inoculations. Tissues were inoculated as described above, and lesions development was recorded after 72-hours incubation. Treatments were arranged in a randomized complete block design with five replications per trial.

Statistical analysis. Lesion length on stems, percentage of colonization of leaflets, and AUDPC values from the inoculation studies were subjected to analysis of variance using Proc ANOVA (Statistical Analysis System, version 9.0, Cary, NC) to determine significant differences (P=0.05) among treatments, and Fisher's protected least significant difference (LSD) was calculated for mean separations within each study. All subsequent references to significant effects of factors, interactions, or differences among means indicate significance at $P \leq 0.05$ unless otherwise stated. To determine a reliable sample size, sample means, standard deviations, and coefficients of variability were plotted against the sample size (n). Sample size was based on the weighted mean of the variance of lesion development from each tissue layer. To account for differences in leaflet size within the different canopy layers, a sub-sample of thirty leaflets were arbitrarily chosen from each canopy layer. Leaflets were blotted on a paper towel, and scanned using a ScanMaker 5900 48-Bit color scanner (Microtek Lab Inc., Carson, CA). Leaflet area was estimated using the Assess Image

Analysis Software (APS Press, St. Paul MN), and lesion development was converted to a percentage of the leaflet area colonized.

For the fungicide evaluations, the percent inhibition of lesion expansion from each treatment was determined using the equation; % inhibition = 100 – ((lesion measurement ÷ nontreated control) × 100), and values were plotted against their respective $\log_{10}$ transformed fungicide concentration + 1. Data were analyzed using linear regression in Sigma Plot version 8.0 (Systat Software, Inc., Point Richmond, CA). Regression equations were used to estimate fungicide concentrations for 50% inhibition of lesion expansion (EC_{50}).

RESULTS AND DISCUSSION

Inoculation techniques. The interaction of trial by nutrient source was not significant; therefore data were pooled across the four nutrient sources to determine the effect of wounding on leaflets and stems. Experiments demonstrated that wounding was not required for infection of either tissue type, but there was greater colonization of the wounded versus non-wounded leaves at all canopy layers (Table 5.1). Lesion length for stem sections did not differ between the two inoculation methods (Table 5.1). These findings provide additional support that *S. rolsii* is capable of penetrating non-wounded tissues (Aycock, 1966; Punja, 1985).

Lesion development varied significantly according to tissue origin (Table 5.1). Stem tissues obtained from the upper canopy were most rapidly colonized by *S. rolfsii*, followed by tissues from the middle and lower layers, respectively. Colonization of leaflets followed a similar trend, but layers from the middle and lower canopy layers were not significantly different. These results are similar to a report by Brenneman et al., (1988), in which terminal stem segments were more susceptible to infection by *Sclerotinia minor* than were basal

segments. In addition, these results demonstrate the importance of standardizing tissues collected from different canopy layers.

In regard to nutrient source, the analysis of variance showed no significant trial effects; therefore, results were combined over trial. Inoculum produced on PDA resulted in larger lesions on leaflets (Figure 5.1a), and stems (Figure 5.1b). In both assays, WA was an insufficient nutrient source, and ½ PDA, and ¼ PDA both produced intermediate lesions. No significant differences in lesion development were observed between the PDA and ½ PDA nutrient sources, and lesion development was less variable when ¼ PDA was used as an inoculum source (Figure 5.1a-b). These results provide evidence that an exogenous nutrient source is required to initiate infection when using mycelia and the severity of those infections is directly related to the strength of the nutrient source. Reports have described that mycelium from germinating sclerotia can infect host tissue without an exogenous nutrient source; however, mycelial growth is influenced by several factors including volatile compounds from decaying plant tissues and nitrogenous amendments (Melouk and Backman, 1995; Punja, 1985). Lesion development was slower for non-wounded tissues inoculated with ¼ PDA plugs containing *S. rolfsii* mycelium, thus it was better to differentiate treatment effects. This method was used in all subsequent experiments.

Sample size. Increasing the sample size results in a more accurate estimate of parameters (Steel and Torrie, 1980). Using the sample mean, standard deviation, and coefficient of variation as a function of sample size, inferences can be made about the optimum number of samples needed to obtain the most desired level of accuracy. In these studies, mean lesion length and percent colonization differed by tissue origin, and were greatest for the tissues collected from the upper canopy and lowest for tissues collected from

the middle and lower canopies, and reinforces the importance of standardizing tissues when sampling throughout the canopy.

Although differences in lesion size were observed among tissues from different canopy layers, no treatment × canopy layer interaction was observed; therefore, data from all three layers were combined for analysis. Variance for both the leaflet, and stem assay were similar. For the leaflet assay, the sample mean, and standard deviation stabilized at sample sizes of 11, and 9, respectively (Figure 5.2 a-b); whereas, the coefficient of variation was lowest at a sample size of 10 (Figure 5.2 c). For the stem assay, optimal sample size based on the mean, standard deviation, and coefficient of variation were found to be 8, 10, and 11, respectively (Figure 5.2 a-c). These results indicate that a sample size of 8 to 10 stem or leaflet sections are needed to obtain the most reliable parameter estimates. However, other factors such as the availability of space or materials may influence sample sizes.

Evaluation of fungicides. There were no canopy layer × concentration interactions for lesion development in either assay; therefore, data were pooled across canopy layer. Lesion development was significantly reduced for all concentrations of azoxystrobin, flutolanil, and tebuconazole when compared to the control (data not shown). Fungicide performance was similar on both leaflet and stem tissues for all three compounds (Table 5.2, Figure 5.3). A positive linear relationship was found between log transformed fungicide concentration and inhibition of lesion development. The percent inhibition increased linearly as fungicide concentration increased. Linear relationships were significant for all fungicides and tissues (Table 5.2). In general, the inhibition of lesions was greater in stem assays than in leaflet assays, which may have resulted in differences in susceptibility between the two tissues. Similar trends in the EC_{50} values were observed for azoxystrobin, flutolanil, and

tebuconazole in both tissue types (Table 5.2). Field studies have demonstrated that azoxystrobin, tebuconazole, and flutolanil are highly efficacious against stem rot (Csinos, 1987; Brenneman and Culbreath, 1994; Grichar, 2000; Hagan et al., 2004), and those findings are supported in this study. Isolate SR-18 was more sensitive to tebuconazole than azoxystrobin or flutolanil in both assays (Table 5.2). For the leaflet and stem assays, EC_{50} values were 17.2, 9.5, and 18.1 mg/L, and 18.1, 8.3, and 13.5 mg/L azoxystrobin, tebuconazole, and flutolanil.

One potential explanation for the observed differences in fungicide activity could be related to protectant or systemic activity of the compounds evaluated. Fungicides within a chemical class can have very different physiochemical properties; therefore one would expect even greater differences among classes than among fungicides within the same class. Reports have indicated that flutolanil is absorbed by roots, and translocated acropetally in rice (Araki, 1985); however, little information regarding the systemic activity of flutolanil in peanut is available. Although comparisons in absorption between leaflet and stem tissues were not made in this study, it appears flutolanil was more readily absorbed into stems than leaflets. This effect could simply be an artifact of differences between the two tissue types, or that fungicide was more readily taken up through the cut ends. Additional studies may be required to determine differences in the absorption of fungicides between leaflet and stem tissues. The systemic properties of DMI and QoI fungicides are far more defined than those of flutolanil. Studies conducted by Tsuda et al., (2004) document the translaminar (movement from the upper leaf surface to the lower leaf surface) and transcuticular (movement through the cuticle) activity of several DMI fungicides, including tebuconazole. They found that fungicide efficacy against cucumber powdery mildew (*Sphaerotheca*

cucurbitae (Jaczewski) Zhao) on cucumber (*Cucumis sativus* L.) seedlings resulted from permeation and dissipation of the fungicides within leaves. The foliar uptake of azoxystrobin is a gradual process with relatively low amounts of applied material being absorbed within 24 hours of application (Bartlett, et al., 2002). Furthermore, tissue type and age have also been shown to influence uptake of azoxystrobin in a broad range of commercial field crops (Bartlett, et al., 2002). The effect of tissue age on uptake of azoxystrobin could not be ascertained, due to the confounding effects of tissue susceptibility from the three canopy layers.

CONCLUSIONS

Various assays have been developed using excised peanut tissues to study different aspects of peanut disease management. Detached lateral branches to evaluate cultivar susceptibility, and isolate virulence of *Sclerotinia minor* (Brenneman, et al., 1988). Detached shoots, limbs, leaves or leaflets have been used successfully as screening tools to evaluate cultivar resistance to several other peanut pathogens (Franke and Brenneman, 2001; Hollowell and Shew, 2003; Melouk et al., 1992). Such methods also have been used to determine the residual activity of fungicides used to control peanut diseases. Brenneman et al., (1988) used detached lateral limbs to determine the residual activity of fungicides for the suppression of *S. minor*; while Rideout (2002) used similar methods to characterize fungicide residues used to control *S. rolfsii.*

Methods including excised tissue are quick, efficient, require relatively small amounts of plant material, and can be conducted under controlled environmental conditions. Researchers can benefit using these methods, compared to traditional field studies, which require large areas of land and increased labor. The method developed in this study proved

to be useful for determining the susceptibility of stem and peanut tissues from different canopy layers to *S. rolfsii*. Using this method, we demonstrated that tissues from the upper canopy are more susceptible to infection than those from the middle and lower canopy. These differences must be considered in subsequent studies where samples are taken within the peanut canopy. These findings also indicate that inoculations with *S. rolfsii* is a sensitive means of estimating concentrations of fungicide residues on/in peanut tissues, and that the method described here can be used to determine the deposition and redistribution of foliar-applied fungicides.

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Table 5.1. Effects of wounding and tissue origin on the infection of detached peanut leaflets and stems by *Sclerotium rolfsii*[a].

Tissue,	Lesion measurement[b]	
Canopy layer	Wounded	Non-wounded
Leaflet	- - - - - - - - - - % area colonized - - - - - - - - -	
Upper	50.4 a A	40.8 a B
Middle	37.2 b A	34.7 b B
Lower	35.7 b A	32.6 b B
Stem	- - - - - - - - - - Length (mm) - - - - - - - - - -	
Upper	18.5 a A	18.0 a A
Middle	15.2 b A	14.9 b A
Lower	12.2 c A	11.5 c A

[a] Tissues were collected from the three canopy layers as described in the Methods and Materials section. For the wound treatments, a sterile dissecting needle was used to create shallow wounds in the center of each tissue.

[b] Means followed by the same lower-case and upper-case letter are not significantly different (P=0.05) within columns and rows, respectively.

Table 5.2. Relationship between percent inhibition of stem rot lesions on excised peanut tissues and concentrations of three fungicides.

Tissue, Fungicide	Regression Equation[a]	R^2	MSE[b]	p-value	EC_{50}[c]
Leaflet					
Azoxystrobin	y = 8.52 + 32.91x	0.9447	84.65	0.0056	17.2
Tebuconazole	y = 2.84 + 46.25x	0.9870	30.42	0.0006	9.5
Flutolanil	y = 6.85 + 33.60x	0.9677	61.73	0.0025	18.1
Stem					
Azoxystrobin	y = 4.41 + 35.65x	0.9839	27.81	0.0009	18.1
Tebuconazole	y = 7.62 + 43.62x	0.9568	97.75	0.0039	8.3
Flutolanil	y = 5.39 + 38.34x	0.9821	43.88	0.0010	13.5

[a] Linear relationship between percent inhibition of lesions from *S. rolfsii* inoculations (y) and log transformed fungicide concentration + 1 (x).

[b] MSE = mean square error.

[c] Effective concentration (mg a.i./L) for 50% inhibition of lesion development on leaflets and stems.

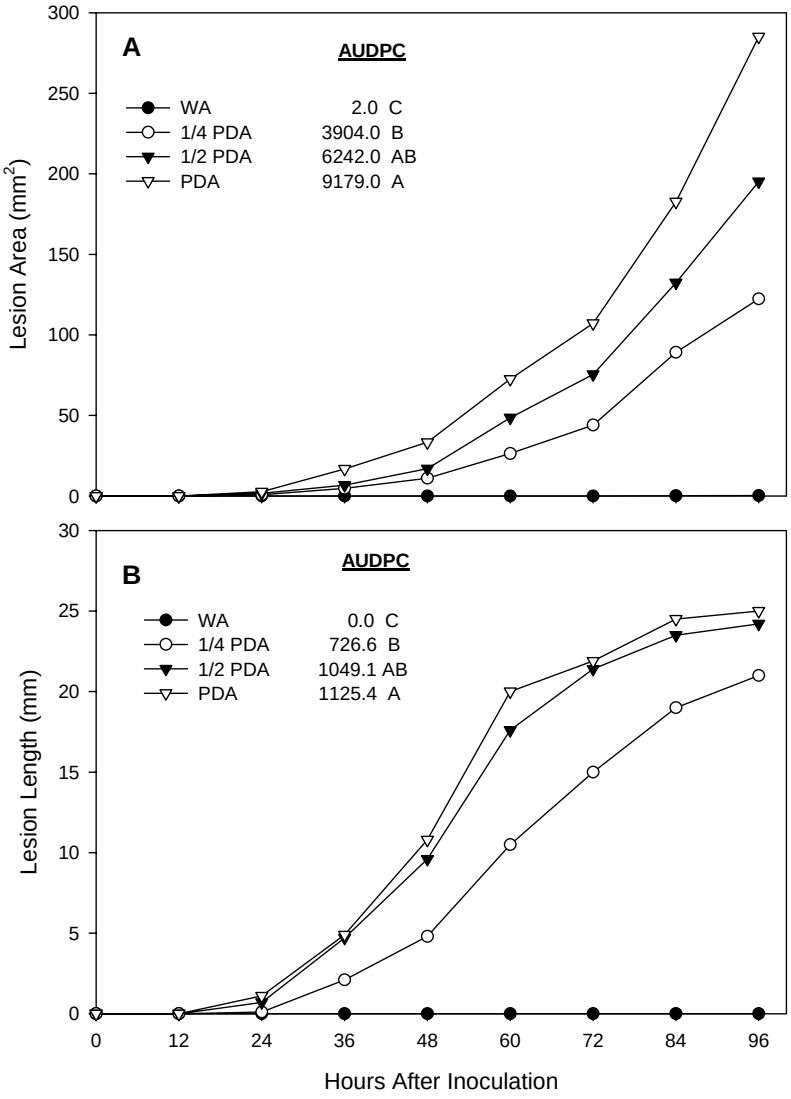

Figure 5.1. Lesion development on excised peanut A. leaflets and B. stems inoculated with *Sclerotium rolfsii* grown on four nutrient sources (WA = water agar, PDA = potato dextrose agar ¼ PDA = quarter strength PDA, ½ PDA = half strength PDA). Lesions were measured at every 12 hours for 96 hours. Data were used to construct disease progress curves, and the area under disease progress curve (AUDPC) was calculated (Shaner and Finney, 1977) for each treatment. Means followed by the same letter within a column are not significantly different (P=0.05) according to Fisher's protected least significant differences test.

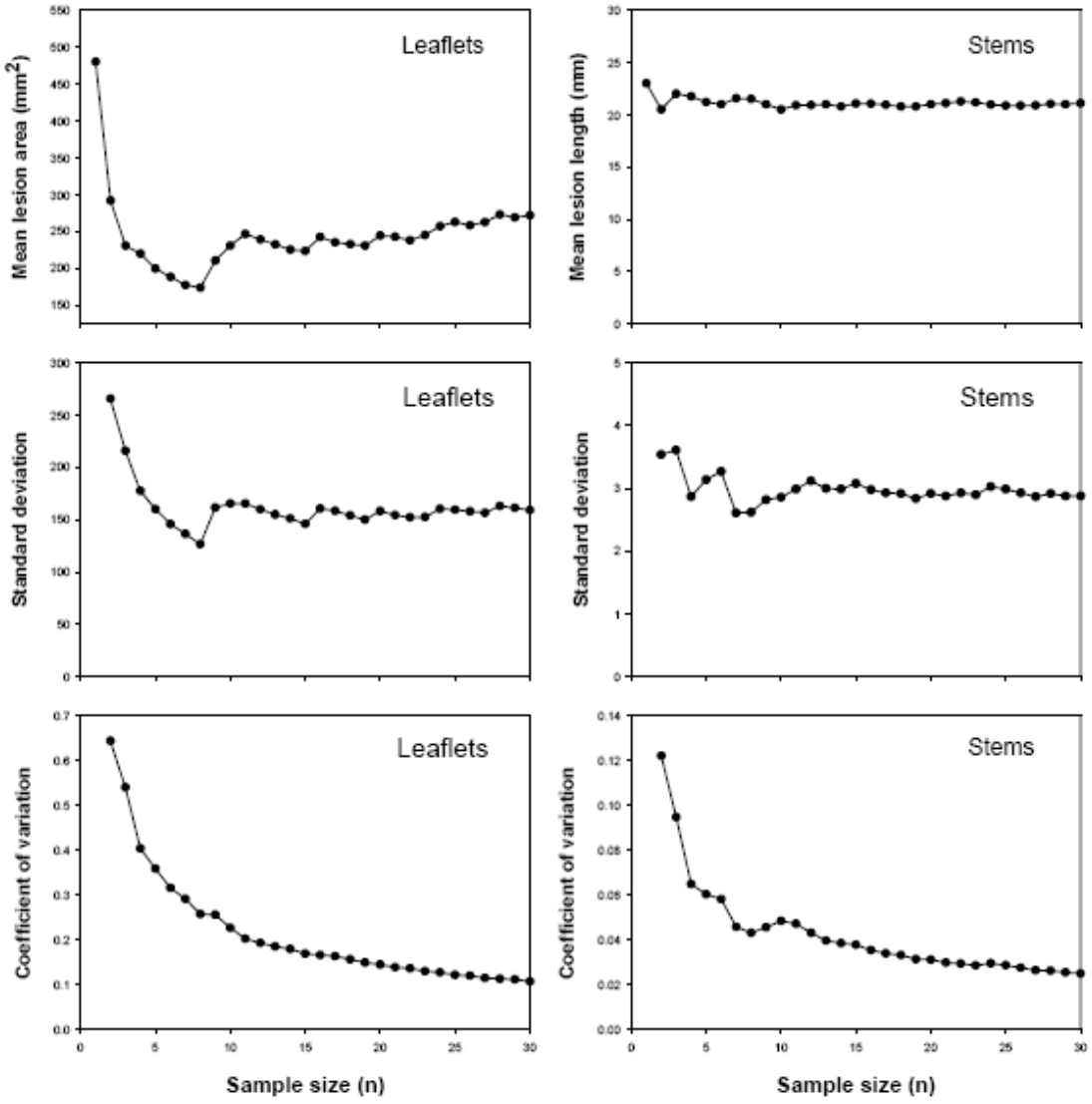

Figure 5.2. Effect of increasing sample size (n) on the sample mean, sample standard deviation, and coefficient of variation of % area colonized and lesion length on excised peanut leaflets and stems inoculated with *Sclerotium rolfsii*.

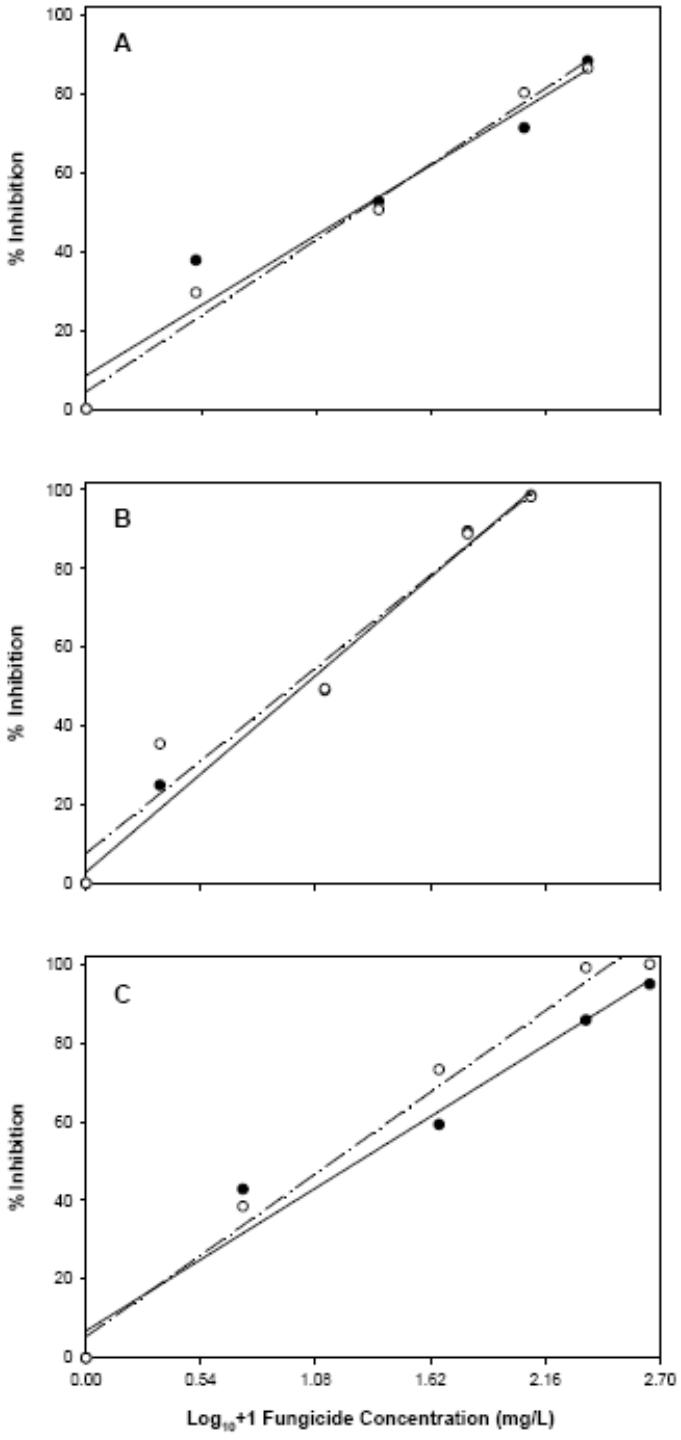

Figure 5.3. Dosage-response effect of azoxystrobin (A), tebuconazole (B), and flutolanil (C) on lesion development on excised peanut leaflets (● and solid-line), and stems (○ and dashed-line) treated with fungicides and inoculated with *S. rolfsii*.

CHAPTER 6

MAXIMIZING CONTROL OF FOLIAR AND SOILBORNE DISEASES OF PEANUT WITH FOLIAR APPLIED FUNGICIDES AND IRRIGATION TIMING[1]

[1] Woodward, J.E., T.B. Brenneman, and B.G. Mullinix. 2006. To be submitted to *Plant Disease*.

Abstract

In the southeastern United States, foliar applied fungicides are routinely used to manage foliar and soilborne diseases. Irrigation is often applied to treated foliage to obtain maximum suppression of soilborne diseases; however, administering irrigation too soon may adversely impact foliar disease control. A microplot study was conducted in 2003, 2004, and 2005 to evaluate the redistribution of azoxystrobin, tebuconazole, and chlorothalonil plus flutolanil following different irrigation timings. Standard fungicide regimes were followed by 1.3 cm of irrigation 0, 6, 12, 24, 48, or 96 h after application, and non-irrigated controls were included. Microplots not receiving irrigation were covered. Early leaf spot was more severe when irrigation was administered immediately following fungicide applications, and was significantly reduced for the 6 and 12 hr irrigation timings. Maximum control was obtained for the 24 hr treatment. *Sclerotium rolfsii* was used to bioassay foliage and pods. Lesion development on leaflets and stems was greater for earlier irrigation timings; however, lesions for the 24 hr and later timings did not differ from controls. Pod colonization for each fungicide increased according to a quadratic function of irrigation timing. Colonization of pods treated with azoxystrobin was similar for all irrigation timings; whereas, suppression was greatest for tebuconazole at earlier irrigation timings. This study demonstrates that irrigation can be used to improve soilborne disease control, but administering irrigation within 24 h may decrease leaf spot control.

Keywords: *Arachis hypogaea*, fungicide redistribution, fungicide efficacy

INTRODUCTION

Multiple applications of chemical fungicides are required to adequately control fungal diseases of peanut (*Arachis hypogaea* L.). In the southeastern United States, standard fungicide programs are initiated approximately 30 days after planting (DAP) and subsequent applications are made on 14-day intervals. Weather conditions are conducive for both foliar and soilborne diseases. As a result, seven or more applications are made per season (Kemerait, 2005). The most important foliar diseases are early leaf spot, caused by *Cercospora arachidicola* S. Hori, and late leaf spot, caused by *Cercosporidium personatum* (Berk. & M. A. Curtis) Deighton, and, southern stem rot (*Sclerotium rolfsii* Sacc.) is the most damaging soilborne disease (Kemerait, 2004).

Various management options have been available to producers for leaf spot control. Copper fungicides were commonly used for suppression of leaf spot until registration of chlorothalonil revolutionized leaf spot management for producers (Smith and Littrell, 1980). Although chlorothalonil is very effective against leaf spot, it has little or no activity aginst stem rot (Smith and Littrell, 1980; Hagan et al., 2004; Culbreath et al., 1995). In the past, stem rot was suppressed through applications of pentachloronitrobenzene (PCNB) (Csinos, 1989), and to a lesser extent, the insecticide chlorpyrifos (Csinos, 1984; Hagan et al., 1986). Since *S. rolfsii* initially infects near the base of main stems of plants (Aycock, 1961; Punja, 1989), these products were formulated as granules to penetrate the foliage, and applied in bands centered over the peanut rows; however, control using these materials was costly and inconsistent (Csinos, 1989).

Registration of the carboximide fungicide flutolanil in the late 1980s has provided producers with a more effective means of managing stem rot (Csinos, 1987; Hagan et al.,

2004); however, flutolanil is not active against leaf spot and must be applied in tank mix combinations with chlorothalonil, or some other effective leaf spot material (Culbreath et al., 1992). Furthermore, the registration of sterol biosynthesis inhibiting (SBI) fungicides (e.g. tebuconazole), and strobilurin (QoI) fungicides (e.g. azoxystrobin) has greatly improved both stem rot and leaf spot management over the past decade (Grichar, 2000; Hagan et al. 2004; Brenneman et al. 1991; Brenneman and Murphy, 1991; Brenneman and Culbreath, 1994). In contrast to granular fungicides, these compounds are applied in water as a broadcast spray to peanut foliage. Fungicide deposition within the canopy contributes to efficacy for leaf spot, but the management of stem rot is more difficult, since the target of spray deposition for stem rot control is at the base of the plant or even below ground. The mechanism by which foliar-applied fungicides affect stem rot is not fully understood.

There is currently limited information available regarding the redistribution of fungicides from rainfall or irrigation. Most of what has been reported pertains to the influence of rainfall and the rainfastness of protectant compounds (Bruhn and Fry, 1982; Smith and MacHardy, 1984; Neely, 1971; Kudsk et al., 1991). Information regarding mechanisms of soilborne disease suppression with foliar applied fungicides is even more limited. Cooke et al. (1989), documented that simulated rainfall increased suppression of eyespot of wheat, caused by *Pseucocercosporella herpotrichoides* for prochloraz. They hypothesized that initial fungicide deposits applied to aerial parts of the plant are washed to the base of the plant by rainfall or dew. A similar phenomenon was observed in peanut. Csinos and Kvien (1988) demonstrated that irrigation was an effective means of delivering foliar-applied dyes to plant crowns and pegs. In leaf spot studies evaluating foliar applied fungicides, other researchers found that some fungicides suppressed stem rot (Backman and

Crawford, 1985). Presumably, fungicides were redistributed from the foliage to lower plant parts where *S. rolfsii* infections originate (Melouk and Backman, 1995).

Concequently, producers in Georgia are advised to irrigate following fungicide applications in order to maximize stem rot control (Kemerait et al., 2006); however, irrigating too soon after a fungicide application may compromise leaf spot control. The effects of irrigation timing following the application of fungicides on the control of foliar and soilborne diseases is not well documented. Optimal timing has not been determined and may well be product specific. The purpose of this study was to investigate the effect of irrigation timing following fungicide application and control peanut leaf spot and stem rot Specific objectives were to: (i) evaluate the effects of irrigation timing relative to fungicide application on leaf spot control, (ii) compare the distribution of fungicide residues on peanut foliage and pods under different irrigation timings, and (iii) determine the irrigation timing that optomizes foliar and soilborne disease control with each product evaluated.

MATERIALS AND METHODS

Field experiment. Microplot studies were conducted at the University of Georgia - Coastal Plain Experiment Station Black Shank Farm located in Tifton, GA in 2003, 2004, and 2005. Microplots were constructed out of cylindrical aluminum rings (0.9 m diameter by 0.3 m high), and buried 15 cm deep in the soil. The soil type for the plot area was a Fuquay sand (loamy, kaolinitic, thermic Arenic Plinthic Kandiult, pH=6.1). Microplots were manually tilled and fumigated with metam sodium (Vapam 32%; AMVAC Chemical Corp., Newport Beach, CA) at 1,429 liters ha^{-1} three to four weeks prior to planting. A total of nine Georgia Green peanut seeds were planted manually in a triangular pattern in each plot on 25 Jun 2003, 14 May 2004, and 10 June 2005. After emergence, plant populations were thinned

to three plants per microplot. Seven fungicide applications were made on a 14-day schedule beginning 21 DAP. The four fungicide programs evaluated were (i) seven applications of 1.26 kg a.i. ha^{-1} chlorothalonil (Bravo Ultrex, Syngenta Crop Protection, Greensboro, NC), (ii) chlorothalonil applications followed by a block of four applications of 0.23 kg a.i. ha^{-1} tebuconazole (Folicur 3.6F, Bayer Crop Protection, Kansas City, MO), (iii) two applications of 0.47 kg a.i. ha^{-1} azoxystrobin (Abound 2.08F, Syngenta Crop Protection, Greensboro, NC) applied 63 and 91 DAP, and (iv) a combintation of 1.26 kg a.i. ha^{-1} chlorothalonil and 1.0 kg a.i. ha^{-1} flutolanil (Moncut 70DF, Gowan, Co., Yuma, AZ) applied 63 and 91 DAP. For the azoxystrobin and chlorothalonil + flutolanil programs described above, the remaining five applications were 1.26 kg a.i. ha^{-1} chlorothalonil. A detailed description of the fungicide programs is shown in Table 6.1. Irrigation (1.3 cm) was administered via solid set sprinklers 0, 6, 12, 24, 48 or 96 h after each fungicide application for applications 4 through 7. Non-irrigated microplots served as controls. Plywood sheets (1.2 m ×1.2 m) were used to cover microplots not scheduled to receive irrigation, or to exclude rainfall during the first 96 hr after each spray. All microplots were exposed to natural rainfall that fell outside this time period. All microplots were irrigated (0.7 cm) prior to the application of fungicides to minimize the effects of additional water. All possible combinations of irrigation treatments and fungicide programs were included, except for microplots that were receiving the seven-spray chlorothalonil program. These microplots were irrigated 24 h after fungicide applications, and served as a commercial standard. The experiment consisted of a 3 × 7 factorial + 1 chlorothalonil standard, resulting in a total of twenty-two treatments, which were arranged in a randomized complete block design with seven replications. All production practices other than disease control and irrigation were based on conventional management

practices specified by the University of Georgia Cooperative Extension Service (Beasley et al., 1997).

Fungicide residue bioassay. One peanut main stem was collected at 68, 96, and 110 DAP from each microplot, twenty-four hours after the final irrigation treatments had been administered. Main stems were cut at the soil surface, placed in plastic freezer bags, and transported to the laboratory at 68, 96, and 110 DAP. Prior to sampling, leaf spot was enumerated as the number of lesions per leaf within each canopy layer for the 110 DAP sampling date. Leaflet and stem sections were taken from the upper, middle, and lower canopies, placed in petri dishes, and inoculated with *S. rolfsii* using the methods described in Chapter 6. Treatments were arranged in a randomized complete block design, and inoculated stems and leaflets were incubated in the dark at 28ºC and 95% relative humidity (RH). After 3 days of incubation, lesion area and length on excised leaflets and stems, respectively, were recorded.

A similar bioassay, using *S. rolfsii*, was developed to assay fungicide residues on peanut pods. Following the removal of main stems, peanut plants were inverted by hand and three pods closest to the tap root were arbitrarily collected and taken to the laboratory. Excised pods were placed in petri dishes (100 × 15 mm) containing moistened, sterile filter paper. Pods were inoculated with 0.5-cm-diam. potato dextrose agar plugs from the growing margin of 3-day-old *S. rolfsii* cultures. Agar plugs were placed mycelium side down on the pods below the point of peg attachment. Petri dishes were covered, and incubated in the dark at 28ºC and 95% RH. The percentage of each pod colonized by *S. rolfsii* was recorded 120 h after inoculation.

Statistical analysis. The experimental design consisted of three years, seven replications, four fungicide programs, seven irrigation treatments, three canopy positions, and three sampling dates during the growing season arranged in a split-split plot for each sampling date. Two different models were employed since the chlorothalonil program only received irrigation after 24 h. Data were analyzed using SAS Proc MIXED (SAS Institute). The first model included all four fungicide programs for the purpose of determining the size of the error in the data collected. The second model excluded the chlorothalonil program. Main effects and all interactions among fungicide program, irrigation timing, and canopy position were considered as fixed effects. Random effects included the following: year, rep(year), year*fungicide, year*irrigation, year*fungicide*irrigation, rep*fungicide*irrigation(year), rep*position, year*fungicide*position, year*irrigation*position, year*fungicide*irrigation*position. The appropriate denominator degrees of freedom (ddfm) were determined using the Satterthwaite method (ddfm=satterth) option in the model statement. The full model was reduced on variable at a time until all factors remaining were significant at the P=0.05 level, and Least square means (LSMEANS) were compared using the PDIFF option. Least significant difference (LSD) values were calculated using the standard errors and t-values representing the adjusted degrees of freedom from the pairwise comparison of means from the analysis. For the regression analysis, the intercept was adjusted to the mean irrigation timing (31 h) as suggested by Draper and Smith (1981). The response of lesion development on pods (as the % colonization) to irrigation timing was evaluated usinf SAS Proc NONLIN for fit to a quadratic equation. Four additional treatments (the 3 non-irrigated controls and the chlorothalonil standard) served as controls. SAS Proc TTEST was used to test for differences among the chlorothalonil

standard, and the non-irrigated controls based on the parameter estimates from the the regression. The chlorothalonil standard was compared with the fungicide intercepts and the non-irrigated treatments.

RESULTS

Fungicide program had a significant effect on the development of *S. rolfsii* lesions on leaflets for the 68 and 110 DAP sampling dates, but not 82 DAP (Table 6.2). The application of tebuconazole, azoxystrobin, or flutolanil significantly reduced lesion area on leaflets compared to those treated with chlorothalonil (data not shown). There was a significant irrigation × canopy layer interaction (P=0.0001) on lesion size on leaflets for all three sampling dates (Table 6.2). Lesions were much larger and significant differences in lesion size were more commonly observed among canopy layers when plants were irrigated soon after fungicides were applied (Table 6.3). The opposite trend was observed for later irrigation timings, and colonization of leaflets irrigated at 96 h was very similar to the non-irrigated control. Although not consistently significant, lesions were generally larger on leaflets from the lower and middle canopy, respectively, when irrigation was applied 12 h or more after fungicides (Table 6.2).

There was a significant fungicide × canopy layer interaction lesion length on stems collected 68 DAP and 110 DAP (Table 6.2). Stem lesions were significantly smaller when treated with tebuconazole, azoxystrobin, or flutolanil compared to chlorothalonil (data not shown). Although not significant, lesions were consistently smaller on stems treated with flutolanil, regardless of tissue origin, whereas, lesions were typically larger on stems treated with azoxystrobin (Table 6.4). In general, lesions were largest on stems obtained from the

upper canopy, followed by the middle and lower canopy, respectively; however, these differences were only significant for flutolanil and tebuconazole on 110 DAP.

There was a significant fungicide × irrigation × canopy layer interaction on lesion length on stems collected 83 DAP (Table 6.2). No clear relationship was found between lesion suppression and fungicide efficacy within the canopy layers. Overall, the lesions were larger on stems treated with azoxystrobin (Table 6.5). Mean lesion lengths for the 0-h irrigation from the upper, middle and lower canopy, repectively, were 16.8, 15.4, and 11.1 mm for azoxystrobin, 12.9, 10.7, and 8.0 mm for flutolanil, and 14.6, 12.9, and 9.5 mm for tebuconazole (Table 6.5). Colonization of stems collected 82 DAP and 110 DAP was significantly affected by irrigation timing for the 82 DAP and 110 DAP sampling dates (Table 6.2). Lesion size among the different irrigation timings was variable across canopy layers for flutolanil and azoxystrobin. Overall, lesions were much larger on stems that were irrigated immediately after fungicides were applied and smaller on stems that did not receive irrigation (Table 5). Significant differences in lesion size were observed among canopy layers. In general, stems from the upper canopy were more rapidly colonized, compared to stems from the middle and lower canopy, respectively. For the most part, this trend was consistent across irrigation timings and fungicides (Table 6.5).

Irrigation timing was the only factor that significantly affected leaf spot intensity (Table 6.2). Due to a lack of any significant interactions, data were pooled across fungicides and canopy layers. Longer delays between fungicide applications and irrigation resulted in lower leaf spot intensity (Figure 6.1). Irrigation immediately following fungicide application resulted in significantly higher number of lesions per leaf compared to all other treatments. Allowing fungicides to remain on the leaf surface for 6 h reduced the number of lesions per

leaf and a further reduction was observed for the 12 h irrigation. When irrigation was applied 24 h or more after fungicides, the number of leaf spot lesions did not differ from the non-irrigated control or the chlorothalonil standard.

The timing of irrigation was the only factor that significantly affected the colonization of peanut pods by *S. rolfsii* (Table 6.2). The regressions of percent pod colonization on time are shown in Figure 6.2. Although the fungicide × irrigation interaction was not significant, analysis revealed differences in the response of irrigation delay among fungicides (data not shown). The three lines were fitted to a second order polynomial across irrigation timing, and the two parameters showed no significant differences among the three fungicides (Figure 6.2). When compared to the respective controls, the intercepts were not significantly different for azoxystrobin (t=1.81, df=93, p=0.05), but highly significant for tebuconazole (t=5.99, df=93, p=0.01), and flutolanil (t=2.86, df=93, p=0.01). The intercept for the non-irrigated tebuconazole control differed significantly from the chlorothalonil standard (t=3.06, df=93, p=0.01), as did the azoxystrobin (t=4.54, df=93, p=0.01) and flutolanil (t=3.88, df=93, p=0.01) non-irrigated controls. Overall, pod colonization increased as irrigation timing was delayed (Figure 6.2).

Tebuconazole was strongly affected by irrigation. Pod colonization was 12.0, 17.3, 22.0, and 29.5% for the 0-, 6-, 12- and 24-h irrigation treatments, respectively (Figure 6.2a). Similar trends were observed for azoxystrobin and flutolanil; however, *S. rolfsii* colonization on pods was greater for all irrigation treatments. Pod colonization ranged from 19.7 to 44.3% and 19.7 to 40.7% for the 0- to 24-h irrigation timings for azoxystrobin (Figure 6.2b) and flutolanil (Figure 6.2c), respectively.

DISCUSSION

Results from this study indicate that *S. rolfsii* is a viable means of assaying fungicide residues applied to peanut foliage. Using this method we were able to quantify the redistribution of foliar applied fungicides using irrigation, and to examine the effects of different irrigation timings. Chemical analyses were not conducted in this study; however, previous reports have indicated that bioassays are an effective means of assessing the biological efficacy of fungicides (Brenneman et al., 1998; Rideout, 2002; VanBruggen, 1986). In this study, *S. rolfsii* lesion development was greatest on peanut leaflets and stems collected from microplots receiving irrigation immediately following the application of fungicides. Presumably, this was due to the removal of fungicide residues from those tissues, which were then deposited on the lower plant parts and/or soil. As expected, the earliest irrigation timing also provided maximum fungicide redistribution and therefore suppression of *S. rolfsii* colonization of the pods. The three fungicide programs evaluated under the various irrigation timings are currently used to manage both foliar and soilborne diseases. The goal of this study was to determine the optimum drying time needed to maintain adequate levels of fungicide on the foliage, while maximizing the amount of fungicides needed to suppress soilborne diseases.

Lesion development was generally smallest on tissues from the lower canopy, followed by the middle and upper canopy, respectively. This trend was most apparent when microplots were irrigated immediately after fungicides were applied; however, it became less obvious for later irrigation timings, as well as the non-irrigated control. Several factors are known to affect fungicide efficacy. Differences in leaf structure, primarily the cuticle, can influence the retention of fungicides (Neely, 1970; Neely, 1971), and changes in the

composition of the cuticle have been attributed to different environmental factors (Skoss, 1955). Theses studies were conducted using field grown plants to mimic the retention of initial fungicide deposits on foliage under field conditions. Pesticide deposition is also greatly affected by canopy density. Researchers have found that higher levels of chlorothalonil are deposited on the upper plant canopy, compared to the lower canopy (Brenneman et al. 1990; Hamm and Clough, 1999). Zhu et al. (2004), found that spray deposits in the upper and lower peanut canopy differed significantly, and that deposits in the lower canopy decreased as plants aged. Differences in the initial deposit of fungicides could not be determined in this study, due to varying levels of tissue susceptibility from the different canopy layers (Chapter 6).

In these studies, larger lesions were observed on leaflets and stems that received earlier irrigation treatments. Lesion development was greatest for these above-ground tissues that were irrigated immediately after the application of fungicides. This trend was evident for azoxystrobin, flutolanil, and tebuconazole on all sampling dates regardless of canopy layer. Overall, a drying time of 24 h provided levels of suppression that were similar to the non-irrigated controls for each respective compound; however, increased suppression was observed for later irrigation timings. Lesion development was not compared among the three sampling dates; however, lesion size on leaflets and stems was numerically higher for the 110 DAP sampling date. Sampling date may also impact colonization by *S. rolfsii*; since growth of the fungus, and disease development are favored by the hot, moist environmental conditions which become present in the peanut canopy as the growing season progresses. A complete canopy may also intercept fungicides being applied to control the disease. These

two factors indicate the importance of redistributing fungicides with irrigation to the lower stems and pods where *S. rolfsii* infections occur.

The three fungicide programs evaluated performed similarly across the different irrigation timings. Trends similar to those observed in the leaflet assay were found for leaf spot and results from the two assays from the final sampling date were significantly correlated for all canopy layers ($0.19 \leq R^2 \leq 0.32$; p=0.0001). Canopy layer effects were not significant for leaf spot in this study, indicating a lack in tissue susceptibility within the peanut canopy. Leaf spot is typically more severe in the lower canopy early in the season prior to infecting other parts of the canopy. The failure to see this trend is likely due to the fact that a fumigant was used prior to plant. Use of the fumigant greatly reduced initial inoculum in the soil and therefore infections originated from inoculum being blown in from adjacent peanut fields.

Significant negative correlations were found to exist between the % pod colonization and the size of lesions on leaflets from the upper canopy for the 110 DAP sampling date, and the number of leaf spot lesions per leaf(data not shown). Later irrigation timings resulted in increased pod colonization, and the % colonization for azoxystrobin, tebuconazole and flutolanil increased according to quadratic functions. Lesion suppression for the earlier irrigation timings was greatest for tebuconazole followed by flutolanil and azoxystrobin, respectively. The rate of colonization increased for tebuconazole after 24 h, whereas the rate of pod colonization for azoxystrobin and flutolanil was at a more consistent rate. The different physiochemical properties of these compounds, such as affinity to the leaf surface, permeability, and the rate of uptake could have attributed to this trend.

Pod colonization was significantly reduced for the non-irrigated controls for azoxystrobin, flutolanil, and tebuconazole when compared to the chlorothalonil standard. Significant differences among the azoxystrobin, flutolanil, and tebuconazole non-irrigated controls were also observed. Pod colonization was greatest for tebuconazole, and lowest for azoxystrobin, whereas, flutolanil provided an intermediate level of suppression. Araki (1985) reported that flutolanil is readily absorbed by rice (*Oryza sativa* L.) roots, and translocated acropetally; however, the systemic activity of flutolanil on peanut foliage poorly understood. Information regarding the systemicity of EBI and QoI fungicides is well documented. Previous reports have found that EBI fungicides such propiconazole (Kelly, 1980), difenoconazole (Dahmen and Staub, 1992), simeconazole (Tsuda et al., 2004), and tebuconazole (Kuck and Thielert, 1987) quickly penetrate leaves after application. However, the foliar uptake of azoxystrobin is more of a gradual process with <5% of the applied material being absorbed within 24 h of application (Bartlett, et al., 2002). The persistence of these fungicides on the leaf surface may also explain the differences in the % pod colonization for the non-irrigated controls. Since tebuconazole is rapidly taken up by the leaf, less of the initial deposits may available for redistribution at the later irrigation timings; whereas, azoxystrobin remains on the leaf surface for a longer period. This trait would be an advantage for azoxystrobin when peanuts are planted in non-irrigated fields. Traditionally azoxystrobin has been used more extensively in irrigated fields due to somewhat higher cost and superior activity on Rhizoctonia limb rot (*Rhizoctonia solani* Kuhn anastomosis group (AG)-4) (Kemerait, 2004), which is primarily a disease of irrigated peanuts (Barnes et al., 1987). Results from these studies can also be used to aid in the decision to retreat fields in the event that rainfall occurs too soon after fungicides are applied.

Possible redistribution of fungicides by rainfall following fungicide application also should be considered in the interpretation of these results. To exclude irrigation and rainfall in controls and treatments not scheduled to receive irrigation, microplots were covered with plywood sheets. However, following the 96h irrigation, all microplots remained uncovered until the next application of fungicides. During this time all microplots were exposed to natural rainfall. Rainfall amounts of 14.0, 6.4, and 6.6 cm were recorded in 2003, 2004, and 2005, respectively. This rainfall undoubtedly redistributed some fungicide residues which remained on the leaf surface longer than 96 h after application (Hislop and Cox, 1970). The effects of this are not fully understood, but would have been uniform across all plots.

In Georgia, multiple management strategies are used to control soilborne diseases of peanut. Control recommendations include crop rotation, the use of moderately resistant cultivars, and timely application of foliar applied fungicide followed by irrigation to redistribute the material to the target site (Kemerait, 2005; Kemerait, 2006). However, if irrigation or rainfall occurs too soon after the fungicide is applied leaf spot control could be reduced. Currently, producers are advised to wait a minimum of 12 h irrigating to obtain adequate leaf spot control (Kemerait, 2006). Results from this study indicate that a longer delay may be required to maximize leaf spot control; however, applying irrigation sooner may be required if stem rot is a primary concern. If fungicides are used being used to soley for the purpose of stem rot control, irrigation should be applied immediately after the fungicides are applied.

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Table 6.1. Description of fungicide programs used to evaluate the effect of irrigation on the redistribution of fungicides applied to peanut foliage

Program, Active ingredient(s)	Trade name	Formulation[a]	Rate kg ha^{-1}	Application[b]	Chemical class	Systemicity[c]
(i) Chlorothalonil	Bravo Ultrex	82.5 WDG	1.26	1 - 7	Broad-spectrum protectant	None
(ii) Chlorothalonil	Bravo Ultrex	82.5 WDG	1.26	1, 2, 3, 5, 7	Broad-spectrum protectant	None
Azoxystrobin	Abound	2.08 F	0.47	4, 6	Strobilurin	Acropetal
(iii) Chlorothalonil	Bravo Ultrex	82.5 WDG	1.26	1 - 3	Broad-spectrum protectant	None
Tebuconazole	Folicur	3.6 F	0.33	4 - 7	Sterol biosynthesis inhibitor	Acropetal
(iv) Chlorothalonil	Bravo Ultrex	82.5 WDG	1.26	1, 2, 3, 5, 7	Broad-spectrum protectant	None
Chlorothalonil +	Bravo Ultrex	82.5 WDG	1.26	1, 2, 3, 5, 7	Broad-spectrum protectant	None
Flutolanil	Moncut	70 DF	1.00	4, 6	Benzanilide	Acropetal

[a] Percentages of active ingredients in commercial products formulated as water dispersible granules (WDG), a flowable, or a dry flowable (DF).

[b] 1 - 7 refers to when applications were made to complete a standard seven spray program.

[c] Refers to fungicide movement in the plant, none (no systemic movement) or acropetal (upward movement through the xyleum).

Table 6.2. Main and interaction effects (*P*-values) of fungicide program, irrigation timing, and canopy layer on peanut leaflets, stems, pods, and leaf spot[a]

	Leaflet assay			Stem assay			Leaf	Pod
Source	68 DAP	82 DAP	110 DAP	68 DAP	82 DAP	110 DAP	Spot	Assay
Fungicide (F)[b]	*	NS	*	NS	NS	NS	NS	NS
Irrigation (I)[c]	****	****	****	NS	****	****	****	*
Layer (L)[d]	NS	NS	NS	NS	**	**	NS	- - -
F × I	NS	NS	NS	NS	NS	NS	NS	NS
F × L	NS	****	NS	NS	NS	NS	NS	- - -
I × L	****	****	****	****	NS	**	NS	- - -
F × I × L	NS	NS	NS	NS	*	NS	NS	- - -

[a] Peanut leaflets and stems were inoculated with *S. rolfsii* as described in Materials and Methods. A similar technique was used to inoculate excised pods; whereas, leaf spot lesion caused by natural inoculum of *C. arachidicola* were determined in each canopy layer. Proc MIXED (SAS 2003) was used to calculate *P*-values, which are based on twenty-one replications from 2003, 2004, and 2005. *, **, **** indicate significance at the 0.05, 0.01, and 0.0001 level, respectively. NS = not significant.

[b] Represents the fungicide programs described in Table 6.1.

[c] Irrigation timings of 0, 6, 12, 24, 48, or 96 hours after the application of fungicides. Non-irrigated controls were also included.

[d] Layer denotes the upper, middle or lower canopy layers. All interactions containing canopy layer were excluded from the model in the analysis of the pod data.

Table 6.3. Effects of irrigation timing on the development of of lesions on detached peanut leaflets obtained from three canopy layers on three sampling dates inoculated with *Sclerotium rolfsii* [a]

Sampling date,	Irrigation timing						
Canopy layer	0 hr	6 hr	12 hr	24 hr	48 hr	96 hr	none
68 DAP	- mm^2 -						
Upper	218.7	58.8	28.0	35.1	25.3	15.4	12.3
Middle	131.6	50.9	33.1	34.1	25.9	21.4	20.3
Lower	109.9	72.5	37.9	62.7	40.3	27.9	35.6
LSD[b]				30.4			
LSD[c]				28.6			
82 DAP							
Upper	175.4	81.1	45.7	17.6	24.1	28.9	15.6
Middle	106.5	69.0	55.0	44.9	53.3	30.4	20.2
Lower	71.4	49.2	59.0	32.8	34.1	25.9	26.6
LSD[b]				26.9			
LSD[c]				31.0			
110 DAP							
Upper	381.0	104.6	56.0	25.1	16.8	8.8	8.0
Middle	254.0	83.9	66.5	36.3	43.0	32.0	11.3
Lower	173.0	74.5	68.3	51.2	46.2	35.6	32.0
LSD[b]				57.9			
LSD[c]				81.4			

[a] Data are the means of 21 replications from 2003, 2004, and 2005.

[b] LSD to compare canopy layers within irrigation timings (P=0.05).

[c] LSD to compare irrigation timings within canopy layers (P=0.05).

Table 6.4. Lesion length on detached peanut stems obtained from the upper, middle and lower canopy of peanut plants treated with fungicides for two sampling dates and inoculated with *Sclerotium rolfsii*[a]

	Sampling date					
	68 DAP			110 DAP		
Fungicide	Upper	Middle	Lower	Upper	Middle	Lower
	Lesion length (mm)					
Axozystrobin	10.9	10.2	4.7	15.1	12.8	7.3
Chlorothalonil	21.5	17.5	16.9	22.5	19.9	17.7
Flutolanil	7.6	4.1	2.7	10.3	7.5	4.6
Tebuconazole	12.4	8.8	6.5	12.3	9.6	5.3
LSD[b]		6.0			6.6	
LSD[c]		6.1			4.9	

[a] Means for azoxystrobin, flutolanil, and tebuconazole, represent data combined across six irrigation timings from 2003, 2004, and 2005; whereas, means for chlorothalonil are from only the 24 hr irrigation timing.

[b] LSD to compare fungicide treatments within a canopy layer (P=0.05).

[c] LSD to compare canopy layers within a fungicide treatment (P=0.05).

Table 6.5. Effects of fungicide, canopy layer, and irrigation timing on the development of *Sclerotium rolfsii* lesions on detached peanut stems sampled 82 DAP[a]

Canopy layer,	Irrigation timing						
Fungicide	0 hr	6 hr	12 hr	24 hr	48 hr	96 hr	none
Upper	- Lesion length (mm) -						
Azoxystrobin	16.8	18.7	10.4	14.3	15.5	12.3	11.4
Flutolanil	12.9	11.1	6.9	8.4	10.9	13.7	7.7
Tebuconazole	14.6	14.1	9.5	11.5	8.7	11.4	4.0
Middle							
Azoxystrobin	15.4	16.9	8.3	8.6	9.1	16.3	7.6
Flutolanil	10.7	9.2	10.2	4.8	9.9	8.4	7.7
Tebuconazole	12.9	7.7	3.6	5.3	7.2	4.3	1.3
Lower							
Azoxystrobin	11.1	9.2	8.9	5.2	6.9	9.1	7.8
Flutolanil	8.0	3.1	4.8	4.8	4.8	8.8	3.6
Tebuconazole	9.5	7.4	2.4	2.5	2.5	2.9	2.1
LSD[b]				7.0			
LSD[c]				4.4			
LSD[d]				4.9			

[a] Data are the means of 21 replications from 2003, 2004, and 2005.

[b] LSD to compare fungicide treatments within a canopy layer and irrigation timing (P=0.05).

[c] LSD to compare canopy layers within a fungicide treatment and irrigation timing (P=0.05).

[d] LSD to compare irrigation timings within a canopy layer and fungicide treatment (P=0.05).

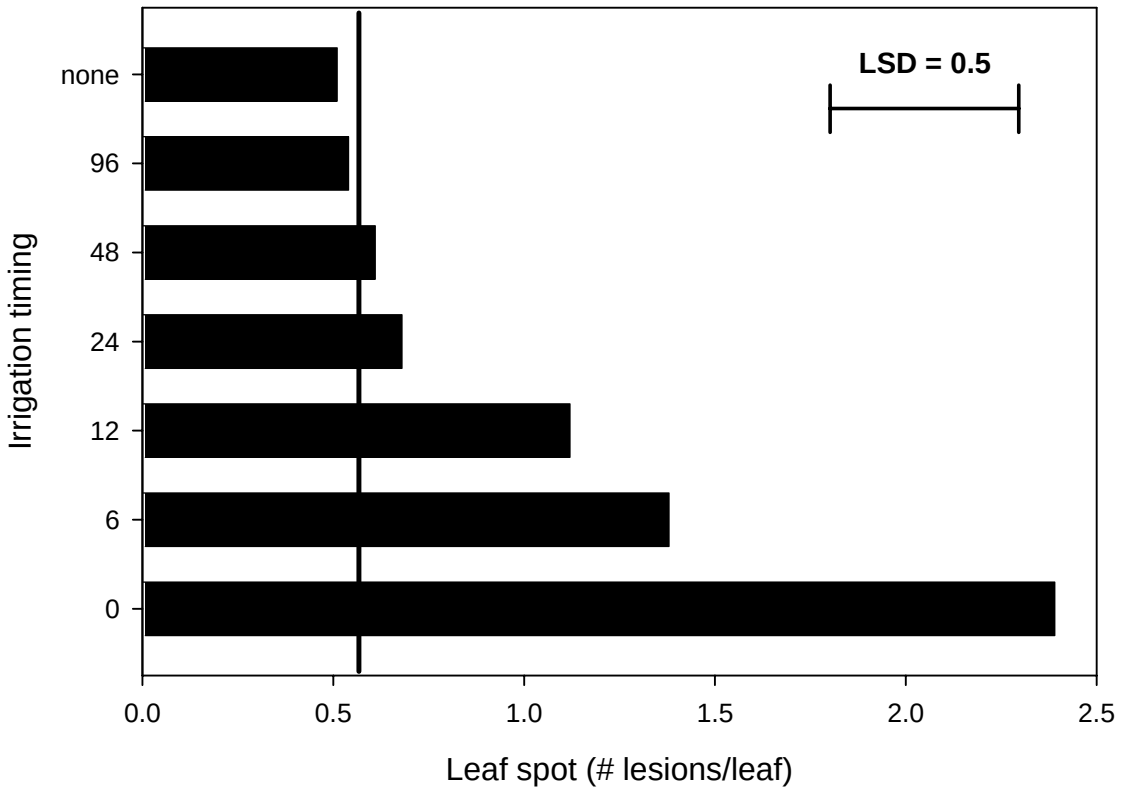

Figure 6.1. Effect of irrigation timing on the development of leaf spot lesions of peanut. Bars are the means of 21 replications from 2003, 2004, and 2005, pooled across canopy layer and fungicide treatments. The vertical line represents the chlorothalonil standard. Means are not significantly different if the magnitude of the difference is not greater than the least significant difference (LSD) value according to Fisher's protected LSD (P=0.05).

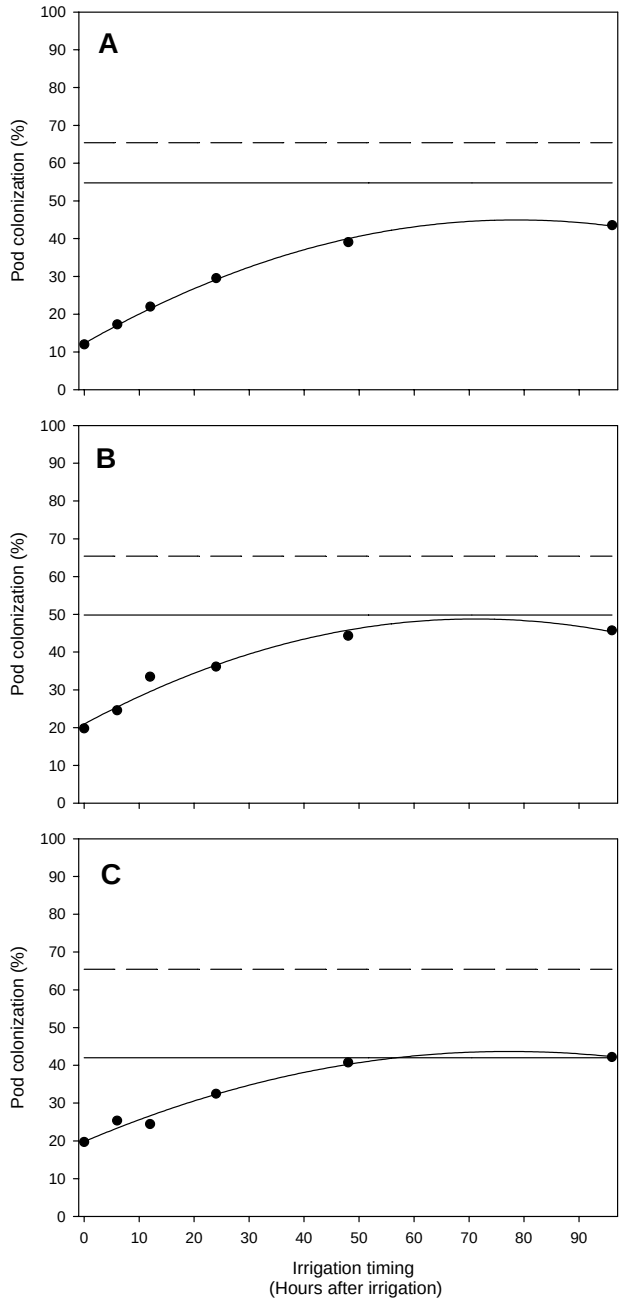

Figure 6.2. Effect of irrigation timing on the percent colonization of peanut pods by *Sclerotium rolfsii*. Points represent the observed means; curved lines represent predicted values; solid horizontal lines represent the respective non-irrigated controls for tebuconazole (A), flutolanil (B), and azoxystrobin (C). Dashed horizontal line represents the chlorothalonil standard.

CHAPTER 7

SUMMARY AND CONCLUSIONS

Peanut (*Arachis hypogaea* L.) is susceptible to infection by numerous foliar and soilborne fungal diseases including early leaf spot (*Cercospora arachidicola* S. Hori), leaf spot (*Cercosporidium personatum* (Berk. & M. A. Curtis) Deighton), and southern stem rot (*Sclerotium rolfsii* Sacc.). Numerous fungicide applications are made each growing season to mitigate losses associated these diseases. Changes to the 2002 Farm Bill resulted in producers receiving approximately 40% less for their commodity, while input costs remain unchanged. With increasing energy costs and suppressed crop value, reductions in input costs are needed if producers are to remain economically competitive. One potential way to reduce costs associated with fungicide inputs would to use an integrated disease management approach. The overall objective of this research was to determine the benefits and feasibility of using reduced input fungicide programs in conjunction with the University of Georgia Fungal Disease Risk Index to maximize profits without compromising yield or disease control. Small and large plot experiments were conducted in fields with varying levels of disease risk. Cultivars with partial resistance to leaf spot and/or stem rot were included in most studies. Yields and grades for these cultivars were equivalent to or greater than Georgia Green, the current commercial standard. Several standard fungicide programs were also compared to their respective reduced programs. Despite increased leaf spot intensity and stem rot incidence for the reduced programs, yields for those programs were generally equal to or greater than their respective standard program. Furthermore, the reduced programs typically provided higher crop values than the standard programs. Bioassays involving *S. rolfsii* were developed to determine examine fungicide residues peanut foliage and pods. *In vitro* trials indicated that wounding was not required for lesion development on leaflet or

stem tissues. In addition, tissues obtained from the upper canopy were more susceptible to infection by *S. rolfsii* than tissues obtained from the middle and lower canopy, respectively. This method was successfully used to determine the effect of irrigation timing on the redistribution of foliar applied fungicides. Lesion development on leaflet and stem tissues was greatest when irrigation was applied immediately after the fungicides compared to later irrigation timings. When irrigation was applied after 24 h lesion size did not differ from the non-irrigated controls. Likewise, early leaf spot was more severe when irrigation was administered immediately following the application fungicides, and was significantly reduced for the 6 and 12 h irrigation timings. Maximum leaf spot control was obtained for the 24 h treatment. Conversely, the colonization of pods was lower for the earlier irrigation treatments. The percent pod colonization was similar for all irrigation timings for azoxystrobin and flutolanil; whereas, suppression was greatest for tebuconazole at earlier irrigation timings. This research demonstrates reduced input fungicide programs can be used within an integrated disease management system to adequately control foliar and soilborne diseases, and that irrigation can be used to improve soilborne disease control, while maintaining adequate levels of leaf spot control.

APPENDICES

APPENDIX A

FUNGAL DISEASE RISK INDEX

Table A.1. Univeristy of Georgia Fungal Disease Risk Index

CULTIVAR SELECTION

Cultivar[1]	Leaf Spot Points	Soilborne Disease Points	
		White mold	Limb rot
Florunner	unknown	unknown	unknown
SunOleic 97R[2]	unknown	unknown	unknown
Flavorunner 458[2]	unknown	unknown	unknown
Perry	30	15	25
NC-V 11	30	25	25
NC12C	unknown	unknown	unknown
AT-201[2]	30	20	unknown
Georgia Green	20	20	15
Virugard	20	20	unknown
Gregory	30	20	25
VC2	unknown	unknown	unknown
Anorden[2]	20	20	20
Andru II[2]	30	20	25
C-99R[4]	10	15	25
Hull[2]	10	15	25
Carver[3]	30	20	25
GA03L	15	10	20
GA02C[2,3]	20	10	20
GA01R[3]	10	15	15
DP1[4]	5	10	25
AP3[4]	25	10	25
Tifrunner	15	25	unknown
Wilson	30	25	unknown
VA98R	35	25	unknown

[1]Adequate research data is not available for all varieties with regards to all diseases. Additional varieties will be included as data to support the assignment of an index value are available.
[2]High oleic variety.
[3]Varieties Carver, GA-02C, and GA-01R have increased resistance to Cylindrocladium black rot (CBR) than do other varieties commonly planted in Georgia.
[4]Varieties AP3, DP1, and C-99R are less resistant to CBR and are not recommended for fields where this disease is a problem.

Table A.1. Univeristy of Georgia Fungal Disease Risk Index contd.

PLANTING DATE

Peanuts are planted:	Leaf Spot Points	Soilborne Disease Points	
		White mold[2]	Limb rot[2]
Prior to May 10	0	5	0
May 11-25 May	5	0	0
May 26-June 5	5	0	5
After June 5	10	0	5

[1]In those years when the normal date of planting for the first peanuts in your area is delayed due to inclement weather, these date ranges should be moved later by an equal amount. In most years, these date ranges will also vary slightl with latitude. Dates can be shifted five days earlier in the extreme southern counties and 5 days later in the extreme northern counties

[2]Earlier planted peanuts will have a small increased risk for white mold. Later planted peanuts may have greater limb rot at the end of the season because soils will be cooler later in the year.

ROW PATTERN

Peanuts are planted in:	Leaf Spot Points	Soilborne Disease Points	
		White mold	Limb rot
Single rows	0	5	0
Twin rows	0	0	0

TILLAGE

Tillage	Leaf Spot Points	Soilborne Disease Points	
		White mold	Limb rot
conventional	10	0	0
reduced*	0	0	5

* For fungal diseases, this is does not apply for reduced tillage situations where peanut is following directly behind peanut in a rotation sequence. Limb rot can exist on some types of crop debris anduse the organic matter as a bridge to the next peanut crop.

Table A.1. Univeristy of Georgia Fungal Disease Risk Index contd.

CROP ROTATION WITH A NON-LEGUME CROP

Years Between Peanut Crops*	Leaf Spot Points	Soilborne Disease Points	
		White mold	Limb rot
0	25	25	20
1	15	20	15
2	10	10	10
3 or more	5	5	5

*All crops other than peanut are acceptable in a rotation to reduce leaf spot. Cotton and grass crops will reduce the severity of white mold. Rhizoctonia limb rot can still be a significant problem, especially with cotton, under a longer rotation
with favorable conditions, e.g. heavy vine growth & irrigation/ rainfall. Rotation with grass crops will decrease the potential risk of limb rot; tobacco and vegetables
will not.

FIELD HISTORY

Previous disease history in field*	Leaf Spot Points	Soilborne Disease Points	
		White mold	Limb rot
NO	0	0	0
YES	10	15	10

* "YES" would be appropriate in fields where leaf spot and/or soilborne diseases were a problem in the field despite use of a good fungicide program.

IRRIGATION

Does the field receive irrigation?	Leaf Spot Points	Soilborne Disease Points	
		White mold	Limb rot
NO	0	0	0
YES	10	5*	10

* Irrigation has a greater affect on Rhizoctonia limb rot than on southern stem rot (white mold) or Cylindrocladium black rot.

Table A.1. Univeristy of Georgia Fungal Disease Risk Index contd.

CALCULATING YOUR RISK

Add your index values from:

	Leaf Spot Points	White Mold Points	Limb Rot Points
Peanut Cultivar			
Planting Date			
Row Pattern			
Tillage			
Crop Rotation			
Field History			
Irrigation			
Your Total Index Value			

Interpreting Your Risk Total

Point total range for leaf spot = 10-100.
Point total range for white mold = 10-85.
Point total range for Rhizoctonia limb rot = 15-75.

RISK

	Leaf spot	**White mold**	**Limb rot**
High Risk	**65-100**	**55-80**	**45-75**
High Risk for fungal diseases: Growers should always use full fungicide input program in a high-risk situation.			
Medium Risk	**40-60**	**30-50**	**30-40**
Medium Risk for fungal diseases: Growers can expect better performance from standard fungicide programs. Reduced fungicide programs in research studies have been successfully implemented when conditions are not favorable for disease spread.			
Low Risk	**10-35**	**10-25**	**15-25**
Low Risk for fungal diseases: These fields are likely to have the least impact from fungal disease. Growers have made the management decisions which offer maximum benefit in reducing the potential for severe disease; these fields are strong candidates for modified disease management programs that require a reduced number of fungicide applications.			

APPENDIX B

APPENDIX TO CHAPTER 2

SUMMARY OF CULTURAL AND MANAGAMENT PRACTICES

Trial: 2003 Gibbs Study

Location: CPES, Gibbs Farm White Mold Nursery, Tifton, GA

Soil Type: Tifton loamy sand, 2-5% slope

Soil Class: Fine-loamy, kaolinitic, thermic Plinthic Kandiudults

Crop History: Corn - 2002, Peanut - 2001, Corn - 2000, Peanut - 1999

Cultivar: Georgia Green (7 seed/row ft.), treated with Vitavax PC

Land Prep: Moldboard plowed and marked rows: 1 April

Soil Fertility: pH - 6.0 P - 108 K - 38 Ca - 417 Mg - 18

Planting date: 7 May

Herbicides: PPI: Dual Magnum (2 pts/A) + Sonalan HFP (2 pts/A): 15 April
POST: Basagran (1.5 pt/A) + Poast Plus (1.5 pt/A) on 30 May
Basagran (1.5 pt/A) + Select (8.0 oz/A) on 5 June

Insecticides: Temik 15G, 4 lb/A in furrow on 7 May

Nematicides: Temik 15G, 18 lb/A (12" band) on 19 May

Gypsum: 650 lb/A broadcast on 14 July

Cultivated: 25 June

Precipitation: May - 2.5", June - 8.5", July - 6.2", August - 8.6", and September - 5.5"

Digging Date: 8 September

Harvest Date: 17 September

Trial: 2003 Georgia Green / Georgia-01R study

Location: CPES, Black Shank Farm Field by Microplots, Tifton, GA

Soil Type: Fuquay Sand, 0-5% slope

Soil Class: Loamy, kaolinitic, thermic Arenic Plinthic Kandiudults

Crop History: Fallow – 2002, Vegetables - 2001

Cultivars: Georgia Green and Georgia-01R (7 seed/row ft.), treated with Vitavax PC

Land Prep: Moldboard plowed and marked rows: 17 April

Soil Fertility: pH - 6.0 P - 108 K - 38 Ca - 417 Mg - 18

Planting date: 20 May

Herbicides: PPI: Dual Magnum (2 pt/A) + Sonalan (1.5 pt/A): 8 May
POST: Storm (1.5 pt/A) + crop oil (1 pt/A)

Insecticides: Temik 15G, 4 lb/A in furrow on 20 May

Nematicides: TeloneII 10 GPA broadcast on 23 April
Temik 15G, 10 lb/A (12” band) on 20 May

Gypsum: 650 lb/A broadcast on 27 June

Cultivated: 24 June

Precipitation: May - 2.8”, June - 6.4”, July - 7.8”, August - 8.1”, and September - 5.2”

Digging Dates: Georgia Green (22 September) Georgia-01R (20 October)

Harvest Dates: Georgia Green (26 September) Georgia-01R (24 October)

Trial: 2003 DP-1 / Georgia-01R Study

Location: CPES, Black Shank Farm Woods Field, Tifton, GA

Soil Type: Fuquay sand, 0-5% slope

Soil Class: Loamy, kaolinitic, thermic Arenic Plinthic Kandiudults

Crop History: Tobacco - 2002, Peanut - 2001, Tobacco - 2000, Peanut - 1999

Cultivars: Georgia-01R and DP-1 (7 seed/row ft.), treated with Vitavax PC

Land Prep: Moldboard plowed and marked rows: 17 April

Soil Fertility: pH - 6.0 P - 108 K - 38 Ca - 417 Mg - 18

Planting date: 20 May

Herbicides: PPI: Dual Magnum (2 pt/A) + Sonalan (1.5 pt/A): 8 May
POST: Storm (1.5 pt/A) + crop oil (1 pt/A)

Insecticides: Temik 15G, 4 lb/A in furrow on 20 May

Nematicides: TeloneII 10 GPA broadcast on 23 April
Temik 15G, 10 lb/A (12" band) on 20 May

Gypsum: 650 lb/A broadcast on 27 June

Cultivated: 24 June

Precipitation: May - 2.8", June - 6.4", July - 7.8", August - 8.1", and September - 5.2"

Digging Date: 20 October

Harvest Date: 24 October

Trial: 2004 Gibbs Study

Location: CPES, Gibbs Farm White Mold Nursery, Tifton, GA

Soil Type: Tifton loamy sand, 2-5% slope

Soil Class: Soil Class: Fine-loamy, kaolinitic, thermic Plinthic Kandiudults

Crop History: Corn -2003, Peanut - 2002, Corn - 2001, Peanut - 2000

Cultivar: Georgia Green (7 seed/row ft.), treated with Vitavax PC

Land Prep: Moldboard plowed and marked rows: 30 March

Soil Fertility: pH - 6.2 P - 104 K - 112 Ca - 468 Mg - 30

Planting date: 11 May

Herbicides: PPI: Dual Magnum (2 pt/A) + Sonalan (1.5 pt/A): 1 April
POST: Cadre (1.44 oz/A) + crop oil (1 pt/A) on 26 May

Insecticides: Temik 15G, 4 lb/A in furrow on 11 May

Nematicides: Temik 15G, 18 lb/A (12" band) on 11 May

Fumigants: Vapam 42%, 20 GPA on 31 March

Gypsum: 1000 lb/A broadcast on 30 June

Cultivated: 16 June

Precipitation: May - 3.18", June - 5.53", July - 2.52", August - 5.02", and September - 14.64"

Digging Date: 20 September

Harvest Date: 23 September

Trial: 2004 Georgia Green / Georgia-01R Study

Location: CPES, Rigdon Farm Long Field, Tifton, GA

Soil Type: Tifton loamy sand, 2-5% slope

Soil Class: Fine-loamy, kaolinitic, thermic Plinthic Kandiudults

Crop History: Cotton - 2003, Peanut - 2002

Cultivar: Georgia Green and Georgia-01R (7 seed/row ft.), treated with Vitavax PC

Land Prep: Moldboard plowed and marked rows: 6 May

Soil Fertility: pH - 6.2 P - 110 K - 90 Ca - 534 Mg - 37

Planting date: 14 May

Herbicides: PPI: Dual Magnum (2 pt/A) + Sonalan (1.5 pt/A): 12 May April

Insecticides: Temik 15G, 4 lb/A in furrow on 11 May

Nematicides: Temik 15G, 18 lb/A (12" band) on 11 May

Gypsum: 1000 lb/A broadcast on 30 June

Cultivated: 16 June

Precipitation: May-2.30", June-11.10", July-7.30", August-5.20", and September-13.40"

Digging Dates: Georgia Green (20 September) Georgia-01R (25 October)

Harvest Dates: Georgia Green (24 September) Georgia-01R (1 November)

Trial: 2004 DP-1 / Georgia-01R Study

Location: CPES, Black Shank Farm Woods Field, Tifton, GA

Soil Type: Fuquay sand, 0-5% slope

Soil Class: Loamy, kaolinitic, thermic Arenic Plinthic Kandiudults

Crop History: Tobacco - 2003, Peanut - 2002, Tobacco - 2001, Peanut - 2000

Cultivar: Georgia-01R and DP-1 (7 seed/row ft.), treated with Vitavax PC

Land Prep: Moldboard plowed and marked rows: 22 April

Soil Fertility: pH - 6.3 P - 74 K - 66 Ca - 564 Mg - 39

Planting date: 18 May

Herbicides: PPI: Dual Magnum (2 pt/A) + Sonalan (1.5 pt/A): 12 May April

Insecticides: Temik 15G, 4 lb/A in furrow on 18 May

Nematicides: TeloneII, 10 GPA broadcast on 29 April
Temik 15G, 18 lb/A (12" band) on 11 May

Gypsum: 1000 lb/A broadcast on 30 June

Cultivated: 16 June

Precipitation: May-2.83", June-12.57", July-6.90", August-4.09", and September-14.04"

Digging Date: 18 October

Harvest Date: 22 October

APPENDIX C

APPENDIX TO CHAPTER 3

SUMMARY OF CULTURAL AND MANAGAMENT PRACTICES

Trial: 2004 Rotation Test

Location: CPES, Rigdon Farm Cotton Field, Tifton, GA

Soil Type: Tifton loamy sand, 2-5% slope

Soil Class: Loamy, kaolinitic, thermic Arenic Plinthic Kandiudults

Crop History: Cotton - 2003, Cotton - 2002, Cotton - 2001

Cultivar: Georgia Green, Georgia-02C, Georgia-03L, AP-3, Georgia-01R, C-99R, Hull, Tifrunner (7 seed/row ft.), treated with Vitavax PC

Land Prep: Moldboard plowed and marked rows: 28 May

Soil Fertility: pH - 6.0 P - 67 K - 81 Ca - 420 Mg - 40

Planting date: 2 June

Herbicides: PPI: Dual Magnum (2 pts/A) + Sonalan HFP (2 pts/A): 1 June

Insecticides: Temik 15G, 4 lb/A in furrow on 2 June

Nematicides: Temik 15G, 10 lb/A (12" band) on 2 June

Gypsum: 1000 lb/A broadcast on 30 June

Cultivated: 1 July

Precipitation: May-2.30", June-11.10", July-7.30", August-5.20", and September-13.40"

Digging Dates: Mid-maturing cultivars (5 October) Late-maturing cultivars (25 October)

Harvest Dates: Mid-maturing cultivars (25 October) Late-maturing cultivars (1 November)

Trial: 2004 Irrigated/Non-irrigated Test

Location: CPES, Black Shank Farm, Tifton, GA

Soil Type: Tifton loamy sand, 2-5% slope

Soil Class: Fine-loamy, kaolinitic, thermic Plinthic Kandiudults

Crop History: Peanut - 2003, Peanut - 2002, Peanut - 2001

Cultivars: Georgia Green, Georgia-02C, Georgia-03L, Georgia-01R, Hull and Tifrunner (7 seed/row ft.), treated with Vitavax PC

Land Prep: Moldboard plowed and marked rows: 22 April

Soil Fertility: pH - 6.0 P - 97 K - 45 Ca - 427 Mg - 28

Planting date: 21 May

Herbicides: PPI: Dual Magnum (2 pts/A) + Sonalan (2 pts/A): 13 May
POST: Cadre (1.44 oz/A) + crop oil (0.25% v/v) on 17 June

Insecticides: Temik 15G, 4 lb/A in furrow on 21 May

Nematicides: TeloneII, 10 GPA broadcast on 29 April
Temik 15G (on 16" band, 6.5 lb/A) on 2 June

Gypsum: 1000 lb/A broadcasted on 30 June

Cultivated: 15 June

Precipitation: May -2.30", June -11.10", July - 7.30", August -5.20", and September-13.40"

Irrigation: May - 1.00", June - 0.00", July - 2.00", August - 2.00", and September - 0.00"

Digging Dates: Mid-maturing cultivars (5 October) Late-maturing cultivars (13 October)

Harvest Dates: Mid-maturing cultivars (25 October) Late-maturing cultivars (28 October)

Trial: 2005 Rotation Test

Location: CPES, Lang Farm Field by Woods, Tifton, GA

Soil Type: Tifton loamy sand, 2-5% slope

Soil Class: Fine-loamy, kaolinitic, thermic Plinthic Kandiudults

Crop History: Corn - 2004, Corn - 2003, Corn - 2002

Cultivars: Georgia Green, Georgia-02C, Georgia-03L, AP-3, Georgia-01R, C-99R, Hull, Tifrunner (7 seed/row ft.), treated with Vitavax PC

Land Prep: Moldboard plowed and marked rows: 2 May

Soil Fertility: pH - 6.4 P - 63 K - 114 Ca - 718 Mg - 123

Planting date: 12 May

Herbicides: PPI: Dual Magnum (2 pts/A) + Sonalan HFP (2 pts/A) on 2 May
POST: Basagran (2 pt/A) + crop oil (1 pt/A)

Insecticides: Temik 15G, 4 lb/A in furrow on 12 May

Nematicides: Temik 15G, 10 lb/A (12" band) on 12 May

Gypsum: 1000 lb/A broadcast on 27 June

Cultivated: 15 June

Precipitation: May - 4.10", June - 6.80", July - 11.20", August - 4.10", and September - 2.70"

Digging Dates: Mid-maturing cultivars (5 October) Late-maturing cultivars (10 October)

Harvest Dates: Mid-maturing cultivars (25 October) Late-maturing cultivars (14 October)

Trial: 2005 Irrigated/Non-irrigated Test

Location: CPES, Black Shank Farm, Tifton, GA, pg 24

Soil Type: Tifton loamy sand, 2-5% slope

Soil Class: Fine-loamy, kaolinitic, thermic Plinthic Kandiudults

Crop History: Peanut - 2004, Peanut - 2003, Peanut -2002, Peanut - 2001

Cultivars: Georgia Green, Georgia-02C, Georgia-03L, Georgia-01R, Hull and Tifrunner (7 seed/row ft.), treated with Vitavax PC

Land Prep: Moldboard plowed and marked rows: 13 May

Soil Fertility: pH - 6.0 P - 97 K - 45 Ca - 472 Mg - 28

Planting date: 19 May

Herbicides: PPI: Dual Magnum (2 pts/A) + Sonalan HFP (2 pts/A): 13 May
POST: Basagran (2 pt/A) + crop oil (1 pt/A) on 23 June
Cadre (1.44 oz/A) on 15 July

Insecticides: Temik 15G, 4 lb/A in furrow on 19 May

Nematicides: Temik 15G, 10 lb/A (12" band) on 19 May

Gypsum: 1000 lb/A broadcast on 27 June

Cultivated: 15 June

Precipitation: May - 3.77", June - 7.97", July - 6.29", August - 8.04", and September - 3.31"

Irrigation: May - 1.00", June - 1.00", July - 4.00", August - 4.00", and September - 4.00"

Digging Dates: Mid-maturing cultivars (27 September) Late-maturing cultivars (19 October)

Harvest Dates: Mid-maturing cultivars (30 September) Late-maturing cultivars (24 October)

APPENDIX D

SCLEROTINIA BLIGHT IN GEORGIA AND EVIDENCE OF RESISTANCE TO *SCLEROTINIA SCLEROTIORUM* IN RUNNER PEANUTS[1]

[1]Woodward, J.E., T.B. Brenneman, R.C. Kemerait, Jr., A.K. Culbreath, and J.R. Clark.

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Abstract

Sclerotinia blight (*Sclerotinia sclerotiorum* (Lib.) de Bary) was recently identified in a commercial peanut (*Arachis hypogaea* L.) field in Appling County, Georgia. Symptoms were first observed on the cultivars Tifrunner and Georgia-02C. Plant inoculations and a detached leaflet assay were conducted to determine the susceptibility of the cultivars Georgia Green, Georgia-02C, Georgia-03L, AP-3, Georgia-01R, Hull, C-99R and Tifrunner. For plant inoculations, lesion lengths were greatest for Okrun, the susceptible control, and Georgia-02C; lesion lengths for C-99R and Georgia-01R did not differ significantly from Tamspan 90, the resistant control. Georgia Green, the current commercial standard, exhibited intermediate lesion lengths. Similar results were obtained from the detached leaflet assay. These results suggest that differing levels of resistance to *S. sclerotiorum* are available in runner cultivars used in the southeastern United States.

Introduction

Sclerotinia blight, caused by the soilborne fungus *Sclerotinia minor* Jagger, is a destructive disease of peanut (*Arachis hypogaea* L.). The disease was first identified in the Virginia-North Carolina region in 1971 (16) and has since become established in Oklahoma (22) and Texas (26). Although *S. minor* is typically associated with Sclerotinia blight, *S. sclerotiorum* (Lib.) de Bary has also been shown to incite the disease (14, 18). While *S. sclerotiorum* is rarely found causing disease on peanut in the United States, it is more prevalent in Australia (4) and Argentina (13).

Sclerotinia sclerotiorum causes severe disease on various members of the family *Brassicasaea* in the southeastern United States (1). In the mid to late 1980's, canola (*Brassica napus* L.) was being evaluated as a winter crop in Georgia. Severe epidemics of stem rot, caused by *S. sclerotiorum* were observed, and isolates were found to be pathogenic to peanut *in vivo* (3); however, attempts at field inoculations with *S. sclerotiorum* were unsuccessful, presumably due to unfavorable environmental conditions. Also, *S. sclerotiorum* generally infects via ascospores produced in apothecia, which are only observed during the winter months in south Georgia (T. Brenneman, unpublished data). Previous reports for *S. minor* suggest that cool air and soil temperatures along with available moisture are required for disease development (8, 15). *In vitro* studies have found that the optimum temperature range for germination of sclerotia is 18 to 26 °C (26) and 21 °C for mycelial growth (17). Such environmental conditions are generally not experienced in the southeastern United States during the peanut growing season.

Tomato spotted wilt, caused by *Tomato spotted wilt tospovirus* (TSWV), is an increasingly important disease throughout the peanut-growing areas of Alabama, Florida and

Georgia. The development and release of spotted wilt resistant cultivars has resulted in the suppression of spotted wilt epidemics (5, 23); however, cultivars with improved resistance to spotted wilt are often late maturing. These cultivars require 150 to 160 days to reach optimum maturity in the southeast, whereas the more commonly grown mid-maturing cultivars, such as Georgia Green, require approximately 135 days to reach maturity (2). As the later maturing cultivars gain popularity, peanut producers in the southeast could be faced with additional disease problems later in the season.

Sclerotinia blight (*S. sclerotiorum*) was identified in a commercial peanut field in Appling County, Georgia in October of 2004 (27, 28). Dense tufts of white mycelium (Figure D.1) and water-soaked lesions were prevalent near the soil surface in diseased areas. Infected tissues were bleached and had a shredded appearance. Large, irregular-shaped sclerotia were found on the surface and imbedded in the pith cavity of stems (Figure D.2). Currently, little information is available regarding Sclerotinia blight resistance in runner cultivars, and that information is limited to *S. minor* (6, 7, 10). The objectives of this research were to 1) document through field observations the susceptibility of commercially available peanut cultivars to *S. sclerotiorum*, and 2) verify the susceptibility of the cultivars with *in vitro* inoculations.

Field observations of *Sclerotinia sclerotiorum* on runner cultivars. The field site where the disease was observed had a long history of corn (*Zea maydis* L.) production, and cotton (*Gossypium hirsutum* L.) had been planted in field the previous two seasons (2002 and 2003). This location was initially chosen to evaluate the response of eight peanut cultivars to reduced fungicide programs for the management of early leaf spot, caused by *Cercospora*

arachidicola Hori, late leaf spot, caused by *Cercosporidium personatum* (Berk. & M.A. Curtis) Deighton and stem rot, caused by *Sclerotium rolfsii* Sacc. (29).

Soils at the location were a Tifton fine-loamy sand with less than 2% organic matter. Cultivars evaluated in this trial included Georgia Green, Georgia-02C, Georgia-03L, AP-3, Georgia-01R, Hull, Tifrunner and C-99R. *Bradyrhizobium* sp., were applied in-furrow as Lift (Nitragin Corp., Brookfield, WI) at a rate of 1.2 L ha^{-1}. Peanuts were stripped-tilled into a heavy rye (*Secale cereale* L.) cover on 11 June 2004 in a single row pattern. Glysophate (Roundup 4 EC, Monsanto, Kansas City, MO) at a rate of 1.28 kg ha^{-1} was applied to kill the cover crop two weeks prior to planting. The strip-till implement (Kelly Manufacturing Company, Tifton GA) had a subsoil shank to loosen the plow pan 30 cm beneath the row, and tilled a strip 20 cm wide. Cultivars were planted at 19.7 seed/m of row on 91 cm row spacing. This was a non-irrigated field, and planting was delayed until adequate soil moisture was present. Regional weather data were obtained from a University of Georgia system located approximately 15 miles south of the field site (12).

Cultivars were planted in three separate trails to evaluate their performance to a standard 7-spray program (Trial 1), a reduced 3-spray program (Trial 2), and a non-treated control program (Trial 3). The fungicide programs evaluated at this location included propiconazole plus chlorothalonil, azoxystrobin and tebuconazole. None of the aforementioned compounds are registered for control *Sclerotinia* spp. in peanut; however, chlorothalonil has been shown to increase Sclerotinia blight at least with *S. minor* (9). Chlorothalonil rates included in these trials were 0.84 kg ai/ha applied as Bravo WeatherStik (Syngenta Crop Protection, Greensboro, NC) with the standard and reduced program receiving 3 and 1 application, respectively. Plots were a single bed 1.8 m wide and 61 m

long with two rows per bed. Because of planter constraints, cultivars were blocked by maturity and planted in alternating strips for each of the three trials. Pod development was monitored using the hull scrape method (24). The mid-maturing cultivars were fully mature and inverted on 1 November; whereas late-maturing cultivars were inverted on 11 November, approximately 10 to 14 days premature, to avoid frost. The incidence of Sclerotinia blight was assessed 24 hours after digging by determining the number of disease loci per plot (<30 cm per locus) (19). Disease incidence was determined for each plot and data were pooled across the three trials.

The 2004 growing season was unique in that several tropical storm systems impacted the area late in the season. In addition to ample rainfall, mean air temperatures below 20 °C were recorded over several periods prior to the disease being observed and harvest (Figure D.3). Because the cultivars could not be randomized, only average disease incidences, and their respective standard deviations are presented (Table D.1). Differences in reaction to *S. sclerotiorum* were observed in the cultivars evaluated. Disease incidence was substantially lower for the mid-maturing cultivars when compared to the late-maturing cultivars. For the mid-maturing cultivars, disease incidence ranged from 0% for Georgia-03L to 3.5% for Georgia-02C, with an overall mean of 1.9%and median of 1.7%; while, disease incidence for the late-maturing cultivars ranged from 4.3% for Hull, to 22.7% for Tifrunner with an overall mean of 10.1% and median of 7.7% (Table D.1).

Screening for resistance to *Sclerotinia sclerotiorium*. Greenhouse tests were conducted on the eight cultivars from the field test. The cultivars Okrun and Tamspan90 were included for comparison and served as susceptible and resistant controls, respectively (7). Seeds were planted in 10-cm pots containing a sand:peat (2:1) potting mix, placed in a

growth chamber and maintained at 28 °C with a 12-hour photoperiod for 10 weeks. Plants were then removed from the growth chamber and stems were wound inoculated 3 cm below the second fully expanded leaf. Pots were placed in a dew chamber, arranged in four randomized complete blocks and incubated at 20 °C and 95% RH. This experiment was repeated for a total of eight replications.

An additional assay used leaflets excised from the second fully expanded leaf of 10-week old greenhouse grown plants (10). Pairs of leaflets were placed in plastic petri plates (25 × 30 mm) lined with sterile filter paper, which was moistened with 2.5 ml sterile, distilled water. Potato dextrose agar plugs (4-mm-diam.) were taken from the leading edge of actively growing cultures of *S. sclerotiorum*, and placed mycelia side down in the center of each leaflet. Petri plates were arranged in a randomized complete block design, and placed in a dew chamber. Plates were incubated as described above for 72 hours. Lesion area was calculated by measuring lesion and width. There were a total of four replications, and the experiment was repeated once. Data from the whole plant inoculation tests and the detached leaflet assays were subjected to analysis of variance and Fisher's protected least significant differences were calculated for the separation of means (21). Subsequent references to significant differences among means are at the $P \leq 0.05$ level.

Cultivar × trial interactions for the whole plant inoculations and detached leaflet assays were not significant; therefore, data from both trials were pooled for analysis. Symptoms appeared three days after stem inoculations. Lesion length at five days after inoculation ranged from 7.7 to 14.8 cm (Figure D.4). All mean lesion lengths were significantly less than those on Okrun, the susceptible control. Mean lesion lengths for the

cultivars C-99R and Georgia-01R did not differ from Tamspan 90, the resistant control cultivar; whereas, lesion lengths of Georgia Green were intermediate.

Similar results were observed in the detached leaflet assays (Figure D.5). Lesions were largest on the cultivars Okrun and Georgia-02C with areas of 388 and 314 mm^2, respectively. Lesion areas for AP-3, Hull, C-99R, and Georgia-01R did not differ significantly from Tamspan 90 and ranged from 45.6 to 93.7 mm^2. Georgia Green and Georgia-03L expressed intermediate levels of resistance with lesion areas of 198 and 196 mm^2, respectively.

Conclusions

Sclerotinia blight is an economically important disease throughout peanut producing regions of Oklahoma, Texas, and Virginia and North Carolina (18). Although *S. sclerotiorum* is commonly recovered from soils in Georgia, Sclerotinia blight of peanut has never been found there previously. One explanation for this could be that typical environmental conditions during the peanut growing season are not conducive for growth of the fungus. Phipps (15) has speculated that activity of *S. minor* is inhibited when soil temperatures exceed 28 °C. The average soil temperatures during the growing season in south Georgia ranges from 25.1-31.3 °C (unpublished data). Although, *S. sclerotiorum* typically infects following carpogenic germination, the authors have not observed apothecia within the peanut growing season. Infections within the field all developed at the soil surface and appeared to have originated from myceliogenic germination of sclerotia, supporting previous reports that mycelia are capable of causing basal infections in other hosts (25).

Ample precipitation and unseasonably low temperatures during the latter part of the 2004 growing season were favorable for development of Sclerotinia blight (8, 15). Results

from the field observations suggested that varying levels resistance to *S. sclerotiorum* may be present in the cultivars evaluated. Overall, less disease was observed in the earlier maturing cultivars at harvest than in the later maturing cultivars; however, the earlier maturing cultivars had less exposure to favorable environmental conditions at the end of the season. The cultivars evaluated reacted differently to *S. sclerotiorum* in the field than in the growth chamber experiments, although the resistant and susceptible control cultivars separated out as previously reported (7) in both *in vivo* assays. In the field, the cultivar Tifrunner exhibited the highest level of disease incidence, whereas Georgia Green and Georgia-02C had substantially less disease. Results from growth chamber experiments indicated that disease development for Tifrunner, Georgia Green and Georgia-02C was similar to Okrun, the susceptible control. These findings are consistent with field resistance data for *S. minor* (7). Damicone et al. (6) reported that the majority of highly resistant entries from a core collection of peanut accessions exhibited an upright growth habit whereas two of the moderately resistant entries had a prostrate growth habit. In addition, resistance to Sclerotinia blight appeared to be associated with earlier maturity.

Detached leaf and leaflet inoculations have been used to evaluate host resistance to *S. minor* in peanut (10) and *S. sclerotiorum* in common bean (20). Results from leaf and plant inoculations were highly correlated (R^2=0.76, *P*=0.003), suggesting that either method can be used to identify differences in reaction to Sclerotinia blight. Results from both assays indicated that C-99R and Georgia-01R possess levels of resistance similar to Tamspan 90, even though the two cultivars were not originally selected for Sclerotinia blight resistance. Despite these findings, little information is available regarding *S. sclerotiorum* on peanut;

therefore, additional studies are required to further define the levels of resistance to *S. sclerotiorum* in runner cultivars used in the southeast.

The long-term implications of these findings are uncertain. The excessive moisture and cool temperatures late in the season compounded by late harvest may have been unique to the 2004 season. The field had a history of winter weeds belonging to the *Brassicaceae* family (J. Clark, personal observation), which could have served as a source of initial inoculum (11). Field experiments were repeated in an adjacent field in 2005, but environmental conditions were not conducive for Sclerotinia blight. No further occurrences of the disease have been reported since the initial observation. It is unlikely that Sclerotinia blight will become a problem in the southeastern production region unless planting late-maturing cultivars to minimize losses associated with TSWV becomes a common practice. In that case, Sclerotinia blight-related losses could be incurred when peanuts are planted in infested fields and exposed to prolonged cool, wet periods late in the fall.

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Table D.1. Mean Sclerotinia blight incidence in field plantings of mid- and late-maturing runner peanut cultivars in 2004[a].

Cultivar	Maturity	Growth Habit	N[b]	Disease Incidence±s.e.
Georgia Green	Mid	Upright	6	1.0±0.6
Georgia-02C	Mid	Upright	4	3.5±1.0
Georgia-03L	Mid	Upright	4	0.0±0.0
AP-3	Mid	Upright	2	2.5±0.7
C-99R	Late	Mod. Prostrate	4	6.0±3.4
Georgia-01R	Late	Prostrate	8	7.3±4.1
Hull	Late	Prostrate	4	4.3±3.8
Tifrunner	Late	Upright	4	22.7±2.9

[a] Incidence per 61 m of row.
[b] Number of observations.

Figure D.1. Active mycelium and sclerotial initials of *Sclerotinia sclerotiorum* on peanut stems.

Figure D.2. Shredding of an infected peanut mainstem caused by *Sclerotinia sclerotiorum* with sclerotia on and within the infected tissue.

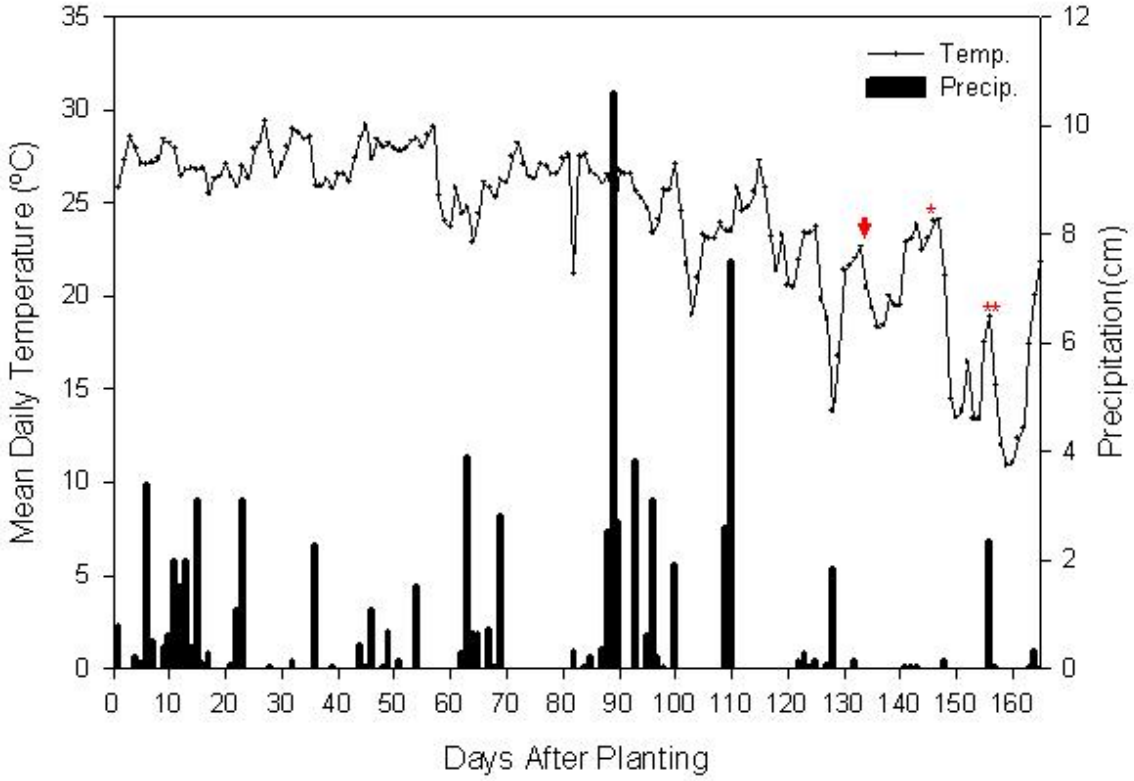

Figure D.3. Daily rainfall and mean daily temperature during the 2004 growing season Data were obtained from a regional weather station located in Alma, Georgia. Symbols denote initial disease observation (arrow), and disease rating date for mid-maturing (asterisk) and late-maturing (double asterisks) cultivars,

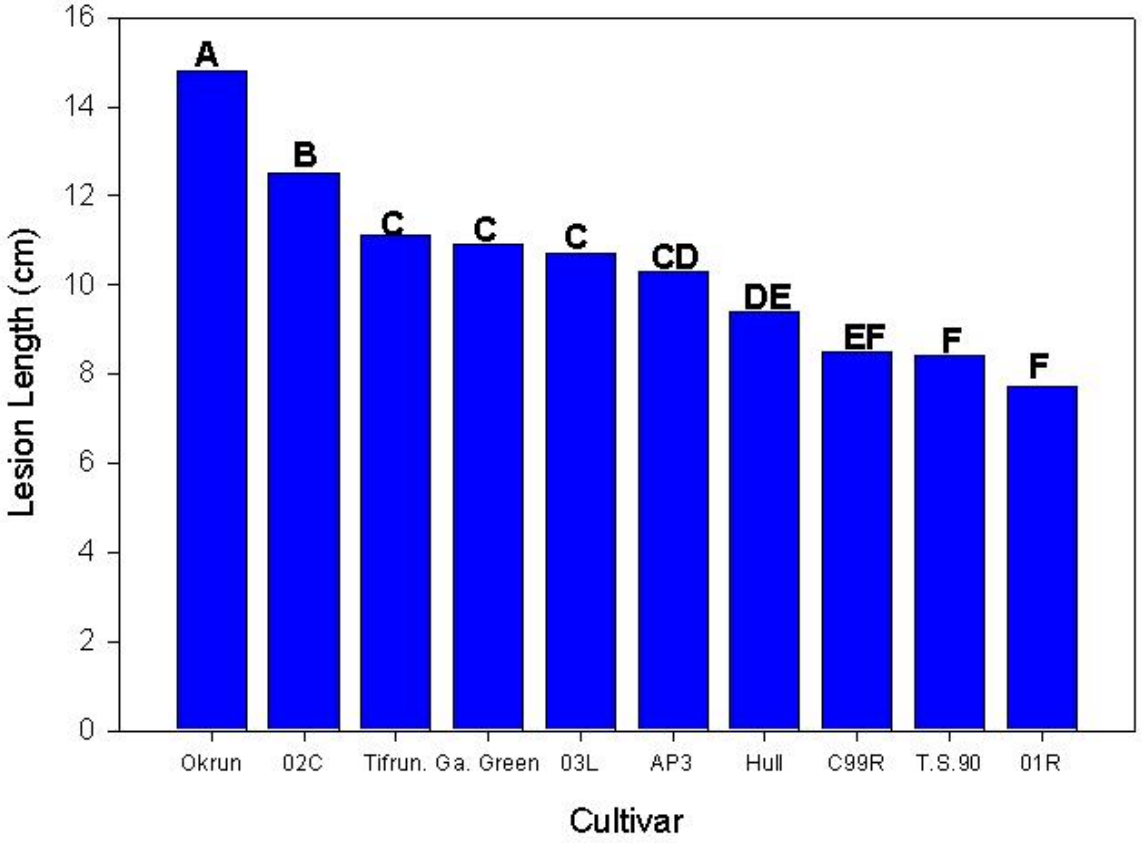

Figure D.4. Mean lesion lengths caused by stem inoculations of *Sclerotinia sclerotiorum* on 10 peanut cultivars. Bars with the same letter are not significantly different according to Fisher's protected least significant difference ($P \leq 0.05$). Cultivars evaluated included Okrun, Georgia-02C, Tifrunner, Georgia Green, Georgia-03L, AP-3, Hull, C-99R, Tamspan 90, and Georgia-01R.

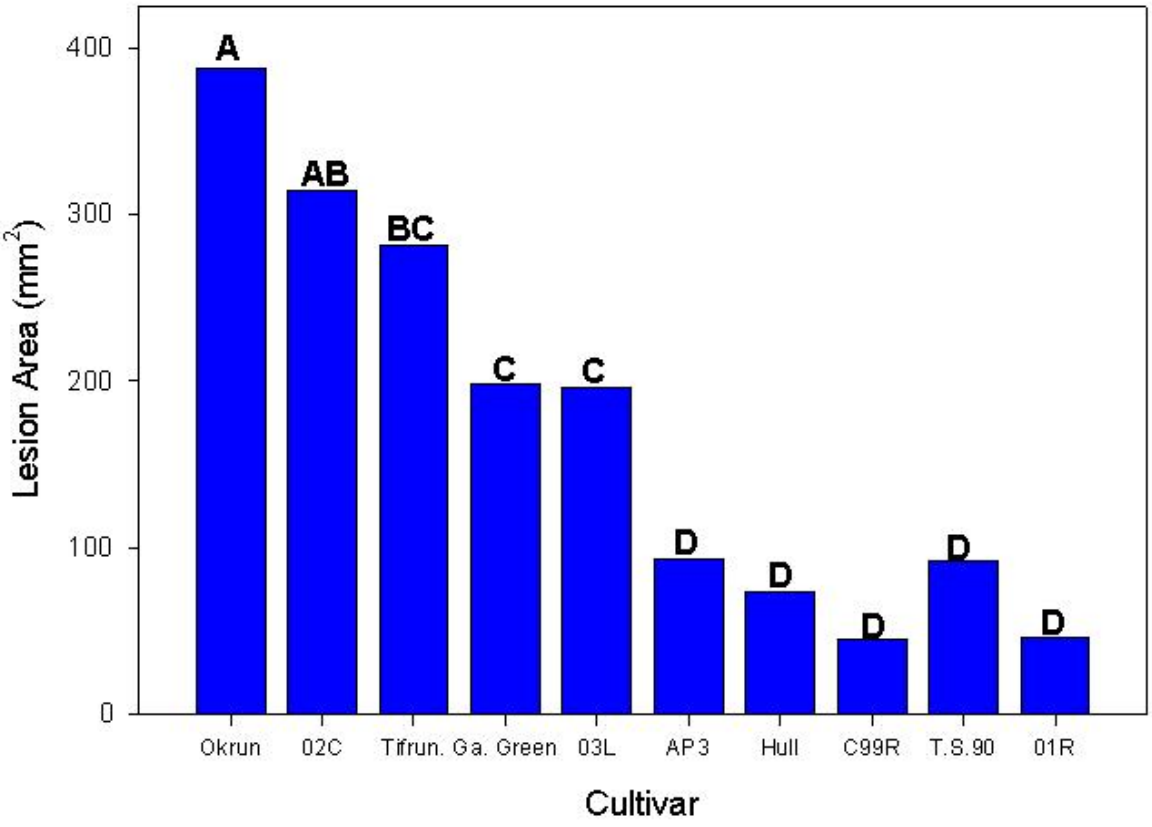

Figure D.5. Mean lesion area caused by *Sclerotinia sclerotiorum* on detached leaflets of 10 peanut cultivars. Bars with the same letter are not significantly different according to Fisher's protected least significant difference ($P \leq 0.05$). Cultivars evaluated included Okrun, Georgia-02C, Tifrunner, Georgia Green, Georgia-03L, AP-3, Hull, C-99R, Tamspan 90, and Georgia-01R.

APPENDIX E

APPENDIX TO CHAPTER 6

Table E.1. Effects of fungicides, irrigation timing, and/or canopy layer on the development of *Sclerotium rolfsii* lesions on detached peanut leaflets for three sampling dates

Main effect	68 DAP	82 DAP	110 DAP
Fungicide			
Azoxystrobin	75.0	67.6	105.8
Tebuconazole	44.9	28.5	56.4
Flutolanil	36.9	56.2	67.6
Chlorothalonil	252.1	234.6	421.6
LSD[a]	37.0	35.3	57.8
Irrigation timing			
0 hr	153.4	117.8	269.4
6 hr	60.7	66.4	88.0
12 hr	33.0	53.2	63.6
24 hr	44.0	31.8	37.5
48 hr	30.5	37.2	35.3
96 hr	21.6	28.4	25.4
none	22.7	20.8	17.1
LSD	64.9	16.4	27.1
Canopy layer			
Upper	55.3	42.7	68.8
Middle	45.3	54.2	75.3
Lower	56.2	55.5	87.8
LSD	71.6	12.7	136.2

[a] LSD to compare main effects within a column (P=0.05)

Table E.2. Effects of fungicides, irrigation timing, and/or canopy layer on the development of *Sclerotium rolfsii* lesions on detached peanut petioles for three sampling dates

Main effect	68 DAP	82 DAP	110 DAP
Fungicide			
Azoxystrobin	5.9	5.6	7.8
Tebuconazole	5.1	3.1	4.7
Flutolanil	2.8	4.9	4.1
Chlorothalonil	12.4	10.6	15.4
LSD[a]	5.4	7.5	8.1
Irrigation timing			
0 hr	7.9	10.9	11.0
6 hr	4.5	5.8	7.6
12 hr	4.8	3.3	4.9
24 hr	5.1	2.8	4.5
48 hr	4.4	3.9	4.7
96 hr	2.8	3.2	3.9
none	2.6	1.8	2.1
LSD	4.9	3.7	3.0
Canopy layer			
Upper	4.9	4.5	5.9
Middle	4.7	5.3	6.1
Lower	4.1	3.9	4.5
LSD	2.9	3.2	2.7

[a] LSD to compare main effects within a column (P=0.05)

Table E.3. Effects of fungicides, irrigation timing, and/or canopy layer on the development of *Sclerotium rolfsii* lesions on detached peanut stems for three sampling dates

Main effect	68 DAP	82 DAP	110 DAP
Fungicide			
Azoxystrobin	8.6	11.4	11.7
Tebuconazole	9.2	6.9	9.1
Flutolanil	4.8	8.1	7.4
Chlorothalonil	18.7	17.8	24.5
LSD[a]	10.8	15.3	7.9
Irrigation timing			
0 hr	10.3	12.4	14.4
6 hr	8.2	10.8	11.2
12 hr	6.8	7.2	8.2
24 hr	6.7	7.3	7.9
48 hr	7.6	8.4	9.1
96 hr	6.3	9.7	8.5
none	6.7	5.7	6.6
LSD	3.1	2.8	3.5
Canopy layer			
Upper	10.3	11.7	12.6
Middle	7.6	8.8	10.0
Lower	4.6	5.9	5.7
LSD	3.1	2.6	3.8

[a] LSD to compare main effects within a column (P=0.05)

Table E.4. Effects of fungicides, irrigation timing, and/or canopy layer on the number of leaf spot lesions, and the development of *Sclerotium rolfsii* lesions on excised peanut pods

Main effect	Leaf spot lesions	Pod colonization
Fungicide		
Azoxystrobin	1.1	35.7
Tebuconazole	1.1	34.5
Flutolanil	0.9	39.9
Chlorothalonil	0.6	65.3
LSD[a]	0.4	18.3
Irrigation timing		
0 hr	2.4	22.5
6 hr	1.4	27.2
12 hr	1.1	30.3
24 hr	0.7	35.5
48 hr	0.6	44.7
96 hr	0.5	47.8
none	0.5	49.0
LSD	0.5	17.4
Canopy layer		
Upper	1.1	-----
Middle	1.3	-----
Lower	0.8	-----
LSD	0.9	-----

[a] LSD to compare main effects within a column (P=0.05)

Table E.5. Effects of fungicides and irrigation timing on *Sclerotium rolfsii* lesion development on detached peanut petioles[a]

	Irrigation timing						
Fungicide	0 hr	6 hr	12 hr	24 hr	48 hr	96 hr	none
Azoxystrobin	7.2	5.4	6.1	7.1	6.4	4.9	4.0
Tebuconazole	8.5	4.7	6.7	7.6	4.1	3.3	0.5
Flutolanil	8.1	3.3	1.3	0.7	2.8	0.4	3.1
LSD[b]				4.2			
LSD[c]				4.0			

[a] Data are the means of 21 replications from 2003, 2004, and 2005.

[b] LSD to compare fungicides within irrigation timings (P=0.05).

[c] LSD to compare irrigation timings within fungicides (P=0.05).

Table E.6. Effects of canopy layer and irrigation timing on the number of peanut leaf spot lesions per leaf[a]

Canopy	Irrigation timing						
layer	0 hr	6 hr	12 hr	24 hr	48 hr	96 hr	none
Upper	2.2	1.1	0.8	0.4	0.3	0.3	0.6
Middle	2.9	1.8	1.4	0.8	0.8	0.6	0.3
Lower	2.1	1.2	1.2	0.9	0.7	0.7	0.3
LSD[b]				0.5			
LSD[c]				0.6			

[a] Data are the means of 21 replications from 2003, 2004, and 2005.

[b] LSD to compare canopy layers within irrigation timings (P=0.05).

[c] LSD to compare irrigation timings within canopy layers (P=0.05).

Table E.7. Effects of fungicides and irrigation timing on the number of peanut leaf spot lesions per leaf[a]

	Irrigation timing						
Fungicide	0 hr	6 hr	12 hr	24 hr	48 hr	96 hr	none
Azoxystrobin	2.5	1.4	1.1	0.7	0.8	0.8	0.5
Tebuconazole	2.4	1.9	1.3	0.7	0.4	0.5	0.5
Flutolanil	2.2	0.9	1.0	0.7	0.6	0.3	0.5
LSD[b]				0.4			
LSD[c]				0.6			

[a] Data are the means of 21 replications from 2003, 2004, and 2005.

[b] LSD to compare fungicides within irrigation timings (P=0.05).

[c] LSD to compare irrigation timings within fungicides (P=0.05).

Table E.8. Correlations between bioassays evaluating the effects of irrigation on fungicide redistribution (upper peanut canopy)[a]

Assay	Leaflet 68 DAP	Leaflet 82 DAP	Leaflet 110 DAP	Leaf 68 DAP	Leaf 82 DAP	Leaf 110 DAP	Stem 68 DAP	Stem 82 DAP	Stem 110 DAP	Leaf spot	Pod
Leaflet (68 DAP)	- - - - -	0.5520	0.5375	0.3998	0.3034	0.3907	0.3802	0.2615	0.3064	0.2536	-0.0659
		0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0702
Leaflet (82 DAP)	- - - - -	- - - - -	0.5360	0.1809	0.4456	0.3933	0.1699	0.3016	0.3063	0.2324	-0.0290
			0.0001	0.0001	0.0001	0.0001	0.0006	0.0001	0.0001	0.0001	0.5640
Leaflet (110 DAP)	- - - - -	- - - - -	- - - - -	0.20300	0.2817	0.5082	0.2218	0.2184	0.3993	0.3178	-0.0774
				0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.1162
Leaf (68 DAP)	- - - - -	- - - - -	- - - - -	- - - - -	0.0971	0.3092	03691	0.1080	0.1778	0.1454	-0.0999
					0.0718	0.0001	0.0001	0.0001	0.0004	0.0046	0.0412
Leaf (82 DAP)	- - - - -	- - - - -	- - - - -	- - - - -	- - - - -	0.3985	0.1318	0.3135	0.2340	0.1634	-0.0987
						0.0001	0.0108	0.0001	0.0001	0.0028	0.0588
Leaf (110 DAP)	- - - - -	- - - - -	- - - - -	- - - - -	- - - - -	- - - - -	0.2023	0.1559	0.4012	0.2013	-0.0837
							0.0001	0.0035	0.0001	0.0002	0.1042
Stem (68 DAP)	- - - - -	- - - - -	- - - - -	- - - - -	- - - - -	- - - - -	- - - - -	0.0675	0.2040	0.1480	-0.0983
								0.1730	0.0001	0.0027	0.0470
Stem (82 DAP)	- - - - -	- - - - -	- - - - -	- - - - -	- - - - -	- - - - -	- - - - -	- - - - -	0.2851	0.1223	-0.0259
									0.0001	0.0194	0.6059
Stem (110 DAP)	- - - - -	- - - - -	- - - - -	- - - - -	- - - - -	- - - - -	- - - - -	- - - - -	- - - - -	0.1762	-0.0645
										0.0006	0.0851
Leaf spot	- - - - -	- - - - -	- - - - -	- - - - -	- - - - -	- - - - -	- - - - -	- - - - -	- - - - -	- - - - -	-0.2114
											0.0001

[a] The top number for each entry is the Pearson's correlation coefficient between methods evaluating the redistribution of foliar applied fungicides, and the bottom number is the level of significance (p-value).

Table E.9. Correlations between bioassays evaluating the effects of irrigation on fungicide redistribution (middle peanut canopy)[a]

Assay	Leaflet 68 DAP	Leaflet 82 DAP	Leaflet 110 DAP	Leaf 68 DAP	Leaf 82 DAP	Leaf 110 DAP	Stem 68 DAP	Stem 82 DAP	Stem 110 DAP	Leaf spot	Pod
Leaflet (68 DAP)	- - - - -	0.2558	0.4062	0.3359	0.1928	0.1349	0.3142	0.2178	0.3469	0.1432	-0.0521
		0.0001	0.0001	0.0001	0.0002	0.0096	0.0001	0.0001	0.0001	0.0039	0.2746
Leaflet (82 DAP)	- - - - -	- - - - -	0.3697	0.2270	0.3194	0.0991	0.1488	0.3116	0.2004	0.2239	-0.0519
			0.0001	0.0001	0.0001	0.0785	0.0037	0.0001	0.0001	0.0001	0.3151
Leaflet (110 DAP)	- - - - -	- - - - -	- - - - -	0.1684	0.1589	0.2097	0.1589	0.2736	0.3579	0.1913	-0.0445
				0.0009	0.0014	0.0001	0.0014	0.0001	0.0001	0.0003	0.3741
Leaf (68 DAP)	- - - - -	- - - - -	- - - - -	- - - - -	0.1568	0.1475	0.3738	0.1122	0.1022	0.0992	-0.0507
					0.0035	0.0056	0.0001	0.0279	0.0413	0.0516	0.2987
Leaf (82 DAP)	- - - - -	- - - - -	- - - - -	- - - - -	- - - - -	0.1019	0.1894	0.3626	0.1053	0.2832	-0.0789
						0.0522	0.0009	0.0001	0.0517	0.0001	0.1345
Leaf (110 DAP)	- - - - -	- - - - -	- - - - -	- - - - -	- - - - -	- - - - -	0.0305	0.1684	0.1732	0.1163	-0.1361
							0.5672	0.0011	0.0016	0.0351	0.0089
Stem (68 DAP)	- - - - -	- - - - -	- - - - -	- - - - -	- - - - -	- - - - -	- - - - -	0.1098	0.2071	0.0668	-0.0570
								0.2073	0.0001	0.1787	0.1647
Stem (82 DAP)	- - - - -	- - - - -	- - - - -	- - - - -	- - - - -	- - - - -	- - - - -	- - - - -	0.2180	0.1499	-0.0025
									0.0001	0.0040	0.9591
Stem (110 DAP)	- - - - -	- - - - -	- - - - -	- - - - -	- - - - -	- - - - -	- - - - -	- - - - -	- - - - -	0.1465	-0.0228
										0.0044	0.6421
Leaf spot	- - - - -	- - - - -	- - - - -	- - - - -	- - - - -	- - - - -	- - - - -	- - - - -	- - - - -	- - - - -	-0.3463
											0.0001

[a] The top number for each entry is the Pearson's correlation coefficient between methods evaluating the redistribution of foliar applied fungicides, and the bottom number is the level of significance (p-value).

Table E.10. Correlations between bioassays evaluating the effects of irrigation on fungicide redistribution (lower peanut canopy)[a]

Assay	Leaflet 68 DAP	Leaflet 82 DAP	Leaflet 110 DAP	Leaf 68 DAP	Leaf 82 DAP	Leaf 110 DAP	Stem 68 DAP	Stem 82 DAP	Stem 110 DAP	Leaf spot	Pod
Leaflet (68 DAP)	- - - - -	0.1298	0.2667	0.2935	0.1039	0.1787	0.1079	0.0985	-0.0082	-0.0540	-0.1200
		0.0198	0.0001	0.0001	0.0001	0.0011	0.0256	0.0554	0.8721	0.3080	0.0144
Leaflet (82 DAP)	- - - - -	- - - - -	0.2089	0.1840	0.2223	0.2049	0.0397	0.4210	0.1750	0.0617	-0.0456
			0.0003	0.0014	0.0001	0.0007	0.4643	0.0001	0.0017	0.2869	0.4035
Leaflet (110 DAP)	- - - - -	- - - - -	- - - - -	0.0837	0.2592	0.4139	0.1003	0.2798	0.3133	0.1017	-0.0120
				0.1296	0.0001	0.0001	0.0633	0.0001	0.0001	0.0753	0.8190
Leaf (68 DAP)	- - - - -	- - - - -	- - - - -	- - - - -	0.1477	0.1361	0.1756	0.0214	-0.0162	-0.0456	-0.0377
					0.0124	0.0156	0.0004	0.6869	0.7562	0.4076	0.4561
Leaf (82 DAP)	- - - - -	- - - - -	- - - - -	- - - - -	- - - - -	0.3352	0.0799	0.3232	0.2057	0.0840	-0.0743
						0.0001	0.1499	0.0001	0.0003	0.1590	0.1840
Leaf (110 DAP)	- - - - -	- - - - -	- - - - -	- - - - -	- - - - -	- - - - -	0.1478	0.1857	0.1787	-0.0088	-0.0539
							0.0001	0.0008	0.0007	0.8804	0.3126
Stem (68 DAP)	- - - - -	- - - - -	- - - - -	- - - - -	- - - - -	- - - - -	- - - - -	0.0943	0.0867	-0.0019	0.0932
								0.0577	0.0757	0.9709	0.0487
Stem (82 DAP)	- - - - -	- - - - -	- - - - -	- - - - -	- - - - -	- - - - -	- - - - -	- - - - -	0.3520	0.0716	-0.0347
									0.0001	0.1849	0.4919
Stem (110 DAP)	- - - - -	- - - - -	- - - - -	- - - - -	- - - - -	- - - - -	- - - - -	- - - - -	- - - - -	0.1774	0.0279
										0.0009	0.5704
Leaf spot	- - - - -	- - - - -	- - - - -	- - - - -	- - - - -	- - - - -	- - - - -	- - - - -	- - - - -	- - - - -	-0.1642
											0.0014

[a] The top number for each entry is the Pearson's correlation coefficient between methods evaluating the redistribution of foliar applied fungicides, and the bottom number is the level of significance (p-value).

Table E.11. Correlations between bioassays evaluating the effects of irrigation on fungicide redistribution 68 days after planting[a]

Assay	Upper leaflet	Middle leaflet	Lower leaflet	Upper leaf	Middle leaf	Lower leaf	Upper stem	Middle stem	Lower stem	Leaf spot	Pod
Upper leaflet	- - - - -	0.7273 0.0001	0.4371 0.0001	0.3998 0.0001	0.3282 0.0001	0.1771 0.0004	0.3802 0.0001	0.3145 0.0001	0.1603 0.0006	0.3059 0.0001	-0.0659 0.0702
Middle leaflet	- - - - -	- - - - -	0.4973 0.0001	0.3635 0.0001	0.3359 0.0001	0.1495 0.0028	0.3902 0.0001	0.3142 0.0001	0.2235 0.0001	0.1772 0.0005	-0.0621 0.2746
Lower leaflet	- - - - -	- - - - -	- - - - -	0.2495 0.0001	0.3284 0.0001	0.2035 0.0001	0.3665 0.0001	0.3238 0.0001	0.1079 0.0256	0.0460 0.3853	-0.1199 0.0144
Upper leaf	- - - - -	- - - - -	- - - - -	- - - - -	0.3471 0.0001	0.1041 0.0401	0.3691 0.0001	0.3469 0.0001	0.1487 0.0020	0.2387 0.0001	-0.0999 0.0412
Middle leaf	- - - - -	- - - - -	- - - - -	- - - - -	- - - - -	0.2064 0.0001	0.2927 0.0001	0.3738 0.0001	0.2274 0.0001	0.0637 0.2284	-0.0507 0.2987
Lower leaf	- - - - -	- - - - -	- - - - -	- - - - -	- - - - -	- - - - -	0.2832 0.0001	0.1980 0.0001	0.1756 0.0004	0.0138 0.8025	-0.0377 0.4561
Upper stem	- - - - -	- - - - -	- - - - -	- - - - -	- - - - -	- - - - -	- - - - -	0.5209 0.0001	0.2077 0.0001	0.1227 0.0164	-0.0938 0.0470
Middle stem	- - - - -	- - - - -	- - - - -	- - - - -	- - - - -	- - - - -	- - - - -	- - - - -	0.3140 0.0001	0.0547 0.2885	-0.0670 0.1647
Lower stem	- - - - -	- - - - -	- - - - -	- - - - -	- - - - -	- - - - -	- - - - -	- - - - -	- - - - -	-0.0099 0.8470	0.0932 0.0487
Leaf spot	- - - - -	- - - - -	- - - - -	- - - - -	- - - - -	- - - - -	- - - - -	- - - - -	- - - - -	- - - - -	-0.3228 0.0001

[a] The top number for each entry is the Pearson's correlation coefficient between methods evaluating the redistribution of foliar applied fungicides, and the bottom number is the level of significance (p-value).

Table E.12. Correlations between bioassays evaluating the effects of irrigation on fungicide redistribution 82 days after planting[a]

Assay	Upper leaflet	Middle leaflet	Lower leaflet	Upper leaf	Middle leaf	Lower leaf	Upper stem	Middle stem	Lower stem	Leaf spot	Pod
Upper leaflet	- - - - -	0.7007 0.0001	0.5396 0.0001	0.4457 0.0001	0.2726 0.0001	0.3352 0.0001	0.3016 0.0001	0.3543 0.0001	0.3730 0.0001	0.2867 0.0001	-0.0290 0.6540
Middle leaflet	- - - - -	- - - - -	0.4854 0.0001	0.3297 0.0001	0.3194 0.0001	0.4348 0.0001	0.2291 0.0001	0.3157 0.0001	0.3705 0.0001	0.1914 0.0005	0.0518 0.3151
Lower leaflet	- - - - -	- - - - -	- - - - -	0.3593 0.0001	0.1045 0.0507	0.2223 0.0001	0.3187 0.0001	0.3557 0.0001	0.4120 0.0001	0.1917 0.0009	-0.0456 0.4036
Upper leaf	- - - - -	- - - - -	- - - - -	- - - - -	0.4109 0.0001	0.3429 0.0001	0.3135 0.0001	0.3806 0.0001	0.3102 0.0001	0.2328 0.0001	-0.0989 0.0588
Middle leaf	- - - - -	- - - - -	- - - - -	- - - - -	- - - - -	0.7855 0.0001	0.2818 0.0001	0.3626 0.0001	0.1469 0.0048	0.2168 0.0001	-0.0782 0.1345
Lower leaf	- - - - -	- - - - -	- - - - -	- - - - -	- - - - -	- - - - -	0.3061 0.0001	0.3934 0.0001	0.3232 0.0001	0.2432 0.0001	-0.0743 0.1840
Upper stem	- - - - -	- - - - -	- - - - -	- - - - -	- - - - -	- - - - -	- - - - -	0.4937 0.0001	0.4827 0.0001	0.2203 0.0001	-0.0258 0.6059
Middle stem	- - - - -	- - - - -	- - - - -	- - - - -	- - - - -	- - - - -	- - - - -	- - - - -	0.4716 0.0001	0.1804 0.0008	0.0026 0.9591
Lower stem	- - - - -	- - - - -	- - - - -	- - - - -	- - - - -	- - - - -	- - - - -	- - - - -	- - - - -	0.1475 0.0061	-0.0345 0.4919
Leaf spot	- - - - -	- - - - -	- - - - -	- - - - -	- - - - -	- - - - -	- - - - -	- - - - -	- - - - -	- - - - -	-0.3228 0.0001

[a] The top number for each entry is the Pearson's correlation coefficient between methods evaluating the redistribution of foliar applied fungicides, and the bottom number is the level of significance (p-value).

Table E.13. Correlations between bioassays evaluating the effects of irrigation on fungicide redistribution 110 days after planting[a]

Assay	Upper leaflet	Middle leaflet	Lower leaflet	Upper leaf	Middle leaf	Lower leaf	Upper stem	Middle stem	Lower stem	Leaf spot	Pod
Upper leaflet	- - - - -	0.6336 0.0001	0.5403 0.0001	0.5082 0.0001	0.2199 0.0001	0.2989 0.0001	0.3993 0.0001	0.3619 0.0001	0.3691 0.0001	0.3249 0.0001	-0.0774 0.0001
Middle leaflet	- - - - -	- - - - -	0.5239 0.0001	0.4762 0.0001	0.2099 0.0001	0.2429 0.0001	0.3907 0.0001	0.3579 0.0001	0.3340 0.0001	0.2907 0.0001	-0.0445 0.3741
Lower leaflet	- - - - -	- - - - -	- - - - -	0.3652 0.0001	0.2549 0.0001	0.4139 0.0001	0.3717 0.0001	0.3614 0.0001	0.3133 0.0001	0.1864 0.0010	-0.0120 0.8190
Upper leaf	- - - - -	- - - - -	- - - - -	- - - - -	0.3525 0.0001	0.3732 0.0001	0.4012 0.0001	0.3988 0.0001	0.2694 0.0001	0.2752 0.0001	-0.0837 0.1042
Middle leaf	- - - - -	- - - - -	- - - - -	- - - - -	- - - - -	0.2541 0.0001	0.2596 0.0001	0.1684 0.0011	0.2369 0.0001	0.1652 0.0038	-0.1361 0.0089
Lower leaf	- - - - -	- - - - -	- - - - -	- - - - -	- - - - -	- - - - -	0.2035 0.0001	0.2819 0.0001	0.1787 0.0007	0.0532 0.3657	-0.0538 0.3126
Upper stem	- - - - -	- - - - -	- - - - -	- - - - -	- - - - -	- - - - -	- - - - -	0.5480 0.0001	0.4663 0.0001	0.2141 0.0001	-0.0845 0.0851
Middle stem	- - - - -	- - - - -	- - - - -	- - - - -	- - - - -	- - - - -	- - - - -	- - - - -	0.5084 0.0001	0.1946 0.0003	-0.0228 0.6421
Lower stem	- - - - -	- - - - -	- - - - -	- - - - -	- - - - -	- - - - -	- - - - -	- - - - -	- - - - -	0.2000 0.0002	0.0279 0.5704
Leaf spot	- - - - -	- - - - -	- - - - -	- - - - -	- - - - -	- - - - -	- - - - -	- - - - -	- - - - -	- - - - -	-0.3228 0.0001

[a] The top number for each entry is the Pearson's correlation coefficient between methods evaluating the redistribution of foliar applied fungicides, and the bottom number is the level of significance (p-value).

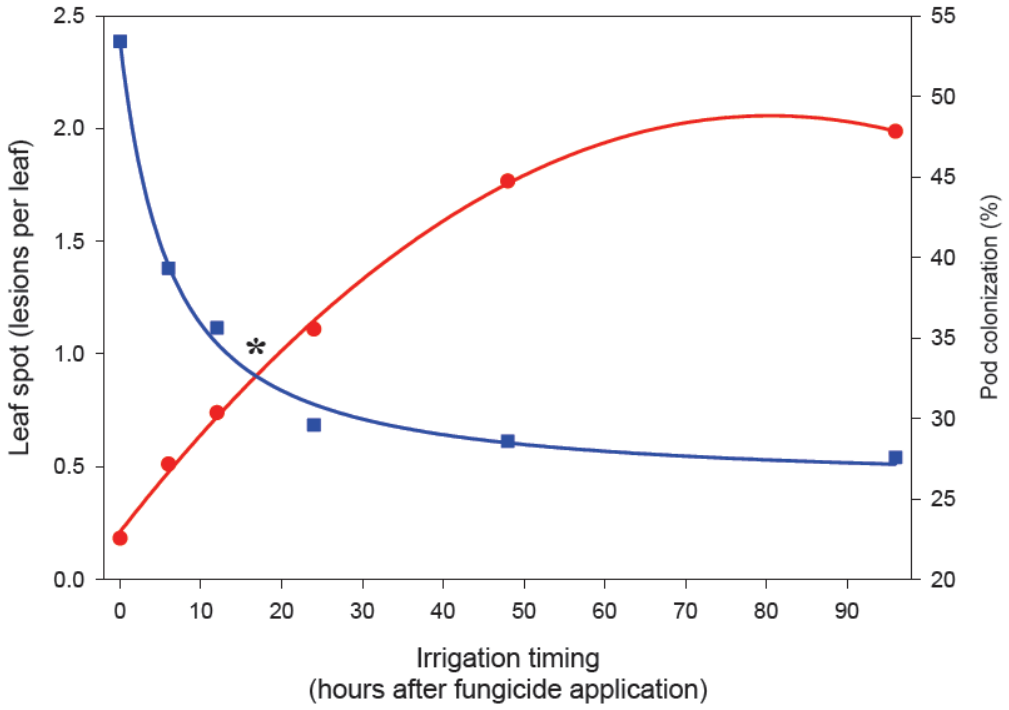

Figure E.1. Effect of irrigation timing on leaf spot intensity (blue line), and the percentage of pods colonized by *Sclerotium rolfsii* (red line). Asterick represents the theretical irrigation timing to achieve optimal suppression of leaf spot and pod colonization.