MANAGEMENT OF MAJOR PEANUT (*Arachis hypogaea* L.) DISEASES USING BAHIAGRASS (*Paspalum notatum* Fluegge) ROTATION

BY

FRANCIS KODJO TSIGBEY

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To my children and entire family

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By

Francis K. Tsigbey

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Chair: James J. Marois
Cochair: Lawrence E. Datnoff
Major: Plant Pathology

Suppression of peanut early leaf spot (ELS) (*Cercospora arachidicola* S. Hori,), and late leaf spot (LLS) [*Cercosporidium personatum* (Berk. & M.A. Curtis) Deighton was accomplished in a cotton (C)-bahiagrass (B)-bahiagrass (B)-peanut (P) [CBBP] rotation when compared to a conventional peanut (P)-cotton (C)-cotton (C)-peanut (P) [PCCP] rotation in north Florida during 2003-2006. The CBBP rotation significantly ($P \leq 0.05$) reduced ELS and LLS in peanut in all years as compared to the PCCP rotation. Final ELS and LLS severities (Florida 1-10 scale) in the PCCP rotation were 7, 8, 7, and 8; whereas those for the CBBP were 5, 6, 6, and 6 during 2003, 2004, 2005, and 2006, respectively. The apparent infection rates (r) were significantly ($P \leq 0.05$) higher in the PCCP than the CBBP rotation in all years. During 2003, peanut in the CBBP rotation had significantly ($P \leq 0.05$) higher incidence of rust (*Puccinia arachidis* Spegg) than those in the PCCP rotation. Pod yields were significantly ($P \leq 0.05$) lower (2,229; 2,297; 1,703; and 3,278 kg/ha) for the PCCP rotation than for the CBBP rotation (2,935; 3,053; 2,250; and 4,504 kg/ha) in 2003, 2004, 2005, and 2006, respectively, when not sprayed with fungicide. Tomato Spotted Wilt (TSW) incidence and severity were lower in the CBBP than the PCCP peanut in all years. Incidence of TSW on peanut ranged 6-16, 24-36, 21-37, 18-25% in 2003,

2004, 2005, and 2006, respectively, in a CBBP rotation, whereas the incidence ranged 15-24, 28-73, 28-77, 39-53% in 2003, 2004, 2005, and 2006, respectively, in a PCCP. Peanut seedlings suffered more thrips feeding damage (100%) under the PCCP rotation as compared to 45% under the CBBP rotation. Thrips (*Frankliniella* spp.).population on peanut seedlings were similarly higher on the PCCP than the CBBP rotation in 2005. Reduction in the incidence of southern stem rot (SSR) [*Sclerotium rolfsii* Sacc.] was achieved in CBBP rotation when compared to a PCCP rotation in north Florida during 2003. Peanut grown in the CBBP rotation had significantly ($P \leq 0.05$) lower SSR incidence. Field soils amended with leaves and roots of bahiagrass reduced survival of sclerotia of *S. rolfsii* in the range of 75-100%. Incorporation of plant parts encouraged colonization of sclerotia by *Trichoderma* spp. and bacteria. Amendments with higher proportions of leaf material reduced sclerotia survival the most and encouraged the growth of antagonists. Bahiagrass rotations reduced soil populations of *Meloidogyne* spp., *Rotylenchulus* spp., and *Helictylenchulus* spp., in exception of *Criconemoide*s spp. Bahiagrass root exudates actively attracted juveniles of *M. arenaria* to root zones in water agar. Field soils incorporated with bahiagrass residues significantly ($P \leq 0.05$) suppressed egg production of *M. arenaria* when compared to non-amended soils. Amendments with higher proportions of leave were more effective in suppressing egg production.

CHAPTER 1
INTRODUCTION AND LITERATURE REVIEW

Importance of Peanut in the United States (US) Economy

The cultivated peanut (*Arachis hypogaea* L.) is an annual self-pollinating, herbaceous legume native to South America (Hammons, 1973). As a geotropic plant it produces pods (fruits) in the soil. After flower fertilization 4-6 weeks after planting, carpophores (pegs or pointed needle-like structures) develop and grow into the soil to form the pod seed. Peanut is one of the most important legume crops in the US economy. The southeastern US is the largest peanut production region, with Florida producing approximately 8.5% of the total crop during 2006 (USDA, 2006). The US is a major exporter as well as consumer of peanuts. The use of peanut in confectionery is a widespread practice and constitutes 24% of total production. A greater proportion of peanut produced worldwide is pressed for oil and meal. It accounts for one-sixth of the world's supply of vegetable oil (Garciacasellas, 2004).

According to Fletcher (2002), counties in the southeastern US obtain 50-70% of their agricultural income from peanuts, and the crop serves as an integral component of their agriculture. Profit of any agricultural commodity is a function of yield, price, quality and cost, thus farmers must pay particular attention to these factors. However, farmers have least control over price, and hence, the only way to achieve profitability is to reduce costs. Approximately 30-50% of input costs in peanut production are allocated to managing weeds, insects, and disease (Garciacasellas, 2004). The quest by southeastern farmers is to find ways to reduce input costs to boost profit. One approach will be the use of crop rotation with compatible crops to reduce disease impact.

Overview of Peanut Diseases and their Management

Two major leaf spot diseases, early leaf spot (ELS) caused by *Cercospora arachidicola* S. Hori (teleomorph: *Mycosphaerella arachidis* Deighton) and late leaf spot (LLS) *Phaeoisariopsis personata* (Berk. & M.A. Curtis) Arx (also referred to as *Cercosporidium personatum* (Berk. & M.A. Curtis) Deighton (teleomorph: *Mycosphaerella berkeleyi* Jenk.)), are the most devastating diseases of peanut in the southeastern US. Both ELS and LLS are prevalent in all peanut producing regions of the world and result in yield reductions in the range of 50-70%, and may cause complete defoliation in the absence of management practices (Nutter and Shokes, 1995).

Both ELS and LLS are initiated during prolonged periods of high leaf wetness. The primary inocula for these diseases are from stromatic tissue that are resident in soils previously grown to peanut as well as the formation of conidia from volunteer peanuts (Jackson and Bell, 1969). Infections of *C. arachidicola* affect all above ground parts (leaves, petioles, and stems) of the peanut plant resulting in the formation of brown necrotic lesions which may be either discrete or coalesce to form larger lesions. Primary infections usually occur on the adaxial leaf surfaces of lower leaves on the stem (Smith and Littrel, 1980). Extensive research on the epidemiology of ELS and LLS has been conducted by several researchers over the years (Poter and Wright, 1991; Nutter and Shokes, 1995). The incubation and latent periods of ELS and LLS vary in different peanut varieties, and this is influenced by environmental conditions but, can be as short as 9 to 18 days (Shew et al., 1988). Secondary spread of both ELS and LLS by conidia is weather dependent, with wind, rain splash, and insects as the major dispersal agents (Shokes and Culbreath, 1997).

Management of leaf spot diseases of peanut has been accomplished through the combination of crop rotation, burying of crop residue with moldboard plow, and multiple applications of fungicides (Nutter and Shokes, 1995; Smith and Littrell, 1980; Kucharek, 1999).

Brenneman et al. (1995) reported increased peanut yield under bahiagrass rotations as well as the reduction of ELS and LLS, and noted that this was dependent upon the number of years between rotations with the perennial grass. The frequency of cropping peanut and rotation crop selection had a significant impact on peanut yield although yield did not always increase as the time interval between peanut crops was lengthened (Hagan et al., 2003). Peanut yields in bahiagrass-peanut (Brenneman et al., 1995; Johnson et al., 1999), corn-peanut (Johnson et al., 1999), and cotton-peanut (Johnson et al., 1999; Rodriguez-Kabana et al., 1991) cropping patterns were consistently higher than those observed in plots maintained in a peanut monoculture.

Southern stem rot (SSR) caused by *Sclerotium rolfsii* Sacc., teleomorph, *Atelia rolfsii* (Curzi) Tu & Kimbrough, can be a devastating pathogen on peanut (Backman and Brenneman, 1984). Stems, pegs, and pods of the peanut plant are susceptible to the pathogen, and all commercially grown cultivars are susceptible. *Sclerotium rolfsii* attacks most plant species and is difficult to control due to the production of sclerotia that can survive in soil under varied conditions for several years (Backman and Brenneman, 1984). Signs of SSR on peanut consist of the presence of white fluffy and cottony mycelia of *S. rolfsii* (but most often originating from the soil line on the stem of affected plant parts). Management of SSR using fungicides was difficult prior to the development of Folicur (tebuconazole, Bayer Crop Science) and later Moncut (flutolanil, Bayer Crop Science) (Brenneman et al., 1995). Aycock (1966) and Umaerus (1992) described the difficulty in managing stem rot due to the presence of numerous hosts and ability of the fungus to survive as sclerotia and dry mycelia on debris. Crop rotation using grasses has been found to suppress SSR (Flowers, 1976; Minton et al., 1991). The actual mechanism of SSR reduction in a bahiagrass rotation has not been studied and may not possibly be solely due to the non-host status of bahiagrass to *S. rolfsii*. *Sclerotium. rolfsii* grew and produced sclerotia on agar-grown bahiagrass seedlings that were co-inoculated with *S. rolfsii* (Tsigbey, unpublished). Other factors such as the enhancement of microbial population antagonistic to *S. rolfsii* propagules as well as gaseous products from the decomposition of bahiagrass may contribute to population decrease of *S. rolfsii*. Timper et al. (2001) reported lower incidence of stem rot on peanut grown after two years of bahiagrass than in continuous peanut or two years cotton, or corn before peanut in plots that were sprayed with fungicide. In the previous study, yield increase of 22% was reported for plots grown to peanut after two years of bahiagrass than two years of corn (12%), but it was not clear whether those plots received either aldicarb or aldicarb and flutolanil combined.

Tomato spotted wilt (TSW) of peanut is caused by thrips-vectored tomato spotted wilt virus (TSWV), a Tospovirus that belongs to the family Bunyaviridae, and causes severe problems in many of the world’s cropping systems (Moyer, 1999). Symptoms of TSW on peanut vary and could be dictated by cultivar, but characteristically include concentric ringspots, chlorotic leaflets, stunting of plants, misshapen pegs, pods, and kernels, reddish discoloration, and cracking of the seed coats (Costa, 1941; Culbreath et al. 1992). Tobacco thrips [*Frankliniella fusca* Hinds (Sakimura)] and western flower thrips [*F. occidentalis* (Pergande)] are confirmed vectors of peanut TSWV, and these insects are present in the southeastern US (Todd et al., 1993; Todd et al., 1995). TSWV is acquired and transmitted by both larvae and adults (Wijkamp et al., 1993) through feeding. TSW is now a serious and complex disease of peanut (*Arachis hypogaea* L.) and is common across the peanut growing regions in southeastern US including Alabama, Florida, Georgia, and North Carolina (Culbreath et al., 1997). The impact of TSW on peanut production in southeastern US has been devastating since its first appearance in 1971 (Culbreath et al., 2003). Less than two decades after its entry, TSW of peanut destroyed 50% of the peanut crop in southern Texas in 1985 with near 100% loss in some fields (Black et al., 1987), while losses to peanut due to TSW were around $40 million in Georgia in 1997 (Culbreath et al., 1999).

Volunteer peanuts and weeds in fields serve as virus reservoirs and hosts to thrips which aids the persistence of the virus in fields (Chamberlin et al., 1992; Chamberlin et al., 1993). Several factors including crops in rotation with peanut, cultivar susceptibility, pesticide, soil type, tillage methods, and time of planting affect TSW incidence and severity. However, the role of soil type and rotation crops on the survival of thrips and their impact on TSW have not been thoroughly studied.

Information on the contribution of soil to thrips infestation is scanty, however Barbour et al (1994) found fewer thrips emerging from soils than those collected on open-sticky cards in North Carolina and concluded that soils from peanut fields were not a major source of thrips. Timper et al. (2001) did not find any significant difference in injury due to thrips feeding as a result of rotation, though the combined treatment of aldicarb and flutolanil significantly reduced thrips feeding damage in comparison to control plots.

Management of peanut TSW poses tremendous challenges due to the multi-factors involved in disease incidence and severity. Since TSW is vectored by insects, the first approach was to control the thrips vectors, but that has been found to be inconclusive (Todd et al., 1996). Chemical control of thrips has not been effective in managing TSW on peanut (Mitchelle et al., 1991; Todd et al., 1996), possibly due to the mode of virus transmission and vector mobility. Modified thrips feeding behavior has been reported for *F. fusca* when Admire (imidacloprid, Bayer Crop Science) was applied on tomato (Chaisuekel and Riley, 2001). Black et al. (1993) reported the difficulty in quantifying the effect of insecticide treatments on the incidence and severity of TSW on peanut due to interplot interference by thrips from non-insecticide treated plots as well as insects from other locations. In-furrow application of phorate suppressed TSW epidemics on peanut, and Culbreath et al. (2003) reported that in-furrow application of thimet 20-G (phorate, Amvac Chemical Corp) reduced TSW in 63 out of 93 tests over a 3 year period, though the mechanism of suppression did not correlate with thrips control. Gallo-Meagher et al. (2001) reported that the mechanism of TSW control in phorate treated peanuts appeared to be due to activation of defense genes. However, the application of acibenzolar-S-methyl, a known defense gene activator, failed to show any significant suppression of TSW on peanut (Culbreath et al., 2003). Winter and spring insecticide spray application of Furadan (carbofuran, FMC Agr. Chem) reduced initial thrips population but gave no consistent TSW reduction (Todd et al., 1996). Application of Classic (chlorimuron ethyl, DuPont) was reported to increase the incidence of TSW on peanut (Prostko et al., 2002). In an extensive review of the epidemiology and management of TSW on peanut, Culbreath et al. (2003) proposed the integration of chemical, genetic, and cultural practices involving planting date, manipulation of plant population, tillage practices, row pattern as well as in-furrow insecticide application among other options in the management of TSW on peanut. Genetic resistance holds promise to manage TSW, but incorporating resistance to all economic diseases of peanut with acceptable yield and quality is a major challenge.

No-till and minimum tillage systems for peanut have become an economic option for peanut cultivation in the southeastern US. Use of minimum tillage in peanut has been reported to reduce the impact of TSW and leaf spots compared to a conventional till (Baldwin et al., 2001; Johnson et al., 2001; Monfort, 2002). Cantowine et al. (2006) reported the interaction effect of cultivar and tillage method on the suppression of ELS and TSW.

Peanut Diseases Caused by Nematodes

Plant parasitic nematodes are damaging to peanut causing an estimated loss of 12% or US$ 1.03 billion annually (Sasser and Freckman, 1987). Several nematode species attack peanut but the most prevalent include *Meloidogyne* spp., *Pratylenchus brachyurus*, and *Belonailamus longicaudatus* (Shama, 1985). Sasser (1977) designated three species of *Meloidogyne* that are damaging to peanuts: *M. arenaria*, *M. javanica*, and *M. hapla*. Among these *M. arenaria* (the most dominant species on peanut in the US) and *M. javanica* occur in warm and hot regions of the world while *M. hapla* occurs only in cooler regions (Dickson and Waele, 2005). Nematodes are widespread and destructive pests on peanut and could be described as "the hidden enemy'' since their damage is often imperceptible to farmers. Damaging nematodes are not evenly distributed across a field and scattered patches with damage can range in size from a few meters to several hectares.

Impact of Crop Rotations on Diseases

Crop rotations have been used for centuries in the management of crop diseases and most often are more effective in the management of soil-borne disease (Sullivan, 2004). The exact modes of disease suppression during rotation is not fully understood, though it ranges from the reduction of pathogen inoculum during periods when non-host crops are cultivated, soil microbial population and diversity changes that favor non-pathogenic organisms to increasing the number of pathogen antagonists. The efficiency of crop rotation in the management of plant diseases is influenced by the interacting factors of various components, ranging from environmental, edaphic (soil texture, structure, infiltration, fertility etc), type of rotation crop, the target pathogen, as well as the time interval between rotations (Summer, 1982). One major principle in crop rotation for plant disease management is the planting of a poor host plant for pathogen reproduction for more than one year (Dickson, 1956). It is the complexity of these interacting factors that make it difficult to attribute the actual mechanisms involved in disease suppression under any rotation system. Katsvairo et al. (2007) reported that bahiagrass rotation in a traditional southeastern US agricultural system improved cotton root development, biomass, and increased earthworm densities in the soil.

Cover Crops and Crop Disease Management

Green-manuring and cover cropping are somewhat similar with the exception that cover crops are often killed before incorporation into the soil. In a bahiagrass rotation scheme, the grass is killed either late fall or early spring and the most common tillage system currently practiced is strip-till. To a large extent, both improve soil characteristics, and many times control soil pests. The mechanisms of soil pest suppression are also identical. Whether cover crops are incorporated as green manure or as killed rotation crops, the process of decomposition releases a large array of active compounds that tremendously impact the diversity of soil microbial populations. Organic amendments bring about significant changes in soil physical and biological properties during the process of decomposition which affects the survival and multiplication of both pathogen inocula and antagonists (Bulluck and Ristaino, 2002).

Influence of Organic Amendments on Plant Diseases

Cover crops alter both the diversity and abundance of pathogen and pest antagonists, thus aiding in their reduction. Several mechanisms are proposed to be responsible for the reduction of plant-parasitic nematodes by cover crops including: 1) cover crops act as non-host or poor hosts (Rodriguez-Kabana et al., 1992, 1994); 2) production of allellochemicals that are toxic or inhibitory (Haroon and Smart, 1983; Gommens and Baker, 1988; Halbrent, 1996); 3) cover crops provide a niche for antagonistic flora and fauna (Linford et al., 1937; Evans et al., 1988; Caswell at al., 1990; Kloepper et al., 1991); and 4) cover crops may act to trap nematodes (Gallaher et al., 1991; Gardner and Caswell-Chen, 1994; Lamondia, 1996). Cover crops can also influence soil nematode populations by their failure to reproduce in non-hosts, and in some cases, produce fewer eggs (Rich and Rahi, 1995, McSorley, 1999). Organic amendments and other naturally occurring compounds can effectively suppress a number of plant-parasitic nematodes. Chavarria-Carvajal et al. (2001) evaluated pine bark, velvetbean, kudzu *(Peuraria montana* var. *lolobata)*, paper waste , and benzaldehyde for control of plant-parasitic nematodes and found that most amendments alone or in combination with benzaldehyde reduced damage from nematodes. Wang (2000) suggested that the reduction in *R. reniformis* population in a pineapple-*Crotalaria juncea* intercropping cycle might be due to the enhanced activities of bacterivorous nematode population as well as nematode-trapping fungi. Timper et al. (2001) observed a cropping system effect on *M. arenaria* and its antagonist *Pasteuria penetrans*, where populations of *P. penetrans* endospores were higher in a continuous peanut than a system of bahiagrass for two years followed by peanut. The ability of bahiagrass to support *P. penetrans* or other antagonistic organisms has not been well studied.

The influence of plant residue incorporation on the survival of pathogens and reproduction of nematodes has been well studied in greenhouse experiments (Haroon and Smart, 1983; Akhtar and Malik, 2000; Widmer and Abawi, 2000), though the successful application of such studies to large scale field research has been limited. Such studies notwithstanding, allow the understanding of the probable modes of disease suppression of organic residues in the field. Most often, such studies were designed to study the impact of amendments on soil-borne diseases but could as well be used to study the effect of such systems on foliar diseases. Organic amendments could release gases during decomposition that affect both foliar and soil-borne pathogens (Sayre et al., 1964; Hollis and Rodriguez-Kabana, 1966; Elmiligy and Norton, 1973). Incorporation of organic amendments affect survival of soil-borne pathogens such as *S. rolfsii*, and *Sclerotinia minor*. Ferguson and Shew (2001) reported that although stem rot incidence of peanut was not affected by application of wheat straw mulch and the final inoculum density of *S. rolfsii* was highest in those plots. Straw application reduced *Sclerotinia* blight in some years of their study and was found to be dependent on the initial inoculum density. All agricultural soils have a variety of micro-organisms that can suppress plant pathogens with mycorrhizal fungi found among them.

Role of Root Exudates in Rhizosphere Interactions

The term allelopathy was coined by Molisch in 1937 and was later adopted by Rice (1984) to include both harmful and beneficial interactions between all types of plants and interactions involving microorganisms (Alam et al., 1980). Effects of allelopathy in plants are manifested under several conditions including incorporating crop residues as green manure, as well as mulch stubble, replanting problems, autotoxicity, and rotation using different plants (Alam, 1980). Rice (1984) reported that plants influence each other by means of exudates, and similarly, reports by Buchholtz (1971), Fisher et al. (1978), Bhowmik and Doll (1980, 1983) suggested that leachates from residues incorporated into the growing medium or residues in natural undisturbed condition may also play a role. Allelopathic substances escape into the environment by volatilization, exudation from roots, or from decay of plant materials, and it appears that all plant parts possess allelopathic properties (Alam et al., 1980). Beneficial allelopathic interaction effects were reported between crops and weeds to the extent that the presence of one type of weed resulted in the suppression of another kind of weed (Alteiri and Doll, 1978).

Bais et al. (2006) reported that some of the most complex chemical, physical, and biological interactions experienced by terrestrial plants occur between roots and their surrounding environment of soil. Several workers (Kneer et al., 1999; Bais et al., 2003; Bais et al., 2002) reported the importance of root exudates in biological processes including root-root,

root-insect, and root-microbe interactions. The rhizosphere is also considered a dynamic front for interactions between roots and beneficial soil microbes, invertebrates, and root systems of competitors (Hirsch et al., 2003). Chemical signaling is believed to occur between plant roots and other soil organisms and is often based on root-derived chemicals (Bais et al., 2006). Chemical components of root exudates may deter one organism while attracting others with varied consequences to the plant and its neighbors. Morris et al. (1998) reported that the secretion of isoflavones by soybean roots attract both a mutualist (*Bradyrhizobium japonicum*) and a pathogen (*Phytophthora sojae*). Root exudates may play direct roles as phytotoxins in mediating chemical interference as seen in allelopathic relationships, and are critical to the development of associations between some parasitic plants and their hosts as well as playing indirect roles in resource competition by altering soil chemistry (Bais et al., 2006).

Allelopathic Properties of Bahiagrass

Allelopathy has been demonstrated in bahiagrass. Fisher and Adrian (1981) observed that as the percentage of ground covered with bahiagrass increased, the height of a 3-year-old pine decreased markedly, and further demonstrated that both living and decaying bahiagrass residue are allelopathic to pine. Watering pine seedlings with root leachates of bahiagrass also reduced root, shoot and total dry weight of pine seedlings, which clearly demonstrated allelopathic effect. An allelopathic effect of bahiagrass on peanut have not been directly demonstrated. Despite the previous observations, vigorous growth and higher yield of have been reported when peanut is grown after bahiagrass in comparison to a conventional cotton-cotton-peanut rotation (Hagan et al., 2003; Katsvairo et al., 2006). It has been known for centuries that crop rotation is generally beneficial to crop production, and suggestions are that these benefits are due to improved nutrition, decreased disease levels and improved soil structure (Abawi and Widmer, 2000).

Johnson and Pfleger (1992) indicated that the beneficial effects of a rotation may be due to the population dynamics of VAM fungi. It is therefore highly probable that the presence of VAM fungi in bahiagrass may be accounting for the higher yields and lower diseases in a bahiagrass-peanut rotation system. Bahiagrass exudates have been reported to enhance mycelial and spore production in VAM fungi (Ishii et al., 1996; Cruz et al., 2003). Higher hyphal as well as high root infection and spore numbers of *G. margarita* were found in a bahiagrass and millet compartment than in an adjacent papaya compartment when each were separated from a central compartment in which *Gigaspora margarita* spores were placed (Cruz et al., 2003). Methanol extraction of bahiagrass and millet roots eluates showed a similar result as above (Cruz et al., 2003), an indication that bahiagrass produced compounds that stimulate VAM fungi development. Bahiagrass root extracts stimulated the growth of *Gigaspora ramisporophora* in axenic culture (Ishii et al., 1997), and the substances later identified as flavonoids: eupalitin and two other unidentified compounds (Ishii et al., 1997).

CHAPTER 2

EFFECT OF BAHIAGRASS (*Paspalum notatum fluegge*) AND CONVENTIONAL ROTATION ON EARLY LEAF SPOT (*Cercospora arachidicola s. hori*), LATE LEAF SPOT (C*ercosporidium personatum* (BERK. & M.A. CURTIS) *Deighton*), AND RUST (P*uccinia arachidis* Speg.) DISEASES ON PEANUT IN NORTH FLORIDA

Introduction

Importance of Peanut Diseases and their Management

All parts of the peanut plant are susceptible to insect pests and diseases (Jackson and Bell, 1969). The three major leaf spot diseases are early leaf spot (ELS) caused by *Cercospora arachidicola* S. Hori (teleomorph: *Mycosphaerella arachidis* Deighton) and late leaf spot (LLS) caused by *Phaeoisariopsis personata* (Berk. & M.A. Curtis) Arx, also referred to as *Cercosporidium personatum* (Berk. & M.A. Curtis) Deighton, (teleomorph: *Mycosphaerella berkeleyi* Jenk.), and rust (*Puccinia arachidis*) (Jackson and Bell, 1969). ELS and LLS are prevalent in all peanut producing regions of the world and can result in complete defoliation and yield reductions of 50 to 70% in the absence of management practices (Nutter and Shokes, 1995). ELS infections result in defoliation, loss of integrity of the peg, poor pod filling, as well as fewer pods per plant that result in yield loss. Seed quality is also affected since photosynthetic ability of the plant is compromised. Aerts and Nesheim (2001) found that yield losses to ELS and LLS may vary from near zero to as much as 91% in Florida, and on a statewide basis, annual yield losses attributed to peanut leaf spot vary from 5 to 40%. Their assessment is consistent with reports of the diseases in other parts of the world where peanut is grown (Waliyar et al., 2000; Tsigbey et al., 2003). Garciacasellas (2004) reported that currently 25 to 30% of the input costs of producing peanuts are allocated to managing the major insect pests and diseases, and a greater proportion of these budgets are allocated to managing leaf spot diseases.

In view of the extensive input requirements in leaf spot management, producers will require sound science in making decisions in order to minimize cost. Management of leaf spot diseases poses challenges to farmers due to the influence of weather on disease onset, severity, and dissemination. The fungi that cause ELS and LLS are persistent in most locations but are especially troublesome during wet and humid years. Frequent rainfall or irrigation during the growing season exacerbate the difficulty in managing these diseases.

Epidemiology of ELS and LLS

Both ELS and LLS are initiated during prolonged periods of high leaf wetness. The primary inocula for these diseases are from stromatic tissue that are resident in soils previously grown to peanut as well as the formation of conidia from volunteer peanuts (Jackson and Bell, 1969). Infections of *C. arachidicola* affect all above ground parts (leaves, petioles, and stems) of the peanut plant resulting in the formation of brown necrotic lesions which may be either discrete or coalesce to form larger lesions. Primary infections usually occur on the adaxial leaf surfaces of lower leaves on the stem (Smith and Littrel, 1980). Extensive research on the epidemiology of ELS and LLS has been conducted by several researchers over the years (Poter and Wright, 1991; Nutter and Shokes, 1995). The incubation and latent periods of ELS and LLS vary in different peanut varieties, and this is influenced by environmental conditions but, can be as short as 9 to 18 days (Shew et al., 1988). Secondary spread of both ELS and LLS by conidia is weather dependent, with wind, rain splash, and insects as the major dispersal agents (Shokes and Culbreath, 1997).

Besides weather factors, the epidemics of ELS and LLS are influenced by host resistance, leaf spot management practices, tillage, and cropping system. Monfort et al. (2004) reported the suppression of ELS in strip-till plots compared to those in conventionally-tilled plots. Similarly, Cantonwine et al. (2006) characterized the suppression of ELS of peanut under strip-till and conventional tillage. It was established in the previous study that the reduction of ELS in peanut under strip-till is due to the reduction in initial inoculum in the form of stroma which in turn delays the epidemics (Cantonwine et al., 2006). An average of 8 to 11 days of delay in ELS onset was reported by Cantonwine et al. (2006) under a strip-till system, which can significantly prolong the timing of the first fungicide application without compromising yield. They further reported that the epidemic rate (r) was significantly lower for the strip-till than the conventional tillage system.

Peanut Rust (*Puccinia arachidis* Speg.)

Peanut rust is caused by *Puccinia arachidis* Speg., and affects all above ground parts of the plant, (Kucharek, 1979). The disease is characterized by rusty pustules particularly on the undersides of peanut leaves with associated chlorotic symptoms on the corresponding adaxial surfaces. Mixed infections of rust, ELS, and LLS are a common occurrence in peanut fields and complicate their individual impact on yield reduction. While all of them manifest as leaf spots, a characteristic distinguishing feature of peanut rust is the observation that rust affected peanut leaves still remain attached to the stem and give the field a burnt appearance, whereas leaves attacked by both ELS and LLS are shed onto the ground. Though still attached, rusted leaves lose their photosynthetic ability and serve as a drain to the plant. Peanut rust appears as minute leaf spots or flecks that are visible from both sides of the leaf. As the number of infections increase and become older, leaves become chlorotic. The fungus produces uredospores within uredial pustules found primarily on the leaves of the host. Uredospores readily become airborne and serve to disseminate the fungus. Under appropriate conditions of temperature and moisture, uredospores germinate, penetrate, and infect the host within hours and a new crop of uredospores matures within 10 days (Bromfield and Kenneth, 1969). Infections may also develop on stems and leaf petioles. Kucharek (2000) reported that occurrence of peanut rust does not follow any predictable manner in fields in Florida and often only becomes noticeable in August. Since rust occurs late in the cropping season, its contribution to yield reduction could be minimal.

Management of Peanut Leaf Spots

Management of leaf spot diseases of peanut has been accomplished through the combination of crop rotation, burying of crop residue with moldboard plow, and multiple applications of fungicides (Nutter and Shokes, 1995; Smith and Littrell, 1980; Kucharek, 1999). However, increased production costs, suppressed crop prices, high energy costs, and a reduced labor force is making peanut cultivation increasingly risky. To be competitive, farmers need to be more innovative and adopt sustainable production methods in order to reduce production costs and preserve soil productivity. One such approach is crop rotation by alternating peanut and cotton, which is a traditional production pattern in the southeastern United States. Peanut in rotations with corn and bahiagrass are also a viable option, particularly in the management of soil-borne fungi and nematodes (Flowers, 1976; Brenneman et al., 1995; Johnson et al., 1999; Timper et al., 2001), although Hagan et al. (2003) did not find any significant differences in the populations of root-knot nematode juveniles when peanut was planted after bahiagrass, corn or cotton.

Rotations of peanut with perennial grasses such as bahiagrass have been extensively researched in the management of soil-borne diseases, with other advantages including soil health maintenance (Beaty and Tan, 1972; Katsvairo et al., 2007) and improved yields. Although the impact of a bahiagrass-peanut rotation on nematode population reduction is well documented, (Timper et al., 2001; Dickson and Hewlett,1989; Norden et al., 1980; Rodriguez et al., 1988), the same cannot be said for other major peanut diseases such as leaf spots and TSW. In most studies, where peanut leaf spot was reportedly reduced by bahiagrass, the crop was also sprayed with a fungicide (Hagan, 2003; Brenneman et al., 1995).

Continuous cropping often results in yield reduction and the build up of pathogenic organisms in soils, whereas crop yields are generally higher in rotation with other crops (Garrett, 1944). Crop rotations with perennial grasses increased yields through improved soil nutrition and structure and reduction of plant pathogens (Katsvairo et al., 2006). The primary pathogens reduced by crop rotations are those infecting the roots and stems, though soil nutrition may play a part in influencing crops reaction to other diseases. Efficient crop rotation systems to manage diseases must consist of at least one non-host plant species of the target pathogen(s). This is important in order to reduce pathogens that rely on one single plant species for proliferation. The rate of decline and length of rotation necessary for effective suppression depend on the longevity of the pathogen survival stage and the choice of crop(s) in the rotation cycle.

Disease management involves practices that reduce the initial levels of inoculum and include selecting appropriate planting materials, destruction of crop residues (elimination of living plants that carry pathogens), and crop rotation. The efficiency of crop rotation systems in the management of plant diseases is influenced by the interacting factors of various components, ranging from environmental, edaphic (soil texture, structure, infiltration, fertility etc), type of rotation crop, and the target pathogen as well as the time interval between rotations (Summer, 1982). Several workers (Johnson et al., 1999; Rodriguez-Kabana et al., 1994; Rodriguez-Kabana et al., 1991) have reported yield increases in peanut under one or more rotation cropping system.

Brenneman et al. (1995) reported increased peanut yield in bahiagrass rotations as well as the reduction of ELS and LLS, and noted that this was dependent upon the number of years between rotations with the perennial grass. The frequency of cropping peanut and rotation crop selection had a significant impact on peanut yield although yield did not always increase as the time interval between peanut crops was lengthened (Hagan et al., 2003). Peanut yields in bahiagrass-peanut (Brenneman et al., 1995; Johnson et al., 1999), corn-peanut (Johnson et al., 1999), and cotton-peanut (Johnson et al., 1999; Rodriguez-Kabana et al., 1991) cropping patterns were consistently higher than those observed in plots maintained in a peanut monoculture. The use of perennial crops in rotation with peanut has not been a common practice, possibly due to the fact that many farmers may not receive direct economic benefits from the grass between rotations (Brenneman et al., 1995). Of the crops evaluated in a one year rotation with peanut, consistent yield gains were obtained in both years with velvet bean and winter rye/summer fallow and in two of three years with corn, when compared with the yield recorded for continuous peanuts (Flanders et al., 2005).

Hagan et al. (2003) reported a study in Georgia where it was found that ELS and LLS diseases on peanut were more severe in short term rotations. This was contrary to the report of Bowen et al. (1996), who did not find any impact due to cropping pattern on the level of leaf spot-induced defoliation on peanut in fields in Alabama. Thus, the effect of rotations on leaf spot diseases has been inconsistent. Such inconsistencies might be due to the fact that in most of these studies leaf spot was controlled using different fungicides and spray regimes. Consequently, the regimes as well as fungicide types and cultivar differences would have introduced these variations across locations. In order to fully quantify the impact of rotations on leaf spot diseases, non-fungicide treated control plots need to be assessed for disease severity as well.

The objective of this study was to determine the suppressive effect of bahiagrass rotations on peanut leaf spots in a bahiagrass-peanut rotation cropping systems.

Materials and Methods

Rotations and Field Practices

The study was conducted on a Dothan sandy loam (fine loamy siliceous, thermic Plinthic Kandiudult) at the North Florida Research and Education Center, Quincy, FL from 2003 to 2006. Rotation plots were established in the year 2000 and consisted of a bahiagrass rotation with peanut and a conventional rotation for peanut typical in the southeastern US. The cropping sequence for the bahiagrass rotation involved the growing of cotton in the first year and then followed by bahiagrass for two consecutive years and in the fourth year the plots were planted to peanut (CBBP). The conventional rotation consisted of growing peanut in the first year with cotton in the two subsequent years followed by peanut in the fourth year (PCCP). Each plot in the rotation cycle was split into irrigated and non-irrigated sub plots. The irrigation sub-plots were then split again, one of which was treated with fungicide and the other was not treated when peanut was planted in the rotation year. Irrigated plots received scheduled amounts of water over the four years as needed according to standard extension recommendations for peanut production in Florida (Smajstrla et al., 2006). General weed management practices in all years (2003-2006) were done in accordance with the Florida Cooperative Extension Services recommendations for peanut (Aerts and Nesheim, 2001; Whitty, 2002; Whitty and Chambliss, 2002). Except for 2003 in which two fungicide treatments were carried out during the earlier part of the season 30 days after planting (DAP), the same split sections of the plots under fungicide treatments remained treated or not treated (zero spray) for 2004, 2005, and 2006. Each (rotation* irrigation*fungicide) sub-sub-plot consisted of ten rows measuring 22.8 m long by 9.2 m wide (10 peanut rows).

Field Practices in 2003 and 2004

The bahiagrass cover crop was killed in December of 2003 and 2004 by applying glyphosate (Roundup WeatherMAX; Monsanto, Kansas City, MO). The winter oats (*Avena sativa* L.) cv. Florida 501 cover crop that was planted at 125 kg/ha, and killed 124 DAP in 2003 and 97 DAP in 2004 by broadcast spraying with glyphosate. Seedbeds were prepared in both years by strip-tilling with a KMC (Kelly Mfg. Corporation, Tifton, GA). Georgia Green peanut cultivar was planted on 7 May 2003 and 10 May in 2004 with a Monosem pneumatic planter

(ATI, Inc. Lenexa, KS) at 6 seeds per 31 cm of row on 91-cm row spacing. Phorate (Thimet® 20-G; Micro Flo Company LLC. Memphis, TN) at 5.6 kg/ha was applied in furrow at planting.

Leaf spot management during 2003 and 2004 involved the alternating broadcast applications of chlorothalonil (Bravo Weatherstik 720 F; Syngenta, Crop Protection, Inc., Greensboro, NC) at 1.26 kg a.i/ha, tebuconazole (Folicur 3.6 F; Bayer CropScience Research Triangle Park, NC) at 0.23 kg a.i./ha, and pyraclostrobin (Headline; BASF Corporation, Research Triangle Park, NC) at 224 g a.i./ha. During 2003, plots were sprayed with chlorothalonil on 36, 78, and 121 DAP; tebuconazole on 51, 96, and 134 DAP; pyraclostrobin on 64, and 106 DAP. However, at 106 DAP mancozeb (Dithane M-45; Dow AgroSciences, Indianapolis, IN) was tank-mixed with Headline. All fungicides were applied using tractor (John Deer Model 6415, Johns Tractor Company, Jay FL.) mounted boom sprayers (nozzle size 1103). The tractor was driven at C-range at 1,600 RPM and the pressure was 30 PSI, that delivered 47 gals water/ha. The same tractor specifications were used in all years. During 2004, leaf spots were controlled by alternating applications of chlorothalonil at 1.26 kg a.i./ha and tebuconazole at 0.23 kg a.i./ha tank-mixed with Induce® as a spreader at 41, 55, 69, 73, 87, 101, and 115 DAP, respectively.

Field Practices in 2005 and 2006

Bahiagrass cover crop was killed in fall of 2004 and 2005 for the coming year's cropping season. Oats (cv. Chapman, Maynand Douglas Farms, Cottondale, FL.) were planted at 125 kg/ha on 26 November 2004 as winter cover crop for the 2005 cropping season, and cv. Florida 501 (Maynand Douglas Farms, Cottondale, FL.), was planted on 10 December 2005 at 125 kg/ha for the 2006 season. Cover crops were managed according to recommended practices in both years, and killed 123 DAP in 2005 and 120 DAP in 2006. The seedbed was prepared by double-ripping 10 rows using a KMC (Kelly Mfg. Corporation, Tifton GA) 4 row ripper in April of both years, and subsequently planted to peanut cv. AP3 on 13 May 2005 and 17 May 2006 with a Monosem pneumatic planter (ATI, Inc. Lenexa, KS) Twin Row Planter at three seeds per 30 cm of row with simultaneous application of phorate (Thimet) at 6 kg/ha into furrows.

Leaf spot management in 2005 involved the alternate sprays of chlorothalonil (Bravo Ultrex 82.5 DWG; Syngenta, Crop Protection, Inc., Greensboro, NC) at 32, 75, and 116 DAP at 1.26 kg a.i/ha, tebuconazole (Folicur 3.6 F, Bayer CropScience) at 0.23 kg a.i./ha at 45, and 88 DAP; and pyraclostrobin (Headline) at 0.22 kg a.i./ha at 61 and 103 DAP. All fungicides were applied using tractor (John Deer Model 6415, Johns Tractor Company, Jay FL.) mounted boom sprayers (nozzle size 1103). The tractor was driven at C-range at 1,600 RPM and the pressure was 30 PSI, that delivered 178 L water/ha. The same tractor specifications were used in all years. Leaf spot management in 2006 was done by alternating sprays of chlorothalonil, tebuconazole, and pyraclostrobin in a resistance management strategy on 44, 57, 71, 85, 99, 113, and 127 DAP.

Disease Assessments

ELS and LLS were assessed in all four years when leaf spots first appeared until harvest using the Florida 1 -10 scale [where 1 = no leaf spot; 2 = very few spots on leaves with none on upper canopy leaves; 3 = few lesions on the leaves, very few on upper canopy; 4 = some lesions with more on the upper canopy, 5 % defoliation; 5 = lesions noticeable on upper canopy, 20% defoliation; 6 = lesions numerous and very evident on upper canopy, 50 % defoliation; 7 = lesions numerous on upper canopy, 75 % defoliation; 8 = upper canopy covered with lesions, 90 % defoliation; 9 = very few leaves remaining and those covered with lesions, 98 % defoliation; and 10 = plants completely defoliated and killed by leaf spot (Chiteka et, al. 1988)]. Twenty plants were randomly scored in all plots. Disease assessments were conducted 32, 46, 61, 75, 100, 137 days after planting (DAP) in 2003; 40, 63, 91,104, 124, 132, and 140 DAP in 2004; 34, 45, 52, 64, 96, 12, and 134 DAP in 2005; and 34, 51, 66, 85, 100, 123, 145 DAP in 2006.

Disease severity data were analyzed separately for each year for the non-fungicide sprayed plots, and the standardadized area under the disease progress curve (SAUDPC) was computed (Shaner and Finey, 1977).

Disease assessments were converted into proportions [y = (Florida rating – 1) / 9], and transformed using the linearizing transformation for the Gomperzt = [-In(-In y)], and logistic = [In(y/(1-y))] models. Transformed data were linearly regressed on time and with the first date of each year of assessment set as the beginning of the epidemic. The logistic model, which consistently had the highest R^2 value, was selected for the epidemics, and the slope of the linearly regressed transformed data was used as the rate parameter (r) to estimate the epidemic rate for each year and rotation. Effects of rotation on SAUDPC and r were determined for each rotation and year separately. Southern stem rot incidence was assessed only in 2003 by examining twenty plants for signs of the pathogen, *S. rolfsii,* and similarly for peanut rust (*Puccinia arachidis*).

Pod Yield and Grade

Peanuts were inverted 144 DAP and picked 24 h later, then dried at 115 ^{o}C for 24 hours and brought to 10% moisture before weight determination. A 500 g sample of harvested pods per plot was removed and analyzed for commercial grading according to Federal Inspection Services methods (USDA, 2002).

Statistical Analysis

All the data were analyzed using Statistical Analyses System (version 8.0, SAS Institute Inc Cary, NC) GLM approach. Data for all years were first analyzed as a split-split experiment to investigate interaction of main and subplots. In the absence of a consistent interaction effect, the data was subjected to analyses of variance (ANOVA) as a randomized block design.

Means from the rotations were compared using the least significance difference (LSD) test to determine the differences ($P \leq 0.05$) in severity measured by the SAUDPC, yield, and quality between the PCCP and CBBP rotation for each year separately.

Results

Two years of a bahiagrass rotation (CBBP) significantly reduced severity of ELS and LLS when compared to the conventional (PCCP) system in all years. The increase in disease severity over time was best described by the logistic model for each plot rotation in all years; $R^2 = 0.92$ and 0.91 for the PCCP and CBBP rotations, respectively. In 2003, ELS began appearing on plants 32 DAP (Fig. 2.1) and gradually progressed over time. Estimates of the apparent infection rate of epidemics (r) computed from the slope of the linearized logistic model was comparable for both rotations but were slightly higher for the PCCP (0.024) than for the CBBP (0.019) rotation. Leaf spot epidemics measured by the standardized area under the disease progress curve (SAUDPC) were not significant for either rotation (Table 2.1). Initial infections on peanuts were caused by ELS but LLS become the dominant leaf disease 90 DAP. LLS was the predominant disease until harvest throughout the four years of the study. Since distinctions were not made when rating ELS and LLS, the mean severity was a combined score for both diseases and hereafter, referred to as leaf spots. There was no significant difference in severity rating between the CBBP and PCCP peanuts at earlier dates of disease assessment, but thereafter was consistently significant ($P \leq 0.05$) until harvest (Fig. 2.1). Similarly, the proportion of plants showing higher ratings was higher in the PCCP rotation than in the CBBP rotation resulting in a higher proportion ($P \leq 0.05$) of disease throughout 2003.

Similar to the observations in 2003, leaf spot in 2004 started significantly earlier ($P \leq 0.05$) for the PCCP rotation compared to the CBBP rotation (Fig. 2.2). Except at 132 DAP, severity ratings were higher ($P \leq 0.05$) for the PCCP rotation than for the CBBP until harvest. Estimates of the apparent infection rate of epidemics (r) computed from the slope of the linearized logistic model were higher ($P \leq 0.05$) in 2004 than 2003 and comparable for the PCCP and the CBBP rotation (Table 2.1). Leaf spot epidemics (SAUDPC) were not significantly different between the two rotations (Table 2.1). However, there was a significantly higher leaf spot development for the PCCP rotation for the individual assessment dates in comparison to the CBBP rotation.

The increase in disease severity over time was best described by the logistic model (logistic = [In(y/(1-y))]) for each rotation in 2005; $R^2 = 0.98$ and 0.90 for the PCCP an CBBP rotations, respectively (Fig. 2.3). Estimates of the apparent infection rate of epidemics (r) computed from the slope of the linearized logistic model were almost the same as were observed in the rotations in 2004. Leaf spot epidemics measured by the standardized area under the disease progress curve (SAUDPC) were not significantly different between the two rotations (Table 2.1) although higher for the PCCP rotation.

As in the previous years, disease onset was evident as early as one month after planting in some years, but incidence was lower in both rotations (Fig. 2.3). There was no significant difference ($P \leq 0.05$) between rotations at 34 and 45 DAP. At 54 DAP, leaf spot severity increased sharply for the PCCP rotation while the CBBP peanut remained relatively disease-free. There was a corresponding higher ($P \leq 0.05$) disease proportion on the PCCP rotation peanut than those in the CBBP rotation. In the PCCP rotation, leaf spot reached 6.0 and 7.0 rating while in the CBBP rotation, leaf spot reached 5.0 and 6.0 ratings at 123 and 134 DAP, respectively.

Leaf spot progression on AP3 peanut during 2006 was best described by the logistic model for each rotation in 2006, $R^2 = 0.90$ and 0.88 for the PCCP and CBBP rotations, respectively (Fig. 2.4). Estimates of the apparent infection rate of epidemics (r) computed from the slope of the linearized logistic model was comparable and similar for both rotations but slightly higher

(0.044) for the PCCP than (0.040) for the CBBP rotation. Leaf spot epidemics measured by SAUDPC were not significantly different between the rotations (Table 2.1) although they were higher for the PCCP rotation. Leaf spot severity remained significantly higher in the PCCP rotation than the CBBP rotation throughout the season.

Rust (*Puccinia arachidis*)

Rust was virtually absent in 2004, 2005, and 2006. In 2003, rotations significantly ($P \leq 0.05$) affected the incidence of rust, and the incidence was found to be more pronounced on the CBBP rotation than on PCCP rotation (Fig. 2.5).

Influence of Rotations on Peanut Pod Yield and Quality

Significant differences ($P \leq 0.05$) were found between the yields from the bahiagrass and conventional rotations in both fungicide sprayed and non-sprayed plots in all four years (Table 2.2). In 2003 and 2004 when c.v. Georgia Green was planted, peanut yields were higher ($P \leq 0.05$) in the bahiagrass rotation whether sprayed or not sprayed than in the conventional rotation with corresponding fungicide spray regime.

Similarly, significantly higher yields were recorded in the bahiagrass rotations than in the conventional rotations in 2005 and 2006 with similar fungicide spray regimes (Table 2.2). Peanuts grown in the bahiagrass rotation produced consistently greater pod yields (6-35 %) over the four year period. CBBP rotation increased peanut yield 24, 25, 24, and 33 % in 2003, 2004, 2005, and 2006, respectively, over those in the PCCP rotation when both received no fungicide sprays. Peanut grade was significantly ($P \leq 0.05$) improved under CBBP than PCCP rotation, and the same was observed for percent damaged kernels (Table 2.3).

Discussion

In this study, epidemics of peanut leaf spot were suppressed by two years of bahiagrass rotation (CBBP) when compared to a conventional cotton-peanut (PCCP) rotation. Under a no fungicide spray regime, cultivating peanut after two years of bahiagrass significantly reduced the severity of leaf spot diseases by delaying disease onset when compared to the PCCP system. Though leaf spot disease suppression in a bahiagrass rotation has been extensively reported (Brenneman et al., 1995; Hagan et al., 2003), such studies involved bahiagrass plots that were either burned before planting peanut (Brenneman et al., 1995) or the peanuts were sprayed with fungicide (Hagan et al., 2003). Such treatments made it difficult to estimate the actual contribution of bahiagrass rotation to leaf spot suppression since there were confounding effects due to the fungicide spray or burning. It appeared that the initial two fungicide sprays during 2003 resulted in a lower disease severity although it was higher for the PCCP rotation than in the CBBP. Consequently lower final leaf spot severity ratings for both rotations were recorded in 2003 compared to 2004. The fluctuations in disease severity in 2004 and other years could be attributed to weather variations that were experienced (Fig. 2.6, 2.7, and 2.8). Whereas temperature variations followed similar patterns in all four years, those of total rainfall and relative humidity varied greatly both across years and within years. The epidemic rate parameter (r) calculated from the logistic transformation was similar for both rotations however; linearization of the actual Florida severity ratings produced a slightly higher rate parameter in all years in the PCCP than the CBBP rotation. Fluctuations in leaf spot severity as a result of environmental conditions could have lowered the epidemic rate in the logistic model. The influence of rotation on leaf spot severity was most noticeable in 2006 when disease severity was high and the CBBP rotations still had moderate disease. Nearly 60% defoliation occurred in the CBBP in 2006 compared to nearly 90% for the PCCP rotation.

Rotations have been reported to manage peanut leaf spot (Kucharek, 1975), but the mechanism of disease suppression in a rotation is difficult to identify. A general conclusion is that planting an incompatible crop in the rotation cycle will help break the pathogen cycle (Curl, 1963; Flowers, 1976; Brenneman et al., 1995). However, other mechanisms such as the contribution of the crops in the cycle in modification of soil properties and their benefits to plant health by means of proper nutrition must be considered. Bahiagrass has an extensive deep rooting system that breaks through hardpan layers in the soil, and thus, improves water infiltration. Katsvairo et al. (2007) demonstrated that cotton plants in a bahiagrass rotated plots had improved root biomass. Other mechanisms might include allelopathic properties of crops, rhizosphere interactions of microbial population and root exudates that could enhance mycorrhizal associations in soils (Harsh et al., 2006).

Since the rate of disease increase was comparable for both rotations in all four years, the impact of the rotations on leaf spot severity was mainly due to the delayed onset in the CBBP rotation based on the disease progress curve. Laboratory studies (data not presented) indicated that a greater proportion (83%) of inoculated detached leaflets taken from peanut growing in the PCCP rotation on the field showed symptoms of ELS compared to 33% recorded on those from the CBBP rotation four weeks post-inoculation. It is likely leaf spot epidemics could follow similar trends as was observed in field disease progression over the four years of the study.

Pod yield and quality were significantly greater in the CBBP peanut than in the PCCP rotation in all years. CBBP rotations with no fungicide had 26 and 25% increase in pod yield when GA Green was the cultivar planted in single row pattern in 2003 and 2004, respectively. An increase of 32 and 28% was recorded, respectively, during the same period of time when the plots were both treated with fungicide. This indicates that whether fungicide treated or not, the CBBP rotation resulted in a higher peanut yield than in the PCCP rotation. These yields were comparable to those of the AP3 variety that was grown in 2005 and 2006. When not treated with fungicide, the AP3 variety in the CBBP rotation had a 24 and 33% yield increase over the PCCP rotation during 2005 and 2006, respectively. However, under a fungicide treated regime, the AP3 in the CBBP had a 6% increase in yield over the PCCP rotation in both years. The lower percentage increase in yield of the fungicide-treated plots for the rotations suggests that fungicide sprays in a twin row system benefited both rotations. Thus, an AP3 variety under the CBBP rotation which was not sprayed had a better chance of producing higher yield increases than when sprayed compared to the PCCP rotation. Peanuts treated with fungicides in bahiagrass (CBBP) rotation gave 11 and 29% yield increase in the same rotation over an unsprayed plot, whereas 3 and 26% yield increase was recorded for the PCCP rotation in 2003 and 2004, respectively. During 2005 and 2006, sprayed peanut in the CBBP rotation had 26 and 8% increase in pod yield above those in unsprayed plots in the respective years compared to that of 41 and 22% in the PCCP rotation.

Fungicide application to peanut in the CBBP rotation, thus, appeared not to be as beneficial as it was in the PCCP rotation as consequence of the lower disease severity in the CBBP than the PCCP rotation.

Increased yield in peanut under a bahiagrass rotation had been reported by several workers (Brenneman et al., 1995; Hagan et al., 2003; Katsvairo et al., 2007), though there has been no measurement of yield increase in a no-fungicide sprayed regime. The results of this research suggest a possible beneficial effect of reduced fungicide sprays on a bahiagrass rotation that could result in subsequent cost reduction. Such studies will be necessary in order to further encourage farmers to adopt the sod rotation in peanut production. There have been no reports on the influence of varying fungicide sprays on peanut under a bahiagrass rotation in comparison to that on the conventional (cotton-cotton-peanut) rotation. Though the percentage increase in yield realized under the same rotation whether sprayed or not sprayed had not been consistent throughout the four years of the studies, it does suggest that fewer number of fungicide sprays on the CBBP rotation may be possible. Garciacasellas (2004) reported that about 30 to 50% of the farmers' cost in peanut production is used on pest management; hence any system that will help them to reduce such costs might be helpful.

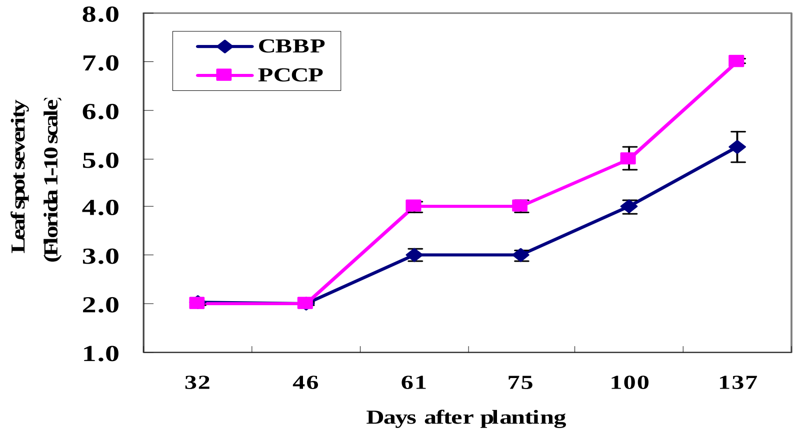

Figure 2-1. Effect of bahiagrass (CBBP) and conventional (PCCP) rotation on progression of leaf spot severity measured using the Florida 1-10 scale, over time on Georgia Green peanut during 2003. Treatment means for a minimum of 4 replications and the standard error bars are shown for each assessment date. Plots received only two fungicide sprays during early stages of growth. Yearly rotation sequences were bahiagrass (B), cotton (C), and peanut (P).

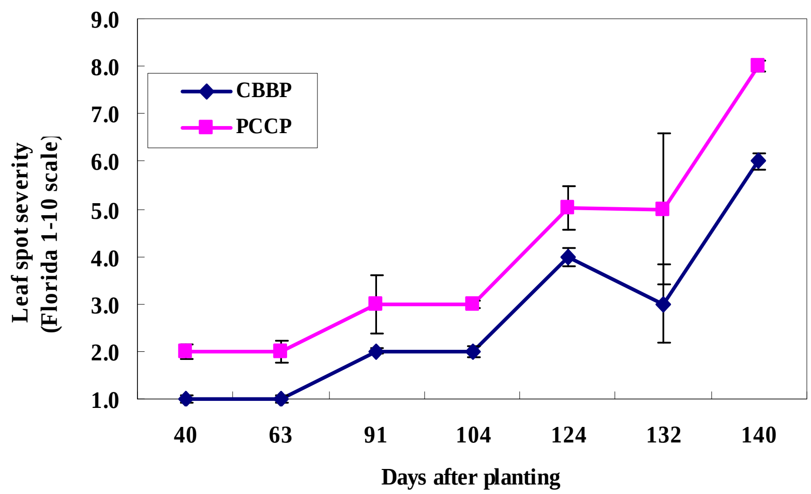

Figure 2-2. Effect of bahiagrass (CBBP) and conventional (PCCP) rotation on disease progress leaf spot severity measured using the Florida 1-10 scale, over time on Georgia Green peanut during 2004. Treatment means for a minimum of 4 replications and the standard error bars are shown for each assessment date. None of the plots were sprayed with fungicide. Yearly rotation sequences were bahiagrass (B), cotton (C), and peanut (P).

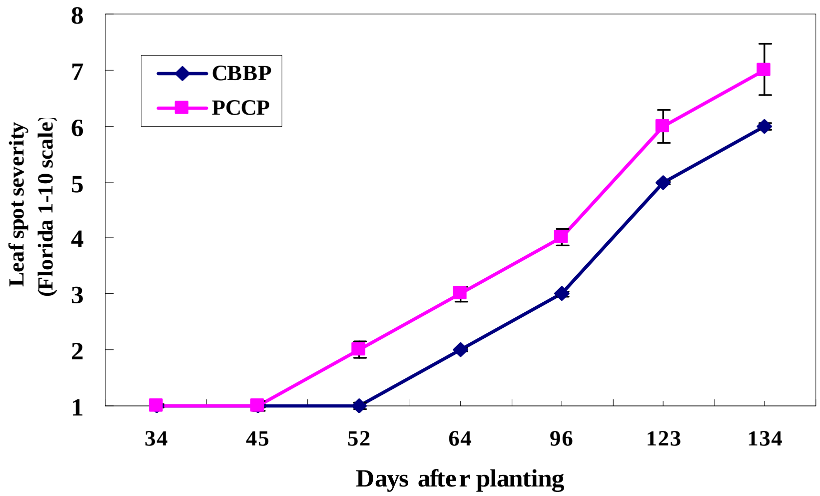

Figure 2-3. Effect of bahiagrass (CBBP) and conventional (PCCP) rotation on disease progress leaf spot severity measured using the Florida 1-10 scale, over time on AP3 peanut during 2005. Treatment means for 6 replications and the standard error bars are shown for each assessment date. None of the plots were sprayed with fungicide. Yearly rotation sequences were bahiagrass (B), cotton (C), and peanut (P).

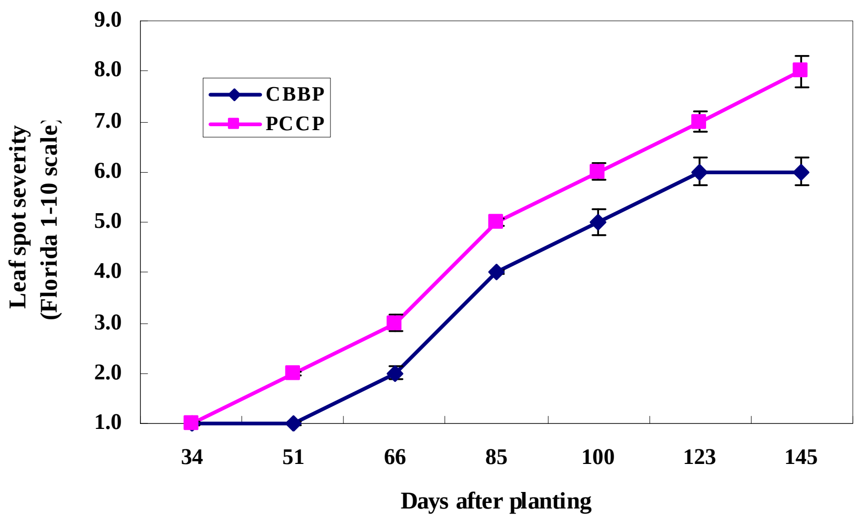

Figure 2-4. Effect of bahiagrass (CBBP) and conventional (PCCP) rotation on disease progress leaf spot severity measured using the Florida 1-10 scale, over time on AP3 peanut during 2006. Treatment means for a minimum of 6 replications and the standard error bars are shown for each assessment date. None of the plots were sprayed with fungicide. Yearly rotation sequences were bahiagrass (B), cotton (C), and peanut (P).

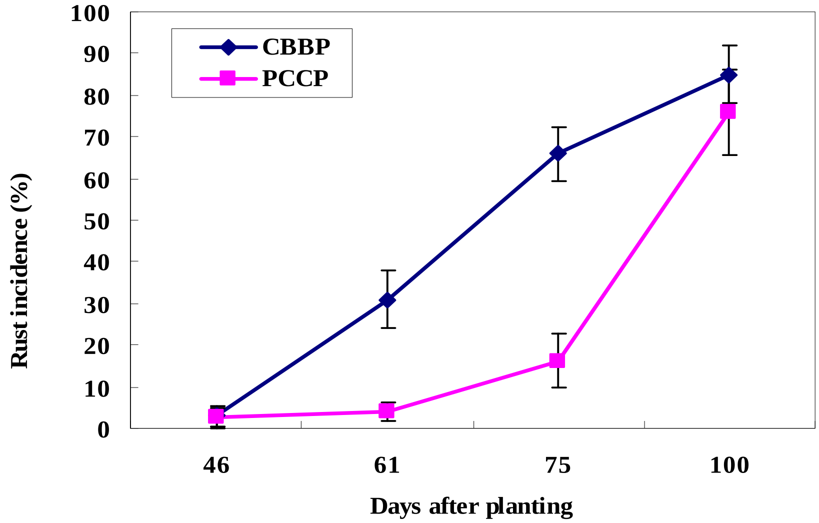

Figure 2-5. Effect of bahiagrass (CBBP) and conventional (PCCP) rotation on the incidence of peanut rust during 2003. Incidence represents the percentage of 20 plants showing pathogen signs. Data represents means for a minimum of 4 replications and the standard error bars are shown for each assessment date. None of the plots were sprayed with fungicide. Yearly rotation sequences were bahiagrass (B), cotton (C), and peanut (P).

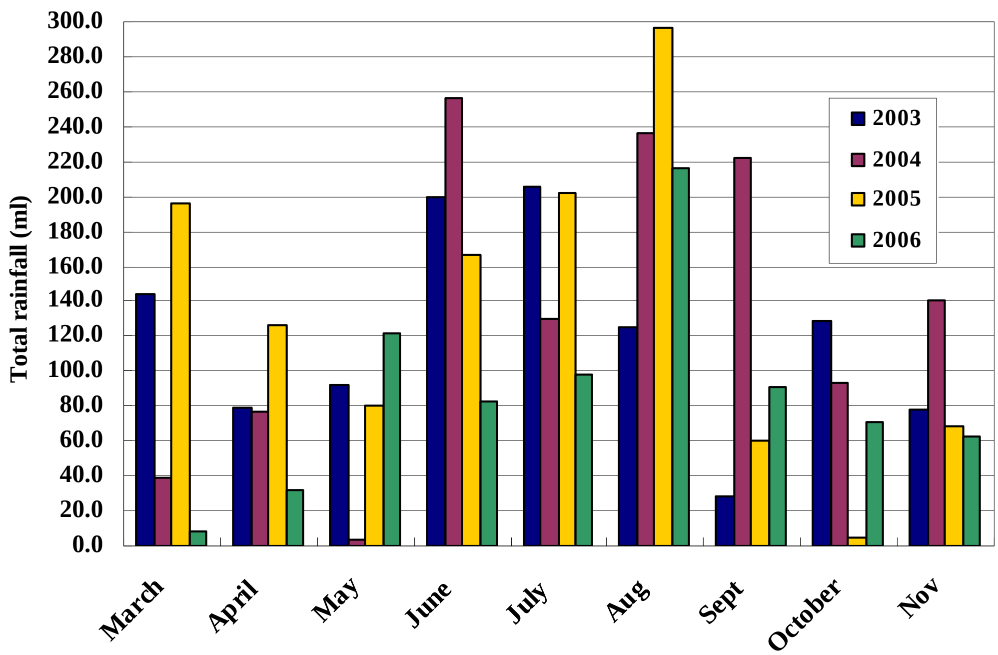

Figure 2-6. Total monthly rainfall in Quincy, FL during 2003-2006. Source: http://fawn.ifas.ufl.edu/

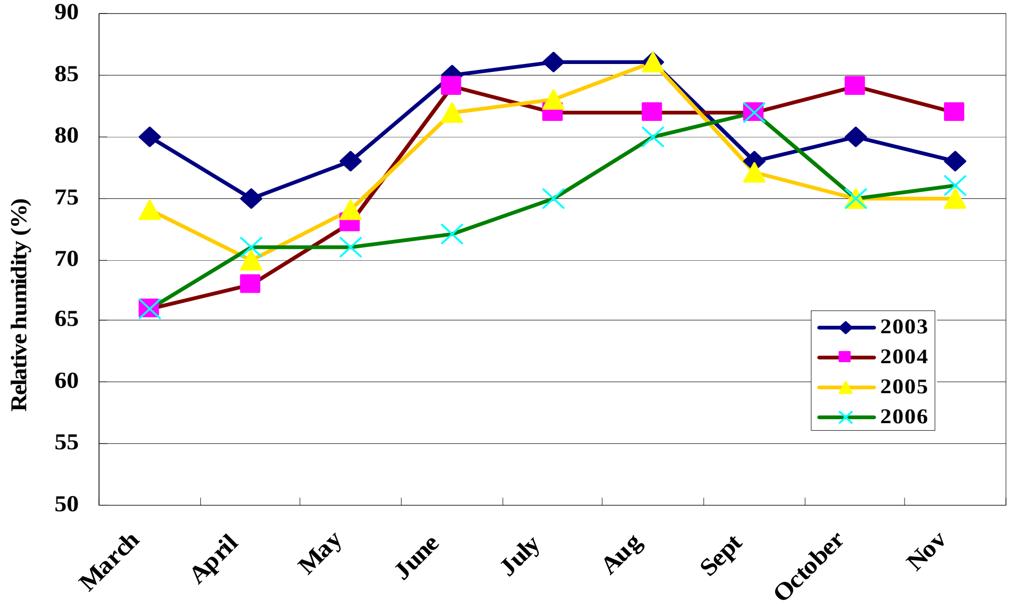

Figure 2-7. Variation in mean monthly relative humidity in Quincy, FL during 2003-2006. Source: http://fawn.ifas.ufl.edu/

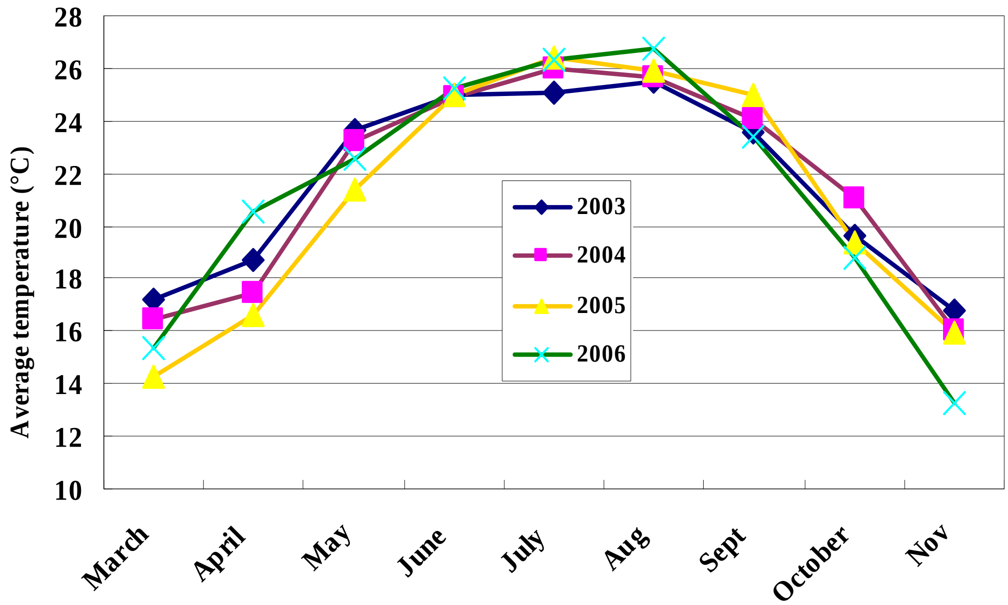

Figure 2-8. Variation in average atmospheric temperature in Quincy, FL. Source: http://fawn.ifas.ufl.edu/

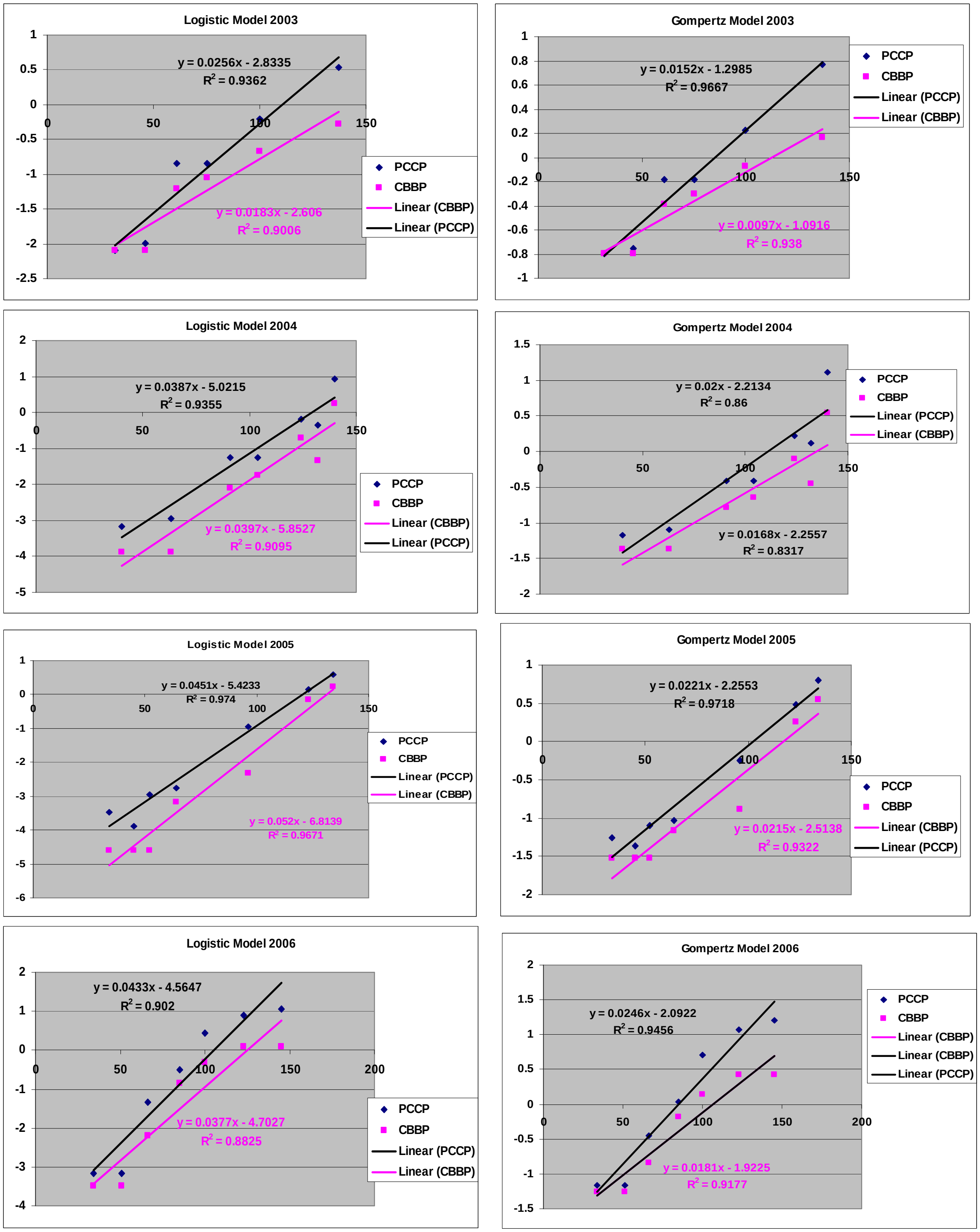

Figure 2-9. Linearized transformation of Cercospora leaf spot severity (Florida 1-10 scale) data on peanut using the Logistic = ([In(y/(1-y))]) and Gompertz = ([-In(-In y)]) model transformations. Disease assessments were converted into proportions [y = (Florida rating– 1) / 9] before transformation.

Table 2-1. Effect of rotations on final severity (Florida 1-10 scale), apparent infection rate (r) and SAUDPC on peanut in Quincy during 2003-2006

Year, Variety	Rotation[a]	Final severity rating[b]	r[c]	SAUDPC[d]
2003, Georgia Green				
	CBBP	5	0.019	72.3
	PCCP	7	0.024	92.7
	LSD ($P \leq 0.05$)	1	-	56.7 NS[e]
2004, Georgia Green				
	CBBP	6	0.039	35.8
	PCCP	8	0.04	52.6
	LSD ($P \leq 0.05$)	0.6	-	21.0 NS
2005, AP3				
	CBBP	6	0.047	38.8
	PCCP	7	0.05	52.6
	LSD ($P \leq 0.05$)	0.08	-	56.6 NS
2006, AP3				
	CBBP	6	0.04	70.4
	PCCP	8	0.044	92.5
	LSD ($P \leq 0.05$)	1	-	70.5 NS

[a] Yearly rotation sequences were bahiagrass (B), cotton (C), and peanut (P). [b] Severity represents the proportion of twenty plants assessed. [c] Epidemic rate determined from the slope of the linearized disease progress curve. [d] Standardized area under the disease progress curve throughout the assessment period. [e] NS = non significance ($P \leq 0.05$).

Table 2-2. Effect of bahiagrass (CBBP) and conventional (PCCP) rotation on peanut pod yield in Quincy, FL during 2003-2004 under no-fungicide and fungicide regimes

Rotation[a]	Fungicide	Variety	2003	2004	2005	2006
CBBP	no	GA Green	2,935	3,053	-[b]	-
PCCP	no	GA Green	2,229	2,297	-	-
CBBP	no	AP3	-	-	2,250	4,504
PCCP	no	AP3	-	-	1,703	3,278
LSD ($P \leq 0.05$)	-	-	321.1	536.6	550.7	805
CBBP	yes	GA Green	3,299	4,302	-	-
PCCP	yes	GA Green	2,160	3,114	-	-
CBBP	yes	AP3	-	-	3,048	4,866
PCCP	yes	AP3	-	-	2,865	4,216
LSD ($P \leq 0.05$)	-	-	348.1	470.2	717.1 NS)[c]	222

[a] B = bahiagrass; C = cotton; P = peanut. [b] Variety not planted in that year. [c] NS = non significance ($P \leq 0.05$).

Table 2-3. Influence of bahiagrass (CBBP) and conventional (PCCP) rotations, and fungicide treatments on peanut grade and damaged kernels in Quincy FL

			Damaged kernels (%)			Grade (SMK + SS)[b]		
Rotation[a]	Fungicide	Variety	2004	2005	2006	2004	2005	2006
PCCP	no	GA Green	1.0	-[c]	-	85.2	-	-
CBBP	no	GA Green	0.2	-	-	87.5	-	-
PCCP	no	AP3	-	0.9	NS[d]	-	83	NS
CBBP	no	AP3	-	0.0	NS	-	87.4	NS
LSD ($P \leq 0.05$)			0.04	-	-	2.0	-	-
PCCP	yes	GA Green	0.8	-	-	85.4	-	-
CBBP	yes	GA Green	0.3	-	-	87.4	-	-
PCCP	yes	AP3	-	0.5	NS	-	84	NS
CBBP	yes	AP3	-	0.3	NS	-	86	NS
LSD ($P \leq 0.05$)			0.5	-	-	3.2	-	-

[a] B = bahiagrass; C = cotton; P = peanut represents the yearly rotation of the crop. [b] Grade equals the percent sound mature kernels plus sound splits (SMK + SS). [c] Variety not planted in that year. [d] No significant difference ($P \leq 0.05$).

CHAPTER 3
SUPPRESSION OF TOMATO SPOTTED WILT (TSW) OF PEANUT IN A BAHIAGRASS (*Paspalum notatum* Fluegge) ROTATION

Introduction

Tomato spotted wilt virus (TSWV), causal agent of Tomato Spotted Wilt (TSW) is a tospovirus in the Bunyaviridae family. TSW is one of the major peanut diseases in the southeastern US. TSW of peanut is difficult to manage for various reasons including: 1) insect (thrips) transmitted, 2) effective chemical control options were lacking, 3) there is limited availability of plant resistance, and 4) there are increased costs of peanut production with decreasing commodity prices. Tobacco thrips [*Frankliniella fusca* Hinds (Sakimura)] and western flower thrips *F. occidentalis* (Pergande) are confirmed vectors of peanut TSW, and these insects are prevalent in the southeastern US (Todd et al., 1993; Todd et al., 1995).

A prevalent peanut cropping system in southeastern US consists of 2 years of cotton followed by peanut with a winter small grain (wheat, oats) cover crop (Sholar et al., 1995). Less than two decades after its arrival, TSW of peanut destroyed 50% of the peanut crop in southern Texas in 1985, with some fields nearing 100% loss (Black et al., 1986). In Georgia, losses to peanut due to TSW were around $40 million in 1997 (Culbreath et al., 1999). Symptoms of TSW on peanut vary and could be influenced by cultivar, but characteristically include concentric ringspots, chlorotic leaflets, stunting of plants, misshapen pegs, pods, and kernels, reddish discoloration, and cracking of the seed coats (Costa, 1941; Culbreath et al., 1992). TSWV is acquired by larvae and transmitted by both the larvae and adult thrips through feeding (Wijkamp et al., 1993). The presence of volunteer peanuts in fields as well as many weed species serves as virus and thrips reservoirs which aids the persistence of the virus within fields (Chamberlin et al., 1992; Chamberlin et al., 1993).

Management of peanut TSW poses tremendous challenges due to the multiple factors involved in disease incidence and severity. Since TSW is vectored by insects, the first approach was to control the thrips vectors but that has been found to be inconclusive. Chemical control of thrips has not effectively manage TSW on peanut as reported by Mitchelle (1991) and Todd et al. (1996), possibly due to the mode of virus transmission and vector mobility. Increased thrips feeding has been reported on the for *F. fusca* when imidacloprid (Culbbreath et al., 2003) was applied on tomato (Chaisuekel and Riley, 2001). In-furrow application of phorate has been reported to suppress TSW epidemics on peanut. Culbreath et al. (2003) reported on results from a 3-year Georgia-Florida statewide insecticide tests in which in-furrow application of phorate reduced TSW in 63 out of 93 tests, though the reduction of disease did not correlate with thrips control. The current recommendation of in-furrow phorate applications does not appear to effectively reduce TSW. However, Ames (2007) reported that spraying foliar insecticides in addition to the phorate application could successfully manage TSW. It is difficult to quantify the effect of insecticide treatments on the incidence and severity of TSW on peanut due to interplot interference by thrips from non-insecticide treated plots as well as insects from adjacent cotton plots (Black et al., 1993). Combined treatment of aldicarb and flutolanil or aldicarb alone significantly reduced thrips feeding damage (Timper et al., 2001).

No-till and minimum tillage systems for peanut have become an economic option for peanut cultivation in the southeastern US. Use of minimum tillage in peanut has been reported to reduce the impact of TSW and early leaf spot (ELS) (*Cercospora arachidicola* S. Hori,), late leaf spot (LLS) [*Cercosporidium personatum* (Berk. & M.A. Curtis) Deighton], and rust (*Puccinia arachidis* Spegg) as compared to conventional tillage (Baldwin et al., 2001; Johnson et al., 2001; Monfort, 2002). Cantowine et al. (2006), reported the interaction of cultivar and tillage method on the suppression of both leaf spots and TSW. Tillage systems have a significant influence on thrips populations as well as feeding injury with less of both occurring in a strip-till and no-till system (Brown et al., 1996; Campbell, 1986; Campbell et al., 1985). However, the roles of soil type and rotation crops on the survival of thrips and their impact on TSW have not been thoroughly studied. Barbour et al. (1994), however, found fewer thrips emerging from soils than those collected on open-sticky cards in North Carolina, and concluded that soils from peanut fields were not a major source of thrips. In studying the impact of cropping systems on stem rot and nematode antagonists to *Meloidogyne arenaria*, Timper et al. (2001) did not find any significant difference in injury due to thrips feeding as a result of rotation.

In an extensive review on the epidemiology and management of TSW on peanut, Culbreath et al. (2003) proposed the integration of chemical, genetic, and cultural practices that incorporates; planting date, manipulation of plant population, tillage practices, row pattern as well as in-furrow insecticide application among other options in the management of TSW on peanut. The recommendation to manipulate plant population resulted in the adoption of the twin-row planting system to enhance early canopy closure (Culbreath et al., 2003).

The advantages of using perennial grasses such as bahiagrass in peanut disease management has been well documented for leaf diseases (Brenneman et al., 1995; Timper et al., 2001). However, there is little information on the influence of perennial grasses in the management of TSW.

The objectives of this research were to: 1) to assess the potential impact of bahiagrass rotation in peanut on TSW epidemics and 2) investigate possible mechanisms of TSW suppression.

Materials and Methods

Rotation and Cultural Practices

Experiments were conducted at the University of Florida, North Florida Research and Education Center in Quincy, Florida during 2003-2006. Rotation plots were first established in year 2000 and consisted of a bahiagrass (cv. Pensacola, Florida Seed Company) rotation with peanut and a conventional cotton-peanut rotation for peanut. Except for 2005 where some plots were in one year bahiagrass rotation (PCBP), and two years of consecutive peanut (CCPP) in order to synchronize other rotations, the cropping sequence for the bahiagrass rotation involved the growing of cotton in the first year and then followed by bahiagrass for two consecutive years and in the fourth year the plots were planted to peanut for one year (CBBP), whereas the conventional rotation consisted of growing peanut in the first year with cotton in the two subsequent years followed by peanut in the fourth year (PCCP). Each plot in the rotation cycle was split into an irrigated and non-irrigated section, and these were further split into fungicide spray and non-sprayed sections to produce a split-split plot.

Irrigated plots received scheduled applications of water over the four years as and when needed according to standard extension recommendations for peanut production in Florida (Smajstrla et al., 2006). Weed and other crop management practices were done based on the Florida Cooperative extension Services recommendations (Aerts and Nesheim, 2001; 2002; Whitty, 2002; Whitty and Chambliss, 2002). Each (rotation* irrigation*fungicide) sub-sub-plot consisted of ten rows measuring 22.8m in length by 9.2 m (10 peanut rows).

Field Practices in 2003 and 2004

The bahiagrass cover crop was killed in December of 2003 and 2004 by spraying recommended herbicides. A winter cover crop of oats (*Avena sativa* L.) cv. Florida 501 was planted at 125 kg/ha, and was killed 124 DAP in 2003 and 97 DAP in 2004 by broadcast spraying glyphosate (Roundup WeatherMAX; Monsanto, Kansas City, MO). Seedbeds were prepared in both years by strip-tilling with a KMC (Kelly Mfg. Corporation, Tifton, GA). Georgia Green peanut cultivar was planted on 7 May 2003 and 10 May 2004, with a Monosem pneumatic planter (ATI, Inc. Lenexa, KS) at 6 seeds per 31 cm of row and 91-cm row spacing. Phorate (Thimet® 20-G; Micro Flo Company LLC. Memphis, TN) at 5.6 kg/ha was applied in furrow at planting to manage thrips.

Field Practices in 2005 and 2006

The bahiagrass cover crop was killed in the fall of 2004 and 2005 for the next cropping season. Oats (cv. Chapman) were planted at 125 kg/ha on 26 November 2004 as a winter cover crop for the 2005 cropping season, and cv. Florida 501 was planted in December 2005 at 125 kg/ha for the 2006 season. Cover crops were managed according to recommended practices in both years, and killed 123 DAP in 2005 and 120 DAP in 2006. For subsequent peanut planting, seedbed was prepared by double-ripping 10 rows using a KMC (Kelly Mfg. Corporation, Tifton GA) 4 row ripper in April of both years, and planted to peanut cv. AP3 on 13 May 2005, and 17 May 2006 with a Monosem pneumatic planter (ATI, Inc. Lenexa, KS) Twin Row Planter at 3 seeds per 30 cm of row with simultaneous application of phorate (Thimet) at 6 kg/ha into furrows. The cv. Georgia Green was planted in 2003 and 2004 in a single row pattern, whereas in 2005 and 2006 the cv. AP3 was planted in a twin-row pattern.

Tomato Spotted Wilt Assessment

TSW disease assessment was done on 32, 46, 61, 75, 100, and 137 DAP in 2003; 40, 63, 91, and 104 DAP in 2004; 34, 45, 52, 64, 96, 123, and 134 DAP in 2005; and 34, 51, 66, 85, and 100 DAP in 2006. Peanut plants were assessed by examining twenty plants within two rows at each time of assessment, and different rows were assessed at each point in time. Plants were examined at 2 m intervals within rows for TSW symptoms on leaves and scored using a modified scale of 0-3: where 0 = no visible symptoms; 1= presence of TSW symptoms on at least one leaf on the plant; 2 = symptoms on majority of leaves with moderate stunting of plant; and 3 = severe stunting of plant, and associated death. This method of assessment was chosen since measured TSW progression over time. TSW incidence on any date of assessment was determined as the number of peanut plants showing visible symptoms on any plant part out of the twenty plants assessed on each plot and rotation, expressed as a percentage. TSW severity index was then computed from severity ratings; [Severity Index = {Σ(Ratings for 20 plants)/20} * 100], and was used to compute the Standard Area Under the Disease Progress Curve (SAUDPC) over the period of assessment.

Thrips Infestation Studies

In addition to the traditional rotation plots being studied (CBBP and PCCP), an attempt to synchronize the rotation cycles resulted in some plots having two years of continuous peanut after two consecutive years of cotton (CCPP), whereas others had peanut after one year bahiagrass rotation (PCBP). Advantage was taken of these scenarios to investigate their impact on thrips population, feeding damage on peanut seedlings; and subsequent TSW epidemics. During 2005, thrips feeding injury as well as populations on peanut seedling were assessed by placing 10 peanut seedlings from the different rotations into jars containing 50% ethanol. The mean number of thrips per plant was computed for seedlings at 14 and 45 DAP for each rotation. A simple regression analysis was conducted by investigating the relationship between feeding damage, population, and final TSW incidence.

Based on 2005 results and before planting in peanut in May 2006, volunteer peanut seedlings (25 plants) in adjacent cotton plots, oat cover crop (25 plants), and 20 volunteer peanut plants in both killed and green bahiagrass plots were assessed for thrips infestation, and their possible contribution to subsequent TSW epidemic were analyzed. Samples of 20 bahiagrass inflorescences and leaves (20 main stems), 20 winter oat panicles, and 50 developing seeds of the oat cover crop were also examined for thrips infestation during this period. Both adult and larvae were counted together with no regard to species, though most of the adults were found to be *F. fusca*.

Statistical Analysis

TSW incidence and severity data were analyzed using Statistical Analyses System (version 8.0, SAS Institute Inc Cary, NC) GLM. Data for all years were first analyzed as a split-split experiment to investigate interaction of main and subplots. In the absence of a consistent interaction effect, the data was subjected to analyses of variance (ANOVA) as a randomized block design, and the data were pooled for all sub-plots and analyzed with rotation as the only factor. Means from the rotations were compared using the least significance difference (LSD) test to determine the differences ($P \leq 0.05$) in TSW incidence and severity as measured by SAUDPC between the PCCP and CBBP rotation within each year.

Results

Tomato spotted wilt (TSW) epidemics in the experimental fields was variable each year. However, it remained consistently higher in the PCCP rotated peanut than the CBBP peanut in all four years irrespective of which variety was grown (Fig. 3.1). TSW incidence across years (2003-2006) revealed that the rotations significantly ($P \leq 0.05$) affected the incidence (Fig. 3.1) and severity of TSW of peanut in all years. Peanut in the CBBP rotation had consistently lower incidence and severity throughout all four years. Since there was no consistent significant effect of irrigation and fungicide treatment on TSW incidence and severity, the data were pooled for each rotation and analyzed further.

In 2003, significant differences ($P \leq 0.05$) between the rotations were observed for both incidence and severity 32 DAP, with the peanut in the PCCP rotation having 39% incidence as opposed to 22% in the CBBP rotation (Fig. 3.2). Between 32 DAP and 64 DAP, a decrease in the incidence of TSW was observed for both rotations. However, there was a significant difference in the severity, which was higher for the PCCP peanuts plants. Incidence of TSW of peanut in the PCCP rotation was consistently higher (20, 26, and 25%) compared to that in the CBBP rotation (5, 8,and 6%) at 61, 75, and 100 DAP, respectively, for the rotations. TSW severity was similarly higher in the PCCP rotation than in the CBBP rotation at all these times. There was no significant difference in TSW incidence between the rotations 137 DAP, though overall severity was higher for the PCCP than on the CBBP rotation as depicted by significant SAUDPC (Table 3.1).

In 2004, incidence of TSW 40 DAP was significantly different ($P \leq 0.05$) between the two rotations with incidence of 38 and 24 % in the PCCP and CBBP rotations, respectively (Fig. 3.3). Subsequent assessments had 45, 70, and 72% incidence for the PCCP and 26, 32, and 32% incidence for the CBBP rotation at 63, 91, and 124 DAP, respectively. Differences in severity are represented by the greater SAUDPC (103.7) for the PCCP, compared to 44.5 for the CBBP rotations (Table 3.1).

In 2005, the rotations were planted with AP3 peanut variety in a twin-row planting pattern, an approach that is recommended to suppress TSW epidemics. TSW incidence and severity was consistently higher and significantly different ($P \leq 0.05$) at each time of assessment on peanut in the PCCP than the CBBP rotation (Fig. 3.4). TSW incidence sharply increased for the PCCP rotation within two months after the first assessment, with only a slight increase for the CBBP rotation within the same time period. TSW incidence was 29, 39, 66, 67, 72, 59, and 59% in PCCP rotation and 21, 23, 31, 33, 33, 30, and 31% in the CBBP rotation on the days of assessment (Fig. 3.4). SAUDPC for TSW was significantly greater on the PCCP (121) than on the CBBP (60) rotation (Table 3.1).

Progression of TSW incidence on AP3 peanut in the rotations during 2006 (Fig. 3.8) showed incidence and severity of TSW was significantly higher ($P \leq 0.05$) in the PCCP rotation than in the CBBP rotation. This trend had a strong correlation with the number of thrips found on volunteer peanuts in the plots and on the cover crop prior to planting peanut (Fig. 3.9). Subsequently, peanut in the PCCP rotation had 40, 45, 51, 53, and 53% incidence compared to 22, 18, 22, 23, and 23% for peanut in the CBBP rotation when assessed at 34, 51, 66, 85, and 100 DAP, respectively. Thrips feeding damage was variable in 2006, and it was evident that there was greater damage on peanut in the PCCP than the CBBP rotation as was observed in previous years.

Monitoring of Thrips Activity

In addition to the traditional rotation plots being studied (CBBP and PCCP) in 2005, some plots had two years of continuous peanut after two consecutive years of cotton (CCPP), whereas others had peanut after one year bahiagrass rotation (PCBP). Monitoring of thrips revealed that double cropping of peanut (CCPP) had the highest number of thrips per plant (42) compared to PCCP (22), CBBP (6), and PCBP (4) (Fig. 3.5). Plots exhibiting greater thrips feeding damage also had higher TSW incidence (Figs. 3.6 and 3.7), respectively.

There was a significant effect ($P \leq 0.05$) for the number of thrips per seedling and damage on the final incidence of TSW, $R^2 = 87.9$ (Fig. 3.10). Overall, differences in the feeding damage correlated with the number of thrips per plant, ($r = 0.60$, Pearson correlation). Similarly there was a stronger correlation, $r = 0.94$, between the number of thrips per seedling and the final TSW incidence. The number of damaged seedlings correlated ($r = 0.84$) with the final TSW incidence on plots. A simple regression analysis of damaged seedlings on number of thrips in 2005 revealed that as thrips population increased, damage also increased (r = 0.60) (Fig. 3.10). There was a stronger association (r = 0.84) between number of plants with feeding damage and final TSW incidence. This was evident in the field, where an average 13 out of 20 plants showed damage for the CCPP rotation and had a correspondingly higher final TSW incidence (61%), while rotation with a single year of bahiagrass had the least number of damaged plants (5 plants) and also the lowest final TSW incidence (23%) (Figs. 3.6, 3.7). The two main rotations tested for all four years (PCCP and CBBP) had similar relationships. PCCP rotated peanut had 19 damaged plants with a final TSW incidence of 54% compared to a CBBP with 9 damaged plants, and a final TSW incidence of 31% (Figs. 3.6 and 3.7). The number of thrips per peanut plant had a significant impact on the final incidence of TSW with a correlation coefficient of r = 0.94. This relationship was evident in 2005, where the CCPP rotation with 42 thrips per plant had 61% final TSW incidence, the PCBP had 3 thrips per plant with a correspondingly low final TSW incidence (23%), a value not different from the CBBP of six thrips per plant and a final TSW incidence of 31% (Figs. 3.5 and 3.7). The PCCP rotation mimicked what was found on the CCPP plots with 22 thrips per plant and a final TSW incidence of 54% (Figs. 3.5 and 3.7).

During 2006, thrips populations in winter oats, bahiagrass leaves and inflorescences and volunteer peanut were different on these plants and plant parts. Volunteer peanut seedlings emerging from plots previously planted to the winter oat cover crop had a higher thrips population, 45 thrips per seedling (Fig. 3.9) than plots not previously planted to winter oats, and were associated with severe feeding damage. Volunteer peanuts in nearby bahiagrass plots that were either killed or green had 21 and 7 thrips per seedling, respectively. Bahiagrass inflorescences harbored 4 thrips per head on average compared to 18 thrips per panicle, and six thrips per seed of winter oat (Fig. 3.9). Incidence and severity of TSW on peanut in plots planted to winter oats, and being representative of what prevailed on the PCCP rotation had both initial (40%) and a final (53%) TSW incidence (Fig. 3.8) during the 2006 season. TSW incidence on the CBBP rotation that was not planted to oats previously had both lower initial (22%) and final (23%) incidence and was significantly different from the PCCP rotation ($P \leq 0.05$) (Fig. 3.8).

Pod Yield and Grade

Significant differences ($P \leq 0.05$) were found between the yields from the bahiagrass (CBBP) and conventional (PCCP) rotations in all four years (Table 2.2) in Chapter II of this dissertation.

Discussion

Tomato spotted wilt (TSW) incidence and severity on peanut was significantly suppressed by two years of bahiagrass rotation (CBBP) compared to the conventional (PCCP) rotation system over the course of four years (2003-2006). Incidence and severity of TSW varied between years but was consistently higher for the PCCP rotation than on the CBBP rotation. TSW was particularly severe in 2004 and 2005 for the PCCP rotated peanut but remained significantly less in the CBBP peanuts in those years. The lowest incidence and disease severity in both rotations was recorded in 2003. The disease was suppressed in the CBBP rotation throughout 2003-2006 (12-32%) compared to the PCCP rotation (21-72%), with the highest severity in 2004 for both rotations. Except for 2003, when TSW incidence was high 32 DAP and suddenly dropped at 46 DAP, incidence in all other years increased more rapidly in the PCCP rotation compared to the CBBP rotation. The sudden decrease in 2003 May was due to the death of highly infected plants.

Tomato spotted wilt on peanut is transmitted by thrips hence their population dynamics on peanut play a primary role in disease incidence and severity (Culbreath et al., 1999). Based on thrips population and damage data in 2005 and 2006, it appears that the initial thrips population even at peanut emergence could be one of the most important factors in determining the incidence and severity of TSW over time on the crop. In this study, thrips damage as a result of feeding had a significant correlation (r = 0.60) with insect population. The number of plants damaged was highly correlated (r = 0.84) with the final incidence and severity of TSW. The high correlation coefficient (r = 0.94) observed between number of thrips per seedling and the final TSW incidence is consistent with the general assumptions of the influence of thrips population on TSW incidence (Culbreath et al., 1999). This research suggests that the initial thrips population in the field even before seedling emergence could significantly affect TSW incidence. These data are supported by the observation that when the number of thrips per seedling in the CBBP rotation was low in both 2005 and 2006 there was a correspondingly lower final spotted wilt incidence. Similarly, higher populations of thrips in the PCCP rotation resulted in high TSW incidence. It has been hypothesized that thrips move from afar to infest newly planted peanut plants. However, the contribution of resident thrips population even before seedling emergence has not been fully considered. The results from these trials suggest that the contribution of resident thrips before seedling emergence could be significantly contributing to TSW incidence and/or severity.

The role of rotations and the crops in the cycle on TSW epidemics has been little studied. Brenneman et al. (1995) reported the advantages of the bahiagrass rotation on stem rot, limb rot, and leaf spot diseases on peanut but did not report on the influence of the rotation on TSW. The role of the winter cover crop (winter oats) in this research was found to be a significant contributor to early thrips infestation on the PCCP rotation that resulted in higher TSW incidence and severity. These experiments suggest that peanut after an oat cover crop, a conventional practice had higher incidence and severity of TSW. The high number of thrips in oat seed is a significant contributing factor to the initial thrips population on peanut. Feeding of thrips on peanut was observed just as the hypocotyls broke the soil surface. Intense larval feeding and damage from thrips could predispose peanut seedlings to subsequent viral infection and render them infectious.

In 2005, peanut in a PCCP plot adjacent to that of a plot in one year bahiagrass rotation (PCBP) had lower thrips numbers per plant, and less feeding damage as well as low TSW incidence. Behaviors such as the above could be due to the fact that; 1) the oat cover crop might have been a good reproductive host to thrips with all developmental stages, thus once peanuts were planted the thrips had close proximity to a suitable food source and therefore did not move further, 2) bahiagrass might have not been a good host as evidenced in the low number of thrips recorded and thus did not support thrips reproduction when compared to oats, 3) decomposing bahiagrass residue may have been releasing some volatile compounds that could serve to repel thrips from such plots. It does appear in this research that bahiagrass is not as suitable host to thrips, as evidenced by the lower number of thrips recorded on both leaves and inflorescence compared to the winter oat. The contribution of volunteer peanuts in adjacent plots to TSW epidemics have been suggested but not quantified. The role of volunteer peanuts in TSW severity could be aggravated when there is already an existing reproductive host such as oats in the field. Although oats had not been previously reported as a host of TSWV, this plant could harbor the virus since there are numerous asymptomatic hosts of TSWV.

Crop rotations have not been considered as a viable management practice for TSW on peanut. This research has established a consistent pattern over a period of four years on the advantages of a bahiagrass rotation in significantly reducing TSW epidemics on peanut compared to a conventional PCCP system. Any attempt to assess the influence of TSW suppression on yield can be best done in peanut plots under no fungicide spray regimes that exclude the effects of leaf spots and other soil-borne pathogens. In these trials the margin of yield increase in 2003 and 2004 were comparable, and again that of 2005 and 2006 (data presented in Chapter II f this dissertation), it was inferred that at least some of the yield increases could have been due to TSW suppression in the CBBP system. The higher percentage yield under the CBBP system over that in the PCCP system could be attributed to the lower TSW severity as evidenced by the lower SAUDPC in all four years.

During 2005 and 2006 when the AP3 variety was planted in a twin-row pattern, the percentage increase in yield between the PCCP and CBBP rotations were lower than in 2003 and 2004 when GA Green variety was planted in a single-row pattern. This trend suggested that the and also the twin-row pattern did reduce the impact of yield loss due to TSW confirming the recommendations of Culbreath et al. (2003). The mechanism employed by the twin-row system in affecting TSW epidemics was reported to be possibly due to visual interference of migrating thrips in host recognition (Culbreath et al., 2003). Since the plots studied in these experiments were all strip tilled, the reduction in TSW incidence and severity may be attributed to an inherent ability of bahiagrass rotation to suppress the disease. The low percentage increase in yield between the peanut in the PCCP and CBBP that were planted in a twin-row pattern in 2005 and 2006 could be attributed to plant compensation, in which case severely stunted plants in the rotation were smothered by other healthy plants thus reducing the impact of TSW severity in the PCCP plots. Other yield qualities such other kernels (data not presented), which was significantly higher in the PCCP rotations could better reflect the severity of spotted wilt for the PCCP rotation than the actual harvestable and gradable pods, since TSW infection affect pod filling (Culbreath et al., 1992).

While irrigation did not have any consistent significant impact on TSW epidemics in this experiment, results suggest a possible impact of irrigation on TSW epidemics especially at the early stages of growth. The recommendation of planting peanuts in early to mid-May to manage TSW could be due to the normally dry April month that predisposes peanut to severe thrips feeding. Severe thrips feeding observed in this trial in early May resulted in significantly higher TSW epidemics and suggest that irrigation at the early stages of peanut may play a role in reducing TSW.

In conclusion, planting peanut after two years of bahiagrass in bahiagrass consistently reduced peanut TSW epidemics and improved yield during 2003-2006. Bahiagrass rotation reduced the number of thrips per peanut seedling, number of damaged peanut seedlings and TSW incidence and severity.

Based on the results of this research the following are suggested, 1) investigate the actual mechanisms of thrips population reduction on bahiagrass rotated to peanut, 2) study a one-year rotation system for bahiagrass in the management of TSW , 3) and determine the critical time that thrips populations peak influence TSW epidemics.

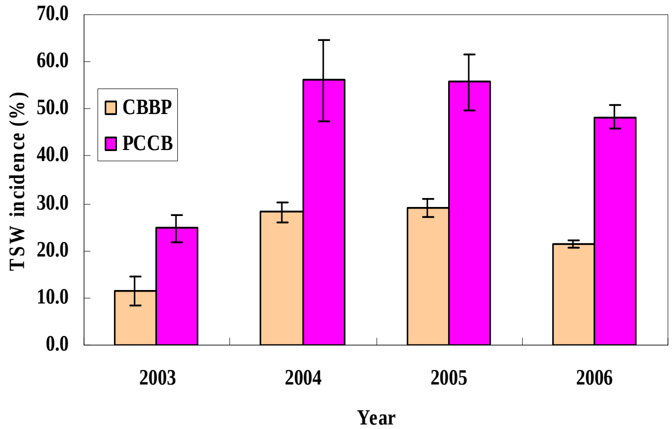

Figure 3-1. Effect of rotations on the across year incidence of TSW on peanut. The standard error bars are displayed in the chart and represent 4-7 assessment times within a cropping cycle. B = bahiagrass, P = peanut, C = cotton.

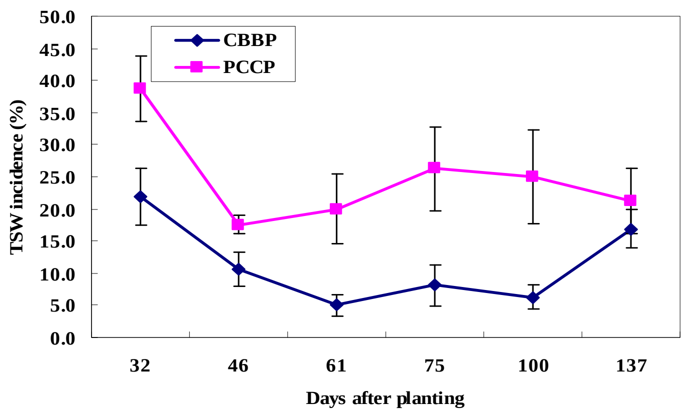

Figure 3-2. Effect of bahiagrass (CBBP) and conventional (PCCP) rotation on progression of TSW incidence on Georgia Green peanut during. Treatment means of 20 plants for a minimum of 4 replications and the standard error bars are shown for each assessment date.

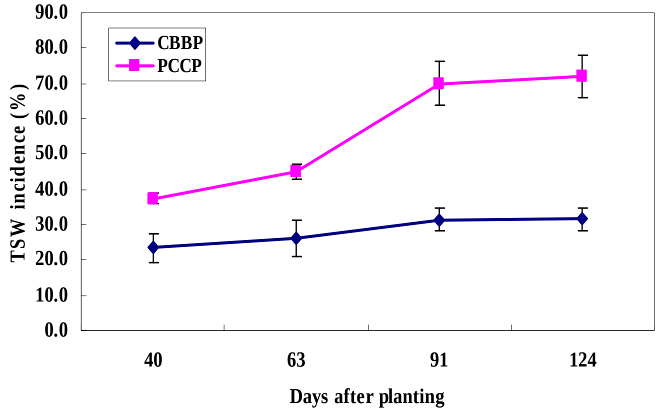

Figure 3-3. Effect of bahiagrass (CBBP) and conventional (PCCP) rotation on progression of TSW incidence on Georgia Green peanut during 2004. Treatment means of 20 plants for a minimum of 4 replications and the standard error bars are shown for each assessment date.

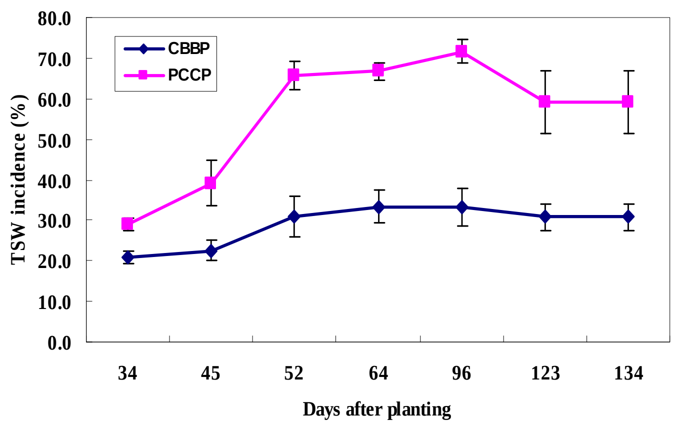

Figure 3-4. Effect of bahiagrass (CBBP) and conventional (PCCP) rotation on progression of TSW incidence on AP3 peanut during 2005. Treatment means of 20 plants for 6 replications and the standard error bars are shown for each assessment date.

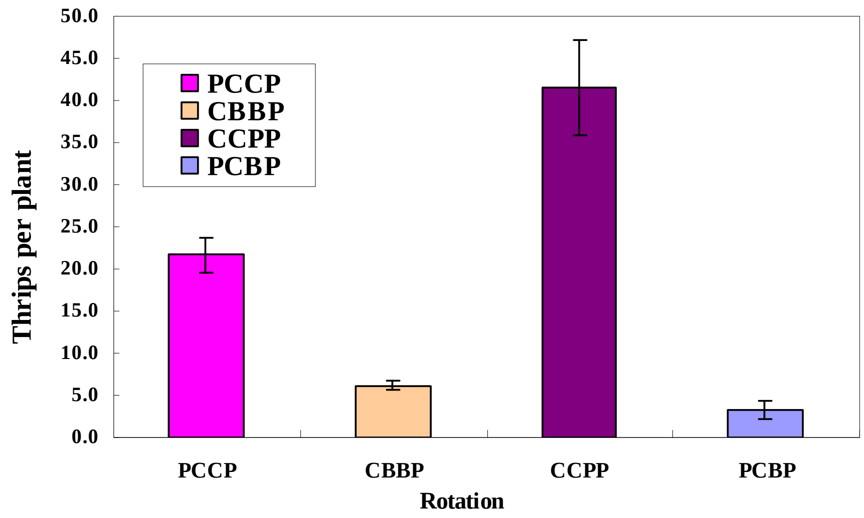

Figure 3-5. Effect of different cropping sequences on thrips population on AP3 peanut seedlings during 2005. Treatment means of 20 plants for 6 replications. Cropping sequences are represented by: B = bahiagrass, C = cotton, P = peanut.

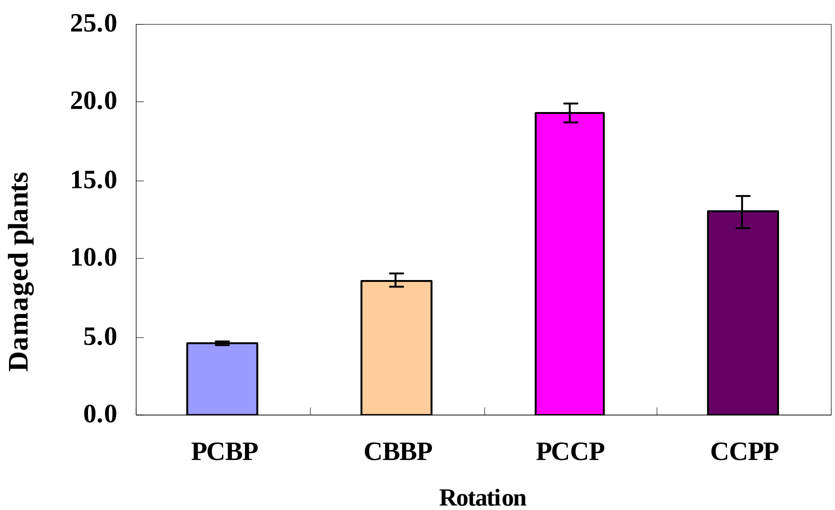

Figure 3-6. Effects of rotations on thrips feeding damage on peanut seedlings in Quincy FL during 2005. Points represent average number of plants damaged out of 20 in plots with different cropping sequences represented. Points represent mean number of plants assessed 14 and 54 DAP. Cropping sequences are represented by: B = bahiagrass, C = cotton, P = peanut.

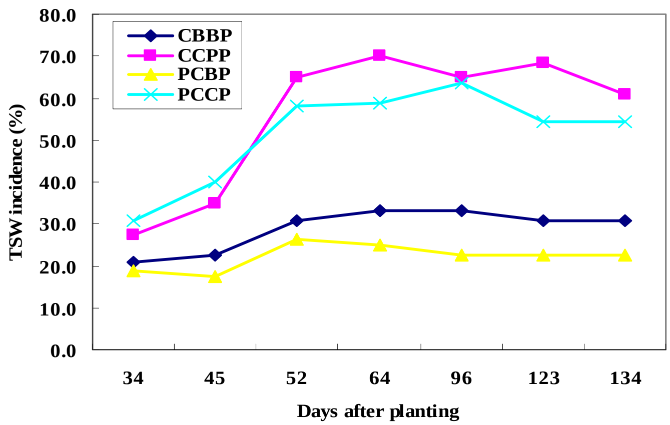

Figure 3-7. Effect of different cropping sequences on progression of TSW incidence on AP3 peanut during 2005 in Quincy, FL. Treatment means of 20 plants for 6 replications. Cropping sequences are represented by: B = bahiagrass, C = cotton, P = peanut.

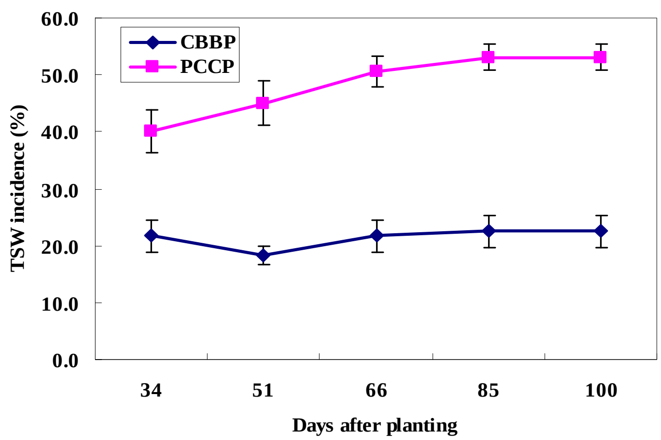

Figure 3-8. Effect of bahiagrass (CBBP) and conventional (PCCP) rotation on progression of TSW incidence on Georgia Green peanut during 2006 in Quincy, FL. Treatment means of 20 plants for minimum of 6 replications and the standard error bars are shown for each assessment date.

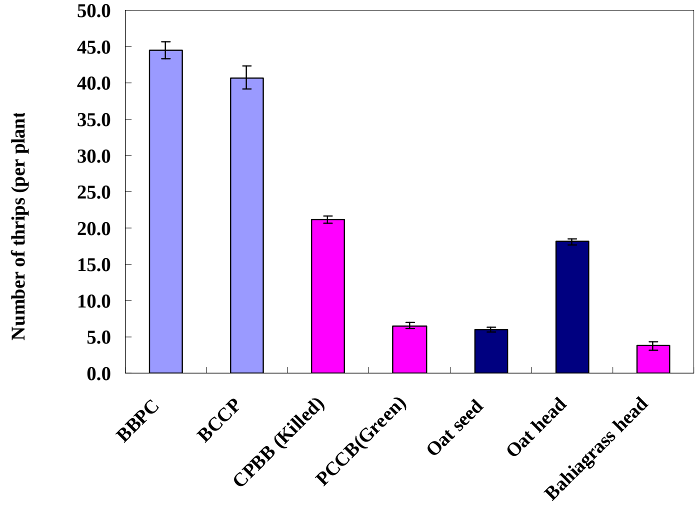

Figure 3-9. Thrips population on peanut seedlings, oat seed, and bahiagrass inflorescence in Quincy, FL during early May 2006, with standard error bars displayed within bars. B = bahiagrass, P = peanut, C = cotton; representing cropping sequences in those plots. Data on BBPC was from volunteer peanuts in adjacent cotton plots; BCCP was volunteer peanuts on plots to be planted to peanut in the summer of 2006; CPBB volunteer peanut in killed bahiagrass plots to be planted to peanut.

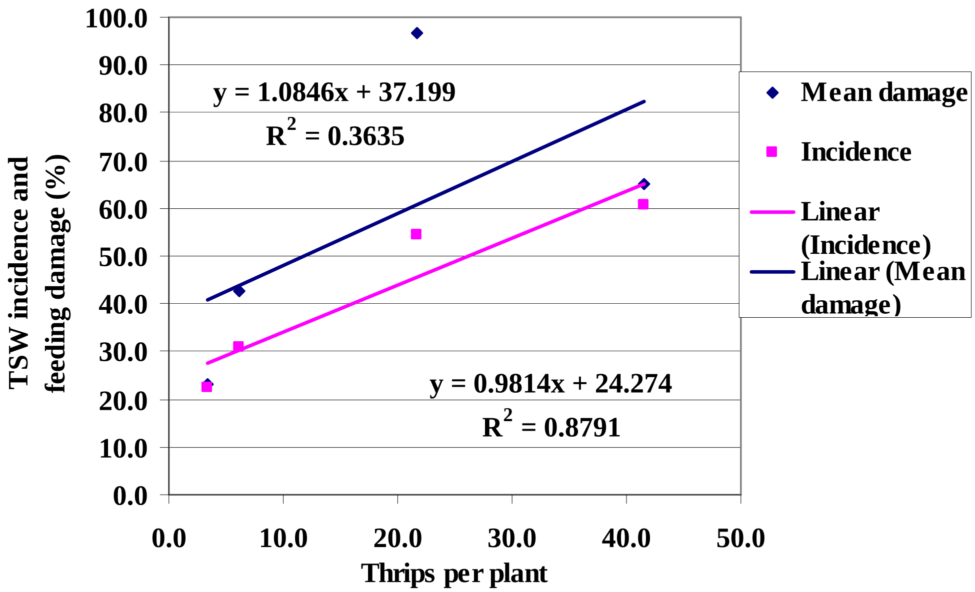

Figure 3-10. Relationship of early thrips population on peanut seedlings on feeding damage and the final TSW incidence on peanut. Points represent average number of thrips per plant in plots with different cropping sequences as represented in Figure 3.4 above (PCBP, CBBP, PCCP, and CCPP). B = bahiagrass, P = peanut, C = cotton.

Table 3-1. Effect of rotations on final TSW incidence and SAUDPC, on peanut in Quincy during 2003-2006.

Year	Variety/Rotation[a]	Final TSW incidence (%)[b]	SAUDPC[c]
2003	Georgia Green		
	CBBP	16.9	10.7
	PCCP	21.3	28.5
	LSD ($P < 0.05$)	12.3	4.4
2004	Georgia Green		
	CBBP	31.7	44.5
	PCCP	71.9	103.7
	LSD ($P < 0.05$)	13.7	43.7
2005	Georgia Green		
	CBBP	30.8	59.6
	PCCP	59.2	121.1
	LSD ($P < 0.05$)	18.6	29.2
2006	Georgia Green		
	CBBP	22.5	33.6
	PCCP	53.1	90.1
	LSD ($P < 0.05$)	7.1	30.4

[a] B = bahiagrass; C = cotton; P = peanut. Each letter represents the sequence of cultivating that crop in a year. [b] Incidence represents the proportion of twenty plants assessed for TSW symptoms on a scale of 0-3: where 0 = no visible symptoms; 1= presence of TSW symptoms on at least one leaf on the plant; 2 = symptoms on majority of leaves with moderate stunting of plant; and 3 = severe stunting of plant, and associated death. [c] Standardized area under the disease progress curve throughout the assessment period.

CHAPTER 4
EFFECT OF ROTATIONS ON SOUTHERN STEM ROT (SSR) (S*clerotium rolfsii sacc*) AND SURVIVAL OF SCLEROTIA IN FIELD SOIL AMENDED WITH BAHIAGRASS CUTTINGS UNDER GREENHOUSE CONDITIONS.

Introduction

Soil-borne pathogens cause yield losses in most plants, but their management is complex because most develop resistant structures that are not easily destroyed and the soil ecology is not well understood (Jackson and Bell, 1969). The soil-borne fungus *Sclerotium rolfsii* Sacc., [teleomorph, *Atelia rolfsii* (Curzi) Tu & Kimbrough] causes southern stem rot (SSR) (Jackson and Bell, 1969). It is both devastating and difficult to manage. Although no worldwide estimates of host genera have been published, Fichtner (2007) reported that over 270 genera have been reported as hosts in the US alone. Far et al. (1989) reported that susceptible agricultural hosts include corn (*Zea mays*), wheat (*Triticum vulgare*), soybean (*Glycine max*), as well as numerous horticultural crops. Losses in peanut yield due to SSR are 10% in the southeastern US (Melouk and Backman, 1995). Stem, pegs, and pods of the peanut plant are susceptible to the pathogen. In addition, all commercially grown cultivars are susceptible. Signs of SSR on peanut consist of the presence of white fluffy and cottony mycelia of *S. rolfsii* on affected parts, but most often originating from the soil line on the stem. Brenneman et al. (1995) reported that, until recently, available fungicides were not very effective and thus complicated the management of this disease.

Sclerotia serve as the principal overwintering structure and primary inoculum and persist in soil freely and in association with plant debris (Jackson and Bell, 1969). Infection is promoted by dense planting, high soil moisture and frequent irrigation (Aycock, 1966; Sconyers et al., 2005). *Sclerotium rolfsii* does not produce spores; hence dissemination is through movement of infested soil and plant materials. While debris on the soil surface supports survival of sclerotia, such environments also harbor antagonistic organisms that degrade *S. rolfsii* by biocontrol agents (Smith, 1972). Addition of stubble from rotational or cover crops suppress disease by enhancing production of decomposition products by antagonistic microbial populations that inhibit pathogens and promote host development (Hoitink and Boehm, 1999).

A variety of methods are available for managing diseases caused by *S. rolfsii*, including fungicide applications, solarization, use of antagonistic microorganisms, deep plowing, crop rotation, and incorporation of organic and inorganic residues (Punja, 1985). However, Aycock (1966) and Umaerus (1992) described how difficult it is to manage stem rot due to the presence of numerous hosts and ability to survive as sclerotia and dry mycelia on debris.

Brenneman et al. (1995) reported a 10-fold increase in SSR incidence during the four years of continuous peanut rotation as compared to peanut grown after bahiagrass. Timper et al. (2001) reported lower incidence of stem rot on peanut grown after two years of bahiagrass than in continuous peanut, two years cotton, or corn before peanut in plots that were sprayed with fungicide. The actual mechanism of SSR reduction in a bahiagrass rotation has not been studied and may not possibly be due to the non-host status of bahiagrass to *S. rolfsii*, as *S. rolfsii* grew and produced sclerotia on agar-grown bahiagrass seedlings that were co-inoculated with *S. rolfsii* (Tsigbey, unpublished). Other factors such as the enhancement of microbial population antagonistic to *S. rolfsii* propagules as well as gaseous products from the decomposition of bahiagrass may contribute to population decrease of *S. rolfsii*. Burying sclerotia 5 to 6 cm beneath the soil reduced survival of sclerotia, which supports the program of clean tillage in disease management (Smith et al., 1989). However, with the current trend towards minimum tillage, the challenge of maintaining surface debris and its impact on sclerotia survival gives a new dimension to disease management.

Though crop rotation using grasses has been found to suppress stem rot of peanut (Flowers, 1976; Minton et al., 1991), the introduction of the third generation fungicides such as tebuconazole and flutolanil increased the prospects of stem rot management (Brenneman et al., 1991; Hagan et al., 2003). These fungicides are also effective against other diseases of peanut, though the continuous extensive use of these chemicals could result in pathogen resistance development. Organic amendments have been widely studied in the management of soil-borne pathogens. Chemical composition of organic additives determines the efficacy and the type of microorganisms that develop during degradation. Decomposing microorganisms have antagonistic activities and these can be exploited as a practical biocontrol tool to manage plant parasitic nematodes. Stirling (1991) reported that antagonistic interactions among microorganisms determine the diversity of organisms that inhabit the rhizosphere. Addition of organic matter to soil has been reported to stimulate microbial populations of bacteria and fungi that might be antagonistic to nematodes and other plant pathogens (Morgan-Jones and Rodriguez-Kabana, 1987). Many researchers have reported the occurrence of volatile compounds with nematicidal and fungicidal properties (Bauske et al., 1994; Soler-Serratosa et al., 1996). Camllo et al. (1992) and Soler-Serratosa et al. (1993) reported that these decomposition products stimulated the development of populations of fungi and bacteria that are antagonistic to soil-borne pathogens; while Chavarria-Carrayal et al. (1994) also reported increased parasitism of eggs of *Meloidogyne* spp.

When used properly, organic amendments not only reduce pathogen populations but also improve soil fertility and induce soil suppressiveness by stimulating activities of antagonists in soil. Amendments may also stimulate the germination of *S. rolfsii* in soil and render them vulnerable to antagonist attack (Beute and Rodriguez-Kabana, 1979). Smith (1972) reported that germinated sclerotia are more susceptible to antagonists than non-germinated ones. Hadar and Gorodecki (1991) found that non-germinated sclerotia can have their viability decreased by some amendments and render them sensitive to antagonistic action by other organisms.

The beneficial effect of bahiagrass rotation on the reduction of peanut diseases including *Sclerotium rolfsii* has been extensively demonstrated in the field. However, the mechanism of such suppression in the case of *S. rolfsii* has not been fully investigated. The objectives of this study were to: 1) monitor SSR occurrence on peanut in a bahiagrass and conventional rotation, and 2) investigate the possible mode of *Sclerotium rolfsii* suppression in soils amended with bahiagrass residue.

Material and methods

Field Studies

The study was conducted on a Dothan sandy loam (fine loamy siliceous, thermic Plinthic Kandiudult) at the North Florida Research and Education Center, Quincy, FL from 2003. Rotation plots were established in year 2000 and consisted of a bahiagrass rotation with peanut and a conventional cotton-peanut rotation. The cropping sequence for the bahiagrass rotation involved growing cotton in the first year and then followed by bahiagrass for two consecutive years and in the fourth year the plots were cultivated to peanut for one year (CBBP). The conventional rotation consisted of growing peanut in the first year with cotton in the two subsequent years followed by peanut in the fourth year (PCCP).

Bahiagrass cover crop was killed in December 2003 by spraying recommended herbicides. The winter oats (Avena sativa L.) cv. Florida 501 cover crop was planted at 125 kg/ha, killed 124 days after planting (DAP) in 2003 by broadcast spraying glyphosate (Roundup WeatherMAX; Monsanto, Kansas City, MO). The seedbeds for peanut were prepared in both years by strip-tilling with a KMC (Kelly Mfg. Corporation, Tifton, GA) Georgia Green peanut cultivar was planted on 7 May 2003 with a Monosem pneumatic planter (ATI, Inc. Lenexa, KS) at six seeds per 31 cm of row and 91-cm row spacing. Phorate (Thimet® 20-G; Micro Flo Company LLC. Memphis, TN) at 7 kg/ha was applied in furrow at planting for thrips control. Twenty plants were randomly assessed for signs (presence or absence) of SSR at 46, 61, 75, 100, 137 DAP in all plots during 2003.

Isolation and Maintenance of Micro-organisms

Peanut (*Arachis hypogaea* L.) plants showing stem rot symptoms with sclerotia were collected from peanut fields at the NFREC, Quincy. The pathogen was isolated on potato dextrose agar (PDA) medium. Cultures were incubated in the laboratory until they produced sclerotia and were identified according to their morphology and colony characteristics.

Soil Treatment

Field soil was collected and then solarized for one month under greenhouse conditions to heat-kill most soil organisms before the start of the experiment. The soil was spread thinly (2 cm thick) on a white polythene sheet with periodic stirring to allow drying. The dry soil was sieved to remove clods and other large debris. Pot culture assay of bahiagrass roots and leave pieces on sclerotia survival was conducted in 16-cm diameter plastic pots containing 1.2 kg of field. Bahiagrass leaves and roots that had been previously cut into 2 cm pieces and dried were weighed in different ratios to constitute 1% organic matter content (wt:wt) of the measured soil. The various treatments and amendment ratios were as follows: T1 - Only sclerotia inoculation, T2 -1:1 Leaves to roots (12 g of leaves and 12 g of roots), T3 - 1:2 Leaves to roots (8 g of leaves and 16 g of roots), T4 - 2:1 Leaves to roots (16 g of leaves to 8 g of roots), T5 - 1% dry cut root (24 g dry root), T6 - 1% OM dry cut bahiagrass leaves (24 g dry cut leaves), T7 - 1% OM (24 g) dry finely ground bahiagrass leaves, and T8 - 1% (24 g) dry finely ground root were added per pot and thoroughly mixed into the soil. Twenty sclerotia of *Sclerotium rolfsii* were harvested from PDA by brushing the propagules onto sterile Petri dishes. These sclerotia were deposited into 25 micron nylon mesh pouches 2 cm x 2 cm and buried at 2-cm depth of soil in pots. Except for T8 that was carried out in duplicate, all other treatments were carried out in triplicate in 4-6 replicate pots. The pots were immediately watered and left for eight days before infesting with sclerotia and thereafter when necessary. The pots were left to incubate for two and a half months. For the first experiment, ten incubated sclerotia per replication for each treatment were plated onto PDA, whereas twelve were plated for each pot of six replications for the second and third experiments.

Determination of Sclerotia Survival in Soils

Buried sclerotia in nylon mesh were retrieved from each pot and soil was washed off under tap water and rinsed in three changes of sterile distilled water. The mesh with the sclerotia was air dried and then opened under sterile conditions and sclerotia transferred onto PDA and incubated under laboratory conditions. In the event where most sclerotia were macerated during incubation, pieces of the sclerotia were plated to investigate possible survival or the presence of other microorganisms.

Data Analyses

The field data and each experiment in the greenhouse were analyzed separately and the greenhouse data later pooled for analysis to investigate how the treatments performed using Statistical Analyses System (version 8.0, SAS Institute Inc Cary, NC) GLM approach. The ANOVA was used to evaluate the efficacy of amendments on survival of sclerotia and presence of antagonists. A comparison among treatment means was done using Tukey's Studentized Range (HSD) test at ($P \leq 0.05$).

Results

Field Results

In 2003 rotations significantly ($P \leq 0.05$) affected the incidence of stem rot. Peanut in the PCCP rotation had 30% of sampled plants showing of *S. rolfsii*, whereas only 5% were observed in the CBBP rotation. Incidence of the disease fluctuated during 2003 due to weather conditions (Figs. 2.6 and 2.7, in chapter 2 of this dissertation), but generally remained higher for the PCCP rotation than the CBBP rotation (Fig. 4.1).

Greenhouse Results

Amendment of field soils with bahiagrass cuttings significantly ($P \leq 0.05$) reduced survival of sclerotia of *Sclerotium rolfsii* in all three experiments when sclerotia were buried for two months in amended soils (Figs. 4.2, 4.3, and 4.4). This was irrespective of the plant part though there was variability in the extent of reduction depending on the proportions of which plant combination were used. Most of the recovered sclerotia were either disintegrated or simply did not regenerate when plated on PDA.

A significant number ($P \leq 0.05$) of non-germinated sclerotia recovered from the amended soil showed signs of colonization by Trichoderma spp, bacteria, and other unidentified fungal species. Survival of sclerotia in non-amended soils varied between 80% in the first experiment and 100% in both the second and third experiments, whereas those in the amended soils were 20-50% in the first experiment, and 8-75% in both the second and third experiments. Among plant parts, few significant differences were found in their ability to affect survival of sclerotia. Similarly, though amended soils had comparable numbers of colonized sclerotia, soils amended with higher proportions of bahiagrass leaves significantly ($P \leq 0.05$) encouraged more bacteria colonization than those with root pieces and reduced sclerotia survival the greatest. Cut or ground bahiagrass leaves reduced sclerotia survival in all three experiments, and amendments with higher proportion of leaves performed better than those with roots. *Trichoderma* spp. were found to grow on root pieces of bahiagrass collected from the field and those surfaced sterilized in 5% Chlorox® and 2% lactic acid and were incubated in Petri dishes under laboratory conditions (data not presented). Some of the bacterial isolates recovered from amended soils exhibited inhibition zones when co-plated on agar medium. Sclerotia that were incubated in soils amended with bahiagrass germinated faster (6 hours after plating) on media than those incubated in only field soil (18 hours).

Discussion

Incidence of SSR in the field study was found to be consistent with previous studies on the ability of bahiagrass to suppress peanut SSR (Johnson et al., 1999; Brenneman et al., 2003). Incidence of SSR was significantly lower on the CBBP than the PCCP rotation for most of the season, and the fluctuations were attributed to changing weather during the season. The sharp decline in incidence between 75 and 100 DAP was attributed to a pronounced dry period (Fig. 2.6). However, the improved leaf retention by peanut in the CBBP rotation 100 DAP provided a conducive microclimate for survival of *S. rolfsii* even though there was a dry period, thus resulting in the slightly higher incidence on the CBBP rotation (Fig. 4.1). Signs of SSR on peanut in the field under the CBBP rotation were atypical for SSR, as they appeared disintegrated. Increasing rates of chitin in the soil led to reduced sclerotia germination possibly due to the enhancement of chitinolytic microorganisms (Rodriguez-Kabana et al., 1987), and similarly inhibitory effects of grape compost was attributed to the high numbers of *Penicillium* isolated from embedded sclerotia (Hadar and Gorodecki, 1991). In this study, the two most common organisms isolated from sclerotia were *Trichoderma* spp. and bacteria. Although data were not taken on individual effects on sclerotia, observations on their cultural interaction when co-plated with sclerotia suggest their role in sclerotial decay. Cut pieces of roots and leaves of bahiagrass performed better in suppressing sclerotia survival and encouraged more of the antagonists than powdered components. This observation suggests that during decomposition of large debris the diversity of microorganisms in the soil will be enhanced. In addition, bahiagrass produces large quantities of leaves over time, and when dead, leaves form a thick mat on the soil surface that can serve as suitable substrate for antagonistic organisms to act on and subsequently degrade sclerotia. Field observations of peanut plants attacked by *S. rolfsii* showed signs of degeneration in the cottony hyphae of the pathogen suggesting that some form of microbial antagonism might be taking place. There have been no reports of bahiagrass root colonization by *Trichoderma* spp., but the results from this research suggest that could be a possibility since *Trichoderma* grew exclusively on root pieces of bahiagrass collected from the field that were surface sterilized with Clorox and lactic acid.

Adoption of new cropping patterns such as minimum tillage and twin-row planting pattern will result in significant changes in microclimate within a peanut field that could enhance *S. rolfsii* survival. Porter (1980) reported increased severity of *Sclerotinia minor* on peanut in fields with lush canopy as a result of fungicide sprays to control leaf spot. Other reports also suggest that efficient management of peanut leaf spot through fungicide sprays could create a microclimate that will favor SSR (Shew and Beute, 1984). Although current fungicides can control both leaf spots and SSR at the same time, investing in a cropping system that will naturally lower peanut diseases as in the case of bahiagrass rotations will be more profitable and sustainable. Results from this research indicate that bahiagrass rotation may reduce SSR by way of encouraging the activities of antagonistic microorganisms in soils. It is important to study how bahiagrass rotation influences soil microbial diversity, since that will give a clearer understanding of why soils planted to bahiagrass are suppressive.

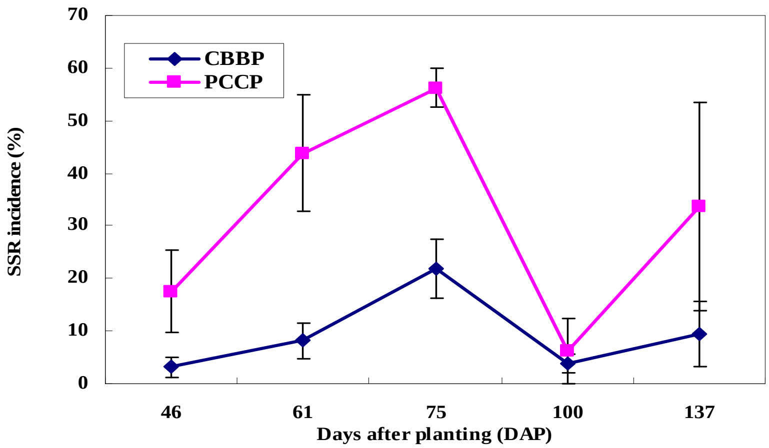

Figure 4-1. Effect of bahiagrass (CBBP) and conventional (PCCP) rotation on the incidence of southern stem rot (SSR) in Quincy, FL during 2003. Incidence represents the percentage number of plants out of 20 showing pathogen signs. Data represents means of a minimum of 4 replications. Standard error bars are displayed for each rotation and assessment time.

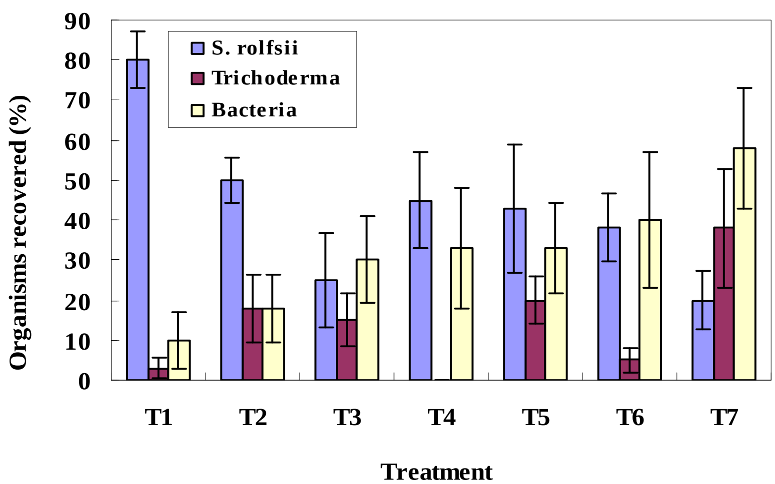

Figure 4-2. Experiment 1: Effect of bahiagrass amendments on survival of sclerotia of *Sclerotium rolfsii*. T1 – Infestation with only sclerotia, T2 -1:1 Leaves to roots (12 g of leaves and 12 g of roots), T3 - 1:2 Leaves to roots (8 g of leaves and 16 g of roots), T4 - 2:1 Leaves to roots (16 g of leaves to 8 g of roots), T5 – 24 g dry cut roots, T6 - 24 g dry cut bahiagrass leaves, and T7 – 24 g dry finely ground (powder) bahiagrass leaves. Bars represent percentage of sclerotia recovered that produced *S. rolfsii* or were colonized by *Trichoderma* spp. and bacteria.

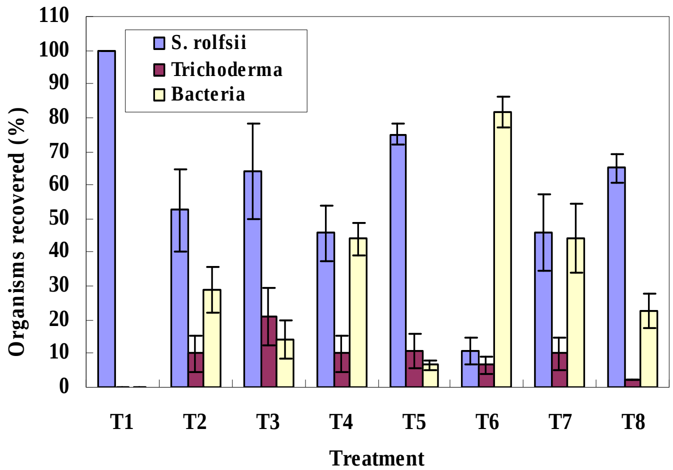

Figure 4-3. Experiment 2: Effect of bahiagrass amendments on survival of sclerotia of *Sclerotium rolfsii*. T1 - Infestation with only sclerotia, T2 -1:1 Leaves to roots (12 g of leaves and 12 g of roots), T3 - 1:2 Leaves to roots (8 g of leaves and 16 g of roots), T4 - 2:1 Leaves to roots (16 g of leaves to 8 g of roots), T5 – 24 g dry cut roots, T6 - 24 g dry cut bahiagrass leaves, T7 - 24g dry finely ground (powder) bahiagrass leaves, and T8 – 24 g dry finely ground (powder) bahiagrass roots. Bars represent percentage of sclerotia recovered that produced *S. rolfsii* or were colonized by *Trichoderma* spp. and bacteria.

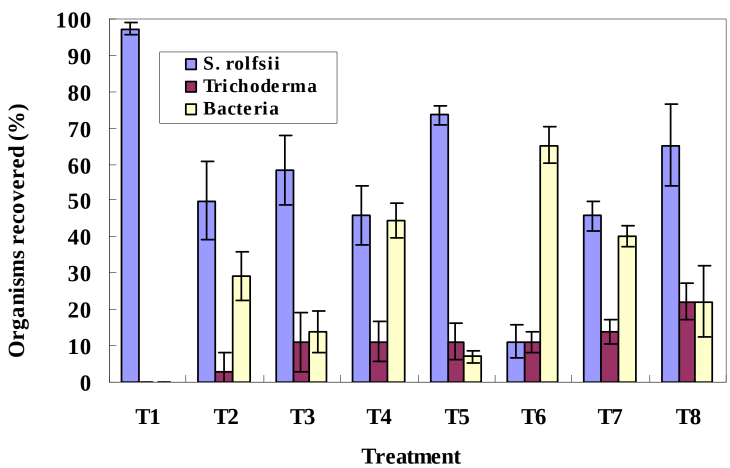

Figure 4-4. Experiment 3: Effect of bahiagrass amendments on survival of sclerotia of *Sclerotium rolfsii*. T1 - Infestation with only sclerotia, T2 -1:1 Leaves to roots (12 g of leaves and 12 g of roots), T3 - 1:2 Leaves to roots (8 g of leaves and 16 g of roots), T4 - 2:1 Leaves to roots (16 g of leaves to 8 g of roots), T5 – 24 g dry cut roots, T6 – 24 g dry cut bahiagrass leaves, T7 – 24 g, dry finely ground bahiagrass leaves, and T8 – 24 g ground (powder) bahiagrass roots. Bars represent percentage of sclerotia recovered that produced *S. rolfsii* or were colonized by *Trichoderma* spp. and bacteria.

CHAPTER 5
EFFECT OF BAHIAGRASS ON NEMATODE POPULATION, REPRODUCTION, AND MOVEMENT IN THE FIELD, GREENHOUSE AND LABORATORY CONDITIONS

Introduction

Peanut is an important crop worldwide and was listed as one of the crops standing between man and starvation (USDA 2007). Among the attributes of the peanut plant is the ability to grow and produce on marginal soils and produce seeds that are rich in calories and contain 25% protein. Peanut is extracted for oil and the protein rich by-product is used for human consumption or as animal feed. Peanut hay is also used as animal feed in both developing and developed countries. Peanut is one of the most important nut crops in the United States (US) and a major crop for farmers in the southeastern US. Farmers in the state of Florida produce approximately 6 percent of the total crop. Approximately 30-50% of input costs in peanut production are allocated to managing weeds, insects, and disease (Garciacasellas, 2004); hence the quest by southeastern farmers is to find ways to reduce input costs in order to boost profit. The current trend of escalating production costs associated with low commodity price exerts tremendous pressure on farmers who seek alternative but sustainable production methods to cut costs and preserve the environment. One opportunity is the use of crop rotation with compatible crops to reduce pest pressures, and additionally, to improve and sustain soil fertility.

Nematodes Diseases of Peanut in the Southeastern US and their Management

Plant-parasitic nematodes are damaging to peanut and cause an estimated 12% loss in crop yield and quality annually (Sasser and Freckman, 1987). Several nematodes species attack peanut but the most prevalent include *Meloidogyne* spp., *Pratylenchus brachyurus*, *Belonailamus longicaudatus* (Shama 1985). Sasser (1977) listed three species of *Meloidogyne* that are damaging on peanuts: *M. arenaria*, *M. javanica*, and *M. hapla*. Among these, *M. arenaria* (the most dominant species in the US) and *M. javanica* occur in warm and hot regions of the world and *M. hapla* occurs only in cooler regions (Dickson and Waele, 2005). Nematodes are widespread and destructive pests on peanuts and are sometimes described as "the hidden enemy'' since their damage are often imperceptible to farmers. In Alabama, 5 to 10% of potential peanut yield is estimated to be lost due to nematodes (Hagan, 1994; Koenning et al., 1999). Typically, nematodes infect small areas of fields but can occasionally destroy crops when the infection is widespread. Root-knot nematodes cause galling on peanut roots, pegs, and pods and severely infected plants have stunted growth. Root-lesion nematodes affect roots, pegs, and pods and can be identified by the presence of small spots that are tan with darker centers in color on pods (Rich and Kinloch, 2007). According to Hagan (1994), nematode populations are generally highest in light and sandy soils and the more often peanuts are grown in a field, the greater the risk of damage caused by nematodes, especially peanut root-knot nematode. Nematode-damaged peanuts typically show yellow foliage and may wilt at midday, even if soil moisture levels are adequate for good plant growth. Vines may be so stunted that they do not lap or shade out the row middles, making the peanuts more sensitive to drought. Severely stunted peanuts frequently die if stressed by hot, dry weather. Damaging nematodes are not evenly distributed across a field and scattered patches with damage can range in size from a few feet to several acres. Control of a nematode pest of peanut can be accomplished with crop rotation and nematicides.

Organic Amendments and Nematode Suppression

Organic amendments have been widely studied in the management of soil pests such as nematodes and other soil-borne pathogens that cause disease on agronomic crops. Nematode populations have been negatively or positively correlated with soil organic matter content (Rodriguez- Kabana et al., 1987; Akhtar and Mahmood, 1994). Chemical composition of organic matter determines the efficacy and the type of microorganisms that develop during degradation.

Rodriguez-Kabana et al. (1995) reported the release of nematicidal compounds such as organic acids, hydrogen sulfide, nitrogenous ammonia, phenols, and tannins during degradation of amendments. Soler-Serratosa et al. (1996) reported the occurrence of volatile compounds with nematicidal and fungicidal properties on incorporation of plant residues, while Chavarria-Carrayal et al. (1994) reported increased parasitism of eggs of *Meloidogyne* spp. upon incorporation of plant residues into soil.

A considerable amount of research has been devoted to the use of cover crops in nematode management (Haroon and Smart, 1882; Widmer and Abawi, 2000). Whether cover crops are incorporated as green manure or as killed rotation crops, the process of decomposition releases a large array of active compounds that tremendously impact on the diversity of soil microbial populations (Haroon and Smart, 1983; McLeod and Steel, 1999; Widmer and Abawi, 2000). Koon-Hui et al. (2002) extensively reviewed the use of *Crotalaria* as a cover crop in the management of nematodes. Wang (2000) suggested that the reduction in *R. reniformis* population in a pineapple-*C. juncea* intercropping cycle might be due to the enhanced activities of bacterivorous nematode population as well as nematode-trapping fungi.. Several mechanisms are proposed to be responsible for the reduction of plant-parasitic nematodes by cover crops including: 1) cover crops act as non-host or poor host as reported by (Rodriguez-Kabana et al.,1992, 1994); 2) production of allellochemicals that are toxic or inhibitory (Haroon and Smart, 1983; Gommens and Baker 1988; Halbrent, 1996); 3) cover crops could provide a niche for antagonistic flora and fauna (Caswell at al., 1990; Kloepper et al., 1991); 4) cover crops may act to trap nematodes (Gardner and Caswell-Chen, 1994; Lamondia, 1996).

Cover crops influence soil nematode populations in several ways such as their failure to reproduce in non-hosts and in some cases produced fewer eggs (Rich and Rahi, 1995, McSorley, 1999).

Greenhouse studies on the influence of plant residues incorporation on the survival of pathogens and reproduction of nematodes have been well studied, though the successful application of such studies in large scale in field has been limited (Haroon and Smart, 1983; Widmer and Abawi, 2000). Organic amendments and other naturally occurring compounds can effectively suppress a number of plant parasitic nematodes (Yeates and Coleman, 1982; Rodriguez-Kabana, 1991. Another option for nematode management will be the use of plant-growth promoting substances that have the ability to suppress plant pathogens. Timper et al., (2001) observed a cropping system effect on *M. arenaria* and its antagonist *Pasteuria penetrans*, where populations of *P. penetrans* endospores were higher in a continuous peanut compared to peanut after two years.

Role of Root Exudates in Rhizosphere Interactions

Several researchers (Buchholtz, 1971; Fisher et al., 1978) implicate the role of leachates from residues incorporated into the growing medium, or residues in natural undisturbed condition in allelopathic interactions. Different plants produce various metabolites that act as allelopathic compounds against nematodes with little environmental impact (Soler-Serratosa et al., 1996). *Crotalaria* spp. reduced root-knot galling in greenhouse test and this plant is known to produce pyrrolzidine alkaloids and monocrotaline which could be toxic to nematodes (Rich and Rahi, 1995). Fassuliotis and Skucas (1969) reported that exposure of root-knot nematode juveniles to monocrotaline caused them to jerk and reduced their infectivity. Allelopathy was demonstrated in bahiagrass when

Fisher and Adrian (1981) observed that as the percentage of ground covered with bahiagrass increased the height of a 3-year-old pine decreased markedly, and further demonstrated that both living and decaying bahiagrass residue were allelopathic to pine.

Crop rotation is generally beneficial to crop production and suggestions are that these benefits are due to improved nutrition, decreased disease levels and improved soil structure. Johnson and Pfleger (1992) indicated that the beneficial effects of a rotation may be due to the population dynamics of VAM fungi. Bahiagrass root exudates have been reported to enhance mycelia and spore production in VAM fungi (Cruz et al., 2003; Ishii et al., 1996). It is, therefore, probable that the presence of VAM fungi in bahiagrass may be responsible for the higher yields and lower disease levels in a bahiagrass-peanut rotation system. Higher hyphal as well as high root infection, and higher spore numbers of *G. margarita* were found in a bahiagrass and millet root environments than in an adjacent papaya root environment when each was separated from each other where *Gigaspora margarita* spores were placed (Cruz et al., 2003. Similarly, methanol extraction of bahiagrass and millet roots eluates showed a similar result as above (Cruz et al., 2003), an indication that bahiagrass produced compounds that stimulate VAM fungi development. Bahiagrass root extracts stimulated the growth of *Gigaspora ramisporophora* in axenic culture (Ishii et al., 1996), and the substances later identified as flavonoids: eupalitin and two other unidentified compounds (Ishii et al., 1997). It is well established that rotating peanut with bahiagrass suppresses plant-parasitic nematodes, and other soil-borne pathogens (Johnson et al., 1999; Rodriguez-Kabana et al., 1994; Summer 1982), however, the mechanisms of such activity is not fully understood due to the complexity of the soil ecosystem.

The objectives of this research were to: 1) monitor soil nematode population on peanut in a bahiagrass and conventional rotation, 2) investigate further the effects of bahiagrass stem cuttings on the reproduction of *M. arenaria*, and 3) investigate nematode behavior on agar-grown bahiagrass seedlings.

Materials and Methods

Rotation and Cultural Practices

Field ~~e~~xperiments were conducted at the North Florida Research and Education Center in Quincy, Florida from 2003 to 2006. Rotation plots were first established in the year 2000 and consisted of a ~~b~~ahiagrass (B) rotation with peanut (P) and a conventional cotton-peanut (CP) rotation. The cropping sequence for the bahiagrass rotation involved the growing of cotton in the first year and then followed by bahiagrass for two consecutive years and in the fourth year the plots were cultivated to peanut for one year (CBBP). The conventional rotation consisted of growing peanut in the first year with cotton in the two subsequent years followed by peanut in the fourth year (PCCP). Crop management practices were conducted according to the Florida Cooperative Extension Service~~s~~ recommendations. Each plot measured 22.8 m in length by 18.4 m (20 peanut rows).

The bahiagrass cover crop was killed in the fall of each year by spraying recommended herbicides. A winter oat (*Avena sativa* L.) cv. Florida 501 cover crop was planted at the seeding rate of 51 kg/A and was killed 124, 97, 123, and 120, DAP in 2003, 2004, 2005, and 2006, respectively by broadcast spraying glyphosate (Roundup WeatherMAX; Monsanto, Kansas City, MO). Seedbeds were prepared in all years by strip-tilling all plots with a KMC (Kelly Mfg. Corporation, Tifton, GA). Georgia Green peanut cultivar was planted on 7 May, 2003 and 10 May in 2004with a Monosem pneumatic planter (ATI, Inc. Lenexa, KS) at 6 seeds per 31 cm of row and 91-cm row spacing and phorate (Thimet® 20-G; Micro Flo Company LLC. Memphis, TN) at 2.3 kg/A was applied in furrow at planting. AP3 peanut variety was planted on 13 May 2005and 17 May 2006 with a Monosem pneumatic planter (ATI, Inc. Lenexa, KS) Twin Row Planter at 3 seeds per 30 cm of row with simultaneous application of phorate (Thimet) at 2.5 kg/A into seed furrows. Soil nematode population in the fields were monitored by randomly taking 10 soil cores (2.5 cm diameter × 20 cm deep) at harvest in October of each year within peanut rows from each plot for extraction of *M. arenaria* second-stage juveniles (J2). The 10 soil cores were combined, and nematodes were extracted from a 100 cm^3 sub-sample from each plot by centrifugal flotation (Jenkins, 1964).

Effect of Bahiagrass Cuttings on Populations of *M. arenaria* Inter-Planted with Tomato

The effect of bahiagrass root and leaf cuttings on survival of *M. arenaria* was investigated in the greenhouse using tomato cv. Rutgers as the test plant. Field soil (fine loamy siliceous, thermic Plinthic Kandiudult) was collected and dried under greenhouse conditions to heat-kill nematodes present before experiment initiation. The soil was spread thinly (2 cm thick) on a white polythene sheet with periodic stirring to allow drying by solarization for one month. The dry soil was sieved to remove clods and other large debris. Pot culture assays of bahiagrass roots and stem cuttings on survival and reproduction of nematodes were carried out in six 16-cm diameter plastic pots containing 1.2 kg of the dry field soil. Bahiagrass leaves and roots that had been previously cut into 2 cm pieces and dried were weighed in different ratios to constitute 2% organic matter content (w:w) measured soil. The *M. arenaria* eggs for the bioassay were extracted from galled roots of tomato (*Lycopersicon solanacerum*) cv. Rutgers using NaOCl (Hussey and Barker, 1973). The various treatment and amendment ratios were as follows: T1- Field soil without nematode inoculation, T2 - Only nematode egg inoculation, T3 -1:1 Leaves to roots (12g of leaves and 12 g of roots), T4 - 1:2 Leaves to roots (8g of leaves and 16g of roots), T5 - 2:1 Leaves to roots (16g of leaves to 8g of roots), T6 - 2% dry cut root (24g dry root), and

T7 - 2% OM dry cut bahiagrass leaves (24g dry cut leaves)were added to each pot and thoroughly mixed into the soil. Soil incorporated with the amendments were watered and allowed to drain for 24 hours before addition of nematode eggs. Three holes (1 cm diameter by 2 cm deep) were created using a spatula into the potted soil. Egg suspensions of *M. arenaria* (10,000 eggs per pot) were deposited into the holes and then covered with soil for three days to allow eggs time to hatch. Water was added to soil in the pots to prevent drying.. Pots were maintained for 10 days in this manner to allow for residue decomposition before three-week-old Rutgers tomato seedlings were transplanted. The plants were watered as necessary for two months when the experiments were terminated. Plant roots were removed from each pot by washing under tap water. Fresh weight of the shoots and roots were determined after the plant parts were allowed to air dry under laboratory conditions to remove excess water. The plant roots were rated for root-knot galling using the 0 – 10 scale where, 0 = no galling, and 10 = complete root galling (Zeck, 1971). Nematode egg numbers on the roots were determined as described above (Hussey and Barker, 1973). The experiments were repeated three times.

Nematode Juvenile Movement on Agar-grown Bahiagrass and Tomato Seedlings

Bahiagrass cvs. Pensacola, Paraguay, Argentine, and tomato cv. Rutgers seeds were surface sterilized twice in 100% sodium hypochlorite for 30 minutes and thereafter washed in several changes of sterile distilled water. The surface sterilized seeds were air dried in the laboratory under sterile conditions and later plated on 0.6% water agar (3 g agar in 500 ml de-ionized water) and incubated in Petri dishes (150 by 20 mm) under laboratory conditions for two weeks. The plates were inoculated with approximately 500 eggs of *Meloidogyne arenaria* suspended in sterile distilled water by placing them at measured distances (2-10 cm) from bahiagrass and tomato seedling roots. Similarly root pieces of two-month-old bahiagrass seedlings grown on agar were excised and placed into holes that were dug in the agar medium in

Petri dishes. Egg suspensions of *M. arenaria* were deposited 10 cm from each root piece as described above. The number of juveniles that migrated to living and excised roots were counted under a stereoscopic microscope at 40X magnification and their behavior along roots noted. Five days after inoculation, and thereafter weekly, roots of both bahiagrass and tomato were decolorized in NaOCl (Clorox®). The decolorized roots were later stained in red food dye (Thies et al., 2002) to detect any penetration by nematode juveniles. The experiment was terminated after three months.

Data Analyses

Field data were analyzed by SAS PROC GLM statistical analysis programs and Fisher's least significant difference was used for means separation. The greenhouse data were transformed using (log 10) for large numbers greater than 100 before analyses using SAS version 9.1. Treatment means for the greenhouse and the laboratory data were separated by Tukey's Studentized (HSD) test at $P \leq 0.05$.

Results

Soil populations of ring, spiral, reniform, and root-knot nematodes in the rotations varied from year to year. Across all the four years (2003-2006) and regardless of peanut variety , populations of ring nematodes were higher in the bahiagrass than in the conventional rotation (Table 5.1). On the other hand, soil populations of spiral, reniform, and root-knot nematodes remained consistently higher in the PCCP than in CBBP rotation soils throughout the four years. Except during 2004, populations of ring nematodes were highest in the bahiagrass (CBBP) rotation than in the conventional (PCCP) (Table 5.2). Both reniform and root-knot nematodes, the most damaging to cotton and peanut, respectively, were lower in the bahiagrass rotation that in the conventional rotation.

Incorporation of bahiagrass plant parts had significant effects ($P \leq 0.05$) on tomato shoot weight, galling index, mean number of nematode eggs per root, and per gram root but not on the root weight (Table 5.3). Tomato plants amended with 16 g of leaves to 8 g of roots (T5) had the highest shoot weight (67.5 g) but least root weight (27.6 g) whereas, those planted into pots amended with 8 g of leaves and 16 g of roots (T4) showed least shoot weight (Table 5.3). Plants grown in pots un-amended with bahiagrass cuttings had a significantly higher galling index ($P \leq 0.05$), than those amended with cuttings (Table 5.4). Total number of eggs per root and per gram root were significantly higher ($P \leq 0.05$) for plants grown in un-amended soil than in amended soil regardless of plant part proportions Table (5.3). No significant differences in egg production on tomato were observed from incorporating differing ratios of bahiagrass leaves androots. However,, plants grown in soil amended with higher proportions of bahiagrass leaves had the most impact on reducing egg production Table (5.3).

In the tests utilizing water agar, second-stage *M. arenaria* juveniles were observed moving on the surface of the agar within three days after inoculation of egg suspension. Nematode juveniles moved equally to root zones of tomato and bahiagrass seedlings on agar. There were no significant differences ($P \leq 0.05$) in the number seedlings of bahiagrass and tomato assessed for nematode juvenile movement in agar. However, significant differences ($P < 0.05$) were recorded for the maximum distances traveled by nematode juveniles towards seedling roots in media (Table 5.4). Juveniles moved on average 3.7 cm to living roots of tomato, and 2.5, 3.1, and 2.6 cm towards bahiagrass cvs. Argentine, Paraguay, and Pensacola, respectively (Table 5.4). The maximum distance moved (6.3 cm) by juveniles was recorded on cut bahiagrass root pieces that were embedded in agar (Table 5.4). Juveniles colonized tomato roots and produced galls that were absent on bahiagrass seedlings.

Discussion

Soil nematode population densities were lower in the bahiagrass (CBBP) than the conventional (PCCP) rotation, particularly in relation to juveniles of *Meloidogyne* spp. These data are consistent with those previously reported by Rodriguez-Kabana et al., 1994; Timper et al., 2001). Previous studies have demonstrated population reductions in *Meloidogyne* spp in peanut after bahiagrass rotation (Johnson et al., 1999). Mechanisms of nematode reduction under a bahiagrass rotation were attributed to the non-host status of bahiagrass, and the encouragement of the nematode antagonists such as *Pasteuria penetrans* (Timper et al., 2001). The bahiagrass rotation did not suppress the population of ring (*Mesocriconema* spp) nematode populations, although Nyczepir and Bertrand (2000) successfully used pre-plant bahiagrass to suppress populations of ring nematodes in young peach orchards. Similarly, Zehr et al (1990) reported that bahiagrass did not support *M. xenoplax* populations under greenhouse conditions when seedlings were inoculated with the nematode. The high populations of ring nematodes could not be explained from present data.

The non-host status of bahiagrass to *Meloidogyne* spp and other nematode species has been well studied (Rodriguez-Kabana et al., 1989); Dickson and Hewllet, 1989). However, the behavior of nematode juveniles around the root zones of bahiagrass has not been documented. In the present study, that juveniles of *M. arenaria* actively moved towards both living and excised bahiagrass roots in water agar. Since no feeding or root penetration was observed when juveniles moved onto roots, these results confirm previous studies on the non-host status of bahiagrass to *Meloidogyne* spp. The movement of juveniles to cut root pieces in media in large numbers is an indication that exudates from bahiagrass roots may be acting as an attractant to nematodes. Thus root exudates may act to reduce nematode populations in soils by trapping juveniles into root zones where they can not feed and therefore may die. In addition, bahiagrass root exudates may be encouraging the diversity of other antagonistic organisms in the rhizosphere, which could contribute to nematode population reduction. This research has demonstrated that juveniles of *M. arenaria* are strongly attracted to bahiagrass, and no evidence of repellency was found. It suggests that nematode stimuli in finding host may be different than the response to enter roots and feed.

Incorporation of plant residues into soil and their role in nematode suppression has been studied and reported to be successful (Sikora, 1992). Soil amendment with either fresh or decomposed plant residue alters soil physical, chemical, and biological equilibrium and will affect the diversity of microbial populations that will enhance nematode suppression. Development of *M. incognita* was inhibited in soils amended with digitgrass (Haroon and Smart, 1983). Similarly, chopped leaves of brassicas have been reported to successfully lower *M. javanica* numbers when incorporated into soils (McLeod and Steel, 1999). The incorporation of bahiagrass residues into soil in this study successfully reduced *M. arenaria* reproduction on tomato. Both roots and leaves were equally effective in reducing egg production regardless of plant part proportion. The mechanism of nematode suppression when using bahiagrass amendments was not investigated in these studies. However, the results suggested that mechanisms previously implicated in other studies were involved (Haroon and Smart, 1983; McLeod and Steel, 1999; Widmer and Abawi, 2000) which include the release of volatile compounds and encouragement of antagonists may be playing some role.

It is concluded from these studies that bahiagrass rotations reduced populations of *Meloidogyne* spp., *Helicotylenchus* spp., *Rotylenchulus* spp.but not for *Criconemoides* spp. Bahiagrass root exudates may also be acting to actively attract *M. arenaria* juveniles.

When attracted to the root zone, the juveniles of *M. arenaria* become trapped and in the absence of feeding and root penetration, they either die or become more exposed to antagonists in the rhizosphere.

Table 5.1. Effect of rotations on soil nematode populations during 2003-2006[s]

		Nematode population/100 cm^3 soil[w]			
Year/Variety	Rotation[t]	Ring	Spiral	Reniform	RKN
2003, Georgia Green					
	CBBP	239.0 a	18.0 b	8.0 b	3.0 b
	PCCP	83.0 b	32.0 a	122.0 a	20.0 a
	LSD ($P \leq 0.05$)	99.8	20.4	66.9	13.0
	Standard error	30.6	4.8	21.4	3.8
2004, Georgia Green					
	CBBP	85.0 a	8.0 b	23.0 b	23.0 b
	PCCP	190.0 a	30.0 a	343.0 a	26.0 a
	LSD ($P \leq 0.05$)	120.3	26.7	252.2	
	Standard error	29.3	6.0	68.0	5.0
2005, AP3					
	CBBP	180.0 a	13.0 b	6.0 b	5.0 b
	PCCP	81.0 b	34.0 a	97.0 a	37.0 a
	LSD ($P \leq 0.05$)	78.7	22.1	38.6	11.8
	Standard error	22.0	5.6	14.9	5.1
2006, AP3					
	CBBP	81.0 b	34.0 a	97.0 a	37.0 a
	PCCP	81.0 b	36.0 a	538.0 a	40.0 a
	LSD ($P \leq 0.05$)	86.6	22.6	248.9	11.5
	Standard error	20.8	4.8	84.2	4.4

[s] Means within a column followed by the same letters are not significantly different according Fisher's LSD test ($P \leq 0.05$). Each value in table represents the mean for a minimum of 8 replications. [t] Yearly rotation sequences were bahiagrass (B), cotton (C), and peanut (P). [w] Ring nematode (*Criconemoides* spp.), Spiral nematode (*Helicotylenchus* spp.) Reniform nematode (*Rotylenchulus* spp.), and RKN (*Meloidogyne* spp.).

Table 5.2. Effect of rotations on soil nematode populations across 2003-2006 [s]

Years	Rotation[t]	Nematode population/100 cm^3 soil [w]			
		Ring	Spiral	Reniform	RKN
2003 - 2006					
	CBBP	188.0 a	17.0 b	15.0 b	11.0 b
	PCCP	82.0 b	33.0 a	275.0 a	31.0 a
LSD ($P \leq 0.05$)		45.2	10.3	103.9	8.2

[s] Means within a column followed by the same letters are not significantly different according to Fisher's LSD test ($P \leq 0.05$). Each value in table represents the mean for a minimum of 8 replications. [t] Yearly rotation sequences were bahiagrass (B), cotton (C), and peanut (P). [w] Ring nematode (*Criconemoides* spp.), Spiral nematode (*Helicotylenchus* spp.) *Reniform* nematode (*Rotylenchulus* spp.), and RKN (*Meloidogyne* spp.).

Table 5-3. The influence of bahiagrass residues on development of tomato plants infected with *M. arenaria*[w]

Treatment	Fresh weight (g)		Galling index	Log number of eggs	
	Shoot	Root		Total per root	per gram root
T2	48.2 a	28.4 a	6.7 a	5.6 a	4.2 a
T3	59.5 a	32.0 a	4.1 b	5.2 ab	3.7 b
T4	48.1 b	28.7 a	4.5 b	5.1 a	3.6 b
T5	67.5 a	27.6 a	3.9 b	5.0 b	3.6 b
T6	54.7 ab	31.4 a	4.5 b	5.2 b	3.7 b
T7	59.0 b	32.0 a	4.2 b	4.9 b	3.4 b
LSD ($P \leq 0.05$)	14.1	8.3	1.6	0.4	0.4
Standard error	1.5	0.8	0.2	0.1	0.1

[w] Means within a column and followed by the same letters are not significantly different according to Tukey's HSD test ($P \leq 0.05$). Each value in table represents the mean for 90 observations for three experiments. [x] Treatment represents the proportion of bahiagrass shoot and root ratios: T2 - Only nematode egg inoculation, T3 -1:1 Leaves to roots (12g of leaves and 12 g of roots), T4 - 1:2 Leaves to roots (8g of leaves and 16g of roots), T5 - 2:1 Leaves to roots (16g of leaves to 8g of roots), T6 - 1% dry cut root (24g dry root), and T7 - 1% OM dry cut bahiagrass leaves (24g dry cut leaves). Soils of all the treatments were infested with 10,000 eggs of *M. arenaria*. [y] Galling index scored on a scale of 0-10 where 0 = no galling, 10 = complete root galling.

Table 5-4. Effect of bahiagrass and tomato roots on the behavior of juveniles (J2) of *M. arenaria* on water agar[w]

Plant [x]	Number of seedlings	Number of juveniles per seedling	Mean number of juveniles on roots	Distance moved by juveniles to roots (cm)
Argentine	11 a	0.9 a	9 b	2.5 a
Paraguay	13 a	0.3 ab	4 a	3.1 a
Pensacola	14 b	1.4 a	16 b	2.6 a
Rutgers	9 b	1.3 a	12	3.7 a
Bahiagrass root pieces	-	-	7.0 b	6.3 b
Standard error ($P \leq 0.05$)	0.76	0.13	1.25	0.32

[w] Means within a column followed by the same letters are not significantly different according to Tukey's HSD test ($P \leq 0.05$). Numbers within a column followed by the same letter are not significantly different ($P \leq 0.05$) from each other. [x] Rutgers is a variety from tomato whereas, Argentine, Paraguay, Pensacola are varieties of bahiagrass (*Paspalum notatum*), bahiagrass root pieces were regardless of variety.

CHAPTER 6
SUMMARY AND CONCLUSIONS

Severity of early leaf spot (ELS) and late leaf spot (LLS) on peanuts that were planted after two years of bahiagrass rotation was lower than those planted after two years of cotton. Results during 2003-2006 showed significant reductions in ELS and LLS severity in a consistent manner. By utilizing the Florida 1 – 10 leaf spot assessment scale, [where 1 = no leaf spot; 2 = very few spots on leaves with none on upper canopy leaves; 3 = few lesions on the leaves, very few on upper canopy; 4 = some lesions with more on the upper canopy, 5 % defoliation; 5 = lesions noticeable on upper canopy, 20% defoliation; 6 = lesions numerous and very evident on upper canopy, 50 % defoliation; 7 = lesions numerous on upper canopy, 75 % defoliation; 8 = upper canopy covered with lesions, 90 % defoliation; 9 = very few leaves remaining and those covered with lesions, 98 % defoliation; and 10 = plants completely defoliated and killed by leaf spot], final disease severities in the bahiagrass rotation were 5, 6, 6, and 6 compared to 7, 8, 7, and 8 in the conventional system during 2003, 2004, 2005, and 2006, respectively. Defoliation of peanut as result of ELS and LLS was greater (near 90%) in some years in the conventional system compared to 60% in the bahiagrass rotation. Onset of ELS and LLS was delayed on the bahiagrass rotation compared to the conventional rotation, and the rate of disease increase remained higher on the conventional rotation in all years.

Inoculations of peanut leaves taken from plants growing in the two rotations had 83% of leaflets from the conventional compared to 33% from the bahiagrass rotation showing symptoms of ELS after four weeks of incubation under laboratory conditions. It is likely the delayed onset of disease may be accounting for the variability in ELS and LLS epidemics that were observed in the field.

Peanut yield in the bahiagrass rotation was greater (2,935; 3,053; 2,250; and 4,504 kg/ha) than the conventional (2,229; 2,297; 1,703; and 3,278 kg/ha) rotation during 2003, 2004, 2005, and 2006, respectively when peanut plants were not sprayed with fungicides. Similarly, higher yields were obtained in the bahiagrass rotation than in the conventional rotation in all years when the plots were sprayed with fungicides throughout the period of the study. Peanut grade was higher in the bahiagrass rotation than in the conventional system. The incidence of peanut rust (*Puccinia arachidis* Spegg), however, was higher on the bahiagrass rotation than in the conventional system during 2003, and the reasons for this observation could not be explained.

The impact of bahiagrass rotation on the incidence and severity of tomato spotted wilt (TSW) on peanut was studied during 2003-2006 in the same rotational system described above. The peanut cv. Georgia Green was planted in 2003 and 2004 in a single row pattern, whereas, cv. AP3 was planted in 2005 and 2006 in a twin-row pattern as recommended for the management of thrips population on peanut. Peanut grown after two years of bahiagrass rotation reduced the incidence and severity of TSW in all years compared to the conventional system irrespective of the variety or row planting pattern, although there was variability in severity and incidence among years. Incidence of TSW at the beginning of the season in all years was higher in the conventional system than in the bahiagrass rotation, and remained higher at all times of assessment in all years of the study (2003-2006). The incidence of TSW 32 DAP in 2003 was 22% on peanut in the bahiagrass rotation compared to 39% in the conventional rotation, and 24% and 38% 40 DAP, respectively during 2004. Final TSW incidence was similarly lower at 17 and 32 % for the bahiagrass compared to 21 and 72% for the conventional rotation during 2003 and 2004, respectively.

Monitoring of thrips populations on peanut seedlings was conducted in 2005, and it was observed that thrips per peanut seedling under the bahiagrass system was lower (6) than those in the conventional system (22). Seedling damage due to thrips feeding was 100% in the conventional system compared to 45% in the bahiagrass rotation during 2005. The number of thrips per seedlings on two years of continuous peanut was 42 compared to 4 per plant on peanut grown after one year of bahiagrass rotation. Feeding damage of thrips positively correlated ($r = 0.60$) with the number of thrips per seedling, and the final TSW incidence ($r = 0.94$). Similarly, a strong correlation existed for the number of damaged seedlings and final TSW incidence ($r = 0.84$). During 2006, differences in thrips populations were observed on volunteer peanut seedlings in plots planted to winter oat cover crop (45), compared to 21 and 7 on peanut seedlings in killed and green bahiagrass plots, respectively. Bahiagrass inflorescences harbored 4 thrips per head compared to 18 thrips per panicle and 6 thrips per seed of winter oat. The incidence and severity of TSW on peanut planted in those plots previously planted to winter oat had both higher initial (40%) and final TSW (53%) incidence compared to plots not planted to winter oat that had 22 and 23% TSW, respectively in 2006. These data indicate that oat may be acting as a host to thrips when compared to bahiagrass, and thus harbor thrips that subsequently attack peanut grown afterwards.

Investigations into the impact of bahiagrass on southern stem rot (SSR) of peanut caused by *Sclerotium rolfsii* was monitored on peanut in the bahiagrass and conventional rotations during 2003. Incidence of SSR was variable during the season but remained higher on the conventional than on the bahiagrass rotation. Fluctuations in the incidence of SSR were attributed to changing weather conditions prevailing during 2003. The average incidence of SSR in the conventional rotation was 30% compared to 5% in the bahiagrass rotation. The mechanisms involved in the suppression of SSR by bahiagrass was investigated in the greenhouse in field soil amended with different proportions of bahiagrass root pieces and leaves. Sclerotia of *S. rolfsii* were buried in both amended and non-amended dried field soil in the greenhouse and incubated for ten weeks. Survival of sclerotia in non-amended soils ranged from80 to 100% compared to 8 to 75% in amended soils. Sclerotia recovered from soils were disintegrated and were colonized either by *Trichoderma* spp., bacteria or by both which resulted in inhibition zones in media. Bahiagrass seedlings co-grown with *S. rolfsii* on media were killed and sclerotia were produced, whiles *Trichoderma* spp. grew on incubated bahiagrass roots that were surface sterilized under laboratory conditions.

Bahiagrass rotations reduced soil nematode populations of Meloidogyne spp., *Helicotylenchulus* spp., *Rotylenchulus* spp., in exception of *Criconemoides* spp through 2003-2006. Incorporation bahiagrass roots and leaves in varied proportions reduced egg production by *M. arenaria* on tomato under greenhouse conditions. Both roots and leaves were equally effective in reducing egg production regardless of plant part proportion however; residues higher in bahiagrass leaves were more effective in nematode suppression. The mechanism of nematode suppression was not investigated when bahiagrass residues were incorporated in this study. Juveniles of *M. arenaria* actively moved onto roots of bahiagrass seedling grown in agar, and did not feed nor penetrated the roots. Juveniles moved equal distances to roots of both live tomato and bahiagrass seedlings as well as cut root pieces of bahiagrass seedlings embedded in media. There were no differences in the numbers that colonized root zone for both plants, although significantly higher numbers were found on cut root pieces that living plants. When attracted to the root zones the juveniles become trapped, and in the absence of feeding and root penetration, they either die or become more exposed to antagonists in the rhizosphere.

It is concluded from these studies that bahiagrass suppresses ELS, LLS, TSW, SSR, and nematodes of peanut under natural conditions without the assistance of chemical inputs. Suppression of ELS and LLS may be attributed to delayed disease onset as well as increased tolerance of peanut to leaf spots, while the possible modes in the suppression of TSW is in the reduction of initial thrips population. Reduction of SSR in a bahiagrass rotation could be attributed to the enhancement of antagonists that degrade sclerotia of *S. rolfsii*. Bahiagrass root exudates may be acting to actively attract *M. arenaria* juveniles to the root surfaces where they can not feed and may be prone to antagonistic attack by other soil organisms.

Further in-depth studies are needed to determine how bahiagrass rotation influences soil microbial diversity, and mechanisms of disease suppression.

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BIOGRAPHICAL SKETCH

Francis Kodjo Tsigbey was born in Hoviefe, in the Volta Region of Ghana, in 1963. After attending village schools at the primary and middle school levels, he attended Peki and Mawuli Secondary High schools. Francis Tsigbey later went to the University of Ghana, Legon, where he earned his Bachelor of Science (1990) and Master of Science (1996) degrees in crop science. He later took on a job as a research plant pathologist near Tamale in Ghana at the Savannah Agricultural Research Institute Nyankpala, an institute under the Council for Scientific and Industrial Research (CSIR, Ghana) in 1996. Until 2003 his research focus was on the development of disease management strategies on legumes. Francis worked with the Peanut Collaborative Research Support Program (Peanut CRSP) at North Carolina State University and the University of Florida. Francis took up a research assistantship with Dr. Jim Marois where he investigated the impact of bahiagrass rotation on peanut diseases. Francis completed his Ph.D. in December 2007.