Perennial Grass Based Crop Rotations in Virginia: Effects on Soil Quality, Disease Incidence, and Cotton and Peanut Growth.

James M. Weeks, Jr.

Thesis submitted to the faculty of the Virginia Polytechnic Institute and State University in partial fulfillment of the requirements for the degree of

Master of Science
In
Crop and Soil Environmental Sciences

Joel C. Faircloth, Chair
Marcus M. Alley, Co-Chair
Patrick M. Phipps
Christopher D. Teutsch

April 24, 2008
Blacksburg, VA

Key words: Crop rotation, Cotton, Peanut, Perennial grass, Soil quality, Soilborne pathogens

Perennial Grass Based Crop Rotations in Virginia: Effects on Soil Quality, Disease Incidence, and Cotton and Peanut Growth.

James M. Weeks, Jr.

ABSTRACT

In 2003 eight peanut and cotton crop rotations were established in southeastern Virginia, 4 of which included 2 or 3 years of tall fescue or orchardgrass grown as high-value hay crops. Each crop rotation was evaluated for changes in soil quality indicators including soil carbon and nitrogen, water stable soil aggregates, plant available water content, bulk density, cone index values, and soil moisture. Cotton and peanut growth and yield were also observed to evaluate changes in crop growth associated with differences in soil quality. Soilborne plant pathogens including root-knot nematode, stubby root nematode, ring nematode, stunt nematode, and *Cylindrocladium parasiticum* microsclerotia were measured in the spring and fall of each year to determine differences associated with crop rotations. Water stable soil aggregates in 2007 were higher in rotations with 3 years of either perennial grass. Soil moisture tended to be the highest at depths 30 - 60 cm in the 3-year tall fescue rotation in August and September 2007. Cotton in 2006 and peanut in 2007 had higher growth and yield where the annual crop directly followed a perennial grass. Root-knot nematode tended to decrease in all rotations over time. Stubby root nematode populations tended to increase in rotations with either duration of orchardgrass. Including perennial grasses in cotton and peanut rotations has the potential to increase growth and yield as demonstrated in this research.

ACKNOWLEDGEMENTS

I owe a great deal of thanks to Dr. Joel Faircloth. As my principal advisor he taught me a great deal about both agriculture and research. He always pushed me to strive for high standards in research and competition. Dr. Faircloth aided me in the preparation of this manuscript, even after his career path took him down another road. I am grateful for both his example as a researcher and for his friendship over the past 3 years. Thank you also to Dr. Mark Alley, who aided me in the preparation of this manuscript as well as helped develop my research. Thank you to Dr. Pat Phipps who helped me with research associated with plant pathology and development of my thesis. Thanks to Dr. Chris Teutsch and his research team who were involved with all aspects of the perennial grass portion of my research. Dr. Teutsch was also of great assistance in writing this thesis. Also, thank you to Dr. Cavelle Brownie who helped me with statistical analysis.

I also owe a great deal of thanks to David Horton and Gail White, the technicians for our program, for their help with anything I needed. Thanks also to Barron Keeling for her assistance in the lab and showing infinite patience when I borrowed her glassware. I would also like to thank Carolyn Crowder and Debbie Estienne for their warmth and kindness. I am also grateful to fellow students Nathan O'Berry and Kathy Kamminga who became true friends over the years and were always there for the highs and lows along the way. Further, without the help from our summer workers Lee Abernathy, Justin Ashley, Brian Ashburn, Jay Brock, and Jeff Brock my research would not have been possible.

Thank you to my parents, Mike and Carol Weeks and my sisters Courtney Weeks and Kirsten Richter for their support and love. Also thank you to my soon-to-be in-laws, Guye and Suzanne Stroud and their family for all the support through the years. Most of all thank you to my wife-to-be Molly Stroud for her love, support, and understanding.

Finally thank you to Cotton Incorporated, Virginia Cotton Growers Association, Virginia Agricultural Council, and the Virginia Peanut Growers Association who funded my research.

TABLE OF CONTENTS

List of Tables **Page**

List of Figures **Page**

CHAPTER 1

Literature Review

James M. Weeks, Jr.

James M. Weeks, Jr. Crop and Soil Environmental Sciences Department, Virginia Polytechnic Institute and State University.
Email: jmweeks@vt.edu; Phone: (919) 291-1066

Abbreviations: CBR, Cylindrocladium Black Rot

In southeastern Virginia, production of Virginia-type peanuts (*Arachis hypogaea* L.) has been important to the economic base throughout the past century. Following the loss of the quota program in 2001, peanut acreage in southeastern Virginia has declined from 30,300 ha (75,000 ac) in 2001 to 8,800 ha (22,000 ac) in 2007 (NASS, 2007). Disease control comprises a large portion of the input costs associated with peanut production in southeastern Virginia due to the high incidence of soilborne disease associated with short rotation intervals (e.g., 1 or 2 years between peanut crops) (Hagan et al., 2003). Sclerotinia blight (*Sclerotinia minor* Jagger*)* is a soilborne disease that occurs frequently in Virginia and northeastern North Carolina and is an expensive disease to control. South Carolina, on the other hand, has an unfavorable climate for Sclerotinia blight which has allowed its growers to escape the disease and increase their peanut acreage from 4,450 ha in 2001 to 22,600 ha in 2007 (NASS, 2007).

In the early 1990's, many producers in southeastern Virginia began growing cotton (*Gossypium hirsutum* L.) again due to availability of high yielding short season varieties and the success of the boll weevil (*Anthonomous grandis* Boheman) eradication program. Area planted to cotton increased from 21,448 ha (53,000 ac) in 1990 to a peak of 44,515 ha (110,000 ac) in 1999 (NASS, 2008). Since 1999, cotton planted in Virginia has ranged from 44,500 ha (110,000 ac) to 24,281 ha (60,000 ac) (NASS, 2008). The cotton industry is characterized by volatile prices, uncertain government support programs, and increasing input costs including fuel, machinery, and fertilizers. In the past several years, producers have had to rely upon government price supports due to low cotton prices. The price supports are currently being scrutinized by the World Trade Organization, and many economists believe price supports may be reduced in future farm bills (M. Roberts, personal communication, 2007).

Environmentally and economically sustainable cotton and peanut production will reduce dependency on government support payments and enable farmers in this region to be more economically competitive. Farming systems with lower economic risks, higher yield potential, and more environmentally favorable practices need to be developed and their benefits demonstrated to gain widespread acceptance.

The integration of perennial grass crops into the peanut/cotton rotation in Florida and Alabama has demonstrated potential to improve soil quality, decrease overall pesticide inputs, reduce nitrate leaching, and reduce financial risks without sacrificing profitability (Katsvairo et al., 2006). The potential benefits and feasibility of integrating perennial grass crop production into row crop systems in southeastern Virginia needs to be examined for enhancing the sustainability of cotton and peanut production. In a review of historical experiments (Franzluebbers, 2007), changes in soil loss in cotton rotations with perennial grasses in the southeast were described. Soil loss in one experiment was reduced from 45 Mg ha^{-1} under continuous cotton to less than 1 Mg ha^{-1} when planted in perennial grass. In a separate study soil loss was halved when oats (*Avena sativa* L.) and lespedeza (*Lespedeza bicolor* Turcz.) were rotated with cotton in a 3-year rotation compared to continuous cotton (Franzluebbers, 2007).

University and USDA researchers in other states (Florida, South Carolina, Alabama, and Georgia) have perennial grass-based peanut and cotton rotation research underway and have demonstrated significant yield, economic, and environmental benefits (Katsvairo et al., 2007a; Wright et al., 2002). Most recent efforts in the southeastern United States have utilized bahiagrass (*Paspalum notatum* Flueggē) as the grass crop in the rotation to be baled and sold or for cattle grazing. Producers in South American countries such as Brazil, Argentina, and Uruguay have made extensive use of perennial grass based rotations for row crop production. In the absence of a government price support program, 52% of farms in Uruguay utilize such systems (Prechac et al., 2002).

Benefits of Rotation with Perennial Grasses for Soil Quality

Crop rotation has long been recognized as an important cultural practice for sustaining soil quality, economic stability and yields (Bullock, 1992). Rotation of continuous row crops such as corn (*Zea mays* L.) and soybean [*Glycine max* (L.) Merr.] are common in farming systems of the Southeast, particularly utilizing no-till and minimum tillage strategies with cover crops planted to reduce soil erosion and increase organic matter (Wright et al., 2002). Winter cover crops, though effective in reducing soil loss through wind and water erosion, offer little to no overall soil improvement due to their short duration in the field (Wright et al., 2002). Incorporation of perennial grasses into traditional row crop rotations may enhance economic and environmental returns. Potential environmental benefits of perennial grasses include enhanced soil carbon sequestration, soil stabilization, and decreased nutrient loss (Bullock, 1992). Potential benefits to producers are increased yield in row crops following perennial grasses through soil enhancement with minimal purchased inputs, and a potentially more economically stable system when livestock are included (Siri-Prieto et al., 2002; Prechac et al., 2002).

Soil Organic Matter and Carbon

While carbon dioxide (CO_2) is the fundamental gas from which dry matter is built through photosynthesis and the Calvin cycle, its increasing atmospheric concentration through the burning of fossil fuels and other natural means contributes to global warming through the greenhouse effect (IPCC, 2007). Agricultural practices can alter this increasing greenhouse gas concentration. Soil that is constantly disturbed acts as a source of CO_2 through the respiration of organic carbon (C) by soil microbes, while undisturbed soils may act as a sink for C (Gebhert et al., 1994; Al-Kaisi et al., 2005).

Soils planted to perennial grasses that are undisturbed for several seasons are potential C sinks because the grass crops are adding organic matter to soils through root growth, and organic matter decomposition is reduced by not tilling the soil (Paustian et al., 1997; Conant et al., 2001; Gentile et al., 2005). Further, soils that have been depleted of organic matter by continuous tillage, as historically occurred in peanut and cotton rotations, can become potential C sinks when placed into perennial grasses (Paustian et al., 1997). In a review of published data from 167 studies conducted dominantly in the United Kingdom, New Zealand, Canada, Brazil, and the United States, C sequestration ranged from 0.11 Mg ha^{-1} yr^{-1} to 3.04 Mg ha^{-1} yr^{-1} with an average of 0.54 Mg ha^{-1} yr^{-1} when improved management practices were utilized (Conant et al., 2001). Temperature for the various locations ranged between -1.4°C to 28.8°C and rainfall ranged between 140 and 1040 mm. Management practices with C sequestration higher than 1 Mg ha^{-1} yr^{-1} included conversion from cultivation to pasture, earthworm introduction, and introduction of improved grass species (Conant et al., 2001). Soil aggregate formation is also associated with the amount of particulate organic matter present (Gale et al., 2005). Fibrous roots of perennial grass crops contribute to the particulate organic matter pool and increased soil aggregate stability due to continuous cycles of roots growing and dying throughout multiple seasons.

A review of cropping systems experiments in Uruguay by Prechac et al. (2002) reported a trend of increasing soil C content after 4 years in perennial grass, at which point row crops came into rotation without perennial grasses and C pools began to decrease until perennial grasses were rotated back into the sequence. This was in comparison to a continuous cropping system that continually decreased C in soil over the 26-year period of the experiment. Recent experiments in Georgia have also demonstrated enhanced C sequestration in no-till management, but only when high residue is maintained through high biomass winter cover crops. Sainju et al.

(2006) reported C sequestration in the 0 - 10 cm depth of 233 to 300 kg C ha^{-1} yr^{-1} with cover crops. Losses of 167 kg C ha^{-1} yr^{-1} were observed under no-tillage when plots were in weed fallow in the winter. These data sets collectively illustrate the potential for a sustainable soil C pool when perennial grasses or high residue crops and minimum tillage are utilized.

Moisture Conservation

Irrigation of cotton and peanuts in the Virginia peanut production region is the exception due to the lack of easily available irrigation water sources. Producers typically rely on stored soil moisture from the winter, and rain-fall during the growing season which generally occurs as scattered thunder showers and/or heavy rain-fall from tropical storms. According to climatic modeling, moderate drought is predicted in the Northeastern United States, including Virginia, 1 out of every 5 years and a severe drought 1 in every 10 years (Dickerson and Dethier, 1970). Capturing and utilizing the little precipitation which may occur during a drought year is vital to maintaining a crop.

Row crops following perennial grasses in rotation may experience less drought stress than those in continuous row cropping. There are several mechanisms which may create this effect. When rooting is limited to the dominantly sandy (low water holding capacity) upper horizons of the soil profile, growing season rainfall events are the major source of plant available water. Perennial grasses have the potential to grow deep roots over several seasons because moisture will be adequate for root growth through compacted soil layers at some point during the several year period of perennial grass growth. The roots of the perennial grasses create channels in the compacted soil layers for roots of subsequent row crops to reach greater depths for moisture and nutrients (Prechac et al., 2002). Research in Maryland, though not in perennial grass based rotations, demonstrated the ability of winter cover crops such as radish (*Raphanus sativus* L.) to create "biopores" in compacted layers. Using a minirhizotron camera, radish roots were observed growing through the compacted layer during the winter with soybean root observed growing through the same channel during the summer after the decomposition of the radish root (Williams and Weil, 2004). Further, the lower horizons that are often restrictive to root growth tend to have higher clay content and plant available water holding capacity (Wright et al., 2002), assuming chemical toxicity to roots is not a factor. Increases in earthworm populations have been observed in rotations including bahiagrass (Katsvairo et al., 2007a).

Earthworms may create channels in the soil increasing the opportunity for root exploration. Perennial grass crops can increase soil organic matter and evidence indicates that increases in soil organic matter are tied directly to increases in available water between field capacity and the permanent wilting point. According to Hudson (1994), an increase in soil organic matter by mass from 1% to 3% would double the plant available water across diverse soil types. Increasing plant available water is of particular importance in cotton and peanut production. The combination of greater rooting depth along with greater soil moisture holding capacity may reduce drought stress.

Impact of Cultural Tactics on Disease

Crop rotation and residue management are significant cultural tactics for managing diseases of major food and fiber crops. Without effective cultural practices costly pesticide applications may be needed to prevent significant crop losses, reducing economic returns (Brenneman et al., 2003). Several factors must be considered to select the most appropriate crop to bring into a rotation. To reduce pest levels in soils, alternative rotational crops should be a non-host of the pathogen of concern (Brenneman et al., 2003). However, crops that are chosen to be placed in rotation must be economically profitable or increase the yields of susceptible high value crops that follow in rotation significantly enough to compensate for the low value non-host crop (Koenning et al., 2004). Peanut and cotton complement each other well in rotation because they host relatively few common pests. For this reason many peanut producers throughout the United States are also cotton producers. While the profitability of growing cotton in rotation with peanut is economically attractive, the greatest disease suppression and associated increases in yield are realized when a non-host perennial crop, particularly perennial grass crops, are grown for several years without soil disturbance (Hirunsalee et al., 1995; Thies et al., 1995; Timper et al., 2001; Brenneman et al., 2003; Hagan et al., 2003; Cetintas and Dickson, 2004). Growing grass crops for high quality hay can be profitable in Virginia where there are over 225,000 head of horses and there is a net import of horse hay into the area (C.D. Teutsch, personal communication, 2008)

In the portions of Southeast where the area of cotton cultivation has increased, losses to nematodes can be as high as 4% with lack of rotation being a major contributing factor (Koenning et al., 2004). Losses in Virginia from southern root-knot nematode [*Meloidogyne* *incognita* (Kofoid & White) Chitwood] were estimated at 2% in 2006 with losses from other nematodes estimated at 4% (Virginia Cooperative Extension, 2007). Root damage by sting (*Belonolaimus longicaudatus* Rau) and southern root-knot nematode may also provide infection sites for *Fusarium oxysporum* (Schlect.), the cause of Fusarium wilt (Koenning et al., 2004).

Fungal diseases are among the most devastating pathogens to peanut yields. Hagan et al. (2003) reported yield reductions as high as 50% with lack of control of early leaf spot (*Cercospora arachidicola* Hori) and late leaf spot (*Cercosporidium personatum* Berk. & Curt). Virginia yield losses for 2006 to early and late leaf spot were estimated at just over 2% (Virginia Cooperative Extension, 2007). Virginia peanut losses for other fungal diseases were 2, 3, < 1, and 4% for Sclerotinia blight, southern stem rot (*Sclerotium rolfsii* Sacc.), Rhizoctonia limb and pod rot (*Rhizoctonia* spp. Whet. & J.M. Arth.), and Cylindrocladium black rot (*Cylindrocladium parasiticum* Creus, M.J. Wingfield, & Alfenas), respectively (Virginia Cooperative Extension, 2007). Pod and root galling by root-knot nematode [*Meloidogyne arenaria* (Neal) Chitwood and *Meloidogyne hapla* Chitwood] species parasitic to peanut can also provide infection points for fungi. Timper et al. (2004) found that the incidence of aflatoxin in peanut was higher in fields infested with root-knot nematode and aflatoxin levels increased directly with galling, especially under drought conditions. Total peanut yield loss attributed to all nematodes in Virginia in 2006 was 2% with an estimated value of nearly $240,000 (Virginia Cooperative Extension, 2007).

The onset of foliar and stem diseases is heavily dependent on environmental factors, some which are more consistent seasonally (e.g., soil temperature) and others which vary more year to year (e.g., rain-fall). Phipps and Beute, (1977) found that *C. parasiticum* was most aggressive on peanut when soils were at field capacity in Virginia. The greatest losses were observed when soils were wet during the early portion of the season allowing *C. parasiticum* to develop and infect plants causing damage to root tissue followed by a dry period in the season when a well-developed root system is needed to provide an adequate supply of water. Higher early and late leaf spot, pod rot, and Sclerotinia blight were observed in Virginia under sprinkler irrigation compared to non-irrigated peanuts (Porter et al., 1987), indicating the role of moisture in the development of plant disease.

Crop Rotation and Reduced Tillage for Cotton and Peanut Pathogen and Pest Suppression

Cropping systems which suppress fungal diseases and plant parasitic nematodes are a first line of defense in disease control. Significant yield increases were seen in Oklahoma with multiple years of corn or cotton in rotation with peanut cultivation, with a minimum of 3-year breaks offering the largest yield enhancement (Godsey et al., 2007). Corn and peanut crop rotations in North Carolina had higher yields compared to monoculture peanuts, particularly at one location where Cylindrocladium Black Rot (CBR) was severe (Ayers et al., 1989). Peanut rotations with 2 years of bahiagrass in Georgia were observed to have yield increases as high as 22% compared to continuous peanut with the only differences in disease being southern stem rot (Timper et al., 2001). Bahiagrass rotations in the latter study were observed to have ≈ 8 loci of southern stem rot 15.2 m^{-1} peanut row compared to continuous peanut which had ≈ 12 loci per 15.2 m peanut row. In reduced chemical control systems, southern stem rot was reduced for 2 years following 1 year in bahiagrass, with yield increases as high as 912 kg ha^{-1} following 2 years of bahiagrass compared to continuous peanut (Brenneman et al., 2003). Reductions in southern stem rot incidence in peanut were also observed with increasing rotation breaks with the highest yields achieved after 3 years of bahiagrass or cotton in Alabama (Bowen et al., 1996). In another study in Alabama, early and late leaf spot in peanut were reduced following 3 years of corn, cotton, or bahiagrass and the highest yield benefits attributed to disease suppression were achieved following 4 years of bahiagrass (Hagan et al., 2003).

Production practices which create soil environments unfavorable to pathogens and pathogen spread can also increase peanut yield. This is often accomplished by rotations which do not utilize nematicides and fungicides but allow for a buildup of predatory nematodes, beneficial fungi, and nematode parasitic bacteria (Brenneman et al., 2003; Cetintas and Dickson, 2004; Katsvairo et al., 2006). Bahiagrass has been shown to facilitate an increase in the nematode antagonist *Pasteuria penetrans* (Sayre & Starr) (Brenneman et al., 2003; Cetintas and Dickson, 2004), which in conjunction with the non-host susceptibility of bahiagrass, resulted in peanut yield increases in Florida following bahiagrass compared to continuous peanut (Cetintas and Dickson, 2004). While many perennial grasses are capable of suppressing plant parasitic nematode populations they often act as alternate hosts of certain nematodes, decreasing the benefit of the perennial grass. For instance, tall fescue (*Shedonorus phoenix* Scop.) has been demonstrated to build populations of sting nematode, a detrimental parasite of peanut roots (Holdeman and Graham, 1953).

Tillage practices may also have a significant impact on disease development and severity. In Georgia, reduced and minimum tillage treatments showed lower damping off of cotton seedlings 1 of 4 years (Johnson et al., 2001). The same research observed 42% less spotted wilt virus (*Tomato Spotted Wilt Virus, Tospovirus*) in peanut under reduced or minimum tillage management compared to conventional tillage treatments; however, yield differences were not observed. In a separate experiment in Georgia, strip tillage showed lower incidence of early leaf spot of peanut compared to conventional tillage when fungicide application was reduced below normal spray intervals (Monfort et al., 2004). Where more frequent fungicide intervals were used, lower early leaf spot was observed for three of nine cultivar/fungicide treatments in peanut under strip tillage for the first year of the experiment, and for all nine treatments in the second year. In year one, early leaf spot incidence was 7.1 and 10.1% for strip till compared to conventional tillage, respectively, and 6.1 and 9.6% for strip tillage compared to conventional tillage in the second year. In a third experiment in Georgia, early leaf spot of peanut was lower in incidence and severity for strip tillage versus conventional tillage (Cantowine et al., 2007). The conclusion of this research was that strip tillage delays the onset of early leaf spot compared to conventional tillage by 5.7 to 11.7 days. In North Carolina, research utilizing straw mulch to create surface residue displayed similar levels of CBR and southern stem rot of peanut for 3 seasons and less Sclerotinia blight 2 of 3 seasons compared to no-mulch treatments (Ferguson and Shew, 2001).

Tillage and crop rotation can also have impacts on insect pests of cotton and peanut. Peanut tillage and cover crop research in South Carolina reported higher burrower bug (*Pangaeus bilineatus* Say) populations and kernel feeding where strip tillage was utilized in corn or wheat (*Triticum aestivum* L.) residue compared to conventional tillage or strip tillage into rye (*Secale cereal* L.) residue (Chapin and Thomas, 2003). In Texas, thrips (Thysanoptera: Thripidae) and cotton flea hoppers (*Pseudatomoscelis seriatus* Reuter) were higher in conventional tillage compared to strip tillage (Parajulee et al., 2006). Other research in South Carolina showed more thrips in cotton in full tillage management compared to no-till (Manley et al., 2002). International research in Turkey showed no difference in aphids (*Aphis gossypii* Glover) or thrips in cotton-based on tillage practice; however, yields were consistently higher and fruit matured earlier in no-till management compared to full tillage (Gencsoylu and Yalcin, 2004). Boll weevil (*Anthonomous grandis* Boheman) research in Texas reported greater over-wintering and survival of boll weevil in conventionally-tilled compared to no-till cotton (Greenberg et al., 2004). Differences were associated with burial of abscised cotton fruit in which weevils were feeding in conventional tillage preventing desiccation during the winter, compared to no-till where infected fruit were left on the surface allowing for desiccation. Crop rotation in Georgia utilizing bahiagrass showed no effect on thrips and leaf hoppers (*Empoasca fabae* Harris) on peanut; however, yields were greater where there were multiple years of bahiagrass (Johnson et al., 1999).

Summary

Crop rotations that include perennial grass crops in conjunction with conservation tillage are beneficial in annual crops. Benefits have been attributed to enhancements in soil quality parameters and disease suppression. In many studies the main influence of perennial grass is an increase in soil organic carbon and organic matter. Benefits are often associated with greater soil organic matter including but not limited to increased aggregate stability, increased available water content, and increased nutrient availability. Further, conservation tillage utilized in annual crops following a perennial grass has large amounts of surface residue that aids in moisture conservation through decreased evaporation and moisture capture by decreasing raindrop impact and surface sealing leading to higher infiltration rates. Other changes in soil quality that have been seen following perennial grasses include decreases in resistance to root penetration and increases in rooting depths of annual crops. Pathogen suppression has been observed in many studies as well. Pathogens suppressed in peanut following perennial grass include soilborne fungi, insect transmitted viruses, and plant parasitic nematodes. Some studies observed little or no differences in soil quality parameters and disease suppression where perennial grasses were included in the rotation with annual crops. Despite that, most of these studies observed greater yields of annual crops following perennial grasses. Historical and current studies support the hypothesis that perennial grasses in rotation with annual crops enhance annual crop growth by several mechanisms, some of which are likely unknown.

This study investigates the effect of including 2 or 3 years of cool-season perennial grass crops in rotation with cotton and peanut in Virginia. Observations include those of soil quality parameters, levels of soilborne pathogens common in Virginia cotton and peanut production, and measurements of crop development and yield. Cool season grass rotations are compared to common crop rotations in the Virginia cotton-peanut belt.

CHAPTER 2

Perennial Grasses in Cotton and Peanut Rotations in Virginia: Soil Quality Parameters and Crop Growth

James M. Weeks, Jr.,* Joel C. Faircloth, Mark M. Alley, Pat M. Phipps, and Chris Teutsch

J. Michael Weeks, Jr. and Pat M. Phipps, Tidewater Agricultural Research and Extension Center, Virginia Polytechnic Institute and State University, Suffolk, VA 23437; Joel C. Faircloth, Dow Agrosciences, Collierville, TN 38017; Mark M. Alley, Crop and Soil Environmental Sciences, Virginia Polytechnic Institute and State University, Blacksburg, VA, 24061; and Chris Teutsch, Southern Piedmont Agricultural Research and Extension Center, Virginia Polytechnic Institute and State University, Blackstone, VA 23824. *Corresponding Author (jmweeks@vt.edu).

Abbreviations: AWC, available water content; CI, cone index; DK, damaged kernel; ELK, extra large kernel; NSA, non-stable aggregates; OK, other kernel; SMK, sound mature kernel; SOM, soil organic matter; TM, total meat; WAE, weeks after emergence; WSA, water stable aggregates

ABSTRACT

Several studies in the southeastern United States have demonstrated benefits of including multiple years of perennial grass in cotton (*Gossypium hirsutum* L.) and peanut (*Arachis hypogaea* L.) rotations. There has been little research in the Virginia cotton and peanut growing region to examine this effect. The objective of this study was to examine the effects of multiple years of tall fescue (*Shedonorus phoenix* Scop.) or orchardgrass (*Dactylis glomerata* L.) in rotation with cotton and peanut on soil quality and annual crop growth. In 2003, eight crop rotations were established with each rotation in peanut the first year. Beginning in 2004, the rotation sequences were continuous cotton, cotton-corn-cotton-peanut, cotton-peanut-cotton-peanut, tall fescue-tall fescue-cotton-peanut, orchardgrass-orchardgrass-cotton-peanut, tall fescue-tall fescue-tall fescue-peanut, orchardgrass-orchardgrass-orchardgrass-peanut, and soybean-cotton-cotton-peanut. Evaluations of soil quality and crop growth were limited to 2006 and 2007 when most of the rotations were in cotton or peanut and crop response could be directly compared between rotations. In 2006, cone index measurements, saturated water infiltration, available water holding content, and carbon and nitrogen content showed few differences between rotations. Cotton following 2 years of perennial grass in 2006 had greater plant height, total nodes, monopodial bolls, and total bolls compared to rotations with only annual crops. Cotton yield was 28% higher following 2 years of either perennial grass compared to all other rotations in cotton in 2006. In 2007, percent water stable soil aggregates was found to be greater following 3 years of either perennial grass compared to any other rotation. *In situ* moisture content measured during August and September 2007 in selected rotations was higher following 3 years of tall fescue. Based on the addition of nodes, peanut in 2007 displayed greater growth rates following 3 years of perennial grass compared to any other rotation in peanut. Peanut yield in the 3-year perennial grass rotations was higher relative to other rotations and lower where peanut had been grown in the highest frequency over the duration of the crop rotation. The greatest effect on soil quality that may have contributed to yield increases was greater available soil moisture for crop use where the annual crop directly followed a perennial grass crop.

LITERATURE REVIEW

Crop rotation is a beneficial cultural practice for achieving economic and environmentally sustainable agricultural production (Bullock, 1992). An extended interval between the planting of the same annual crop maintains soil quality, decreases input costs, and maintains breaks to prevent soil-borne disease buildup. Common crop rotations in the Southeast region of the United States often include corn (*Zea mays* L.), soybean [*Glycine max* (L.) Merr.], wheat (*Triticum aestivum* L.), cotton (*Gossypium hirsutum* L.), and peanut (*Arachis hypogaea* L.) (Franzluebbers, 2007). In the 2007 growing season producers in North Carolina and Virginia planted 668,000 ha of corn, 778,000 ha of soybean, 348,000 ha of wheat, 227,000 ha of cotton, and 45,000 ha of peanut (NASS, 2007).

Studies have reported potential for using perennial grass crops, typically bahiagrass (*Paspalum notatum* Flueggē), and perennial grass and legume mixes to improve soil quality. Soil quality parameters which may be influenced by perennial grass crops include greater organic carbon (C) sequestration, less soil disturbance, alleviation of soil compaction, increased water stable aggregates (WSA), and increased water infiltration (Wright et al., 2002). Research in the Midwest comparing continuous corn, corn and soybean, oat (*Avena sativa* L.) and legume meadows, and mixed legume meadow, has shown no significant differences for soil cone index (CI) values to a depth of 15 cm; however, bulk density was 7% higher in annual crop rotations compared to meadow rotations combined (Karlen et al., 2006). In replicated experiments at multiple sites, the latter research also found higher total organic C, total microbial C, and percent WSA in meadow rotations compared to annual crop rotations. Similar results were reported for smooth bromegrass (*Bromus inermis* Leyss) and switchgrass (*Panicum virgatum* L.) rotations when compared to corn, soybean, and alfalfa (*Medicago sativa* L.) rotations in the Midwest where organic C was higher in the 0 – 15 cm and 15 – 30 cm depth following either grass compared to annual crops (Al-Kaisi et al., 2005). Total nitrogen (N) was higher following smooth bromegrass compared to the annual crop rotation. In Uruguay, research utilizing tall fescue (*Shedonorus phoenix* Scop.), white clover (*Trifolium repens* L.), and birdsfoot trefoil (*Lotus corniculatus* L.) rotations showed 2.5 times higher particulate organic C at a depth of 20 – 60 cm compared to rotations including sorghum (*Sorghum bicolor* L.), barley (*Hordeum vulgare* L.), flax (*Linum perenne* L.), sunflower (*Helianthus annuus* L.), and wheat (Gentile et al., 2005).

However, after 38 years of rotation there were no differences in total organic C comparing the pasture rotation to continuous cropping rotations. In another extended cropping systems research project in Uruguay, researchers demonstrated a trend of decreasing soil C content over a 26-year period while annual crops were continuously produced (Prechac et al., 2002). This is in contrast to a production system where 4 years of pasture was followed by 4 years of continuous annual cropping. Soil C content in the Ap horizon in this cropping system showed a pattern of decreasing C over the annual cropping period and then a return to a C content of approximately 4% by the final year of pasture.

In the Virginia cotton and peanut growing region, irrigation is rare and producers typically rely on rainfall and stored soil moisture between rainfall events (J.C. Faircloth, personal communication, 2007). Soil organic matter (SOM) can often have dramatic effects on plant available water or available water content (AWC). In a review of published data on SOM and AWC, it was found that increasing SOM content from 1 to 3% by mass results in a doubling of AWC, particularly where soils were dominated by the sand fraction with a low water holding capacity (Hudson, 1994). Olness and Archer (2005) found a 2.5 to 5% increase in available water content (AWC) with every 1% increase of SOM by mass in soils with less than 40% clay. They conclude that the effects of SOM on AWC are dependent on the adhesion of organic matter onto clay particles creating stronger aggregates, enhanced structure, and stable pores. Increased structure results in not only greater AWC water but also increased infiltration of surface water and resistance to compaction (Hudson, 1994). Infiltration and resistance to compaction is also aided by the extensive soil coverage provided by perennial grasses which reduces the impact of rain-drops, protects soil aggregates, and prevents the sealing of soil pores (Ghadiri and Payne, 1977; Romkens et al., 2001; Kinell, 2005). Crop rotation research in Florida showed higher rates of saturated infiltration for 2 years at the surface and 1 year in the compacted zone in soils under cotton following 2 years of bahiagrass compared to cotton and peanut rotations (Katsvairo et al., 2007a). Further, perennial grasses have the potential to grow deep roots over several seasons, pushing through restrictive plow layers when soil moisture is adequate, which creates channels in compacted zones for roots of row crops to reach moisture below compacted zones (Prechac et al., 2002). According to Elkins et al. (1977), by increasing the rooting depth in sandy coastal plains soils from approximately 15 to 61 cm, days without drought following a saturating rainfall can be increased from 3 to 12 days.

Perennial grasses grown in relatively long rotations (i.e., at least 3 to 4 years of grass) have been observed to be beneficial to plant growth in several crops in the United States, Europe, South America, and Australia including peanut, cotton, sugarcane (*Saccharum* spp. L.), potatoes (*Solanum tuberosum* L.), and grain crops (Eltun el al., 2002; Prechac et al., 2002; Wright et al., 2002; Pankhurst et al., 2005; Katsvairo et al., 2006). Early research in Florida examining bahiagrass in peanut rotations reported increases in peanut yields of 684 kg ha^{-1} following 1 year of bahiagrass compared to peanut following corn (Norden et al., 1977). When peanut followed 4 years of bahiagrass in the latter study, yields were increased by 881 kg ha^{-1} compared to peanut following corn. In recent research in Florida and Alabama, peanut preceded by 2 years of bahiagrass had higher yields in both irrigated and non-irrigated systems in 2 of the 4 years of the study (Katsvairo et al., 2007b). Differences in cotton yield were only observed in 1 of the 4 years of the latter study where yields were higher following bahiagrass compared to cotton and peanut rotations. Lack of differences was thought to be due to rank cotton growth following bahiagrass. In a related study, cotton following 2 years of bahiagrass had higher total root biomass, area, length, and crown root diameter compared to cotton following peanut; however, yields were similar (Katsvairo et al., 2007a).

Little data exists on the effect of inclusion of cool season perennial grasses in cotton and peanut rotations in Virginia. The objective of this study was to examine changes in soil quality parameters as influenced by crop rotations including perennial grasses compared to crop rotations including only annual crops and if cotton and peanut growth and development expressed any differences observed in soil quality.

MATERIALS AND METHODS

The study was conducted at the Virginia Tech Tidewater Agricultural Research and Extension Center in Suffolk, VA (36° 40’ N, 76° 43’ W). The soil type was Nansemond fine loamy sand (Coarse-Loamy, Siliceous, Subactive, Thermic Aquic Hapludults). Eight crop rotations were arranged in a randomized complete block design with four replications (Table 2.1). Rotations were continuous cotton (Ct-Ct-Ct-Ct), cotton-corn-cotton-peanut (Ct-C-Ct-P), cotton-peanut-cotton-peanut (Ct-P-Ct-P), tall fescue-tall fescue-cotton-peanut (F-F-Ct-P), orchardgrass (*Dactylis glomerata* L.)-orchardgrass-cotton-peanut (O-O-Ct-P), tall fescue-tall fescue-tall fescue-peanut (F-F-F-P), orchardgrass-orchardgrass-orchardgrass-peanut (O-O-O-P), and soybean-cotton-cotton-peanut (S-Ct-Ct-P). In results and discussion, the underlined letter in a rotation abbreviation indicates the crop being grown that season (e.g. F-F-Ct-P for results in 2006 where cotton was the crop grown). Plots were 7.38 m (24 ft) wide by 12.3 m (40 ft) long and soybean, corn, cotton, and peanuts rows were planted on 0.9 m (3 ft) centers. Perennial grasses were planted using a self-propelled walk behind cultapack-type seeder with spacing of approximately 15 cm. Plots transitioning from perennial grass to a row crop were killed with glyphosate in either the proceeding fall or spring. Strip tillage into residue was used prior to planting for rotations transitioning into cotton in 2006 and cotton and peanut in 2007. A ripper – bedder implement was used to create a strip into residue and to make a rip to a depth of approximately 30 cm in one pass prior to planting (Figure 2.1). A second tractor pass was used to plant the annual crop. In 2004, cultivars DP 451 BG/RR, AG 5603 RR, Jessup with the Max-Q endophyte, and WP300 were planted for cotton, soybean, tall fescue, and orchardgrass crops, respectively. In 2005, cultivars DP 451 BG/RR, Pioneer 33M54, and VA 98R were planted for cotton, corn, and peanut crops, respectively. In 2006 the cotton cultivar planted was DP 444 BG/RR. In 2007 cultivars DP 444 BG/RR and variety Perry were planted for cotton and peanut, respectively. Cotton was planted 11 May 2006 and 27 Apr. 2007. Mepiquat Pentaborate (9.6% ai) was applied as a growth regulator in early and late July to all cotton plots at rates of approximately 0.44 L ha^{-1} (6 oz a^{-1}) to 0.59 L ha^{-1} (8 oz a^{-1}) depending on extension recommendations (Faircloth et al., 2007b). Peanut was planted 15 May 2007. Fertility, pest, and weed management for cotton and peanut were conducted according to Virginia Cooperative Extension recommendation (Faircloth et al., 2007a; Faircloth et al., 2007b).

Available Water Content and Bulk Density

Available water content and bulk density measurements were made in October 2006 using the methods described by Klute (1986) and Blake and Hartge (1986). Intact soil cores were removed from each plot using 5 cm copper pipe segments with 5 cm diameters, taped end to end to a length of 15 cm. In 2 random locations in each plot, the pipe was driven into the soil using a rubber mallet. Soil cores were then excavated and sliced into 5 cm segments. Measurements of AWC were made on the upper 5 cm segment and lower 5 cm segment of each intact core. Cheese cloth was placed on the bottom of each core to prevent soil from escaping. Cores were placed on a permeable ceramic pressure plate cloth side down. Ceramic plates were selected based on equilibration pressure desired. Cores were saturated for 24 hours by capillary flow from the bottom up and weighed. Available water content was measured using pressure pots equilibrated to 33 kPa (field capacity), 100 kPa, or 1500 kPa (permanent wilting point) in which the pressure plates with cores were placed (Klute, 1986). All cores were subjected to each pressure. After each equilibration period (4 days, 1 week, and 2 weeks, respectively) cores were weighed and re-saturated. After the final equilibration at 1500 kPa, cores were dried and weighed to determine the total water maintained at each pressure as well as bulk density of the soil in each core.

Resistance to Penetration

Soil resistance to penetration was measured following the methods described by Bradford (1986). A data-logging soil compaction meter (Field Scout SC900 Soil Compaction Meter, Spectrum Technologies, Inc. Plain Field, IL) was used to measure CI values at 6 locations selected arbitrarily per plot with the exception of avoiding ripper streaks in strip tillage or row middles where wheel traffic regularly occurred. The data logging soil compaction meter took CI readings at 2.5 cm increments to a depth of 45 cm in kPa. Samples were taken during the season following saturating rain-fall (5 - 10 cm) then allowing 24 hours for drainage to eliminate differences in soil resistance associated with moisture status. Sampling dates were 20 and 28 June 2006 and 7 June 2007.

Carbon and Nitrogen Content

Changes in soil C and N content were measured in 2006 at depths 0 to 7.5 cm and 7.5 to 15 cm. Samples were taken using aforementioned 5 cm diameter copper rings taped end to end, then air-dried for 24 to 48 hours in a 3 cm layer and sieved through a 2 mm (number 10) sieve and then a 180 µm (number 80) sieve (Fisher Scientific Company, Pittsburgh, PA). Total soil C and N levels were determined in duplicate by dry combustion using a VarioMax CNS macro elemental analyzer (Elementar Americas Inc., Mt. Laurel, NJ). In 2007 similar methodology was employed, except samples were limited to depths 0 - 2.5 cm and 0 - 5 cm to increase the chance of observing differences in C and N by decreasing dilution of the sample with soil from lower depths.

Stable Soil Aggregates

Percent WSA were measured from each treatment using methods described by Kemper and Rosenau (1986). Each plot was sampled at 4 arbitrarily selected locations to a depth of 2.5 cm. Each sample was spread out to a 3 mm thickness and then air-dried for 24 hours. Following drying, samples were passed through a 2 mm sieve onto a 1 mm sieve to break out aggregates in the 1 to 2 mm size class. Two, 4 g sub-samples were then taken from each larger sample of aggregates. Sub-samples were placed into 0.76 mm sieves and brought to field capacity using a cold air vaporizer. Time to obtain field capacity was initially found by placing dried soil in the vaporizer for varying durations and continuously weighing to indicate the desired level of moisture. This method showed an average time to reach moisture status of 45 minutes which coincided with color change. Samples were then placed in an oscillator (Five Star Cablegation and Scientific Supply, Kimberly, ID). Samples were oscillated into de-ionized water for 3 minutes at a rate of 34 oscillations min^{-1}. Water and soil in each can for each paired sample were washed into drying tins. Samples were then oscillated for 5 minutes in 100 ml of sodium hydroxide (NaOH) solution (2 g L^{-1}) and a rubber spatula was used to crush remaining stable aggregates. Samples were then oscillated for an additional 3 minutes. This process dispersed any WSA and prevented any large sand particles or particulate organic residue from being measured. Sodium hydroxide solution and dispersed soil was washed into drying tins. All H_2O and NaOH soil solutions from each sample were then dried at 105°C for 48 hr. Percent WSA was determined as:

Water Stable Aggregates (WSA) = grams soil in NaOH wash - 0.2g NaOH.

Non-stable aggregates (NSA) = grams soil collected in H_2O wash.

Percent WSA= (WSA/ (NSA+ WSA)) x 100

In Situ Soil Moisture

In August 2007 and the first 2 weeks of September 2007 soil moisture measurements were taken in 3 rotations 3 days wk^{-1}. Measurements were made using a moisture probe which utilized time domain reflectometry and permanent access tubes (PR2 Moisture Probe, Delta-T Devices Ltd, Cambridge, UK). Soil moisture measurements in m^3 H_2O m^{-3} soil at depths of 10, 20, 30, 40, 60, 100 cm were recorded. Measurements at 20, 30, 40, and 60 cm are reported. Moistures at 10 cm were not reported due to air gaps between the access tubes and soil caused by dry conditions on several sampling dates during August and September. Moisture values at 100 cm were similar and are not reported.

Forages

Tall fescue and orchardgrass were harvested 22 Dec. 2004; 4 May, 14 June, and 14 Dec. 2005; and 3 May and 28 July 2007. Grasses were harvested with a sickle bar mower with one pass down the center of each plot at a width of 1.2 m. Subsamples from each plot were collected and dried at 60°C for 5 days in a forced-air oven to determine dry matter ha^{-1}.

Cotton Growth and Development

In 2006, cotton height measurements were taken four times at 3, 5, 9, and 11 weeks after emergence (WAE) and total nodes 3 times during the season at 5, 9, and 11 WAE as a measure of growth rate. Each measurement was taken on 10 plants in each plot within the 2 rows per plot designated for harvest. Reproductive maturity was observed by counting nodes above the uppermost node on the plant with an open white flower. Five nodes above white flower is considered physiological cutout. Nodes above white flower at physiological cutout do not typically contribute to yield. Nodes above white flower were measured at 9 and 11 WAE. At the end of the season, 10 cotton plants from each plot were mapped for height, total monopodial nodes, total nodes, total monopodial bolls, total reproductive bolls, first position retention, second position retention, and retention of bolls by zone up the plant. Two rows from each plot were harvested with a spindle-type cotton harvester and samples were retained for microginning using a 7 saw microgin to determine lint percentage. Lint samples were sent to the USDA Classing Office in Florence, SC for lint quality determination using high volume instrumentation analysis.

Peanut Growth and Development

In 2007, measurements made of growth in peanut were initially weekly counts of nodes on the main stem of ten peanut plants from each plot following emergence according to the methods described by Boote (1982). Measurement of growth was then changed to rate of canopy closure. This was done by randomly measuring the width of exposed soil between 2 rows at 5 locations per harvested rows (those which total nodes had previously been counted). When pod blasting indicated acceptable pod maturity across treatments (Williams and Monroe, 1986), peanuts from the 2 rows where all growth measurements had been taken were dug, air-dried for 1 week on the soil surface, and then threshed for total yield. Sub-samples were taken from each plot for grading into categories: fancy pod, extra large kernel (ELK), sound mature kernel (SMK, includes ELK), sound splits (SS), other kernel (OK), damaged kernel (DK), and total meat (TM). Total meat is equal to SMK plus SS.

Statistical Analysis

Data analyses of soil resistance to penetration and *in situ* soil moisture content measurements were conducted utilizing repeated measures of the mixed models procedure (PROC MIXED) in Statistical Analysis Systems Suite version 9.1 (SAS Institute, Cary, NC). Cone index values for each treatment were grouped into five depth ranges. Depth ranges one through five represent depths 0 - 8 cm, 8 - 18 cm, 18 - 28 cm, 28 - 38 cm, and 38 - 45 cm, respectively. *In situ* soil moisture content measurements were averaged over the week for all 6 weeks for analysis due to increased continuity seen in the data in predicted versus residual plots for combined data compared to running each sampling event separately. Total nodes in peanut were analyzed using the regression procedure (PROC REG) in SAS. All other data sets were analyzed as a randomized complete block design using the general linear model procedure (PROC GLM) in SAS.

RESULTS AND DISCUSSION

Seasonal Rainfall

Below normal rain-fall occurred during periods of the growing season in both 2006 and 2007. During 2006 rain-fall was below normal during July and August (Figure 2.2), and rain-fall in June, September, and October was above normal. During the 2007 season there was below normal precipitation for every month until October. Between July and October rain-fall decreased each month with minor precipitation occurring on 6 days in September for a total accumulation of 0.25 cm. Total precipitation over the growing season was 39.57 cm compared to a normal precipitation of 68.83 cm for the same period. More than 25% of all precipitation during the growing season in 2007 occurred in October.

Available Water Content

Bulk density values were similar across rotations with a grand mean of 1.47 g cm^{-3}. Moisture content values of soil cores in the 0 – 5 cm depth and 10 – 15 cm depth were similar for all rotations after equilibration at 0, 33, 100, or 1500 kPa and were averaged over rotations and depths (data not shown). The mean moisture content values at 0, 33, 100, and 1500 kPa across rotations and depths were 14.3, 5.2, 4.5, and 3.4 ml H_2O 100 g^{-1} soil respectively. Thus, volumetric moisture content based on bulk density and moisture content after equilibration was 0.20, 0.07, and 0.06 m^3 H_2O m^{-3} soil for saturation (0 kPa), field capacity (33 kPa), and wilting point (1500 kPa). Available water content was moisture held between field capacity and the permanent wilting point or 0.01 m^3 H2O m^{-3} soil. Low AWC was expected due to the predominantly sandy fraction of the soil.

Soil Resistance to Penetration

The root limiting CI value for cotton is thought to be 2000 kPa; however this value varies with clay and moisture content (Vepraskas and Wagger, 1989; Taylor and Gardner, 1963). Three samples of CI values were taken during the study: two in 2006 and one in 2007. Data were analyzed for interactions by sampling event and rotation at each depth range. Significant interactions between sampling event and rotations were found at depth ranges one, two, and three (P = 0.0052, 0.0011, and 0.0199 respectively). For this reason sampling events were analyzed separately.

On 20 June 2006, there were significant differences in CI values for rotations at depth ranges one and three (P = 0.0435 and 0.0100 respectively). At depth range one all rotations were below root restrictive CI values with values ranging between 592 and 890 kPa (Table 2.2). Orchardgrass-O-<u>Ct</u>-P and Ct-P-<u>Ct</u>-P were observed to have the highest CI values at depth range one and were similar to continuous cotton and F-F-<u>Ct</u>-P. At depth range three, Ct-P-<u>Ct</u>-P and continuous cotton had the highest CI values with continuous cotton similar to all rotations except S-Ct-<u>Ct</u>-P. At depth range three, CI values for all rotations were above root limiting with values ranging between 2,288 and 3,323 kPa. On 28 June 2006, CI values at depth range four (P =

0.0303) were highest in Ct-P-Ct-P and Ct-C-Ct-P. Cotton-C-Ct-P was similar to all rotations except O-O-Ct-P and again all rotations showed values above root limiting with values ranging between 2,123 and 2,971 kPa. Higher values were observed on some sampling dates in 2-year perennial grass rotations at shallower depth ranges compared to other rotations. Perennial grass based rotations had experienced less tillage throughout the rotation but some level of equipment traffic for hay harvest was maintained. This may have created a compacted soil with higher CI values in the upper horizons compared to rotations with tillage every year; however, CI values typically were not higher than root restrictive values.

Cone index values in 2007 were significantly different for rotations at depth ranges one, two, and three (P = 0.0190, 0.0007, and 0.0032 respectively). At depth range one the highest CI values observed were in Ct-Ct-Ct-Ct, F-F-F-P, and O-O-O-P, which were not significantly different from each other. Higher CI values at depth range one in peanut following 3 years of perennial grass is consistent with results for the first sampling event in 2006 where higher CI values were seen in cotton following 2 years of perennial grass. Values were comparable to those observed in 2006 overall ranging between 324 and 714 kPa. At depth range two the 3-year perennial grass rotations and continuous cotton had higher CI values compared to all other rotations. However, all rotations continued to have CI values below root restrictive with values ranging between 1,006 and 1,831 kPa. At depth range three the 3-year perennial grass and continuous cotton rotations continued to have the highest CI values. The F-F-F-P rotation was similar to Ct-P-Ct-P. Continuous cotton and 3-year perennial grass rotations approached root restrictive CI values in this depth range with values ranging between 2,199 and 2,337 kPa. All other rotations had CI values between 1,451 and 1,751 kPa. Cone index values at depth range three indicate that 3-year perennial grass rotations had little effect on the compacted soil zone. Two- and 3-year perennial grass rotations may not have been a sufficient duration to affect compacted zones. Benjamin et al. (2007) found lower compaction in grass-legume mixes compared to a continuous annual crop system, however these results were seen after 15 years of the study. Measurement of CI with a cone penetrometer does not necessarily mean that roots were limited to the upper profile. Using minirhizotron cameras, previous research reported that despite a lack of change in CI values following cover crops, subsequent soybean crop roots were observed exploiting root channels left by the previous cover crops (Williams and Weil, 2004).

Soil Carbon and Nitrogen Analysis and Aggregate Stability

There were no differences in soil C or N analysis in 2006 at 0 - 7.5 cm or 7.5 - 15 cm depths in any rotations (data not shown). Soil C to N ratio at 0 - 7.5 cm ranged from 8.4 to 10.0. Soil N at 0 - 7.5 cm ranged from 0.8 to 0.9 g kg^{-1}. Soil C at 0 - 7.62 cm ranged from 7.0 to 9.6 g kg^{-1}. At 7.5 - 15 cm soil C to N ratio ranged from 7.7 to 9.9. Soil N ranged from 0.8 to 0.9 g kg^{-1}. Soil C ranged from 5.8 to 8.7 g kg^{-1}.

In 2007 at the 0 - 2.5 cm depth there were differences in C to N ratio and soil N ($P = 0.0171$ and 0.0097, respectively). At the depth 0 - 2.5 cm soil from continuous cotton rotations had a C to N ratio of 14.9 which was the highest and similar to Ct-C-Ct-P, Ct-P-Ct-P and F-F-Ct-P (Table 2.3). Soils from O-O-O-P had a C to N ratio of 13.0 which was the lowest and similar to F-F-F-P, O-O-Ct-P and S-Ct-Ct-P. Soil N for O-O-O-P was 1.3 g kg^{-1} which was the highest and similar to F-F-Ct-P, O-O-Ct-P and F-F-F-P. The lowest soil N content was observed in Ct-P-Ct-P which was similar to S-Ct-Ct-P, Ct-C-Ct-P and Ct-Ct-Ct-Ct. Soil C ranged from 12.3 to 17.4 g kg^{-1}. Soil C to N ratio at the 0 - 5 cm depth was the highest for Ct-C-Ct-P at 14.8 which were similar to Ct-Ct-Ct-Ct, F-F-Ct-P, and Ct-P-Ct-P ($P = 0.0368$). The lowest soil C to N ratio was observed in F-F-F-P at 13.0 which were similar to O-O-O-P, S-Ct-Ct-P, O-O-Ct-P, and Ct-P-Ct-P. Soil N ranged from 0.8 to 1.1 g kg^{-1} and soil C ranged from 10.9 to 14.3 g kg^{-1}.

Water stable aggregates (WSA) in the 1 - 2 mm size range showed variable stabilities across rotations. Fescue-F-F-P had the highest percent WSA at 93.4% and was similar to O-O-O-P ($P \leq 0.0001$) (Table 2.3). The lowest percent WSA were in Ct-P-Ct-P at 66.5% followed by Ct-C-Ct-P. Rotations Ct-Ct-Ct-Ct, F-F-Ct-P, O-O-Ct-P, and S-Ct-Ct-P were similar with percent WSA ranging from 78.1% to 83.2%.

Increases in soil carbon and SOM have been observed in cropping systems including perennial grass and pasture. In Uruguay, Gentile et al. (2005) observed subtle changes in total organic carbon in cropping systems with pasture rotations compared to annual cropping systems; however, this was after 38 years of the system. The 2 and 3 years of perennial grasses in the rotations this research studied may not have had sufficient time to accumulate organic carbon. Increased aggregate stability is generally associated with increases in soil C, however higher aggregate stability in this study was not associated with measurable increases in C. Gale et al. (2005) found that new stable soil aggregates were formed with the decomposition of roots in no-till cropping systems. Extensive fibrous rooting systems of the perennial grasses and the decomposition of these roots may have been the cause of the increased aggregate stability observed in this research.

In Situ Soil Moisture Content

In August and September 2007, interactions between rotation and week and also week and depth were observed for *in situ* moisture content ($P \leq 0.0001$ for both). Therefore, an analysis was conducted by depth each week. The highest total weekly precipitation occurred during weeks one and two of moisture measurement at 0.36, 1.70, 0.69 cm wk^{-1} (Table 2.4). In weeks four through six of moisture measurement total precipitation was 0.16 cm with precipitation of 0.08 cm occurring in both weeks four and six. At the 20 cm depth soil moisture measurements were higher in F-F-F-P for all weeks but never significantly different from the other rotations measured (Table 2.4). Overall, soil moisture measurements at 20 cm were the highest in all rotations in week three where moisture ranged from 0.18 to 0.19 m^3 H_2O m^{-3} soil corresponding with the second highest weekly precipitation measured over the period of soil moisture measurement. The lowest soil moisture measurements at 20 cm were observed during week six where soil moistures ranged from 0.05 to 0.07 m^3 H_2O m^{-3} soil. During week six there was precipitation of 0.08 cm however the 3 weeks prior to this had total precipitation of 0.77 cm occurring over 2 events in weeks three and four and no precipitation occurred in week five.

Differences were observed in soil moisture measurements for rotations at 30 cm in all weeks except week six ($P = 0.0192$, 0.0271, 0.0186, 0.0018, and 0.0036 for weeks one through five respectively). Soil moisture was highest for F-F-F-P compared to either rotation where data were significant. The highest soil moisture measurement at 30 cm was observed in week three for each rotation, ranging from 0.19 to 0.24 m^3 H_2O m^{-3} soil. The lowest measurements were in weeks one and two at 30 cm. During weeks one and two soil moisture ranged from 0.08 to 0.12 m^3 H_2O m^{-3} soil. At 30 cm, soil moisture acted contrary to precipitation with the lowest moistures occurring the weeks with the highest precipitation. Precipitation which occurred over the first 2 weeks of measurement may have only provided enough moisture to provide for transpiration and evaporative demand. The third week of measurement had the second highest total precipitation over the period of moisture measurement. This precipitation may have increased soil moisture over the transpiration and evaporative demand allowing for some moisture recharge at the 30 cm depth.

With the exception of weeks four and six, differences in soil moisture measurements were observed each week at 40 cm ($P = 0.0470$, 0.0100, 0.0042, and 0.0241 for weeks one, two, three, and five, respectively). Overall, soil moisture values were higher in F-F-F-P in weeks three and four. In weeks one, two, and five, soil moisture measurements in F-F-F-P and F-F-Ct-P were similar and higher than Ct-P-Ct-P. The highest soil moisture measurements were observed in week three where soil moisture ranged from 0.18 to 0.25 m^3 H_2O m^{-3} soil. The lowest soil moisture measurements were observed in week six where soil moisture ranged from 0.09 to 0.15 m^3 H_2O m^{-3} soil again corresponding with several weeks of little precipitation.

Differences were observed in soil moisture measurements for all weeks at the 60 cm depth ($P = 0.0325$, 0.0290, 0.0144, 0.0027, 0.0050, and 0.0453 for weeks one through six, respectively). The highest soil moisture values were observed in weeks one and four. Soil moisture during weeks one and four ranged from 0.16 to 0.23 m^3 H_2O m^{-3} soil. The lowest soil moisture conditions were observed at 60 cm during week six for all rotations where soil moistures ranged from 0.14 to 0.20 m^3 H_2O m^{-3}. Soil moisture at this depth was highest in F-F-F-P for all weeks of moisture measurement. The high and low moisture contents at the 60 cm depth showed relatively little difference compared to the shallower depths measured. This may indicate that at the 60 cm depth there were no roots present and therefore no moisture lost to transpiration. Changes in moisture at the 60 cm depth may have been associated with what little moisture moved through the shallow depths before being lost to transpiration or evaporation and slight evaporative loss following the prolonged dry period over the last 3 weeks of measurement.

In situ moisture content in the rotations showed differences by rotation, depth, and week in August and September 2007. In most cases, F-F-F-P had higher moisture content throughout the month of August and the first half of September (Figure 2.3). Soil moisture was only measured in Ct-P-Ct-P, F-F-Ct-P, and F-F-F-P. Comparing values for the permanent wilting point by pressure plate analysis and moisture content during August and September, only Ct-P-Ct-P dropped below the permanent wilting point. This occurred only once and the value was similar to values for both perennial grass rotations measured. However, low soil moistures approaching the permanent wilting point become increasingly difficult for crops to extract, and may have detrimental effects on crop growth. Peanut growth reflected the differences observed for soil moisture, where 3-year tall fescue rotations had closed rows, Ct-P-Ct-P had the least row closure, and F-F-Ct-P was intermediate compared to the latter 2 rotations for row closure.

Differences in moisture content are likely associated with the amount of ground cover which decreases evaporative loss (Williams and Weil, 2004). Based on visual observation, more residue was on the surface in 3-year tall fescue rotations compared to F-F-Ct-P, and Ct-P-Ct-P which had little to no residue present. Also based on visual observation, residue decreased significantly in F-F-Ct-P by 2007 which may explain why this rotation was similar to the Ct-P-Ct-P rotation for *in situ* soil moisture content.

Tall Fescue and Orchardgrass

In 2004, either rotation with tall fescue had statistically higher dry matter yields compared to orchardgrass ($P = 0.0173$). The only other statisitical differences were observed following the third hay harvest in 2005 where F-F-F-P had higher yields than F-F-Ct-P, which was similar to O-O-O-P ($P < 0.0001$). Orchardgrass-O-Ct-P had the lowest yields for this harvest. Tall fescue numerically had higher yields at each harvest compared to orchardgrass. One cutting of tall fescue and orchardgrass in 2004 yielded 2.88 and 1.66 Mg ha^{-1} of dry matter, respectively. In 2005, three cuttings of tall fescue and orchardgrass yielded 13.57 and 10.48 Mg ha^{-1} of dry matter, respectively. In 2006, two cuttings of tall fescue and orchardgrass yielded 11.89 and 10.48 Mg ha^{-1} of dry matter, respectively. Over three years of the rotation tall fescue and orchardgrass yielded 28.34 and 22.62 Mg ha^{-1} of dry matter, respectively. The average value at auction of premium grass hay over the 3 years where grass was in the rotation was approximately \$100 metric ton^{-1}, however prices have since increased by nearly \$30 metric ton^{-1} (VDACS, 2008). The gross income from hay sold from tall fescue and orchardgrass crops over the three years in perennial grass rotations would be approximately \$3,500 and \$2,800 ha^{-1}, respectively, assuming the hay was of premium quality and dried without rain-fall. In the current market the value of hay would be higher (C.D. Teutsch, personal communication, 2008).

Cotton Growth, Development, and Yield

Differences in cotton plant height were observed at all sample dates ($P = 0.0161$, ≤ 0.0001, $= 0.0176$, and $= 0.0156$ for 3, 5, 9, and 11 WAE, respectively) in 2006. The lowest plant height at 3 WAE was in Ct-P-Ct-P at 13.1 cm which was similar to Ct-C-Ct-P and S-Ct-Ct-P (Table 2.5). At 5 WAE plant height in Ct-P-Ct-P remained the lowest at 49.2 cm which was similar to all rotations aside from those with 2 years of perennial grass. Cotton-C-Ct-P was shortest at 9 WAE at 51.5 cm, which was similar to S-Ct-Ct-P, Ct-P-Ct-P and Ct-Ct-Ct-P. At 11 WAE, Cotton-C-Ct-P had the lowest plant height at 54.9 cm, which was similar to all rotations except F-F-Ct-P and O-O-Ct-P.

Plant height was numerically the highest in F-F-Ct-P followed by O-O-Ct-P at 3, 5, 9, and 11 WAE. Plant height in F-F-Ct-P was significantly higher than all other rotations examined at 3 WAE and similar to O-O-Ct-P at 5, 9, and 11 WAE. Plant height in O-O-Ct-P and continuous cotton were similar at 3 WAE.

Similar to observations in plant height, in 2007 the total number of nodes plant^{-1} in cotton was numerically the highest in F-F-Ct-P followed by O-O-Ct-P on all sample dates (Table 2.5) (P = 0.0274, 0.0486, and 0.0192 for 5, 9, and 11 WAE, respectively). At 5 WAE cotton in F-F-Ct-P had the highest mean number of nodes with 8.1 nodes plant^{-1}. Cotton in S-Ct-Ct-P had the fewest nodes with 7.1 nodes plant^{-1} which was similar to all rotations except F-F-Ct-P. At 9 WAE, cotton in F-F-Ct-P had the highest number of nodes at 14.3 nodes plant^{-1} which was similar to O-O-Ct-P and Ct-Ct-Ct-Ct. Cotton in Ct-P-Ct-P had the fewest nodes with 13.1 nodes plant^{-1} which was similar to all rotations except those with 2 years of perennial grass. At 11 WAE cotton in F-F-Ct-P continued to have the highest total nodes with 15.3 nodes plant^{-1} which was similar to O-O-Ct-P and Ct-P-Ct-P. Cotton-C-Ct-P had cotton with the fewest nodes with 13.2 nodes plant^{-1} and was similar to S-Ct-Ct-P.

Prior to harvest cotton following either perennial grass had higher plant height (P ≤ 0.0001), monopodial bolls (bolls not on main branch) plant^{-1} (P = 0.0033) and total bolls plant^{-1} (P ≤ 0.0001). Height was highest in F-F-Ct-P at 82.4 cm which was similar to O-O-Ct-P (Table 2.6). Cotton following tall fescue had the highest number of monopodial bolls plant^{-1} at 3.5 which was again similar to O-O-Ct-P. Monopodial bolls were at least 1.8 bolls plant^{-1} more in cotton following a perennial grass compared to any other rotation which is comparable to results from Pettigrew (2004), where irrigated cotton had 1.5 more monopodial nodes plant^{-1} compared to dryland cotton. In the current study, total bolls plant^{-1} were highest in F-F-Ct-P at 16.8 which was similar to O-O-Ct-P. Total nodes plant^{-1} were highest in F-F-Ct-P which was similar to O-O-Ct-P, Ct-Ct-Ct-Ct and Ct-P-Ct-P (P ≤ 0.0001).

Lint yield in F-F-Ct-P was highest at 2,044 kg ha^{-1} which was similar to O-O-Ct-P at 1,940 kg ha^{-1} (P = 0.0136) (Table 2.6). Lint yield in all other rotations was similar and ranged from 1,510 to 1,298 kg ha^{-1} for Ct-P-Ct-P and Ct-C-Ct-P, respectively. Increases in overall growth of cotton plants provided for more fruiting positions which contributed to higher overall yield. In 2006 no differences in soil quality among rotations were observed which would contribute to the differences seen in cotton growth and yield. Katsvairo et al. (2007a) found some differences in soil quality in bahiagrass-cotton rotations compared to continuous cotton rotations, namely increases in earthworm populations and water infiltration, as well as increases in cotton root growth. However, lint yield differences were not seen in the latter study which was attributed to rank growth.

Peanut Growth, Development, Yield, and Grade

Accumulation of nodes plant^{-1} in peanut each week for 6 WAE showed a linear relationship but numbers were initially less in perrenial grass rotations until 3 WAE when values in perennial grass rotations surpassed those in annual crop rotations for the remainder of sample dates in 2007. The R^2 values for rotations ranged from 0.976 to 0.988. Both intercept ($P = 0.0029$) and slope ($P \leq 0.0001$) of nodes wk^{-1} were significant. The highest intercept value was 3.68 for Ct-P-Ct-<u>P</u> which was similar to all rotations except those following 3 years of a perennial grass (Table 2.7). The lowest intercept value was 3.08 for F-F-F-<u>P</u> which was similar to O-O-O-<u>P</u>. The highest growth rates were observed in rotations with 3 years of a perennial grass. Peanuts in F-F-F-<u>P</u> had a growth rate of 1.85 nodes wk^{-1} and was similar to O-O-O-<u>P</u> (Table 2.7). The lowest peanut growth rate was observed in Ct-P-Ct-<u>P</u> at 1.39 nodes wk^{-1} which was similar to Ct-C-Ct-<u>P</u>. After the second WAE, peanuts in F-F-F-<u>P</u> and O-O-O-<u>P</u> had increasingly more nodes per plant each week numerically compared to other rotations (Figure 2.4).

Differences were observed in row closure in peanut at weekly sampling dates, measured as the distance between peanut growth on adjacent rows where soil or residue was exposed ($P = 0.0075$, 0.0119, 0.0014, 0.0104, 0.0162, and 0.0035 at 7 – 12 WAE respectively). Data presented is the mean exposed soil between adjacent rows for 7 - 12 WAE. At 7 WAE, exposed soil between adjacent rows was the highest in Ct-P-Ct-<u>P</u> (28 cm) and was similar to Ct-C-Ct-<u>P</u> (Table 2.8). Fescue-F-F-<u>P</u> had the least exposed soil between adjacent rows (11 cm) and was similar to O-O-O-<u>P</u> and O-O-Ct-<u>P</u>. At 8 WAE, exposed soil between adjacent rows in Ct-P-Ct-<u>P</u> again was the highest (19 cm) which was similar to Ct-C-Ct-<u>P</u> and S-Ct-Ct-<u>P</u>. Exposed soil between adjacent rows in F-F-F-<u>P</u> was numerically the lowest (2 cm) which was similar to O-O-

O-P. At 9 WAE rotation Ct-P-Ct-P had 14 cm of exposed soil between adjacent rows which was similar to Ct-C-Ct-P. Fescue-F-F-P had the least exposed soil between adjacent rows (1 cm) which was similar to O-O-Ct-P, O-O-O-P, and S-Ct-Ct-P. At 10 WAE rotation Ct-P-Ct-P had the most exposed soil between adjacent rows (12 cm) which was similar to Ct-C-Ct-P. Fescue-F-F-P again had 1 cm of exposed soil between adjacent rows at 10 WAE which was similar to all other rotations except Ct-P-Ct-P. At 11 WAE only Ct-P-Ct-P was signifcantly different from other rotations with 7 cm of exposed soil between adjacent rows. Fescue-F-F-P had 0 cm of exposed soil between adjacent rows; however, all other rotations aside from Ct-P-Ct-P were approaching row closure. By 12 WAE, the final measurement of row closure, Ct-P-Ct-P remained the only significant rotation with 5 cm of exposed soil between adjacent rows.

Peanut yield was highest in the O-O-O-P rotation at 5,749 kg ha^{-1} and was similar to F-F-F-P, S-Ct-Ct-P and O-O-Ct-P, while the lowest yield was in Ct-P-Ct-P at 3,857 kg ha^{-1} ($P \leq 0.0001$) (Table 2.9). The next lowest yield was in Ct-C-Ct-P which was similar to rotations other than those with 3 years of perennial grass or Ct-P-Ct-P.

Grading data were based on evaluation of a 500 g subsample of whole pods according to Federal-State Inspection Service Methods (USDA, 1948; USDA, 1959). The only significance in grade data was for ELK ($P = 0.0017$). The highest percent ELK was in S-Ct-Ct-P at 51.2% which was similar to all rotations except Ct-P-Ct-P at 43.8% which is significantly different from all other rotations (Table 2.9). The aforementioned low soil moisture observed in Ct-P-Ct-P in August and September may have decreased pod fill resulting in smaller kernels overall.

The growth response of peanut following a 3-year sequence of perennial grasses in 2007 had a similar response to that observed in cotton following 2 years of perennial grasses in 2006. Based on *in situ* moisture measurements previously discussed, rotations with 3 years of perennial grasses tended to have more access to moisture at depths between 20 and 60 cm (Figure 2.1). However, based on penetrometer results, it is not known if roots would be unrestricted past 30 – 40 cm in any rotation. Higher moisture in the 20 and 30 cm depths in rotation F-F-F-P, and potentially also in the 3-year orchardgrass rotations, could have been the main contributing factor to higher growth and yield in peanut. There was no observed incidence of disease or damage by parasitic nematodes of peanut in 2007 which may have been because of low precipiation throughout most of the growing season relative to average rainfall for the region. Had disease been a major issue in 2007, it is unclear how peanut in perennial grass rotations would have responded.

CONCLUSIONS

Inclusion of perennial grass crops in rotation with cotton and peanut had a beneficial effect on cotton and peanut growth and yield compared to annual crop rotations. The largest changes in annual crop growth following a perennial grass crop were seen when either cotton or peanut followed the grass crop directly in rotation. Effects on growth and yield of peanut in 2007 were not apparent in 2-year grass rotations where cotton was grown in 2006 in between perennial grass and peanut in the cropping sequence. These rotations did not allow for observations of peanut growth with an annual crop rotated between the perennial grass crop. Effects of perennial grass crops on the soil may have been associated with more efficient capture of moisture when there was precipitation and moisture conservation between precipitation events. Moisture capture was enhanced by higher WSA following a grass crop preventing surface sealing when rainfall occurred. Furthermore, more ground cover may have prevented the destruction of non-WSA by protection from impact by raindrops. Water loss from runoff was also visually observed to be reduced following perennial grass during heavy precipitation events, however this was never measured. Other than WSA, the effects of 2 or 3 years of perennial grass crops on soil phyiscal properties were limited. One of the more consistent soil observations following perennial grass crops was an increase in CI values in the shallower depth ranges measured, however the values did not exceed root restrictive resistances. Based on the positive impact of perennial grasses on cotton and peanut yield, an assessment of the economic benefits of integrating these grasses into traditional row crop rotations is warranted. Ways to increase profitablity may include grazing grass crops rather than cutting hay or maintaining a high enough quality forage that could be square baled and sold as high-value horse hay. Further there is growing potential that grass crops, particularly high biomass C_4 crops, will be used as feedstock for biofuels once the cellulothic ethanol fermentation process is made economically feasible. Future research should focus on the potential of high biomass feedstock grass crops such as switchgrass (*Panicum virgatum* L.) for improving soil quality and the growth and yield of cotton and peanut following in rotation.

Table 2.1. Sequence of crops used in eight crop rotations (2003-2007). All rotations begin in peanut in 2003. Abbreviations: Ct, cotton; C, corn; P, peanut; F, tall fescue; O, orchardgrass; S, soybean.

Rotation	2003	2004	2005	2006	2007
Ct-Ct-Ct-Ct	Peanut	Cotton	Cotton	Cotton	Cotton
Ct-C-Ct-P	Peanut	Cotton	Corn	Cotton	Peanut
Ct-P-Ct-P	Peanut	Cotton	Peanut	Cotton	Peanut
F-F-Ct-P	Peanut	Tall fescue	Tall fescue	Cotton	Peanut
O-O-Ct-P	Peanut	Orchardgrass	Orchardgrass	Cotton	Peanut
F-F-F-P	Peanut	Tall fescue	Tall fescue	Tall fescue	Peanut
O-O-O-P	Peanut	Orchardgrass	Orchardgrass	Orchardgrass	Peanut
S-Ct-Ct-P	Peanut	Soybean	Cotton	Cotton	Peanut

Table 2.2. Cone penetration index for selected rotations in 2006 and 2007.

Sample Date	Rotation	Depth Group†				
20 June 2006		1	2	3	4	5
		kPa				
	Ct-Ct-Ct-Ct	766	2252	2901	3114	2204
	Ct-C-Ct-P	576	2204	2764	3239	2287
	Ct-P-Ct-P	806	2485	3323	3862	2266
	F-F-Ct-P	750	2287	2693	3252	2485
	O-O-Ct-P	890	2266	2485	2606	1736
	S-Ct-Ct-P	592	1736	2288	3134	2252
	LSD (0.05)*	212	NS	505	NS	NS
28 June 2006						
	Ct-Ct-Ct-Ct	429	1520	2277	2868	2071
	Ct-C-Ct-P	494	2070	2723	3225	2677
	Ct-P-Ct-P	548	2063	2971	3532	2379
	F-F-Ct-P	606	1874	2368	2745	2488
	O-O-Ct-P	585	1907	2343	2581	1817
	S-Ct-Ct-P	489	1496	2123	2954	2149
	LSD (0.05)	NS	NS	518	NS	NS
7 June 2007						
	Ct-Ct-Ct-Ct	714	1792	2305	2903	2293
	Ct-C-Ct-P	445	1093	1630	2895	3008
	Ct-P-Ct-P	362	1057	1751	3081	3022
	F-F-Ct-P	447	1158	1716	2674	3054
	O-O-Ct-P	324	1006	1683	2613	2285
	F-F-F-P	604	1734	2199	2704	2085
	O-O-O-P	583	1831	2337	3000	2613
	S-Ct-Ct-P	416	1096	1451	2660	2532
	LSD (0.05)	221	448	473	NS	NS

NS = not significant; * denotes significance at $P \leq 0.05$ according to Fisher's LSD.

† Means averaged by depth group. 1 = 0 – 8 cm; 2 = 8 – 18 cm; 3 = 18 – 28 cm; 4 = 28 – 38 cm; 5 = 38 – 45 cm. Means averaged by depth group due to lack of interaction of depths within groups.

Table 2.3. Soil water stable aggregates, carbon and nitrogen contents, and carbon to nitrogen ratio of soil samples from crop rotations in 2007. Abbreviations: WS, water stable soil aggregates; C:N, carbon to nitrogen ratio.

Depth†	Rotation	WS‡	Carbon	Nitrogen	C:N
cm		%	——g kg^{-1} soil——		
0 - 2.5	Ct-Ct-Ct-Ct	78.1	14.5	1.0	14.9
	Ct-C-Ct-P	72.6	13.9	0.9	14.9
	Ct-P-Ct-P	66.5	11.9	0.8	14.2
	F-F-Ct-P	81.1	17.4	1.3	13.9
	O-O-Ct-P	83.2	15.4	1.1	13.4
	F-F-F-P	93.4	14.9	1.1	13.0
	O-O-O-P	91.7	16.9	1.3	13.0
	S-Ct-Ct-P	82.5	12.3	0.9	13.4
	LSD (0.05)	5.0	NS	0.2	1.2
0 - 5	Ct-Ct-Ct-Ct	NA	14.0	0.9	14.6
	Ct-C-Ct-P	NA	13.7	0.9	14.8
	Ct-P-Ct-P	NA	10.9	0.8	14.2
	F-F-Ct-P	NA	14.3	1.0	14.4
	O-O-Ct-P	NA	14.1	1.1	13.5
	F-F-F-P	NA	12.8	1.0	13.0
	O-O-O-P	NA	13.4	1.0	13.1
	S-Ct-Ct-P	NA	11.7	0.9	13.5
	LSD (0.05)	NA	NS	NS	1.2

NS = not significant; * denotes significance at $P \leq 0.05$ according to Fisher's LSD.

†Sample depth range.

‡Aggregates in the 1 to 2 mm size range.

Table 2.4. Soil moisture contents by depth over a 6-week period for selected rotations in 2007.

Soil moisture							
		Week†					
Depth‡	Rotation	1	2	3	4	5	6
cm		m^3 H_20 m^{-3} soil					
20	Ct-P-Ct-P	0.089	0.083	0.183	0.126	0.068	0.053
	F-F-Ct-P	0.072	0.071	0.183	0.139	0.072	0.048
	F-F-F-P	0.102	0.093	0.190	0.164	0.094	0.067
	LSD (0.05) *	NS	NS	NS	NS	NS	NS
30	Ct-P-Ct-P	0.088	0.089	0.189	0.141	0.087	0.185
	F-F-Ct-P	0.084	0.085	0.207	0.174	0.095	0.183
	F-F-F-P	0.122	0.118	0.245	0.219	0.125	0.186
	LSD (0.05)	0.025	0.023	0.034	0.029	0.019	NS
40	Ct-P-Ct-P	0.104	0.102	0.179	0.154	0.106	0.090
	F-F-Ct-P	0.125	0.122	0.214	0.193	0.132	0.108
	F-F-F-P	0.182	0.176	0.254	0.249	0.181	0.147
	LSD (0.05)	0.061	0.064	0.039	NS	0.058	NS
60	Ct-P-Ct-P	0.166	0.161	0.159	0.161	0.155	0.144
	F-F-Ct-P	0.162	0.155	0.159	0.176	0.158	0.144
	F-F-F-P	0.225	0.218	0.216	0.227	0.217	0.196
	LSD (0.05)	0.048	0.046	0.037	0.028	0.036	0.045
		cm w^{-1}					
	Precipitation	0.36	1.70	0.69	0.08	0.00	0.08

NS = not significant; * denotes significance at $P \leq 0.05$ according to Fisher's LSD.

† Moisture sampled 3 days of each week in Aug. and first half of Sept. 2007. Data are the mean of 3 samples per week.

‡ Moisture sampled in 1 location per plot at depths of 20, 30, 40, and 60 cm.

Table 2.5. Cotton growth and development in 2006 indicated by plant height on four sampling dates, nodes on three sampling dates, and nodes above white flower on two sampling dates. Abbreviations: WAE, weeks after emergence; NAWF, nodes above white flower.

Rotation	WAE	Height	Nodes	NAWF
		cm	no. plant^{-1}	no. plant^{-1}
Ct-Ct-Ct-Ct	3	15.0	…	…
Ct-C-Ct-P		14.0	…	…
Ct-P-Ct-P		13.1	…	…
F-F-Ct-P		15.9	…	…
O-O-Ct-P		15.5	…	…
S-Ct-Ct-P		14.0	…	…
LSD (0.05)*		1.4	…	…
Ct-Ct-Ct-Ct	5	50.1	7.1	…
Ct-C-Ct-P		49.7	7.2	…
Ct-P-Ct-P		49.2	7.3	…
F-F-Ct-P		62.7	8.1	…
O-O-Ct-P		58.6	7.4	…
S-Ct-Ct-P		50.7	7.1	…
LSD (0.05)		4.2	0.6	…
Ct-Ct-Ct-Ct	9	56.0	13.7	6.5
Ct-C-Ct-P		51.5	13.2	6.1
Ct-P-Ct-P		55.7	13.1	6.4
F-F-Ct-P		67.8	14.3	6.4
O-O-Ct-P		63.5	14.0	6.5
S-Ct-Ct-P		52.5	13.1	6.1
LSD (0.05)		8.6	0.8	NS
Ct-Ct-Ct-Ct	11	64.2	14.2	3.8
Ct-C-Ct-P		54.9	13.2	3.4
Ct-P-Ct-P		66.1	14.3	4.0
F-F-Ct-P		77.0	15.3	4.8
O-O-Ct-P		75.1	14.7	4.1
S-Ct-Ct-P		59.4	13.8	3.5
LSD (0.05)		11.3	1.0	NS

NS = not significant; * denotes significance at $P \leq 0.05$ according to Fisher's LSD.

Table 2.6. End of season height, nodes, monopodial bolls, total bolls, and yield for cotton in 2006 for all rotations except those in third year of perennial grass. Abbreviations: Mono, monopodial.

Rotation	Height	Total Nodes†	Mono Bolls‡	Total Bolls§	Yield
	cm	no. plant^{-1}	no. plant^{-1}	no. plants^{-1}	kg ha^{-1}
Ct-Ct-Ct-Ct	64.8	17.1	1.3	12.6	1331
Ct-C-Ct-P	56.1	15.7	1.5	12.3	1298
Ct-P-Ct-P	69.9	16.7	1.5	13.2	1510
F-F-Ct-P	82.4	17.8	3.5	16.8	2044
O-O-Ct-P	80.8	17.7	3.3	15.8	1940
S-Ct-Ct-P	61.1	16.0	1.5	12.7	1356
LSD (0.05)*	8.9	1.2	1.4	2.2	394

NS = not significant; * denotes significance at $P \leq 0.05$ according to Fisher's LSD.

† Total nodes, no. plant^{-1}, at time of final mapping.

‡ Total vegetative bolls, no. plant^{-1}, at time of final mapping.

§ Total bolls, no. plant^{-1}, at time of final mapping.

Table 2.7. Peanut growth rate based on accumulation of nodes over the initial 6 weeks after emergence. Abbreviations: WAE, weeks after emergence.

	Peanut growth rate 0 - 6 WAE		
Rotation	Slope†	Intercept	R^2
	nodes plant^{-1} w^{-1}		
Ct-C-Ct-<u>P</u>	1.49	3.65	0.979
Ct-P-Ct-<u>P</u>	1.39	3.68	0.976
F-F-Ct-<u>P</u>	1.54	3.54	0.982
O-O-Ct-<u>P</u>	1.52	3.62	0.983
F-F-F-<u>P</u>	1.85	3.08	0.980
O-O-O-<u>P</u>	1.78	3.21	0.988
S-Ct-Ct-<u>P</u>	1.51	3.53	0.984
LSD (0.05)*	0.12	0.36	

NS = not significant; * denotes significance at $P \leq 0.05$ according to Fisher's LSD.

† Slope of regression of main stem nodes plant^{-1} counted weekly for 0 – 6 weeks after emergence. Nodes counted on 10 plants row^{-1} in 2 rows plot^{-1}.

Table 2.8. Exposed soil between peanut rows in each rotation except continuous cotton 7 to 12 weeks after emergence in 2007. Abbreviations: WAE, weeks after emergence.

	Exposed soil between adjacent rows†					
Rotation	WAE					
	7	8	9	10	11	12
	——cm——					
Ct-C-Ct-P	22	15	9	6	3	2
Ct-P-Ct-P	28	19	14	12	7	5
F-F-Ct-P	21	10	9	5	1	1
O-O-Ct-P	18	8	2	2	1	0
F-F-F-P	11	2	1	1	0	0
O-O-O-P	15	4	2	2	1	0
S-Ct-Ct-P	19	12	4	3	1	0
LSD (0.05)*	7.0	8.0	5.2	5.4	3.4	1.9

NS = not significant; * denotes significance at $P \leq 0.05$ according to Fisher's LSD.

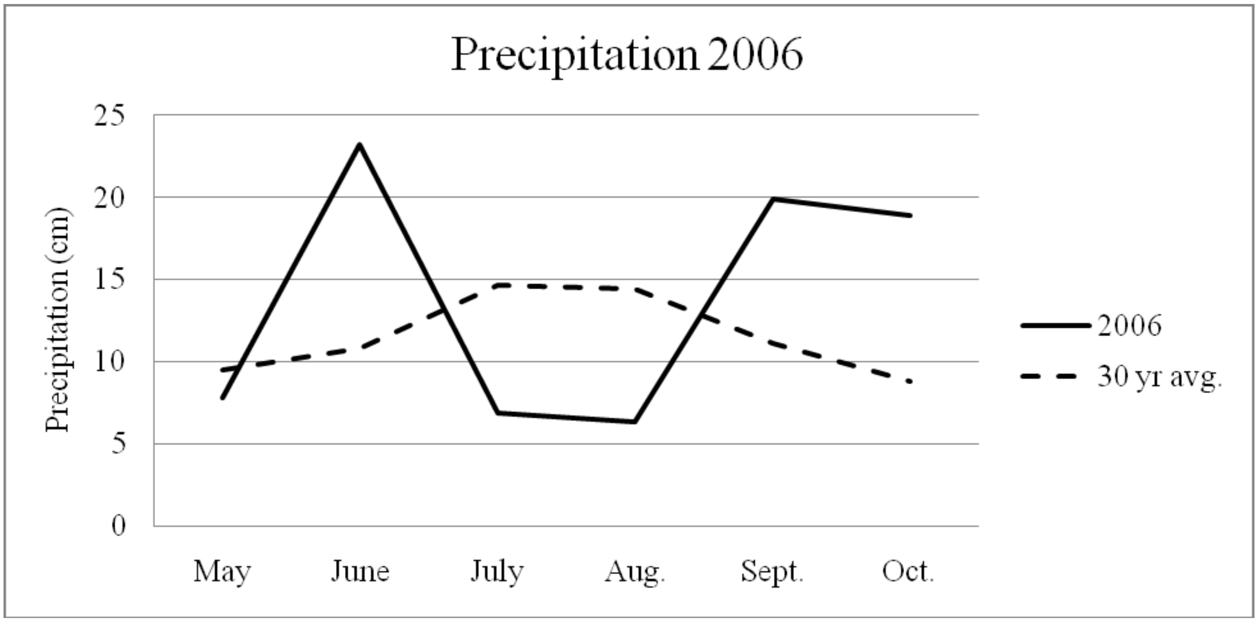
†Width (cm) of exposed soil between peanut rows measured at five arbitrarily selected locations between 2 rows.

Table 2.9. Peanut yield and grade of Virginia type peanut in 2007. Peanut grading is reported as the percent of a 500 g pod subsample at 7% moisture content. Abbreviations: Fancy, fancy sized pods; ELK, extra large kernels; SMK, sound mature kernels; SS, sound splits; DK, damaged kernels; OK, other kernels; TM, total meat.

		Grading category						
Rotation	Yield	Fancy	ELK	SMK	SS	DK	OK	TM
	kg ha^{-1}	%						
Ct-C-Ct-P	5022	90.6	49.0	69.6	1.8	0.4	0.8	71.4
Ct-P-Ct-P	3857	88.1	43.8	69.0	2.4	0.4	0.7	71.3
F-F-Ct-P	5064	90.4	48.7	69.8	1.7	0.3	0.9	71.5
O-O-Ct-P	5244	88.5	49.9	70.5	1.4	0.2	0.8	72.0
F-F-F-P	5709	93.5	50.1	70.4	1.7	0.3	0.8	72.1
O-O-O-P	5749	91.0	49.2	69.9	2.3	0.1	0.8	72.2
S-Ct-Ct-P	5249	91.8	51.2	70.0	1.3	0.2	0.7	71.3
LSD (0.05)*	610	NS	3.49	NS	NS	NS	NS	NS

NS = not significant; * denotes significance at $P \leq 0.05$ according to Fisher's LSD.

Figure 2.1. Appearance of plots transitioning from 2-year tall fescue to cotton in 2006 (top) compared to plots transitioning from an annual crop to cotton following a wheat cover crop in 2006 (bottom) after strip tillage in the spring. Photographed 27 May 2006 in Suffolk, VA by James M. Weeks, Jr.



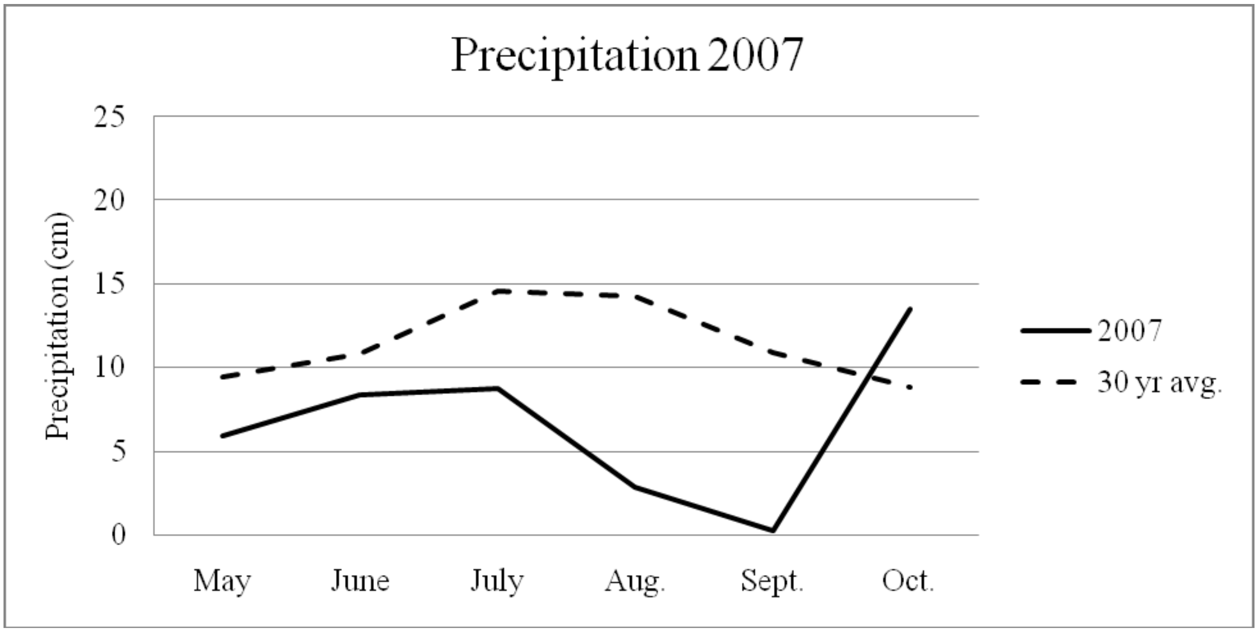


Figure 2.2. Total monthly precipitation for Suffolk, VA during the cotton and peanut growing season in 2006 and 2007.

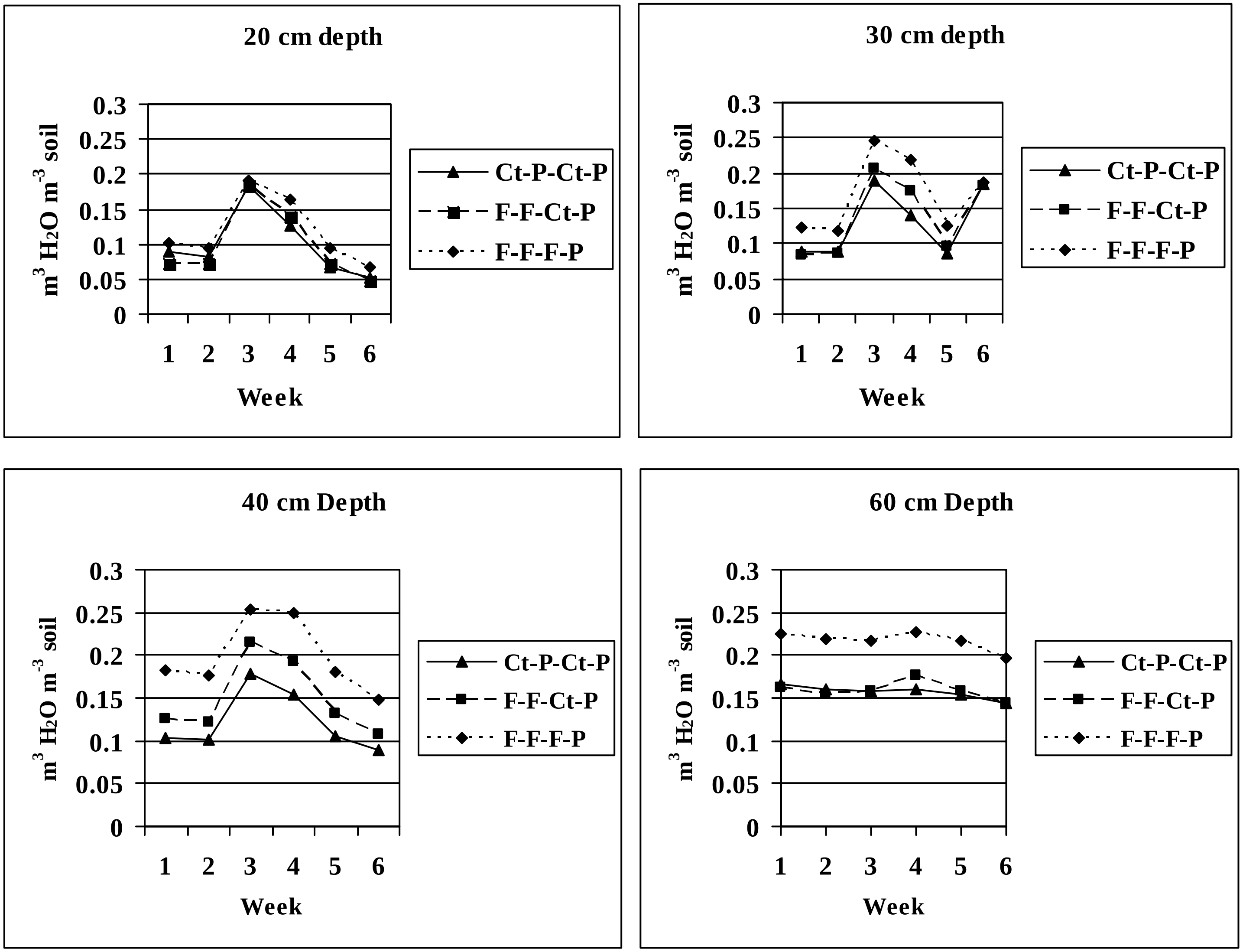


Figure 2.3. Soil moisture trends in selected crop rotations measured 6 weeks in Aug. and early Sept. 2007.

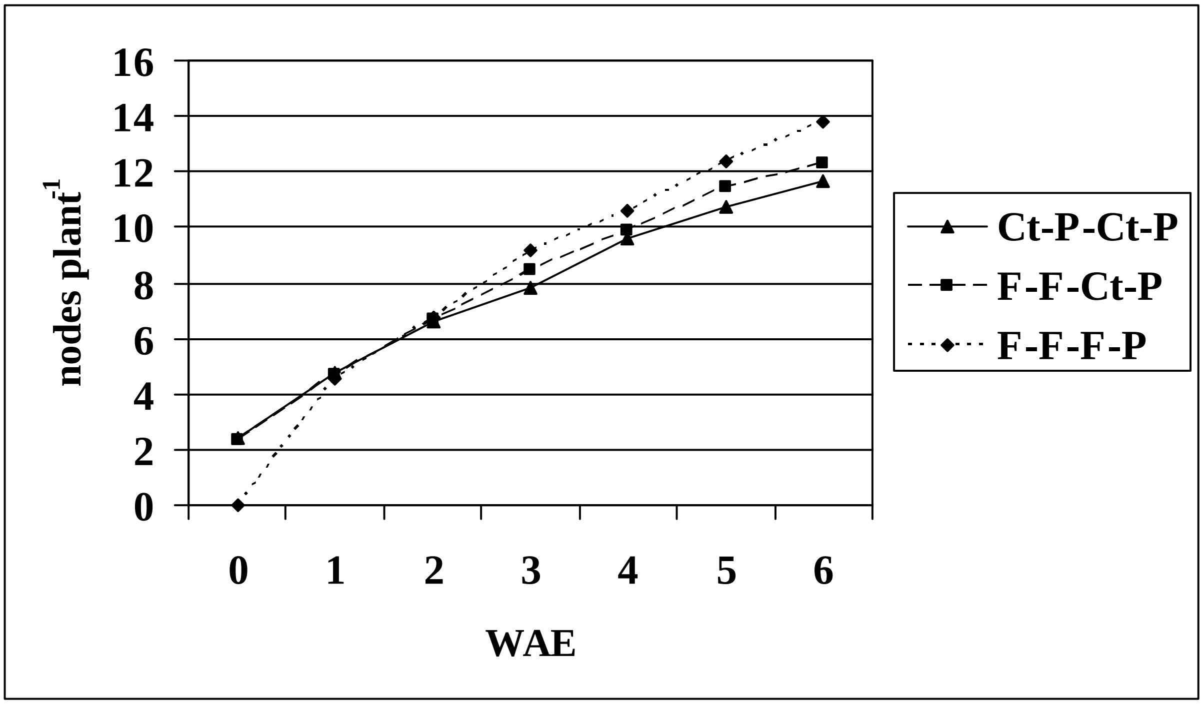


Figure 2.4. Peanut growth in selected rotations over the initial 6 weeks after emergence based on nodes on the main stem of 20 plants per plot. Abbreviations: WAE, weeks after emergence.

CHAPTER 3

Perennial Grass in Cotton and Peanut Rotations: Impact on Soilborne Pathogens

James M. Weeks, Jr.,* Joel C. Faircloth, Mark M. Alley, Pat M. Phipps, and Chris Teutsch

J. Michael Weeks, Jr. and Pat M. Phipps, Tidewater Agricultural Research and Extension Center, Virginia Polytechnic Institute and State University, Suffolk, VA 23437; Joel C. Faircloth, Dow Agrosciences, Collierville, TN 38017; Mark M. Alley, Crop and Soil Environmental Sciences, Virginia Polytechnic Institute and State University, Blacksburg, VA, 24061; and Chris Teutsch, Southern Piedmont Agricultural Research and Extension Center, Virginia Polytechnic Institute and State University, Blackstone, VA 23824. *Corresponding Author (jmweeks@vt.edu).

Abbreviations: CBR, Cylindrocladium black rots; MS, microsclerotia

ABSTRACT

Managing levels of soilborne pathogens is of particular importance for successful cultivation of peanut (*Arachis hypogaea* L.) in Virginia. The objective of this study was to evaluate the effects of crop rotations including multiple years of perennial grass on disease incidence and soilborne pathogens in peanut and cotton (*Gossypium hirsutum* L.) rotations compared to continuous row crop rotations. Rotation sequences for perennial grass based rotations were tall fescue (*Shedonorus phoenix* Scop.)-tall fescue-cotton-peanut, tall fescue-tall fescue-tall fescue-peanut, orchardgrass (*Dactylis glomerata* L.)-orchardgrass-cotton-peanut, and orchardgrass-orchardgrass-orchardgrass-peanut. Perennial grass rotations were compared to annual crop sequences of continuous cotton, cotton-corn (*Zea mays* L.)-cotton-peanut, cotton-peanut-cotton-peanut, and soybean [*Glycine max* (L.) Merr.]-cotton-cotton-peanut. Soil populations of root-knot (*Meloidogyne* spp.), stubby root [*Paratrichodorous minor* (Colbran) Siddiqi], ring [*Macroposthonia* ornata (Raski) DeGrisse & Loof], and stunt (*Tylenchorhynchus* spp.) nematodes as well as populations of microsclerotia of *Cylindrocladium parasiticum* (Creus, M.J. Wingfield, & Alfenas). Typically only populations of root-knot and stubby root nematode showed differences between rotations. Populations of root-knot nematode tended to be highest in the cotton-peanut-cotton-peanut rotation, however higher populations were seen occasionally in tall fescue rotations. Stubby root nematode populations were often highest in rotations with orchardgrass. Populations tended to increase to the highest level in orchardgrass rotations after killing the grass crop with herbicide prior to planting an annual crop in the spring. Numbers of microsclerotia of *Cylindrocladium parasiticum* surviving in soil were not different across rotations. Cotton-peanut-cotton-peanut was expected to have higher levels of microsclerotia due to the higher frequency of peanut. The peanut cultivar Perry, which was planted in 2007, has resistance to Cylindrocladium Black Rot which is caused by *C. parasiticum.* This may have contributed to lower than expected microsclerotia as well as dry weather stress which occurred in some years. Perennial grass rotations had little or no effect on survival of microsclerotia in soil. Often nematode populations were higher in perennial grass rotations. However, incidence of disease incited by fungi, nematodes, and viruses was low in all plots planted to cotton or peanut. Annual crops directly following perennial grasses showed significantly higher growth and yield. Below normal rain-fall, particularly in 2007, was likely the main factor contributing to low incidence of disease.

LITERATURE REVIEW

Failure to control plant pathogenic microorganisms can result in crop damage and yield losses. Yield losses in cotton (*Gossypium hirsutum* L.) to plant parasitic nematodes alone have been reported to be as high as 4% of potential yield without disease (Blasingame, 2002). In 2006, lint losses in Virginia due to nematode damage, mostly caused by southern root-knot nematode [*Meloidogyne incognita* (Kofoid & White) Chitwood], were $1.3 million (Virginia Cooperative Extension, 2007). Nematode damage accounted for two thirds of all losses from plant pathogens in 2006 in Virginia. Diseases of peanut (*Arachis hypogaea* L.) such as early leaf spot (*Cercospora arachidicola* Horia) and late leaf spot (*Cercosporidium personatum* Berk. & Curt) can reduce expected yields by 50% or more if left uncontrolled (Shokes and Culbreath, 1997). Effective ways to manage diseases include routine fungicide applications and soil fumigation. With the loss of the peanut quota system in 2001 costs associated with chemical disease control can substantially reduce producer profits. Other management practices that can potentially impact disease incidence with less input costs are crop rotation, residue management, and resistant cultivar selection.

Crop rotation is an important management strategy for reducing plant pathogen populations and damage potential. Timper et al. (2001) reported lower incidence of stem rot caused by *Sclerotium rolfsii* (Sacc.) when following multiple years of bahiagrass (*Paspalum notatum* Flueggē) compared to rotations with 2 years of cotton, 2 years of corn (*Zea mays* L.), or continuous peanut. This study also reported decreases in populations of peanut root-knot nematode [*Meloidogyne arenaria* (Neal) Chitwood] in rotations with 2 years of peanut or continuous peanut. In the continuous peanut rotation, increases in the population of the bacteria *Pastueria penetrans* (Sayre & Starr) were observed. *Pastueria penetrans* is antagonistic to the peanut root-knot nematode possibly explaining why continuous peanut maintained similar peanut root-knot nematode populations compared to bahiagrass rotations. In Florida peanut research, peanut yields were increased following either 2 years of corn, cotton, or bahiagrass with the highest yields found following bahiagrass (Brenneman et al., 2003). However, researchers reported greater incidence of peanut root-knot nematode root galling following bahiagrass compared to other rotational crops, potentially due to maintaining peanut root-knot nematode populations on weeds while the rotation was in bahiagrass. Stem rot incidence in peanuts following bahiagrass was lower compared to all other rotations, however, all rotations aside from monoculture peanut suppressed stem rot (Brenneman et al., 2003). Conversely, Hagan et al. (2003) reported no differences in peanut stem rot when peanut was grown continuously or in rotation with cotton, corn, or bahiagrass. They suggest a buildup of suppressive fauna in the peanut monoculture similar to the observations of Timper et al. (2001), but do not suggest a potential candidate organism. While stem rot was not affected by rotation in this study, early and late leaf spot were lower following 2 or 3 years of bahiagrass or 3 years of cotton or corn compared to continuous peanut. Fungicide applications to peanut were still required following cotton, corn, and bahiagrass rotations; however, fungicide applications were less warranted for the latter rotations compared to continuous peanut. Cantowine et al. (2006) reported less need for fungicide application in strip tillage for control of early and late leaf spot of peanut, with applications reduced from seven to four or five applications per season for conventional tillage and strip tillage, respectively. This study also reported reduced incidence of peanut spotted wilt (*Tomato Spotted Wilt Virus, Tospovirus*) where strip tillage was used compared to conventional tillage.

Crop rotation research in North Carolina investigating the impact of monoculture peanut compared to corn and peanut rotations found enhanced peanut yields in rotation with corn which was associated with decreased populations of the parasitic nematode *Criconemella ornata* [(Raski) Raski & Luc] (Ayers et al., 1989). Yields were greater in this study at one location compared to another which was associated with higher incidence of Cylindrocladium Black Rot (CBR), and higher weed populations in monoculture peanut at the lower yielding location.

Higher soil moisture can result from more surface residue in conservation tillage systems compared to conventional tillage systems (Daniel et al., 1999). While this is beneficial for crops with respect to moisture status, it can also lead to increases in crop infection and damage by pathogens. *Cylindrocladium parasiticum* has been shown to be more aggressive in soils at field capacity compared to drier conditions (Phipps and Beute, 1977). This study showed the highest losses to CBR when rainfall occurred frequently over the early portion of the growing season followed by a dry late season. Early season root damage by *C. parasiticum* accentuated drought stress and CBR at the end of the season. Porter et al. (1987) similarly reported greater incidence of Sclerotinia blight, early and late leaf spot, and pod rot in irrigated peanut compared to non-irrigated peanut. However, pod yield was still 200% greater in irrigated plots compared to non-irrigated.

Little data exists on the impact of crop rotations utilizing perennial grasses on pathogens of cotton and peanut. The objective of this study was to investigate the effects of crop rotations including perennial grasses on soilborne pathogens of cotton and peanut. In addition disease incidence in cotton and peanut were evaluated throughout the study. Effect of rotation on crop growth and yield were also evaluated.

MATERIALS AND METHODS

The study was conducted at the Virginia Tech Tidewater Agricultural Research and Extension Center (36° 40' N, 76° 43' W) in Suffolk, VA. The soil type was Nansemond fine loamy sand (Coarse-Loamy, Siliceous, Subactive, Thermic Aquic Hapludults). Eight crop rotations were arranged in a randomized complete block design with four replications (Table 3.1). In 2003 all rotations were planted in peanut. From 2004 to 2007, crops used in rotations included cotton, peanut, corn, soybean [*Glycine max* (L.) Merr.], tall fescue (*Shedonorus phoenix* Scop.), and orchardgrass (*Dactylis glomerata* L.). Crop sequences for each rotation beginning with 2004 were Cotton-Cotton-Cotton-Cotton (Ct-Ct-Ct-Ct), Cotton-Corn-Cotton-Peanut (Ct-C-Ct-P), Cotton-Peanut-Cotton-Peanut (Ct-P-Ct-P), Tall fescue-Tall fescue-Cotton-Peanut (F-F-Ct-P), Orchardgrass-Orchardgrass-Cotton-Peanut (O-O-Ct-P), Tall fescue-Tall fescue-Tall fescue-Peanut (F-F-F-P), Orchardgrass-Orchardgrass-Orchardgrass-Peanut (O-O-O-P), and Soybean-Cotton-Cotton-Peanut (S-Ct-Ct-P) (Table 3.1). Underlined letters in rotation abbreviations indicate the crop grown in the year discussed where applicable (e.g, F-F-<u>Ct</u>-P indicates cotton was the crop being grown when discussing results for that season). Plots were 8 rows, 7.4 m (24 ft) wide by 12.3 m (40 ft) long. Row crops were planted on 0.9 m (3 ft) centers. In 2004 cultivars DP 451 BG/RR, AG 5603 RR, Jessup with Max-Q endophyte, and WP300 were planted for cotton, soybean, tall fescue, and orchardgrass crops, respectively. In 2005 cultivars DP 451 BG/RR, Pioneer 33M54, and VA 98R were planted for cotton, corn, and peanut crops, respectively. In 2006 and 2007 the cotton cultivar planted was DP 444 BG/RR. Perry was the peanut variety planted in 2007. Perennial grasses were planted using a self-propelled walk behind cultapack type seeder with spacing of approximately 15 cm. Where a row crop followed a perennial grass, grasses were killed with glyphosate in the early spring or late fall for the 2005 to 2006 and 2006 to 2007 transition, respectively. In 2006 and 2007, cotton and peanut were planted using strip tillage into residue in all rotations. A ripper – bedder implement was used to create a strip in residue and to make a rip to a depth of approximately 30 cm in one pass prior to planting. A second tractor pass was used to plant the annual crop. Cotton was planted 11 May 2006 and 27 Apr. 2007. Mepiquat Pentaborate (9.6% ai) was applied to cotton in early and late July to all cotton plots at rates of approximately 0.44 L ha^{-1} (6 oz a^{-1}) to 0.59 L ha^{-1} (8 oz a^{-1}) depending on extension recommendations (Faircloth et al., 2007b). Peanut was planted 15 May 2007. Crop fertility and insect management were conducted according to Virginia Cooperative Extension recommendations (Faircloth et al., 2007a; Faircloth et al., 2007b).

Full tillage and metam sodium fumigation were used prior to planting peanut in 2005. As previously mentioned, strip tillage was used prior to planting peanut in 2007 and no metam sodium was applied. All rotations of cotton received aldicarb (15% ai) in furrow at a rate of approximately 5.6 kg ha^{-1} (5 lb a^{-1}) at planting. In 2005 and 2007 peanut received aldicarb (15% ai) at a rate of approximately 7.85 kg ha^{-1} (7 lb a^{-1}). Fungicide was applied three times in 2005 on peanut plots. Tebuconazole (38.7% ai) was applied first on 19 July 2005 at a rate of approximately 0.59 L ha^{-1} (8 oz a^{-1}) and again on 3 Aug. 2005 at the same rate. Chlorothalonil (720 g L^{-1} ai) was applied at a rate of approximately 1.75 L ha^{-1} (1.5 pt a^{-1}) on 20 Sept. 2005. In 2007 fungicides were applied four times to peanut plots. A combination of prothioconazole (12.9% ai) and tebucanazole (25.8% ai) were applied at a rate of 0.59 L ha^{-1} (8 oz a^{-1}) on 23 July 2007 and again on the 7 Aug. 2007 at the same rate. Pyraclostrobin (23.6% ai) was applied on 28 Aug. 2007 at a rate of approximately 0.66 L ha^{-1} (9 oz a^{-1}). On the same date as the latter application, fluazinam (40% ai) was applied at a rate of approximately 1.17 L ha^{-1} (1 pt a^{-1}). Chlorothalonil (720 g L^{-1}) was applied at a rate of approximately 1.75 L ha^{-1} (1.5 pt a^{-1}) on 14 Sept. 2007.

Soils were sampled to a depth of 20 cm at 20 arbitrarily selected locations per plot using a soil probe (1.27 cm diameter) beginning on 4 May 2005 for the spring sample and 20 Aug. 2005 for the fall sample. Subsequent samples in the spring were conducted within a week of the initial spring sample. Subsequent fall samples were moved back to 26 October 2006 and 18 November 2007. Soil samples were placed in plastic sample bags and maintained at approximately 4°C until processed for nematodes and MS of *C. parasiticum*. A 500 cc subsample of soil was removed for plant parasitic nematode assay in the Virginia Tech

Nematode Assay Lab. Populations of root-knot (*Meloidogyne* spp.), stubby root (*Tylenchorhynchus* spp.), ring [*Macroposthonia* ornate (Raski) DeGrisse & Loof], and stunt [*Paratrichodorous minor* (Colbran) Siddiqi] nematodes were measured. A 200 g subsample of soil was processed by soil elutriation for surviving MS of *C. parasiticum* following the methods of Phipps et al. (1976). Peanuts were scouted throughout 2007 for incidence of disease.

Data with respect to soilborne pathogens, nematode populations and MS counts of *C. parasiticum*, were subjected to analysis of variance (ANOVA) utilizing the general linear model procedure (PROC GLM) in the Statistical Analysis Systems Suite version 9.1 (SAS Institue Cary, NC). All data were analyzed using observed values and square root transformed data. Transformed data were used where predicted versus residual plots displayed greater consistency. Only stunt and ring nematode populations were analyzed using transformed data. Within each rotation and seasonal sampling period, ANOVA by year was conducted to determine changes in root-knot and stubby root nematode populations as well as counts of surviving MS in soil of *C. parasiticum* over time within a rotation. Where significance was observed, Fisher's protected LSD ($P \leq 0.05$) was used to determine significant differences in rotations.

RESULTS AND DISCUSSION

Comparison of Spring and Fall Nematode Populations Across Rotations

In the spring of 2005, root-knot nematode populations were highest in O-O-O-P and S-Ct-Ct-P ($P = 0.0015$) (Table 3.2). In the spring of 2006, root-knot nematode populations were the highest in Ct-P-Ct-P where the root-knot nematode population increased from 50 (spring 2005) to 4,180 nematodes 500 cc soil^{-1} ($P \leq 0.0001$) (Table 3.3). The crop prior to sampling in 2006 was peanut. This suggests that the increase in root-knot nematode population was likely either *Meloidogyne arenaria* or *M. hapla*. By the spring of 2007, root-knot nematode populations were the highest in the Ct-P-Ct-P rotation as well as rotations with 3 years of a perennial grass ($P = 0.0139$) (Table 3.4). Overall populations in all rotations were much lower in the spring of 2007 than in the spring of 2006 with the crop prior to sampling being cotton except in rotations with 3 years of perennial grass.

The risk of cotton and peanut damage was evaluated by comparing actual nematode populations in the fall to crop damage thresholds reported for these crops in Virginia (Table 3.5). In the fall of 2005, root-knot nematode populations were the highest in rotations with 3 years of a perennial grass (following 2 seasons of perennial grass), however, they were similar to most of the other rotations (P = 0.0413). Moderate risk thresholds were surpassed in O-O-Ct-P, F-F-F-P, O-O-O-P, and S-Ct-Ct-P rotations if the next crop was peanut. In the fall of 2006, root-knot nematode populations were highest in Ct-P-Ct-P (P ≤ 0.0001) with cotton being the crop grown that season; however, the population was less than 4% of that observed in the spring of the same year. Counts in this rotation would exceed the damage threshold only if the next crop was peanut. No significant differences in root-knot nematode populations were seen across rotations in the fall of 2007. Risk thresholds of moderate were surpassed in all rotations except continuous cotton in the fall of 2007 if the next crop was peanut. The high risk threshold for crop damage was surpassed in Ct-P-Ct-P, F-F-Ct-P, F-F-F-P, and O-O-O-P rotations if the next crop would be peanut.

Populations of stubby root nematode in the spring of 2005 were highest in rotations with orchardgrass (P = 0.01). In the spring of 2006, populations remained the highest in O-O-Ct-P (P = 0.0178). By the 2006 spring sampling date, the orchardgrass in O-O-Ct-P had been killed for several months in preparation for planting cotton while the orchardgrass in O-O-O-P was left for one more season. In the spring of 2007, stubby root populations were the highest in either rotation with 3 years of a perennial grass (P = 0.0064). Again at this point grasses in the 3-year perennial grass rotations had been dead for several months for the transition to peanut.

In the fall of 2005, stubby root nematode populations were highest in rotations with orchardgrass as was observed in the spring (P ≤ 0.0001). Thresholds for moderate risk of crop damage were surpassed in all rotations except Ct-P-Ct-P in the fall of 2005 if the next crop was either cotton or peanut. Thresholds for high risk of crop damage were surpassed in rotations with orchardgrass in the fall of 2005 if the next crop was either cotton or peanut. No differences could be found in the fall of 2006 for stubby root nematode populations across rotations. Only Ct-Ct-Ct-Ct and Ct-P-Ct-P had stubby root nematode populations lower than the moderate damage threshold in the fall of 2006 if the next crop was either cotton or peanut. The highest risk threshold was surpassed in O-O-O-P in the fall of 2006 if the next crop was cotton or peanut and in S-Ct-Ct-P if the next crop was cotton. In the fall of 2007, there was no significance across rotations and no rotations had stubby root nematode populations that surpassed the moderate damage threshold.

Perennial forage grasses including orchardgrass and endophyte-free tall fescue are known to be hosts of the stubby root nematode (Bell and Watson, 2001). There are several possible explanations why other rotations with annual crops did not show as high a population of stubby root nematode. Rotations with cotton and peanut received nematicides (aldicarb) at planting each year. Rotations such as Ct-P-Ct-P and Ct-Ct-Ct-Ct would have received nematicide in furrow in four consecutive years whereas rotations with 2 and 3 years of perennial grass received nematicides for 2 years and 1 year, respectively, when planted to either cotton or peanut. Furthermore, stubby root nematode has been shown to be less prevalent in dry soils (Baujard and Martiny, 1995). Seasonal rainfall was low relative to the 30-year average in 2006 and particularly in 2007 (Figure 3.1). However, soils tended to have higher water content following 3 years of tall fescue compared to Ct-P-Ct-P and F-F-Ct-P when measured over several weeks in 2007 (Figure 3.2). Measurement of moisture directly following 2 years of either perennial grass or 3 years of orchardgrass were not conducted. If soil moistures in these rotations was higher, however, it may have favored higher stubby root nematode populations. Increases in stubby root nematode populations were also seen in orchardgrass rotations following the destruction of the grass for the planting of the annual crop. Once the orchardgrass was killed, bermudagrass [*Cynodon dactylon* (L.) Pers.] began to infest the rotation. Bermudagrass has also been shown to be a host of stubby root nematode (Crow, 2005).

Comparing square root transformed stunt nematode populations in the spring across rotations, differences were observed only in 2006 where Ct-P-Ct-P had the lowest populations compared to other rotations (P = 0.0081). The previous crop in this rotation was peanut.

Square root transformed populations of stunt nematode in the fall were only significant in 2005. Populations were the highest in O-O-O-P; however, all rotations were similar except Ct-P-Ct-P (P = 0.0402).

The square root transformed ring nematode populations in the spring of 2005 were highest in the O-O-Ct-P, O-O-O-P, and Ct-P-Ct-P (P = 0.0371). Populations were not different in the spring of 2006, however in 2007 Ct-P-Ct-P and O-O-O-P had the highest ring nematode populations (P = 0.0271).

Transformed populations of ring nematode in the fall were highest in Ct-P-Ct-P in both 2005 and 2006 (P = 0.0023 and 0.0239, respectively). In 2006, the latter rotation was similar to O-O-O-P. Damage thresholds for ring nematode only apply where peanut is the next crop. In the fall of 2005, non-transformed ring nematode populations surpassed moderate risk thresholds for crop damage in all rotations and the high risk threshold was surpassed in Ct-P-Ct-P and O-O-O-P. In the fall of 2006, Ct-P-Ct-P and either rotation with 3 years of a perennial grass surpassed the moderate risk threshold for ring nematode and no rotation surpassed the highest risk threshold. In the fall of 2007, square root transformed ring nematode populations were not significant across rotations. Moderate risk thresholds were surpassed in all rotations except Ct-Ct-Ct-Ct and the highest threshold was surpassed in rotations with 3 years of perennial grass in the fall of 2007.

Changes in Selected Nematode Populations within a Rotation by Year

Root-knot nematode populations showed differences within rotation by year in the spring but not the fall. Continuous cotton had the highest root-knot nematode population in 2005 and decreasing populations numerically each successive spring. However, 2006 and 2007 populations were similar (P = 0.0127) (Table 3.6). Soybean-Ct-Ct-P had a trend similar to continuous cotton where the highest population was observed in the spring of 2005 following soybean, populations decreased numerically each successive spring, and the 2006 and 2007 root-knot nematode populations were similar (P = 0.0012). Cotton-P-Ct-P had the lowest and similar root-knot nematode population following cotton in the spring of 2005 and 2007 and higher a population in the spring of 2006 following peanut (P = 0.0011). The spring population of root-knot nematode in F-F-F-P was the highest in 2005 following the first year in tall fescue, the lowest in 2006 after the second year in tall fescue, and showed a signifcant increase in 2007 following the third year of tall fescue and the destruction of the tall fescue crop. The 2007 population was lower than the the 2005 population (P = 0.0044) for the latter rotation. Orchardgrass-O-O-P overall had a similar trend to F-F-F-P over time. Lower root-knot nematode populations were seen in 2006 compared to 2005 (P = 0.0051). The root-knot nematode population again numerically increased in 2007 following the destruction of the orchardgrass; however, 2006 and 2007 populations were similar.

By year comparisons of stubby root nematode populations showed differences only for the fall sampling. Continuous cotton had the highest population in 2005 (P = 0.0296) (Table 3.7). Stubby root nematode populations numerically decreased each successive fall in continuous cotton; however, populations were similar in 2006 and 2007. Cotton-P-Ct-P had the highest stubby root nematode population in 2006 following cotton, with the lowest and similar populations in 2005 and 2007 following peanut ($P = 0.0386$). For O-O-Ct-P and F-F-F-P, populations of stubby root nematode were highest in 2005 and 2006 where the crop was either a perennial grass or cotton, with a significant decrease in 2007 following peanut ($P = 0.0238$ and 0.0190 for O-O-Ct-P and F-F-F-P respectively). Other rotations did not show significant changes in stubby root nematode population by year.

Comparison of Spring and Fall Microsclerotia Levels Across Rotations

Elutriation and plating in the spring for MS of *C. parasiticum* showed significance only in 2006 where continuous cotton and Ct-C-<u>Ct</u>-P were observed to have the highest MS g^{-1} soil (Table 3.8). At this sampling date any rotation with perennial grass displayed significantly lower counts of MS g^{-1} soil. No differences for *C. parasiticum* MS g^{-1} soil were observed in the fall across rotations.

Changes in Microsclerotia Levels within a Rotation by Year

Numerically by year and within a given rotation levels of *C. parasiticum* MS g^{-1} soil in the spring were highest in all rotations in 2005 and numerically decreased with each successive sample (Figure 3.3). Levels of MS g^{-1} soil were not significant within rotations across years in the spring for continuous cotton, F-F-F-P, and O-O-O-P. All other rotations had the highest levels of MS g^{-1} soil in the spring of 2005 and similar levels in 2006 and 2007.

Fall samples again tended to show numerically lower MS g^{-1} soil each successive year of sampling (Figure 3.4). Cotton-C-Ct-P had the highest MS g^{-1} soil in the fall of 2005 and 2006 which were similar, and significantly lower in the fall of 2007 following peanut ($P = 0.0270$). Cotton-P-Ct-P had the highest MS g^{-1} soil in the fall of 2005 following peanut compared to 2006 and 2007 which were similar ($P = 0.0043$). The level of MS g^{-1} soil in F-F-Ct-P was highest in the fall of 2005 which was similar to 2006 but not 2007 ($P = 0.0465$). The level of MS g^{-1} soil in F-F-F-P was lowest in 2007 following peanut and 2005 and 2006 measurements were similar ($P = 0.0122$). The latter rotation was the only one to show a numeric increase in the level of MS g^{-1} soil with a small increase observed from 2005 to 2006.

Levels of MS g^{-1} soil were expected to be highest following peanut as it is the best host of *C. parasiticum* in the rotation followed by soybean (Phipps and Beute, 1979). The only time the level of MS g^{-1} soil was higher following peanut in the fall was in 2005 in Ct-P-Ct-P. In 2005, variety VA 98R was used for peanut crops while in 2007 (the only other year when peanut was planted in rotation aside from 2003 when data were not taken) variety Perry was used. Perry has resistance to *C. parasiticum* (Isleib et al., 2003). Alternatively, significant drought in Virginia in the 2007 season may have not allowed for the germination of MS and the propagation of secondary inoculum of *C. parasiticum* (Phipps and Beute, 1977).

Observed peanut disease incidence caused by *C. parasiticum*, as well as other common pathogens in Virginia, was low in 2007 and typically low throughout the rotation. A combination of seasonal below normal rainfall as well as preventative applications of fungicides and nematicides may have suppressed disease incidence. Differences in disease incidence across rotations were never observed in peanut in 2007 (Data not shown).

CONCLUSIONS

Based on root-knot nematode counts in spring and fall soil samples, there is little evidence that crop rotations utilizing tall fescue or orchardgrass had an effect on root-knot nematode populations. Stubby root nematode populations in the spring and fall confirmed that orchardgrass is a good host for the nematode, though there are other possible explanations for higher stubby root populations following orchardgrass (e.g., less nematicide applied over the duration of the rotation and potentially higher soil moisture following a perennial grass). Furthermore, populations seemed to be enhanced following the destruction of the orchardgrass crop (spring 2006 for 2006 cotton crop, fall 2006 for 2007 peanut crop) for preparation of row crop planting possibly due to bermudagrass which was present in perennial grass plots until the planting of the annual crops. For the fall samples of the 2- and 3-year orchardgrass rotations in 2005 and 2006, populations surpassed the risk threshold for recommending a nematicide for cotton and peanut crops to be grown in 2006 and 2007, respectively. In general, MS of *C. parasiticum* decreased in all rotations despite the frequency of peanut. Microsclerotia were expected to be higher following peanut in the fall of 2007; however, MS numbers had decreased since spring measurements of the same year. Further, *C. parasiticum* may not have been actively infecting peanut plants in 2007 due to dry weather; hence, *C. parasiticum* would be less aggresive in colonizing roots and MS production would have been low (Phipps and Beute, 1977).

Perennial grasses tended to have neutral or negative effects on soilborne pathogen populations when in rotation with cotton and peanut. Where significance was seen in grass rotations, it tended to be in increases of nematode populations, particularly following orchardgrass in the case of stubby root nematode where levels exceeded thresholds. Despite increases in stubby root populations following orchardgrass, yields of cotton and peanut were improved when planted after either perennial grass (Figure 3.5). Soil moistures were found to be higher following 3 years of tall fescue and may have been higher following 3 years of orchardgrass though this was not determined. Potential root damage by stubby root nematodes and other plant parasitic nematodes was possibly negated by greater available water in the soil profile.

Table 3.1. Sequence of crops used in eight crop rotations (2003-2007). All rotations begin in peanut in 2003 Abbreviations: Ct, cotton; C, corn; P, peanut; F, tall fescue; O, orchardgrass; S, soybean.

Rotation	2003	2004	2005	2006	2007
Ct-Ct-Ct-Ct	Peanut	Cotton	Cotton	Cotton	Cotton
Ct-C-Ct-P	Peanut	Cotton	Corn	Cotton	Peanut
Ct-P-Ct-P	Peanut	Cotton	Peanut	Cotton	Peanut
F-F-Ct-P	Peanut	Tall fescue	Tall fescue	Cotton	Peanut
O-O-Ct-P	Peanut	Orchardgrass	Orchardgrass	Cotton	Peanut
F-F-F-P	Peanut	Tall fescue	Tall fescue	Tall fescue	Peanut
O-O-O-P	Peanut	Orchardgrass	Orchardgrass	Orchardgrass	Peanut
S-Ct-Ct-P	Peanut	Soybean	Cotton	Cotton	Peanut

Table 3.2. Populations of plant parasitic nematodes in spring and fall for each crop rotation in 2005.

Sample timing	Rotation	Root-knot	Stubby root	Ring	Stunt
		nematodes 500 cc soil^{-1}		(nematodes 500 cc soil^{-1})$^{-1/2}$	
Spring	Ct-Ct-Ct-Ct	95.00	185.00	13.67	7.77
	Ct-C-Ct-P	82.50	107.50	12.45	6.34
	Ct-P-Ct-P	50.00	162.50	16.88	4.96
	F-F-Ct-P	90.00	247.50	9.80	8.34
	O-O-Ct-P	150.00	445.00	17.54	11.26
	F-F-F-P	162.50	222.50	9.50	9.41
	O-O-O-P	300.00	402.50	16.98	14.31
	S-Ct-Ct-P	375.00	137.50	12.77	9.66
	(LSD 0.05)*	131.83	175.11	5.17	NS
Fall	Ct-Ct-Ct-Ct	17.50	190.00	11.70	4.79
	Ct-C-Ct-P	7.50	130.00	8.07	8.48
	Ct-P-Ct-P	20.00	17.50	20.08	1.58
	F-F-Ct-P	25.00	175.00	7.19	7.10
	O-O-Ct-P	32.50	310.00	12.58	6.08
	F-F-F-P	40.00	247.50	9.62	6.23
	O-O-O-P	40.00	352.50	14.56	10.57
	S-Ct-Ct-P	37.50	115.00	11.00	6.02
	LSD (0.05)	22.06	103.07	5.12	4.86

NS = not significant; * denotes significance at $P \leq 0.05$ according to Fisher’s LSD.

Table 3.3. Populations of plant parasitic nematodes in spring and fall for each crop rotation in 2006.

Sample timing	Rotation	Root-knot	Stubby root	Ring	Stunt
		nematodes 500 cc soil^{-1}		(nematodes 500 cc soil^{-1})$^{-1/2}$	
Spring	Ct-Ct-Ct-Ct	15.00	75.00	7.81	5.12
	Ct-C-Ct-P	12.50	72.50	5.19	7.56
	Ct-P-Ct-P	4180.00	50.00	20.46	0.79
	F-F-Ct-P	55.00	180.00	5.79	7.05
	O-O-Ct-P	45.00	462.50	9.51	5.98
	F-F-F-P	7.50	70.00	10.58	5.95
	O-O-O-P	7.50	45.00	7.30	8.05
	S-Ct-Ct-P	37.50	35.00	7.49	5.59
	LSD (0.05)*	608.03	225.48	NS	3.23
Fall	Ct-Ct-Ct-Ct	0.00	90.00	6.09	4.47
	Ct-C-Ct-P	0.00	167.50	3.35	5.85
	Ct-P-Ct-P	165.00	65.00	11.82	2.89
	F-F-Ct-P	0.00	155.00	3.49	6.02
	O-O-Ct-P	17.50	210.00	5.40	5.86
	F-F-F-P	20.00	170.00	7.23	7.93
	O-O-O-P	5.00	1757.50	8.79	8.69
	S-Ct-Ct-P	17.50	267.50	5.30	5.80
	LSD (0.05)	52.32	NS	4.35	NS

NS = not significant; * denotes significance at $P \leq 0.05$ according to Fisher's LSD.

Table 3.4. Populations of plant parasitic nematodes in spring and fall for each crop rotation in 2007.

Sample timing	Rotation	Root-knot	Stubby root	Ring	Stunt
		nematodes 500 cc soil^{-1}		(nematodes 500 cc soil^{-1})$^{-1/2}$	
Spring	Ct-Ct-Ct-Ct	5.00	85.00	7.78	5.15
	Ct-C-Ct-P	10.00	87.50	7.34	6.89
	Ct-P-Ct-P	72.50	30.00	12.65	0.79
	F-F-Ct-P	7.50	70.00	3.68	4.41
	O-O-Ct-P	22.50	187.75	7.74	5.29
	F-F-F-P	72.50	202.50	4.46	6.09
	O-O-O-P	60.00	312.50	10.45	8.91
	S-Ct-Ct-P	20.00	102.50	7.10	9.68
	LSD (0.05)*	48.32	122.16	4.55	NS
Fall	Ct-Ct-Ct-Ct	0.00	2.50	3.49	0.79
	Ct-C-Ct-P	30.00	0.00	10.76	1.12
	Ct-P-Ct-P	200.00	0.00	10.91	0.00
	F-F-Ct-P	362.50	5.00	11.29	0.00
	O-O-Ct-P	30.00	2.50	9.96	1.58
	F-F-F-P	147.50	0.00	14.69	1.58
	O-O-O-P	97.50	27.50	16.04	2.16
	S-Ct-Ct-P	62.50	2.50	9.19	0.00
	LSD (0.05)	NS	NS	NS	NS

NS = not significant; * denotes significance at $P \leq 0.05$ according to Fisher's LSD.

Table 3.5. Nematode risk thresholds for selected species in Virginia for cotton and peanut.

Crop	Nematode Species	Damage Potential		
		Low	Moderate	High
		——nematodes 500 cc^{-1} soil——		
Cotton	Root-knot	0 - 190	200 - 490	500 +
	Stubby root	0 - 90	100 - 240	250 +
Peanut	Root-knot	0 - 20	30 - 90	100 +
	Stubby root	0 - 90	100 - 290	300 +
	Ring	0 - 30	40 - 190	200 +

Thresholds are for populations sampled from 1 Aug. to 20 Nov.

Table adapted from Nematode Threshold Recommendations (VPI&SU) found at http://oak.ppws.vt.edu/~clinic/thresholds.html.

Table 3.6. Root-knot nematode from the spring sampling period analyzed by year within each rotation for significant changes within a rotation over time.

Rotation	Preceding Crop†	Year	Root-knot
			nem 500 cc soil^{-1}
Ct-Ct-Ct-Ct	Cotton	2005	95.0
	Cotton	2006	15.0
	Cotton	2007	5.0
		LSD (0.05)*	39.1
Ct-C-Ct-P	Cotton	2005	82.5
	Corn	2006	12.5
	Cotton	2007	10.0
		LSD (0.05)	NS
Ct-P-Ct-P	Cotton	2005	50.0
	Peanut	2006	4180.0
	Cotton	2007	72.5
		LSD (0.05)	1172.8
F-F-Ct-P	Fescue	2005	90.0
	Fescue	2006	55.0
	Cotton	2007	7.5
		LSD (0.05)	NS
O-O-Ct-P	Orchardgrass	2005	120.0
	Orchardgrass	2006	45.0
	Cotton	2007	22.5
		LSD (0.05)	NS
F-F-F-P	Fescue	2005	162.5
	Fescue	2006	7.5
	Fescue	2007	72.5
		LSD (0.05)	55.0
O-O-O-P	Orchardgrass	2005	300.0
	Orchardgrass	2006	7.5
	Orchardgrass	2007	60.0
		LSD (0.05)	106.5
S-Ct-Ct-P	Soybean	2005	375.0
	Cotton	2006	37.5
	Cotton	2007	20.0
		LSD (0.05)	100.8

NS = not significant; * denotes significance at $P \leq 0.05$ according to Fisher's LSD.

†The preceding crop given is the crop grown in the previous season.

Table 3.7: Stubby root nematode from the fall sampling period analyzed by year within each rotation for significant changes within a rotation over time.

Rotation	Preceding crop†	Year	Stubby root
			nem 500 cc soil^{-1}
Ct-Ct-Ct-Ct	Cotton	2005	190.0
	Cotton	2006	90.0
	Cotton	2007	2.5
		LSD (0.05)*	98.3
Ct-C-Ct-P	Corn	2005	130.0
	Cotton	2006	167.5
	Peanut	2007	0.0
		LSD (0.05)	NS
Ct-P-Ct-P	Peanut	2005	17.5
	Cotton	2006	65.0
	Peanut	2007	0.0
		LSD (0.05)	34.2
F-F-Ct-P	Fescue	2005	175.0
	Cotton	2006	155.0
	Peanut	2007	5.0
		LSD (0.05)	NS
O-O-Ct-P	Orchardgrass	2005	137.5
	Cotton	2006	35.0
	Peanut	2007	102.5
		LSD (0.05)	NS
F-F-F-P	Fescue	2005	247.5
	Fescue	2006	170.0
	Peanut	2007	0.0
		LSD (0.05)	113.3
O-O-O-P	Orchardgrass	2005	352.5
	Orchardgrass	2006	1757.5
	Peanut	2007	27.5
		LSD (0.05)	NS
S-Ct-Ct-P	Cotton	2005	115.0
	Cotton	2006	267.5
	Peanut	2007	2.5
		LSD (0.05)	NS

NS = not significant; * denotes significance at $P \leq 0.05$ according to Fisher's LSD.

†The preceding crop given is the crop grown in the same season.

Table 3.8. Microsclerotia of *Cylindrocladium parasiticum* for each rotation in the fall or spring.

	Cylindrocladium parasiticum		
Year	Rotation	Spring	Fall
		ms g soil^{-1}	
2005	Ct-Ct-Ct-Ct	6.10	5.40
	Ct-C-Ct-P	8.40	5.80
	Ct-P-Ct-P	5.50	13.00
	F-F-Ct-P	9.00	7.00
	O-O-Ct-P	12.30	5.40
	F-F-F-P	9.30	3.80
	O-O-O-P	8.40	6.60
	S-Ct-Ct-P	7.10	6.80
	LSD (0.05)	NS	NS
2006	Ct-Ct-Ct-Ct	4.30	4.06
	Ct-C-Ct-P	4.00	3.54
	Ct-P-Ct-P	3.30	3.96
	F-F-Ct-P	2.10	4.27
	O-O-Ct-P	2.00	4.48
	F-F-F-P	2.10	4.48
	O-O-O-P	2.20	3.75
	S-Ct-Ct-P	2.80	3.85
	LSD (0.05)	0.48	NS
2007	Ct-Ct-Ct-Ct	1.90	0.63
	Ct-C-Ct-P	2.20	1.15
	Ct-P-Ct-P	3.20	0.83
	F-F-Ct-P	2.00	1.45
	O-O-Ct-P	2.00	1.35
	F-F-F-P	2.40	0.63
	O-O-O-P	2.50	0.83
	S-Ct-Ct-P	1.80	0.83
	LSD (0.05)	NS	NS

NS = not significant; * denotes significance at $P \leq 0.05$ according to Fisher’s LSD.

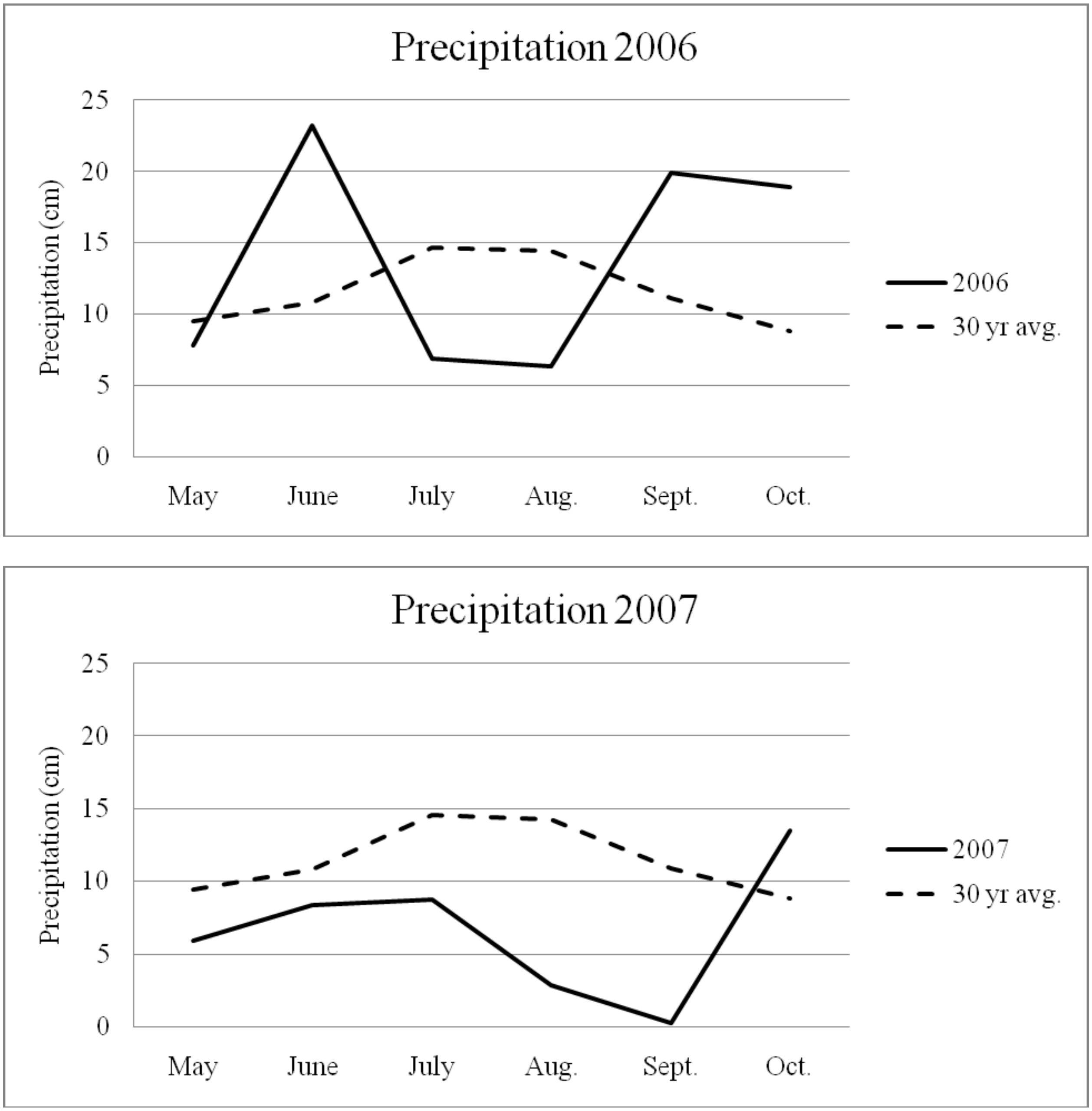


Figure 3.1. Total monthly precipitation for Suffolk, VA during the cotton and peanut growing season in 2006 and 2007.

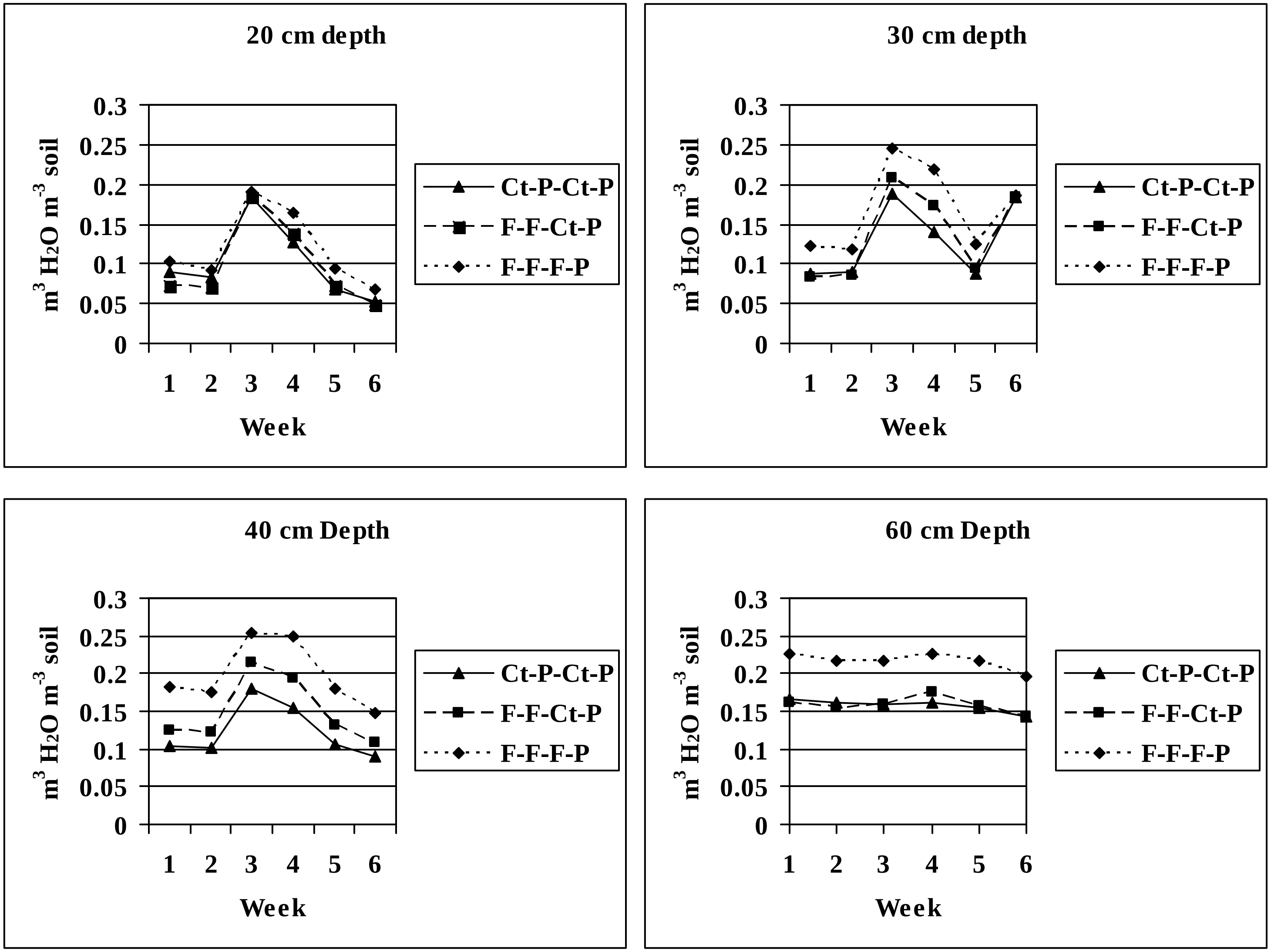


Figure 3.2. Soil moisture trends in selected crop rotations presented by depth. Soil moisture was measured three times a week for 6 weeks during Aug. and Sept. 2007 and averaged by week.

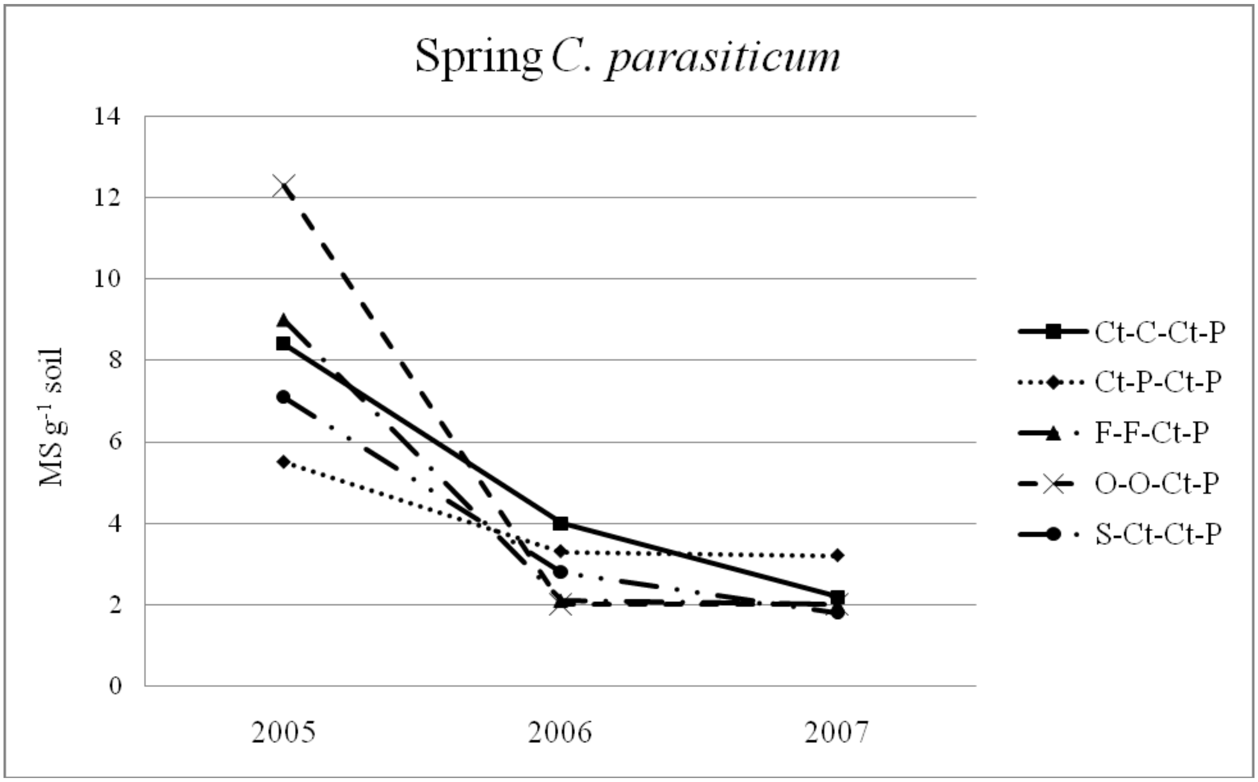


Figure 3.3. Level of microsclerotia of *Cylindrocladium parasiticum* in the spring for 2005 through 2007 for selected rotations.

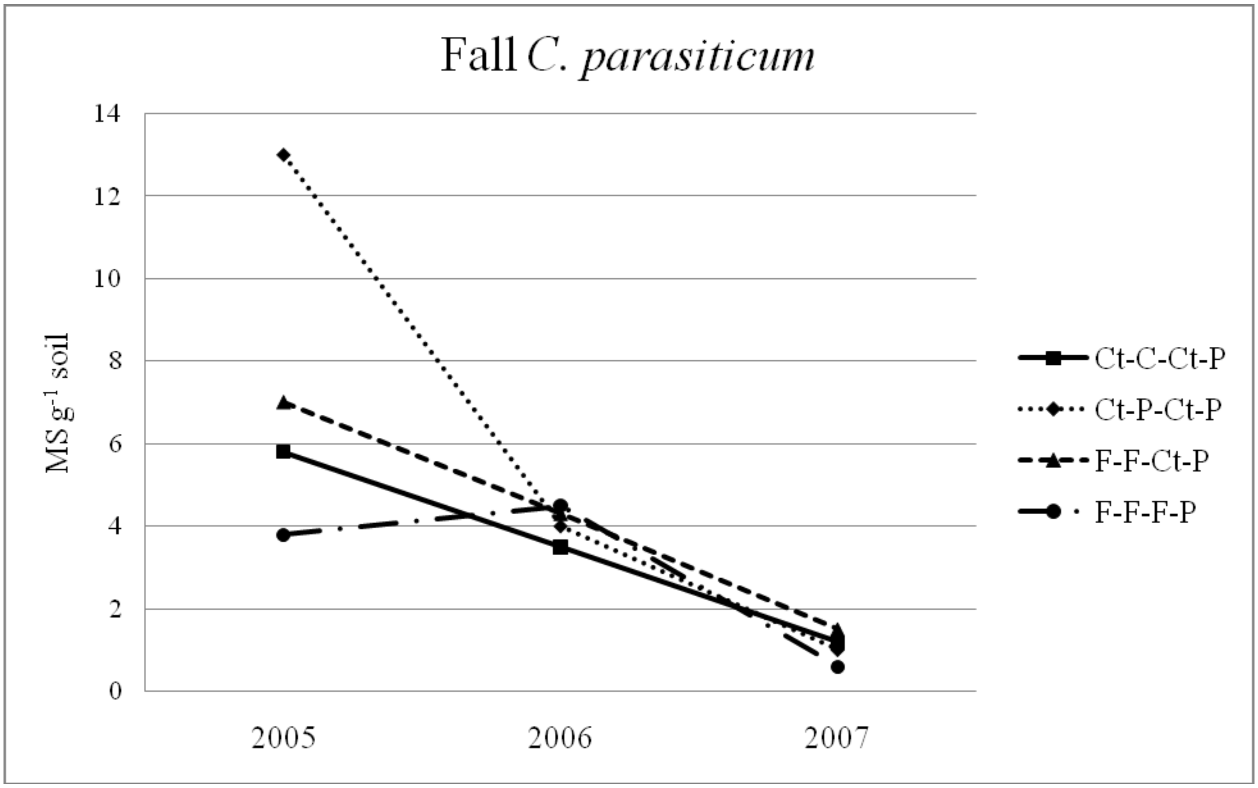


Figure 3.4. Levels of microsclerotia of *Cylindrocladium parasiticum* in the fall for 2005 through 2007 in selected rotations.

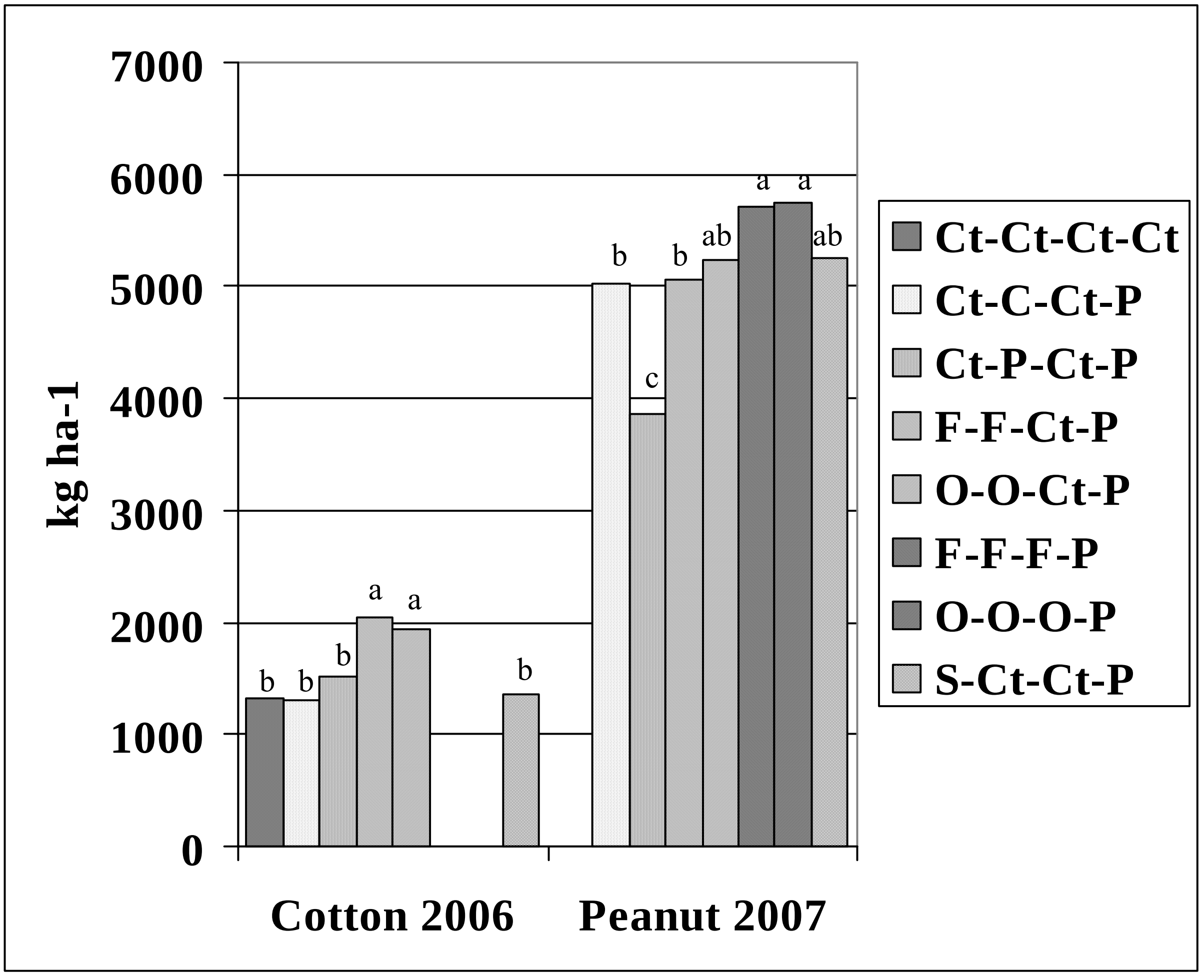


Figure 3.5. Cotton and peanut yields in 2006 and 2007 for each rotation. Cotton is kg lint ha^{-1} and peanut is kg whole dry pods ha^{-1}. Columns with the same letter do not significantly differ according to Fisher's LSD ($P \leq 0.05$).

CHAPTER 4

Summary and Conclusions

Perennial grasses in cotton (*Gossypium hirsutum* L.) and peanut (*Arachis hypogaea* L.) rotations significantly affected cotton and peanut development and yield when either crop followed a grass. Cotton and peanut growth was increased following perennial grasses compared to other crop rotations. Cotton yield was higher following 2 years of perennial grass compared to other rotations and peanut yield was higher following 3 years of perennial grass compared to most other rotations. Peanut following cotton in rotations with 2 years of perennial grass showed a lower rate of node accumulation, slower row closure and reduced yield compared to peanut that followed 3 years of grass. Growth and yield in 2-year perennial grass rotations was similar to some annual crop rotations but still higher than the Ct-P-Ct-P rotation. Based on these observations, the yield benefits for annual crops from growing perennial grass in rotation with them diminishes after the initial annual crop season following the grass, possibly due to the loss of grass residue over the annual cropping season leading to lower moisture conservation.

Though many aspects of soil quality were measured, observations of changes associated with the inclusion of perennial grass were limited because of the relatively short duration of the grass crop. Cone index (CI) measurements to indicate resistance to root penetration showed no observable decrease in CI values associated with perennial grass rotations. Variability in CI measurements resulted in no significant observations at depths below the compacted layer. However, the ability for annual crop roots to grow deeper following perennial grasses has not always been associated with lower CI values. Pores created in compacted layers by multiple years of perennial grass are thought to be channels that subsequent annual crops could explore. These channels would not necessarily be indicated by CI measurements. Deeper rooting has been observed when annual crops followed a perennial grass (Katsvairo et al., 2007a); however, rooting depth was not measured in this research.

There were only slight differences in soil carbon (C) and nitrogen (N) content and ratio in 2007 at the 0 - 2.5 cm depth. Soil C:N was lower following 3 years of perennial grass at the 0 - 2.5 cm depth compared to other rotations. Water stable aggregates were also significantly greater following 3 years of perennial grasses. Lower C:N and water stable aggregates at the 0 -

2.5 cm depth may be related because lower C:N indicates greater organic matter stability and stable organic matter is the "glue" which holds soil aggregates together. Stable soil aggregates are typically thought to increase water infiltration because of resistance to sealing during heavy rainfall events. More surface residue directly following perennial grass crops in addition to increased aggregate stability likely aided in prevention of sealing by reducing raindrop impact. Attempts to quantify differences in saturated water infiltration using double ring infiltrometers did not detect differences between perennial grass and row crop rotations and data showed high variability. During actual rainfall events perennial grass rotations always had less standing water between rows compared to conventional rotations, but this was only observed, and not quantified.

The soil measurement that possibly had the largest effect on crop growth was *in situ* moisture content. Numerically, soil moisture was higher in the peanut crop following 3 years of tall fescue (*Shedonorus phoenix* Scop.) compared to rotations with 2 years of tall fescue or Ct-P-Ct-P at all depths and for all 6 weeks. Measurements at 10 cm were not reported due to inconsistent sampling because of excessively dry soils. At all other depths and sampling events, with the exception of 20 cm and during one week at 30 and 40 cm, soil moisture was higher in peanut in 3-year tall fescue rotations compared to the other rotations measured. Differences in moisture content were possibly associated with more residue following 3 years of tall fescue which would have decreased evaporative losses. In 2-year tall fescue rotations residue was visually observed to have decreased during the 1 year of cotton in 2006 prior to peanut in 2007. In 2006, cotton following 2 years of tall fescue had similar surface residue to what was seen in peanut in 2007 following 3 years of tall fescue. If decreased evaporative loss was the main factor increasing soil moisture in August 2007, soil moisture may have been higher in cotton in 2006 following 2 years of tall fescue.

In general, root-knot nematode populations decreased when a crop other than peanut was brought into rotation. This suggests that the root-knot species present was *Meloidogyne hapla* (Chitwood) or possibly *M. arenaria* [(Neal) Chitwood] rather than southern root-knot nematode *M. incognita* [(Kofoid & White) Chitwood] as cotton is not a host to the former while peanut is a host. Aside from Ct-P-Ct-P that had the highest frequency of peanut among rotations, all other rotations had relatively equal effects on root-knot populations. Rotations with any duration of orchardgrass (*Dactylis glomerata* L.) tended to have the highest populations of stubby root nematode (*Tylenchorhynchus* spp.) whether measured in the spring or fall. Populations of stubby root nematode also tended to increase in orchardgrass rotations in the spring transition from orchardgrass to an annual crop following the destruction of the orchardgrass. This supports that orchardgrass may be an important host for stubby root nematodes and not the most suitable perennial grass where stubby root nematodes are a concern. Despite higher populations in orchardgrass, typically above risk thresholds, crop growth did not appear to be affected.

Primary inoculum (MS) of the soilborne pathogen, *Cylindrocladium parasiticum* (Creus, M.J. Wingfield & Alfenas), showed some differences among rotations over time, but differences were small and likely of no epidemiological significance in terms of disease. Counts of disease incidence in peanuts were low in all rotations in 2007, but included low incidence of southern stem rot (*Sclerotium rolfsii* Sacc.), Cylindrocladium Black Rot, Sclerotinia blight (*Sclerotinia minor* Jagger.), tomato spotted wilt virus (*Tomato Spotted Wilt Virus, Tospovirus*), early leaf spot (*Cercospora arachidicola* Horia), and web blotch (*Phoma arachidicola* Marasas, Pauer & Boerema). Cotton-P-Ct-P was expected to have the highest MS g^{-1} soil due to the higher frequency of a host crop; however, this was only observed once in this rotation following peanut in the spring of 2006. Increases in *C. parasiticum* MS may not have been seen following peanut in 2007 because of the dry season and the cultivar grown, Perry, may have also contributed to low *C. parasiticum* MS as it displays the best level of resistance to *C. parasiticum* that is available in Virginia-type peanut varieties. No differences were observed in actual incidence of disease in cotton or peanut following perennial grasses. Both 2006 and 2007 seasons were abnormally dry, which has been observed repeatedly to suppress diseases caused by most pathogenic fungi in the region. Incidence of *Aspergillus flavus* (Link ex Gray) and *A. fumigatus* (Fresenius) in seed and levels of aflatoxin in peanuts harvested in 2007 were not determined in peanut kernels from the various rotation schemes. However, the risk of aflatoxin would be expected to increase in peanuts grown under conditions of soil moisture stress which may have been lower in soils planted previously to perennial grasses.

Enhanced cotton and peanut growth and yield may have been associated with higher soil moisture content in annual crops following perennial grasses. Irrigation was not used in this research, and it is rarely used by producers in the Virginia peanut and cotton production area. Furthermore, 2006 and 2007 were abnormally dry. Had rainfall been timely throughout the season, yield differences may not have been observed. However, in non-irrigated production, having a crop following multiple years of a perennial grass could improve moisture conservation alleviating yield declines if timely rainfall did not occur over the growing season.

REFERENCES

Al-Kaisi, M.M., X. Yin, M.A. Licht. 2005. Soil carbon and nitrogen changes as influenced by tillage and cropping systems in some Iowa soils. Agric. Ecosyst. Environ. 10:635-647.

Ayers, A.R., H.E. Duncan, K.R. Barker, and M.K. Beute. 1989. Effects of crop rotation and non-fumigant nematicides on peanut and corn yields in fields infested with *Criconemella* species. J. Nematol. 21:268-275.

Baujard, P. and B. Martiny. 1995. Ecology and pathogenicity of trichorid species from the semiarid region of West Africa. Nematologica 41:98-105.

Bell, N.L. and R.N. Watson. 2001. Identification and host range assessment of *Paratylenchus nanus* (Tylenchida: Tylenchulidae) and *Paratrichodorus minor* (Triplonchida: Trichodoridae). Nematologica 3:483-490.

Benjamin, J.G., M. Mikha, D.C. Nielson, M.F. Vigil, F. Calderon, and W.B. Henry. 2007. Cropping intensity effects on physical properties of a no-till silt loam. Soil Sci. Soc. Am. J. 71:1160-1165.

Blake, G.R. and K.H. Hartge. 1986. Bulk density. pp. 363-375. *In*: A. Klute (ed.). Methods of Soil Analysis. Part I-Physical and Mineralogical Methods, 2nd Ed. Am. Soc. Agron., Madison, WI.

Blasingame, D.C. 2002. Cotton disease loss data base. Proc. Belt. Cot. Conf. 2002.

Boote, K.J. 1982. Growth stages of peanut (*Arachis hypogaea* L.). Peanut Sci. 9:35-40.

Bowen, K.L., A.K. Hagan, and J.R. Weeks. 1996. Soil-borne pests of peanut in grower's fields with different cropping histories in Alabama. Peanut Sci. 23:36-42.

Bradford, J.M. 1986. Penetrability. pp. 463-478 *In*: A. Klute (ed.). Methods of Soil Analysis. Part I-Physical and Mineralogical Methods, 2nd Ed. Am. Soc. of Agron., Madison, WI,.

Brenneman, T.B., P. Timper, N.A. Minton, and A.W. Johnson. 2003. Comparison of bahiagrass, corn, and cotton as rotational crops for peanut. Proc. Sod Based Cropping Systems Conf. 59-65.

Bullock, D.G. 1992. Crop-rotation. Critical Reviews in Plant Sciences. 11:309-326.

Cantonwine, E.G., A.K. Culbreath, and K.L. Stevenson. 2007. Characterization of early leaf spot suppression by strip tillage in peanut. Phytopathology. 97:187-194.

Cantowine, E.G., A.K. Culbreath, K.L. Stevenson, R.C. Kemerait, Jr., T.B. Brenneman, N.B. Smith, and B.G. Bullinex, Jr. 2006. Integrated disease management of leaf spot and spotted wilt of peanut. Plant Dis. 90:493-500.

Cetintas, R. and D.W. Dickson. 2004. Persistence and suppressiveness of *Pastueria penetrans* to *Meloidogyne arenaria* race 1. J. Nematol. 36:540-549.

Chapin, J.W. and J.S. Thomas. 2003. Burrower bugs (Heteroptera: Cydnidae) in peanut: Seasonal species abundance, tillage effects, grade reduction effects, insecticide efficacy, and management. J. Econ. Entomol. 96:1142-1152.

Conant, R.T., K. Paustian, and E.T. Elliott. 2001. Grassland management and conversion into grassland: Effects on soil carbon. Ecol. Applic. 11:343-355.

Crow, W.T. 2005. Diagnosis of *Trichodorus obtusus* and *Paratrichodorus minor* on turfgrasses in the Southeastern United States. Plant Health Progress. [Online]. Available at www.plantmanagementnetwork.org/pub/php/diagnosticguide/2005/stubby (verified 1 May 2008).

Daniel, J.B., A.O. Abaye, M.M. Alley, C.W. Adcock, and J.C. Maitland. 1999. Winter annual cover crops in a Virginia no-till cotton production system: II. Cover crop and tillage effects on soil moisture, cotton yield, and cotton quality. J. Cotton Sci. 3:84-91.

Dickerson, W.H. and B.E. Dethier. 1970. Drought frequency in the Northeastern United States. West Virginia University Agricultural Experiment Station Bulletin 595. West Virginia University, Morgantown, WV.

Elkins, C.B., R.L. Haaland, and C.S. Hoveland. 1977. Grass roots as a tool for penetrating soil hardpans and increasing crop yields. pp. 21-26. In Proc. 34th Southern Pasture and Forage Crop Improvement Conf., Auburn Univ., Auburn, AL. 12-14 Apr. 1977. USDA-ARS, New Orleans, LA.

Eltun, R., A. Korsaeth, and O. Nordheim. 2002. A comparison of environmental, soil fertility, yield, and economical effects in six cropping systems based on an 8-year experiment in Norway. Agric. Ecosyst. Environ. 90:155-168.

Faircloth, J.C., D.A. Herbert, P.M. Phipps, D.L. Coker, J.W. Pease, M. Roberts, and B.B. Ross. 2007a. 2007 Virginia peanut production guide. Virginia Polytechnic Institute and State University Cooperative Extension Publ. 432-101. J.C. Faircloth, ed. Virginia Polytechnic Inst. State Univ., Blacksburg, VA.

Faircloth, J.C., D.A. Herbert, P.M. Phipps, and M. Roberts. 2007b. 2007 Virginia cotton production guide. Virginia Polytechnic Institute and State University Cooperative Extension Publ. 424-300. J.C. Faircloth, ed. Virginia Polytechnic Inst. State Univ., Blacksburg, VA.

Ferguson, L.M. and B.B. Shew. 2001. Wheat straw mulch and its impacts on three soil borne pathogens of peanut in microplots. Plant Dis. 85:661-667.

Franzluebbers, A.J. 2007. Integrated crop-livestock systems in the Southeastern USA. Agron. J. 99:361-372.

Gale, W.J., C.A.Cambardella, and T.B. Bailey. 2005. Root-derived carbon and the formation and stabilization of aggregates. Soil Sci. Soc. Am. J. 64:201-207.

Gebhert, D.L., H.B. Johnson, H.S. Mayeux, and H.W. Polley. 1994. The CRP increases soil organic carbon. (Conservation Reserve Program). J. Soil Water Conserv. 49:488-493.

Gencsoylu, I. and I. Yalcin. 2004. Advantages of different tillage systems and their effects on the economically important pests, *Thrips tabaci* Lind. and *Aphis gossypii* Glov. in cotton fields. J. Agron. Crop Sci. 190:381-388.

Gentile, R.M., D.L. Martino, and M.H. Entz. 2005. Influence of perennial forages on subsoil organic carbon in a long-term rotation study in Uruguay. Agric. Ecosyst. Environ. 105:419-423.

Ghadiri H. and D. Payne. 1977. Raindrop impact stress and the breakdown of soil crumbs. J. Soil Sci. 28: 247–258.

Godsey, C.B., J. Vitale, J.P. Damicone, J.R. Sholar, J. Nickels, and J. Baker. 2007. Rotational effects in Oklahoma peanut production: Prospects for peanut rotations in the post-quota era. Agron. J. 99:1238-1244.

Greenberg, S.M., A.T. Showler, T.W. Sappington, and J.M. Bradford. 2004. Effects of burial and soil condition on postharvest mortality of boll weevils (Coleoptera: Curculionidae) in fall cotton fruit. J. Econ. Entomol. 97:409-413.

Hagan, A.K., L.H. Campell, J.R. Weeks, M.E. Rivas-Davila, and B. Gamble. 2003. Impact of bahiagrass, cotton, and corn cropping frequency on the severity of diseases of peanut. Proc. Sod Based Cropping Systems Conf. 46-58.

Hirunsalee, A., K.R. Barker, and M.K. Beute. 1995. Effects of peanut-tobacco rotations on population dynamics of *Meloidogyne arenaria* in mixed race populations. J. Nematol. 27:178-188.

Holdeman, Q.L. and T.W. Graham. 1953. Population trends of the sting nematode under different crops in greenhouse pot culture. Phytopathology. 43:291.

Hudson, B.D. 1994. Soil organic matter and available water capacity. J. Soil Water Conserv. 49:189-195.

IPCC (Intergovernmental Panel on Climate Change). 2007. Fourth Assessment. [Online]. Available at www.ipcc.ch (Verified 1 May 2008).

Isleib, T.G., P.W. Rice, R.W. Mozingo, II, J.E.Bailey, and H.E. Pattee. 2003. Registration of ‘Perry’ peanut. Crop Sci. 43:739-749.

Johnson, A.W., N.A. Minton, T.B. Brenneman, B.W. Burton, A.K. Culbreath, G.J. Gascho, and S.H. Baker. 1999. Bahiagrass, corn, cotton rotations, and pesticides for managing nematodes, disease, and insect pests. J. Nematol. 31:191-200.

Johnson, W.C., T.B. Brenneman, S.H. Baker, A.W. Johnson, D.R. Sumner, and B.G. Mullinex, Jr. 2001. Tillage and pest management considerations in a peanut-cotton rotation in the Southeastern coastal plain. Agron. J. 93:570-576.

Karlen, D.L., E.G. Hurley, S.S. Andrews, C.A. Cambardella, D.W. Meek, M.D. Duffy, and A.P. Mallarino. 2006. Crop rotation effects on soil quality at three northern corn/soybean belt locations. Agron. J. 98:484-495.

Katsvairo, T.W., D. L. Wright, J. J. Marois, D. L. Hartzog, J. R. Rich, and P. J. Wiatrak. 2006. Sod-livestock integration into the peanut-cotton rotation: A systems farming approach. Agron. J. 98:1156-1171.

Katsvairo, T.W., D.L.Wright, J.J. Marois, D.L. Hartzog, K.B. Balkcom, P.P. Wiatrak, and J.R. Rich. 2007a. Cotton roots, earthworms, and infiltration characteristics in sod-peanut-cotton cropping systems. Agron. J. 99:390-398.

Katsvairo, T.W., D.L. Wright, J.J. Marois, D.L. Harzog, K.B. Balkcom, P.P. Wiatrak, and J.R. Rich. 2007b. Performance of peanut and cotton in a bahiagrass cropping system. Agron. J. 99:1245-1251.

Kemper, W. D., and R. C. Rosenau. 1986. Aggregate stability and size distribution. pp. 425-442 *In*: A. Klute (ed.) Methods of Soil Analysis. Part I-Physical and Mineralogical Methods, 2nd Ed. Am. Soc. Agron., Madison, WI.

Kinnell, P.I.A. 2005. Raindrop-impact-induced erosion processes and prediction: A review. Hydrol. Process. 19:2815-2844.

Klute, A. 1986. Water retention: Laboratory methods. pp. 635-662 *In*: A. Klute (ed.) Methods of Soil Analysis. Part I-Physical and Mineralogical Methods, 2nd Ed. Am. Soc. Agron., Madison, WI.

Koenning, S.R., T.L. Kirkpatrick, J.L. Starr, J.A. Wrather, N.R. Walker, and J.D. Mueller. 2004. Plant-parasitic nematodes attacking cotton in the United States. Plant Dis. 88:100-113.

Manley, D.G., DuRant, J.A. Bauer, P.J., and Frederick, J.R. 2002. Rye cover crop, surface tillage, crop rotation, and soil insecticide on thrips numbers in cotton in the southeastern coastal plain. J. Agric. Urban Entomol. 19:217-226.

Monfort, W.S., A.K. Culbreath, T.B. Brenneman, D.W. Gorbet, and S.C. Phatak. 2004. Effects of reduced tillage, resistant cultivars, and reduced fungicide inputs on progress of early leaf spot of peanut (*Arachis Hypogaea*). Plant Dis. 88:858-864.

NASS (National Agricultural Statistics Service). 2007. Peanut acreage. [Online]. Available at www.nass.usda.gov/QuickStats (Verified 30 Oct. 2008).

NASS (National Agricultural Statistics Service). 2008. Cotton acreage years 1990 through 2007 in Virginia. [Online]. Available at www.nass.usda.gov/QuickStats (Verified 30 Oct. 2008).

Norden, A.J., V.G. Perry, F.G. Martin , and J. NeSmith. 1977. Effect of age of bahiagrass sod on succeeding peanut crops. Peanut Sci. 4:71-74.

Olness, A., and D. Archer. 2005. Effect of organic carbon on available water in soil. Soil Sci. 170:90-101.

Parajulee, M.N., R.B. Shrestha, and J.F. Leser. 2006. Influence of tillage, planting date, and Bt cultivar on seasonal abundance and within-plant distribution patterns of thrips and cotton fleahoppers in cotton. Int. J. Pest Management. 52:249-260.

Paustian, K., H. P. Collins, and E. A. Paul. 1997. Management controls on soil carbon. Soil organic matter in temperate agroecosystems. E. A. Paul, K. Paustian, E. T. Elliot, and C. V. Cole, editors. CRC Press, Boca Raton, Fl, USA. pp. 15–49.

Pankhurst, C.E., G.R. Stirling, R.C. Magarey, B.L. Blair, J.A. Holt, M.J. Bell, and A.L. Garside. 2005. Quantification of the effects of rotation breaks on soil biological properties and their impact on yield decline in sugarcane. Soil Biol. Biochem. 37:1121-1130.

Pettigrew, W.T. 2004. Moisture deficit effects on cotton lint yield, yield components, and boll distribution. Agron. J. 96:377-383.

Phipps, P.M., M.K. Beute, and K. R. Barker. 1976. An elutriation method for quantitative isolation of *Cylindrocladium crotalariae* microsclerotia from peanut field soil. Phytopathology. 66:1255-1259.

Phipps, P.M. and M.K. Beute. 1977. Influence of soil temperature and moisture on the severity of Cylindrocladium Black Rot in peanut. Phytopathology. 67:1104-1107.

Phipps, P.M. and M.K. Beute. 1979. Population dynamics of *Cylindrocladium crotalariae* microsclerotia in naturally-infested soil. Phytopathology. 69:240-243.

Plant Disease Clinic and Nematode Assay Lab. Virginia Tech. [Online] Available at www.ppws.vt.edu/~clinic/thresholds.html (Verified 1 May 2008).

Porter, D.M., F.S. Wright, and N.L. Powell. 1987. Effects of sprinkler irrigation on peanut diseases in Virginia. Plant Dis. 71:512-515.

Prechac, F.G., O. Ernst, G. Siri, and J.A. Terra. 2002. Integrating no-till into livestock pastures and crops rotation in Uruguay. Proc. 25th Annu. Southern Conserv. Tillage Conf. Sustainable Agric. 74-80.

Romkens, M.J.M., K. Helming, and S.N. Prasad. 2001. Soil erosion under different rain-fall intensities, surface roughness, and soil water regimes. Catena 46:103–123.

Sainju, U.M., B.P Singh, W.F. Whitehead, and S. Wang. 2006. Carbon supply and storage in tilled and nontilled soils as influenced by cover crops and nitrogen fertilization. J. Environ. Qual. 35:1507-1517.

SAS Institute. 2002. Statistical Analysis Systems. Version 9.1. SAS Inst., Cary, NC.

Shokes, F.M. and A.K. Culbreath. 1997. Early and late leaf spots. pp. 17-20 *In*: N. Kokalis Burelle, D.M. Porter, R. Rodriguez-Kabana, D.N. Smith, and P. Subrahmanyam (eds.). Compendium of Peanut Diseases, 2nd Edition. APS Press, St. Paul, MN.

Siri-Prieto, G., D.W. Reeves, and R.L. Raper. 2002. Conservation tillage systems for a cotton and peanut following winter-annual grazing. Int. Soil Tillage Res. Organ. Conf. 1143-1148.

Taylor H.M. and H.R. Gardner. 1963. Penetration of cotton seedling taproots as influenced by bulk density, moisture content, and soil strength. Soil Sci. 96:153-156.

Thies, J.A., A.D. Petersen, and D.K. Barnes. 1995. Host suitability of forage grasses and legumes for root-lesion nematode *Pratylenchus penetrans*. Crop Sci. 35:1647-1652.

Timper, P., D.M. Wilson, C.C. Holbrook, and B.W. Maw. 2004. Relationship between *Meloidogyne arenaria* and aflatoxin contamination in peanut. J. Nematol. 36:167-170.

Timper, P., N.A. Minton, A.W. Johnson, T.B. Brenneman, A.K. Culbreath, G.W. Burton, S.H. Baker, and G.J. Gascho. 2001. Influence of cropping systems on stem rot (*Sclerotium rolfsii*), *Meloidogyne arenaria,* and the nematode antagonist *Pasteuria penetrans* in peanut. Plant Dis. 85:767-772.

USDA (United States Department of Agriculture). 1948. United States standards for grades of cleaned Virginia type in the shell peanuts. [Online]. Available at www.ams.usda.gov/AMSv1.0/getfile?dDocName=STELPRDC5050495 (verified 23 June 2008).

USDA (United States Department of Agriculture). 1959. United States standards for grades of shelled Virginia type peanuts. [Online]. Available at www.ams.usda.gov/AMSv1.0/getfile?dDocName=STELPRDC5050498 (verified 23 June 2008).

Vepraskas, M.J. and M.G. Wagger. 1989. Cone index values diagnostic of where subsoiling can increase corn root growth. Soil Sci. Am. J. 53:1499-1505.

Virginia Cooperative Extension. 2007. Applied research on field crop disease control 2006. [Online]. Available at www.ext.vt.edu/pubs/plantdiseasefs/424-236/424-236.html (verified 1 May 2008).

VDACS (Virginia Department of Agriculture and Consumer Services). 2008. Virginia market news service. Hay and feed prices. [Online]. Available at www.vdacs.virginia.gov/marketnews/hay.shtml (verified 8 June 2008).

Williams, E. J., and G. E. Monroe. 1986. Impact blasters for peanut pod maturity determination. Trans. Am. Soc. Agric. Eng. 29**:**263–266, 275.

Williams, S.M. and R.R. Weil. 2004. Crow cover root channels may alleviate soil compaction effects on soybean crop. Soil Sci. Soc. Am. J. 68:1403-1409.

Wright, D.L., J.J. Marois, and P.J. Wiatrak. 2002. Perennial forage in rotation with row crops in the Southeast. Proc. 25th Annu. Southern Conserv. Tillage Conf. Sustainable Agric.. 87-92.