THE EFFECTS OF STRIP TILLAGE AND IRRIGATION IN PEANUT AND COTTON AND AN INVESTIGATION OF THE RELATIONSHIP BETWEEN COTTON SAP FLOW AND SOIL MOISTURE

By

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To my loving wife and best friend, Sara, for always being loving and supportive of everything I do

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Water availability for peanut and cotton has become a major limiting factor for production in the southeastern U.S. as rainfall has become less reliable and irrigation sources are being depleted. Conservation tillage, as well as irrigation, could provide relief during drought conditions. Additionally, irrigated cotton growers are in need of an accurate standard by which to schedule irrigation. Currently, soil moisture sensors are commonly used to support irrigation decisions but may not accurately represent crop water demand.

The objective of the first study was to compare the effects of strip tillage (ST), conventional tillage (CT) and irrigation on peanut and cotton production. The design was a randomized strip-plot using two cultivars of peanut (Florida-07 and Tifguard) and cotton (Phytogen 375 and 499). Irrigation increased yields in 2011 for both crops and all cultivars tested. In 2012, total rainfall during the growing season was much greater than 2011 (102 vs. 47 cm) and overcame potential differences between irrigated and non-irrigated treatments in either peanut or cotton. These findings indicate that ST may be a

viable option for irrigated or non-irrigated peanut and cotton growers in north central Florida, although there may be no yield benefit over CT.

The purpose of the second study was to quantify the relationship between soil moisture and cotton water use. The design was a complete randomized block design with irrigated and non-irrigated conditions. Sap flow and soil moisture measurements were logged continuously from 30 June 2012 until 30 July 2012 during the peak water use period for cotton. Soil moisture was measured at 20 and 60 cm depths to determine the depth of water uptake in the crop. Analyses showed a significant quadratic relationship in non-irrigated cotton sap flow with soil moisture at 60 cm only. This relationship indicates that plant water use is related to soil moisture at certain depths and that scheduling irrigation using the appropriate depth is critical.

CHAPTER 1
LITERATURE REVIEW

Water Conservation for Southeastern U.S. Cropping Systems

Peanut (*Arachis hypogaea* L.) and upland cotton (*Gossypium hirsutum* L.) are crops well adapted to the climate and environment of the southeastern United States. These two crops have proven to work well in rotation in many parts of the southeast (FL, GA, AL) and Virginia/Carolina region (SC, NC, VA), with over 566,800 hectares of peanut and 5.1 million hectares of upland cotton planted in 2012, respectively (USDA/NASS, 2012). The commodities produced from these crops are essential for meeting national and global needs for food and fiber as well as supporting local economies. Because of the critical economic importance of cotton and peanut, there is research that needs to be conducted investigating production methods that will maximize producers' profits and protect natural resources. A major factor that is currently affecting the profitability and sustainability of these two crops is water availability. Ground and surface waters are being depleted at alarming rates because of the expansion of urban water use, changes in precipitation patterns in the past 2-3 decades, and increased agricultural irrigation use as necessitated by changes in precipitation patterns and growing demand for agricultural products. Consequently, the agricultural sector has received much of the blame for the depletion of water resources because irrigated agriculture uses approximately 60% of the total water withdrawals in the U.S. (Kenny et al., 2009). Therefore, it is essential that agricultural practices maximize the efficiency of water use.

Part of the solution for improving water conservation in crop production is to utilize both rainfall and irrigation water in a way that maximizes the crop's water-use efficiency. This can partly be achieved by using conservation tillage, which is defined as, “Any tillage and planting system that covers 30 percent or more of the soil surface with crop residue…” (CTIC 2002). Conservation tillage consists of a variety of reduced tillage practices, often depending on climatic characteristics, soil types, crop species, and a variety of management factors including grower preference (Knowler and Bradshaw, 2007). All of these factors influence the amount of soil disturbance and crop residue within a conservation tillage system. Research on conservation tillage began in the 1930’s, where reduced tillage was shown to decrease soil loss from wind and water erosion (Cole, 1938). Since then, conservation tillage has been widely studied and adapted in the U.S. for its environmental and economic benefits. It is commonly used in corn and soybean production and to a lesser extent in other row crops such as cotton and peanut. The most common conservation tillage system in the southeast U.S. consists of utilizing winter cover crops to protect the soil against erosion and improve soil structure (Langdale et al., 1990). During the subsequent summer crop season, the winter crop residue can be rolled or left aboveground to provide a barrier against wind and water erosion as well provide some shade to inhibit weed seed germination during the growing season (Langdale et al., 1990). To plant the summer crop into the winter cover residue, many southeastern U.S. growers utilize a particular type of conservation tillage called strip tillage (ST). Strip tillage is an operation that typically tills 18-30 cm wide strips into the winter crop residue prior to planting. Planting will then occur in the middle of these tilled strips.

There are many purported benefits to conservation tillage that have been the subject of research over the past several decades. First, conservation tillage has been shown to increase soil water infiltration (Arshad et al., 1999; Dao, 1993; Franzluebbers, 2002; Thierfelder and Wall 2009). Franzluebbers (2002) conducted a study that compared the soil organic carbon and water infiltration rates between long term conventional till (CT) and no-till (a type of conservation tillage that involves direct seeding into an un-tilled soil surface) sites that had been in crop production for approximately 25 years. The no-till system in this study proved to have greater soil organic carbon at shallow depths and, thus, an infiltration rate that was 3 times greater than the soil under CT (Franzluebbers, 2002). Arshad et al. (1999) similarly found that long-term no-tillage lead to increased soil organic matter, which improved the soil structure, allowing for greater water infiltration as compared to CT. However, some studies have found that conservation tillage can decrease soil water infiltration (Lindstrom and Onstad, 1984; Unger, 1992) due to increased soil bulk density, penetrometer resistance, and presence of macropores in the top layers of soil. Other research demonstrates that conservation tillage can increase bulk soil volumetric water content (Blevins et al., 1971; Gantzer and Blake, 1978; Sullivan et al., 2007; Tollner et al., 1984), especially during the early season when surface evaporative losses of tilled soils are high (Zhai et al., 1990). Blevins et al. (1971) showed that under a no-till system, soil water was conserved to a greater degree than under CT to a depth of 60 cm; below which, no differences in soil moisture were detected. Gantzer and Blake (1978) also found that no-till increased soil water content as compared to CT in the top 30 cm of the soil profile, attributing the difference to increased evaporation in the loose soil of the conventionally tilled plots.

In addition to increasing plant available water in the soil, conservation tillage also has the capability to enhance rooting depth and root proliferation, possibly because of the formation of root channels formed by residual crop roots (Loison et al., 2012; Wright et al., 2004; Rasse and Smucker, 1998). A study in West Texas in which rooting characteristics were measured in peanut and cotton with a minirhizotron system found that cotton roots explored deeper soil depths and had much greater rooting development in ST than in CT (Rowland et al., 2008). This study concluded that the root channels left by the rye (*Secale cereale* L.) in the ST system likely provided space for cotton roots to explore deeper soil depths (Rowland et al., 2008). Other root studies comparing the effects of conservation and conventional tillage have been conducted on corn. Newell and Wilhelm (1987) conducted a study that examined corn root lengths near the soil surface (0-15 cm) and remaining rooting profile (15-150 cm) under irrigated, partially irrigated, and non-irrigated conditions in both CT and conservational tillage systems. Their results showed that under conservational tillage, root length was increased in both surface and deeper profile regions compared to CT. They also noted that non-irrigated roots tended to explore deeper into the soil profile and that conservation tillage may be a way to reduce irrigation requirements. Hilfiker and Lowery (1988) showed that reduced tillage increased corn root density as compared to CT, attributing the differences to increased wheel traffic in the CT plots. In contrast, Dwyer et al., (1996) showed that reduced tillage actually decreased the rooting depth of corn. This study compared root mass distribution in corn between CT and three forms of conservation tillage (chisel, ridge, and no-till). Root mass was estimated from soil cores and taken in 10 cm increments to a depth of 60 cm and it was found that rooting depth was increased under increased tillage. They surmised that since soil moisture was decreased in the top layers of soil under CT, roots were then encouraged to explore deeper soil depths (Dwyer et al., 1996).

Despite the benefits seen for some individual environmental characteristics in systems utilizing conservation tillage, impacts on overall crop yield have been variable. This is likely due to the wide variability in tillage operations that are classified as conservation tillage, as well as variability caused by environmental and management factors that are unique to particular regions and field characteristics. For example, a study in Virginia compared corn grain yield under no-till and CT and found that no-tillage increased yields by an average of 1523 kg ha^{-1} which was attributed to greater soil moisture within the top 30 cm of the soil profile (Jones et al., 1969). Shear and Moschler (1969) also conducted a study in Virginia and found that high corn grain yields could be maintained without rotation under no-tillage into a killed winter cover crop. Olson and Schoeberl (1970) conducted a study in North Dakota that compared three vastly different reduced tillage methods with CT including: planting directly into wheel tracks made into plowed soil, leaving the inter-rows in roughly plowed condition; a single blade opener prior to the planter which was similar to no-till; and the use of a lister to open a furrow to plant the seed. Despite these broad operational differences, there were no significant impacts on yield among the tillage treatments. A more recent study conducted in Georgia compared no-till and CT as well as synthetic and organic (poultry litter) forms of nitrogen and the effects on corn yield (Endale et al., 2008). This study found that no-till by itself increased grain yield by 11% and the combined effects of no-till and poultry litter increased grain yield by 18% as compared to CT and synthetic fertilizer. The increased yield from no-till was attributed to the 18% greater soil moisture in the top 10 cm of the no-till system. A study conducted in Idaho compared the effects of reduced tillage to CT systems on winter wheat production. They found that no-till yields were only 78% of conventional yields and attributed the yield decrease to impeded root growth and hindered exploration of deeper soil profiles (Hammel, 1995).

Overall, there are many studies that have shown a yield benefit from conservation tillage (Smiley and Wilkins, 1993; Wagger and Denton, 1989); while still others have shown that conservational tillage is detrimental to yield (Graven and Carter, 1991; Halvorson et al., 2006; Hammel, 1995.) In an effort to synthesize this variability among different study results, meta-analyses have been undertaken to determine overall yield impacts between conservation and conventional tillage. A meta-analysis was conducted to compare crop yields under conventional and conservation tillage in 47 different studies in Europe with a variety of crops (Van den Putte et al., 2010). The analysis showed no reduction in yield under reduced tillage operations (excluding no-till) for potato and sugar beets but a significant reduction in yield for grain corn, and to a lesser extent in other cereals. The reason for this is uncertain; however, these researchers believe that reduced tillage may hinder root proliferation and development in fibrous roots in cereals (Pietola, 2005; Quin et al., 2006). Miguez and Bollero (2005) conducted a meta-analysis of 37 studies in the United States and Canada and showed that the presence of a winter cover crop, regardless of subsequent tillage operations in the spring, increases the yield of corn, with a 21% increase for the use of a grass/legume mixture as compared to fallow conditions in the winter. The increase in corn yield was attributed to reduced soil erosion and improved tilth as well as reduced weed pressure (Miguez and Bollero, 2005).

Similar to the previous crops discussed above, the yield impacts of conservation tillage in peanut have been variable (Brandenburg, et al., 1998; Hurt et al., 2006; Marois and Wright, 2003; Tubbs and Gallaher et al., 2005; Zhao et al., 2009). Marois and Wright (2003) conducted a two year study to compare the effects of tillage on *Tomato spotted wilt virus* (TSWV) incidence in peanut, an economically important disease that is vectored by thrips (*Frankliniella sp.*). The first year of the study they found that conservation tillage in the form of ST had 50% less TSWV incidence than conventional till as well a significantly greater yield (2510 vs. 1900 kg per hectare); however the second year showed no differences in disease or yield. The first year of the study was a significantly drier year which resulted in up to 30% greater soil moisture in ST, likely contributing to increased yield that year (Marois and Wright, 2003). Tubbs and Gallaher (2005) conducted a two year study that compared peanut utilizing ST into terminated rye with CT and found no significant difference in peanut yields between the two tillage systems. Another study compared the yield of peanut strip-tilled into a terminated bahia grass sod with conventionally tilled peanut (Zhao et al., 2009) and found a yield benefit to ST one year out of the two year study. Conversely, other studies have shown negative effects of ST in peanut (Wright and Porter, 1995; Wright and Porter 1991; Colvin et al., 1988;) Colvin et al. (1988) conducted a study of several different tillage methods in peanut including no-till, strip till, and conventional till into cut wheat stubble. They found that yields were consistently higher in CT plots than in ST and no-till plots, attributing the result to lower water availability. The ST and no-till equipment included ripper or subsoil shanks which disrupted a shallow hardpan, resulting in drainage in these sandy soils which decreased water availability in the conservation tillage plots (Colvin et al, 1988). Finally, a 4-year study conducted in Virginia tested the yield effects of ST on three virginia-type cultivars, which have a more upright growth pattern and larger pods as compared to runner-type cultivars, and found that ST reduced peanut yields by 15% compared to CT (Wright and Porter, 1995).

In cotton, yields under ST have also been variable. Lascano et al. (1994) showed that in the high plains of Texas, ST reduced soil evaporation and increased crop transpiration leading to increased lint yield by 35% as compared to CT. This study also observed greater leaf area index during the early part of the season under ST as compared to CT. In contrast, a study in the Florida panhandle showed that ST cotton into wheat residue did not increase yield over CT (Wiatrak et al., 2005). Studies using other types of conservation tillage aside from ST, such as no-till, have a longer history in cotton. A study in northern Alabama showed that no-till increased lint yields as compared to conventional till by conserving soil moisture in the top 7 cm of the soil (Nyakatawa et al., 2000). Bauer et al. (2010) in coastal South Carolina conducted a six year study that coincided with a considerable five year drought (1998-2002) and found that no-till increased cotton yields in each year, except in the year with normal rainfall. These results indicate that no-till can be good insurance against drought conditions for non-irrigated farmers in that region. Other studies show either no differences in yield or decreased yield through the use of conservation tillage (Brown et al., 1985; Pettigrew and Jones, 2001; Stevens et al., 1992). Pettigrew and Jones (2001) conducted a study in the Mississippi delta which compared CT and no-till cotton. They found that no-till generally delayed emergence and canopy growth until mid-bloom, when leaf area indices reached those which were similar to CT. They saw an 11% decrease in lint yield under no-till, attributing this difference to fewer bolls per plant.

The variety of responses from peanut and cotton to ST and other types of conservation tillage are likely attributable to the wide range of environments and tillage systems where these conservation tillage systems have been tested. One major consideration that is not addressed in any of these studies is the quantification of the amount of cover crop residue in each conservation tillage system. This amount could have a major effect, given that the majority of the benefits in conservation tillage come from the presence of crop residue (Langdale et al., 1990). Although the definition of conservation tillage includes a requirement of 30% or more of soil surface to be covered in crop residue (CTIC, 2004), this requirement is not necessarily met in each of these studies claiming to test a form of conservation tillage. Additionally, soil types on which these studies were performed were broadly variable. Soil types ranging from clay loams to fine sands were used in these studies and the impact of different tillage types in these differing soils should be highly dependent on soil physical characteristics such as porosity and bulk density. With the exception of two (Colvin et al., 1988; Tubbs and Gallaher, 2005), none of these studies have been conducted in both a hot, humid environment in combination with sandy, drought prone soils. This is because the majority of peanut and cotton production in the southeast is not in north central Florida, and thus research has been focused elsewhere where production is greater.

Further, irrigation may be heavily contributing to the variability in yield results among studies on conservation tillage. Of the peanut and cotton studies mentioned above, three were irrigated throughout the season, three were partially irrigated, and five did not report the use of irrigation, implying irrigation was not used. None of these studies however, compared the use of ST with and without irrigation. The USDA Ag Census (2007) reported that there were over 1 million hectares of irrigated cropland in the southeastern U.S. where much of the country's peanut and cotton production occurs (Alabama, Florida, Georgia). It is generally understood that irrigation will improve yields for both crops (Masters and Lamb, 2003). An eight year study in Georgia showed that irrigation increased peanut yields 5 out of the 8 years and by an average of 569 kg ha^{-1} (Lamb et al., 1997). There were 3 years of the study in which irrigation had no significant impact on yield, but these years were characterized by considerable rainfall which reduced the amount of supplemental irrigation needed. Additionally, the study showed that the profitability of irrigation depended heavily on the annual commodity price (Lamb et al., 1997). Despite the benefit of irrigation on overall yield, many farmers do not have irrigation because of the high initial expense, high energy cost to run the systems, and the difficulty of obtaining permits to drill wells for aquifer withdrawals.

Because of the economic and environmental costs of irrigation, there is potential for decreasing the need for irrigation with conservation tillage and in particular ST. Strip tillage allows greater rainfall infiltration and storage in the soil thus reducing the amount of supplemental irrigation required (Arshad et al., 1999; Dao, 1993; Franzluebbers, 2001; Thierfelder and Wall 2009). A study in Georgia in 2007 was conducted to test the effects of simulated rainfall on conventional and conservation tillage studies across the state, where 90% of the conservation tillage in these studies was ST (Sullivan et al., 2007). They estimated that conservation tillage decreased irrigation requirements by 4-

14%. Although ST may decrease irrigation requirements, the degree to which ST impacts irrigation benefits has not been documented in additional studies or regions outside of Georgia. It is therefore imperative that further research be conducted to determine if ST can allow growers to reduce irrigation applications. Further, for non-irrigated growers, it is important to document possible increases in plant available water in an ST system.

If conservation tillage is to have any effects compared to CT on soil water relations, soil physical properties, and ultimately crop growth and yield, we would expect those to be found under the sandy conditions and environment of north central Florida where low water holding capacity soils are coupled with high temperatures and seasonally sparse rainfall. Under these conditions, the potential for differences between ST and CT should be high. Only a few of the studies mentioned above have investigated plant characteristics such as leaf area index, reproductive development, or rooting characteristics along with yield under these conservational tillage systems (Lascano et al., 1994; Pettigrew et al., 2004; Marois and Wright, 2003). The absence of these types of data to explain differences in yield prevent complete understanding of why peanut and cotton yields have been variable in conservation tillage. Therefore, there is a need for conservation tillage research in peanut and cotton on the sandy soils of north central Florida, and to study relevant crop responses to understand how this practice may effect crop production in a region that has great potential for improved water use efficiency.

The objective of this study is to compare the effects of strip tillage with and without irrigation on peanut and cotton yields in north central Florida. Additionally, this study will characterize the effect of tillage on soil moisture, soil temperature, leaf area index, peanut reproductive development, cotton petiole nutrition, and cotton root development, along with yield of both crops under these treatments.

Estimating Crop Water-use in Irrigated Systems

Cotton is an efficient user of water compared to other crops and has the potential to perform well even under water deficit (Ackerson & Krieg, 1977). However, the sandy, drought prone soils in some parts of the southeastern U.S. challenge the water-use efficiency of cotton, especially in years when rainfall is not timely or is reduced. It is therefore important for growers and researchers to understand how soil moisture is related to crop water use responses during changes in the soil moisture environment. Further, because many growers use supplemental irrigation, the relationship between soil moisture and crop water-use has important implications for irrigation scheduling because soil moisture sensors are commonly used for triggering water application. Irrigated growers have a deep responsibility for water conservation and resource stewardship because irrigated agriculture is a primary user of both surface and aquifer water sources (Hutson et al., 2004). This makes efficient irrigation scheduling critical to achieve sustainable water application systems.

There are a variety of irrigation scheduling techniques, from checkbook methods (Lundstrom and Stegman, 1988), evapotranspiration (ET) estimations (Wright and Jensen, 1978) and crop modeling (George et al., 2000); but many irrigation decision systems now rely solely on soil moisture estimations to determine crop water-use. Typically, a soil moisture threshold in terms of volumetric water content or soil matric potential is determined and soil moisture is monitored through the season, so that when levels fall below the threshold, irrigation is applied (Campbell and Campbell, 1982). The most common measure of soil moisture has been by measuring soil matric potential (SMP) and SMP sensors for irrigation scheduling have been shown to be effective for many crops including many vegetable crops (Thompson et al., 2007) and field crops such as cotton and rice (Vellidis et al., 2008; Kukal et al., 2005). In particular, Irrigator Pro for cotton, a commonly used irrigation scheduling system for cotton in the southeast (www.ars.usda.gov), utilizes gypsum block sensors for scheduling irrigation. However, in all of the irrigation scheduling systems utilizing measurements of soil moisture, the identification of accurate thresholds and soil depths which represent crop water use are essential. If soil moisture thresholds used for irrigation decisions are too high, the potential for improving water-use efficiency is removed. The key to optimizing water-use efficiency would be to insure there was an accurate match between soil moisture measurement and actual crop water use. Further, determining which soil depth represents the zone of active root activity and, thus is the most appropriate for soil moisture monitoring, is often not known and little studied. Despite the heavy reliance on soil moisture sensors for triggering irrigation, few studies have investigated and quantified the direct measure of soil moisture with crop water-use during the growing season to verify that soil moisture is an adequate surrogate for indicating crop water need.

To better understand the relationship between soil moisture and actual plant water use, a comparison between soil moisture dynamics and direct measurements of plant water use is needed. To measure water use directly on an individual plant, the heat pulse method can be used (Baker and van Bavel, 2006). The heat pulse method is able to calculate the flow of sap through the stem using an insulated collar containing a heating strip with one thermocouple on either side. The temperature difference between the thermocouples is measured several times per second, as well as the amount of time between the exertion of the heat pulse and the return of the sap to its initial temperature. These calculations, indexed to a stem diameter, provide a direct calculation of stem sap flow from a given plant (Smith and Allen, 1996). Cohen et al., (1988) demonstrated that the heat pulse method can be effectively used on cotton and Lascano (2000) demonstrated that cotton sap flow measurements can be more effective for irrigation scheduling than ET replacement models.

Water uptake and transpiration in cotton increases relative to canopy development so that the crop can transpire between 5-7 mm of water per day when the canopy is fully mature (Lascano and Baumhardt, 1996; Lascano, 2000). If cotton is under water deficit stress, however, osmotic adjustment will occur and transpiration will decrease (Oosterhuis and Wullschlegger, 1987). This would indicate that transpiration would be lower in a cotton plant that does not receive supplemental irrigation or has experienced some drought stress compared to a plant that receives ample irrigation. Measurements of sap flow in cotton have been used successfully to identify proper crop coefficients to calculate ET (Lascano, 2000) which could be used for scheduling irrigation. However if soil moisture methods are to be used, identification of the appropriate soil depths to monitor for irrigation scheduling is also essential to matching sap flow with measurements of soil moisture. Information about basic root architecture would be needed to accomplish this and could provide important insight into how to manage deficit irrigation in cotton production, in particular. Few studies relate root architecture to both direct and indirect measurements of crop water use (Taylor and Klepper, 1974; Lascano and van Bavel, 1984).

Therefore, what is needed to justify the use of soil moisture monitoring for cotton irrigation scheduling is a simultaneous measurement of soil moisture at varying depths and sap flow, combined with quantification of rooting architecture over time. To address this research need, the objective in this study was to correlate measurements of soil moisture at two depths that are likely active zones of water uptake for southeastern cotton (20 and 60 cm) with daily sap flow during the mid to late season, a period representing peak water use in the crop. Further, root growth and architecture were quantified and related back to patterns of soil moisture and water uptake rates that were observed. This information could then be used to confirm the utility of soil moisture sensors for scheduling irrigation in southeastern cotton.

CHAPTER 2
THE FEASIBILITY OF STRIP TILLAGE FOR WATER CONSERVATION IN PEANUT AND COTTON PRODUCTION IN FLORIDA

Summary

Water availability for peanut and cotton production has become and will continue to be a major production factor in the southeastern U.S., including Florida, as rainfall has become less reliable and irrigation sources are being depleted. Further, the deep sandy soils in many parts of the region critically exacerbate any water deficit experienced during the growing season. Conservation tillage coupled with irrigation could provide increased plant available water and ensure crop production even during drought conditions in this region. The objective of this 2-year study was to compare the effects of strip tillage (ST) and conventional tillage (CT) as well as irrigation on peanut and cotton production in the sandy soils of north central Florida. The study was located at the University of Florida's Plant Science Research and Education Unit in Citra, Florida. The design was a randomized strip-plot with tillage (CT and ST) as the main plots and irrigation (irrigated or non-irrigated) assigned to the sub plot, with three replications. Two cultivars of peanut (Florida-07 and Tifguard) and two cultivars of cotton (Phytogen 375 and 499) were used. In 2011, peanut cultivar Florida-07 produced fewer pegs per plant in ST. Irrigation increased yields in 2011 for both crops and all cultivars tested, with 15 and 19% increases for Florida-07 and Tifguard peanut cultivars; and 43 and 25% for Phytogen 375 and 499 cotton cultivars, respectively. In 2012, total rainfall during the growing season was much greater than 2011: 102 vs. 47 cm, minimizing potential differences between irrigated and non-irrigated treatments in either peanut or cotton. These findings indicate that ST may be a viable option for irrigated or non-irrigated peanut and cotton growers in north central Florida, although there may be

no yield benefit over CT. However, decreased fuel consumption associated with conservation tillage systems may make ST a sustainable option for this region even without significant yield increases.

Introduction

Water availability is a major factor affecting the success of peanut and cotton growers in the southeastern U.S., and because these two crops represent approximately 32% of total harvested crop acres in this region (USDA/NASS), increasing water-use efficiency is essential. Additionally, disputes over the use of water in the lower southeast (Alabama, Georgia, Florida) will continue to be an issue as the three states fight for access to water for residential, commercial and agricultural use (Ruhl, 2009). It is therefore imperative that peanut and cotton producers in the southeast maximize the water-use efficiency of their operations. One method of improving crop water-use efficiency is through the use of conservation tillage. Conservation tillage is defined as, “Any tillage and planting system that covers 30 percent or more of the soil surface with crop residue…” (CTIC 2002). Conservation tillage encompasses a range of tillage practices which are used to improve soil structure. This is compared to more intensive forms of tillage, considered conventional tillage (CT), which usually involve moldboard plowing and subsequent harrowing or cultivation. It has been demonstrated that conservation tillage can reduce run-off and can increase soil water infiltration (Arshad et al., 1999; Dao, 1993; Franzluebbers, 2001; Katsvairo et al., 2006; Thierfelder and Wall 2009) and increase volumetric soil water content (Blevins et al., 1971; Gantzer and Blake, 1978; Sullivan et al., 2007; Tollner et al., 1984), especially during the early season when surface evaporative losses from tilled soils are high (Zhai et al., 1990).

The most common conservation tillage system in the southeastern U.S. consists of utilizing winter cover crops to protect the soil against erosion and improve soil structure (Langdale et al., 1990). During the subsequent summer crop season, the winter crop residue can be rolled or left aboveground to provide a barrier against wind and water erosion as well as provide shade to inhibit weed seed germination during the growing season (Langdale et al., 1990). When planting the summer crop into the winter cover residue, many southeastern U.S. growers utilize a particular type of conservation tillage called strip tillage (ST). Strip tillage is an operation that typically tills 18-30 cm wide strips into crop residue prior to planting. The crop is then planted in the middle of the previously tilled strips. However, the yield effects of ST in the southeastern U.S. for peanut and cotton have been variable.

In peanut, both benefits and yield losses in ST systems have been documented (Brandenburg, et al., 1998; Hurt et al., 2006; Marois and Wright, 2003; Tubbs and Gallaher et al., 2005; Zhao et al., 2009). Marois and Wright (2003) conducted a two year study to compare the effects of tillage on *Tomato spotted wilt virus* (TSWV), an economically important disease that is vectored by thrips (*Frankliniella sp.*). They found that ST peanuts had 50% less TSWV incidence than CT as well as a significantly greater yield (2510 vs. 1900 kg ha^{-1}) in year one; however the second year showed no differences in disease or yield. The first year of the study was a significantly drier year which resulted in up to 30% greater soil moisture in ST, likely contributing to the increased yield that year. Similarly, Tubbs and Gallaher (2005) found no significant difference in peanut yields between ST and CT in a two year study conducted near Gainesville, FL. Another study compared the yield of peanut strip-tilled into a terminated bahia grass sod with conventionally tilled peanut (Zhao et al., 2009) and found a yield benefit from ST in one year out of the two year study. Conversely, other studies have shown negative effects of ST (Wright and Porter, 1995; Wright and Porter 1991; Colvin et al., 1988). Most relevant for the feasibility of the use of ST in Florida, Colvin et al. (1988) conducted a study near Williston, FL (within 20 miles of the experimental area in the current study) and found yields in CT were consistently higher than in ST and no-till plots, attributing the result to lower water availability. The ST and no-till equipment included ripper or subsoil shanks which disrupted a shallow hardpan, resulting in drainage in these sandy soils which decreased water availability in the conservation tillage plots.

In cotton, yields under ST have also been variable. Lascano et al. (1994) showed that in the high plains of Texas, ST reduced soil evaporation and increased crop transpiration, thereby increasing lint yield by 35% as compared to conventional tillage. This study also observed greater leaf area index during the early part of the season under ST as compared to conventional tillage. Relevant to Florida production conditions, a study in the panhandle showed that ST cotton did not increase yield over conventional tillage (Wiatrak et al., 2005). Some studies have shown that the benefits of ST are more prevalent under drought conditions. Bauer et al. (2010) in coastal South Carolina conducted a six year, non-irrigated study that coincided with a considerable 5-year drought (1998-2002) and found that no-till increased cotton yields in the five years of the study that were under drought conditions. These results indicate that the benefits of a conservation tillage system may be solely or mostly evident in dry production years.

Greater root proliferation under conservation tillage may be at least partially responsible for the enhanced benefits of reduced tillage under drought conditions. Along with increasing plant available water in the soil, conservation tillage also has the capability to enhance rooting depth and root proliferation because of the formation of root channels formed by crop roots (Katsvairo et al., 2006; Wright et al., 2004). A study in West Texas, in which rooting characteristics were measured on peanuts and cotton with a minirhizotron system, showed that cotton roots explored deeper soil depths and had much greater rooting development in ST than in CT (Rowland et al., 2008). Other root studies comparing the effects of conservation and conventional tillage have been conducted on corn. Newell and Wilhelm (1987) conducted a study that examined corn root lengths near the soil surface (0-15 cm) and remaining rooting profile (15-150 cm) under irrigated, partially irrigated, and non-irrigated conditions in both CT and conservational tillage systems. Their results showed that under conservation tillage, root length was increased in both surface and deeper profile regions compared to CT. They also noted that non-irrigated roots tended to explore deeper into the soil profile and that conservation tillage may be a way to reduce irrigation requirements. Hilfiker and Lowery (1988) also showed that reduced tillage increased corn root density as compared to CT, attributing the differences to increased wheel traffic in the CT plots. In contrast, Dwyer et al., (1996) showed that reduced tillage actually decreased the corn rooting depth. This study compared root mass distribution in corn between CT and three forms of conservation tillage (chisel, ridge, and no-till). Root mass was estimated from soil cores and taken in 10 cm increments to a depth of 60 cm and found that rooting depth was increased under increased tillage. They surmised that since soil moisture was decreased in the top layers of soil under CT, roots were then encouraged to explore deeper soil depths.

Because there is evidence that the benefits of ST may be enhanced under dry conditions, the interaction between irrigation and conservation tillage would be important to consider. The benefits of ST may be additively enhanced by irrigation; may disappear; or ST may be detrimental under irrigation. Very few studies have even considered the reciprocal action of conservation tillage and irrigation, yet describing the dynamic of these two production management strategies is critical for determining the water conservation potential of each alone, or in combination. Since the economic and environmental costs of irrigation are high and increasing, there is potential for decreasing the need for irrigation with the use of ST. Strip tillage allows greater rainfall infiltration and storage in the soil, thus possibly reducing the amount of supplemental irrigation required (Arshad et al., 1999; Dao, 1993; Franzluebbers, 2001; Thierfelder and Wall 2009). A study in Georgia in 2007 was conducted to test the effects of simulated rainfall on conventional and conservation tillage studies (90% of which utilized ST) across the state (Sullivan et al., 2007). They estimated that conservation tillage decreased irrigation requirements by 4-14%. Although ST may decrease irrigation requirements, it has not been documented in additional studies or regions outside of Georgia; nor is it widely thought of by producers as a primary reason for adopting ST. It is therefore imperative that further research be conducted to determine if ST can allow growers to reduce irrigation applications. Further, for non-irrigated growers, it is important to document possible increases in plant available water in an ST system.

The objective of this study was to compare the effects of tillage and irrigation on peanut and cotton production yield and grade. To understand the mechanisms behind the interaction of these two factors, this study quantified the root architecture, leaf area index, peanut reproductive development, and cotton petiole nutrition throughout the growing season.

Materials and Methods

Field Preparation and Crop Maintenance

Field plots were established at the University of Florida's Plant Science Research and Education Unit (PSREU) located near Citra, FL (29°24'28" N, 82°10'30" W, elevation 21 meters) on a Sparr fine sand (loamy, siliceous, subactive, hyperthermic Grossarenic Paleudults). Field trials were conducted in 2011 and 2012 using plots consisting of eight rows spaced at 0.91 m apart and 19.8 m in length in a randomized strip-plot design with tillage being the strip treatment and irrigation being the sub-treatment. Treatments included: two crops (peanut and cotton); two cultivars of each (Florida-07 and Tifguard for peanut; Phytogen 375 and Phytogen 499 for cotton); two tillage treatments (conventional and strip); and irrigated and non-irrigated conditions. Prior to the initial crop in 2011, 'Wren's Abruzzi' rye (*Secale cereal* L.) was planted in late December 2010 across the entire experimental area. At the senescence of the rye cover crop in March 2011, the rye was cut at a 0.2 m height with flail chopper and removed from the conventional tillage plots. Plots where then disked twice, turned with a moldboard plow and smoothed by disk harrow and field cultivator. During this same time period in the ST plots, the rye was rolled with a flat drum roller. In the fall of 2011, the rye cover crop was planted in mid-November only in the strip till plots, and the peanut and cotton plots were rotated with each other the following spring. Other field operations remained the same. The rye biomass dry weight was on average 10,500 and 6,550 kg ha^{-1} in 2011 and 2012, respectively.

After completion of field preparation, cotton and peanut were planted. In the first year of the study, both peanut and cotton were initially planted on 2 May 2011. However, due to an equipment issue which caused large skips in the peanut plantng, peanuts were replanted on 24 May 2011. The second year of the study peanut and cotton were planted on 17 April and 16 April 2012, respectively. The plots for both crops were planted with a two-row Monosem (Edwardsville, KS) planter with an intra-row seed population of 19.7 seed m^{-1} for peanut and 13.1 seed m^{-1} for cotton. The strip tilled cotton and peanut plots were tilled with a two-row KMC Rip Strip tiller (Tifton, GA) prior to planting. The tiller and planter were linked for cotton (in 2011 only) and were separate operations for peanut in both years.

Irrigation for peanut and cotton was scheduled according to measurements of potential evapotranspiration (ET) modified by a crop coefficient for peanut (FAO, 1998). The daily potential ET values, calculated from the Penman-Monteith model (Monteith, 1965), were obtained from the Florida Automated Weather Network (www.fawn.ifas.ufl.edu) located at the PSREU. The irrigation treatment was applied to replace ET losses minus rainfall. This was calculated from the following equation where K_c is the crop coefficient for peanut relating to growth stage and ET_p is the potential ET derived from a standard Penman- Monteith ET calculation:

$$ET = (K_c \times ET_p) - (Rainfall + Irrigation)$$

Management of pesticides, growth regulators, and fertilization was conducted according to University of Florida IFAS (Institute of Food and Agricultural Sciences) recommendations. Tables 2-1 and 2-2 identify the specific applications and timings of pesticides, growth regulators, and fertilizer. The peanut crops were managed exactly the same both years; however, cotton management varied slightly between years. Recommended bloom fertilizer based on petiole analyses were followed in 2011, but no plant response to additional N and K according to these recommendations occurred during that phase. Consequently the petiole recommendations were not followed in 2012 and a standard IFAS fertilizer recommendation was followed.

Yield was determined from four center rows within each eight row plot that were 15.2 m in length for both peanut and cotton. In 2011, peanuts were mechanically dug on 30 September (non-irrigated) and 3 October (irrigated). Both peanut and cotton were harvested mechanically using a two row peanut combine (Lilliston 7500, Lilliston Corporation, Albany, GA) and two row cotton picker (John Deere 9910, John Deere and Company, Moline, IL), respectively. Harvest occurred on 4 October (non-irrigated) and 14 October (irrigated) for peanut; while cotton was picked on 16 September (Phytogen 375) and 4 October (Phytogen 499). In 2012, peanuts were dug on 31 August (all) and cotton was picked on 12 September (all). Peanut samples were dried to 10% moisture content before recording yield weights. Lint yield was estimated using the relationship of 44.2% of seed cotton being lint weight based on an average lint yield obtain from ginning samples from a portion of the plots in 2011.

Plant and Soil Measurements

Soil moisture measurements at 10, 20, 30, 40, 60, and 100 cm depths were taken from in-row points with a capacitance probe three times per week from each plot to quantify soil moisture status in 2011 and 2012. The device used was the PR2 soil moisture probe from Delta-T technologies (www.delta-t.co.uk). In 2012 soil temperatures were logged every hour using a Hobo temperature pendant (Onset Computer Corporation; www.onsetcomp.com) buried at a depth of 7.5 cm. This depth recorded the soil temperature that represented the pegging environment.

Crop measurements included: root architecture in cotton; leaf area index (LAI) in peanut and cotton; reproductive development (number of flowers, pegs, and pods per plant) in peanut; and petiole nutrient levels in cotton. Root architecture was measured using a minirhizotron camera system (Bartz Technology Corp; www.bartztechnology.com) which allows *in situ*, non-destructive measurements of roots throughout the growing season. The technology uses acrylic access tubes inserted within and parallel to a crop row at a 45 degree angle from the plane of the soil. This tube allows access to a camera that images the roots growing along the top surface of the tube which can then be analyzed on a computer program for characteristics including rooting depth, root length, and root surface area. The images are taken along the tube at the same locations over time so changes in these parameters during the growing season can be quantified. Within two weeks after planting, 12 minirhizotron tubes were installed into strip and conventional tillage plots in irrigated cotton plots. Images were taken for the cultivar Phytogen 375 WRF approximately once per month in 2011 beginning on 23 June and repeated on 2 August and 1 September; and once every three weeks in 2012 on 25 May, 15 June, 6 July, 26 July, and 9 August. Individual root image analyses were grouped into 10 zones (0-9), each zone encompassing consecutive 10 cm depth sections beginning at the surface of the soil. Images were analyzed using the WinRHIZO Tron software (Regent Instruments, Inc., Canada) for values of total root length (TRL) and total root surface area (TSA). Leaf area index was measured using the LAI 2200 (LiCor Environmental Sciences; Lincoln, NE) approximately every two weeks beginning on 29 June and ending on 30 August in 2011; and beginning on 6 June and ending on 9 August in 2012. Leaf area index was measured in the peanut cultivar Florida-07 and the cotton cultivar Phytogen 499 (in 2011 and 2012) and Phytogen 375 (in 2012) in each tillage and irrigation treatment. The number of peanut flowers, pegs and pods were recorded on a per plant basis in both cultivars by sampling 3 plants per plot every week once flowering began, and continuing until approximately 90 days after planting (DAP). Cotton petioles from Phytogen 499 (in 2011and 2012) and Phytogen 375 (in 2012) were collected once per week during the 9 week bloom period beginning on 27 and 20 June 2011 and 2012, respectively; samples were analyzed by Water's Agrilab (www.watersag.com; Camilla, GA) for levels of nitrate, phosphate, potassium and sulfur.

Statistical Analysis

Data were analyzed using Generalized Linear Mixed Models for a randomized strip plot design using JMP 9.0 software (SAS Institute Inc., Cary, NC). Tillage, irrigation level, date (when applicable), and all interactions were treated as fixed effects and replication and all interactions between replication and fixed effects were treated as random effects. Years were analyzed separately because the year effect was significant at $P < 0.001$. For root analyses, each depth zone (0-9) was analyzed separately for the effects of tillage and irrigation.

Results and Discussion

The 2011 and 2012 cropping seasons proved to be very different in terms of total rainfall with 47 cm (cotton) and 42 cm (peanut) in 2011 and 102 cm (cotton and peanut) in 2012. Greater rainfall in 2012 is mostly attributed to several tropical storms that occurred in July and August of 2012.

Yield and Grade

In 2011 overall peanut yields were substantially less than in 2012 with the average across all plots being 3740 kg ha^{-1} in 2011 and 6172 kg ha^{-1} in 2012 (Table 2-2). The decreased yields in 2011 were likely due to the late replanting which may have increased the heat stress and disease pressure in the late summer. In 2011, tillage type did not affect yield in either peanut cultivar; while irrigation increased pod yield in Florida-07 by an average of 15% (540 kg ha^{-1}) and in Tifguard by an average of 19% (639 kg ha^{-1}). Conversely, irrigation and tillage had no effect on peanut yields in 2012 (Table 2-3). The lack of an irrigation effect in 2012 is probably because of rainfall received (102 cm) during that year that was absent in 2011 (40 cm). Grade was not affected by tillage or irrigation in either cultivar or year; average farmer grades were 72.8 and 74.3 for Florida-07 and Tifguard, respectively (Table 2-4).

Normally, irrigation has a significant benefit to peanut yield in the southeast, but is highly dependent on annual precipitation. A 3-year study in Georgia showed that sprinkler irrigation increased peanut yields by an average of 906 kg ha^{-1} but benefits were absent in the last year of the study when rainfall was high (Lamb et al., 2004). Additionally an 8-year study in Georgia showed that irrigation increased peanut yield and grade 5 out of the 8 years and by an average of 569 kg ha^{-1} (Lamb et al., 1997). The current study results are in agreement with the utility of irrigation being evident primarily in 2011 when precipitation amounts were relatively low.

In this study, there were no significant differences between ST and CT. This is not surprising because the effects of ST on peanut yield have been variable across studies. Some have found ST to be beneficial to yield (Brandenburg, et al., 1998; Hurt et al., 2006; Marois and Wright, 2003; Zhao et al., 2009); while others have found it to be detrimental; (Wright and Porter, 1995; Wright and Porter 1991; Colvin et al., 1988); or to have no benefit (Tubbs and Gallaher, 2005; Wiatrak et al., 2004). The cases in which ST was beneficial, yield increases were attributed to: decreased insect feeding; decreased *Tomato spotted wilt virus*; and increased soil water content and soil water infiltration. Of the two studies that were conducted on soils in the same region as the current study in north central Florida, one showed no effect on yield (Tubbs and Gallaher, 2005) and one showed a slight decrease (Colvin et al., 1988). Similar to Tubbs and Gallaher (2005), the current study found that ST did not affect yield.

In contrast to peanut, cotton yields were much lower in 2012 than in 2011 with average yields of 1453 and 712 kg ha^{-1} (Table 2-2). The reason for the decrease in yield is unclear; however heavy rains in 2012 during squaring and boll formation may have leached nutrients in the sandy soils resulting in N and K deficiency as shown in petiole sampling taken during the bloom period of each year (Figure 2-13). In 2011, irrigation increased yields by 43% and 25% in Phytogen 375 and Phytogen 499, respectively (Table 2-3). Increased yield due to irrigation in 2011 is supported by other data that report irrigation can substantially increase yield in dry years (Masters and Lamb, 2003) by reducing water stress which can limit production and retention of cotton bolls (Guinn and Mauney, 1984). Tillage type did not affect lint yield in 2011; however, there was an interaction between tillage and irrigation for Phytogen 499 in 2011, where irrigation increased yields in ST but not in CT. In 2012, neither tillage nor irrigation affected lint yield in either cultivar. As with peanuts, the lack of an impact of irrigation in 2012 may in part be due to increased precipitation that year. In our study ST showed no effect on lint yield in either year. Others have similarly found no yield advantage to ST or other types of conservation tillage (Brown et al., 1985; Pettigrew and Jones, 2001; Stevens et al., 1992; Wiatrak et al., 2005). Brown et al. (1985) conducted a study that compared CT with no-till cotton and found that no-till reduced yields unless additional N was applied. In contrast, the study by Wiatrak et al. (2005) showed that cotton lint yields were similar between ST and CT. The benefit to cotton yield by ST may only be evident in regions where the vapor pressure deficit is high (unlike the conditions in the current study) and the often increased soil moisture in ST may translate into a yield advantage. For example, Lascano et al. (1994) in Texas showed that ST reduced soil evaporation, increased crop transpiration, and thereby increased lint yield by 35% as compared to conventional tillage in this semi-arid environment.

In-season Plant and Soil Characteristics

Soil environmental conditions and overall crop physiological functioning were similar across irrigation and tillage treatments in both years of the study. This supports the yield results and indicates that tillage and irrigation did not have a dramatic impact on soil conditions and the resulting crop performance. Further, it appears that both peanut and cotton cultivars reacted similarly to the tillage and irrigation treatments, indicating that there is consistent cultivar performance under north central Florida environments.

Over both years, soil moisture in irrigated peanut and cotton plots appeared to remain higher than non-irrigated plots for the majority of the season (Figures 2-1, 2-2, 2-3, 2-4). Further, soil moisture trends tended to be higher at the 10, 20 and 30 cm depths under CT as compared to ST in both crops. This may have been related to greater water infiltration in the ST because of the open pore spaces left by decaying cover crop residue. Consequently, ST may have had greater water storage at the deeper depths (40, 60 and 100 cm) in the irrigated peanut and cotton plots and may explain the often higher soil moisture readings at these depths (particularly in the cotton) in the ST compared to the CT plots (Figures 2-1, 2-2, 2-3, 2-4). Despite the immense rainfall in 2012, these trends were still very noticeable.

Shallow soil temperatures generally seemed to be greater in non-irrigated plots than irrigated plots throughout the season, likely because of the cooling effects of irrigation in both peanut and cotton (Figures 2-5, 2-6). The rye mat in the ST plots appeared to decrease shallow soil temperatures throughout the season but with the greatest effects seen in the beginning of the season prior to canopy closure when the CT plots would have higher evaporative losses and temperature increases due to incident solar radiation.

The responses of peanut flower, peg and pod development to tillage and irrigation appear to be very similar for both the cultivars Florida-07 and Tifguard. The only disparity between 2011 and 2012 in flower, peg, and pod production was for Florida-07 which had more pegs and pods produced in irrigated plots and more pegs in CT plots. This slight disparity between years was likely caused by the major differences in rainfall between 2011 and 2012; with less rainfall in 2011 perhaps increasing the impact of irrigation on improved peg and pod numbers, at least for Florida- 07. Differences in reproductive development between tillage and irrigation occurred more commonly in Florida-07 than in Tifguard, indicating that Florida-07 may be more sensitive to environmental changes that are related to plant available water. For example, Rowland et al. (2007) conducted a two year study on peanut reproductive development and found that in one year ST increased number of flowers per plant as compared to CT. This increase, however, did not result in a greater number of total pegs per plant.

When examining the patterns of individual reproductive structure, some differences due to date were the most prominent. Flower production during both years and for both cultivars was not affected by tillage or irrigation (Table 2-5); however, there were differences among sampling dates in both years as would be expected because flower production typically increases over the season, reaches a peak, and begins to decline (Rowland et al., 2007). In 2011, peak flower production was reached at approximately 59 DAP for both cultivars (Figures 2-7, 2-8); while in 2012 this peak occurred 74-78 DAP for Florida-07 and 78 DAP for Tifguard (Figures 2-9, 2-10). The difference in peak flowering between years was likely caused by the cooler air temperatures linked to increased precipitation experienced in 2012 which could have delayed the physiological maturity of the peanut plants (Johnson and Thornley, 1985). Since heat units accumulated faster in 2011 (data not shown), peanut flowering occurred earlier in than in 2012. The number of pegs per plant was affected by both tillage and irrigation for Florida-07 but not Tifguard (Table 2-5). Over the season in 2011, Florida-07 irrigated treatments had an average of 4.4 more pegs per plant than did non-irrigated treatments and CT treatments had an average of 2.4 more pegs per plant than did ST. In 2011 and 2012, peg numbers were significantly different among dates for both cultivars and the pattern was for more pegs across the season up to the last measurement date (Figures 2-7, 2-8, 2-9, 2-10). Similar to pegs, the number of pods per plant was affected by irrigation for Florida-07 in 2011 (Table 2-5); on average, this cultivar had an increase of 3 pods per plant throughout the measurement period in irrigated plots, and on the last date of measurement, the pod numbers were on average 26 and 14.5 pods per plant in irrigated and non-irrigated plots, respectively (Figure 2-7). This increase in pod numbers per plant was evidenced in the increased yield under irrigated conditions. Pod numbers were not significantly affected by tillage for either cultivar in both years; or by irrigation in either year for Tifguard (Table 2-5). The lack of effect of irrigation on Tifguard pod numbers in 2011, however, was not congruent with the 19% increase in yield that occurred. This could be because the weekly pod samples included any pod that was at the match-head stage (about 5 mm diameter) or larger. Since there was no size differentiation during the sampling, it could be that the non-irrigated plots had greater numbers of smaller pods that never reached maturity, explaining how the pod number per plant was not affected by irrigation and yet the final yield was. Sampling date had an effect, with pod production initiating in 2011 and 2012 in both cultivars approximately 51-60 DAP and increasing over time nearly linearly to the last measurement date (Figures 2-7, 2-8, 2-9, and 2-10). Leaf area index for both peanut and cotton was not affected by tillage or irrigation in either 2011 or 2012 but was different among sampling dates (Table 2-6). For the peanut cultivar Florida-07 in 2011, LAI increased linearly up to the last measurement date (98 DAP), while in 2012, it reached a peak at 80 DAP and began to decrease (Figure 2-11). Peak values in both years approached 7.00. Cotton LAI for both cultivars tended to peak at 80 DAP in both years with the average LAI being 1.10 higher in 2011 than in 2012 (Figure 2-12). This difference in years was likely due to nutrient leaching caused by more than double the amount of rainfall in 2012 as compared to 2011. This effect is evidenced in the overall lower levels of nitrate and potassium levels in petioles sampled during the bloom period (Figure 2-13). The effects of tillage on peanut LAI have not been previously documented to date. This lack of information provokes the need for more research on the effects of ST on peanut phenology. Canopy development and closure may be a concern for some growers considering adopting ST, since canopy closure is necessary for effective weed management and disease prevention in some cases. The current study indicates that ST will not reduce canopy closure in peanut. For cotton, the research on cotton canopy development under CT and reduced tillage systems is also limited and variable. A study in the high plains of West Texas reported that plant height and LAI were greater under ST than under CT in the early part of the season; after which, the difference between the two tillage treatments was negligible (Lascano and Baumhardt, 1996). This study suggested that the early season benefit was attributed to the protective qualities of the cover crop residue for the cotton seedlings against harmful strong winds and insect injury. A study in the Mississippi Delta has shown the opposite effect: no-till significantly reduced LAI in cotton only in the pre-bloom and mid-bloom growth stages, after which LAI in no-till was similar to that of CT (Pettigrew and Jones, 2001). The current study showed that ST had no effect on cotton LAI, which is important considering that excessive canopy growth can make mechanical harvesting difficult and reduced canopy can limit yield potential, especially in the humid southeastern production regions.

There were minor impacts on cotton petiole nutrient levels by tillage and irrigation in both 2011 and 2012; of the 4 nutrients tested (nitrate, potassium, phosphorous, and sulfur) only K and P content were affected by irrigation or tillage (Table 2-7). Potassium levels were increased by irrigation in 2011 and 2012 for the cultivar Phytogen 499 and in 2012 for Phytogen 375 (Figure 2-13). Conversely, there were effects of tillage only for phosphorus in 2012 in the cultivar Phytogen 375 where ST increased P uptake (Figure 2-15). In general, irrigation increased petiole K levels and tillage increased petiole P levels in 2012. There were strong effects of sampling date on most nutrients measured in both years and cultivars; petiole nutrients generally decreased during the 9 week bloom period in 2011 and 2012 (results for K shown as an example of seasonal trends, Figure 2-14). This seasonal trend is indicative of mobilization of leaf nutrients towards the bolls (Hsu et al., 1978; MacKenzie et al., 1963). The lack of a strong effect of tillage is similar to results found by Ishaq et al. (2001), where no-till and CT were shown to have no effect on leaf N, P, or K over the two year study. These findings indicate that ST does not appear to change nutrient uptake in cotton, but irrigation can be beneficial in increasing K uptake.

Root development in cotton was much greater during 2012 than in 2011 with total root length (TRL) reaching a maximum of 1300 mm in 2012 compared to 600 mm in 2011 (Figures 2-15 and 2-16). This is surprising considering the overall decreases in LAI from 2011 to 2012 (Figure 2-12). ANOVA revealed no differences between ST and CT in TRL or total surface area (TSA) in 2011 or 2012 either by zones or over the entire rooting profile (Table 2-8). When examining the distribution of the roots throughout the soil profile, it did appear that ST generally had more roots than CT at deeper depths in 2011 during the middle of the season (92 DAP, Figure 2-17) and throughout the season in 2012 (Figure 2-18). This deeper rooting habit in ST may have been influenced by available soil moisture: the data in the ST plots indicated greater soil moisture at deeper depths (40-100 cm) than CT.

Other research on cotton rooting in ST or any type of conservation tillage is very limited. In one study, comparing ST and CT cotton using a minirhizotron system in west Texas, it was found that ST increased TRL in cotton in the single year that the study was conducted (Rowland et al., 2008). Other studies in corn have shown that conservation tillage increases overall root length and rooting depth (Hilfiker and Lowery, 1988; Newell and Wilhelm, 1987), possibly by crop roots inhabiting root channels left by decaying cover or previous crop roots (Rasse and Smucker, 1998). Similarly, it has been shown that a rye cover crop preceding cotton has the ability to reduce compaction and increase rooting in cotton compared to deep tillage (CT) which increased compaction and hindered root growth (Busschler and Bauer, 2003). The current study's results indicate that ST did not increase overall root length or depth in cotton, but it did have an impact on overall architecture by increasing TRL at deeper depths compared to CT in the second year of the study. This characteristic may be vital for dryland cotton producers in years when rainfall is limiting. A deeper rooting system would allow the crop to exploit water at depths that would otherwise be inaccessible. A key point from this study is that roots under ST were much deeper during the second year of the study indicating that the tillage history may be an important factor in improving root growth. The effects of reduced tillage take time to accumulate, which indicates that two years may not be long enough to fully realize the benefits of ST on cotton rooting.

Summary

The objective of this study was to determine if an ST tillage system was a viable option for irrigated and non-irrigated peanut and cotton growers in north central Florida with possible application to other areas with deep, sandy soils. Additionally, the study sought to characterize the effects of this system on: canopy and root development of cotton; reproductive development in peanut; and cotton nutrition. We found that responses were somewhat different between years, likely related to differences in total precipitation during the growing season. In 2011, irrigation increased yield in all crops and cultivars, as well as benefited peanut peg and pod production (Florida- 07 only) and increased K uptake in cotton (Phytogen 499). The only effects of tillage in either year was in 2011 where ST decreased average peg numbers per plant in the cultivar Florida-07 and in 2012 where ST increased P content in cotton petioles. In 2012, irrigation did not have any effects on peanut or cotton. Our data suggest that ST, with or without irrigation, is a viable option for peanut and cotton growers in north central Florida, but that benefits achieved by conservation tillage in other regions may not be evident unless conditions of water scarcity are particularly severe. However, overall fuel costs may be reduced in ST due to decreased equipment operations, which may override the lack of differences in yields and make ST a more sustainable choice for growers in this region. Irrigation may benefit peanut and cotton yields in north central Florida; however, in wet years like 2012, it does not appear to be needed for optimal production.

Table 2-1. Cotton and Peanut Management. List of pesticide and fertilizer applications. Note that * indicates L/ha of product applied and ** indicates kg/ha of product applied. The symbol "---" indicates that these treatments were not applied during that particular year.

DAP (2011/2012)	Pesticide	Fertilizer
Cotton		
0/0	8.4 **phorate	
2/2	2.34 *pendamethalin	560** 3-9-18
16/16	2.34 *glyphosate	
44/36	0.01 *trioxysulfuron	
38/---		180** 15-5-20
---/37		60** 15-5-20
---/48		60** 15-5-20
51/---	1.16 *mepiquat-chloride	
---/54	2.34 *glyphosate	
64/---	0.15 *acetamiprid	180** 15-5-20
	1.16 *mepiquat-chloride	
---/64		180** 15-5-20
72/94	0.23 *spinetoram	
---/91	0.87 *pyraclostrobin	
80/---		118** 15-0-15
---/94		11** 20-20-20(foliar)
---/100		11** 20-20-20(foliar)
---/104		11** 20-20-20(foliar)
Peanut		
0/0	8.4 **phorate	
2/2	2.34 *pendimethalin	560 ** 3-9-18
	0.03 *diclosulam	
14/14	2.34 *s-metolachlor	0.03 ** boron
	1.16 *paraquat	0.03 ** boron
30/30	1.75 *chlorothalonil	
45/45	1.75 *chlorothalonil	
	1.75 *imazapic	
58/58	0.58 *prothioconazole	
72/72	1.46 *azoxystrobin	
	1.17 *clethodim	
86/86	0.88 *chlorothalonil	
	5.25 *tebuconazole	
100/100	8.76 *pyraclostrobin	
114/114	1.75 *chlorothalonil	

Table 2-2. Peanut and Cotton Yield. Pod and lint yield in kg/ha separated by tillage, irrigation and year.

		Conventional Irrigated	Conventional Non-Irrigated	Strip Irrigated	Strip Non-Irrigated
Florida 07	2011	3819	3229	4343	3854
	2012	6339	6245	6495	6233
Tifguard	2011	3812	3003	4201	3732
	2012	6412	5808	6305	5655
PHY 375	2011	1623	1149	1511	1043
	2012	629	560	803	540
PHY 499	2011	1640	1423	1874	1389
	2012	897	788	759	742

Table 2-3. ANOVA of Peanut and Cotton Yield. F values for treatment effects on pod and lint yield in 2011 and 2012.

2011 Effect	df	FL 07	Tifguard	PHY 375	PHY 499
Tillage	1	1.2765	1.5822	0.5479	0.6571
Irrigation	1	50.1653*	25.9873*	48.7537*	0.0355*
Tillage*Irrigation	1	0.1091	4.3984	0.0289	0.0109*
2012					
Tillage	1	0.0609	1.6435	17.2991	0.9181
Irrigation	1	0.6930	6.3249	9.8476	0.4859
Tillage*Irrigation	1	0.4359	0.0351	2.4929	0.1622

* indicates P < 0.05

Table 2-4. Peanut Grades. Farmer stock peanut grade values (recorded as percent total sound mature kernels, or TSMK) represented by the sum of sound mature kernels (SMK) and sound split (SS) kernels.

		Conventional Irrigated	Conventional Non-Irrigated	Strip Irrigated	Strip Non-Irrigated
Florida 07	2011	74.3	73.5	72.4	74.5
	2012	71.2	71.9	73.0	71.9
Tifguard	2011	75.5	74.6	74.2	73.1
	2012	75.1	74.0	73.9	74.1

* indicates P < 0.05

Table 2-5. ANOVA Peanut Flower, Peg, and Pod Counts. F values of treatment effects on peanut flower, peg, and pod counts per plant for Florida 07 and Tifguard cultivars in 2011 and 2012.

2011		Florida 07			Tifguard		
Effect	df	Flowers	Pegs	Pods	Flowers	Pegs	Pods
Date	6	14.4608*	56.4679*	41.5511*	28.6374*	44.2960*	39.5252*
Tillage	1	0.3858	21.6582*	2.6503	4.6110	0.2595	18.3775
Irrigation	1	3.5011	20.8991*	48.9496*	0.3001	7.6127	2.0847
Tillage*Irrigation	1	9.5526	1.0710	0.0079	0.6975	2.9910	0.5129
Tillage*Date	6	3.7776*	1.7283	1.5097	1.3240	0.6497	1.6480
Irrigation*Date	6	1.7410	4.2434*	7.7318*	2.7501	1.5480	1.8289
Irrigation*Date*Tillage	6	0.4007	6.2651*	0.8095	0.4108	0.9868	2.2101
2012							
Date	7	11.9492*	181.1202*	228.8256*	8.1914*	126.9580*	404.1850*
Tillage	1	1.4089	0.0931	1.8909	1.5819	4.2284	1.1675
Irrigation	1	0.1737	0.0278	3.0424	0.3387	0.2955	0.8015
Tillage*Irrigation	1	0.0135	0.0052	0.4472	0.2139	1.2564	85.1654*
Tillage*Date	7	1.2406	0.4388	0.1606	1.4747	7.4925	0.3744
Irrigation*Date	7	1.9218	1.0641	2.2492	1.1025	0.1920	0.6754
Irrigation*Date*Tillage	7	0.5747	0.1513	0.1276	1.1278	0.5393	1.09924

* indicates $P < 0.05$

Table 2-6. ANOVA Leaf Area Index. F values for treatment effects shown for leaf area index in peanut cultivar FL 07, and cotton cultivars Phytogen 375 and 499.

		2011		2012		
Effect	df	FL 07	PHY 499	FL 07	PHY 499	PHY 375
Date	4	102.7521*	19.6374*	187.1246*	24.1956*	11.2034*
Tillage	1	5.3460	0.0041	0.0544	0.8277	0.2304
Irrigation	1	2.0436	0.8446	9.6862	3.8891	3.2750
Date*Tillage	4	0.6371	0.5974	0.3109	0.7003	1.0991
Date*Irrigation	4	3.6301	0.2093	1.7605	0.1340	0.1477
Date*Irrigation*Tillage	4	0.5928	0.8777	0.1207	0.0619	0.2239
Irrigation*Tillage	1	0.1838	0.8773	1.9032	1.0302	1.8334

* indicates $P < 0.05$

Table 2-7. ANOVA Cotton Petiole Samples. F values of treatment effects on potassium, nitrate, phosphorous, and sulfur contents of cotton petiole samples over the 9 week bloom period in 2011 and 2012 by cultivar.

PHY 499 2011		K	NO^{3-}	P	S
Effect	df	*F value*	*F value*	*F value*	*F value*
Week	8	119.1902*	30.4558*	110.9888*	53.5469*
Tillage	1	7.6235	0.0042	0.2693	0.2516
Irrigation	1	23.1002*	18.1060	0.4227	0.1484
Week*Tillage	8	0.2401	0.4475	0.7852	1.9736
Week*Irrigation	8	11.6017*	6.2510*	1.1348	1.3340
Tillage*Irrigation	1	0.2676	0.0293	0.0077	0.0000
Week*Irrigation*Tillage	8	1.1752	0.1990	2.0242	1.0971
PHY 499 2012					
Week	8	168.9524*	2.3194	9.5875*	19.7539*
Tillage	1	0.0030	1.2565	11.5554	1.3044
Irrigation	1	19.6053*	3.1072	8.8840	10.5369
Week*Tillage	8	1.5585	0.7105	0.5836	0.2803
Week*Irrigation	8	3.8413*	2.5689	2.9008*	1.8802
Tillage*Irrigation	1	1.6226	1.2706	2.7153	0.1364
Week*Irrigation*Tillage	8	0.1457	1.1608	1.0302	0.3637
PHY 375 2012					
Week	8	76.1559*	6.3588*	2.2290*	10.4626*
Tillage	1	4.1845	5.7348	158.8375*	0.0908
Irrigation	1	22.8082*	0.0191	78.5832*	15.4755
Week*Tillage	8	2.0318	0.0149	2.8173*	0.8208
Week*Irrigation	8	2.9894*	1.8336	1.5650	0.3381
Tillage*Irrigation	1	1.2262	0.0149	0.0119	4.2518
Week*Irrigation*Tillage	8	3.2876*	0.0948	0.3692	0.3755

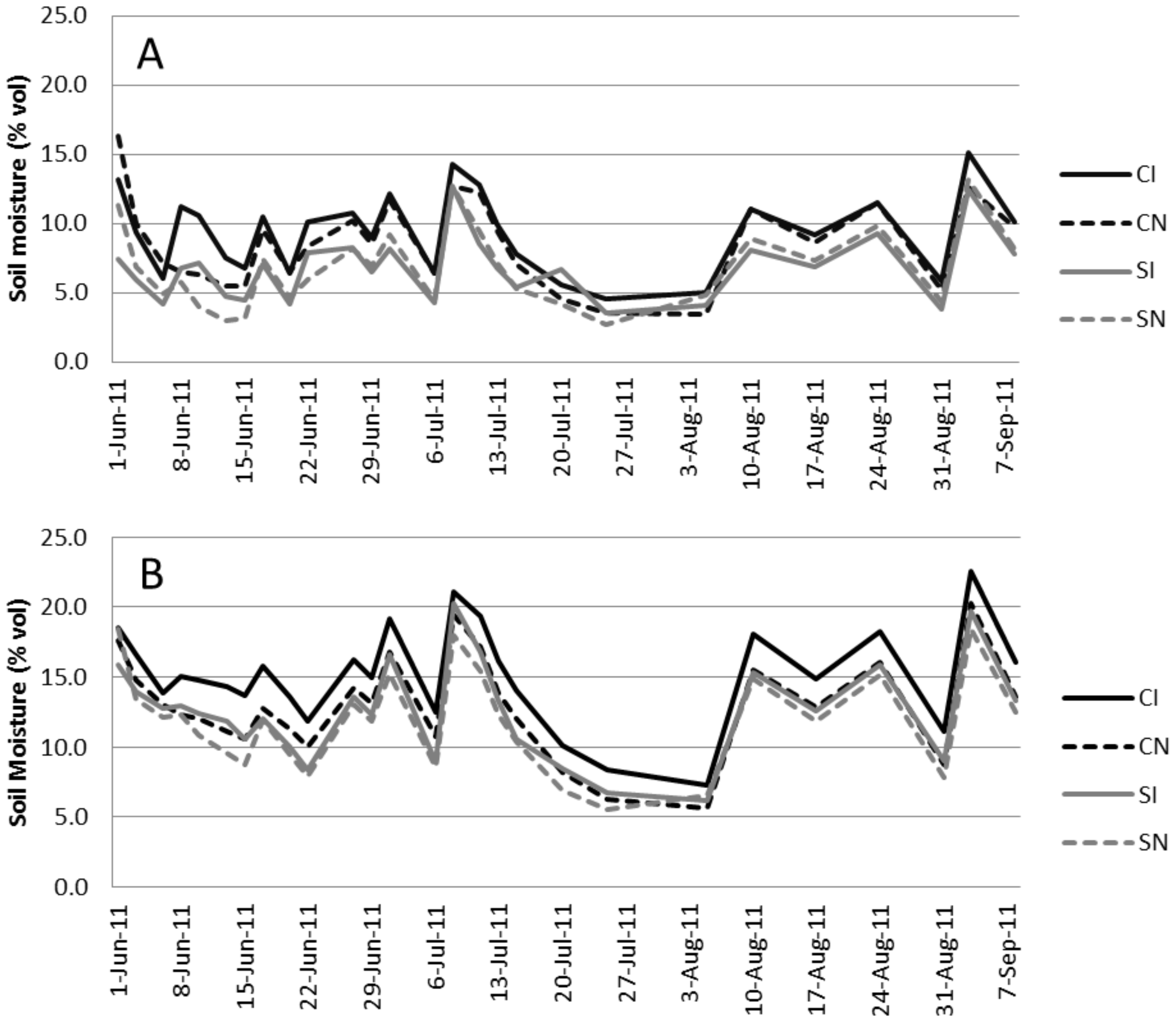
* indicates P < 0.05

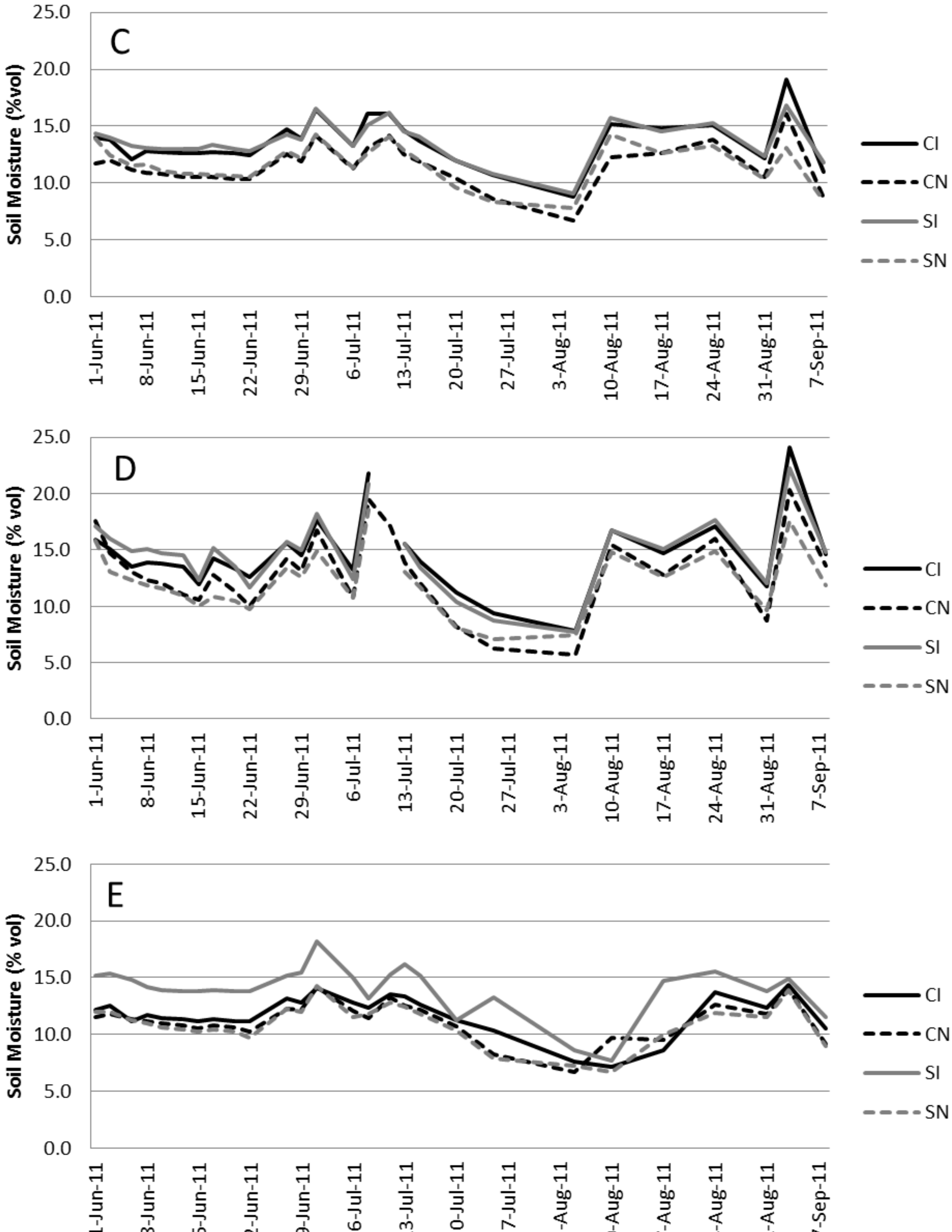
Table 2-8. ANOVA Cotton Root Architecture. F values for treatment effects on cotton total root length (TRL) and total surface area (TSA) in 10 cm depth increments indicated by zone numbers (0-9) in 2012 and 2012.

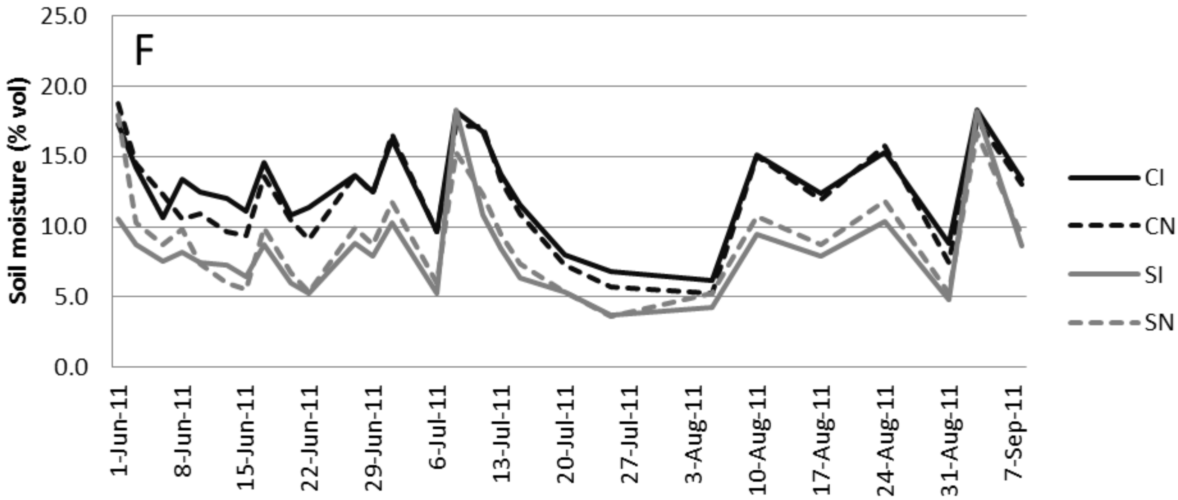
2011											
		Zone 0		Zone 1		Zone 2		Zone 3		Zone 4	
Effect	df	TRL	TSA	TRL	TSA	TRL	TSA	TRL	TSA	TRL	TSA
Tillage	1	0.1134	0.0114	1.6999	0.0079	2.7012	0.3162	3.6831	2.0408	0.0523	0.4016
Date	3	0.4862	0.1369	2.0406	2.4097	2.6333	6.0325	2.2453	1.0615	3.7971	2.7640
Date*Tillage	3	0.4827	0.5442	0.5935	0.1363	0.8946	1.4217	1.0124	0.8817	0.0746	0.3849
		Zone 5		Zone 6		Zone 7		Zone 8		Zone 9	
Effect	df										
Tillage	1	0.8195	1.1483	0.6096	0.6984	0.2370	0.0859	0.8038	0.8784	--	--
Date	3	5.8884	5.2694	1.2806	1.3223	1.7072	2.3703	0.8986	0.9379	--	--
Date*Tillage	3	0.2667	0.5402	0.7000	0.6895	0.5217	0.2723	1.1088	1.0647	--	--
2012											
		Zone 0		Zone 1		Zone 2		Zone 3		Zone 4	
Effect	df										
Tillage	1	0.9349	1.9109	0.0187	0.1370	5.0834	1.5293	0.1335	0.1556	0.0555	0.0244
Date	3	9.0415*	0.9370	11.2236*	25.5163	5.9725	4.6054*	19.3116*	11.3940*	6.0615*	4.3551*
Date*Tillage	3	2.3344	0.6586	0.4071	0.1803	0.2344	0.2906	0.8506	0.5733	0.4300	0.2275
		Zone 5		Zone 6		Zone 7		Zone 8		Zone 9	
Effect	df										
Tillage	1	0.5353	0.7734	7.5640	4.0008	3.2934	0.2413	1.0115	1.1083	0.0078	0.2425
Date	3	3.1942	2.2371	8.8957*	4.8101*	1.5463	0.2724	1.3609	1.4651	1.5388	1.7688
Date*Tillage	3	0.5051	0.5757	5.2838*	3.6275	2.0525	0.2213	0.7800	0.7759	0.4452	0.3356

* indicates $P < 0.05$

Figure 2-1. 2011 Soil Moisture in Peanut. Average soil moisture readings at 10 (A), 20 (B), 30 (C), 40 (D), 60 (E) and 100 (F) cm depths in peanut throughout the 2011 cropping season shown in the conventional tillage irrigated (CI), conventional tillage non-irrigated (CN), the strip tillage irrigated (SI), and the strip tillage non-irrigated (SN).

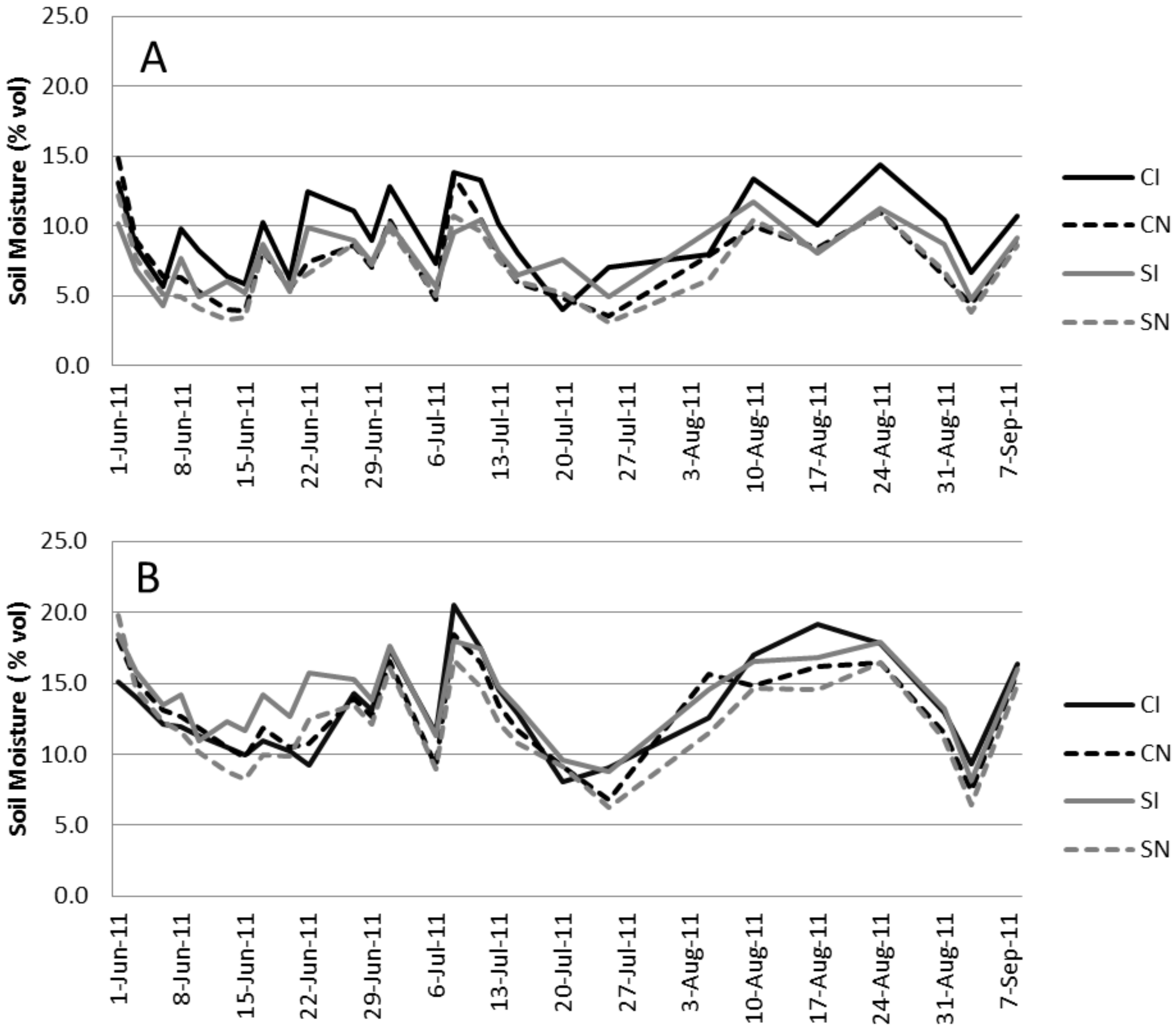


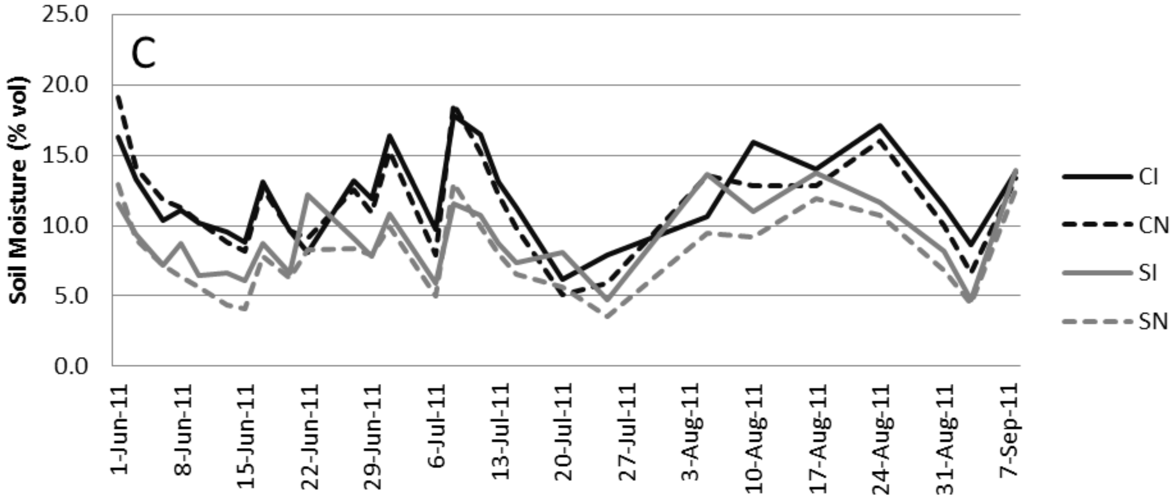

C
D
E
Soil Moisture (%vol)
Soil Moisture (% vol)
Soil Moisture (% vol)
0.0
5.0
10.0
15.0
20.0
25.0
1-Jun-11
8-Jun-11
15-Jun-11
22-Jun-11
29-Jun-11
6-Jul-11
13-Jul-11
20-Jul-11
27-Jul-11
3-Aug-11
10-Aug-11
17-Aug-11
24-Aug-11
31-Aug-11
7-Sep-11
CI
CN
SI
SN

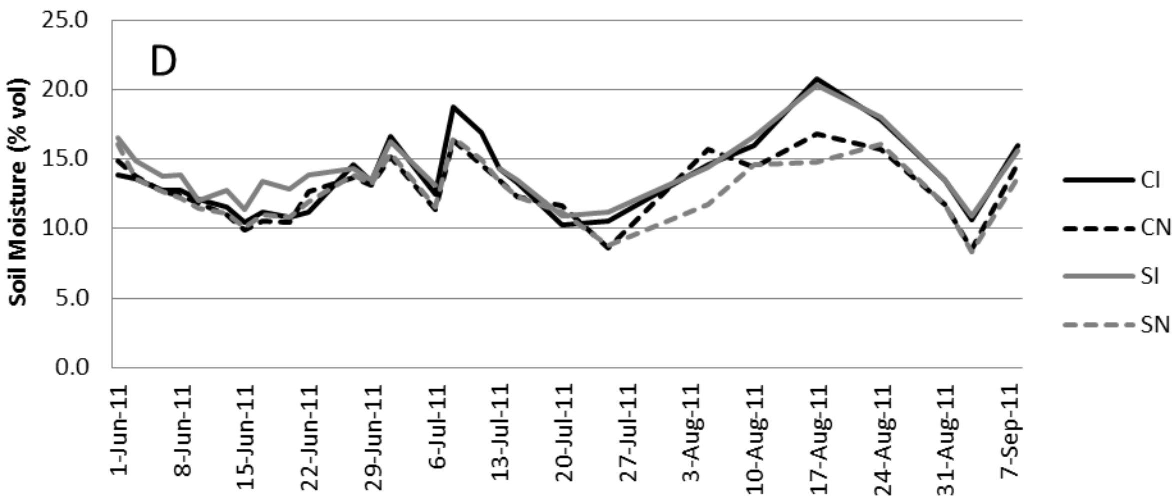


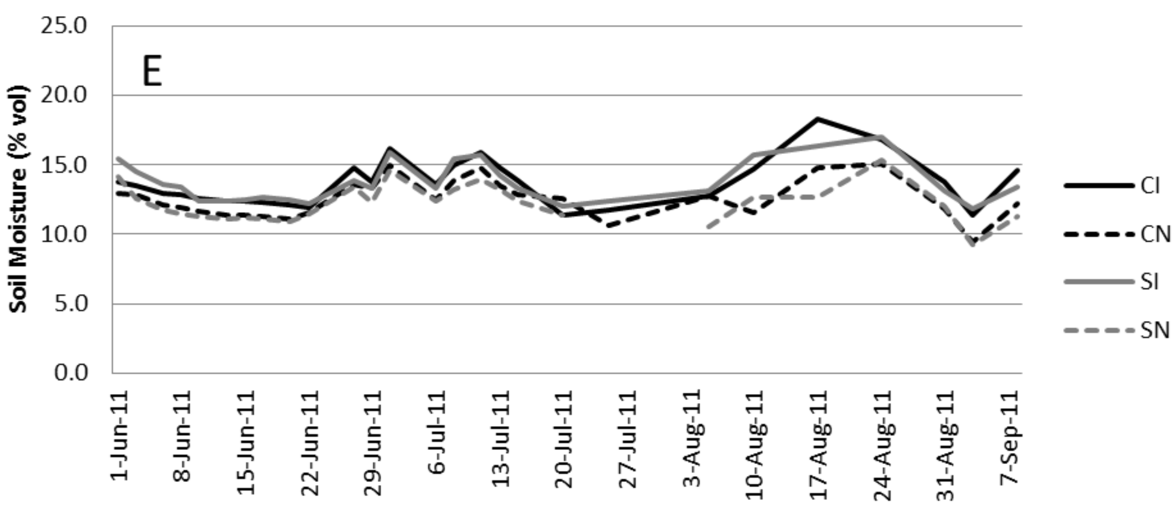
F
Soil moisture (% vol)
25.0
20.0
15.0
10.0
5.0
0.0
1-Jun-11
8-Jun-11
15-Jun-11
22-Jun-11
29-Jun-11
6-Jul-11
13-Jul-11
20-Jul-11
27-Jul-11
3-Aug-11
10-Aug-11
17-Aug-11
24-Aug-11
31-Aug-11
7-Sep-11
CI
CN
SI
SN

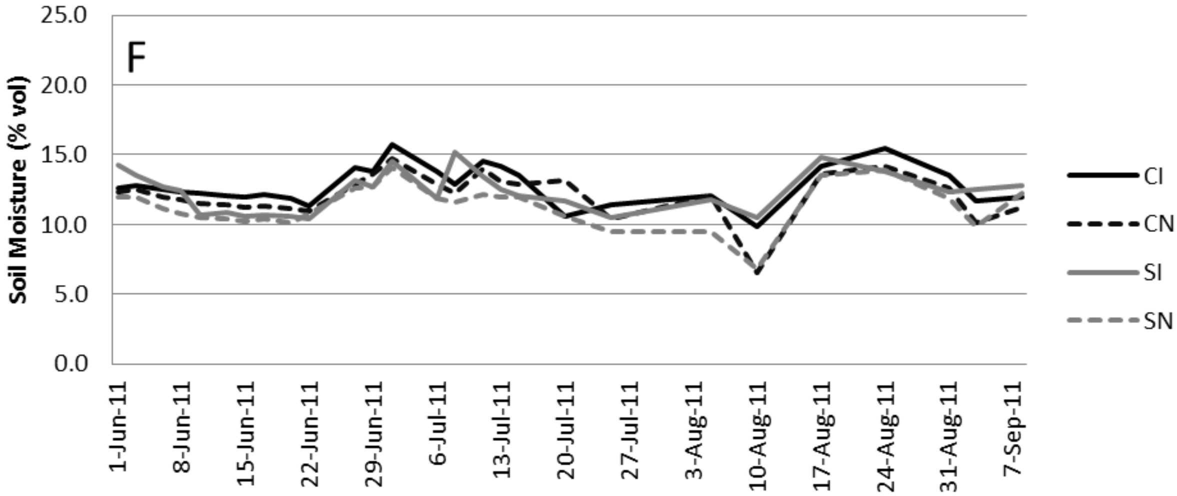
Figure 2-2. 2011 Soil Moisture in Cotton. Average soil moisture readings at 10 (A), 20 (B), 30 (C), 40 (D), 60 (E) and 100 (F) cm depths in cotton throughout the 2011 cropping season shown in the conventional tillage irrigated (CI), conventional tillage non-irrigated (CN), the strip tillage irrigated (SI), and the strip tillage non-irrigated (SN).




C
Soil Moisture (% vol)
25.0
20.0
15.0
10.0
5.0
0.0
1-Jun-11
8-Jun-11
15-Jun-11
22-Jun-11
29-Jun-11
6-Jul-11
13-Jul-11
20-Jul-11
27-Jul-11
3-Aug-11
10-Aug-11
17-Aug-11
24-Aug-11
31-Aug-11
7-Sep-11
CI
CN
SI
SN

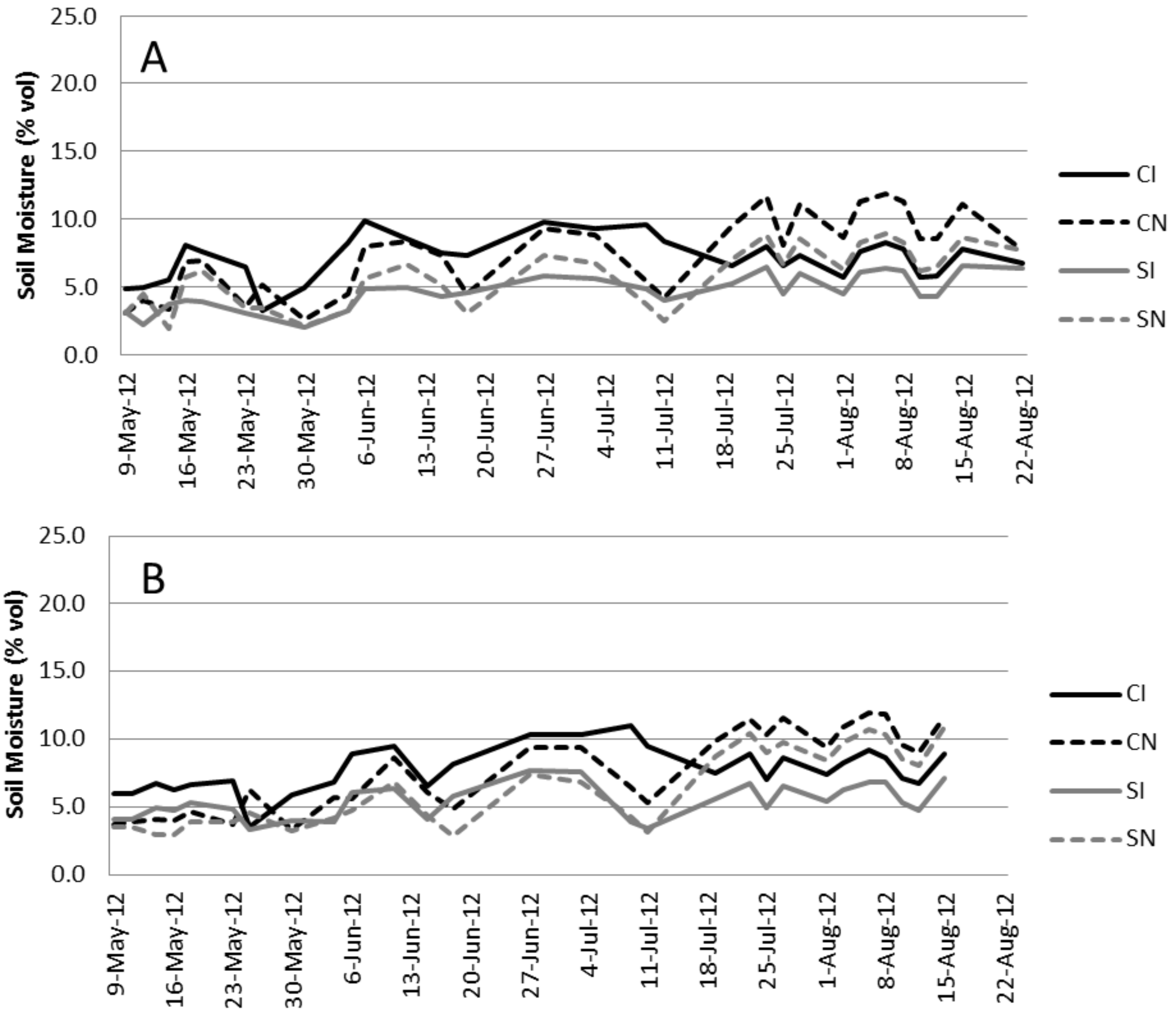

D
Soil Moisture (% vol)
25.0
20.0
15.0
10.0
5.0
0.0
1-Jun-11
8-Jun-11
15-Jun-11
22-Jun-11
29-Jun-11
6-Jul-11
13-Jul-11
20-Jul-11
27-Jul-11
3-Aug-11
10-Aug-11
17-Aug-11
24-Aug-11
31-Aug-11
7-Sep-11
CI
CN
SI
SN

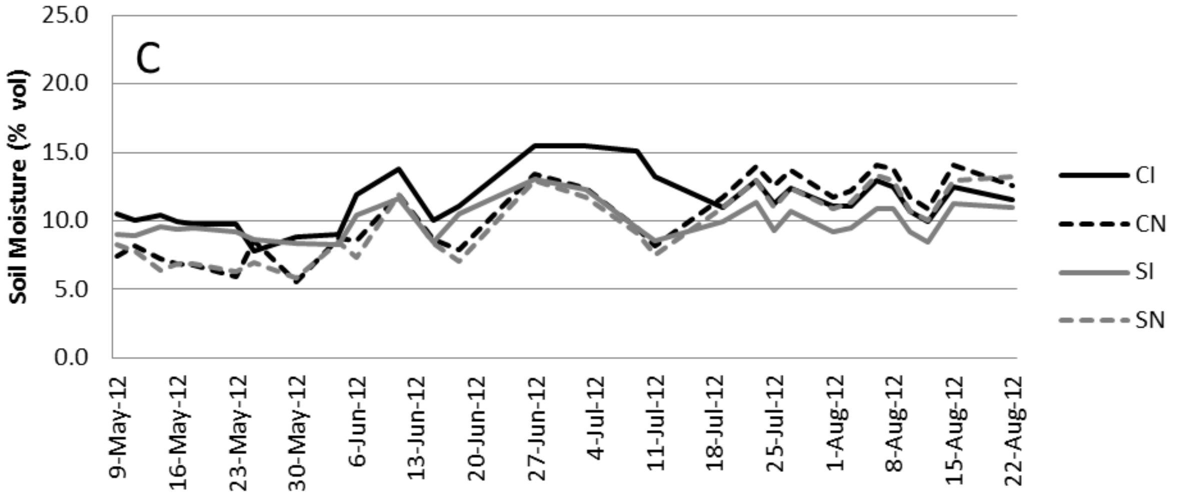

E
Soil Moisture (% vol)
25.0
20.0
15.0
10.0
5.0
0.0
1-Jun-11
8-Jun-11
15-Jun-11
22-Jun-11
29-Jun-11
6-Jul-11
13-Jul-11
20-Jul-11
27-Jul-11
3-Aug-11
10-Aug-11
17-Aug-11
24-Aug-11
31-Aug-11
7-Sep-11
CI
CN
SI
SN

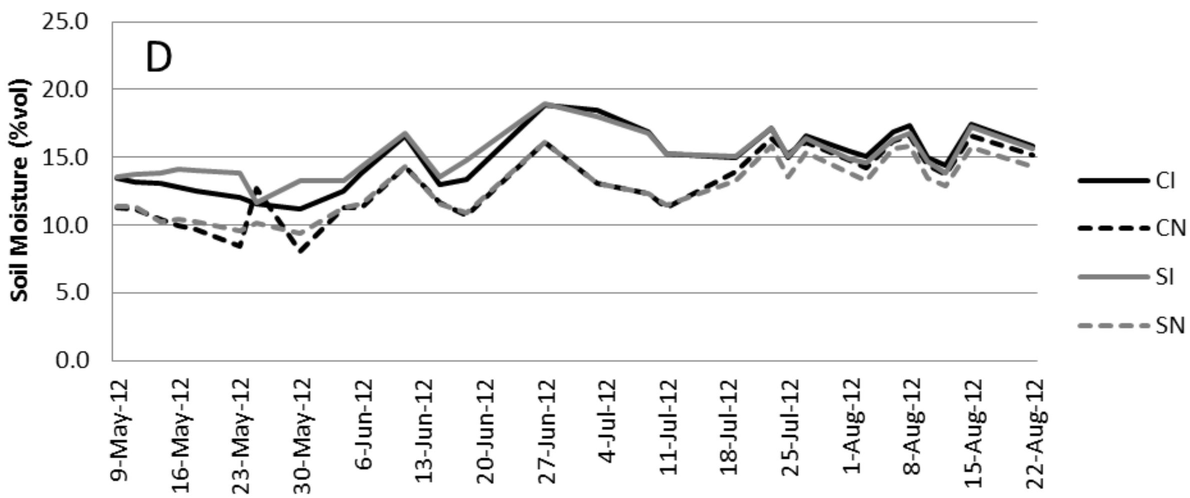


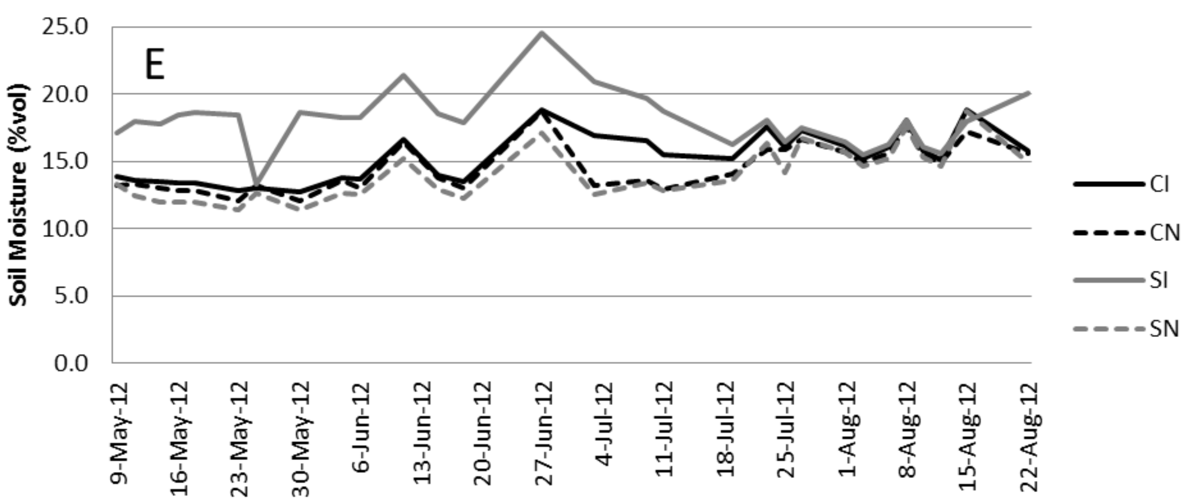
F
Soil Moisture (% vol)
25.0
20.0
15.0
10.0
5.0
0.0
1-Jun-11
8-Jun-11
15-Jun-11
22-Jun-11
29-Jun-11
6-Jul-11
13-Jul-11
20-Jul-11
27-Jul-11
3-Aug-11
10-Aug-11
17-Aug-11
24-Aug-11
31-Aug-11
7-Sep-11
CI
CN
SI
SN

Figure 2-3. 2012 Soil Moisture in Peanut. Average soil moisture readings at 10 (A), 20 (B), 30 (C), 40 (D), 60 (E) and 100 (F) cm depths in peanut throughout the 2011 cropping season shown in the conventional tillage irrigated (CI), conventional tillage non-irrigated (CN), the strip tillage irrigated (SI), and the strip tillage non-irrigated (SN).




C
Soil Moisture (% vol)
25.0
20.0
15.0
10.0
5.0
0.0
9-May-12
16-May-12
23-May-12
30-May-12
6-Jun-12
13-Jun-12
20-Jun-12
27-Jun-12
4-Jul-12
11-Jul-12
18-Jul-12
25-Jul-12
1-Aug-12
8-Aug-12
15-Aug-12
22-Aug-12
CI
CN
SI
SN


D
Soil Moisture (%vol)
25.0
20.0
15.0
10.0
5.0
0.0
9-May-12
16-May-12
23-May-12
30-May-12
6-Jun-12
13-Jun-12
20-Jun-12
27-Jun-12
4-Jul-12
11-Jul-12
18-Jul-12
25-Jul-12
1-Aug-12
8-Aug-12
15-Aug-12
22-Aug-12
CI
CN
SI
SN


E
Soil Moisture (%vol)
25.0
20.0
15.0
10.0
5.0
0.0
9-May-12
16-May-12
23-May-12
30-May-12
6-Jun-12
13-Jun-12
20-Jun-12
27-Jun-12
4-Jul-12
11-Jul-12
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25-Jul-12
1-Aug-12
8-Aug-12
15-Aug-12
22-Aug-12
CI
CN
SI
SN

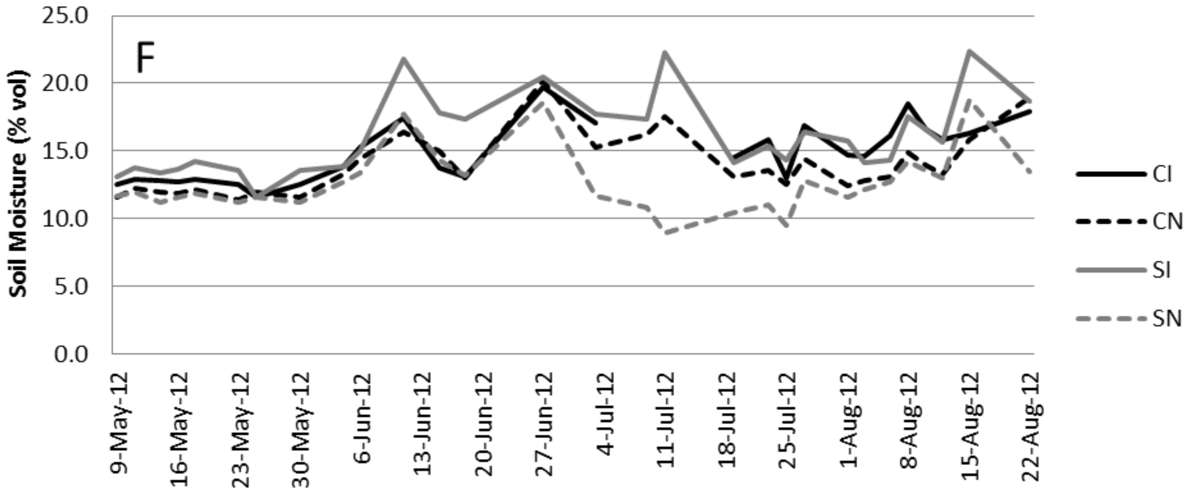
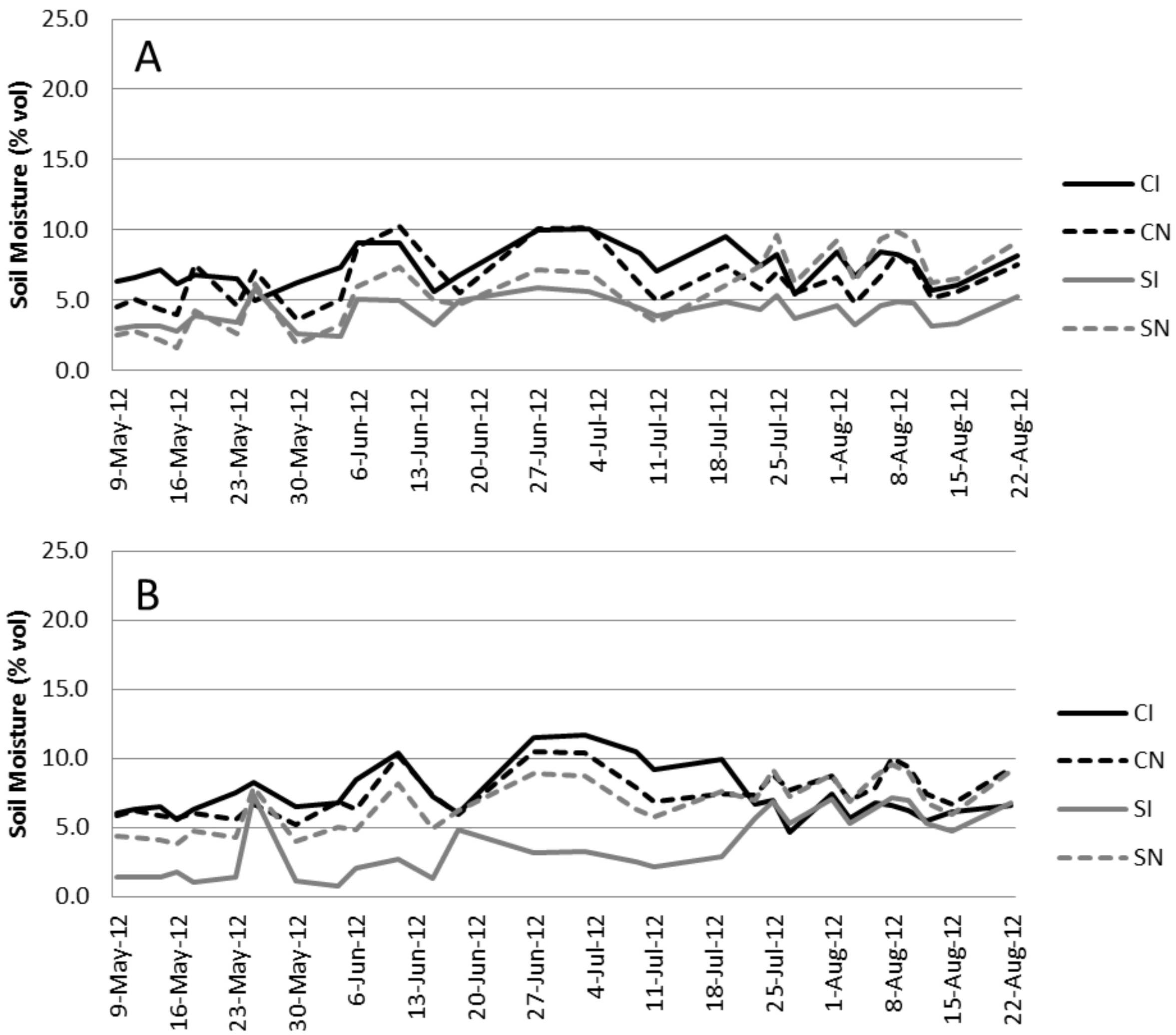
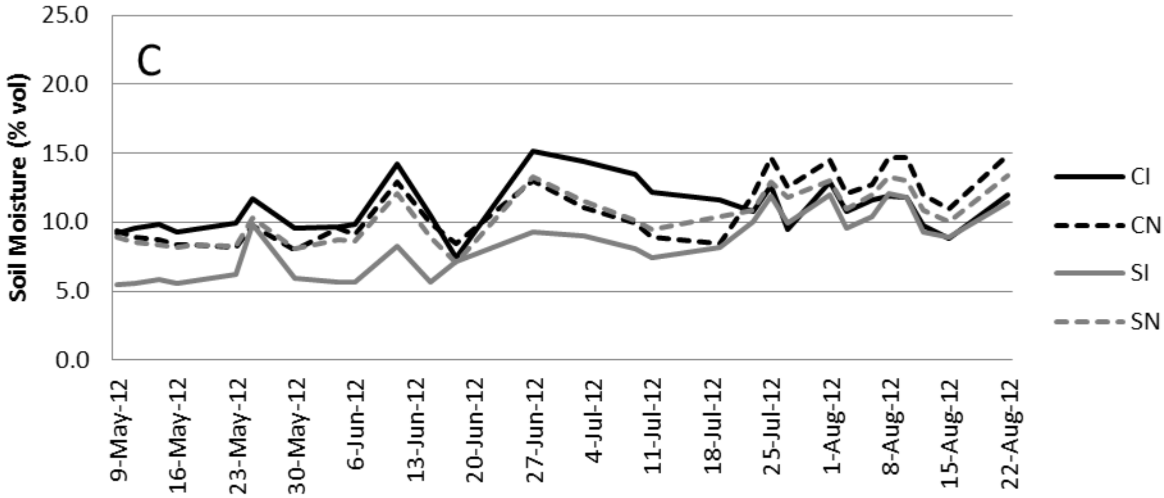

F
Soil Moisture (% vol)
25.0
20.0
15.0
10.0
5.0
0.0
9-May-12
16-May-12
23-May-12
30-May-12
6-Jun-12
13-Jun-12
20-Jun-12
27-Jun-12
4-Jul-12
11-Jul-12
18-Jul-12
25-Jul-12
1-Aug-12
8-Aug-12
15-Aug-12
22-Aug-12
CI
CN
SI
SN

Figure 2-4. 2012 Soil Moisture in Cotton. Average soil moisture readings at 10 (A), 20 (B), 30 (C), 40 (D), 60 (E) and 100 (F) cm depths in cotton throughout the 2011 cropping season shown in the conventional tillage irrigated (CI), conventional tillage non-irrigated (CN), the strip tillage irrigated (SI), and the strip tillage non-irrigated (SN).




C
Soil Moisture (% vol)
25.0
20.0
15.0
10.0
5.0
0.0
9-May-12
16-May-12
23-May-12
30-May-12
6-Jun-12
13-Jun-12
20-Jun-12
27-Jun-12
4-Jul-12
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25-Jul-12
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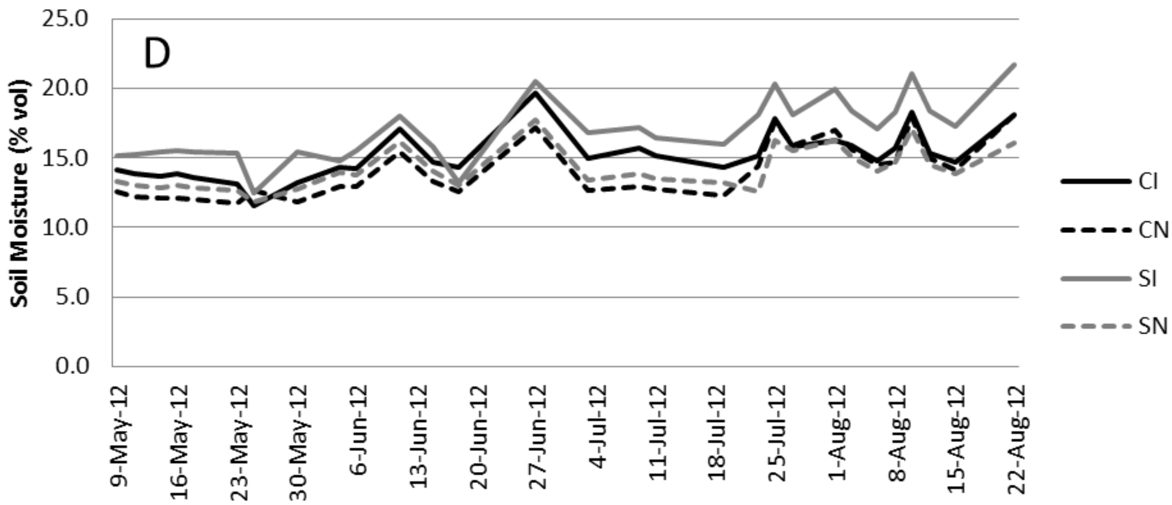
22-Aug-12
CI
CN
SI
SN


D
Soil Moisture (% vol)
25.0
20.0
15.0
10.0
5.0
0.0
9-May-12
16-May-12
23-May-12
30-May-12
6-Jun-12
13-Jun-12
20-Jun-12
27-Jun-12
4-Jul-12
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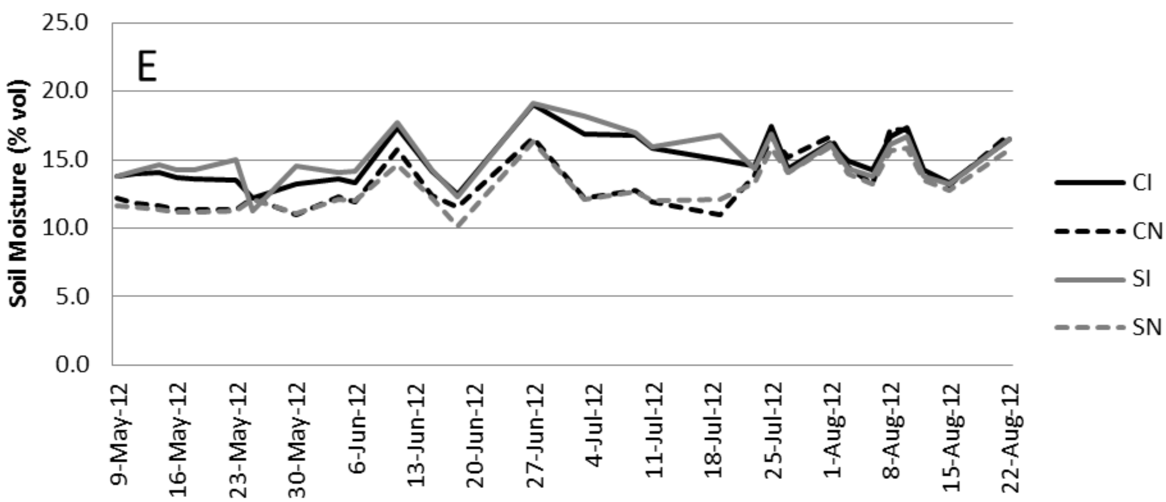
CI
CN
SI
SN


E
Soil Moisture (% vol)
25.0
20.0
15.0
10.0
5.0
0.0
9-May-12
16-May-12
23-May-12
30-May-12
6-Jun-12
13-Jun-12
20-Jun-12
27-Jun-12
4-Jul-12
11-Jul-12
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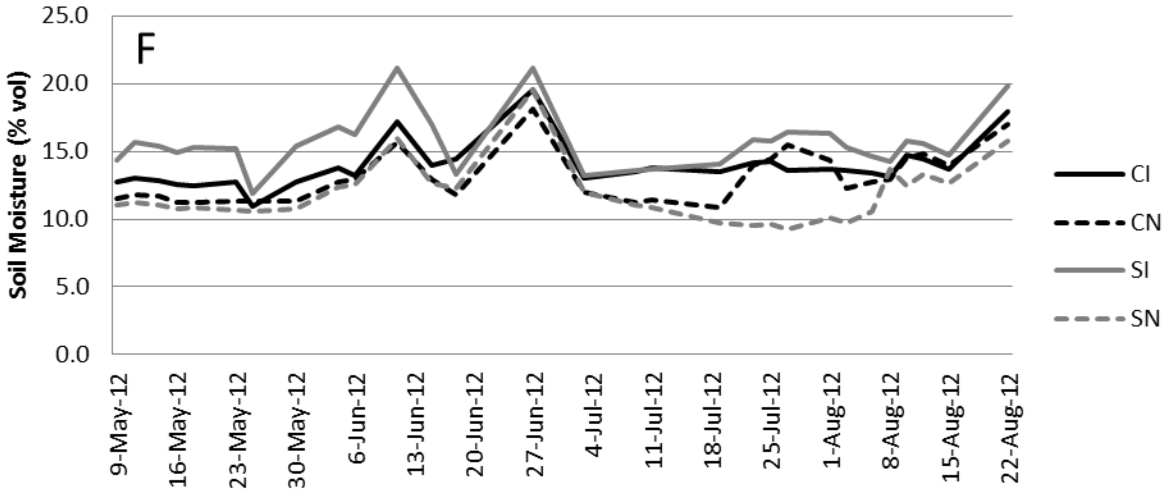
CI
CN
SI
SN


F
Soil Moisture (% vol)
25.0
20.0
15.0
10.0
5.0
0.0
9-May-12
16-May-12
23-May-12
30-May-12
6-Jun-12
13-Jun-12
20-Jun-12
27-Jun-12
4-Jul-12
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CI
CN
SI
SN

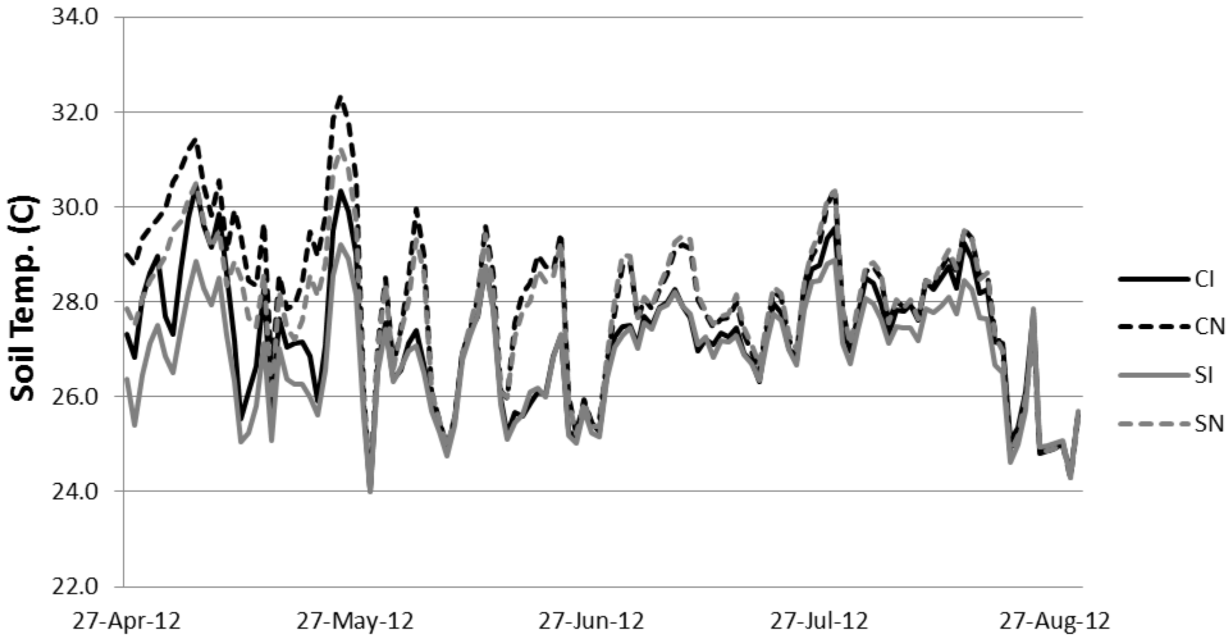


Figure 2-5. Soil Temperature in Peanut. Soil temperature at 7.5 cm depth in peanut throughout the 2012 cropping season shown in the conventional tillage irrigated (CI), conventional tillage non-irrigated (CN), the strip tillage irrigated (SI), and the strip tillage non-irrigated (SN)

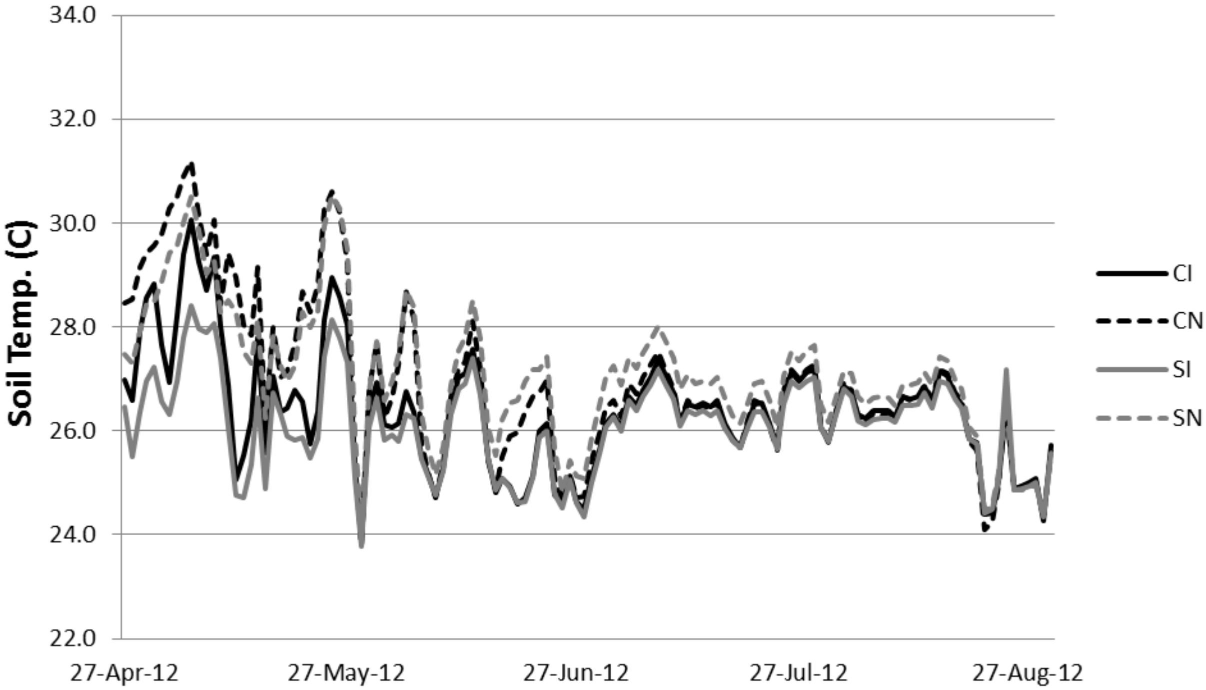
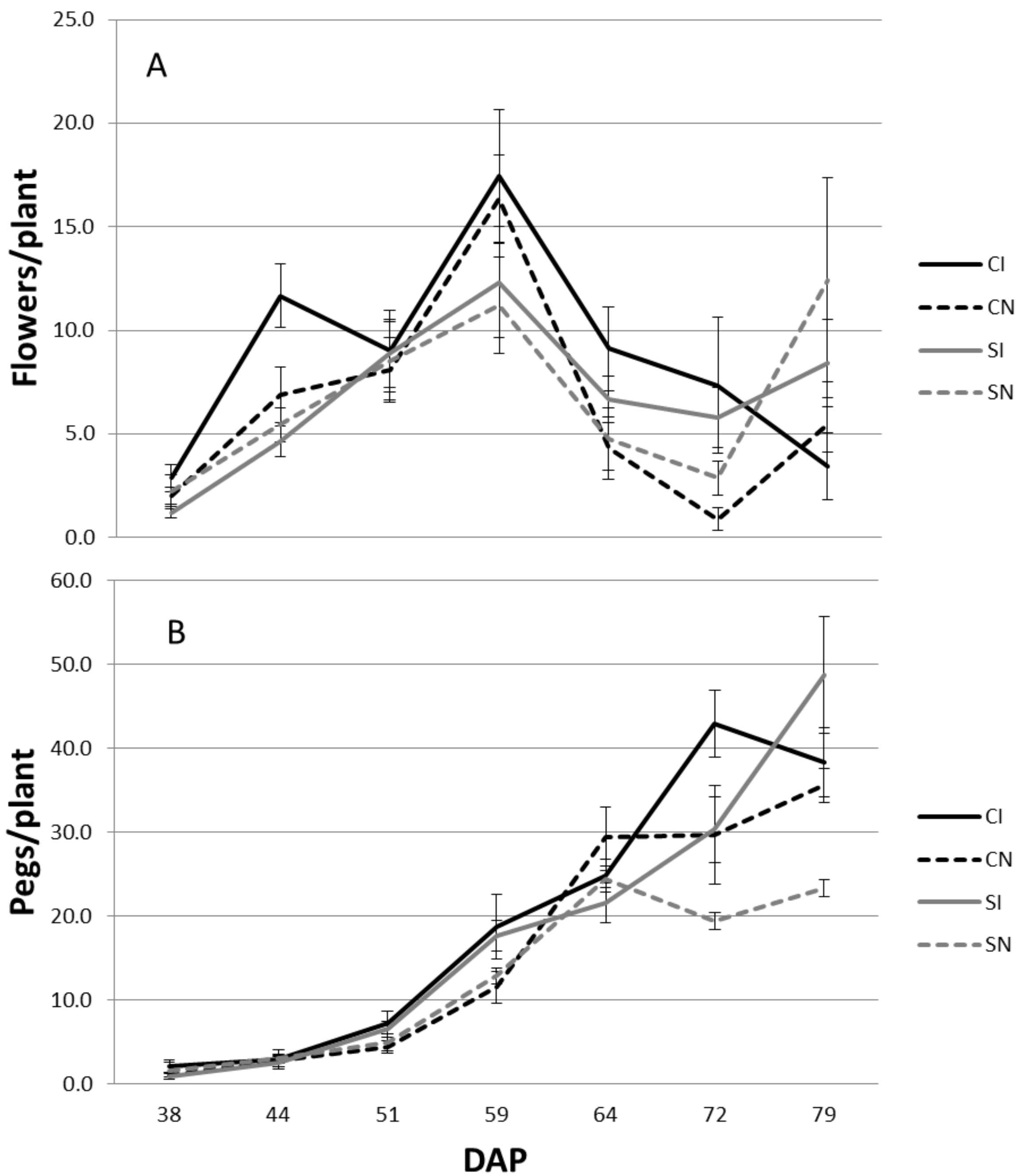


Figure 2-6. Soil Temperature in Cotton. Soil temperature at 7.5 cm depth in cotton throughout the 2012 cropping season shown in the conventional tillage irrigated (CI), conventional tillage non-irrigated (CN), the strip tillage irrigated (SI), and the strip tillage non-irrigated (SN)

Figure 2-7. 2011 Florida-07 Flower, Peg, and Pod Counts. Flowers (A), pegs (B), and pods (C) per plant in the conventional tillage irrigated (CI), conventional tillage non-irrigated (CN), the strip tillage irrigated (SI), and the strip tillage non-irrigated (SN).



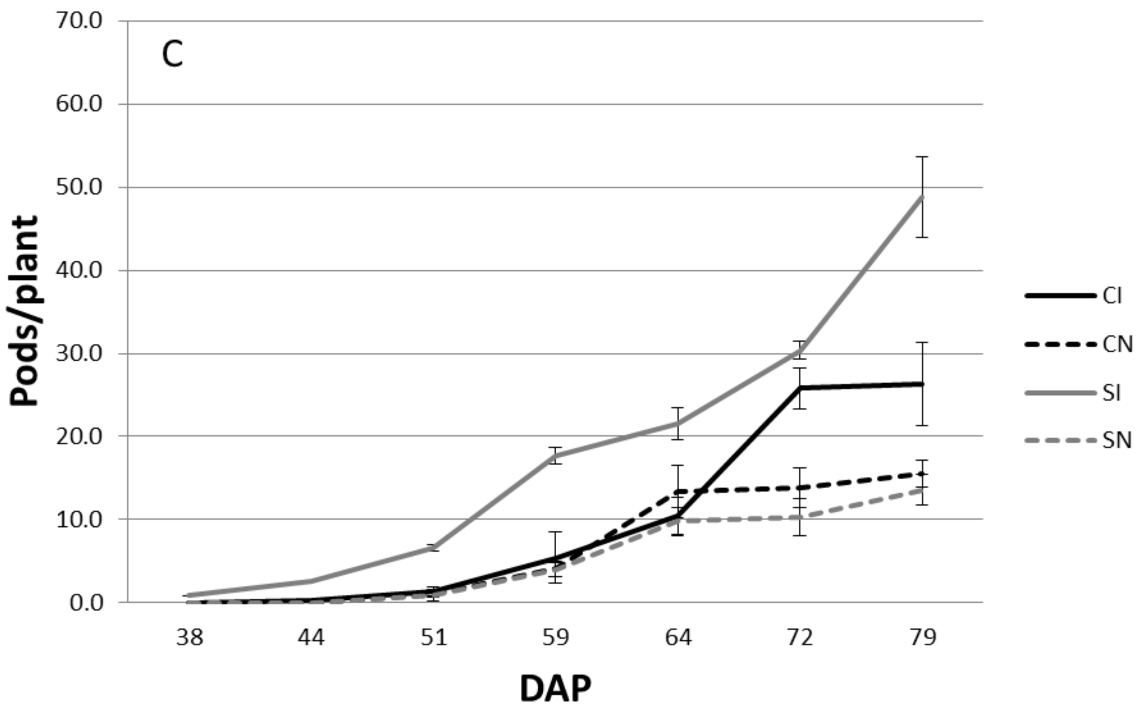
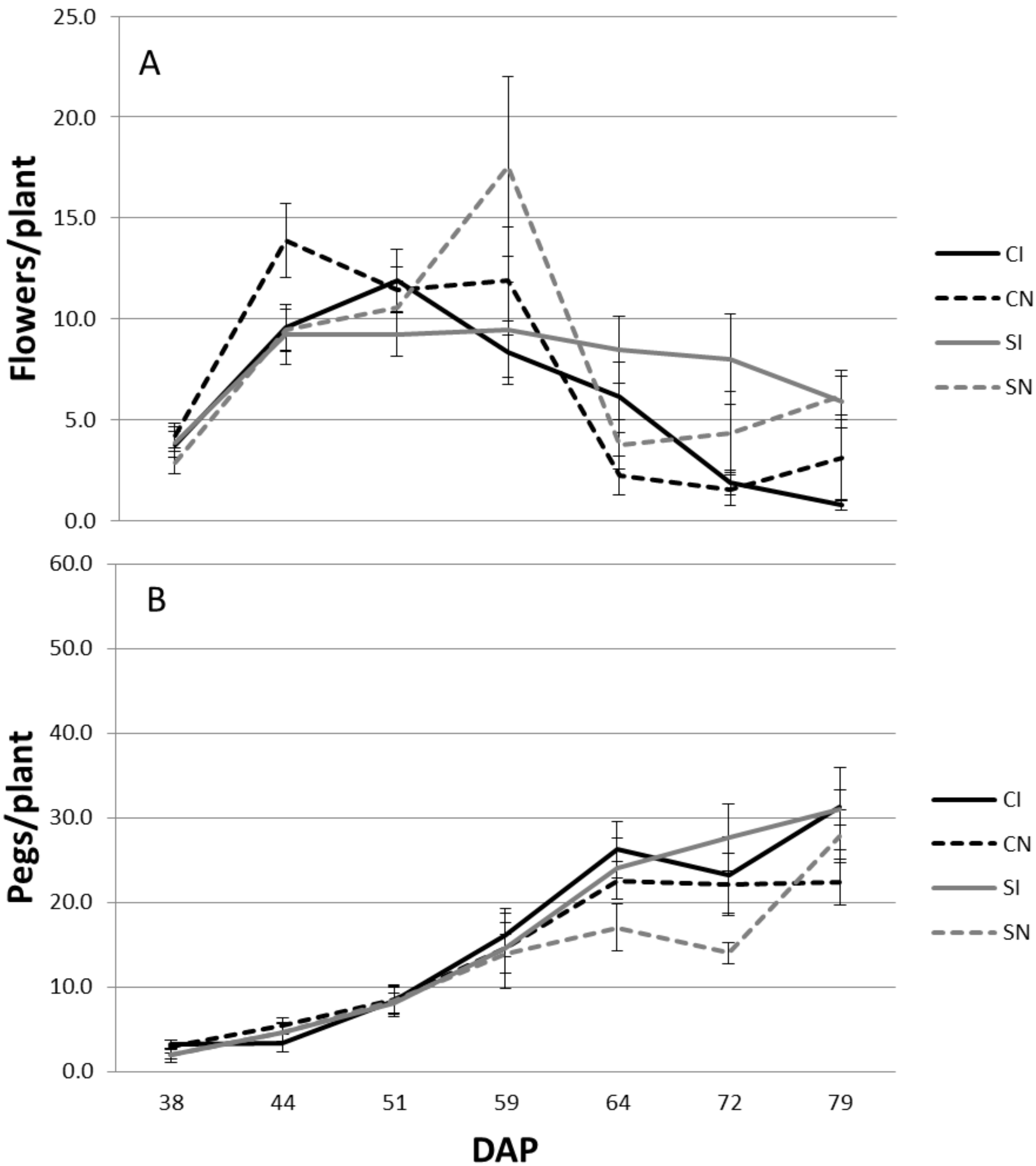
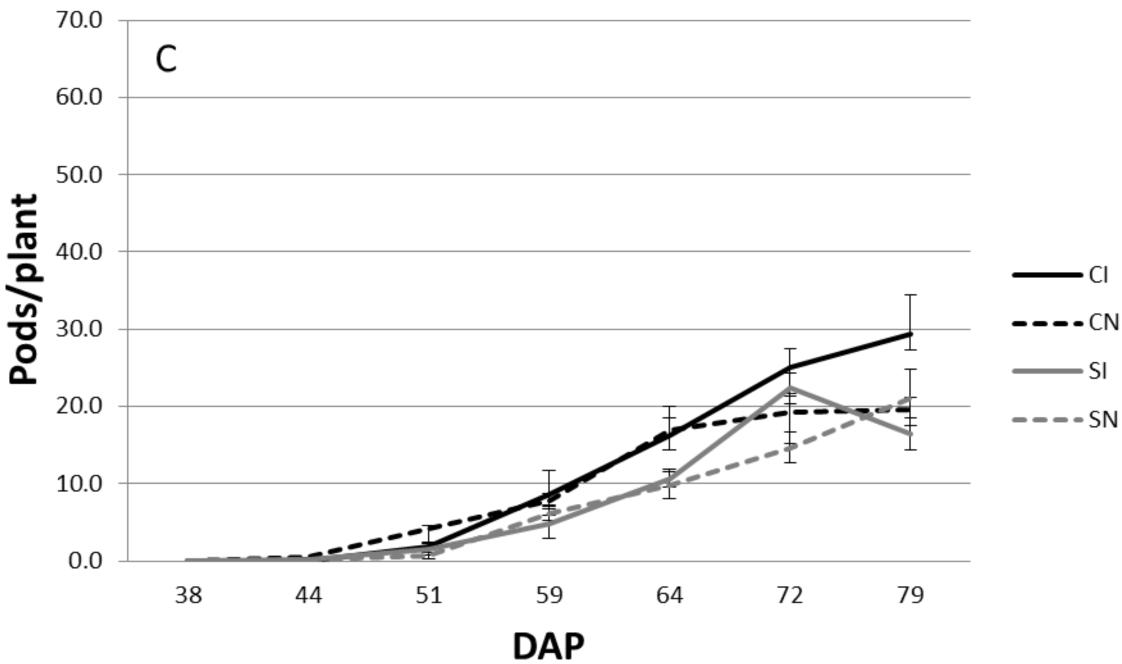

C
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
Pods/plant
38
44
51
59
64
72
79
DAP
CI
CN
SI
SN

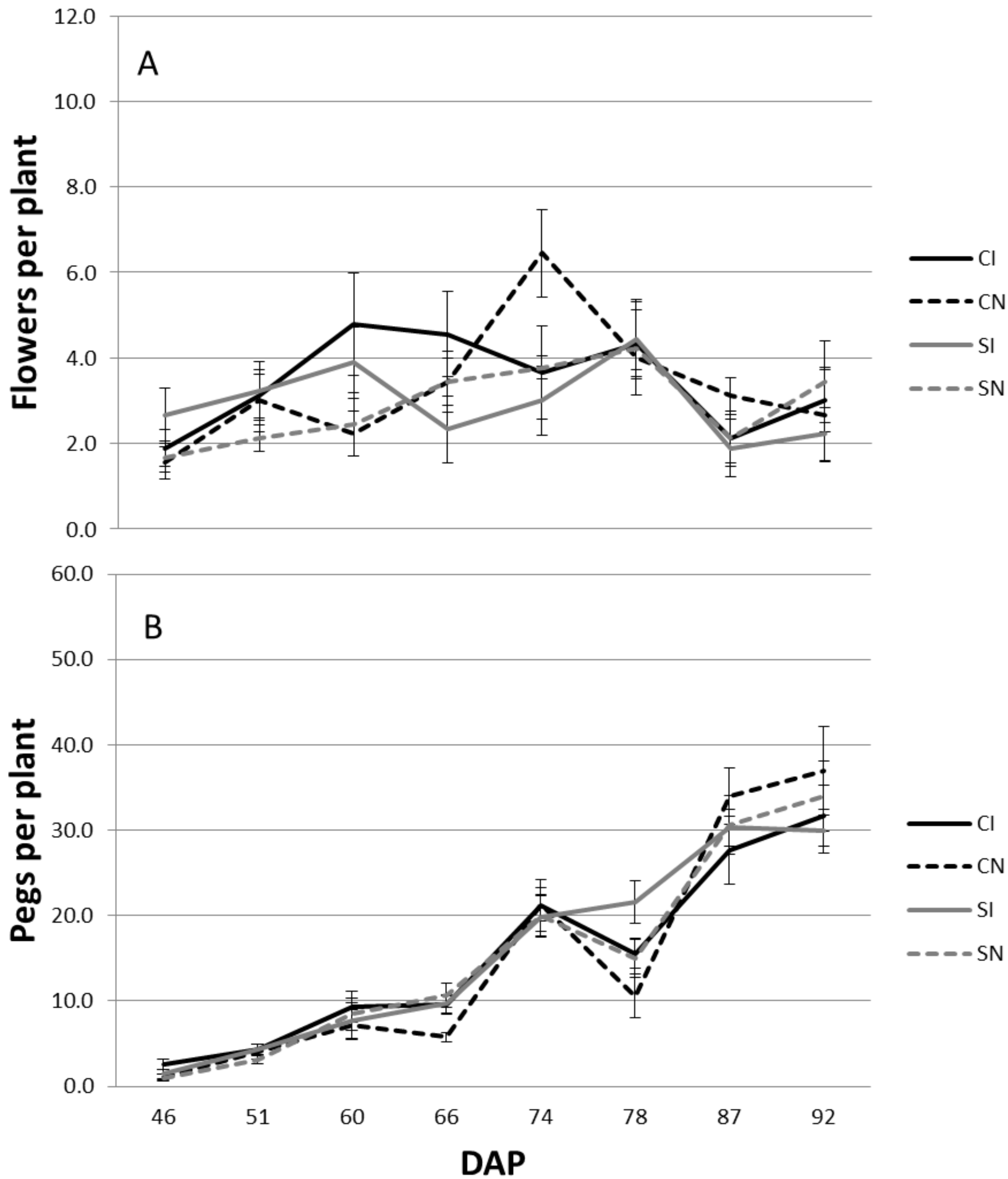
Figure 2-8. 2011 Tifguard Flower, Peg, and Pod Counts. Flowers (A), pegs (B) and pods (C) per plant in the conventional tillage irrigated (CI), conventional tillage non-irrigated (CN), the strip tillage irrigated (SI), and the strip tillage non-irrigated (SN).

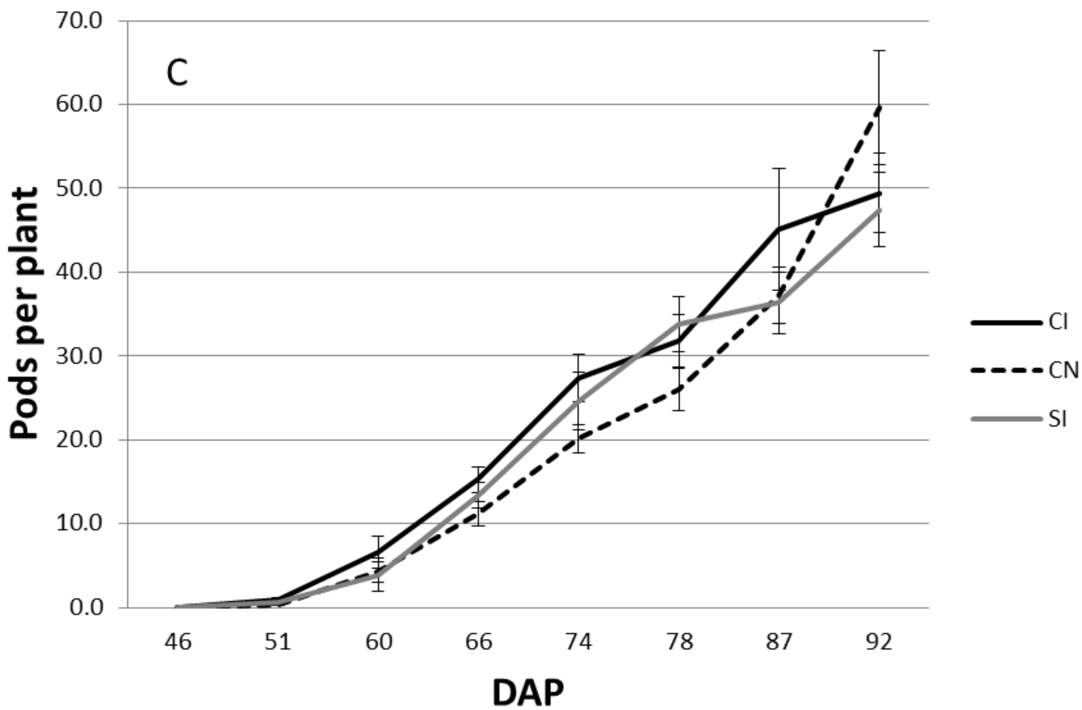




C
Pods/plant
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
38
44
51
59
64
72
79
DAP
CI
CN
SI
SN

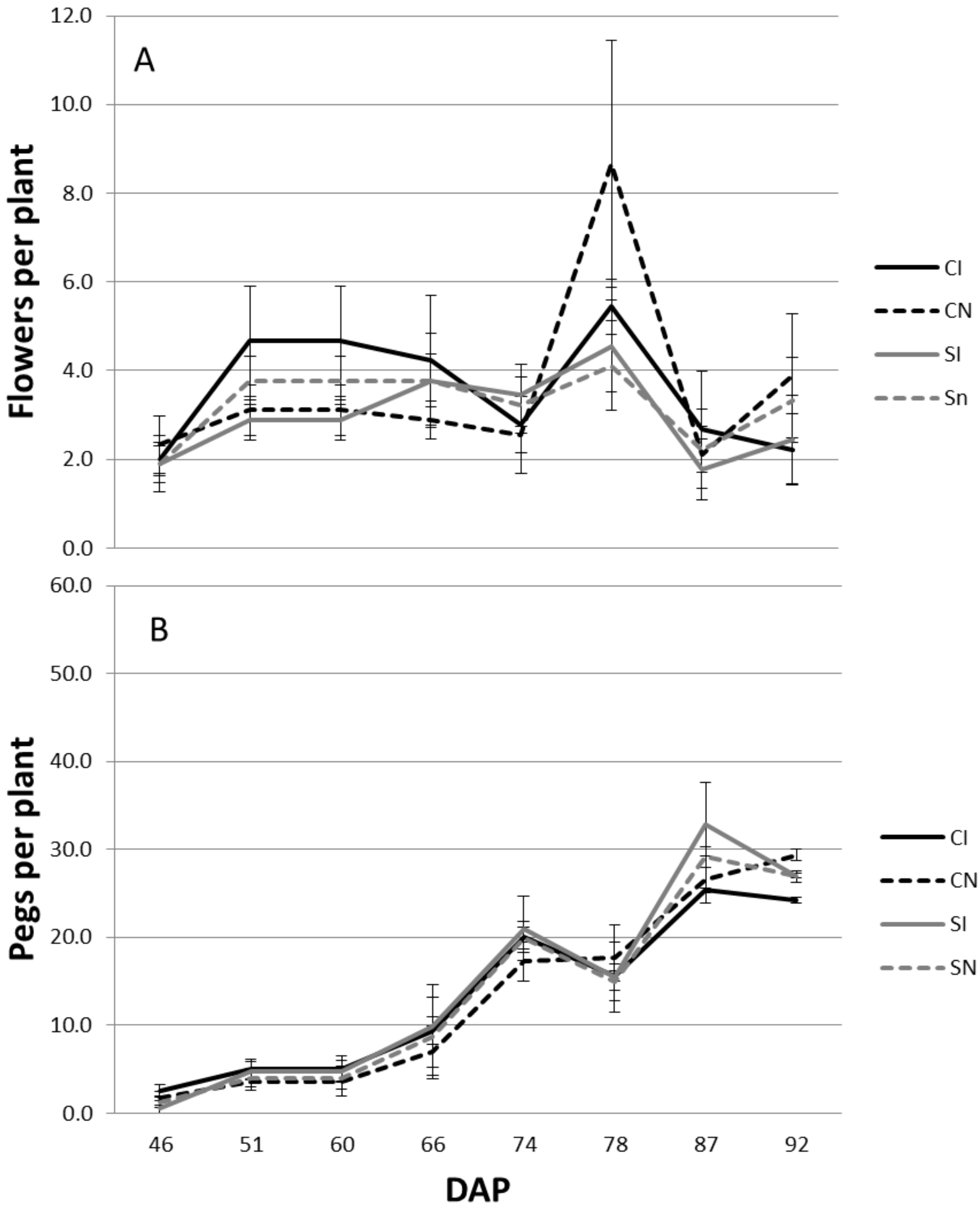
Figure 2-9. 2012 Florida-07 Flower, Peg, and Pod Counts. Flowers (A), pegs (B) and pods (C) per plant in the conventional tillage irrigated (CI), conventional tillage non-irrigated (CN), the strip tillage irrigated (SI), and the strip tillage non-irrigated (SN).





C
Pods per plant
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
46
51
60
66
74
78
87
92
DAP
CI
CN
SI

Figure 2-10. 2012 Tifguard Flower, Peg, and Pod Counts. Flowers (A), pegs (B) and pods (C) per plant in the conventional tillage irrigated (CI), conventional tillage non-irrigated (CN), the strip tillage irrigated (SI), and the strip tillage non-irrigated (SN).



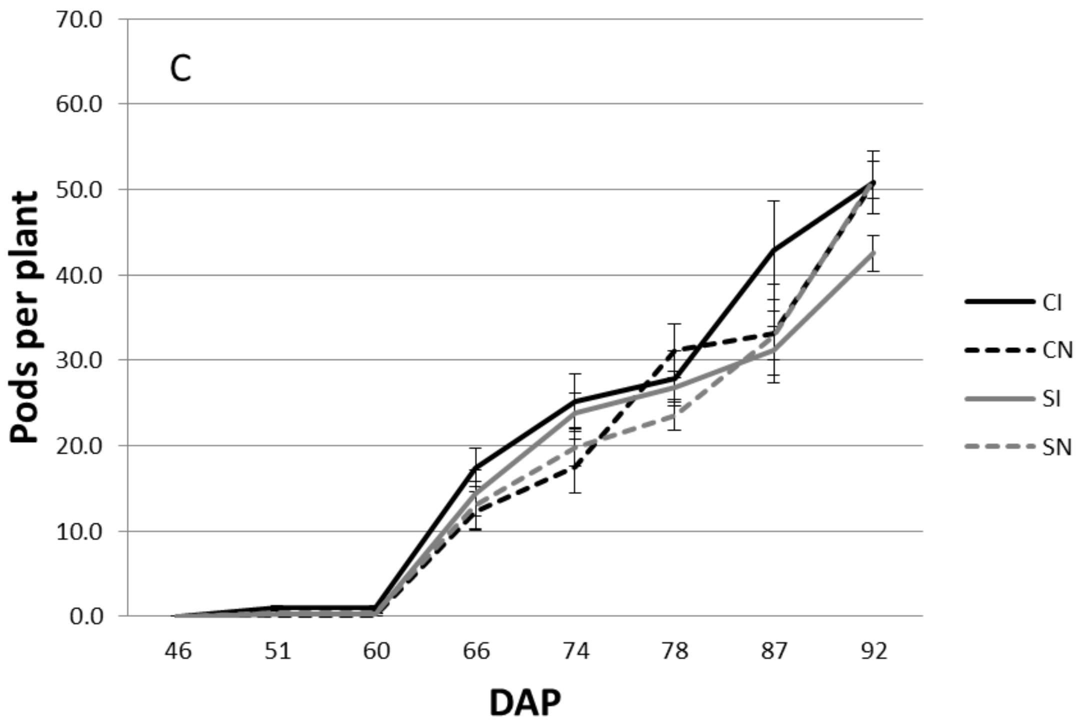

C
Pods per plant
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
46
51
60
66
74
78
87
92
DAP
CI
CN
SI
SN

Figure 2-11. Leaf Area Index Peanut. Leaf area index in 2011 (A) and 2012 (B) for peanut cultivar Florida-07 in the conventional tillage irrigated (CI), conventional tillage non-irrigated (CN), the strip tillage irrigated (SI), and the strip tillage non-irrigated (SN).

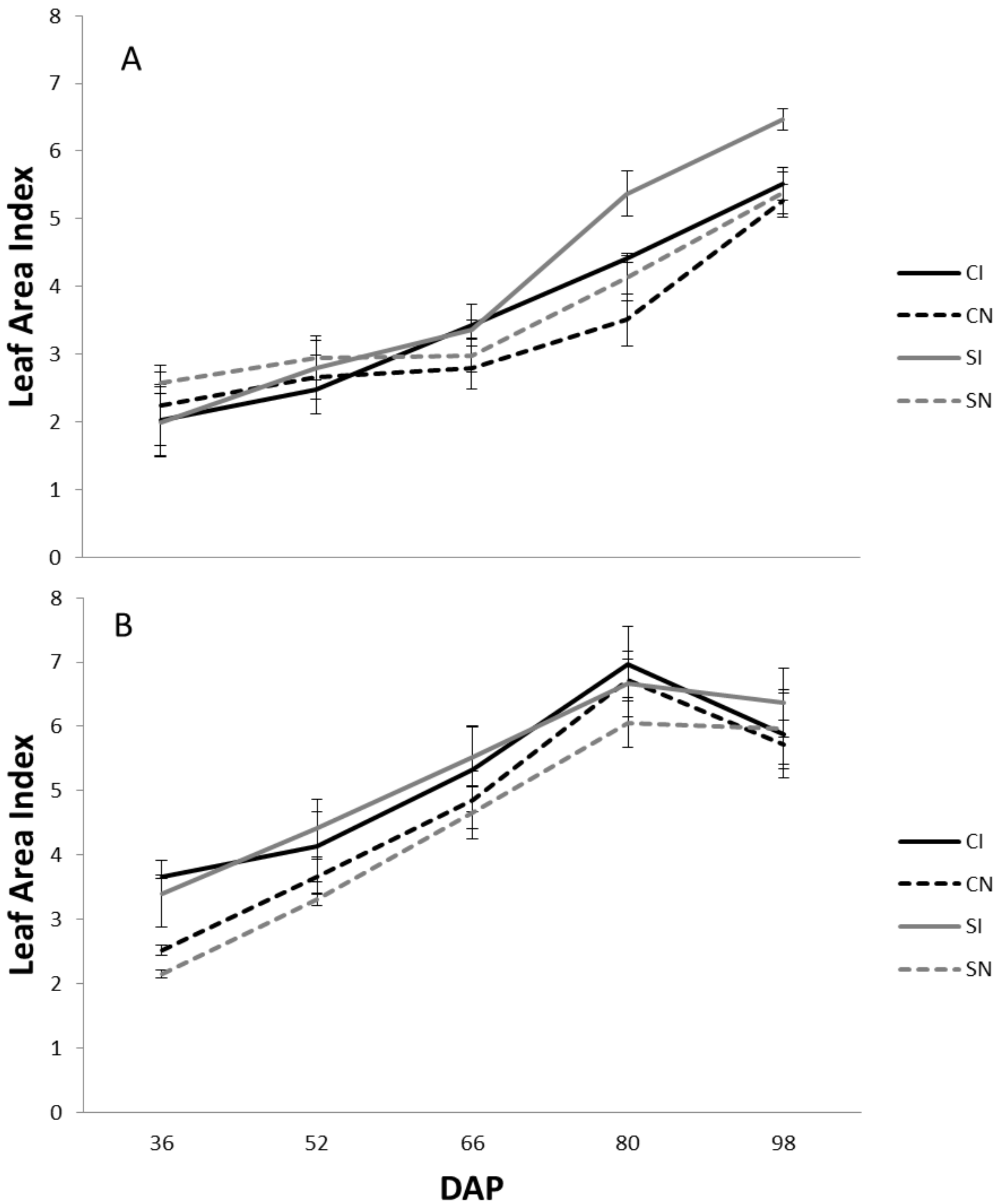
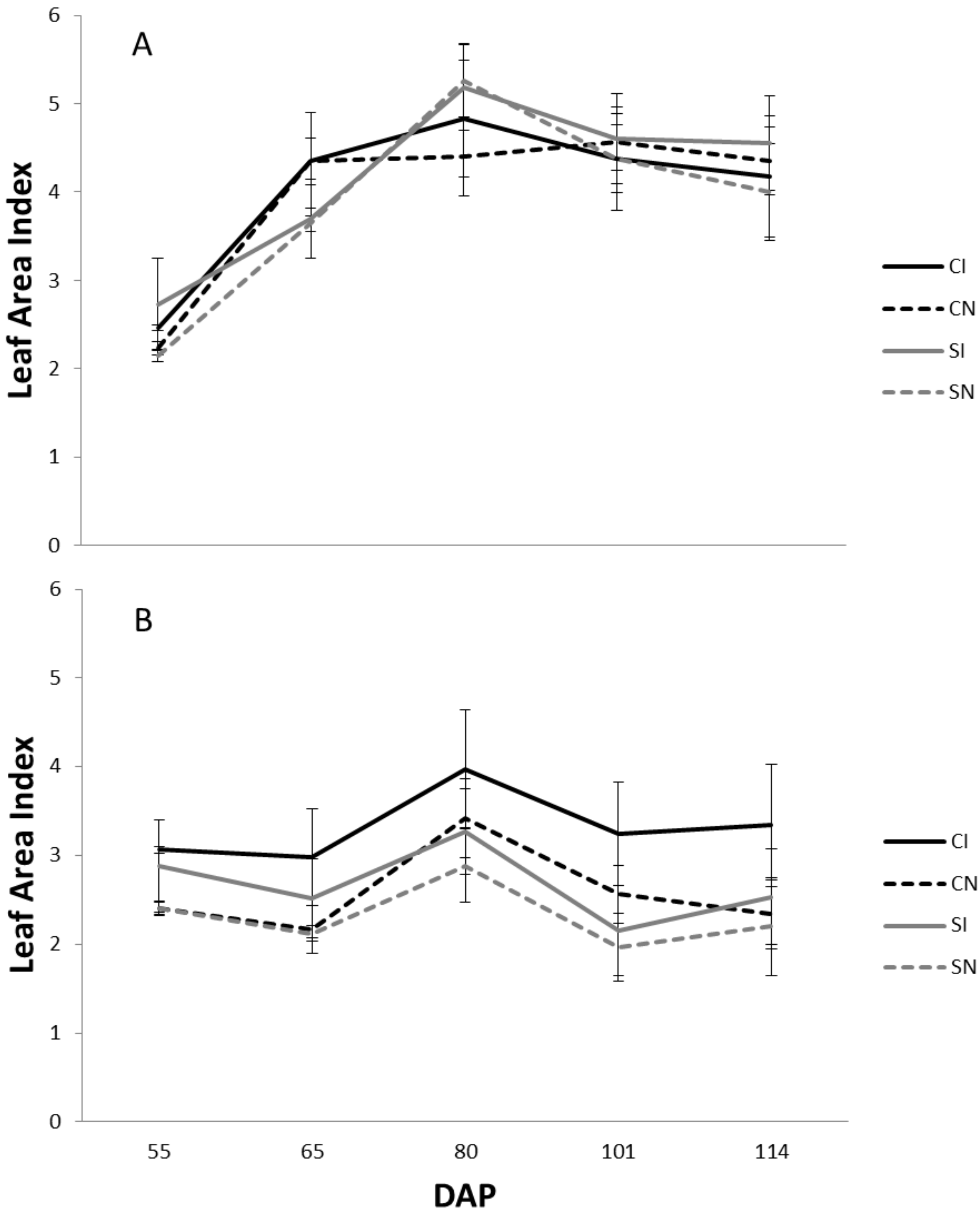
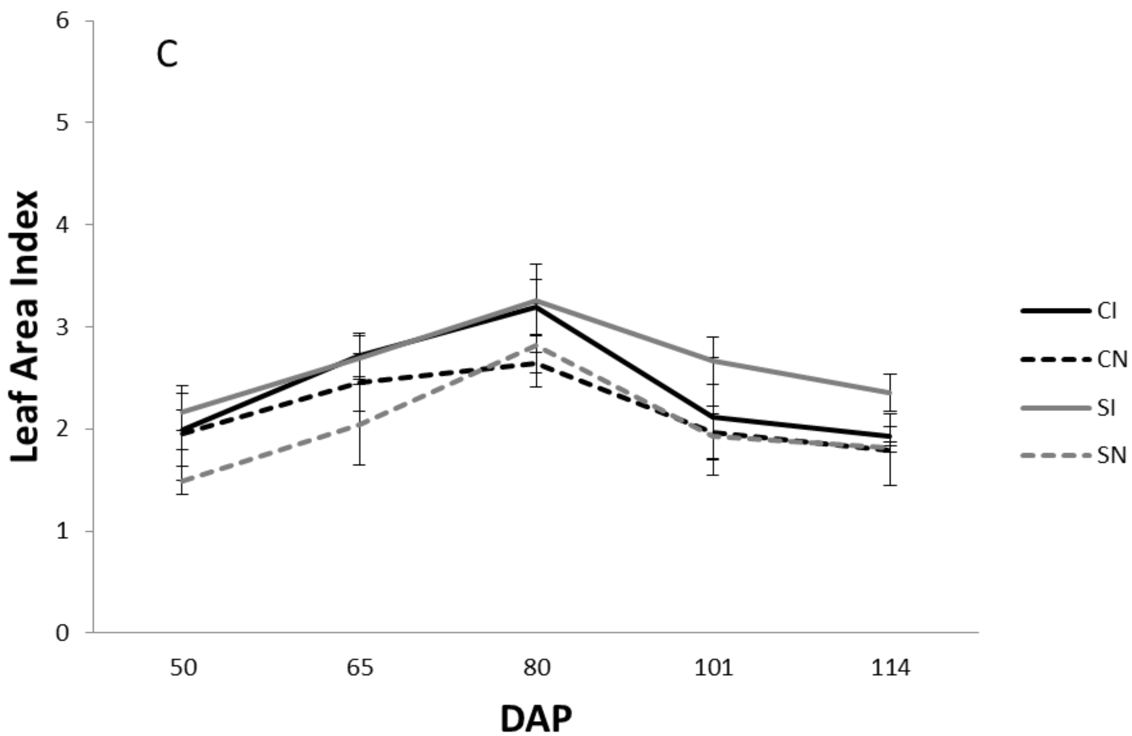


Figure 2-12. Leaf Area Index Cotton. Leaf area index separated by cultivar shown in cultivar Phytogen 499 in 2011 and 2012 (A,B) and Phytogen 375 in 2012 (C) in conventional tillage irrigated (CI), conventional tillage non-irrigated (CN), the strip tillage irrigated (SI), and the strip tillage non-irrigated (SN).




C
Leaf Area Index
6
5
4
3
2
1
0
50
65
80
101
114
DAP
CI
CN
SI
SN

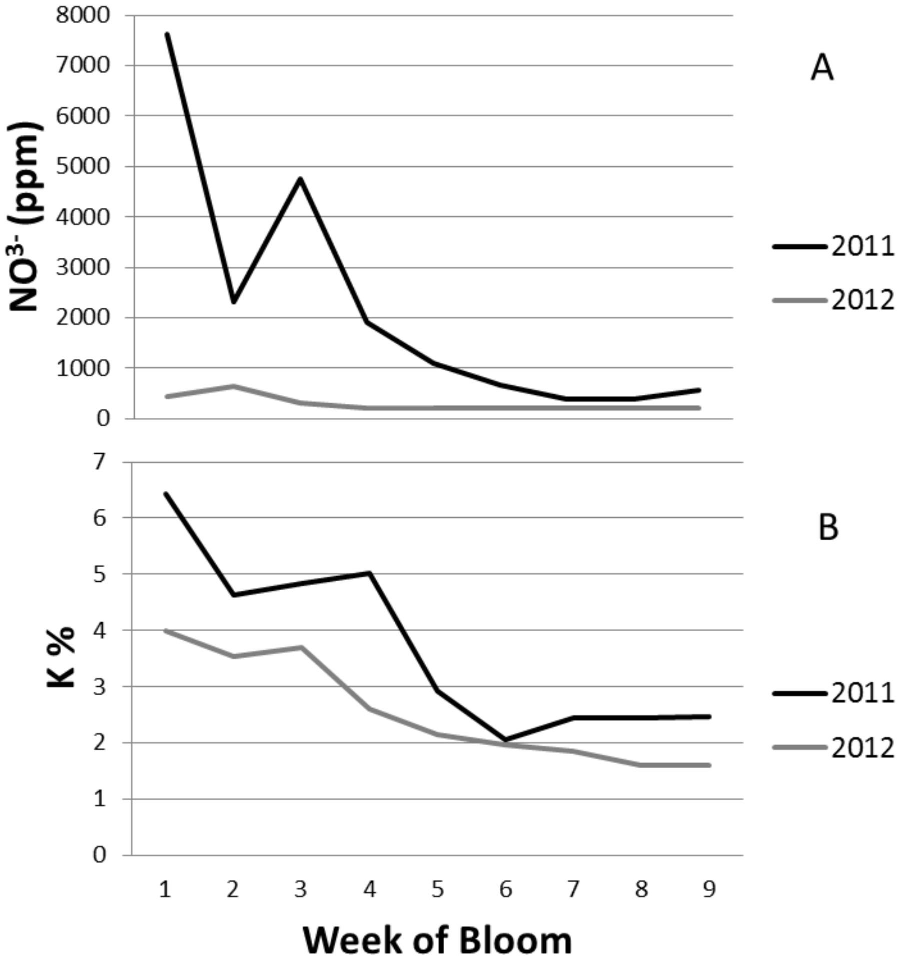


Figure 2-13. Average Nitrate and Potassium 2011 and 2012. Cotton nitrate (A) and potassium (B) content averaged across tillage and irrigation treatments in 2011 and 2012.

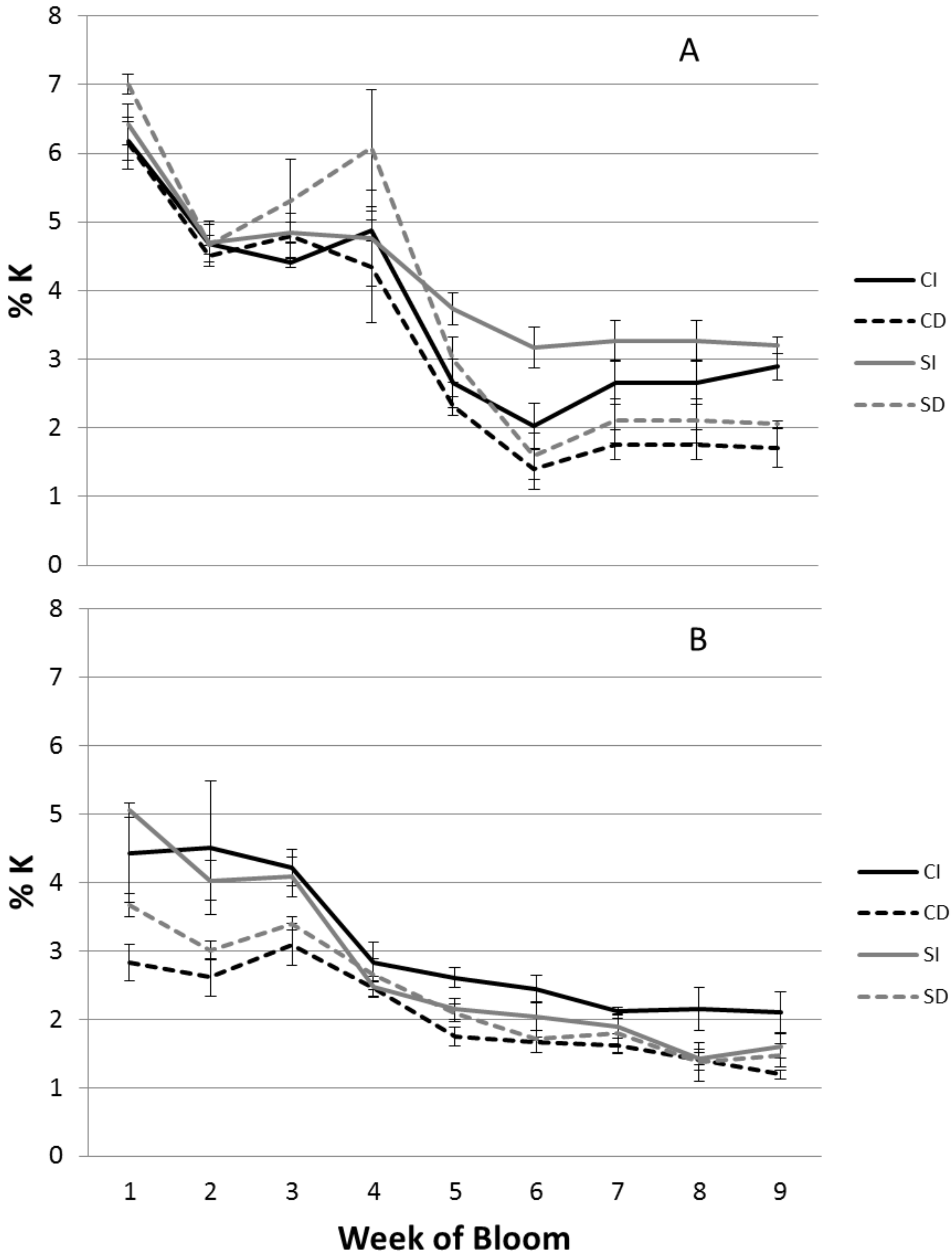


Figure 2-14. Cotton Petiole Potassium 2011 and 2012. Potassium levels in cotton in 2011(A) and 2012 (B) in cultivar Phytogen 499 in the conventional tillage irrigated (CI), conventional tillage non-irrigated (CN), the strip tillage irrigated (SI), and the strip tillage non-irrigated (SN).

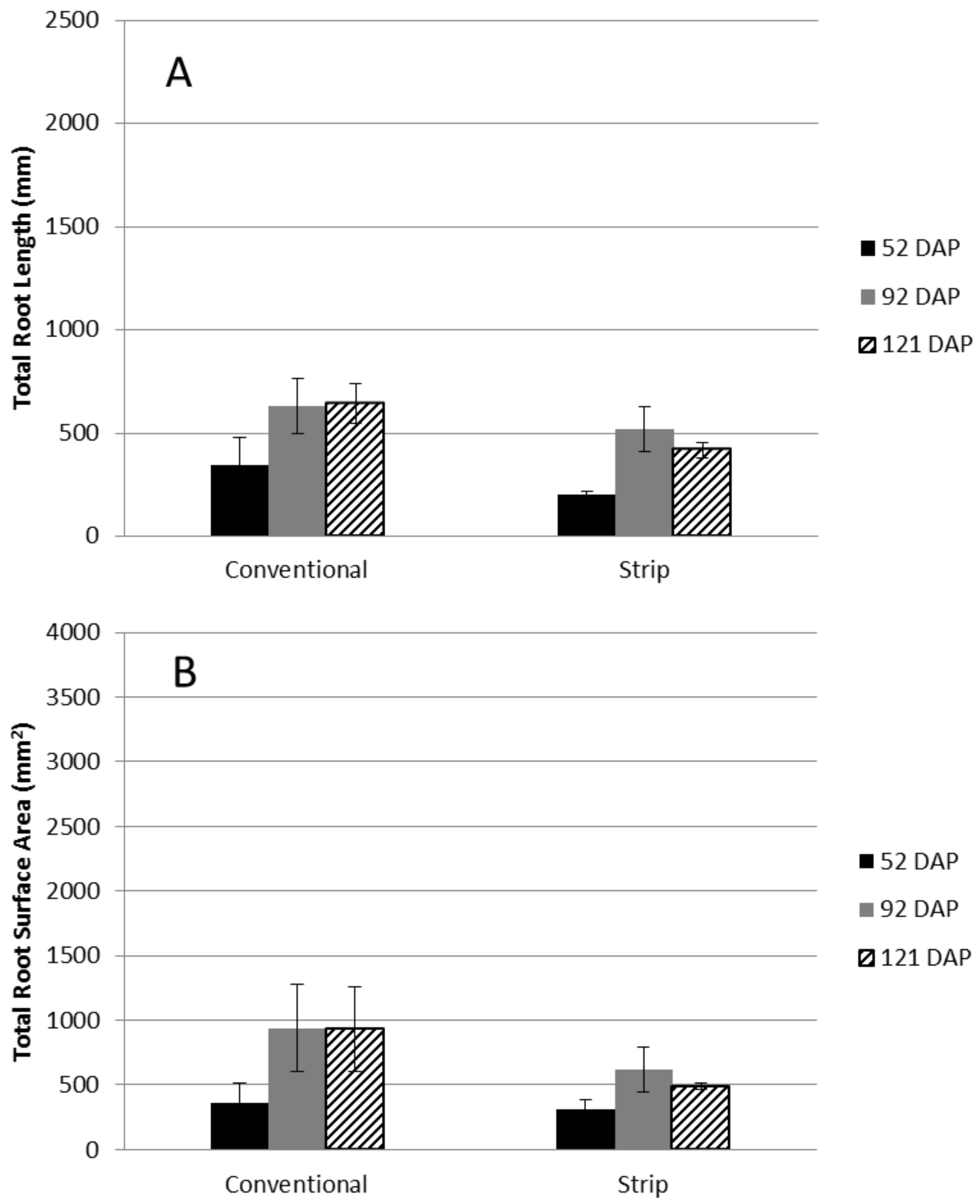


Figure 2-15. TRL and TSA Cotton 2011. Total root length (A) and total root surface area (B) for cotton in 2011.

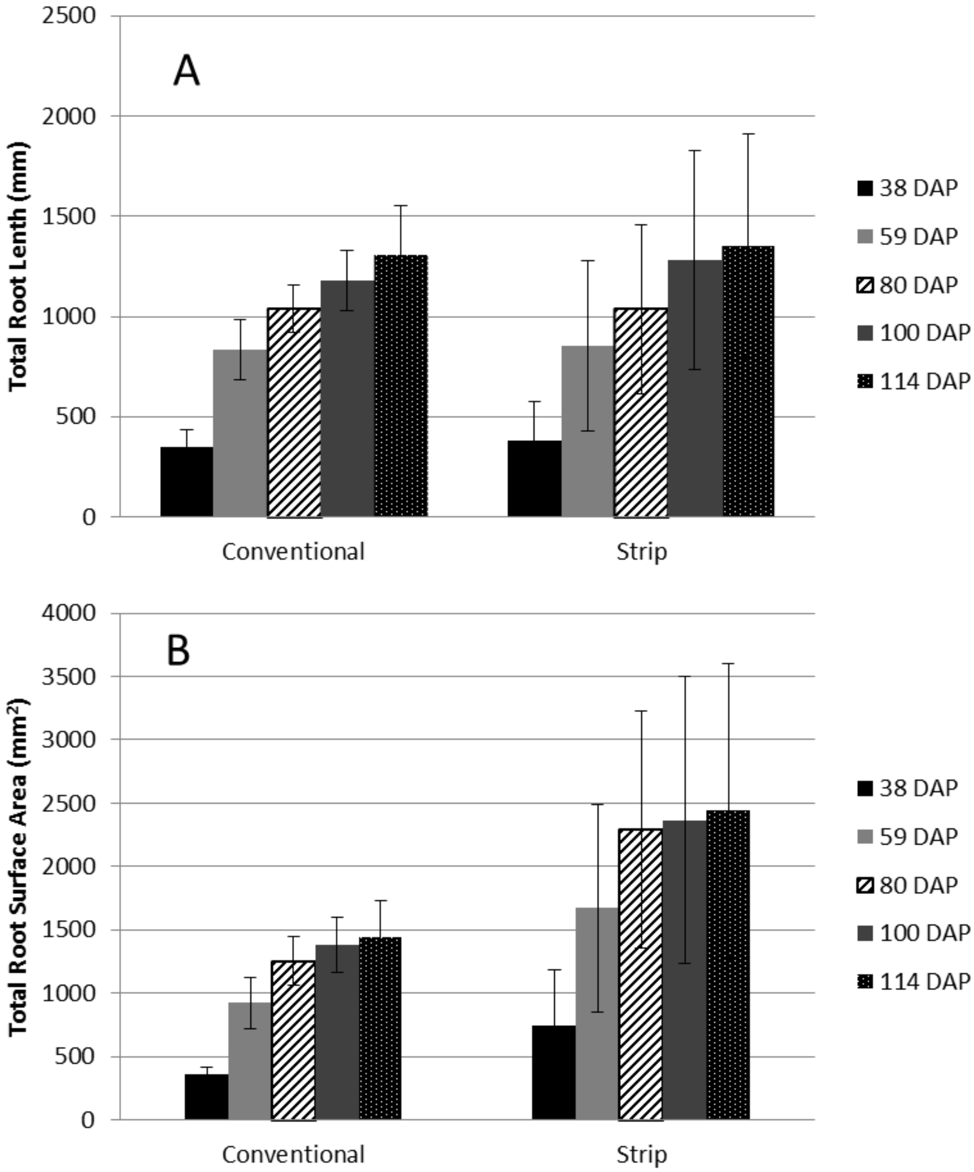
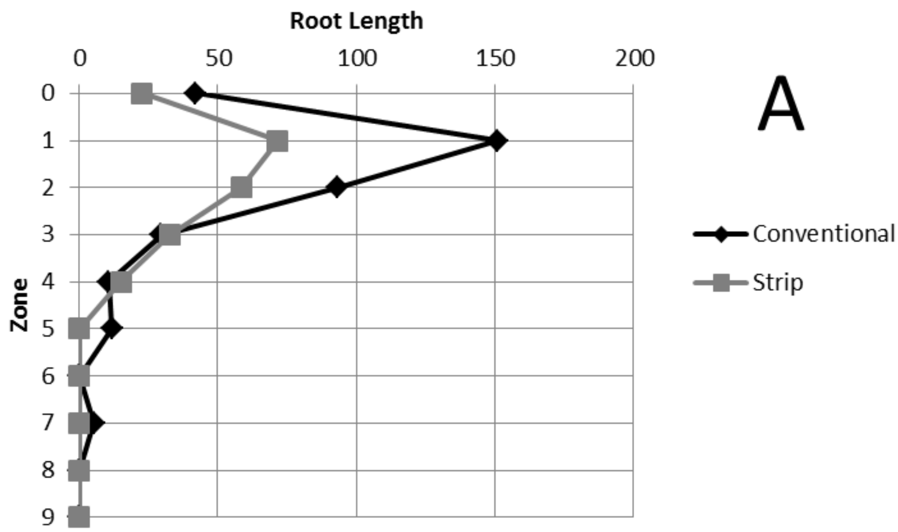
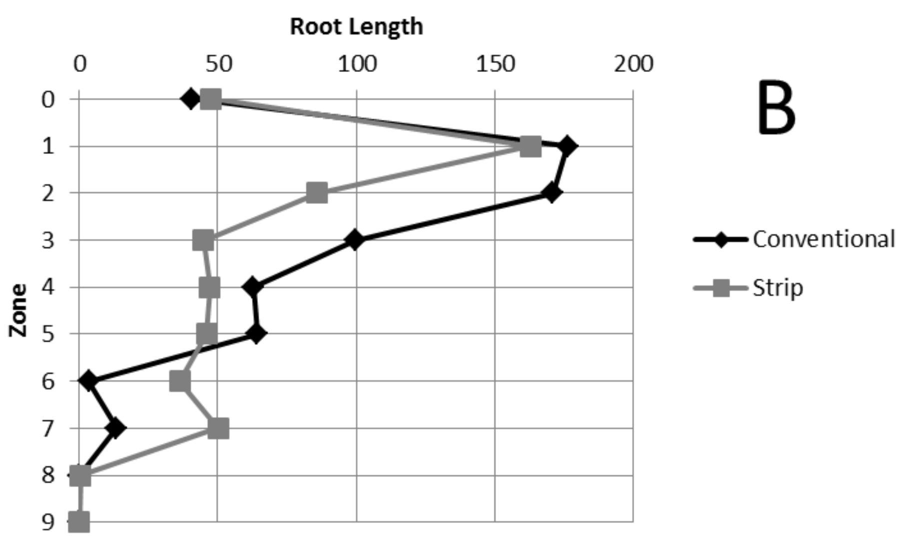


Figure 2-16. TRL and TSA Cotton 2012. Total root length (A) and total root surface area (B) for cotton in 2012.

Figure 2-17. Figure 2-17. Rooting Profile Cotton 2011. Total root length in mm (TRL) down the profile of the soil where each zone is a 10 cm increment. Graphs show measurements at 52 (A), 92 (B), 123 (C) DAP.





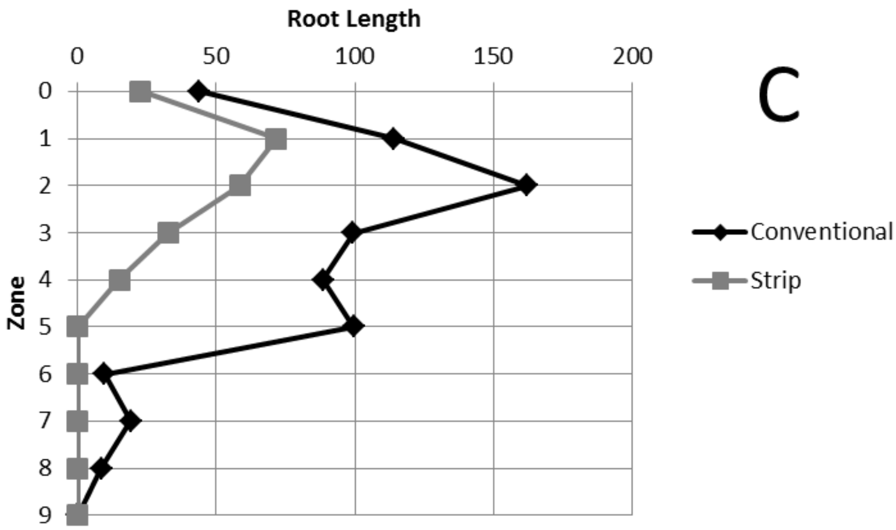
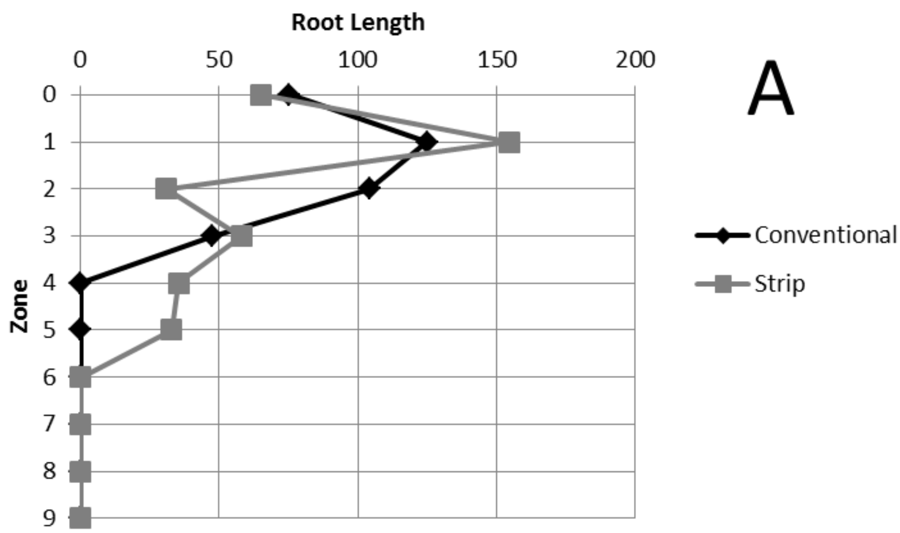
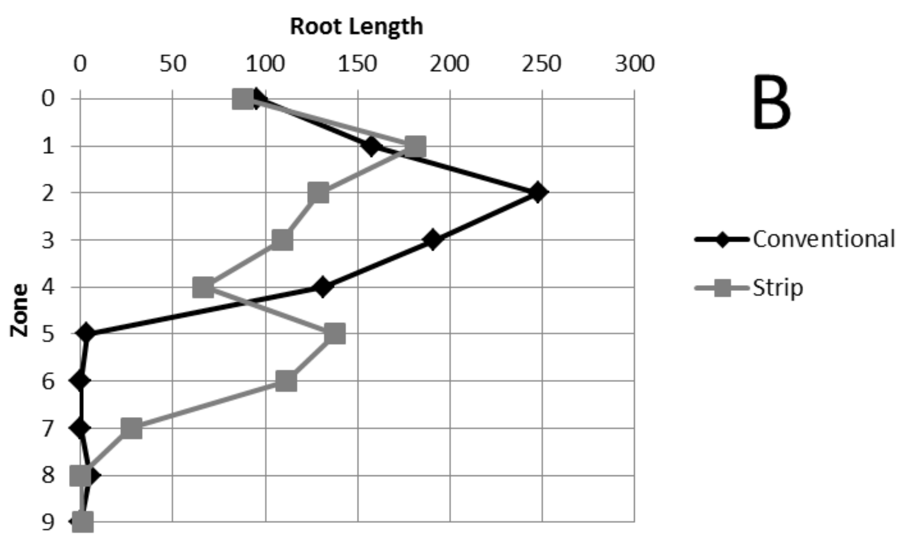
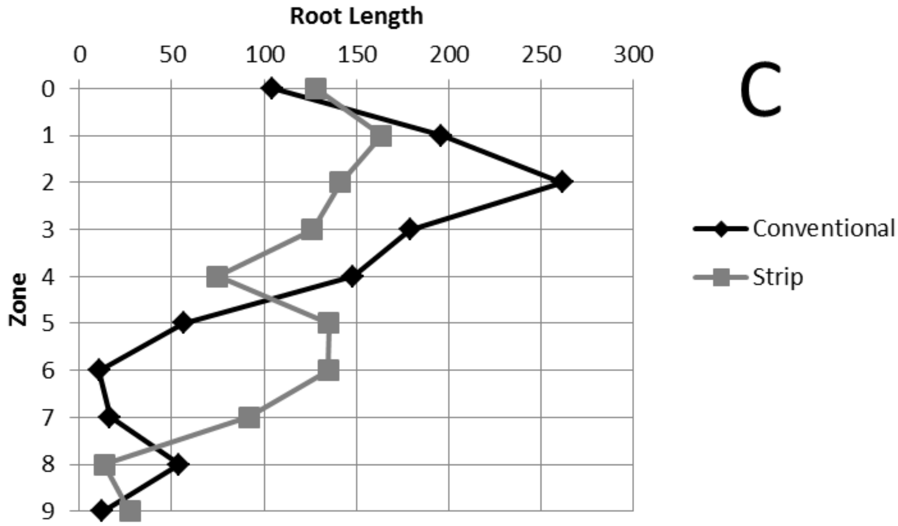
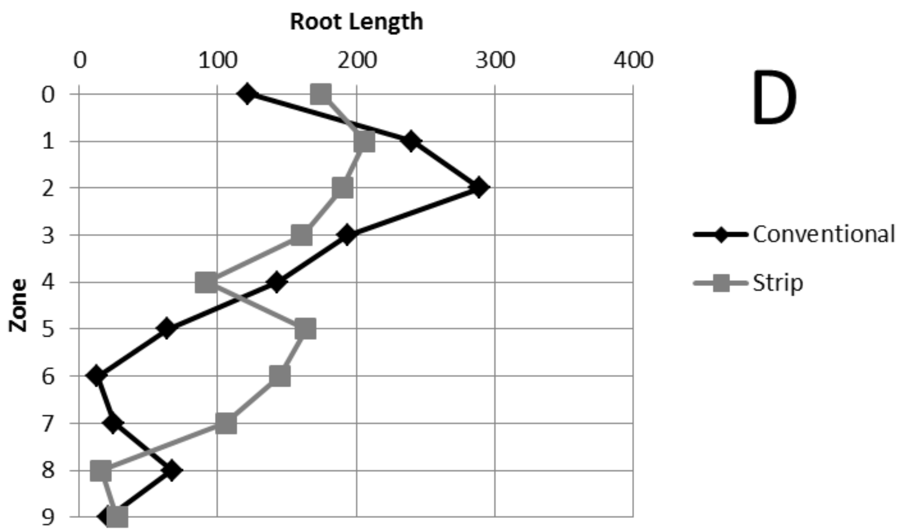

Root Length
0
50
100
150
200
Zone
0
1
2
3
4
5
6
7
8
9
C
Conventional
Strip

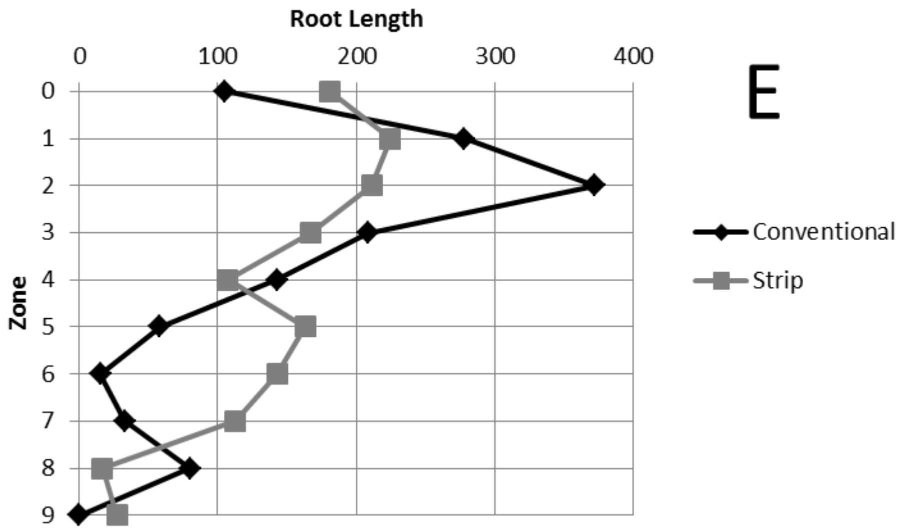
Figure 2-18. Rooting Profile Cotton 2012. Total root length (TRL) down the profile of the soil where each zone is a 10 cm increment. Graphs show measurements at 38 (A), 59 (B), 80 (C), 100 (D), 114 (E) DAP.






Root Length
0
50
100
150
200
250
300
Zone
0
1
2
3
4
5
6
7
8
9
C
Conventional
Strip


Root Length
0
100
200
300
400
Zone
0
1
2
3
4
5
6
7
8
9
D
Conventional
Strip


Root Length
0
100
200
300
400
0
1
2
3
4
5
6
7
8
9
Zone
E
Conventional
Strip

CHAPTER 3
AN INVESTIGATION OF THE RELATIONSHIP BETWEEN SOIL WATER CONTENT AND SAP FLOW IN COTTON UNDER IRRIGATED AND NON-IRRIGATED CONDITIONS

Summary

Efficient irrigation scheduling is a key component to sustainable production strategies for cotton. Soil based measurements have been tested and implemented in commercial irrigation decision systems but may be inadequate to precisely reflect crop water use. The purpose of the current study was to quantify the relationship between volumetric soil water content (as measured with capacitance soil moisture sensors) and cotton water use. The study was conducted in 2012 at the Plant Science Research and Education Unit in Citra, Florida in both irrigated and rain fed conditions. The design of the experiment was a complete randomized block with irrigation being the main treatment. The cotton cultivar Phytogen 375WRF was planted on 17 April 2012 and sap flow and soil moisture measurements were logged continuously from 30 June until 30 July during the peak water use period for the crop. Sap flow rates were adjusted for leaf area and summed by day to calculate total daily water use (TDWU). Soil moisture was measured at 20 and 60 cm depths to determine the depth of active water uptake in the crop. Linear and quadratic regression analyses were made between average daily soil moisture content and plant TDWU. Our analyses showed a significant quadratic relationship for non-irrigated cotton TDWU with soil moisture at 60 cm only. This relationship indicates that plant water use is related more specifically to certain depths (probably reflecting root architecture) and that scheduling irrigation using the appropriate depth is critical. The lack of a relationship in the irrigated plots may have reflected an excess water receipt of these plots due to high precipitation during the

measurement period. This preliminary data provides guidance for the use of soil moisture sensors in scheduling irrigation in southeastern U.S. cotton production and indicates that there is a direct relationship with crop water use and soil moisture at appropriate soil depths.

Introduction

Cotton is an efficient user of water compared to other crops and has the potential to perform well even under water deficit (Ackerson & Krieg, 1977). However, the sandy, drought prone soils in some parts of the southeastern U.S. challenge the water-use efficiency of cotton, especially in years when rainfall is inconsistent or reduced. This makes irrigation application beneficial or even essential during more drought prone years. However, to efficiently apply irrigation to meet crop demand, it is preferable to monitor soil moisture conditions to aid in irrigation scheduling decisions. It is therefore important for growers and researchers to understand how soil moisture is related to crop water use responses during changes in the soil moisture environment.

There are a variety of irrigation scheduling techniques from checkbook methods (Lundstrom and Stegman, 1988), evapotranspiration (ET) estimations (Wright and Jensen, 1978), to crop modeling methods (George et al., 2000); but many irrigation decision systems now rely solely on soil moisture estimations to determine crop water-use. Typically, a soil moisture threshold in terms of volumetric water content or soil matric potential is determined and soil moisture is monitored through the season, so that when levels fall below the threshold, irrigation is applied (Campbell and Campbell, 1982). The most common measure of soil moisture has been soil matric potential (SMP) and SMP sensors for irrigation scheduling have been shown to be effective for many crops including vegetables (Thompson et al., 2007), and field crops such as cotton and rice (Vellidis et al., 2008; Kukal et al., 2005). In particular, Irrigator Pro for cotton, a commonly used irrigation scheduling system for cotton in the southeast (www.ars.usda.gov), utilizes gypsum block sensors for scheduling irrigation. However, in all of the irrigation scheduling systems utilizing measurements of soil moisture or matric potential, the identification of accurate thresholds is essential. If soil moisture thresholds used for irrigation decisions are too high, the potential for improving water-use efficiency is removed. The key to optimizing water-use efficiency would be to ensure there was an accurate match between soil moisture measurement and actual crop water use. Despite the heavy reliance on soil moisture sensors for triggering irrigation, few studies have investigated and quantified the direct measure of soil moisture with crop water-use during the growing season to verify that soil moisture is an adequate surrogate for indicating crop water need. Further, determining which soil depth represents the zone of active root activity and, thus is the most appropriate for soil moisture monitoring, is often not known and little studied.

To better understand the relationship between soil moisture and actual plant water use, a comparison between soil moisture dynamics and direct measurements of plant water use is needed. To measure water use on an individual plant, the heat pulse method can be used (Baker and van Bavel, 2006). The heat pulse method is able to calculate the flow of sap through the stem using an insulated collar containing a heating strip with two thermocouples on either side. The temperature difference between the thermocouples is measured several times per second, as well as the amount of time between the exertion of the heat pulse and the return of the sap to its initial temperature. These calculations, indexed to a stem diameter, provide a direct calculation of stem sap flow from a given plant (Smith and Allen, 1996). Cohen et al., (1988) demonstrated that the heat pulse method can be effectively used on cotton and Lascano (2000) demonstrated that sap flow measurements can be more effective for irrigation scheduling in cotton than ET replacement models.

Identification of the appropriate soil depths to monitor for irrigation scheduling is also essential to matching sap flow with measurements of soil moisture. However, information about basic root architecture would be needed to accomplish this. Studies rarely relate root architecture to both direct and indirect measurements of crop water use (Taylor and Klepper, 1974; Lascano and van Bavel, 1984). Therefore, what is needed to justify the use of soil moisture monitoring for cotton irrigation scheduling is a simultaneous measurement of soil moisture at varying depths and sap flow, combined with quantification of rooting architecture over time.

To address this research need, our objective in this study was to correlate measurements of soil moisture at two depths that are likely active zones of water uptake for southeastern cotton (20 and 60 cm) with daily sap flow during the mid to late season, a period representing peak water use in the crop. Further, root growth and architecture were quantified and related back to patterns of soil moisture and water uptake rates that were observed. This information could then be used to confirm the utility of soil moisture sensors for scheduling irrigation in southeastern cotton.

Materials and Methods

Field Preparation and Crop Maintenance

Field plots were established at the University of Florida's Plant Science Research and Education Unit located in Citra, FL (29°24'28" N, 82°10'30" W, elevation 21 meters) on a Sparr fine sand (loamy, siliceous, subactive, hyperthermic Grossarenic Paleudults). Field trials were conducted in 2012 using the cotton cultivar Phytogen 375 planted on 16 April 2012 with an intrarow seed spacing of 13.1 seed m^{-1}. The design of the experiment consisted of a randomized complete block design with two treatments (irrigation and no irrigation) and three replications (plots). Individual plots consisted of eight rows spaced 0.91 m apart and 19.8 m in length. Within each plot, minirhizotron tubes and soil moisture sensors were installed in the row. For measurement of sap flow, twelve reps (plants) within each treatment were split across the 3 replications for both irrigated and non-irrigated plots within the experimental area.

Plant and Soil Measurements

Soil moisture measurements at 20 and 60 cm depths were logged once per hour using EC-5 soil moisture sensors (Decagon Devices, Inc.; www.decagon.com). For analysis, hourly soil moisture readings were averaged by day. To measure sap flow, the Flow 32-1K system from Dynamax was used (www.dynamax.com). Theory and methodology of operation are described in Smith and Allen (1996). Twenty-four sap flow collars where installed on individual plants (12 in irrigated and 12 in non-irrigated plots) and measurements were logged at 15 minute intervals. Sap flow measurements encompassed 30 June 2012 until 30 July 2012. Due to equipment failures, only 6 plants from irrigated plots and 9 plants from non-irrigated plots were used for analysis. Following removal of the sap flow equipment, total leaf area from each plant was measured with a leaf area meter (Model 3100, LI-COR Biosciences; www.licor.com) and leaf area values were used to normalize sap flow rates on a leaf area basis. Flow rates were summed over a 24 hour period (by day) for total daily water use values (TDWU) that were used to relate to average daily soil moisture.

Differences in overall TDWU between irrigated and non-irrigated plots were analyzed using Generalized Linear Models and linear and quadratic regressions using JMP 9.0 software (SAS Institute Inc., Cary, NC).To determine if a relationship existed between soil moisture content and sap flow, linear and quadratic polynomial regressions related average daily soil moisture content (cm^3 cm^{-3}) with TDWU, the sum of daily sap flow per unit leaf area (g cm^{-2}).

Root architecture was measured using a minirhizotron camera system (Bartz Technology Corp; www.bartztechnology.com) which allows *in situ*, non-destructive measurements of roots throughout the growing season. The technology uses acrylic access tubes inserted within and parallel to a crop row at a 45 degree angle from the plane of the soil. Within two weeks after planting, 12 minirhizotron tubes were installed into irrigated and non-irrigated cotton plots. A camera was inserted into each tube and root images were taken at every 13.5 mm along the top surface of the tube on 6 and 26 July 2012, representing the beginning and end of the measurement period, respectively. These images were then analyzed using Win Rhizo Tron software (Regent Instruments Inc; www.regentinstruments.com) which quantified rooting depth, root length, and root surface area. Individual root image analyses were grouped into 10 zones (0-9), each zone encompassing consecutive 10 cm depth sections beginning at the surface of the soil.

Results and Discussion

The total rainfall during the measurement period was 53 cm. Irrigated plots were irrigated twice during this period, 30 June and 7 July, 2012 with 1.9 cm each time. However, previous to the measurement period, rainfall totaled 58.8 cm and irrigated plots received an additional 15.24 cm of irrigation (Figure 3-1).

TDWU varied between irrigated and non-irrigated treatments for the 31 day period with an average TDWU of 0.41 g cm^{-2} under irrigation and 0.50 g cm^{-2} without irrigation (p-value = 0.0149) (Figure 3-2). These totals were similar to others documented in the literature for cotton (Isoda and Wang, 2002) that recorded sums ranging from 0.40 to 0.90 g cm^{-2} during a 4 day measurement period. Overall, TDWU ranged from 0.22 to 0.89 g cm^{-2} but tended to decrease over the 30-day measurement period as the crop was maturing (Figure 3-2). The average daily soil volumetric water content over the 30 day measurement period at the 20 and 60 cm depths was greater in the irrigated treatment (p-value < 0.001) than in the non-irrigated treatment. At 20 cm, soil moisture in the irrigated plots was 12.0 compared to 8.7% in the non-irrigated treatment; while at the 60 cm depth, soil volumetric water content under irrigation was 9.6 compared to 7.4% in the non-irrigated treatment (Figure 3-3). These numbers are within the general range of unsaturated soil water content values (5-10%) that have been documented in a similar Florida soil (Obreza et al., 1997).

When TDWU and average daily soil moisture were regressed, no linear relationships were found for irrigated or non-irrigated sap flow at either 20 or 60 cm soil depths. However, a significant quadratic relationship was found between TDWU in non-irrigated plots and soil moisture values at the 60 cm depth (Figure 3-4; Table 3-1). This relationship indicates that soil moisture at particular depths (in this case 60 cm) can be directly related to crop water use. The lack of relationship between TDWU and soil moisture (at either depth) for irrigated plots is somewhat surprising because the daily soil moisture patterns were similar for both irrigated and non-irrigated plots and differed only in magnitude (Figure 3-2). The lack of a significant relationship between TDWU and soil moisture in the irrigated plots could represent a moisture content in these plots that was above plant water need, such that additional moisture had no effect on TDWU. Whereas, in the non-irrigated plots, soil moisture availability may have reached levels below crop water requirement, such that TDWU was able to respond to increases in soil moisture. This is supported by the shape of the relationship between TDWU and soil moisture: a negative quadratic shape (Figure 3-4). If this explanation is correct, the overall relationship shows that TDWU increases nearly linearly with soil moisture up to a threshold of 8.5-9% VWC (Figure 3-5); beyond which TDWU drops off and decreases dramatically. This indicates that TDWU increases with increasing VWC up to a threshold and then no longer responds to increases in soil moisture. This is similar to the situation when cotton experiences water deficit stress: osmotic adjustment will occur and transpiration will decrease (Oosterhuis and Wullschlegger, 1987). However, in the current study, TDWU may decrease because of excess water availability in the profile.

However, the overall quadratic shape of the relationship between TDWU and average daily soil moisture is driven almost exclusively by the last five points at the highest soil moisture levels. In the absence of these points, the relationship is solely linear. These last five points represent points collected during the last five days of measurement. It was visually noted that the crop during this period was significantly senesced due to the impact of a developing fungal disease combined with acute nutrient deficiencies. Therefore, the dramatic drop in TDWU for these points may not be indicative of true crop water requirement but more related to the overall rapid maturing and senescence of the crop under suboptimal conditions. If these last five points are removed, the relationship is significantly linear (p-value < 0.001, R^2 = 0.542) (Figure 3-5).

It is also important to note that the relationship between TDWU and soil moisture occurred at the 60 cm depth. This would be expected based on the root architecture, where increased total root length was present at deeper depths (zones 5-7; p-values < 0.001) in the non-irrigated plants during the study period (Table 3-2 and Figure 3-6). The data in the current study show that in north central Florida environments, soil moisture at a relatively shallow depth (20 cm) has a limited direct relationship with cotton water use, and therefore, little utility for scheduling irrigation. This may be due to a lack of significant root proliferation and thus active water uptake in this region. This result agrees with other research including the study by Burke and Upchurch (1995) which showed that non-irrigated cotton had greater root length density at deeper depths (70-120 cm) than irrigated plants. There is some evidence of a relationship between soil moisture content and root proliferation (Taylor and Klepper, 1974). Further research could focus on monitoring TDWU and soil moisture at additional depths.

These findings have important implications for the study of cotton water use as well as irrigation management. Some have noted that the value of using soil moisture readings for irrigation scheduling is limited and that evaporative changes in the plant respond directly to changes in plant water status in different portions of the plant, changes which may not be related to changes in bulk soil moisture (Jones, 2004; Thompson et al., 2007). Jones (2004) also claims that the water status of the plant relies not only on soil moisture but the resistances to water flow that occurs at the interface between the soil, the root, and within the plant. Since plant water use may act independently of soil moisture, using soil moisture as a surrogate for irrigation scheduling may be problematic in some cases. Some studies have shown the validity of using sap flow by itself for irrigation scheduling. Eastham and Gray conducted a study on sap flow in irrigated and non-irrigated grapevines (1998) and found that plant sap flow was sensitive to changes in timing and amounts of water applied. Similarly others have found validity in the use of sap flow to detect differences between flow rates of irrigated and non-irrigated woody plants, showing that sap flow is a good indicator of plant water status (Ameglio et al., 1999; Ginestar et al., 1998; Giorio and Giorio, 2003; Remorini and Massai, 2003). Each of these studies note the validity of using sap flow for irrigation scheduling but there are no examples of replicated studies testing the application of this method in the field. Additionally, the application of sap flow technology, especially in the case of cotton, would be cost prohibitive for commercial production, as well as technically difficult. Therefore, it is essential to validate the relationship between soil moisture and sap flow and to identify the appropriate soil depths to monitor soil moisture for irrigation scheduling. Knowledge about this relationship could determine the success or failure of irrigation scheduling systems utilizing soil moisture sensors and could prove to be essential for improving cotton irrigation scheduling efficiency in the southeast.

Table 3-1. Relationship Between Soil Moisture and Sap Flow.Listed below are the R^2 values for quadratic regressions made between soil volumetric water content and sap flow.

Treatment	Value	20 cm	60cm
Irrigated	R^2	0.083634	0.172355
	equation	$y = 0.096 + 0.028x – 0.015(x – 12.0417)^2$	$y = -0.198 + 0.067x – 0.061(x – 9.554)^2$
Non-Irrigated	R^2	0.122493	0.356712*
	equation	$y = 0.607 – 0.003x – 0.048(x – 8.673)^2$	$y = - 0.075 + 0.092x – 0.119(x – 7.396)^2$

* p-value < 0.05

Table 3-2. ANOVA of Root Analyses. F values of analyses of the effect of irrigation on total root length (TRL) and total surface area (TSA) near the beginning of the measurement period (7/06/2012) and end of the measurement period (7/26/2012). Values are separated by zones (0-9) which encompass a 10 cm region of the rooting profile.

7/06/2012		Zone 0		Zone 1		Zone 2		Zone 3		Zone 4	
Effect	df	TRL	TSA	TRL	TSA	TRL	TSA	TRL	TSA	TRL	TSA
Irrigation	1	4.8951	3.9939	4678.599*	204.4222*	30.5174*	13.9916	0.1781	0.3163	0.1125	0.2474
		Zone 5		Zone 6		Zone 7		Zone 8		Zone 9	
Irrigation	1	73.9832*	31.6747*	15.7674	21.7827*	0.1905	3.2319	0.0116	0.0127	0.5499	0.3416
7/26/2012		Zone 0		Zone 1		Zone 2		Zone 3		Zone 4	
Irrigation	1	3.2829	2.5795	93.5614*	270.8946*	45.4918*	18.3476	0.0508	0.3376	0.0572	0.1935
		Zone 5		Zone 6		Zone 7		Zone 8		Zone 9	
Irrigation	1	78.1563*	25.2871*	14.0159	23.2646	3.6886	3.1048	0.0059	0.0073	0.0494	0.0165

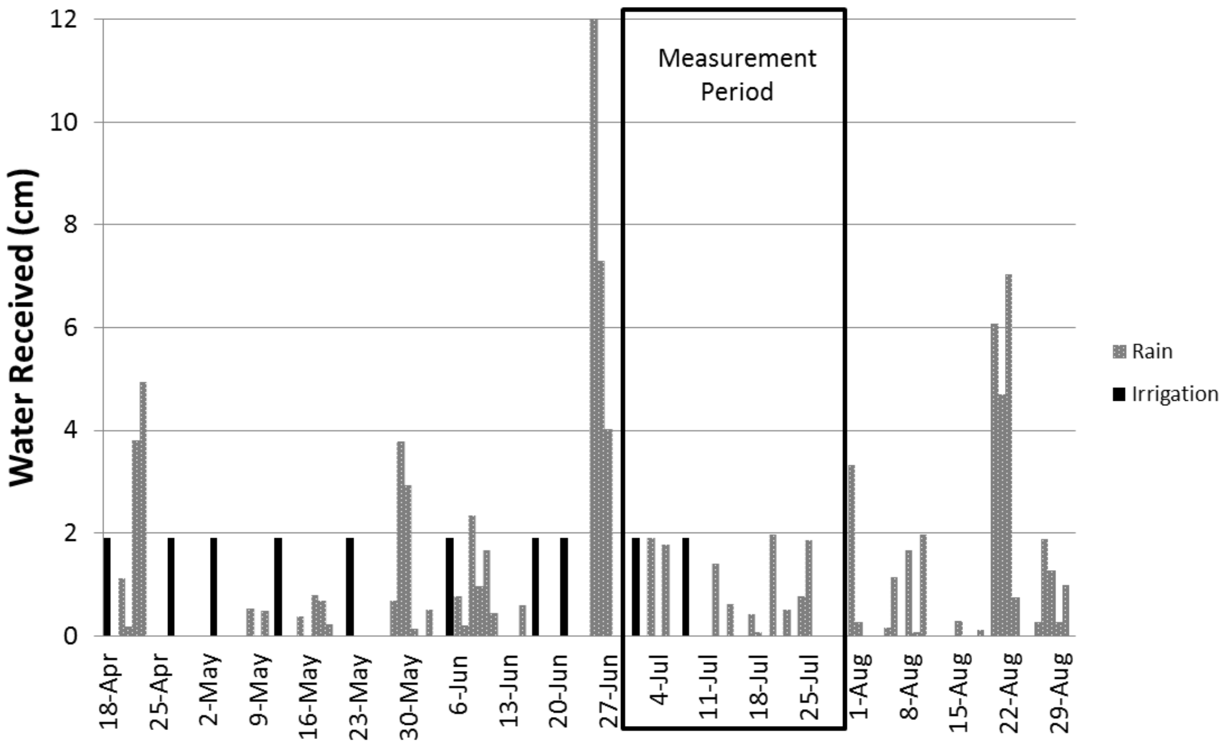


Figure 3-1. Rainfall and Irrigation Distribution. Amounts of rainfall and irrigation received during the cropping season where the box outlines the period of soil moisture and sap flow were measured.

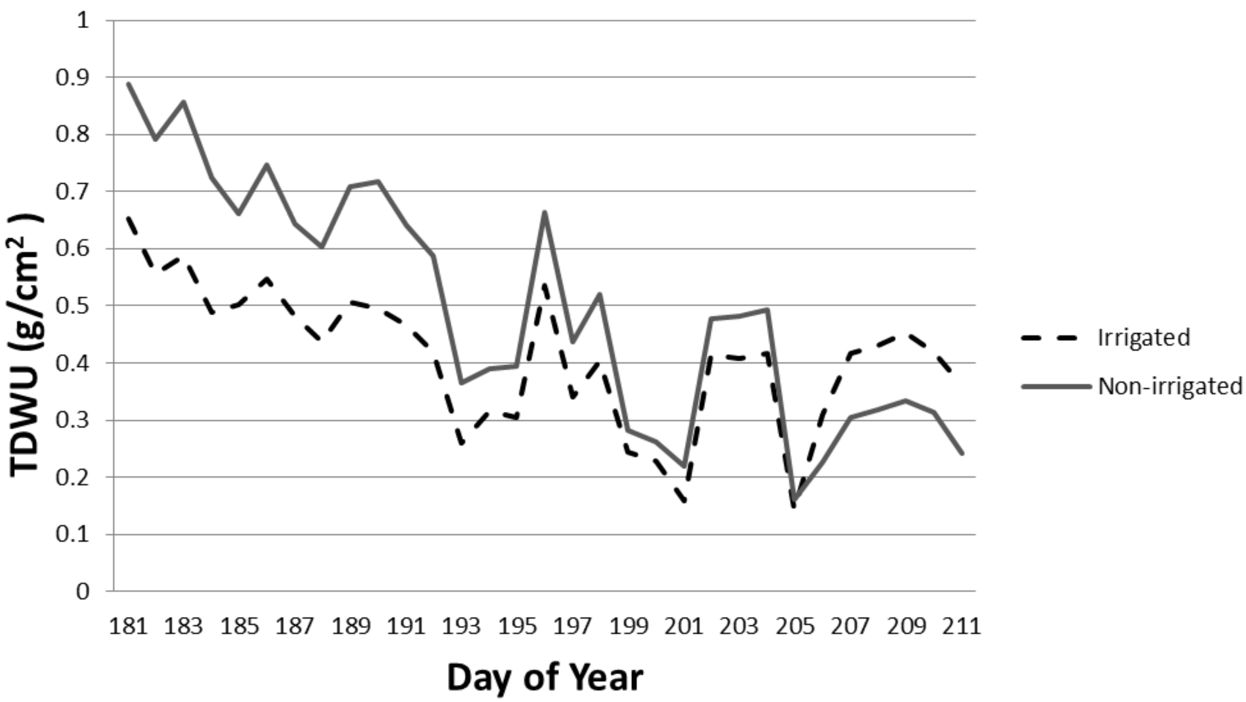


Figure 3-2. Cotton Total Daily Water Use. Total daily water use in units of grams per cm2 leaf area.

Figure 3-3. Soil Moisture. Soil volumetric water content shown in irrigated 20 and 60 cm depths (I-20; I-60) and non-irrigated 20 and 60 cm depths (N-20; N-60).

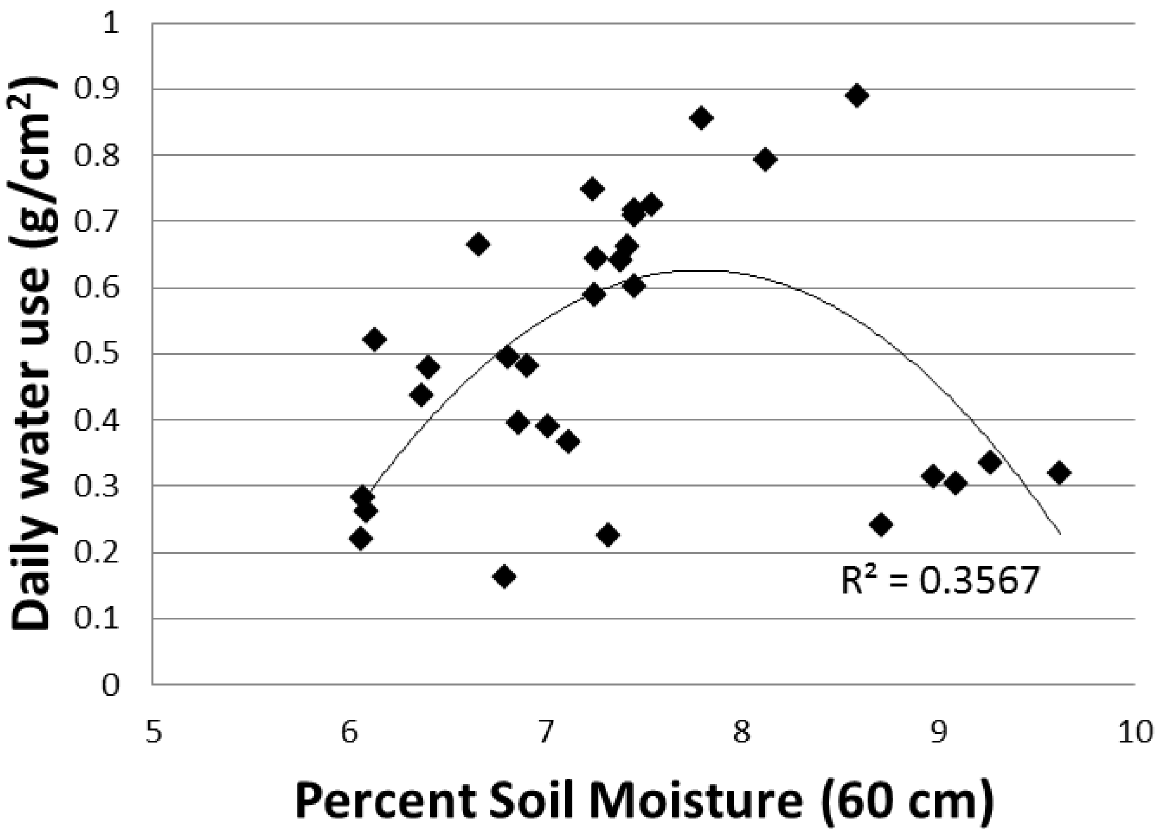


Figure 3-4. Polynomial Regression of TDWU with Soil Moisture. Summed daily sap flow response to volumetric soil moisture content at 60 cm from 30 June 2012 through 30 July 2012.

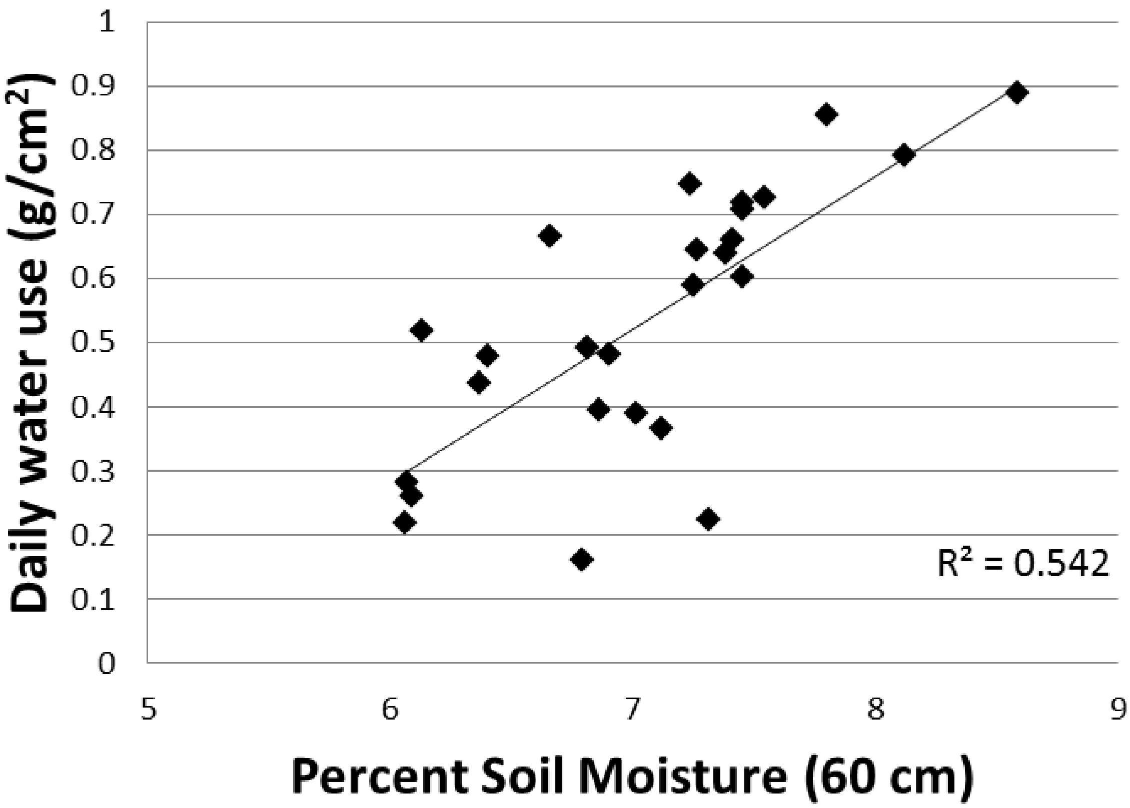


Figure 3-5. Linear Regression of TDWU with Soil Moisture. Summed daily sap flow response to volumetric soil moisture content at 60 cm from 30 June 2012 through 30 July 2012. Five points where soil moisture was over 8.5% were removed.

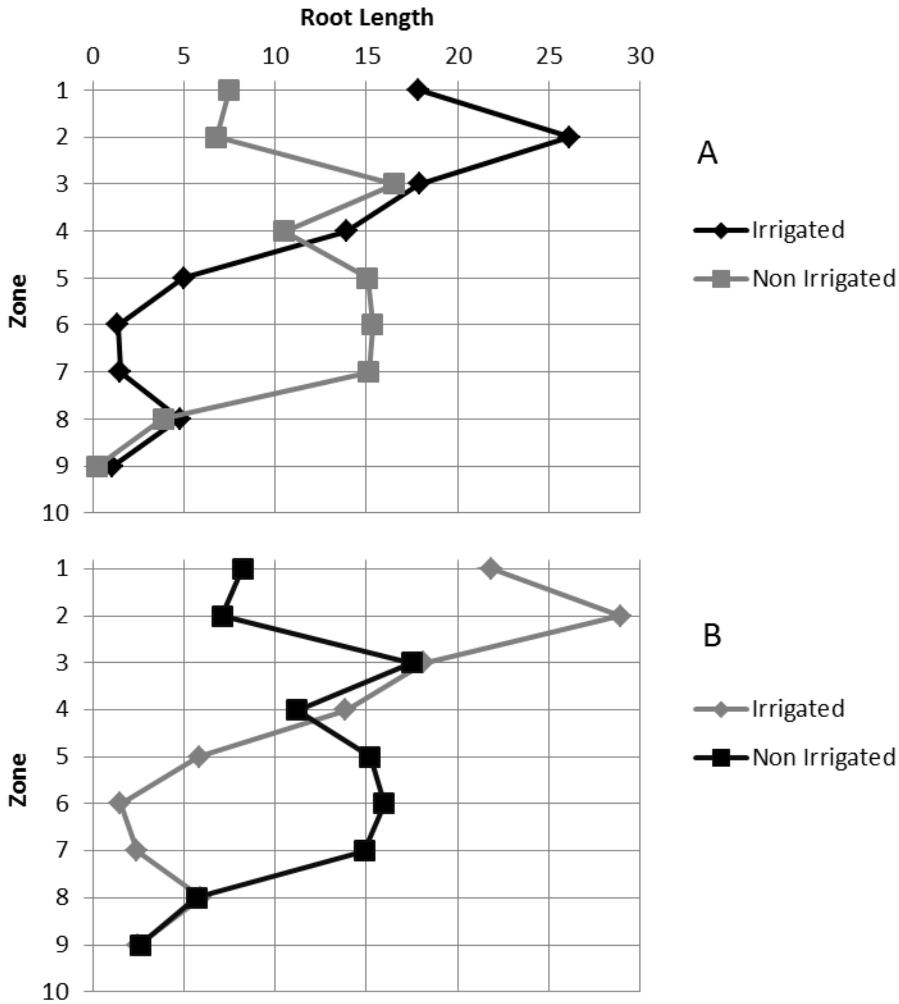


Figure 3-6. Cotton Rooting Profile. Total root length (TRL) near the beginning of the measurement period (7/06/2012; A) and end of the measurement period (7/26/2012; B). Values are separated by zones (0-9) which encompass a 10 cm region of the rooting profile.

LIST OF REFERENCES

Ameglio T, Archer P, Cohen M, Valancogne C, Daudet F, Dayau S, and Cruiziat P. 1999. Significance and limits in the use of predawn leaf water potential for tree irrigation. Plant and Soil 207:155-167.

Arshad MA, Franzluebbers AJ, Azooz RH. 1999. Components of surface soil structure under conventional and no-tillage in northwestern Canada. Soil and Tillage Res. 53:41-47.

Baker JM and van Bavel CHM. 2006. Measurement of mass flow of water in the stems of herbaceous plants. Plant, Cell and Env.10:777-782.

Baldwin JA and Hook J. 1998. Reduced tillage systems for peanut production in georgia. Proc. Am. Peanut Res. Ed. Soc. 30:48.

Ball RA, Oosterhuis DM, Mauromoustakos A. Growth dynamics of the cotton plant during water-deficit stress. Agron. J 86:788-795.

Bauer PJ, Fortnum BA, Frederick JR. 2010. Cotton responses to tillage and rotation during the turn of the century drought. Agron J 102:1145-8.

Black CR, Tang DY, Ong CK, Solon A, Simmonds LP. 1985. Effects of soil moisture stress on the water relations and water use of groundnut stands. New Phytologist 100:313-328.

Blevins RL, Cook D, Phillips SH, Phillips RE. 1971. Influence of no-tillage on soil moisture. Agron. J. 63:593-596.

Brandenburg RL, Herbert DA, Sullivan GA, Naderman GC, and Wright FS. 1998. The impact of tillage practices on thrips injury of peanut in north carolina and virginia. Peanut Sci. 25:27-31.

Brown SM, Whitwell T, Touchton JT, Burmester CH. 1985. Conservation tillage systems for cotton production. Agron. J. 49:1256-1260.

Burke JJ, and Upchurch DR. 1995. Cotton rooting patterns in relation to soil temperatures and the thermal kinetic window. Agron. J. 87:1210-1216.

Busschler WJ and Bauer PJ. 2003. Soil strength, cotton root growth and lint yield in a southeastern usa coastal loamy sand. Soil and Tillage Research 74:151-159.

Campbell GS and Campbell MD. 1982. Irrigation scheduling using soil moisture measurements: theory and practice. Advances in Irrigation 1:25-42.

Cassman KG, Kerby TA, Roberts BA, Bryant DC, and Higashi SL. 1990. Potassium effects on lint yield and fiber quality of acala cotton. Crop Sci. 30:672-677.

Cohen Y, Fuchs M, Falkenflug V, and Moreshet S. 1988. Calibrated heat pulse method for determining water uptake in cotton. Crop Sci. 80:398-402.

Colvin DL, Brecke BJ, and Whitty EB. 1988. Tillage variables for peanut production. Peanut Sci. 15:94-97.

Coker DL, Oosterhuis DM, and Brown RS. 2009. Cotton yield response to soil- and foliar-applied potassium as influenced by irrigation. J. of Cotton Sci. 13:1-10.

[CTIC] Conservation tillage Information Center. 2002. Tillage type definitions [online]. http://www.ctic.purdue.edu (1 October 2012).

Dao TH. 1993. Tillage and winter wheat residue management effects on water infiltration and storage. Soil Sci. Soc. Journal 57:1586-1595.

Dwyer LM, Ma BL, Stewart DW, Hayhoe HN, Balchin D, Culley JLB, McGovern M. 1996. Root mass distribution under conventional and conservation tillage. Canadian Journal of Soil Science 76:23-28.

Eastham J and Gray S. 1998. A preliminary evaluation of the suitability of sap flow sensors for use in scheduling vineyard irrigation. Am. J. Enol. Vitic. 49:171-176.

Endale DM, Schomberg HH, Fisher DS, Jenkins MB, Sharpe RR, and Cabrera ML. 2008. No-till corn productivity in a southeastern united states ultisol amended with poultry litter. Agron. J. 100:1401-1408.

[FAO] Food and Agriculture Organization of the United Nations. 1998. Crop evapotranspiration: guidelines for computing crop water requirements. p. 111.

Franzluebbers AJ. 2002. Soil organic matter stratification ratio as an indicator of soil quality. Soil and Tillage Res. 66:95-106.

Gantzer CJ and Blake GR. 1978. Physical characteristics of le sueur clay loam soil following no-till and conventional tillage. Agron. J. 70:853-857.

George BA, Shende SA and Raghuwanshi NS. 2000. Development and testing of an irrigation scheduling model. Agric. Water Mgmt. 46:121-136.

Ginestar C, Eastham J, Gray S, and Iland P. 2003. Use of sap-flow sensors to schedule vineyard irrigation. i. effects of post-veraison water deficits on water relations, vine growth, and yield of shiraz grapevines. Am. J. Enol. Vitic. 49:413-420.

Giorio P and Giorio G. Sap flow of several olive trees estimated with the heat-pulse technique by continuous monitoring of a single gauge. Env. and Exp. Botany 49:9-20.

Graven LM and Carter PR. 1991. Seed quality effect on corn performance under conventional and no-tillage systems. J. Prod. Agric. 4:366-373.

Guin G and Mauney JR. 1984. Fruiting of cotton.ii. effects of plant moisture status and active boll load on boll retention. Agron. J. 76:94-98.

Halvorson AD, Mosier AR, Reule CA, and Bausch WC. 2006. Nitrogen and tillage effects on irrigated continuous corn yields. Agron. J. 98:63-71.

Hammel JE. 1995. Long-term tillage and crop rotation effects on winter wheat production in northern idaho. Agron. J. 87:16-22.

Hilfiker RE and Lowery B. 1988. Effect of conservation tillage systems on corn root growth. Soil and Tillage Research 12:269-283.

Howell, 1996Howell, T.A., 1996. Irrigation scheduling research and its impact on water use. In: Camp, C.R., Sadler, E.J., Yoder, R.E. (Eds.), Proceedings of the International Conference on Evapotranspiration and Irrigation Scheduling, San Antonio, TX, USA, 3–6 November 1995, ASAE, pp. 21–33.

Hsu HH, Lancaster JD, and Jones WF. 1978. Potassium concentration in leaf-blades and petioles as affected by potassium fertilization and stage of maturity of cotton. Com. in Soil Sci. and Plant Anal. 9:265-277.

Hurt CA, Brandenburg RL, Jordan DL, Royals BM, Johnson PD. 2006. Interactions of tillage with management practices designed to minimize tomato spotted wilt of peanut (arachis hypogaea l.). Peanut Sci. 33:83-89.

Hutson SS, Barber NL, Kenny JF, Linsey KS, Lumia DS, and Maupin MA. Estimated use of water in the united states in 2000. US Geological Survey Circular 1268.

Ishaq M, Ibrahim M, and Lal R. 2001. Tillage effect on nutrient uptake by wheat and cotton as influenced by fertilizer rate. Soil and Tillage Research 62:41-53.

Isoda A and Wang P. 2002. Leaf temperature and transpiration of field grown cotton and soybean under arid and humid conditions. Plant Prod. Sci. 5:224-228.

Johnson MD and Lowery B. 1985. Effect of three conservation tillage practices on soil temperature and thermal properties. Journal - Soil Science Society of America 49:1547-1552.

Johnson IR and Thornley JHM. 1985. Temperature dependence of plant and crop processes. Ann. Bot. 55:1-24.

Jones HG. 2003. Irrigation scheduling: advantages and pitfalls of plant-based methods. J. of Exp. Botany 407:2427-2436.

Jones HG. 2007. Monitoring plant and soil water status: established and novel methods revisited and their relevance to studies of drought tolerance. J. of Exp. Botany 58:119-130.

Jones JN, Moody JE, and Lillard JH. 1969. Effects of tillage, no tillage, and mulch on soil water and plant growth. Agron. J. 61:719-721.

Karamanos AJ, Bilalis D, Sidiras N. 2004. Effects of reduced tillage and fertlization practices on soil characteristics, plant water status, growth and yield of upland cotton. Journal of Agronomy and Crop Sci. 190:262-276.

Katsvairo TW, Wright DL, Marois JJ, Hartzog DL, Rich JR and Wiatrak PJ. 2006. Sod-livestock integration into the peanut-cotton rotation. Agron. J. 98:1156-1171.

Katsvairo TW, Wright DL, Marois JJ, Hartzog DL, Balkcom KB, Wiatrak PP, and Rich JR. 2007. Cotton roots, earthworms, and infiltration characteristics in sod-peanut-cotton cropping systems. Agron. J. 99:390-398.

Kerby TA and Adams F. 1985. Potassium nutrition of cotton. Potassium in Agriculture. American Society of Agronomy Meeting: 843-860.

Knowler D and Bradshaw B. 2007. Farmers' adoption of conservation agriculture: a review and synthesis of recent research. Food Policy 32:25-48.

Kukal SS, Hira GS and Sidhu AS. 2005. Soil matric potential-based irrigation scheduling to rice (oryza sativa). Irrigation Sci. 23:153-159.

Lamb MC, Davidson Jr. JI, Childre JW, and Martin Jr. NR. 1997. Comparison of peanut yield, quality and net returns between nonirrigated and irrigated production. Peanut Sci. 24:97-101.

Lamb MC, Masters MH, Rowland D, Sorenson RB, Zhu H, Blankenship RD, and Butts CL. 2004. Impact of sprinkler irrigation amount and rotation on peanut yield. Peanut Sci. 31:108-113.

Langdale GW, Wilson RL, and Bruce RR. 1990. Cropping frequencies to sustain long-term conservation tillage systems. Soil Sci. Soc. Am. J. 54:193-198.

Lascano RJ. 2000. A general system to measure and calculate daily crop water use. Agron. J. 92:821-832.

Lascano RJ, Baumhardt RL, and Hicks SK. 1994. Soil and plant water evaporation from strip-tilled cotton: measurement and simulation. Agron. J. 86:987-994.

Lascano RJ and Baumhardt RL. 1996. Effects of crop residue on soil and plant water evaporation in a dryland cotton system. Theoretical and Applied Climatology 54:69-84.

Lascano RJ and Van Bavel CHM. 1984. Root water uptake and soil water distribution: test of an availability concept. Soil Sci. Soc. Am. J. 48:233-237.

Lindstrom and Onstad. 1984. Influence of tillage systems on soil physical parameters and infiltration after planting. J. of Soil and Water Cons. 39:149-152.

Loison R, Rowland D, Faircloth W, Marois JJ, Wright DL and George S. 2012. Cattle grazing affects cotton root dimensions and yield in a bahiagrass-based crop rotation. Online. Crop management doi:10.1094/CM-2012-0925-02-RS.

Lundstrom DR and Stegman EC. 1988. Irrigation scheduling by the checkbook method. Bull. AE-792(rev.) North Dakota State Univ. Ext. Serv., Fargo.

MacKenzie AJ, Spencer WF, Stockinger KR, and Krantz BA. 1963. Seasonal nitrate-nitrogen content of cotton petioles as affected by nitrogen application and its relationship to yield. Agron. J. 55:55-59.

Marois JJ and Wright DL. 2003. Effect of tillage system, phorate, and cultivar on tomato spotted wilt of peanut. Agron. J. 95:386-389.

Masters MH and Lamb MC. 2003. Economic feasibility of limiting irrigation on cotton in southwest Georgia. Proceedings of 2003 Beltwide Cotton Conferences, Nashville,TN 421-427.

Meisner CA and Karnok KJ. 1992. Peanut root response to drought stress. Agron. J. 84:159-165.

Miguez FE and Bollero GA. 2005. Review of corn yield response under winter cover cropping systems using meta-analytic methods. Crop Sci. 45:2318-2329.

Mitchell JP, Munk DS, Prys B, Klonsky KK, Wroble JF, DeMoura RL. 2006. Conservation tillage production systems compared in san joaquin valley cotton. California Agriculture 60:140-145.

Newell RL and Wilhelm WW. 1987. Conservation tillage and irrigation effects on corn root development. Agron. J. 79:160-165.

Nyajatawa EZ, Reddy KC, and Mays DA. 2000. Tillage, cover cropping, and poultry litter effects on cotton:ii. growth and yield parameters. Agron. J. 92:1000-1007.

Obreza TA, Pitts DJ, Parson LR, Wheaton TA, and Morgan KT. 1997. Soil water-holding characteristic affects citrus irrigation scheduling strategy. Proc. Fl. State Hort. Soc. 110:36-39.

Olson TC and Schoeberl LS. 1970. Corn yields, soil temperature, and water use with four tillage methods in the western corn belt. Agron. J. 62:229-232.

Oosterhuis DM and Wullschleger SD. 1987. Osmotic adjustment in cotton (gossypium hirsutum l.) leaves and roots in response to water stress. Plant Phys. 84:1154-1157.

Pettigrew WT, and Jones MA. 2001. Cotton growth under no-till production in the lower Mississippi river valley alluvial flood plain. Agron. J. 93:1398-1404.

Pietola LM. 2005. Root growth dynamics of spring cereals with discontinuation of mouldboard ploughing. Soil and Tillage Research 80:103-114.

Rasse DP and Smucker AJM. 1998. Root recolonization of previous root channels in corn and alfalfa rotations. Plant and Soil 204:203-212.

Remorini D and Massai Rossano. 2003. Comparison of water status indicators for young peach trees. Irrigation Sci. 22:39-46.

Rowland DL, Faircloth WH, and Butts CL. 2007. Effects of irrigation method and tillage regime on peanut (arachis hypogaea l.) reproductive processes. Peanut Sci. 34:85-95.

Rowland DL, Faircloth W, Payton P. 2008. Rooting dynamics associated with minimal tillage in the semi-arid peanut production region of west texas. 30th Southern Conservation Tillage Conference for Sustainable Agriculture. www.ag.auburn.edu.

Ruhl JB. 2009. Water wars, eastern style: divvying up the Apalachicola-chattahoochee-flint river basin. Journal of Contemporary Water Research and Eduction 131:47-54.

Smith DM and Allen SJ. 1996. Measurment of sap flow in plant stems. J. of Exp. Bot. 47:1833-1844.

Stevens WE, Johnson JR, Varco JJ, and Parkman J. 1992. Tillage and winter cover management effects on fruiting and yield of cotton. Journal of Production Agriculture 5:570-575.

Sullivan DG, Truman CC, and Schomberg HH. 2007. Potential impact of conservation tillage on conserving water resources in Georgia. J. of Soil and Water Cons. 62:145-152.

Shear GM and Moschler WW. 1969. Continuous corn by the no-tillage and conventional tillage methods: a six-year comparison. Agron. J. 61:524-526.

Smiley RW and Wilkins DE. 1993. Annual spring barley growth, yield, and root rot in high- and low-residue tillage systems. J. Prod. Agric. 6:270-275.

Taylor HM and Klepper B. 1974. Water relations of cotton. i. root growth and water use as related to top growth and soil water content. Agron. J. 66:584-588.

Thierfelder C and Wall PC. 2009. Effects of conservation agriculture techniques on infiltration and soil water content in Zambia and Zimbabwe. Soil and Tillage Res. 105:217-227.

Thompson RB, Gallardo M, Valdez LC, and Fernandez. 2007. Using plant water status to define threshold values for irrigation management of vegetable crops using soil moisture sensors. Agric. Water Mgmt. 88:147-158.

Tollner EW, Hargrove WL and Langdale ,GW. 1984. Influence of conventional and no-till practices on soil physical properties in the southern piedmont. Soil and Water Cons. 39:73-76.

Tubbs RS and Gallaher RN. 2005. Conservation tillage and herbicide management in tow peanut cultivars. Agron. J. 97:500-504.

Unger PW. 1991. Infiltration on simulated rainfall: tillage system and crop residue effects. Agron. J. 56:283-289.

USDA National Agricultural Statistics Service (NASS). (June 2012). National statistics for peanuts/cotton. www.nass.usda.gov

USDA. 2009. State level data. 2007 Census of Agriculture. State Vol. 1, Ch. 2.

Van den Putte A, Govers G, Diels J, Gillijns K, and Demuzere M. 2010. Assessing the effect of soil tillage on crop growth: a meta-regression analysis on european crop yields under conservation agriculture. Euro. J. of Agron. 33:231-241.

Vara Prasad PV, Craufurd PQ, and Summerfield RJ. 1999. Sensitivity of peanut to timing of heat stress during reproductive development. Crop Sci. 39:1352-1357.

Vara Prasad PV, Craufurd PQ, and Summerfield RJ. 2000. Effect of high air and soil temperature on dry matter production, pod yield, and yield components of groundnut. Plant and Soil 222:231-239.

Vellidis G, Tucker M, Perry C, Kvien C and Bednarz C. 2008. A real-time wireless smart sensor array for scheduling irrigation. Computers and Electronics in Agric. 61:44-50.

Wagger MG and Denton HP. 1992. Crop and tillage rotations: grain yield, residue cover, and soil water. Soil Science Society of America J. 56:1233-1237.

Wiatrak PJ, Wright DL, Marois JJ, Koziara W, Pudelko JA. 2005. Tillage and nitrogen application impact on cotton following wheat. Agron. J. 97:288-293.

Wright DM and Porter FS. 1991. Early leafspot of peanuts: effect of conservational tillage practices on disease development. Peanut Sci. 18:76-79.

Wright DM and Porter FS. 1995. Conservational tillage and cultivar influence on peanut production. Peanut Sci. 22:120-124.

Wright DM, Marois J, Katsvairo T, Wiatrak P and Rich J. 2004. Value of perennial grasses in conservation cropping systems. Proceedings of 26th Annual Conservation Tillage Conference, Auburn, Alabama 135-142.

Wright JL and Jensen ME. 1978. Development and evaluation of evapotranspiration models for irrigation scheduling. Trans. of the ASAE 21: 88-91, 96.

Zhai R, Kachanoski RG andVoroney RP. 1990. Tillage effects on the spatial and temporal variations of soil water. Soil Science Society of America-Journal 54:186-192.

Zhao D, Wright DL, and Marois JJ. 2009. Peanut yield and grade responses to timing of bahiagrass termination and tillage in a sod-based crop rotation. Peanut Sci. 36:196-203.

BIOGRAPHICAL SKETCH

Joshua Thompson grew up near Jacksonville, Florida and after graduating Providence School in 2007, began attending the University of North Florida in Jacksonville. After completing two years there, he transferred to the University of Florida in Gainesville and in 2010 received a Bachelor of Science degree in plant science with a focus in agronomy in. He then pursued a master's degree in January of 2011 at the University of Florida in agronomy. Upon graduation in December of 2012, Joshua will take a position as the Regional Integrated Pest Management Extension Agent in Jackson County, Florida.