ALTERNATIVE TILLAGE METHODS OF ROW CROPPING WITH BAHIAGRASS SOD

By

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To my parents for all their support and guidance through the years

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Abstract of Thesis Presented to the Graduate School
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ALTERNATIVE TILLAGE METHODS OF ROW CROPPING WITH BAHIAGRASS SOD

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Although peanut and bahiagrass are both vital to farm economies in Florida, they are primarily two separate industries in Florida. However, there are benefits to rotating summer crops with bahiagrass. Years of research in the southeast have shown that bahiagrass can help improve soil structure, reduce pests such as nematodes and increase crop yields. Despite these benefits, there are barriers to incorporating bahiagrass in a row crop rotation including the high cost of bahiagrass establishment and the costs associated with converting bahiagrass back to row crop production.

Two studies were conducted to evaluate the performance of crops within a bahiagrass system. The objective of the first study was to compare the effects of strip (ST), ST and cultivation (ST/HRC) and conventional (CT) tillage when planting peanut following bahiagrass using the cultivar Florida-07. Peanuts grown under conventional tillage yielded higher than ST/HRC treatment but when economic factors were applied, there was no difference in production returns across all treatments.

The purpose of the second study was to quantify cotton root growth from a long term study established at the North Florida Research and Education Center focused on testing bahiagrass (SC) and conventional rotation systems (CC) and the effect of

irrigation in these rotation systems. Analyses showed greater root length for CC than SC in 2011. There was an interaction for irrigation by rotation, with CC showing a positive root development response to irrigation, while SC root length remained similar whether irrigated or not, possibly indicating higher moisture content for sod based rotations.

CHAPTER 1
LITERATURE REVIEW

With fifty seven thousand hectares of production in the state of Florida, peanut (*Arachis hypogaea* L.) is an important cash crop to the overall farm economy of the state. In 2012 and 2013, Florida tied for second in overall production among the peanut producing states in the US (NASS, USDA). Peanuts are grown in two major regions of Florida: the western region which encompasses the panhandle and the north central region which extends from the Florida/Georgia state line Marion County. In the western region, peanut is typically grown in rotation with cotton(*Gossypium hirsutum* L.), but other row crops such as corn (*Zea mays* L.), sorghum (*Sorghum bicolor* L.), and soybeans (*Glycine max* L.) are commonly used in rotations with peanut. In the north central region of Florida, growers typically lack the options of economically viable rotational crops due to limitations in marketing of other crops. However, many growers already have large areas of their farm operations planted into bahiagrass (*Paspalum notatum* Flueggé) sod for grazing or seed and hay production. Therefore, growers in this region have the possibility of incorporating bahiagrass into a row crop rotation as opposed to planting peanut year after year. This rotational option could be critically important because it is known that growing continuous peanut increases disease risk and significantly reduces yield potential (Jordan et al., 2002; Lamb et al., 2004).

The benefits of rotating peanut and other crops specifically with bahiagrass are well known and include reduced pressure from pests, increased yields, and improved soil structure (Wright et al., 2005). Growers are often reluctant to incorporate bahiagrass into their rotation though, because of high seed cost, the removal of land from production of other crops that often have higher economic return, and the extensive tillage required to bring land back into production following bahiagrass. However, the benefits of bahiagrass may offset many of these economic costs. According to Wright et al. (2006) row crops following bahiagrass sod can result in drastic yield increases and lower production costs with less pesticide use. The perennial bahiagrass sod adds to the soil organic matter and long term soil nitrogen pool as well as helping reduce pests normally found in annual grass or legume crops (Boman et al.; 1996; Elkins et al. 1977). Nematodes, which can greatly affect peanut crops, were found to have significantly less impact when bahiagrass was in the rotation rather than in fallow situations, (Baldwin, J.A. 1992). Katsvairo et al. (2006) reported that crop rotations involving bahiagrass increased organic matter, improved soil quality, and improved yield and farm profits. These increases could be extremely beneficial especially in the North Florida growing area where soils are primarily deep sands and are particularly drought prone. Aside from improvements in overall soil quality, the benefits from increased organic matter could mean a few more days of drought protection due to enhanced water storage capacity in the sod system. Additionally, by utilizing conservation tillage when initially terminating the bahiagrass sod and planting the subsequent crop, the benefits of bahiagrass sod could be compounded.

Conservation Tillage for Managing Bahiagrass Sod in Peanut

Conservation tillage is a relatively new idea in peanut production, where conventional tillage has been the traditional mainstay over many years (Tubbs and Gallaher, 2005). The reluctance to adopt conservation tillage in peanut production is primarily due to concerns over difficulties in digging the peanut crop with reduced tillage and increased mechanical crop losses (Wright and Porter, 1991). According to Mannering and Fenster (1983), conservation tillage is a system in which thirty percent of the soil surface is continually covered by plant residue, either from a previously planted cover crop, fallow weeds, or prior crop residue. Conservation tillage was introduced about 40 years ago into the peanut industry (Sturkie and Buchanan, 1973). Tubbs and Gallaher (2005) state that strip till, a type of conservation tillage, is a suitable alternative for farmers growing peanut on highly erodible land; but growers will only adopt the practice if an economic benefit can be realized. According to Mannering and Fenster (1983), strip tillage is a type of minimum tillage where only a small area (typically 18 to 30 cm in width) directly over the seedbed is tilled. Colvin et al. (1988) conducted research examining the impact of strip tillage on peanut particularly for the North Florida region and showed that growers with marginal land may receive environmental benefits that could possibly outweigh minimal yield loss associated with strip tillage. Since the research by Colvin et al. (1988) further studies have shown that strip tillage has the potential to actually increase peanut yields in southeast peanut production (Hartzog, et al., 1998; Baldwin and Hook, 1998; Marois and Wright, 2003); however, yield reductions or no yield effects are also possible (Jordan et al., 2002; Grichar 1998; Cox and Scholar, 1995). These variable effects on productivity may be related to particular management and climatic conditions within a location. Aside from impacts on overall yield, environmental and economic benefits can be associated with these reduced tillage systems including reduced use of fossil fuels, labor requirements, pesticides, and improved soil quality (Swenson and Johnson, 1982; Gantzer and Blake, 1978; Loison et al. 2012). Conservation tillage can particularly aid in offsetting the effects of drought by increasing soil water infiltration (Thierfelder and Wall, 2009) and soil water holding capacity, especially during the early season (Zhai et al., 1990).

In recent years, research has explored the use of conservation tillage to manage bahiagrass sod when incorporating row crops in rotation, particularly when preparing terminated bahiagrass prior to planting row crops (Katsvairo et al. 2006; Wright et al. 2006; Zhao et al. 2009). Strip tillage eliminates the tillage intensive methods that were typically employed when removing bahiagrass sod in preparation for a subsequent row crop. Traditional tillage operations usually consist of two to three disc passes, followed by a moldboard plow that accomplishes deep tillage normally to a depth of 46 cm, a light discing, and a final field cultivator pass to provide a proper seedbed. Alternatively, when using conservation tillage in a bahiagrass system, the bahiagrass sod is killed chemically and strip-tilled before peanuts are planted.

Benefits of managing the bahiagrass sod using strip till prior to planting the row crop include consistent yields that equal or exceed those of conventional tillage methods (Zhao et al., 2009; Wright et al., 2006). However, a decrease in yield using strip till has been shown in some cases when compared to conventional tillage methods following bahiagrass (Balkcom et al., 2007). There are some indications that these yield losses may be partially due to the timing of the strip tillage operations and the inability of typical strip till to adequately remove the dense biomass of the bahiagrass sod which may impede in-season pegging and digging at harvest (Katsvairo et al., 2007). Research by Zhao et al. (2009) has shown that peanut yields do not differ whether the bahiagrass is terminated in the fall or spring prior to the row crop, allowing a grower more flexibility for preparing bahiagrass sod prior to planting a summer crop. However, there has been no research on the timing of the strip tillage operation after termination of the bahiagrass sod to determine if there are benefits to strip tilling a month prior to planting compared to strip tilling at the time of planting. This difference in timing may provide a more settled seed bed in the early tillage treatment when compared to tillage at planting time.

Another concern of peanut growers considering conservation tillage in a bahiagrass sod system is the thick mat and mass of roots that the bahiagrass left behind after termination in the spring. This large amount of biomass remaining after minimally tilling the bahiagrass residue could cause lowered rates of peg penetration into the soil or excessive digging losses at harvest. A method to manage the bahiagrass residue after planting the summer crop would be the use of a high residue cultivator (HRC) that could be used to undercut weeds and further dislodge the bahiagrass sod mat present during pegging while minimally disturbing the soil surface (Boman et al., 1996). Therefore, the use of an HRC in combination with strip tillage may dislodge bahiagrass roots while also loosening the soil and possibly increasing water infiltration. In addition, this cultivation pass has the potential to lower digging losses at harvest by loosening the soil surrounding the developing pods. However, there may be risks associated with the use of the HRC including destroying developing pegs and pods at the time of the tillage operation, loosening the structure of the soil to the point where soil and peg contact is reduced, or damaging the shallow root system. Therefore, it is important to research the combination of strip tillage with high residue cultivation to determine if this is a viable option for an alternative conservation tillage system in bahiagrass sod.

Conservation Tillage for Managing Bahiagrass Sod in Cotton

Although there has been reluctance to adopt conservation tillage in peanut production, the use of strip till and other reduced tillage systems in cotton is fairly widespread (Brown et al., 1985; Wright et al., 2005; Raper et al., 2000). Further, the production of cotton in a bahiagrass sod rotation actually has been historically used more for cotton than for peanut. Benefits for cotton following bahiagrass were reported nearly three decades ago (Long and Elkins, 1983) and higher cotton yields were attributed to improved soil nutrient and water uptake as a result of a larger cotton root system following bahiagrass (Long and Elkins, 1983). Although cotton yields have been shown to fluctuate similarly to peanut when comparing conventional and conservation tillage systems, cotton grown in a bahiagrass sod rotational system is often higher yielding with reduced input cost (Marois et al., 2002).

Growing cotton in rotation with bahiagrass has shown to specifically impact root growth. In research by Loison et al. (2012), cotton in the bahiagrass rotation had greater overall growth in treatments where cattle had grazed winter cover. Long term research is currently being conducted at the North Florida Research and Education Center in Quincy, FL. At this location, trials have been established to examine the growth and development of two cotton rotations, one more typical for the region and one that incorporates bahiagrass, along with both irrigated and non-irrigated conditions. These two rotation systems consist of a conventional rotation of peanut-cotton-cotton (CC) typically used by growers in the region and a bahia-bahia-peanut-cotton (SC) rotation, with all phases of the rotation being present in all years (Katsvairo et al., 2007). To build on this research, additional information is needed about the impact of these long term rotational systems on cotton root architecture. By examining root growth in these rotations, vital information about root development would be provided that is currently unknown. This project allows the unique opportunity to study the rooting dynamics of cotton in a long term bahiagrass sod rotation.

Examination of Sod Based Tillage Systems

When examining the effectiveness of tillage systems in bahiagrass sod rotations with peanut, it is important to study crop responses to changes in the soil properties, water availability, and other micro-environmental conditions to determine causal factors for variability in crop yield. Because strip tillage has the potential to significantly affect crop water availability, research to monitor physiological responses within each tillage system would be important. The most relevant responses are: leaf water content, photosynthetic and transpiration rates, and chlorophyll content (Lawlor and Cornic, 2002; Jones, 2007; Sikuku et al., 2010). Prior research has shown leaf water potential tends to decrease when there is a soil water deficit and stomata close partially or completely depending on severity of the water deficit (Vaadia et al., 1961; Jones, 2007). Closure of stomata reduces photosynthetic rates (Boyer, 1971; Chaves, 1991). One of the first responses to decreasing water availability is a reduction in expansive growth. This can be determined through measurements of leaf area index (LAI) which is the ratio of the crop leaf area to the ground area (Watson, 1947). Aside from canopy development, overall canopy health can be monitored by measuring the reflectance of the canopy in visible and near infrared wavelengths using the calculation of the normalized difference vegetation index (NDVI) (Bartlett et al., 1990). NDVI data is strongly correlated with the fraction of photosynthetically active radiation (PAR) absorbed by canopy vegetation (Myneni et al., 1997).

With prior bahiagrass strip till research reporting increased root growth (Wright et al. 2005), it is important to follow root development in both conventional and strip tillage systems. If strip tillage in bahiagrass sod improves water infiltration and holding capacity, it would be expected that root and canopy development traits may be improved. Extensive root systems are essential, for maintaining yield, especially in sandy soils and drought prone situations where increased root growth allows for increased surface area for water uptake. However, some studies have shown limited responses of root systems to stress imposition. In a 1992 study focused on peanut root response to drought stress, roots were viewed through a glass chamber and it was shown that there were no significant differences in overall total root length among any of the 30 day stress treatments when root length over all depths were combined for the entire season (Meisner and Karnok, 1992). However, root growth responded differentially depending on the timing of the initial stress, such that when stress was imposed relatively early in development (20-50 DAP), root growth recovered as opposed to treatments when stress was imposed later in development.

Studying root responses is particularly challenging though. Methods often involve destructive harvesting of crop roots making repeated measures of root growth within limited plot areas throughout the growing season impractical (Gray et al., 2013). The development of the minirhizotron technique allowed for the direct measurement of root growth over time without the need for destructive harvests. This technique involves the installation of clear plastic tubes parallel with and in the crop row usually at an angle and allows for repeated imaging of the root system through the season (Milchunas, 2012). A camera is inserted within the tube and roots can be imaged along the length of the tube. Because the tube has a locking mechanism interfaced with the camera, the user can repeatedly image the exact same locations along the length of the tube wall over time.

Reproductive processes can be significantly impacted by tillage treatments due to differences in environmental conditions among different systems. For peanut in particular, a regular count of flower, peg and pod production could reveal important impacts of conservation tillage that may translate into final yield. In a 2007 study by Rowland et al., no differences in reproductive counts were noted among tillage or irrigation treatments, including strip tillage. However, strip tillage does have the capability of influencing plant available water which has been shown to impact peanut reproduction (Rao et al., 1988; Prasad et al., 2000). But because of the paucity of data quantifying the production of flowers, pegs and pods in conservation tillage and sod based strip tillage in particular more research is needed. It is also important to document or refute the impression that strip tillage of bahiagrass has a significant impact on peanut pegging.

Despite positive research findings of bahiagrass/strip-till systems, many peanut growers in the Florida region still view sod based rotations as cost prohibitive due to the seed and sowing costs of bahiagrass and the lack of a cash crop during those years when bahiagrass is being established (Zhao et al., 2009). Growers in the north central FL region lack rotational cash crop options and often grow continuous peanut; however, yields usually begin to drop after three to five years in these monocultures (often related to disease and pest pressure). Therefore, growers may be forced to incorporate bahiagrass sod for at least two years to recover productivity of peanut. Research that examines reduced tillage options in bahiagrass rotations would provide analysis of the cost differences between conventional and conservation systems and answer the question of whether the reduction in fuel use in conservation tillage systems could make these rotations economically viable.

This research project addressed questions about tillage systems and tillage timing with the goal to help growers in the decision of whether to incorporate bahiagrass sod in the north Florida region. To further elucidate the impact of bahiagrass sod managed with both conventional and conservation tillage for both peanut and cotton, research was conducted at both the Plant Science Research and Education Unit (PSREU) in Citra, FL and the North Florida Research and Education Center (NFREC) in Quincy, FL. At the PSREU site, the specific objectives of the project included:
1) Determination of the optimal tillage method and tillage timing when initiating row crop (peanut) production in established (2-5 year) bahiagrass sod; 2) quantification of the associated effects of tillage on root development in the subsequent summer row crop and assessment of the impact of these different management systems on the economic return to the grower; 3) evaluation of the relevant environmental conditions and crop physiological responses that are impacted by the different tillage systems.
At NFREC, the specific objective was to quantify cotton root growth from long term bahiagrass and conventional rotation systems and the effects of irrigation in conventional and sod based rotations. This research addressed the rooting characteristics of cotton in the conventional and sod based rotation. This would particularly benefit the growers in west FL that may be considering bahiagrass sod rotation as an option because of declining yields and soil quality in systems that have been crop monocultures.

CHAPTER 2
EFFECTS OF DIFFERENT TILLAGE SYSTEMS ON PEANUT PLANTED AFTER BAHIAGRASS

Introduction

Peanut has been an economically important agronomic crop for Florida over the past several decades, and Florida is often one of the top three peanut producing states in the U.S. However, with rising overall agricultural production costs, it will be vital to implement best management practices to keep soils healthy, conserve agronomic inputs, minimize environmental impacts, and produce adequate yields. Some of these best management practices include conservative methods of water and nutrient applications, utilizing conservation tillage, and utilizing a crop rotational system.

It is well known that growing continuous peanut increases disease risk and significantly reduces yield potential (Jordan et al., 2002; Lamb et al., 2004). While farm operations in the panhandle region of Florida have the option of other seasonal cash crops to grow in rotation with peanut, growers in the north central region of Florida have limited options and usually will rotate with bahiagrass. This perennial bahiagrass sod increases soil organic matter as well as helping reduce pests normally found in annual grass or legume crops (Boman et al., 1996; Elkins et al., 1977). The documented benefits of bahiagrass rotation are increased yield, decreased nematode activity, and reduced disease pressure (Baldwin et al., 2003). Despite these benefits of a bahiagrass sod based system, many growers in the north central Florida region still view sod based rotations as cost prohibitive due to the seed and sowing costs of bahiagrass and the lack of a cash crop during those years when bahiagrass is being established (Zhao et al., 2009). However, due to the inherent yield losses and increased disease incidence, growers may be forced to incorporate bahiagrass sod for at least two years to recover some soil quality.

Although bahiagrass is widely used in the North Central Florida region, growers use conventional tillage methods to return bahiagrass fields back into peanut production. It has been shown that utilizing conservation tillage in the form of strip tillage can also maintain peanut yields while possibly reducing fuel and other input costs (Balkcom et al., 2007; Wright et al., 2006; Zhao et al., 2009). However, there are limitations to this research since it was conducted only in close proximity to the panhandle region of Florida where soils are typically higher in clay content. Because a large quantity of peanut production in Florida occurs on deep sandy soils in the north central region, testing the bahiagrass rotation utilizing strip tillage under these conditions is essential. While yield evaluations within different cropping systems are the main research priority in most agronomic trials, measurements evaluating the impact on crop growth and performance prior to harvest can be important for understanding why systems may or may not be successful. This includes the evaluation of both above- and below-ground processes. Above ground growth and development can be quantified by measurements of leaf area index that essentially represents the light interception potential of the crop (Watson, 1947). Root development and distribution can also significantly contribute to crop performance, but measurements of these processes are more problematic. Studies evaluating *in situ* changes in root growth and architecture utilizing minirhizotrons are becoming more common (Milchunas, 2012) and have the advantage of providing non-destructive quantification of root characteristics across the growing season (Gray et al., 2013).

Finally, it may be important to evaluate gas exchange to determine assimilation potential and water use of the crop in response to different cropping systems.

Direct quantification of partitioning to reproductive structures through the season can definitely reveal mechanistic variability among cropping systems. For peanut, this involves the periodic quantification of the production of flowers, pegs and pods. It has been shown that these processes can be significantly impacted by several environmental conditions including drought and temperature (Zhai et al., 1990; Prasad et al., 1999). Soil moisture could be significantly impacted by tillage method, so it is likely that reproductive development may be different between conventional and conservation tillage systems. Previous research has shown that flowering and pegging can be impacted by tillage method (Rowland et al., 2007) and are particularly sensitive to soil moisture (Lanier et al., 2004; Sorensen et al., 2005).

By far, the most important characteristic of a cropping system is the net economic return to the grower. Balkcom et al. (2007) observed that the cost of the strip tillage system was less than that of a conventional system; this economic benefit of strip tillage may also have been even greater if the size of equipment used (6-row vs. 2-row) had been taken into account. Other studies have documented at least an equal economic return between conventional and strip tillage peanut systems (Jordan et al., 2001; Tubbs and Gallaher, 2005). The majority of studies examining differences among conservation and conventional peanut tillage systems have concentrated solely on yield differences. However, this may not always be a fair comparison of the two production systems due to inherently lower costs associated with a reduced tillage system.

To address the lack of research examining the use of strip tillage in a bahiagrass rotation, experiments were conducted in long-term bahiagrass sod fields. In particular, this research provided information about the impacts of the tillage system on above- and below-ground crop responses that could be used to evaluate the overall economic performance of each system. The specific objectives of the project included:

1) Determination of the optimal tillage method and tillage timing when initiating row crop production in an established (2-5 year) bahiagrass sod;

2) Quantification of the associated effects of tillage on root development in the subsequent summer row crop and assessment of the impact of these different management systems on the economic return to the grower;

3) Evaluation of the relevant environmental conditions and crop physiological responses that may have been impacted by the different tillage systems.

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, sub active, hyperthermic Grossarenic Paleudults). Trials were conducted in 2012 and 2013 utilizing 8 row plots (on a 0.91 m row spacing) with a length of 30.5 m arranged in a randomized complete block design. Treatments included: three tillage treatments (conventional (CT), strip (ST), and strip tillage followed by tillage with a high residue cultivator (ST/HRC)); and two timings of tillage (all tillage one month prior to planting - DATE1, and all tillage at time of planting – DATE2). All plots were planted to a single commercial cultivar, Florida 07 (Gorbet and Tillman, 2009). In both years, the crop followed a well-established stand of bahiagrass (*Paspalum notatum* Flueggé) which was chemically terminated prior to any tillage operations with glyphosate. The bahiagrass was undisturbed for one month after glyphosate application to allow full herbicidal activity before the first tillage passes (DATE1) were performed. At the time of field preparation for the DATE1 treatments, the CT plots were disced three times, turned to a depth of approximately 32 cm with a moldboard plow, and then smoothed with a disc harrow and field cultivator. The ST and ST/HRC plots were stripped concurrently with the conventional tillage plots using a KMC Rip Strip unit (Tifton, Ga). At the time of planting, the DATE2 plots were treated identically as described above for the DATE1 plots. In both DATE1 and DATE2 plots, approximately fifty days after planting (DAP) the ST/ HRC plots were cultivated using a KMC Hi Residue Cultivator (Tifton, Ga).

After completion of CT and ST tillage operations, all plots were planted using a Monosem (Edwardsville, Ks) vacuum planter with an in row seed population of 20 seed per meter for both years. In 2012 plots were initially planted on 9 May but seed emergence problems occurred, so areas within plots that exhibited poor stands were replanted on the 22 May. In 2013, all plots were planted on 17 April with no replanting. Management of pesticides and nutrients in both 2012 and 2013 followed the University of Florida IFAS (Institute of Food and Agricultural Sciences) recommendations for standard row crop practices for the region. Table 2-1 identifies specific applications and timings of pesticides and fertilizer.

Peanuts were mechanically dug with a KMC (Tifton, Ga) peanut digger shaker inverter on 24 and 5 September in 2012 and 2013, respectively. In both years, a Hobbs Amadas (Albany, Ga) mechanical peanut combine was used to harvest the crop after 4 days in the windrow. Yield was determined by mechanically harvesting 22.9 m from the two center rows within each eight row plot. Harvested peanut samples were force air dried to 10% moisture content before pod weights were recorded. Grading was conducted by the Alabama Department of Agriculture in Dothan Alabama both years to determine total sound mature kernels (TSMK). Digging loss from the mechanical harvest was quantified by placing a frame measuring 0.61 by 1.83 m and excavating the ground within the frame to approximately 10 cm. After collection, the peanuts were dried to ten percent moisture and weighed to determine final digging loss.

Plant and Soil Measurements

Soil moisture tubes were installed in the third row in each plot. Soil moisture measurements were taken from in row points (one per plot) approximately three days a week with a PR2 soil moisture capacitance probe (Delta-T technologies, www.delta-t.co.uk) at 10, 20, 30, 40 60 and 100 cm depths simultaneously. Crop measurements included: root architecture, Leaf Area Index (LAI), reproductive development (flower, peg and pod counts (FPP), gas exchange (photosynthesis and transpiration), normalized difference vegetative index (NDVI), chlorophyll content, relative water content (RWC), and canopy temperature. Root architecture was characterized by utilizing a mini rhizotron camera system (Bartz Technology Corp; www.bartztechnology.com) which allowed for non-destructive measurement of roots throughout the growing season. After planting, clear plastic mini-rhizotron tubes (183 cm in length) were inserted in the third row in each plot adjacent to the soil moisture tube. The minirhizotron tube was installed into the ground at a 45 degree angle to the soil surface. Roots were imaged on four dates in 2012 (12 June, 9 July, 1 August and 17 August). In 2013, roots were imaged on six dates, attempting to capture possible early establishment times that were missed in 2012 (6 May, 16 May, 29 May, 17 June, 7 July, 29 July). The camera system utilizes a locking mechanism which allows for repeated viewing throughout the season of the exact same location. Once taken, images were then analyzed using WinRHIZO, http://www.regent.qc.ca) by tracing each root segment in every image taken within a tube; the software automatically calculates cumulative root length for a single image at a given depth. Leaf area index was non-destructively measured using the LAI 2200 plant canopy analyzer (LiCor Enviromental Sciences; Lincoln, NE) approximately every three weeks beginning 2 July in 2012, and approximately every two weeks in 2013 beginning on 11 June. An individual measurement with this instrument consisted of regularly spaced measurements underneath the canopy spanning the distance between rows with the sensor head held both parallel (4 readings) and perpendicular (4 readings) to the crop row with each orientation paired with one reading above the canopy. Reproductive development was characterized by recording the number of peanut flowers, pegs, and pods per plant weekly once flowering began and continuing until approximately one hundred days after planting. Three plants from each plot were chosen at random each week to obtain these counts. Gas exchange was measured using a LI6400-XT infra-red gas analyzer (IRGA - LiCor Environmental Sciences; Lincoln, NE); leaf conditions were kept constant within the chamber at 1800 micromoles PAR, 360 ppm CO_2, and ambient temperature and atmospheric humidity. Gas exchange was taken three times during the season on 2 July, 23 July, 13 August in 2012, and 3 June, 24 June, and 15 July in 2013. For measurement of gas exchange, two plants were chosen at random from each plot, measured with the IRGA and then removed from the plant. A relative surrogate for chlorophyll content was then immediately measured using the SPAD Minolta chlorophyll meter (SPAD-502DL, www.agriculturesolutions.com) where four readings were averaged per leaf (one reading on each of the four leaflets), avoiding the midrib. The leaf was then transferred to a plastic bag and placed on ice for transport to the laboratory for additional analyses. Once in the lab, leaf area was determined using the LiCor model 3100 leaf area meter (LiCor Environmental Sciences; Lincoln, NE). Relative water content was determined by immediately weighing the leaf to determine fresh weight, soaking in distilled water under a grow light for approximately three hours and weighing again to determine turgid weight, and then drying at 60 ˚C for seventy two hours to constant weight for final dry weight. RWC was then calculated using the equation:

$$\mathrm{RWC} = \frac{\text{fresh weight} - \text{dry weight}}{\text{saturated weight} - \text{dry weight}} \qquad \text{(Barr and Weatherley, 1962)}$$

NDVI was measured using a GeoScout Crop Circle (Holland Scientific; Lincoln, NE). NDVI was taken the same day when the gas exchange measurements were taken with each plot being measured twice - once in morning prior to gas exchange at approximately 0900 h, and again in mid-afternoon at approximately 1300 h. Measurements of NDVI were obtained on the fourth row of each plot by holding the meter head parallel and at a height of approximately 0.31 m to the crop row and walking the full distance of the plot. Canopy temperatures were also taken on the same day as gas exchange at the same time as NDVI. Similarly to NDVI, canopy temperatures were taken once in the morning (at approximately 0900 h) and once in the afternoon (at approximately 1300 h) on each measurement date. Temperatures were measured using a Spectrum Technologies (Aurora, IL) infrared temperature meter. Temperatures were taken at random on five plants within each plot and were completed within twenty minutes to minimize any fluctuations in canopy temperature caused by the hour of the day.

Because the intensity of tillage operations differed among the three systems tested, it was important to examine economic differences among them by taking into account fuel, labor, and maintenance costs. Gross revenue per hectare was calculated by multiplying the yield in metric ton (MT) by the loan value ($391 per MT) (NASS, 2007). Adjusted revenue was calculated by subtracting the sum of all tillage operational costs from the gross revenue. Total operational costs ($/ha) for each tillage system were based on an average fuel cost of $0.96/L and labor costs of $11.63/hr. Total cost per tillage system was calculated by multiplying the total operation costs by the number of tillage passes, and summed for all tillage operations within a single system resulting in costs of: CT ($214/ha), ST ($50/ha) and ST/HRC ($83/ha) (Table 2-2).

Statistical Analysis

Data were analyzed using ANOVA fit models JMP 10.0 (SAS Institute, Inc., Cary, NC) and Tukey's HSD multiple comparisons test was employed to determine the separation among mean values. Tillage, tillage date, measurement time (when applicable) and year (when applicable) were treated as fixed effects and replication and all interactions between replications were treated as random effects. Depending on the amount of measurement times, specific data were run either separate by years or together where possible.

Results

The 2012 and 2013 cropping seasons were quite different in terms of amount of precipitation received and totaled 103 and 69 cm in 2012 and 2013, respectively (Figure 2-1). The larger total precipitation in 2012 as opposed to 2013 was largely due to differences in intensity not to rather than number of rainfall events (53 and 51 in 2012 and 2013, respectively). Several tropical storm systems moved through the area in July and August of 2012.

Digging Loss, Yield and Grade

Tillage had an effect on yield and digging loss but not grade (Table 2-3). Across years, conventional tillage had a significantly higher yield (6941 kg/ha) than ST/HRC (6365 kg/ha) but was not different than ST (6582 kg/ha). In 2012, peanut yields were 30% higher than in 2013; with an average yield across all treatments being 7972 and 6137 kg/ha in 2012 and 2013, respectively (Figure 2-2). Digging losses across both years in both conservation tillage treatments were higher (117, 111 kg/ha in ST and ST/HRC, respectively) than CT (79 kg /ha) (Figure 2-3). Digging losses were significantly larger in 2013 (144 kg/ha) than in 2012 (61 kg/ha). There was an interaction between tillage and tillage date for digging loss indicating that in general, DATE1 for both conservation tillage treatments tended to have larger losses, while DATE2 for conventional tillage had the largest losses. Grade samples showed an average TSMK of 70.4 and 71.0 for 2012 and 2013, respectively. Contrary to the expectation that conservation tillage could lead to higher foreign material, levels were similar across tillage treatments in both years.

Plant Architecture and Soil Measurements

Soil Moisture in both 2012 and 2013 across depths showed few differences across all treatments with the primary differences occurring at the 10 and 30 cm depths (Figure 2-4 and Figure 2-5). There was no clear separation between conventional and conservation tillage with higher soil moisture at any depth range. In both years, CT DATE1 had high soil moisture percentages at the 10 cm depth and at the 30 cm depth CT and ST/HRC DATE2 had high soil moisture percentages.

Root length was not affected by tillage in 2012 or 2013, but there were strong effects by both depth zone and measurement time (Table 2-4). Tillage by tillage date and by soil depth zone interactions were observed in 2012. Over all treatments and both years, the longest root lengths occurred at the shallowest depth (0-10 cm) with the lowest recorded root lengths at depth zones 6, 7 and 8 (corresponding to 50-80 cm below the soil surface). In 2012, maximum root length was reached by the second measurement date (9 July) and equaled an average of 182 mm (Figure 2-6). In 2013, root length gradually increased until the fifth measurement date (8 July) with a maximum of 177 mm (Figure 2-7). Tillage date impacted root length in 2012 only, with an average of 154 and 180 mm for DATE1 and DATE2, respectively.

Leaf area index was affected by measurement time in each year, with no difference in canopy development between tillage treatments or the timing of the tillage operations (Table 2-5). In 2012, LAI appeared to have almost a linear pattern with a peak at the last measurement date (25 August) with values ranging between 5 and 6 (Figure 2-8). In 2013, no increase occurred between the first (11 June) and second (25 June) measurement date followed by a linear increase to the last measurement date (23 July). In this year, maximum LAI values clustered around 4 (Figure 2-8).

Flower, Peg and Pod Counts

Tillage had no impact on reproductive processes as evidenced by flower, peg and pod counts taken in 2012 and 2013 (Table 2-6). These counts varied by measurement time through the season with an interaction between tillage and measurement time in 2012. In 2012, flower number per plant peaked at 52 DAP and ranged between 6 and 8 flowers, with flower production decreasing by 94 DAP to 1 flower per plant (Figure 2-9). The flower production pattern was different in 2013, with flower number per plant peaking at 82 DAP and a range of 8 to18 per plant. Flower number decreased from that date down to one flower per plant at the last measurement date at 103 DAP.

Tillage also had no impact on peg production but like flowers, peg number per plant was similarly impacted by measurement time with an interaction between tillage and measurement time in 2013 and an interaction between tillage date and measurement time in 2012 (Table 2-6). In 2012, peg counts rose at an almost linear increase up to 87 DAP when peg number stabilized at a range between 22 and32 per plant (Figure 2-10). In contrast, there was a profound increase in peg production after 80 DAP reaching a maximum of 36 to 48 per plant.

Even though yield was lower in ST/HRC, pod number per plant was not significantly different among tillage treatments (Table 2-6). However, in looking at absolute number of pods per plant, ST/HRC averaged 1-2 fewer pods per plant in both years than CT and ST. This likely resulted in the decreased yield on a field basis for ST/HRC. As with flowers and pegs, pod number per plant differed by measurement time (Figure 2-11), with a tillage by measurement time interaction in 2013. In both years, pod counts increased linearly with a maximum of 65 to 78 pods per plant in 2012 and 55 to 69 pods per plant in 2013.

Physiology

Physiological indicators used in this study were not impacted by tillage treatment or tillage date as evidenced by measurements of photosynthesis, transpiration, SPAD and RWC (Table 2-7). Average rates of gas exchange were higher in 2013 than 2012 for photosynthesis (27.2 and 29.2 μmol m^{-2} s^{-1}, Figure 2-12), transpiration (7.4 and 10.1 mmol m^{-2} s^{-1}, Figure 2-13), and for RWC (92.6 and 94.3%, (Figure 2-14). However, SPAD measurements (Figure 2-15) were lower in 2013 (41.1) than in 2012 (44.2). Overall, photosynthesis, RWC and SPAD peak were highest at the middle measurement time (approximately 10 weeks after planting); however, transpiration increased linearly through the season.

Canopy level responses, as reflected by canopy temperature and NDVI, also indicated no differences among tillage treatments (Table 2-8). However, canopy temperature across treatments in the morning was slightly higher in DATE2 than DATE1 (24.4 vs. 24.2 °C) but was likely not biologically relevant (Figure 2-16). Canopy temperature was significantly different among measurement times, but with no obvious pattern. Conversely NDVI showed significantly higher values at approximately ten weeks after planting (0.70 for AM and 0.68 for PM measurements) likely due to optimal canopy growth and development at that time (Figure 2-17).

Economics

Tillage had an impact on gross revenue but not on adjusted revenue, while year had an effect on both economic parameters (Table 2-9). Both gross revenue and adjusted revenue are based on calculations utilizing yield; since yield was significantly higher in 2012, year was also a significant factor in these economic parameters (Table 2-10). Across years, gross revenue ($ per hectare) among tillage types was 2716 (CT), 2575 (ST), 2490 (ST/HRC) while adjusted revenue was 2501 (CT), 2525 (ST) and 2407 (ST/HRC). Although tillage had an impact on gross revenue, the lack of an effect on adjusted revenue reflected the costs of varying tillage operations such that production returns were similar across systems.

Discussion

This study documented an impact of tillage system on yield in peanut for both years, with reduced yields occurring in the strip tillage system. These data agree with previous research that showed a reduction in yield when utilizing reduced tillage (Brandenberg et al., 1998; Grichar, 1998; Jordan et al., 2001). These yield results are also consistent with research conducted within the same north Florida region containing similar sandy soils (Colvin et al., 1988). However, studies of ST within the panhandle of Florida (that included bahiagrass sod) have reported higher yields than CT (Wright et al., 2006; Zhao et al., 2009).

However, in both years of this study CT yields were not significantly different from ST, rather the yield differences occurred only with the inclusion of the high residue cultivator in the ST system (ST/HRC). The yield differences between CT and ST/HRC were a result of a decreased number of 1-2 pods in the HRC treatments. This may have occurred because of either a decrease in pod initiation or from pod loss resulting from the mechanical digging process. However, the pod counts per plant revealed that there were actually fewer pods present on the ST/HRC plants; while flower and peg production in this treatment were not different from CT. This could have been caused by the actual timing of the HRC operation at approximately 50 DAP. The reproductive data shows the crop had begun flowering and pegging at this point. It can be speculated that this HRC operation disrupted pegging and possibly removed developing pods at this date (pods that could have become the most mature pods on the plant), thus resulting in final yield losses.

Other concerns regarding conservation tillage peanut production is that mechanical losses when digging ST peanuts will be greater than in a CT system (Wright and Porter, 1991). This could be a particular problem for ST in bahiagrass sod due to the dense, persisting biomass at the soil surface. This was the case for the current study where both conservation tillage systems (ST and ST/HRC) experienced greater digging losses due to the mechanical harvesting process than the CT treatment. It can be speculated that soil moisture may play a critical role in contributing to digging losses due to its impact on the ease of movement of field implements through the soil. Anecdotally, this supposition may have contributed to the overall greater digging losses in 2013 than in 2012, which differed in rainfall during the two week period prior to harvest (3.5 cm in 2013 and 10.5 cm in 2012). Therefore, in conservation tillage systems it may be critical to have adequate soil moisture conditions at the time of digging to avoid excessive losses.

While obtaining consistently equal or higher yields in conservation tillage in comparison to conventional systems is the ultimate concern of growers and usually determines their adoption, the ultimate judgment of a tillage system should be to consider the overall economic return of that system. Tubbs and Gallaher (2005) support this viewpoint when they stated that, “although prior research regarding peanut conservation tillage systems is mixed for yield, the economic and environmental benefits of conservation tillage should be taken into consideration when selecting management strategies". The current study revealed that tillage treatments impacted gross revenue, such that the CT system returns were higher than ST/HRC. However, after applying the cost of the tillage operations through calculation of mechanical, fuel, labor, and maintenance costs, there was no effect of tillage system on adjusted revenue. In fact, the ST system showed numerically greater adjusted returns than the other two tillage systems. This equalizing of revenue between tillage treatments has been noted previously for peanut production systems (Jordan et al., 2001; Balkcom et al., 2007). Therefore, this ST system could be a viable option for growers in the north central Florida region, particularly for those that already have bahiagrass incorporated into their rotational systems.

While comparing the overall yield and economic returns of different tillage systems are critically important, quantifying above- and belowground responses of the crop during the season aids in determining why differences may occur. In this study, tillage did not have an effect on plant architecture, either above- or belowground. Roots in all treatments reached equal depths in both years, with the most rooting occurring in zones from the soil surface to 60 cm. Likewise, canopy development documented by measuring LAI throughout the growing season demonstrated similar development across all tillage treatments. This is a particularly unique component of this study because the effects of tillage on peanut LAI have not been previously documented to date. Like plant architecture, measurements at the leaf level revealed no significant impact of tillage on the crop. However, had there been differences in yield or overall development, these data could have been crucial in determining the cause.

Overall, the objectives of this study were to determine optimal tillage method and tillage timing when following bahiagrass, and to quantify root development and evaluate physiological responses that could have been impacted by the tillage systems. This information is particularly important for the growers of the north central Florida region with possible application to other areas where deep sands may occur. It is important for potential growers to keep in mind the economic and environmental impacts of the system and not just yield. This study was conducted across two very different years, especially in regards to rainfall. This makes the study results particularly valuable because it provides an evaluation of these tillage systems under the range of conditions typical for the region. In both years, if the cost of the tillage system is considered, there was no significant advantage for CT over ST practices. Overall, this study shows no disadvantage of utilizing ST in a bahiagrass system; in fact, there is the potential of increased yields in some years. Adoption of ST also has the potential of delivering environmental benefits including retention of soil moisture, infiltration, reduced labor, and fuel and machinery requirements. Therefore, these data can be used to develop the following recommendations for growers utilizing ST in within a bahiagrass system: 1) if implementing the use of HRC, make the application much sooner than 50 DAP to avoid the potential loss of the most mature pods, and 2) at digging time, it would be optimal to follow a rain event or to delay until rainfall is received to avoid any excessive mechanical digging losses caused by increased resistance of the soil.

Table 2-1. Peanut Management. List of pesticide and fertilizer applications in weeks after planting (WAP)

WAP (2012/2013)	Pesticide Rate (g/ha)		Nutrients (kg/ha)
0/0	907	Glyphosate	560 3-9-18
0/0	375	Pendimethalin	
0/0	22	Diclosulam	
3/3	860	S-Metolachlor	
5/5	1251	Chlorothalonil	0.03 Boron
6/6			2240 Gypsum
7/7	420	Imazapic	
7/7	1251	Chlorothalonil	0.03 Boron
--/8	280	Clethodim	
9/9	84	Prothioconazole	
11/11	368	Azoxystrobin	
--/14	1251	Chlorothalonil	
14/14	84	Prothioconazole	
16/16	220	Pyraclostrobin	
--/16	157	Lambda-Cyhalothrin	
18/18	1251	Chlorothalonil	
20/20	1251	Chlorothalonil	

Table 2-2. Tillage Economics

	$/ ha					Number of tillage passes		
Tillage Operation	Fuel	Labor	Repairs and Maintenance	Fixed Cost	Total Operation Cost	CT	ST	ST/HRC
12’ disc	7.88	5.75	4.30	12.44	30.37	4	0	0
4 bottom MB plow	20.77	15.51	9.48	29.31	75.06	1	0	0
15’ Field Cultivator	4.84	3.46	1.73	7.01	17.01	1	0	0
2 row strip till	14.94	11.19	6.62	16.96	49.73	0	1	1
2 row high res cultivator	12.07	8.89	3.33	8.96	33.28	0	0	1

Table 2-3. ANOVA results for digging loss, yield, and grade of harvested peanuts in 2012 and 2013.

Factor	df	Dig Loss	Yield	Grade
Tillage (T)	2	5.4319**	6.0721**	0.3702
Tillage Date (TD)	1	0.1368	0.0578	0.1448
T x TD	2	3.7660**	1.5302	1.1711
Year(Y)	1	21.3466**	74.1133***	0.4775
T x Y	2	0.2486	2.9363	0.6169
TD x Y	1	0.1785	0.0304	0.0006
T x TD x Y	2	3.6243**	6.8411**	0.3570

*P<0.05

**P<0.01

***P<0.001

Table 2-4. ANOVA results for Peanut Root Length

		Peanut Root Length		
Factor	df	2012	df	2013
Tillage (T)	2	0.3012	2	0.0668
Tillage Date (TD)	1	8.7142**	1	0.5213
T x TD	2	24.3817***	2	0.0097
Zone(Z)	8	9.5471***	7	5.5547***
T x Z	16	1.9569**	14	1.7176
TD x Z	8	4.1645***	7	0.6119
T x TD x Z	16	3.0800***	14	1.7494
Msrmt Time(MT)	3	8.0393***	5	124.6301***
T x MT	6	0.0347	10	2.6481**
TD x MT	3	0.0714	5	1.9273
T x TD x MT	6	0.0839	10	0.9286
Z x MT	24	0.3663	35	3.4707***
T x Z x MT	48	0.0769	70	0.5848
TD x Z x MT	24	0.0749	35	0.5141
T x TD x Z x MT	48	0.1293	70	0.6981

*P<0.05

**P<0.01

***P<0.001

Table 2-5. ANOVA results for leaf area index (LAI) measured in 2012 and 2013.

		LAI	
Factor	df	2012	2013
Tillage (T)	2	0.2943	1.6318
Tillage Date (TD)	1	2.6478	0.0073
T x TD	2	0.8238	1.4860
Msrmt Time(MT)	2	96.1122*	148.5105*
T x MT	4	0.7491	0.7179
TD x MT	2	0.0007	0.1840
T x TD x MT	4	0.2565	1.1596

*P<0.05

**P<0.01

***P<0.001

Table 2-6. ANOVA results for flower, peg, and pod counts in 2012 and 2013

		Trait					
		Flower		Peg		Pod	
Factor	df	2012	2013	2012	2013	2012	2013
Tillage (T)	2	1.2284	2.0928	0.8097	3.4706	1.9288	0.8012
Tillage Date(TD)	1	0.2734	0.2897	0.2438	2.9869	0.1483	0.7190
T x TD	2	1.0579	1.1558	0.8756	0.1720	1.1828	0.7162
MsmtTime(MT)	7	39.5809***	42.5116*	102.7358***	44.8105*	315.9638***	402.5001*
T x MT	14	1.8299*	1.3911	0.9524	2.4327**	0.5068	2.2738*
TD x MT	7	0.9345	1.1765	2.5659*	0.7067	1.2325	0.8112
T x TD x MT	14	11381	0.6831	0.4038	1.3049	1.4517	1.1383

*P<0.05

**P<0.01

***P<0.001

Table 2-7. ANOVA results for gas exchange in 2012 and 2013.

		Trait			
Factor	df	Photosynthesis	Transpiration	SPAD	RWC
Tillage (T)	2	0.0318	0.3978	1.2180	0.2675
Tillage Date (TD)	1	0.3586	0.0027	0.1340	0.7828
T x TD	2	2.7439	1.1238	1.1858	0.2245
Msrmt Time(MT)	2	4.9051*	330.9792***	24.8573***	2.7150
T x MT	4	2.2422	2.6801*	0.5845	1.3215
TD x MT	2	0.1246	1.2019	1.8751	0.6874
T x TD x MT	4	0.4143	0.1486	0.8121	1.3807
Year(Y)	1	11.2450**	69.7218***	10.4205*	12.8237*
T x Y	2	1.2230	0.2944	0.3734	1.6375
TD x Y	1	2.8572	2.0031	2.2422	0.5257
T x TD x Y	2	0.9194	1.8210	2.3102	0.5401
MT x Y	2	7.9099***	184.1549***	11.9825***	24.4989***
T x MT x Y	4	0.2031	0.5443	0.6480	0.6290
TD x MT x Y	2	1.4916	2.0184	2.0258	1.5660
T x TD x MT x Y	4	1.1880	3.0289*	0.8006	1.1179

*P<0.05

**P<0.01

***P<0.001

Table 2-8. ANOVA results for canopy temperature and NDVI measured in the morning (AM) and afternoon (PM) in 2012 and 2013.

		Canopy Temperature		NDVI	
Factor	df	AM	PM	AM	PM
Tillage (T)	2	0.8379	0.2597	0.6128	0.2972
Tillage Date (TD)	1	5.8128*	1.0193	0.4369	0.6381
T x TD	2	0.0679	0.5593	1.8582	0.4322
Msrmt Time(MT)	2	107.1333***	16.3852***	139.0264***	40.5590***
T x MT	4	1.2768	1.7686	0.3751	1.8784
TD x MT	2	2.9036	0.0372	1.4534	0.0993
T x TD x MT	4	0.4450	1.4392	0.3496	1.0671
Year(Y)	1	0.4284	0.0103	137.7996***	65.3209***
T x Y	2	1.1999	2.2683	0.2145	0.4957
TD x Y	1	1.0150	0.0954	2.1566	0.8210
T x TD x Y	2	0.2328	1.9182	1.4475	0.3921
MT x Y	2	244.7018***	0.2592	70.1524***	15.2278***
T x MT x Y	4	0.6321	0.4779	0.5111	1.0283
TD x MT x Y	2	0.6306	0.0117	0.5721	0.5418
T x TD x MT x Y	4	0.4870	0.0685	0.1853	1.2155

*P<0.05

**P<0.01

***P<0.001

Table 2-9. ANOVA results for Peanut Revenue (Gross vs. Adjusted)

		Peanut Revenue	
Factor	df	Gross	Adjusted
Tillage (T)	2	6.0721**	1.7960
Date (D)	1	0.0578	0.0578
T x D	2	1.5302	1.5302
Year (Y)	1	74.1133***	74.1133***
T x Y	2	2.9363	2.9363
D x Y	1	0.0304	0.0304
T x D x Y	2	6.8411**	6.8411**

*P<0.05

**P<0.01

***P<0.001

Table 2-10. Revenue and cost by tillage system

System	Yield (kg/ha)	Digging Loss (kg/ha)	[1]Potential Yield (kg/ha)	[2]Gross Revenue ($/ha)	[2]Adjusted Revenue ($/ha)	[3]Total Cost ($/ha)
CT	6941	79	7020	$2716	$2502	$214
ST	6582	118	6700	$2575	$2525	$50
ST/HRC	6365	111	6467	$2490	$2407	$83

[1]Potential Yield = Yield + Dig Loss
[2]Revenue values calculated from Yield (not Potential Yield)
[3]Total Cost = Operation cost of each tillage system including fuel, labor, repairs and maintenance, and fixed costs.

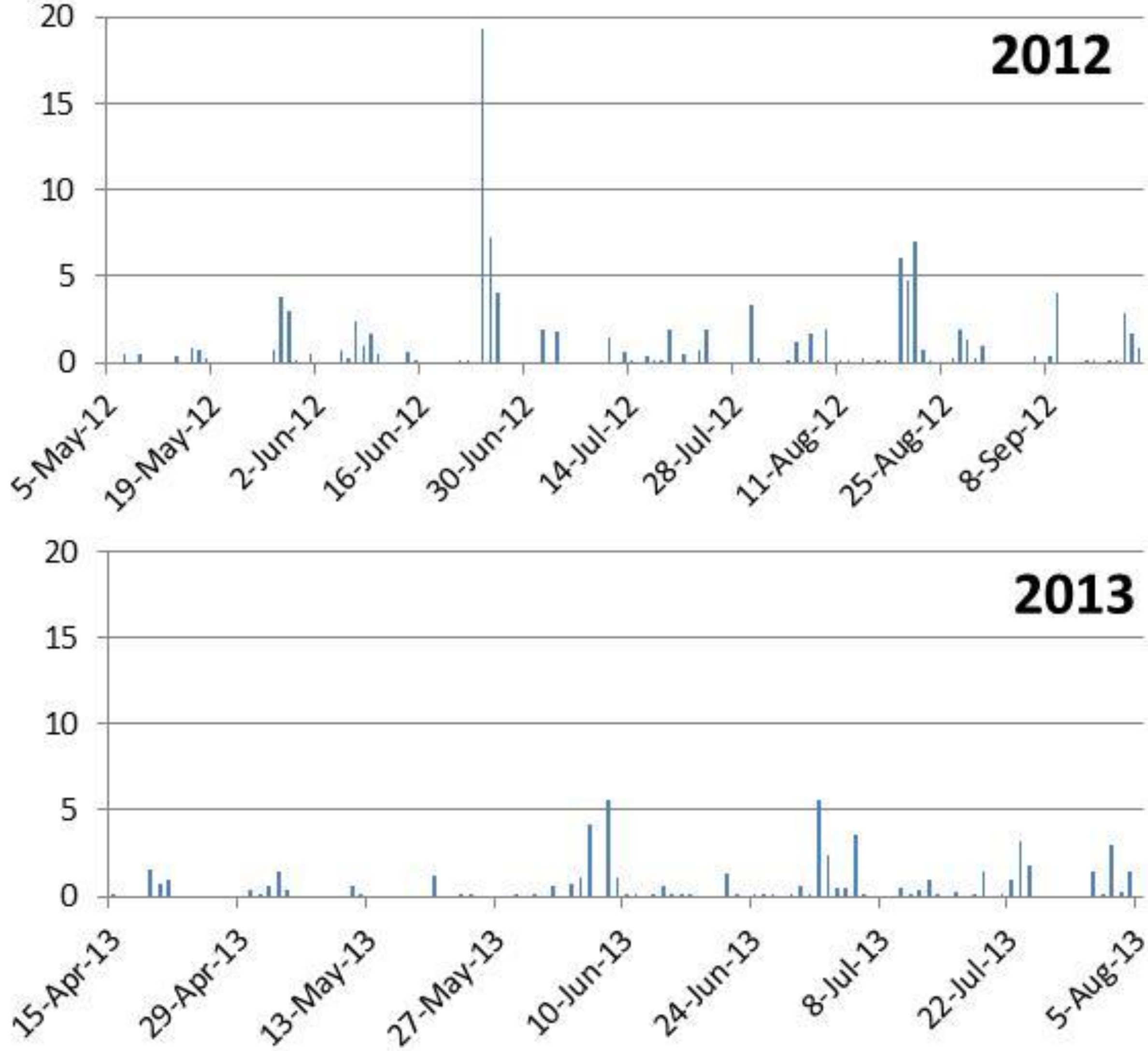


Figure 2-1. Rainfall

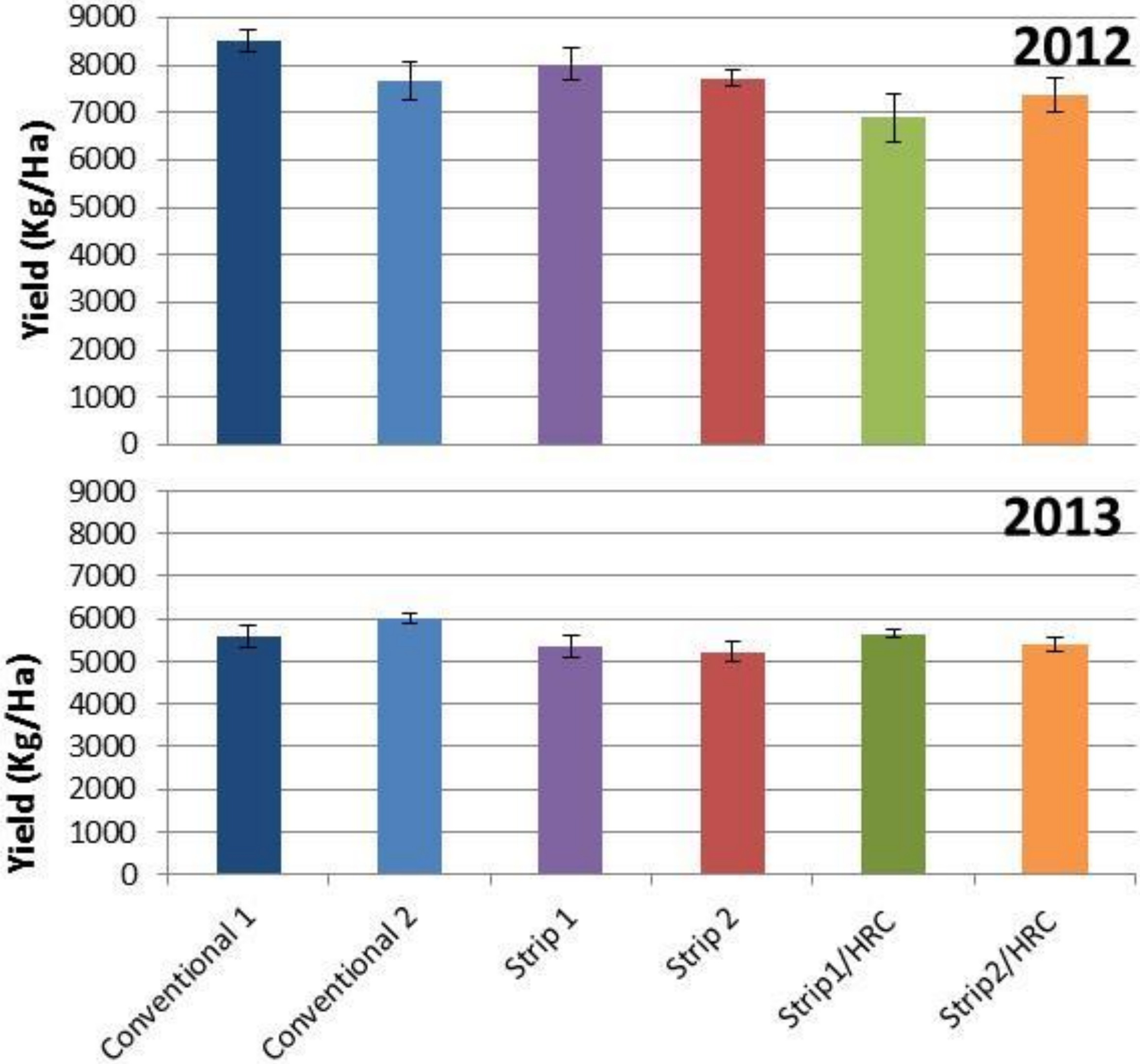


Figure 2-2. Yield

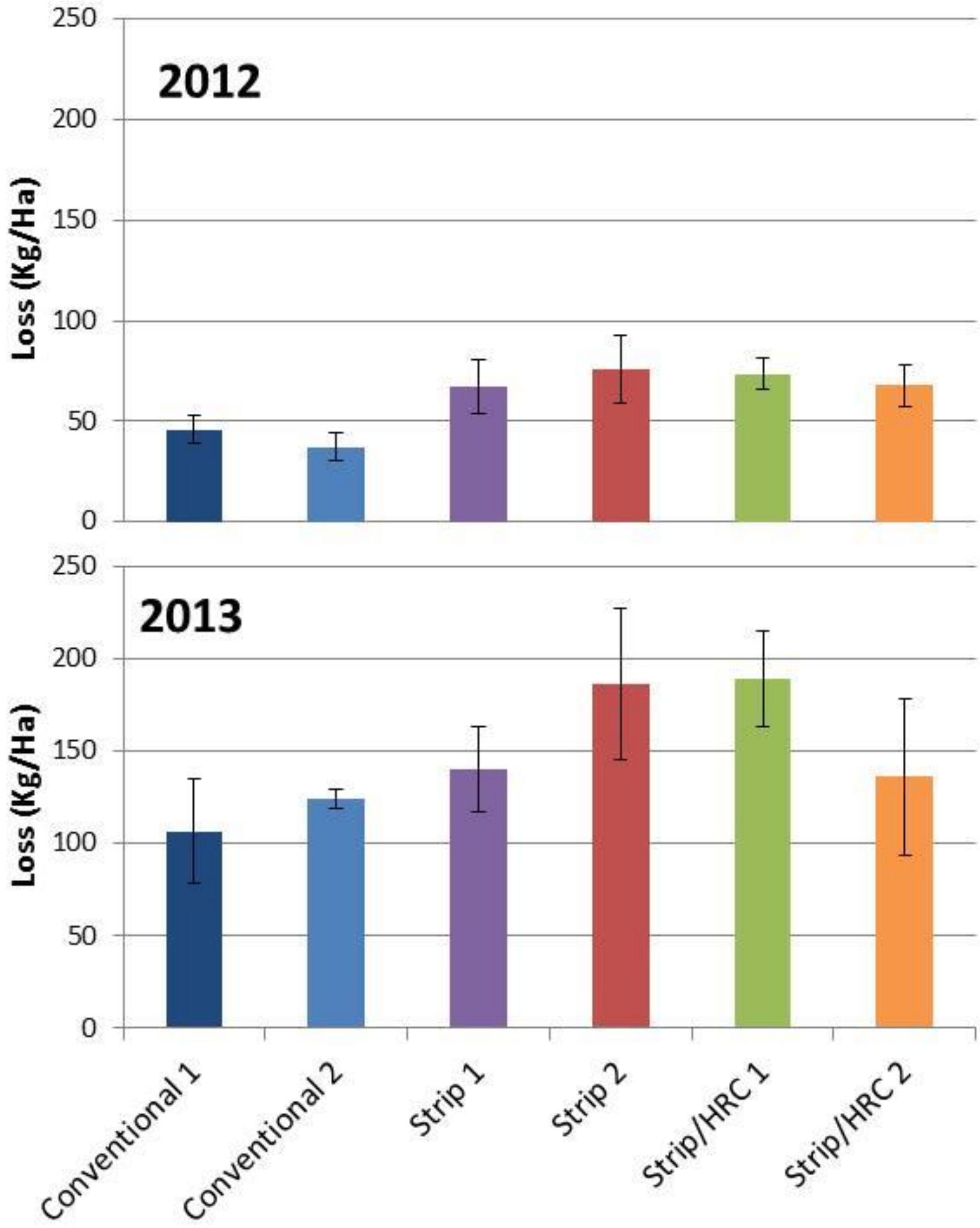


Figure 2-3. Digging Loss

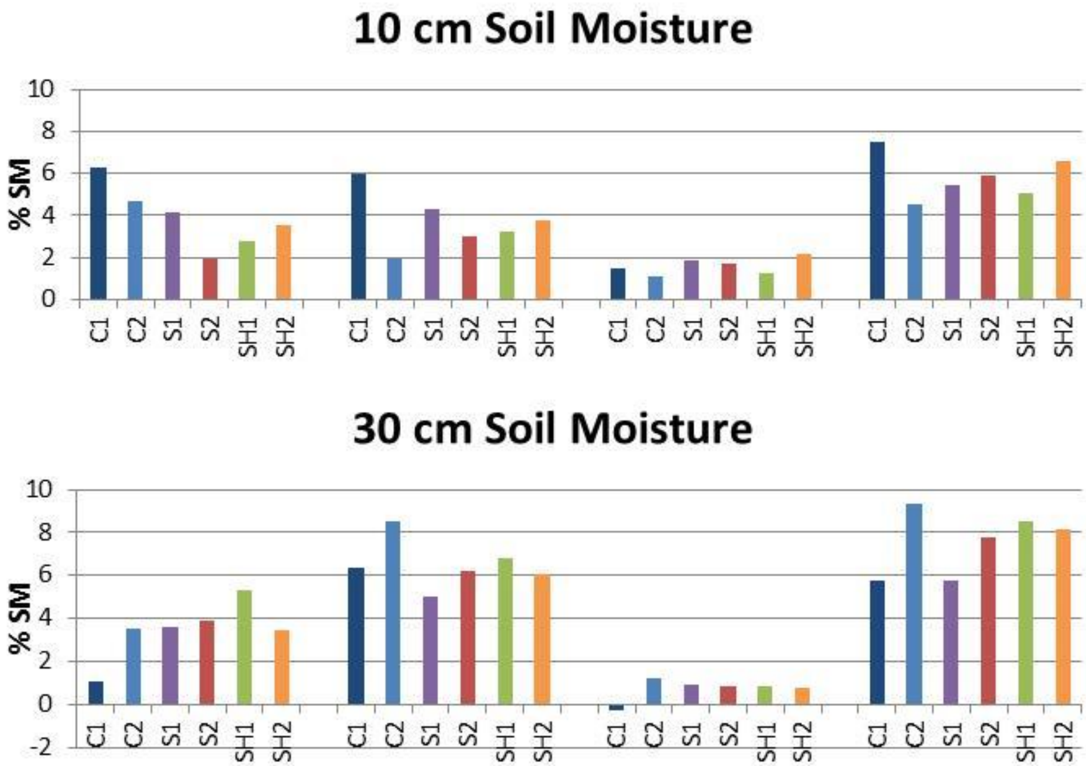


Figure 2-4. 2012 soil moisture

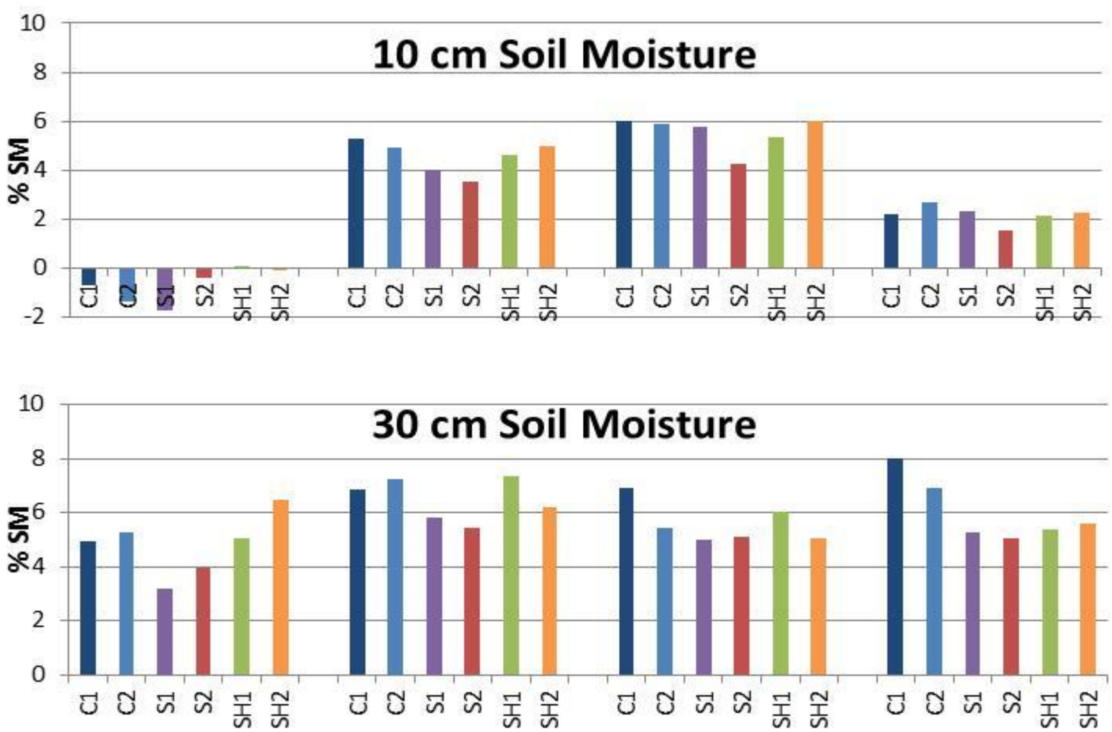


Figure 2-5. 2013 Soil Moisture

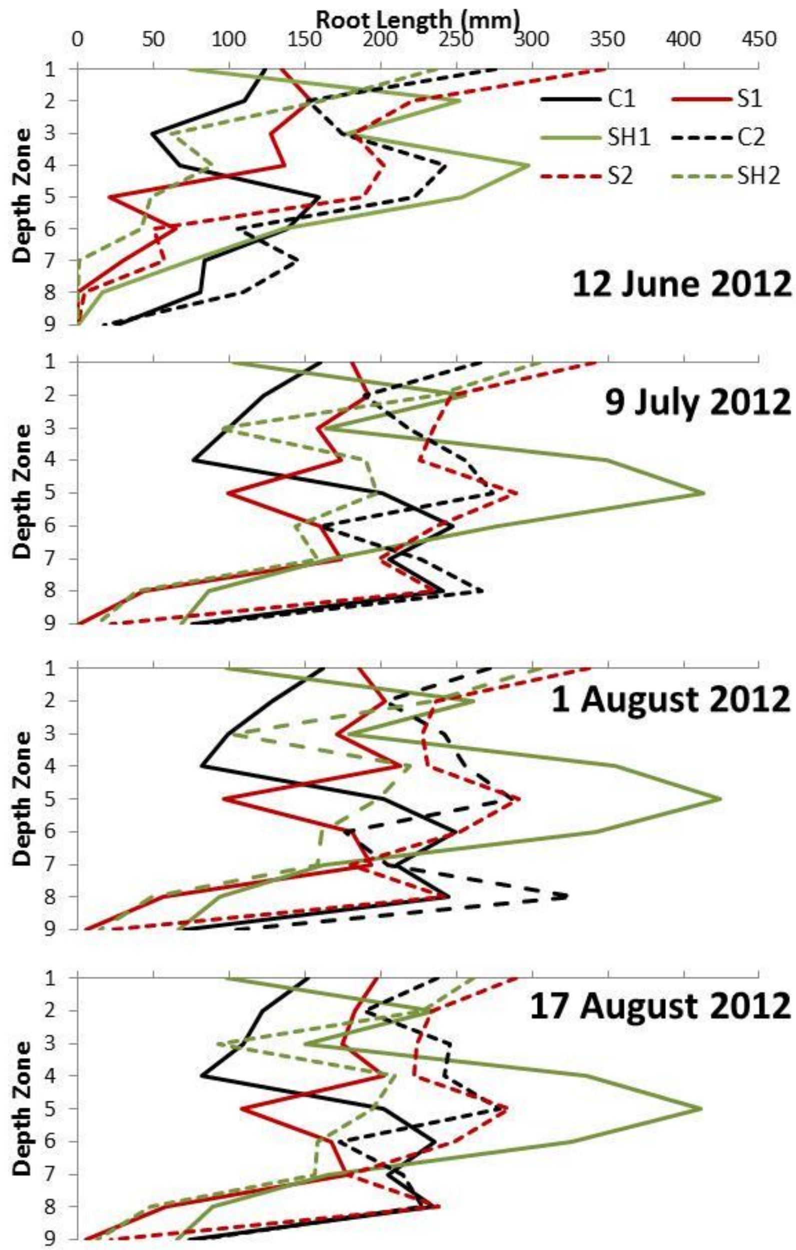


Figure 2-6. 2012 Root Length

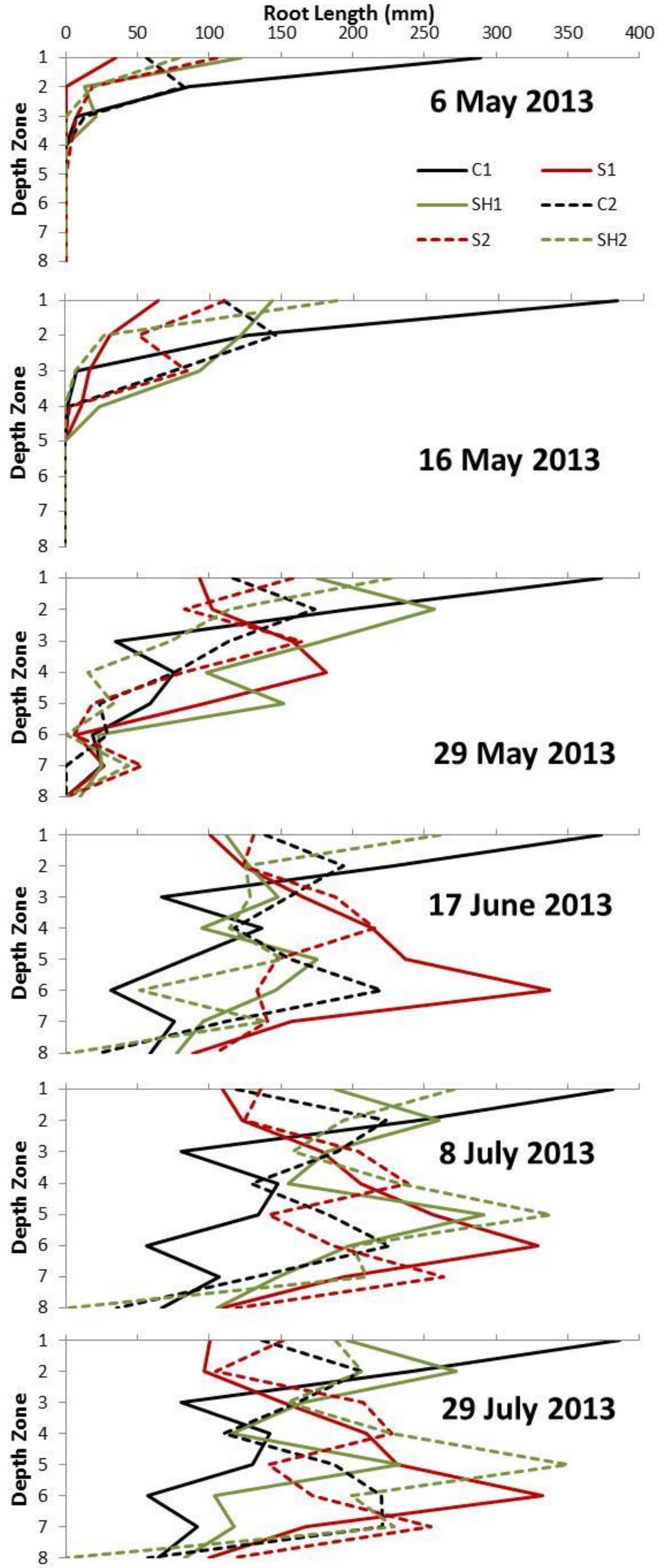


Figure 2-7. 2013 Root Length

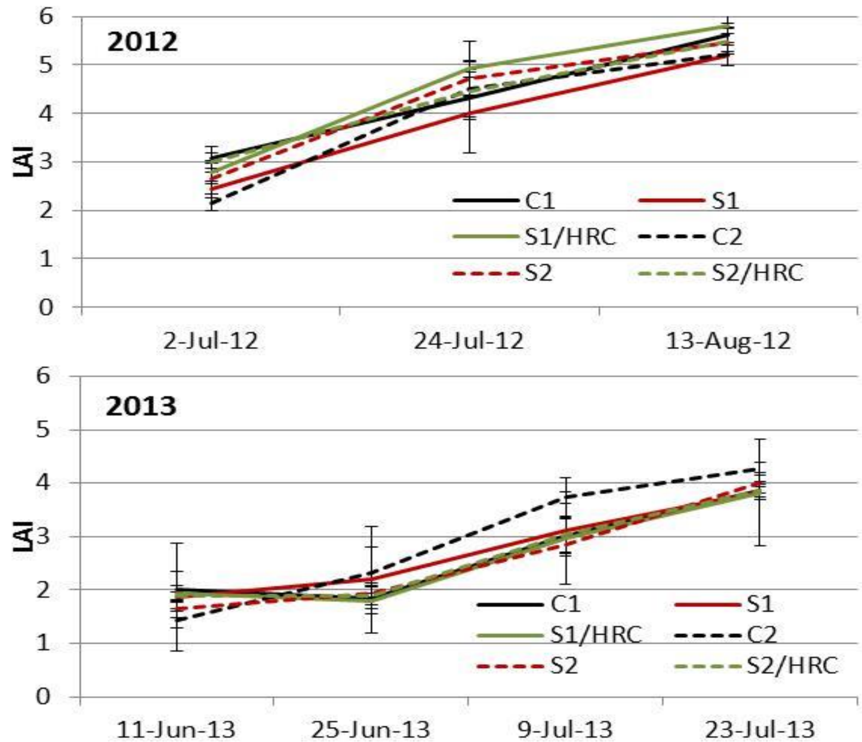


Figure 2-8. LAI

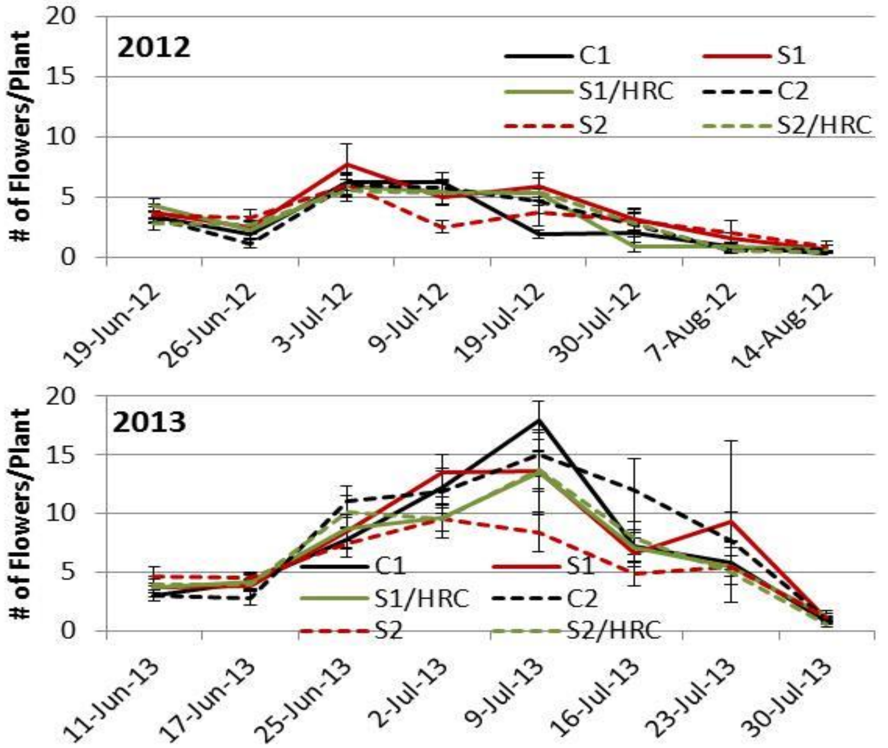


Figure 2-9. Flowers

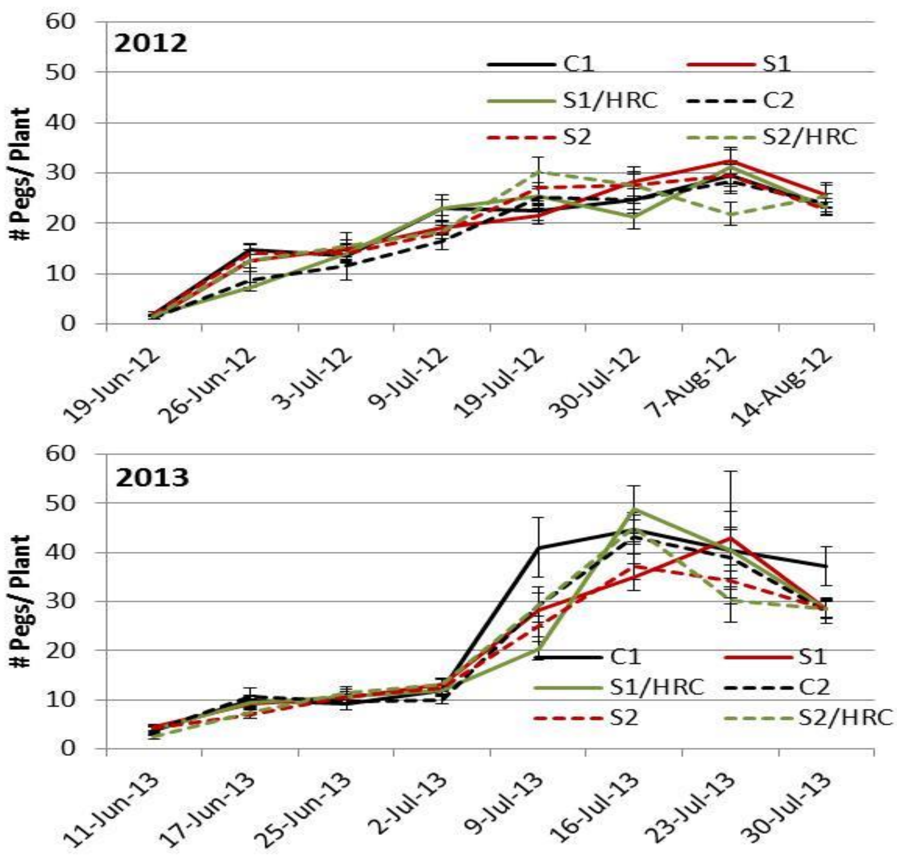


Figure 2-10. Pegs

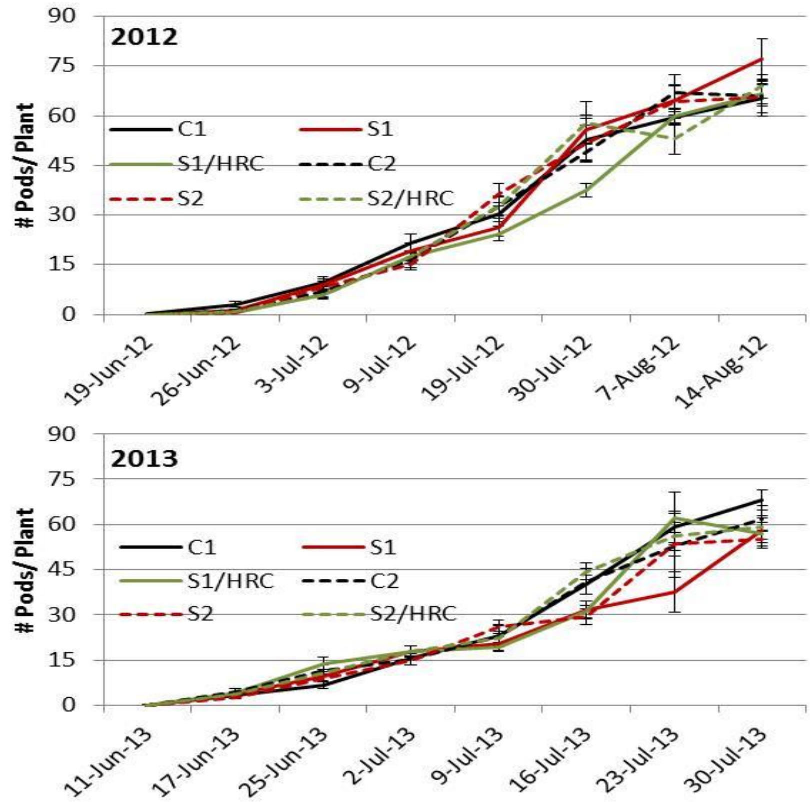


Figure 2-11. Pods

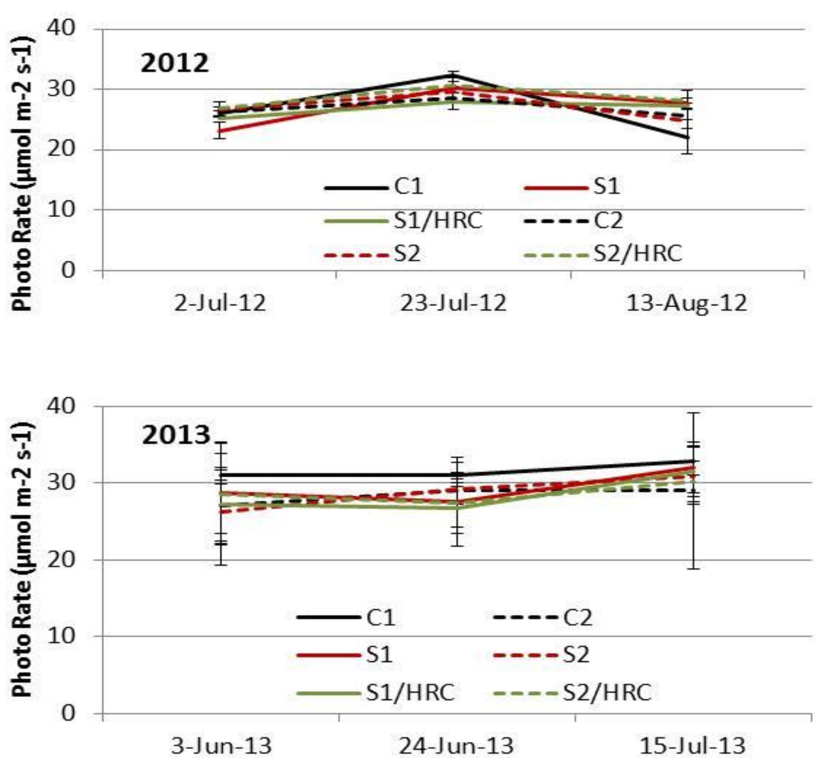


Figure 2-12. Photosynthesis

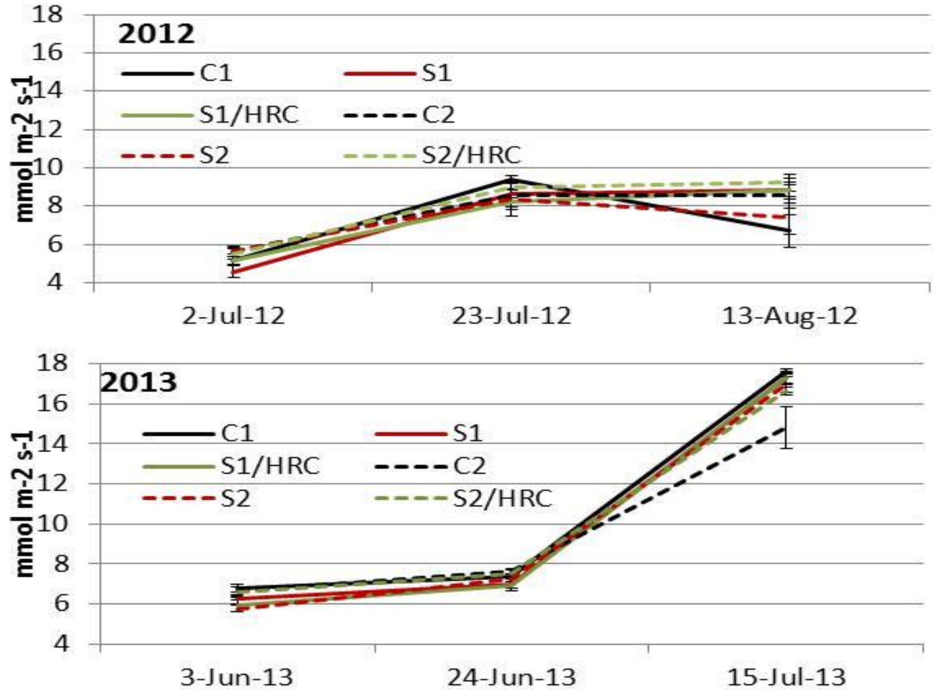


Figure 2-13. Transpiration

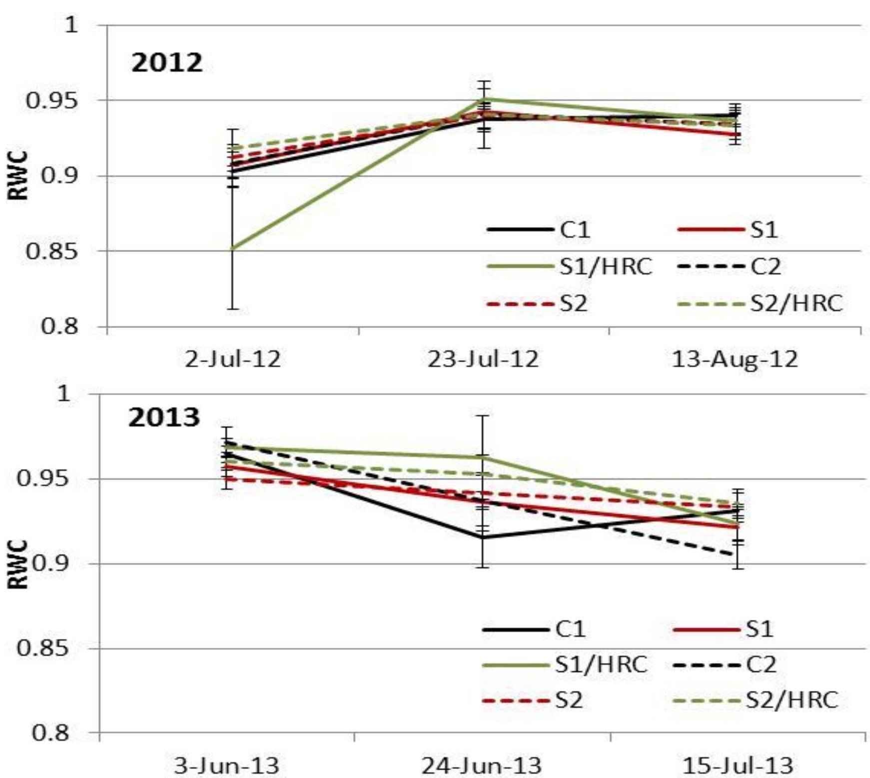
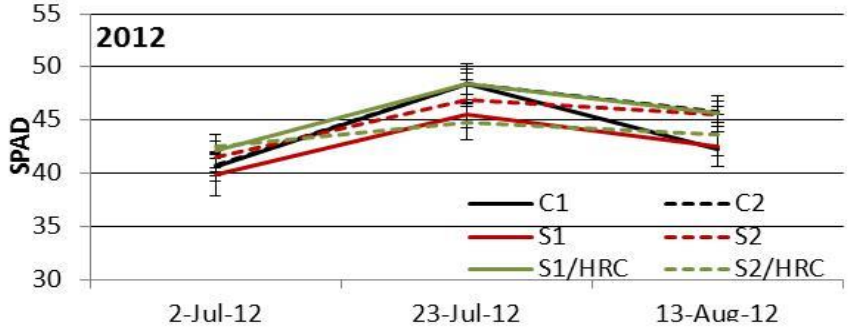


Figure 2-14. Relative Water Content



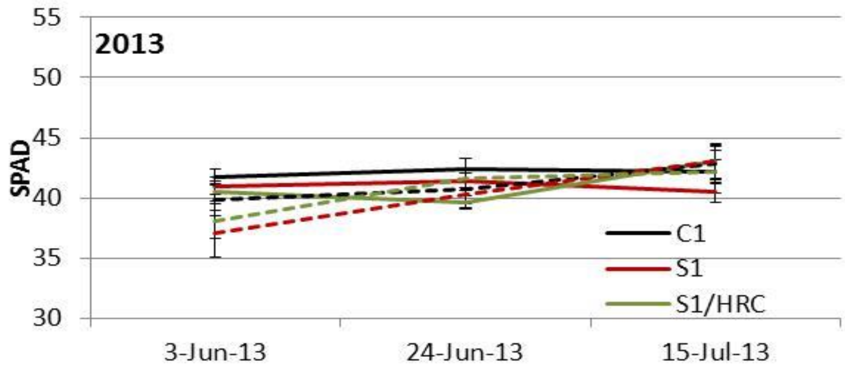


Figure 2-15. SPAD

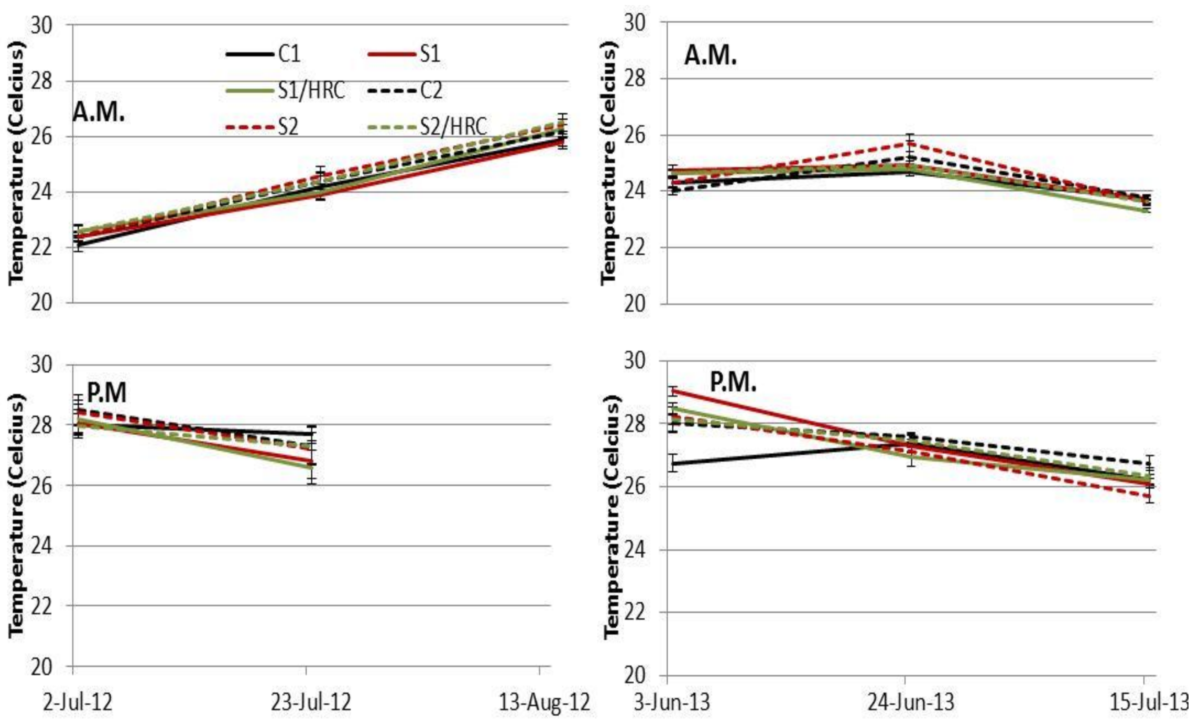


Figure 2-16. 2012 and 2013 Canopy Temperature

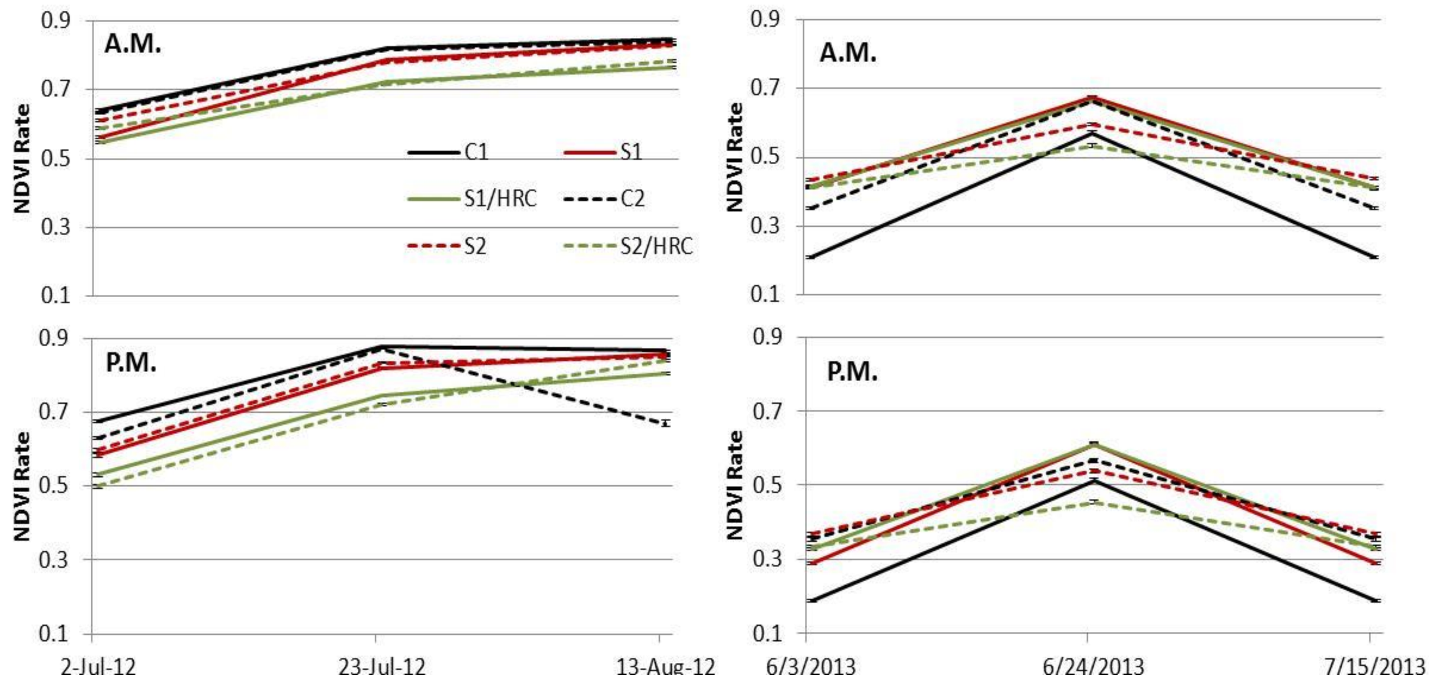


Figure 2-17. 2012 and 2013 NDVI

CHAPTER 3
COTTON ROOT DEVELOPMENT IN LONG TERM ROTATIONAL SYSTEMS

Introduction

The benefits of rotating row crops specifically with bahiagrass (*Paspalum notatum* Flueggé) are well known and include reduced pressure from pests, increased crop yields, and improved soil structure (Wright et al., 2005). Katsvairo et al. (2007) reported that a bahiagrass sod rotation can increase root growth, earthworm densities and soil water infiltration for peanut and cotton. According to Wright et al. (2006) row crops following bahiagrass sod can result in yield increases and lower production costs with less pesticide use. The perennial bahiagrass sod adds to the soil organic matter and long term soil nitrogen pool as well as helping reduce pests normally found in annual grass or legume crops (Boman et al., 1996, Elkins et al., 1977). Katsvairo et al. (2006) reported that rotations involving bahiagrass increased organic matter, improved soil quality, and improved yield and farm profits.

Benefits for cotton following bahiagrass have been reported as far back as 1983, with reports of higher yields in these sod rotations compared to conventional crop rotations (Long and Elkins, 1983). These increased yields were attributed to improved soil nutrient and water uptake by way of a larger root system (Long and Elkins, 1983). Although cotton yields in the bahiagrass system may fluctuate, cotton grown in a bahiagrass sod based system is often higher yielding with reduced input cost (Marois et al., 2002). Growers in the panhandle region of Florida with livestock can uniquely benefit from this system by utilizing the bahiagrass as forage in the non-cash crop years of the rotation. While the benefits of a sod rotation are well known among growers, many remain hesitant about the system due to the cost and time involved in establishing bahiagrass and the lack of a cash crop during that time (Zhao et al., 2009).

One crop characteristic in particular that has been positively impacted by the bahiagrass rotation is root growth and architecture. Rooting characteristics examined by Loison et al. (2012) found that cotton in a bahiagrass rotation had greater overall root length when cattle were allowed to graze winter cover prior to the subsequent cotton crop. When cotton roots were sampled after physiological maturity within a bahiagrass rotation, Katsvairo et al. (2007) found greater root biomass in the sod based rotation as compared to the conventional system, despite the difficulties and limitations associated with the collection of roots within an existing compaction zone.

In 2000, a multi-state project was initiated at the North Florida Research and Education Center (NFREC) located in Quincy, FL to examine the influence of a bahiagrass rotation on peanut and cotton production as compared to a more conventional cotton/peanut rotation. The Quincy research site utilized the harvest of the bahiagrass as hay in the fall; while in winter, a cover crop was established to provide crop residue for the conservation planting of the summer crop. One of the first long-term studies utilizing the plots was reported by Katsvairo et al. (2007) and showed equal or greater yields for cotton in the sod based rotation when compared to the conventional rotation. A second study in revealed that cotton in the sod based rotation showed greater biomass, plant height, LAI and ability to outcompete weeds (Katsvairo et al., 2009). Finally, a study in 2010 showed that an oat cover crop grown in the sod based rotation had greater biomass, leaf petiole sap and chlorophyll concentrations than the conventional rotation (Zhao et al., 2010). While these studies have definitely documented increased plant health and development of the crop above ground, there has been minimal examination of below ground impacts.

By examining root growth in these rotations, vital information for the sod based rotation system was obtained, that was for the most part unknown. This project allowed the unique opportunity of focusing on the rooting dynamics of cotton in a long term bahiagrass sod rotation. At NFREC, the specific objective was to quantify cotton root growth from the long term bahiagrass and conventional rotation system and the effects of irrigation in each system. This research will show rooting characteristics of cotton in the different systems. This would particularly benefit the growers in west FL that may be considering bahiagrass sod rotation as an option because of declining yields and soil quality in systems that have been crop monocultures.

To build on this research, cotton root architecture data were collected from the long term rotations currently ongoing in Quincy, FL that do not incorporate cattle. To do so, a mini rhizotron camera system was utilized. This nondestructive method allows the user to view root growth throughout the season. Because the tube has a locking mechanism interfaced with the camera, exact same locations within a given tube can be repeatedly imaged.

Materials and Methods

Field Preparation and Crop Maintenance

A long term irrigation x rotation study was initiated in 2000 at the University of Florida's North Florida Research and Education Center (NFREC) in Quincy, FL (30° 36' N, 84°33' W). The soil type at the site is a Dothan sandy loam (fine, siliceous, thermic Plinthic Kandiudults). The details of the experimental methodology are included in Kaitsvaro et al. (2009). Briefly, the 1.75 ha experimental site was planted to cotton in the summer of 1999 and was then fallow the following winter. Prior to 1999, the field had been in a conventional tillage/winter cover cropping sequence for several years.

Treatments for the study were arranged as a strip plot design with three replications and included irrigation and crop rotational system. Irrigation treatments were applied using a lateral move irrigation system (Reinke, Deshler, NE) and consisted of three strips, each 128 m long by 45.7 m wide, where alternating irrigated (IR) and non-irrigated (NI) treatments were established. Irrigation events were triggered by measurements of soil tension using tensiometers at 30 cm depth and using soil moisture thresholds determined prior to the experiment. Crop rotations were established as subplots that were 45.7 m long by 18.3 m wide, and were aligned perpendicular to the NI and IR strips. Crop rotations included peanut-cotton-cotton (CC) and a bahiagrass-bahiagrass-peanut-cotton (SC) rotation. All rotations were present each year.

In April of each year, plots were strip tilled two weeks prior to cotton planting, plots were strip tilled using a Brown Ro-till implement (Brown Manufacturing Co., Ozark, AL). Plots consisted of eight rows at 0.91 m row spacing. All plots were planted with a Monosem (Edwardsville, KS) vacuum planter with an in row seed population of 13 seed m^{-1}. In 2011, Deltapine DP1048B2RF variety was used and in 2012 Phytogen PHY499WSRRFX was used. Starter fertilizer (N, P, K = 5-10-15) was banded alongside the row at planting at a rate of 560 kg ha^{-1}. Management of pesticides and nutrients for cotton and bahiagrass followed the University of Florida IFAS (Institute of Food and Agricultural Sciences) recommendations for standard row crop practices for the region.

Plant Measurements

After planting, clear plastic mini-rhizotron tubes (183 cm in length) were inserted in the fourth row in each plot. The minirhizotron tube was installed into the ground at a 45 degree angle to the soil surface. Roots were imaged on three dates in 2011 (20 June, 26 July, and 30 August) using the Bartz minirhizotron camera system (Bartz Technology Corp; www.bartztechnology.com). In 2012, roots were imaged on three dates (22 June, 16 July, and 6 August). The camera system utilizes a locking mechanism which allows for repeated viewing throughout the season of the exact same location. Once taken, images were then analyzed using WinRHIZO Tron software program (http://www.regent.qc.ca). Analysis involves the tracing of each root segment in every image taken within a tube. Once tracing is complete, the software automatically calculates cumulative root length for a single image at a given depth.

Results

Overall rainfall amounts were very similar (from planting through the last measurement period (1 April through 1 September) in 2011 and 2012 (56 and 58 cm, respectively) (Figure 3-1). However, rainfall patterns were different between years with 2011 receiving only 12 cm of rainfall while 2012 received 22 cm from 1 April to 15 June. From 16 June thru 1 September rainfall was 44 cm and 35 cm in 2011 and 2012, respectively. In addition to rainfall, IR plots received 5.4 and 3.5 cm of irrigation in 2011 and 2012 respectively.

Root Architecture

There was an effect of rotational systems in 2011 with the SC (43.7 cm) having significantly lower root length than CC (60.3 cm) (Table 3-1). There was no effect of irrigation in either year, but there was an irrigation by rotation interaction where the IR

CC treatment had increased root length overall whereas IR SC and NI SC were similar in root length. Zones were significantly different in both years; with peak root length occurring in zones 3 and 4 (20-40 cm below the soil surface) in both 2011 and 2012 (Figure 3-2). Root measurement at 90 cm was achievable in both years but roots only reached 60 and 70 cm depths in 2011 and 2012, respectively; these depths had the lowest root lengths as well. In 2011 both IR CC and IR SC roots never reached the maximum depth of 60 cm; while in 2012 all treatments had roots present at 70 cm by 16 July but IR SC and NI CC had senesced at that depth by 6 August. Root length at shallow depths (0-10 cm) was consistently high in 2011 with no clear pattern among treatments in 2012. There was an effect of measurement time in both 2011 and 2012, with the lowest root lengths in June (Figure 3-3). However the peak in root length occurred at different times in both years with the highest root lengths in 2011 by the August measurement date; whereas root length peaked in July in 2012. In that same year root length actually decreased numerically between July and August indicating that some root senescence was occurring during that period.

Discussion

Roots are a vital element of a plant's anatomy. Not only do they allow the plant to anchor itself, their main functions include absorption of water and nutrients from the soil (Kramer and Boyer, 1995). However studying roots, particularly in transient agroecosystems, presents tremendous challenges. Research focused on roots often involves destructive harvest of several plants within a research plot area which often limits the ability to quantify development of root systems over time (Gray et al., 2013). Regardless of these limitations, effects of management techniques on root architecture and function are critical elements and causal agents behind the success or failure of a cropping system in general. This is especially true for tillage and rotational systems that are known to have significant impacts on root growth and soil components (Hilfiker et al., 1988; Dwyer et al., 1995). The current study has been able to contribute to this body of scientific evidence by quantifying cotton root responses to two long-term rotational options that are currently available to growers in the panhandle region of Florida. What is also unique to this study was its ability to quantify cotton root growth over the entire growing season using a non-destructive root measurement system.

Soil moisture is a characteristic that can have a tremendous impact on root growth and extension (Dwyer et al., 1988). Of course, rainfall patterns during the growing season are the main driver of soil moisture patterns, particularly for non-irrigated production, such that periods of inadequate rainfall can elicit dramatic changes to the crop root architecture in general (Merril et al., 1996). Oftentimes, discussing limitations of rainfall appears to be an oxymoron when considering southeastern U.S. production systems. However, when examining intra-annual precipitation patterns, it becomes abundantly clear that sub-optimal rainfall amounts commonly occur during the growing season and can have significant impacts on crop yield. The two years of this study (2011 and 2012) perfectly illustrate this phenomenon. In 2011 and 2012, the total rainfall was nearly identical at 56 and 58 cm, respectively. However when totaling precipitation during the first 75 days of the growing season, rainfall was 12 cm in 2011 and 22 cm in 2012, showing a dramatic difference in rainfall received during root system establishment.

However, soil moisture and plant water availability can be moderated strongly by crop rotations that include bahiagrass sod (Johnson et al., 1999). In years or parts of the season with low amounts of rainfall, bahiagrass sod rotations may have the ability to prolong plant water availability over more conventional rotation systems. The data from this study indicate that this may have been the case. In 2011, the year that had lowered precipitation levels during the first 75 days of the season, there were significant differences in root length between the conventional and sod-based rotation such that the conventional root lengths were nearly 20 mm longer on average than the sod-based system. This may be due to a root priming effect. When plants experience mild to moderately lowered water availability in the early season, roots often respond by increasing growth and extension (Rowland et al., 2012). If water availability was more limited in the conventional system in 2011, then greater root growth over the sod-based system could be expected. Alternatively, these differences in root system growth between rotational systems were not present in 2012, the year when early season precipitation rates were nearly doubled from 2011. The presence of an interaction between irrigation and rotational system in 2011 also supports the hypothesis that water availability may have been lower in the conventional rotation. In 2011, root analysis indicated that at the shallow depth of 10 cm, roots in the irrigated conventional system were highly proliferated, likely due to a direct response to irrigation received. This would indicate the possibility that water was limiting for that rotational system, particularly at the surface layers. In addition, the fact that the irrigated sod system showed no response to the irrigation treatment gives support to possibly higher soil moisture retention in the sod system.

The architecture of a typical cotton root system is structured with a taproot and lateral branching approximately 12 cm below the primary root apex, with tertiary roots 5 cm below the secondary root apex (McMichael, 1986). Roots are usually limited to a depth of 1 m with a lateral extension of up to 2 m (Hayward, 1938; Taylor and Klepper, 1974); however, cotton tap roots have been shown to reach depths of up to 3 m (Balls, 1919). The results from this study indicated that there was a compaction zone at approximately 60-70 cm below the soil surface. This compaction layer likely modified the architecture of the root system somewhat from how a "typical" cotton root system is structured. Root depth in this study could be assessed down to the 90 cm depth; however, roots were only measured as deep as 60-70 cm which is a relatively shallow root system for cotton (Hayward, 1938). This indicates the likely existence of a compaction layer at this depth which supports earlier documentation of such a zone within this NFREC site by Kastvairo et al. (2007). Compaction is known to have a significant impact on root architecture and may actually be one of the most important edaphic factors determining root system shape (Bengough et al., 2011). This is certainly the case for cotton (Grimes et al., 1975), where compaction has been shown to decrease root diameter, decrease elongation rates, increase lateral branching, and reduce water and nutrient uptake (Taylor, 1983; Glinski and Lipiec, 1990).

This study showed cotton root lengths peaked in August and July for 2011 and 2012, respectively. Cotton root length normally shows a linear increase as the plant develops with a maximum architecture achieved by fruit production (Taylor and Klepper, 1974). The August and July time frames for the peak in root length for this study do coincide with the time of maximum boll fill during the study. The difference in the two years may have been related to delayed fruit production in 2011, again due to reduced rainfall patterns in the first 75 days of the growing season for that year. These results are also consistent with the cotton root study conducted by Loison et al. (2012) in Marianna reported that root growth peaking by the month of August across three years.

This study has provided valuable information about cotton root production in two different crop rotations in the panhandle region of Florida. The differential patterns of root variability between the conventional and sod system indicated that the sod system may have the potential to buffer against periods of low rainfall whether in an irrigated setting or not. This capacity makes the bahiagrass rotation a valuable system that farmers in the southeast could implement. This is critical because of the variability in the rainfall throughout the season and the relativity low moisture holding capacity of soils in the region. The use of this system could protect the crop against negative impacts during a short-term drought.

Table 3-1. ANOVA results for cotton root length measured in 2011 and 2012.

	Cotton Root Length			
Factor	df	2011	df	2012
Zone (Z)	5	14.7747***	6	4.3135***
Irrigation (Irr)	1	3.0561	1	0.4215
Z x Irr	5	1.1563	6	0.1882
System (Sys)	1	5.0493*	1	0.4582
Z x Sys	5	2.1098	6	0.6945
Irr x Sys	1	13.5262***	1	0.9062
Z x Irr x Sys	5	4.6797***	6	1.2187
Msrmt. Time(MT)	2	5.0004**	2	3.4413*
Z x MT	10	0.3779	12	1.9293*
Irr x MT	2	0.5965	2	0.1114
Z x Irr x MT	10	0.2863	12	1.6594
Sys x MT	2	0.0348	2	0.7337
Z x Sys x MT	10	0.0842	12	0.6576
Irr x Sys x MT	2	0.1154	2	1.2536
Z x Irr x Sys x MT	10	0.0795	12	1.1351

*P<0.05

**P<0.01

***P<0.001

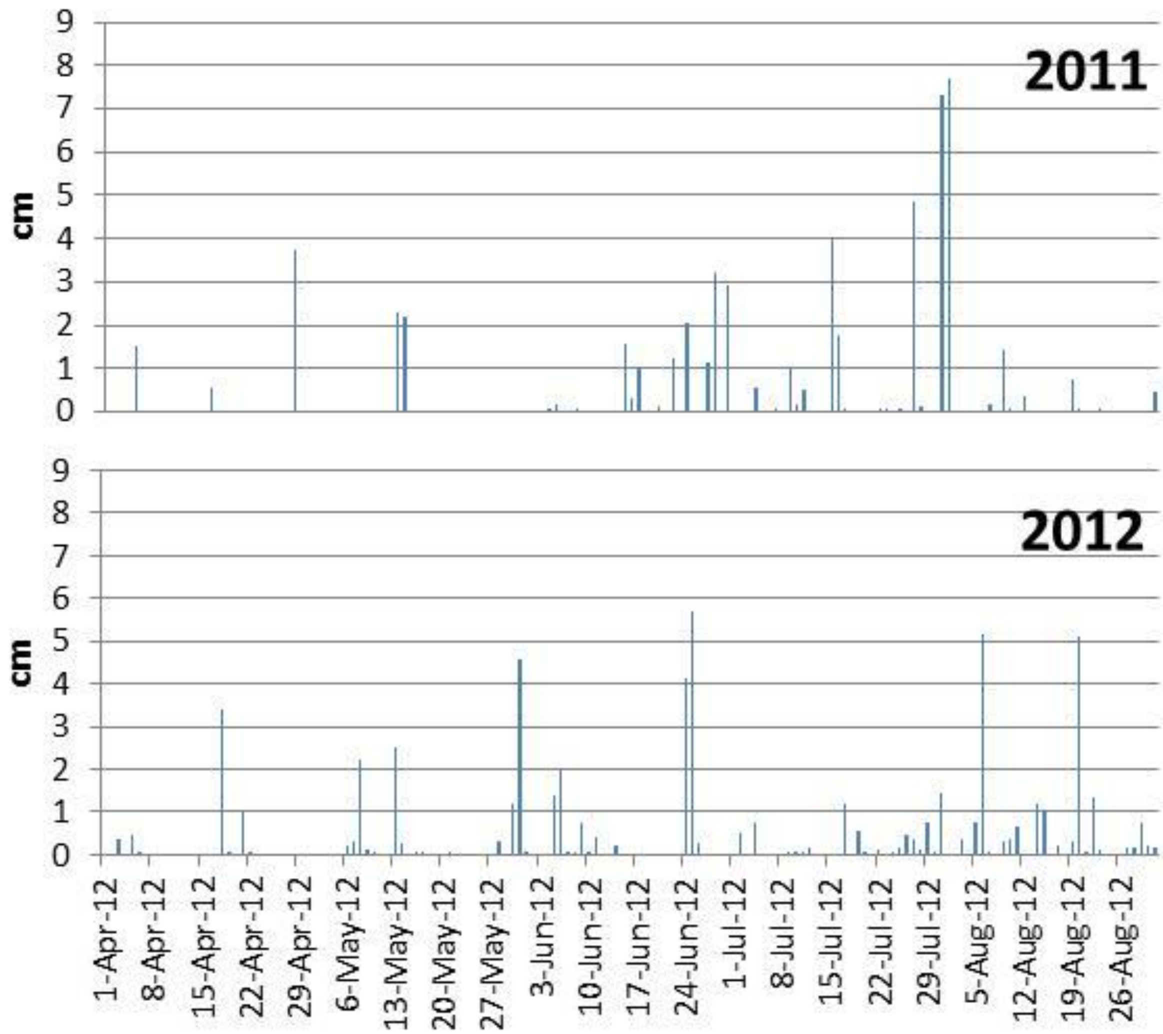


Figure 3-1. Rainfall for the NFREC Quincy, Fl

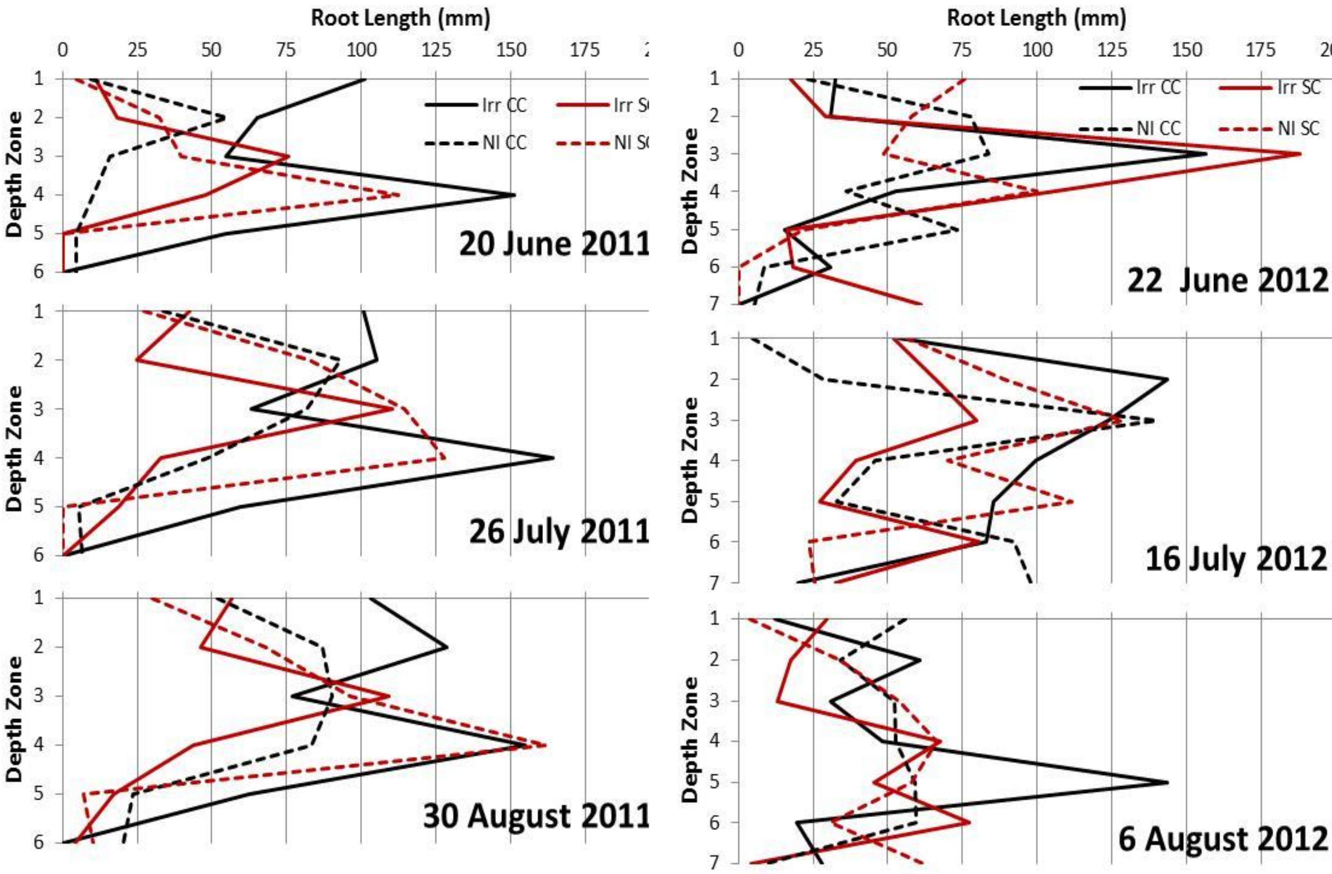


Figure 3-2. Cotton Root length by depth zone

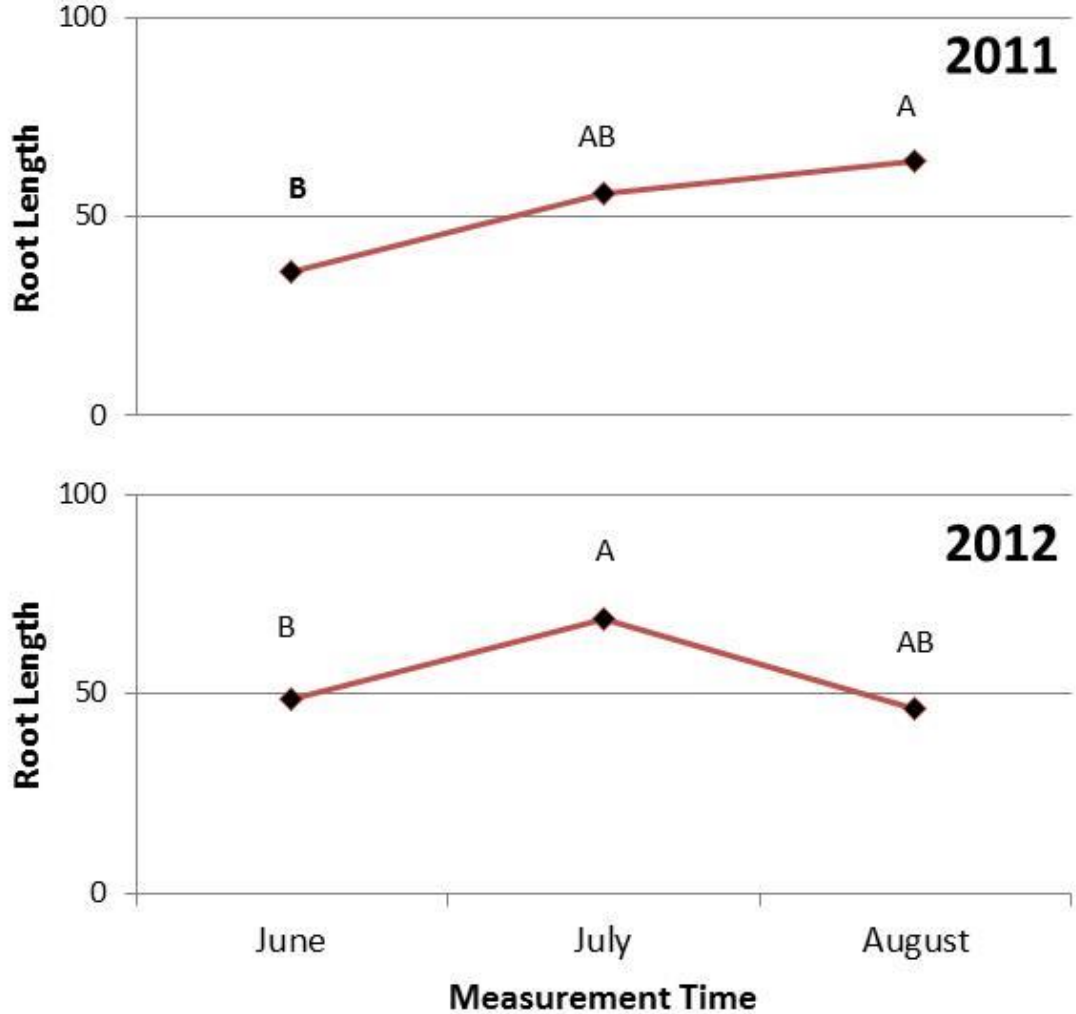


Figure 3-3. Combined cotton root length over season

LIST OF REFERENCES

Baldwin, J.A. 1992. Yield and grade of Florunner Peanut following two years of Tifton 9 bahiagrass, corn, or peanut. Proceedings of Amer. Peanut Res. and Educ. Soc., Inc. Vol. 24 pg 32.

Baldwin, J. A., and J. Hook. 1998. Reduced tillage systems for peanut production in Georgia. Proc. Am. Peanut Res. Educ. Soc. 30:48.

Baldwin, J. A., G. B. Padgett, and A. W. Johnson. 2003. Bahiagrass and other crops in a rotational study to reduce nematodes and other pests affecting peanut yield and quality. In Proc. Sod Based Cropping Systems Conf, pp. 20-21.

Balkcom, K. ,D. Hartzog, T. Katsvairo* and J. L. Smith. 2007. http://www.ag.auburn.edu/auxiliary/nsdl/scasc/Proceedings/2007/posters/Katsvairo_c.pdf

Balls, W.L. 1919. The cotton plant in Egypt. MacMillan and Co., London. 202 pp.

Barr, H. D., and Weatherley, P. E. 1962. A re-examination of the relative turgidity technique for estimating water deficit in leaves. Aust. J. Biol. Sci. 15:413-428.

Bartlett, D.S., G.J. Whiting, J.M Hartman. 1990. Use of vegetation indices to estimate intercepted solar radiation and net carbon dioxide exchange of a grass Canopy. Remote sens. Environ. 30:115-128.

Bengough, A.G., B.M. McKenzie, P.D. Hallett, and T.A. Valentine. 2011. Root elongation, water stress, and mechanical impedance: a review of limiting stresses and beneficial root tip traits. J. Exp. Bot. 62:59-68.

Boman, R. K., S. L. Taylor, W. R. Raun, G.V. Johnson, D. J. Bernardo, and L. L. Singleton. 1996. The Magruder Plots: A century of wheat research in Oklahoma. Div. of Agri. Sciences and Nat. Resources. Pp 1- 1-69.

Boyer J. S. 1971. Recovery of photosynthesis in sunflower after a period of low leaf water potential. Plant Physiology 47: 816-820.

Brown, S. M., T. Whitwell, J. T. Touchton, C. H Burmester. 1985. Conservation tillage systems for cotton production. Soil Sci. Soc. Am. J. 49:1256–1260.

Brandenberg, R.L., D.A. Herbert, Jr., G.A. Sullivan, G.C. Naderman, S.F. Wright. 1998. The impact of tillage practices on thrips injury of peanut in North Carolina and Virginia. Peanut Sci. 25:27-31.

Chaves, M.M. 1991. Effects of water deficits on carbon assimilation. Journal of Experimental Botany 42:1-16.

Colvin, D.l., B.J. Brecke and E.B. Whitty. 1988. Tillage variables for peanut production. Peanut Science 15:94-97.

Cox, F. R., and J. R. Sholar. 1995. Site selection, land preparation, and management of soil fertility. p. 7–10. In H. A. Melouk and F.M. Shokes (ed.) Peanut health management. Am. Phytopathol. Soc., St. Paul, MN.

Djekoun A. and C. Planchon, 1991. Water status effect on dinitrogen fixation and photosynthesis in soybean. Agronomy Journal 83: 316-322.

Dwyer, L.M., D.W. Stewart, D. Balchin. 1988. Rooting characteristics of corn, soybeans, and barley as a function of available water and soil physical characteristics. Can. J. Soil Sci. 68:121-132.

Dwyer, L.M., B.L. Ma, D.W. Stuart, H.N. Hayhoe, D. Balchin, J.L.B. Culley, and M. Mcgovern. 1995. Root Mass Distribution under conventional and conservation tillage. Canadian Journal of Soil Science 76.1: 23-28.

Elkins, C.B., R.L. Haaland, and C.S. Hoveland. 1977. Grass roots as a tool for penetrating soil hardpans and increasing crop yields. Proceedings Southern Pasture and Forage Crop Improvement Conference. 34:21-26.

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

Glinski, J. and J. Lipiec. 1990. Soil Physical Conditions and Plant Roots. CRC Press, Inc., Boca Raton, FL.

Gorbet, D. W., and B. L. Tillman. 2009. Registration of ‘Florida-07’peanut. Journal of plant registrations 3.1: 14-18.

Gray, S.B., R.S. Strellner, K.K. Puthuval, C. Ng, R.E. Shulman, M. H. Siebers, A. Rogers, and A. D. B. Leakey. 2013. Minirhizotron imaging reveals that nodulation of field-grown soybean is enhanced by free-air CO2 enrichment only when combined with drought stress. Functional Plant biology 40: 137-147.

Grichar, W.J., and T.E. Boswell. 1987. Comparison of no-tillage, minimum, and full tillage cultural practices on peanuts. Peanut Sci. 14:101-103.

Grichar, W.J. 1998. Long-term effects of three tillage systems on peanut grade, yield, and stem rot development. Peanut Sci. 25:59–62.

Grimes, D.W., R.J. Miller, and P.L. Wiley. 1975. Cotton and corn root development in two field soils of different strength characteristics. Agron. J. 67:519-523.

Hartzog, D. L., J.F. Adams and B. Gamble. 1998. Alternative tillage systems for peanut. Proc. Am. Peanut Res. Educ. Soc 30:49.

Hayward, H.E. 1938. The structure of economic plants. The MacMillan Co., New York.

Heckathorn, S. A, E. H DeLucia , R. E. Zielinski 1997. The contribution of drought-related decreases in foliar concentration to decreases in photosynthetic capacity during and after drought in prairie grasses. Physiologia Plantarum 101:173-182.

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

Johnson, A. W., N. A. Minton, T. B. Brenneman, G. W. Burton, A. K. Culbreath and S. H. Baker. 1999. Bahiagrass, Corn, Cotton Rotations, and Pesticides for Managing Nematodes, Diseases, and Insects on Peanut. Journal of Nematology 31.2:191–200.

Jones, H.G. 2007. Monitoring plant and soil water status: established and novel methods revisited and their relevance to studies of drought tolerance. Journal of Experimental Botany 58:119-130.

Jordan, D.L., J.S. Barnes, C.R. Bogle, G.C. Naderman, G.T. Roberson, and P.D. Johnson. 2001. Peanut response to tillage and fertilization. Agron. J. 93:1125-1130.

Jordan, D. L., J. E. Bailey, J. S. Barnes., C.R. Bogle, S. G. Bullen, A. B. Brown, K. L. Edmisten, E. J. Dunphy, P. D. Johnson. 2002. Yield and economic return of ten peanut-based cropping systems. Agron. J. 94:1289–1294.

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

Katsvairo, T., D. Wright, J. Marqois, D. Hartzog, K. Balkom, J. Rich, and P. Wiatrak. 2007. Performance of peanut and cotton in a bahiagrass cropping system. Agron. J. 99:1245-1251.

Katsvairo, T.,D. Wright, J. Marqois, J. Rich, and P. Wiatrak. 2009. Comparitive plant growth and development in two cotton rotations under irrigated and non-irrigated conditions. Crop Sci. 49:1-13.

Kramer, P.J. Boyer, J.S. 1995. Water relations of plants and soils. Academic press. 68-72.

Lamb, M. C., M. H. Masters, D. Rowland, R. B. Sorensen, H. Zhu, R. D. Blankenship, and C. L. Butts. 2004. Impact of sprinkler irrigation amount and rotation on peanut yield. Peanut Science 31:108-113.

Lanier, J.E., D.L. Jordan, J.S. Barnes, J. Matthews, G.L. Grabow, W.J. Griffin, Jr., J.E. Bailey, P.D. Johnson, J.F. Spears, and R. Wells. 2004. Disease management in overhead sprinkler and subsurface drip irrigation systems for peanut. Agronomy J. 96:1058-1065.

Lawlor, D. W. and G. Cornic. 2002. Photosynthetic Carbon assimilation and associated metabolism in relation to water deficits in higher plants. Plant, Cell and Environment. 25:275-294.

Loison, R., D. Rowland, W. Faircloth, J. Marois, J. Wright, D. L. and S. George. 2012. Cattle grazing affects cotton root dimensions and yield in a bahiagrass-based crop rotation. Crop Management 11:0-0.

Long, F. L., and C. B. Elkins. 1983. The influence of roots on nutrient leaching and uptake. Nutrient cycling in agricultural ecosystems. Spec. Publ. 23:335-352

Mannering, J. and C. R. Fenster, What is conservation tillage. 1983. Soil and Water Conservation Journal 38:140-143.

Marois, J. J., Wright, D. L., Baldwin, J. A., and Hartzog, D. L. 2002. A Multi-state project to sustain peanut and cotton yields by incorporating cattle and sod in a sod based rotation. 25th Annual Southern Conservation Tillage Conference for Sustainable Agriculture 101-107.

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

McMichael, B. L. 1986. Growth of roots. JR Mauney and J. McD. Stuart, eds. Cotton physiology. Memphis, TN: The Cotton Foundation: 29-38.

Meisner, C. A., and K. J. Karnok. 1992. Peanut root response to drought stress. Agronomy J. 84.2:159-165.

Merrill, S.D., A.L. Black, A. Bauer. 1996. Conservation tillage affects root growth of dryland spring wheat under drought. Soil Sci. Am. J. 60:575-583.

Milchunas, D. G. 2012. Biases and errors associated with different root production methods and their effects on field estimates of belowground net primary production. S. Mancuso (ed.), Measuring Roots, Springer-Verlag, Berlin Heidelberg. 382:303-340.

Miyashita K., S. Tanakamaru, T. Maitani, K. Kimura. 2005. Recovery responses of photosynthesis, transpiration, and stomatal conductance in kidney bean following drought stress. Environmental and Experimental Botany 53:205-214.

Myneni, R.B., C.D. Keeling, C.J. Tucker, G. Asrar , R.R. Nemani. 1997. Increased plant growth in the northern high latitudes from 1981 to 1991. letters to Nature 386, 698-702.

NASS, USDA. http://www.nass.usda.gov/

Prasad, P.V., P.Q. Craufurd, and R. J. Summerfield. 1999. Sensitivity of peanut to timing of heat stress during reproductive development. Crop Sci. 39:352–1357.

Prasad P.V., P.Q. Craufurd, R.J. Summerfield, T.R. Wheeler. 2000. Effects of short episodes of heat stress on flower production and fruit-set of groundnut. J. Exp. Bot. 51:777-784.

Rao N., R.C., J. H. Williams, M. V. K. Sivakumar, K. D. R. Wadia. 1988. Efffect of water deficit at different growth phases of peanut. II. response to drought during preflowering phase. Agron. J. 80:431-438.

Raper, R.L., D.W. Reeves, C.H. Burmester, E.B. Schwab. 2000. Tillage depth, tillage timing, and cover crop effects on cotton yield, soil strength and tillage energy requirements. Applied Engineering in Agriculture Vol. 16 No. 4 pp. 379-385.

Rowland D.L., W.H. Faircloth, C.L. Butts. 2007. Effects of irrigation method and tillage regime on peanut reproductive processes. Peanut Science 34:85-95.

Rowland, D.L., W.H. Faircloth, P. Payton, D.T. Tissue, J.A. Ferrel, R.B. Sorenson, C.L. Butts. 2012. Primed acclimation of cultivated peanut through the use of deficit irrigation timed to crop development periods. Ag. Water Management 113:85-95.

Sikuku P. A, G.W. Netondo, J.C. Onyango, and D.M. Musyimi. 2010. Chlorophyll fluorescence, protein and chlorophyll content of three nerica rainfed rice varieties under varying irrigation regimes. Journal of Agricultural and Biological Science 5:19-25.

Sorensen, R.B., C.L. Butts, and D.L. Rowland. 2005. Five years of subsurface drip irrigation on peanut: What have we learned? Peanut Sci. 32:14-19.

Sturkie, D.G., and G.A. Buchanan. 1973. Cultural practices. peanuts: culture and uses. APREA, Stillwater 299-326.

Swenson, A.L., and R.G. Johnson. 1982. Economics of no-till crop production. Farm Research Vol. 39:14-17.

Taylor, H.M. 1983. Managing root systems for efficient wateruse: An overview. pp. 87-113. In :W.R. Jordan and T.R. Sinclair (eds.). Limitations to Efficient Water Use in Crop Production. Amer. Soc. Agron., Madison.

Taylor, H.M. and B. Klepper. 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 P.C. Wall. 2009. Effects of conservation agriculture techniques on infiltration and soil water content in Zambia and Zimbabwe. Soil and Tillage Research 105:217-227.

Tubbs, S.R. and R.N. Gallaher. 2005. Tillage and Cropping Systems. Agron. J. 97:500-504.

Vaadia, Y., F. C. Raney, R.M. Hagan. 1961. Plant water deficits and physiological processes. Ann. Rev. Plant Physiology 12:265-292.

Watson, D.J. 1947. Comparative physiological studies on the growth of field crops: I. variation in net assimilation rate and leaf area between species and varieties, within and between years. Ann Bot 11: 41-76.

Wright, D., J. Marois, T. Katsvario, P. Wiatrak and D. Hartzog. 2006. Perennial grasses- a key to improving conservation tillage. Southern Conservation Systems Conference 79-84.

Wright, D., J. Marois, T. Katsvairo, P. Wiatrak and J. Rich. 2005. Sod based rotations- the next step after conservation tillage. Southern Conservation Systems Conference 5-10.

Wright, F.S. and D. M. Porter. 1991. Digging date and conservational tillage influence on peanut production. Peanut Science 18:72-75.

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

Zhao, D., Wright, D., Marois, J., & Katsvairo, T. 2007. Peanut yield response to bahiagrass kill time and tillage method in the southeast. Southern Conservation Agricultural Systems Conference 29:25-27.

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

BIOGRAPHICAL SKETCH

Adam Cook grew up near Trenton, Florida and after graduating Trenton High School in 2006, began attending Lake City Community College before transferring to Sante Fe Community College. After graduation from Sante Fe, he transferred to the University of Florida in Gainesville and in 2011 received a Bachelor of Science degree in agricultural operations management. Adam then pursued a master's degree in agronomy in January of 2012 at the University of Florida, graduating May of 2014.