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Cotton (*Gossipium hirsutum* L.) Response to Irrigation and Environment in a Short Season Climate

Matthew Scott Wiggins
mwiggin8@utk.edu

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Christopher L. Main, Major Professor

We have read this thesis and recommend its acceptance:

Brian G. Leib, Thomas C. Mueller

Accepted for the Council:

Dixie L. Thompson

Vice Provost and Dean of the Graduate School

(Original signatures are on file with official student records.)

Cotton (*Gossipium hirsutum* L.) Response to Irrigation and Environment in a Short Season
Climate

A Thesis
Presented for the
Master of Science Degree
The University of Tennessee

Matthew Scott Wiggins
May 2012

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To God, *I can do all things through Him who strengthens me. Philippians 4:13.*

Abstract

Research was conducted in 2010 and 2011 at the West Tennessee Research and Education Center in Jackson, TN to investigate water deficit and irrigation response in cotton to provide a better understanding of physiological growth changes and yield impact on the crop grown in soils of varying depth to a sandy layer. The deep soil yielded more vegetative mass when compared with the shallower soil. This is also true when applying higher rates of irrigation where plants grew two more nodes of growth and 15.2 centimeters of plant height. Time to cotton maturity was delayed seven days in the deep soil and with the application of irrigation. Canopy density, measured by light interception, was increased in plots grown on the shallow soil profile from 48% to 53% when irrigation was applied. Canopy temperature was reduced when grown in the deep soil profile and with the addition of irrigation. Yield and fiber quality increased with irrigation and when cotton was grown on a deep soil.

Research was also conducted to evaluate cotton variety growth, fiber quality, and yield stability of six varieties during 2010 and 2011 at fifteen on-farm production locations. The variety with the most overall response in growth and plant structure was PHY 375 WRF, with the addition of 3.7 nodes and 21.6 cm of plant height over the plants blooming period. In locations receiving more than 7.6 cm of precipitation during the blooming period, PHY 375 WRF had the highest yield at 1280 kg ha⁻¹. Regression analysis of yield stability found R² values ranged from 0.89 for PHY 375 WRF and DP 0912 B2RF to 0.74 for PHY 367 WRF. This indicates that 89% of the variation in PHY 375 WRF and DP 0912 B2RF yield can be accounted for by differences in environment, but only 74% of the yield variation of PHY 367 WRF is due to differing environmental factors.

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Part I.
Introduction

Cotton

Gossypium hirsutum, commonly known as upland cotton, is an indeterminate perennial plant that produces dehiscent fruit that is harvested for lint which serves numerous purposes (Turner et al., 1986). Cotton is cultivated across the world and United States in various climatic and moisture regimes. Although cotton varieties are able to subsist in many different climatic and moisture regimes, water availability, either from artificial irrigation or natural precipitation events proves to be one of the most limiting factors to successful cotton production (Gerik et al., 1996; Howell, 2001; Pettigrew, 2004). Cotton can be grown in areas of limited moisture and irrigation technologies are generally beneficial to commercial production (Howell, 2001; Quisenberry and Roark, 1976). This is true for both areas of arid climates and areas of high humidity. Cotton producers in the southern United States, where there are often times of severe drought and high humidity, are starting to rely more on the use of artificial irrigation due to the erratic nature of natural precipitation events and to aid in an economical enhancement of the crop (Howell T. A., 2001). Irrigation can be a large expenditure for producers. Therefore, an adequate understanding of cotton's growth and development and its water use efficiency (WUE) is needed to maximize profitability.

Cotton, being an indeterminate plant, continually produces both vegetative growth and reproductive growth throughout the growing season (Eaton, 1955; Quisenberry and Roark, 1976). The two types of branches associated with the cotton plant are described as vegetative branches (monopodia) or fruiting branches (sympodia) (Ritchie et al., 2004). The different branches are distinguished by their shape and number of meristems. Vegetative branches have only one meristem, thus having straight and erect growth habits (Ritchie et al., 2004). Fruiting branches on the other hand, can have numerous auxillary meristems and are characterized by a

“zig-zag” growth pattern (Ritchie et al., 2004). Fruiting buds are initiated at the fruiting site closest to the main stem and progress outward through the duration of the growing season. While moving outward on the fruiting branches, the plant also fruits up the main stem. A generality is that new nodes and fruiting branches are generated every three days along the main stem and fruiting sites along the lateral fruiting branches are generated every six days (Ritchie et al., 2004). Total number and location of these branches are due to several environmental and agronomic factors, such as available moisture, sunlight, nutrients, and temperature.

Cotton is grown in a wide range of climates and environments around the world and in the United States. These environments have a large impact on the growth, development, and quality of the crop. Environmental factors, some influenced by managing inputs and some not, will determine the crop’s success (Stewart et al., 2010). Therefore, producers and crop managers have to manage the crop to maximize yield potential regardless of what uncontrollable circumstances may be present in the environment (Stewart et al., 2010). Studies have shown that cotton crops have no limit when it comes to plant development due to its indeterminate, perennial nature (Hearn and Constable, 1984). Limitations in cotton producing environments often relate to the extensiveness of the vegetative and reproductive growth of the crop, ultimately affecting yield. Another factor influencing crop production, other than environments, is the genetic population. Plant populations from differing genetic backgrounds often vary in results due to the environmental response; this is known as the genotype-environment interaction. Ideally, a variety would react in a positive manner in all situations regardless of limitations. Since there is not a single predominate variety adapted to all regions of cotton production, genotype-environment interaction is prevalent wherever cotton is produced.

Supplemental Irrigation

Cotton, as described earlier, has proved to be drought tolerant, but water is still the most limiting factor effecting growth and production of the plants (Gerik et al., 1996). From previous studies conducted in temperate humid climatic conditions, we know that water deficit stress aids in the stunting of growth, reduced leaf area, and reduced yield (Gerik et al., 1996). During times of water stress the plant often sheds fruiting structures, reducing boll load and decreasing yield. Irrigation in these times of drought can be an effective way to reduce yield loss and increase WUE (Howell T. A., 2001). Many studies have been conducted to assist in the determination of WUE, but commonly WUE is defined as:

$$[WUE = \frac{\text{Lint Yield (kg ha}^{-1}\text{)}}{\text{Total Water Applied+Precipitation (cm)}}]$$

or crop yield per unit of water use (Howell T. A., 2001). This does provide an adequate economic model for WUE. However, this does not provide a producer with an in-season method of determining WUE during crop production.

Areas of the humid Southeastern United States have had mixed outcomes with the irrigation of upland cotton varieties. This is due in part to the cotton plants indeterminate growth pattern (Eaton, 1955; Quisenberry and Roark, 1976). Differences in irrigation results are determined by such growth-altering parameters as available moisture, heat accumulation, and quality of growing environment. This can lead to the conclusion that either supplemental irrigation or water-deficit stress can have positive or negative effects on the crop, depending on the situation in which they are applied (Guinn and Mauney, 1984a). Supplemental irrigation is generally accepted as a beneficial contribution to a cotton production system. Typical responses include enhancing the plants ability to establish and carry more fruiting structures throughout the

growing season (Pettigrew, 2004) and the promotion of a healthier, more vigorous growing crop. These have a direct, positive influence on yield, as yield is highly correlated with the number of bolls and flowers produced (Gerik et al., 1996, Guinn and Mauney, 1984b) and overall plant health. However, additional irrigation can also prove to be non-beneficial to a production system. This is especially true in the Mid-South growing area where there is a short-duration growing season (Gwathmey et al., 2011). Additional irrigation has been documented to add an excessive amount of vegetative growth, leading to a lessened boll load and delays in crop maturity (Gwathmey et al., 2011, Spooner et al., 1958). Excessive vegetative growth can be a hindrance when harvest aids are applied at the end of the growing season. The excessive canopy condition can limit the effectiveness of the harvest aid chemicals. The delay of crop maturation delays the beginning of harvest as well and can often result in the harvesting of a crop that has not reached full yield potential.

Cotton Stress

Stress due to water deficit is commonly detrimental to a cotton production system (Pettigrew, 2004). Water, the most limiting factor in most cropping systems (Gerik et al., 1996; Howell, 2001), is needed throughout the cotton plants life to perform all of the growth functions from emergence to defoliation. Commonly water deficit stress symptomology can be readily identified. The lack of water will typically induce an inability to establish and retain blooms and fruiting structures (Whitaker et al., 2008), having a direct negative impact on yield (Guinn and Mauney, 1984a, Guinn and Mauney, 1984b, Pettigrew, 2004). Other deficit symptomology is the stunting of plants and reduced leaf area. Sometimes a shorter plant is desired for certain conditions, but typically a plant with fewer nodes is going to yield less. The lessened leaf area of a plant can time be the first signs of water deficiency. This lack of leaf area causes lessened

transpiration potential for a plant and it loses the ability to cool itself, commonly resulting in the shedding of leaves and fruiting structures (Spooner et al., 1958). Plants suffering from this type of stress are induced into premature reproductive growth stage that results in a crop with a diminished yield. However, at some stages of cotton growth water deficit stress can be beneficial. Typically supplemental irrigation will be turned off toward the end of the growing season (Guinn and Mauney, 1984a). This allows the plant to reach more of its reproductive capabilities and aids in the defoliation process by allowing the plant to dry down before applications of harvest aids are made.

Cotton Measurements

Various measurement techniques have been used and developed for assessment of cotton growth and are performed at various times throughout the growing season (Bourland et al., 2001). Main stem node counts are often associated with morphological and phenological events in the cotton plant (Bednarz & Nichols, 2005). This type of data collection is easily acquired throughout the growing season without excessive disturbance to the plant population and can provide pertinent information about such parameters as growth rate, plant maturity, and earliness. Main stem node data used in this study are: Height to Node Ratio (HNR), Height of First Fruiting Branch (HFFB), Nodes Above White Flower (NAWF), Average Length of Top 5 internodes (ALT-5), and Nodes Above Cracked Boll (NACB).

Height to Node Ratio (HNR) is probably the most widely accepted means for estimating cotton vigor and is often used as a monitoring tool for tracking past growth and growing tendencies within a crop (Guthrie et al., 1993; Silvertooth et al., 1996). HNR throughout the cropping season changes as the plant goes through its different life cycles. Early in the plants

life stage, where smaller leaf area and cooler temperatures are common, HNR are low because of the lack of optimum growing conditions (Guthrie et al., 1993). Once temperatures increase and optimum growing conditions are reached, HNR increases until after bloom. At this point more nutrients and water are being diverted into reproductive production than vegetative growth (Guthrie et al., 1993). HNR also directly reflect growing conditions of the plant such as water availability, nutrients, sunlight, etc (Guthrie et al., 1993).

Height of First Fruiting Branch (HFFB) is a common measurement of maturity of cotton plants (Godoy & Palomo, 1999). HFFB is typically associated with the node in which the first fruiting structure is present on the first fruiting branch. As previously mentioned, fruiting branches are distinguished as branches with a “zig-zag” growth pattern. First fruiting branches normally occur at the 5th or 6th main stem node, but environmental factors can cause this to differentiate. Also, the location of the first fruiting branch will also differ among varieties of different maturity for the same growing environment (Godoy & Palomo, 1999).

Nodes Above White Flower (NAWF) is a main stem node count that is taken during the flowering stage of the cotton plant’s life cycle. This is a measurement that shows the number of nodes from the apex of the plant to the upper most first position “white flower”. At the beginning of the blooming season NAWF can range from 9-10 nodes (Ritchie et al., 2004), but as the growing season progresses this number decreases as the uppermost white flower progresses up the main stem of the plant (Bourland et al., 2001). If initial NAWF is high this is an indicator of strong vegetative growth and vigor and opposite of that with a low initial NAWF count. Low NAWF counts can be the result of lack of water, nutrition, or other optimum growth factors. NAWF is essential in determining “cutout” of the crop. Cutout is defined as the point in

which no more harvestable bolls will be set to the plant and this is when NAWF = 5 (Bourland et al., 2001; Ritchie et al., 2004).

Average Length of Top 5 internodes (ALT-5) are a direct measurement of internode length in newly growing main stem region of the plant (Silvertooth et al., 1996). Similar to HNR, ALT-5 measurements differ throughout the production season in association with plant growth and growing parameters. Shortly after emergence ALT-5 measurements are small and grow larger as more adequate temperatures are acquired. These measurements also can represent growing conditions that the plant has incurred. Also, this measurement is used to judge the plants reaction to a plant growth regulator (PGR), commonly mepiquat chloride, which is used to maintain a manageable amount of vegetative and vertical growth by suppressing internode elongation (Silvertooth et al., 1996).

Nodes Above Cracked Boll (NACB) are main stem node counts that are measured late in the season as the boll accumulation has reached cutout and bolls are starting to open. This measurement tracks the movement of mature bolls up the main stem and aids in providing the producer a time frame in which to apply harvest aids. This movement up the main stem is the same movement as NAWF was until cutout was reached. It is assumed to be safe to apply harvest aids when NACB = 4. Additionally, this measurement is often used as to determine crop maturity between varieties in similar environments.

Canopy Light Interception is a measure of light interception by the canopy of a crop. Crops growing under stress due to water deficits and high temperatures have reduced growth functions, including development of plant canopy (Reddy et al., 1997). Canopy development plays an essential role in determining the amount of photosynthetically active radiation (PAR)

and photosynthetic photon flux density (PPFD) that can be intercepted by the plant. PAR and PPFD are directly related to cotton growth and development (Reddy et al., 1991). Reduced interception of PAR and PPFD leads to a less healthy, under developed plant that ultimately yields less.

Canopy Temperature if high, can be detrimental for both vegetative and reproductive growth in upland cotton varieties (Ashraf et al., 1994). This is particularly true for regions of the southern United States that experience both high temperatures and humidity. When water availability in a leaf becomes limited, transpiration slows and the plant loses its ability to cool its tissues (Keener and Kircher, 1983). Often times, leaf temperatures in these situations can reach ambient air temperatures and possibly higher (Keener and Kircher, 1983; Reddy et al., 1999).

Yield Stability is a measure of consistency or reliability of performance among differing varieties. Plant populations from differing genetic backgrounds often vary in results due to the environmental response; this is known as the genotype-environment interaction. Ideally, a variety would react in a positive manner in all situations regardless of limitations. Since there is not a single predominate variety adapted to all regions of cotton production, genotype-environment interaction is prevalent wherever cotton is produced. A potential way to eliminate the effects of genotype-environment interaction is by selecting varieties that are stable and limit interactions with the environment (Shah et. al., 2005).

Even though cotton has proven itself to be a hardy, drought tolerant plant, often in situations of water-deficit stress the plant responds in a way that is detrimental to a high yield potential. In these situations the plant responds negatively by reducing the amount of vegetative and reproductive growth, typically resulting in a reduced boll load and negatively impacting

yield. An understanding of WUE and the application of supplemental irrigation can make a higher yielding and more profitable crop. Plant measurements and calculation of WUE can help identify varieties that are more stable across environments.

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Part II

Cotton Growth, Yield, and Fiber Quality Response to Irrigation and Water Deficit in Soil of Varying Depth to a Sand Layer

Abstract

Research was conducted in 2010 and 2011 at the West Tennessee Research and Education Center in Jackson, TN to investigate water deficit and irrigation response in cotton to provide a better understanding of physiological growth changes and yield impact on the crop. Each experimental unit included six cotton rows spaced 97 centimeters apart by 9.1 meters in length. PHY 375 WRF cotton seed was planted in a no-tillage system with 10.5-12 seed m^{-1} of row at a planting depth of two cm. The objective of this study was to evaluate plant response to four different irrigation regimes by using main-stem node counts, quantification of canopy light interception, and canopy temperature, while making comparisons across two soils that vary in depth to a sandy layer. Irrigation amounts were applied from drip tape lying adjacent to plants in the row furrow at rates of 0, 1.27, 2.54, and 3.81 $cm\ week^{-1}$. Comparisons were made across two depths of soil. A deep soil is defined as a soil with no sand layer within the top 89 centimeters of soil and a shallow soil is defined as a soil having a sand layer within the top 61 centimeters of the soil profile. Physiological growth indicators plant height, number of nodes, nodes above white flower (NAWF), canopy light interception, and canopy temperature were monitored during the blooming period of the crop each year to determine differences in irrigation response across varying soil depth. The deep soil in this study yielded more vegetative mass when compared with the shallower soil. This is also true when applying higher rates of irrigation where plants grew two more nodes of growth and 15.2 centimeters of plant height. Time to cotton maturity was delayed seven days in the deep soil and with the application of irrigation. Canopy density, measured by light interception, was increased in plots grown on the shallow soil profile from 48% to 53% when irrigation was applied. Canopy temperature was reduced when grown in the deep soil profile and with the addition of irrigation. Yield and fiber quality increased with irrigation and when cotton was grown on a deep soil. These results indicate that differences in

physiological growth patterns, canopy density, canopy temperature, lint yield, and fiber quality are evident when comparing across irrigation amounts and soil depths.

Key words: *canopy temperature, Cotton (Gossypium hirsutum L.), fiber quality, indeterminate, light interception, maturity, PHY 375 WRF, plant response, plant structure, water, water use efficiency, yield.*

Introduction

Cotton (*Gossypium hirsutum* L.) producers in the humid Mid-South and Southeastern United States have observed mixed outcomes with the irrigation of upland cotton varieties. This is due in part to the cotton plants indeterminate growth pattern, where the plant continues to grow vegetatively during reproduction (Eaton, 1955; Quisenberry and Roark, 1976). The level of indeterminacy is related to such growth altering parameters as available moisture, heat accumulation, and quality of growing environment. Research has found that both supplemental irrigation and water-deficit stress can have either positive or negative effects on the crop, depending on the situation in which they occur (Guinn and Mauney, 1984a; Gwathmey et al., 2011).

Stress due to water deficit is usually detrimental to a cotton production system (Pettigrew, 2004a). Water can be the most limiting factor in some cropping systems and is needed throughout the cotton plants life to perform all growth functions from emergence to harvest (Gerik et al., 1996; Howell, 2001). Water deficit stress symptomology can be readily identified, as the lack of water and will typically reduce the plants ability to establish and retain blooms and fruiting structures having a direct negative impact on yield (Guinn and Mauney, 1984a; Guinn and Mauney, 1984b; Pettigrew, 2004a; Whitaker et al., 2008). Water stress can also develop a

plant that is stunted in growth with reduced leaf area, limiting the transpiration and photosynthesis rate of the crop. Lack of leaf area reduces the ability of cotton to transpire and cool itself, commonly resulting in the shedding of leaves and fruiting structures (Spooner et al., 1958). Plants suffering from water stress are induced into premature reproductive growth that results in a crop with diminished yield potential. However, it can prove beneficial to impose water deficit stress in cotton at some times during the growing season. Typically supplemental irrigation will be terminated toward the end of the growing season, allowing the plant to cease vegetative growth and will aid in the defoliation process by allowing the plant to dry down before harvest aids are applied (Guinn and Mauney, 1984a).

High temperatures can be detrimental for both vegetative and reproductive growth in upland cotton varieties (Ashraf et al., 1994). This is particularly true for regions of the southern United States that experience both high temperatures and humidity. When water availability in a leaf becomes limited, transpiration slows and the plant loses its ability to cool its tissues (Keener and Kircher, 1983). Often times, leaf temperatures in these situations can reach ambient air temperatures and possibly higher (Keener and Kircher, 1983; Reddy et al., 1999). Crops growing under stress due to water deficits and high temperatures have reduced growth functions, including development of plant canopy (Reddy et al., 1997). Canopy development plays an essential role in determining the amount of photosynthetically active radiation (PAR) and photosynthetic photon flux density (PPFD) that can be intercepted by the plant. PAR and PPFD are directly related to cotton growth and development (Reddy et al., 1991). Reduced interception of PAR and PPFD leads to a less healthy, under developed plant that ultimately yields less.

Both canopy temperature and leaf area can be readily determined in a cropping system. Infrared thermometers are an effective means for collecting canopy temperatures (Hatfield, 1990). Crop water stress indices have been created from gathering canopy temperature data and ambient air temperatures (Jackson et al., 1981; Wanjura et al., 1984). These indices have been suggested as an irrigation scheduling tool (Howell et al., 1984). PAR and PPFD interception measurements can be more difficult to acquire, but are pertinent to the growth and development of the cotton plant. Quantity of light interception is dependent on the abundance of leafy material that sunlight is directly intercepted by the crop (Sassenrath-Cole, 1995). The combination of plant growth measurements, canopy density and canopy temperature can be utilized to evaluate irrigation response in cotton.

Supplemental irrigation is generally accepted as a beneficial contribution to a cotton production system. Typical responses include enhancing the plants ability to establish and retain more fruiting structures throughout the growing season (Pettigrew, 2004b) and the promotion of a healthier, more vigorous growing crop. This increase in plant structure generally has a positive influence on yield, as yield is highly correlated with the number of bolls produced and overall plant health (Gerik et al., 1996; Guinn and Mauney, 1984b). However, supplemental irrigation has also proved to be detrimental in certain environments, this is especially true in production areas where there is a shorter growing season (Gwathmey et al., 2011). Additional irrigation has been documented to add an excessive amount of vegetative growth, leading to a reduced boll load, boll diseases, and delays in maturity (Gwathmey et al., 2011, Spooner et al., 1958).

Various measurement techniques have been developed and used for assessment of cotton growth and are utilized at various times throughout the growing season (Bourland et al., 2001). Main stem node counts are often associated with morphological and phenological events in the

cotton plant (Bednarz and Nichols, 2005). This type of data collection is easily acquired throughout the growing season without excessive disturbance to the plant population and can provide pertinent information about such parameters as growth rate, plant structure, and plant maturity.

The hypothesis of this study is that physiological growth and yield will not alter with different irrigation applications across varying soil types. The objective of this study was to evaluate plant response to four different irrigation regimes by using main-stem node counts, quantification of canopy light interception, and canopy temperature, while making comparisons across two soils that vary in depth to a sandy layer.

Materials and Methods

An experiment to determine the effects of physiological plant response to supplemental irrigation and water deficit was conducted at the West Tennessee Research and Education Center in Jackson, TN, during the 2010 and 2011 growing seasons. PHY 375 WRF was planted into existing crop residue using a no-tillage system.

This trial was implemented as a randomized incomplete block design with a three factor factorial arrangement of treatments. Plots were six rows by 9.1 m, with a row spacing of 97 cm. Treatment factors included surface drip tape applications of irrigation at rates of 0 cm, 1.27 cm, 2.54 cm, and 3.81 cm per week. Two irrigation initiation timings of at pin-head square and at first bloom were used across a soil varying in depth to a sandy layer, at less than 61 cm and greater than 89 cm, respectively. All other production practices followed University of Tennessee Extension Service recommendations for cotton production.

Evaluations of physiological growth response in cotton were conducted weekly for four weeks, starting when plots began to bloom. This was accomplished by recording weekly main-stem node counts, including number of nodes, plant height, height of first fruiting branch, and nodes above white flower (NAWF). Data was recorded from ten plants selected at random from each plot. Additional measurements recorded during each growing season included characterized canopy light interception and canopy temperature differences across treatments. Data was collected by using a calibrated LI-COR quantum point sensor placed above the crop canopy and line sensor placed under the canopy to determine differences in interception of light and then this data was recorded by a LI-COR 1400 data logger (LI-190 Quantum point sensor, LI-191 Quantum line sensor, LI-1400 Data logger; LI-COR Environmental; Lincoln, NE). Measurements were obtained as close to solar noon as possible, as this is when there is the least amount of variation in PAR and PPFD emitted by the sun. At the same time, canopy temperature differences were measured utilizing a RAYTEK infrared thermometer (ST™ ProPlus; Raytek Corporation; Santa Cruz, CA).

The center two rows of each six row plot were harvested using a spindle cotton picker adapted for small-plot harvesting. A sample of mechanically harvested seed cotton was collected from each plot and used to determine lint percentage and fiber quality. Seed cotton was ginned on a laboratory gin without lint cleaning, and fiber upper half mean length, fiber length uniformity index, fiber strength, and micronaire were determined by high volume instrumentation testing (Sasser, 1981).

Data were subjected to analysis of variance using the PROC MIXED procedure of SAS (ver. 9.2; SAS Institute; Cary, NC). Means were separated using Fishers Protected LSD procedure at the 0.05 significance level. Additionally, regression analysis was used to determine

the relationships between canopy light interception, canopy temperature, and water use efficiency of irrigation treatments and soil depths. The coefficient of determination (R^2) was calculated for each parameter analyzed by regression.

Results and Discussion

Year of the study was not significant based on ANOVA results, as both years accumulated adequate heat units and precipitation to produce a high yield potential cotton crop (NOAA, 2001) (Table 1). Therefore, data were pooled across the two years of the study, and each year was considered as an environment. Replications nested within year and interactions of these effects were considered random; whereas soil depth, irrigation treatment amounts, and interactions of these effects were considered fixed effects. Consideration of environments as a random effect allows interpretations about the treatments to be made in multiple environments (Carmer et al., 1989). A similar statistical method has been utilized by numerous researchers employing a randomized block design (Bond et al., 2005; Hager et al., 2003; Jenkins et al., 1990) as well as those using a factorial arrangement of treatments in a randomized complete block design (Bond et al., 2008; Ottis et al., 2004; Walker et al., 2008). Irrigation initiation time did not impact results, thus data were pooled across pin-head square and first bloom initiation timings, leaving supplemental irrigation level treatments and depth of soil to explain the physiological changes and plant responses.

Cotton Growth and Development

Plant response to irrigation treatments and depth of soil varied, but as in Pettigrew (2004b), the most obvious soil moisture deficit response is a reduction in plant structure. There was an average increase of 1.0 node of plant growth across all irrigation treatments compared to

dry land plots. Dry land plots grew 2.4 nodes during the blooming period, which is a 0.6 node increase per week. The highest increase in total number of nodes was with the 3.81 cm of weekly irrigation treatment where a 3 node increase was observed during the blooming period with a weekly gain of 0.75 nodes. Number of nodes was also significantly impacted by the depth of soil, where there was an average increase of 2.7 nodes of cotton growth throughout the blooming interval (Table 2.). Node development in the deep soil increased by 3.1 nodes during the blooming period. Deeper soil profiles have greater water holding capacities that allow the crop to utilize the moisture applied over a longer period of time. There was a 2.3 node increase in cotton growth in the shallower soil during the bloom period, and typically the shallower soil yielded stunted and less vigorous plants. Plant height increased by an average of 10.7 cm of growth during the blooming interval. The greatest increase in plant height was observed in plots receiving the highest rate of irrigation per week with an increase of 13.2 cm, resulting in an average gain of 3.3 cm per week. The least amount of growth was in the dry land plots where an increase of 4.8 cm of plant height was observed, yielding an average increase of 1.2 cm of growth per week. Soil depth also had a significant impact on the plant height. The deeper soil yielded a healthier, more vigorous growing crop that grew 13.9 cm during blooming period. Plants in shallow soil grew 7.4 cm (Table 2.), resulting from reduced water holding capacity of the shallow soil. Plants in irrigated plots maintained vegetative growth longer than the plants of the dry land plots, as in Pettigrew (2004a).

Maturity

Maturity was recorded throughout the blooming period by monitoring NAWF. Across all irrigated and dry land treatments there was an average change of 4.6 NAWF. NAWF ranged from 0.6 in the dry land plots to 1.2 in the plots receiving 3.81 cm of irrigation per week, in the

fourth week of measurements (Table 2.). Cotton subjected to the dry land treatment had fewer NAWF at each evaluation time, indicating similar results to Whitaker et al. (2008). Application of irrigation allowed plants to continue growing vegetatively and delayed maturity, whereas the dry land treatment allowed plants to mature earlier due to earlier initiation of reproductive growth. Unlike in Gwathmey et al. (2011), and Spooner et al. (1958), where maturity was delayed 10 and 14 days, respectively, this study documented a delay in maturity of seven days. This indicates that variation in soil type may be an important component when determining maturity differences due to irrigation.

Canopy Interception and Temperature

Canopy density and canopy temperature were variable across irrigation treatments. Canopy light interception varied based on irrigation amount, soil depth, and the interaction of irrigation amount and soil depth. Canopy temperature differed across irrigation amounts and depth to sand, but no interaction of irrigation and depth to sand was observed. Results of light interception measurements were similar to results found in Pettigrew (2004b), where dry land plots intercepted significantly less PAR. Light interception by the crop in the deep soil ranged from 85% to 93%, at 0 cm and 3.81cm of water applied weekly, respectively. Light interception by the crop in the shallower soil ranged from 48% at the 0 cm irrigation treatment to 78% at the highest irrigation treatment. The plants in the deep soil averaged canopy light interception of 90%, yielding a plant that is capable of elevated transpiration rates and an increased ability to withstand water deficit stress. In the shallow soil, only 71% of light was intercepted by the canopy. These plants lacked the ability to transpire and cool plant tissue, making them susceptible to water deficit stress and diminished yield. Water stress in these trials decreased the amount of light intercepted in the canopy as in Gerik et al. (1996). The addition of irrigation

significantly increased light interception within the canopy from 67% in the dry land treatment, to 83%, 88%, and 85% with the application of 1.27 cm, 2.54 cm, and 3.81 cm of irrigation applied weekly (Figure 1.). Canopy temperature varied across soil type with the shallow soil averaging a temperature of 31.7°C, whereas the plants growing in the deep soil had an average temperature of 30.0°C. As in Pettigrew (2004b), dry land treatments had significantly higher canopy temperatures during the blooming period. The application of supplemental irrigation reduced canopy temperature significantly from the dry land treatments. Dry land treatments averaged a canopy temperature of 32.6°C. The temperature of plants in the irrigated plots was 30.6°C, 30.3°C, and 30.0°C with 1.27 cm, 2.54 cm, and 3.81 cm of irrigation applied, respectively (Figure 2.). The plants grown in the deeper soil that were irrigated were better adapted to respond to heat and water deficit stress, as they were able to transpire more readily and maintain a plant structure capable of maximizing yield potential.

Lint Yield and Fiber Quality

Variation in lint yield and fiber quality was determined by irrigation amount and soil depth, the interaction of irrigation amount and soil depth did not impact results. Supplemental irrigation increased yield, as in Quisenberry et al. (1976), and fiber quality with the exception of lint percent, where there was a 1% decrease. As in Gwathmey et al. (2011), yield response across irrigation treatments was more quadratic in response than linear, suggesting a loss in water use efficiency at higher rates of supplemental irrigation. Lint yield ranged from 1280 kg ha⁻¹ in the dry land plots to 1500 kg ha⁻¹ at the irrigation rate of 3.81 cm per week (Figure 3.). However, the highest increase in yield was with the 2.54 cm irrigation rate where yield averaged 1560 kg ha⁻¹, suggesting that the plants receiving 3.81 cm per week were more vegetative and were negatively impacted. Lint percent decreased significantly from the dry land plots with the

addition of irrigation. The dry land treatment averaged 40.4% lint, whereas the irrigated plots ranged from 39.8% to 39.1%. Suggesting that the dry land treatment had bolls and seeds more mature than those in the higher irrigation regimes. Micronaire, fiber length, fiber strength, and fiber length uniformity all benefited from the addition of irrigation. Dry land treatments averaged 4.6 micronaire, 1.10 in staple length, 30.0 g tex⁻¹ strength, and 82.2% uniformity, while the application of 3.81 cm per week averaged 4.4 micronaire, 1.15 in staple length, 31.4 g tex⁻¹, and 83.2% uniformity (Table 3.). This increase in fiber quality and yield with the addition of irrigation adds value to the crop. Soil depth also showed differences across treatments. The deeper soil plots averaged 1650 kg ha⁻¹ of lint, while the shallow soil plots averaged 1310 kg ha⁻¹ of lint. Fiber quality increased in the deeper soil versus the shallow soil. An increase of staple length, fiber strength and uniformity from 1.11 in, 30.1 g tex⁻¹, and 82.3% in the shallow soil to 1.15 in, 31.3 g tex⁻¹, and 83.2% in the deeper soil was observed also adding value to the crop.

Water Use Efficiency

Water use efficiency was calculated from total lint yield (kg ha⁻¹) and a summation of irrigation applied during the blooming and fruiting cycle (cm) and accumulated precipitation during the growing season (cm), where:

$$[\text{WUE} = \frac{\text{Lint Yield (kg ha}^{-1}\text{)}}{\text{Total Water Applied+Precipitation (cm)}}].$$

Differences were detected for depth to sand and irrigation treatment effects, suggesting that applied irrigation and depth to a sandy layer was affecting water use efficiency. Water use efficiency varied among years, as different amounts of precipitation and irrigation were accumulated during the growing season. Results show that in both years in the deep soil profile water use efficiency declined readily from the dryland WUE value, suggesting that the economic

return for supplemental irrigation in plots grown in a deeper is negatively impacted. Values in the deeper soil during 2010 and 2011 ranged from 27.5 kg ha⁻¹ to 18.2 kg ha⁻¹ and 47.17 kg ha⁻¹ to 34.5 kg ha⁻¹, respectively (Figure 4.1 and 4.2). However, in the shallower soil, during both years of the study, WUE values increased. This suggests that there is a positive economic return for utilization of supplemental irrigation on a shallow soil. Water use efficiency values in the shallower soil ranged from 16.7 kg ha⁻¹ to 16.8 kg ha⁻¹ and 24.7 kg ha⁻¹ to 26.7 kg ha⁻¹ during the 2010 and 2011 growing season, respectively (Figure 4.1 and Figure 4.2). The data for the shallow soil is represented by a parabolic function for both years, with the optimum water use efficiency value being reached with the supplemental application of 1.27 cm of irrigation per week. This rate is also were the least amount of decrease in water use efficiency values in the deeper soil were observed, suggesting that in a field with a highly variable soil, a rate of 1.27 cm of water per week is the most efficient rate (Figure 4.1 and Figure 4.2).

After evaluating the results of this study, the null hypothesis that physiological growth and yield would not alter with different irrigation applications across varying soil is rejected and the alternate hypothesis that physiological growth and yield will alter with different irrigation applications across varying soil is accepted. Results from these trials indicate that irrigation amount and depth to a sand layer in soil can impact cotton production. Plant structure was increased by being grown in the deeper soil profile and with the addition of irrigation. The plots receiving the highest irrigation rate of 3.81 cm week⁻¹ increased 3.1 nodes and 13.2 cm of height during the blooming period, allowing the crop to reach a high yield potential (Table 2). However, plots grown in the dryland situations gained very little plant structure, restricting its potential for an adequate yield. Soils with a shallow depth to sand benefit greater from supplemental irrigation, not only in plant growth and development, but yield, fiber quality, and WUE was well.

Increased lint yield and improved fiber quality from efficient water use added economic value to cotton grown on variable soils.

Abbreviations Used

HFFB, height of first fruiting branch; HNR, height to node ratio; NAWF, nodes above white flower; PAR, photosynthetically active radiation; PHY, Phytogen™; PPF, photosynthetic photon flux density; WRF, Widestrike™ Roundup Ready Flex™.

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Part III

Investigation of Variety Growth, Fiber Quality, Yield, and Yield Stability of Upland Cotton in Differing Environments

Abstract

Decisions on cotton variety selection are typically based on producers past experience with the varieties and production sites. New germplasm is available every year for purchase and it is important for producers to note genotypic and phenotypic differences in varieties in their region in order to obtain high yields and good fiber quality. Research was conducted to evaluate cotton growth, fiber quality, and yield stability during 2010 and 2011 at fifteen on-farm production locations. Each experimental site included four to twelve cotton rows spaced 97 cm apart with varying plot lengths. Varieties evaluated include: DP 0912 B2RF, DP 0920 B2RF, DP 1034 B2RF, FM 1740B2F, PHY 375 WRF, and ST 4288B2F. No-tillage or reduced tillage production systems were utilized with 10.5-12 seed m^{-1} of row at a planting depth of 2 cm. The variety with the most overall response in growth and plant structure was PHY 375 WRF, with the addition of 3.7 nodes and 21.6 cm of plant height over the plants blooming period. DP 0912 B2RF had the least amount of node and plant growth during this blooming period, with 2.8 nodes of growth and 17.3 cm of accumulated plant height during the evaluation period. This indicates that PHY 375 WRF is less determinate than DP 0912 B2RF, in these experiments. In locations receiving more than 7.6 cm of precipitation during the blooming period, PHY 375 WRF had the highest yield at 1280 $kg\ ha^{-1}$. Whereas DP 0920 B2RF yielded 1140 $kg\ ha^{-1}$, the highest yielding variety in areas that received less than 7.6 cm of precipitation during bloom. The variety with the highest increase in yield was ST 4288B2F, with a 220 $kg\ ha^{-1}$ increase, when grown in areas receiving more than 7.6 cm of precipitation during the blooming period. Micronaire was decreased for all varieties when greater than 7.6 cm of precipitation was received during the bloom period. Slopes of the linear regression for yield stability analysis ranged from 1.17 for DP 1028 B2RF to 0.87 of FM 1740 B2RF, indicating that DP 1028 B2RF has potential to have

higher yields in higher yielding environments than does FM 1740B2F. Y-intercepts ranged from 124.91 of DG 2570 B2RF to -207.08 of DP 1028 B2RF, indicating that FM 1740 B2RF has higher yield potential in lower yielding environments. Regression analysis found R^2 values ranged from 0.89 for PHY 375 WRF and DP 0912 B2RF to 0.74 for PHY 367 WRF. This indicates that 89% of the variation in PHY 375 WRF and DP 0912 B2RF yield can be accounted for by differences in environment, but only 74% of the yield variation of DP 0920 B2RF is due to differing environmental factors. Yield stability parameters can aid in decision making for variety selection and will add economic value to cotton grown in areas of variable rainfall.

Key words; *Cotton (Gossypium hirsutum L.), DP 0912 B2RF, DP 0920 B2RF, DP 1034 B2RF, FM 1740B2F, fiber quality, indeterminate, maturity, PHY 375 WRF, plant response, plant structure, ST 4288B2F, yield, yield stability.*

Introduction

Cotton (*Gossypium hirsutum* L.) is cultivated in a wide range of climates and environments around the world and in the United States. These environments have a large impact on the growth, development, and quality of the crop. Environmental factors, some influenced by managing inputs and some not, will determine the crops success (Stewart et al., 2010). Therefore, producers and crop managers have to manage the crop to maximize yield potential regardless of what uncontrollable circumstances may be present in the environment (Stewart et al., 2010). Studies have shown that cotton crops have no limit when it comes to plant development due to its indeterminate, perennial nature (Hearn and Constable, 1984). Limitations in cotton producing environments often relate to the extensiveness of the vegetative and reproductive growth of the crop, ultimately affecting yield. Another factor influencing crop

production, other than environments, is the genetic population. Plant populations from differing genetic backgrounds often vary in results due to the environmental response; this is known as the genotype-environment interaction. Ideally, a variety would react in a positive manner in all situations regardless of limitations. Since there is not a single predominate variety adapted to all regions of cotton production, genotype- environment interaction is prevalent where ever cotton is produced. A potential way to eliminate the effects of genotype-environment interaction is by selecting varieties that are stable and limit interactions with the environment (Shah et. al., 2005). This has not only been proven beneficial to plant breeders, but can also be applied into production systems where producers are utilizing different environments in crop production. Many methods have been suggested for the evaluation of variety and yield stability. Eberhart and Russell (1966) found that measuring genotypic stability could be accomplished by comparing a single variety yield with the average yield of all varieties over multiple environments. Each variety included in the experiments can be subjected to regression and parameters would provide estimates of stability by the following model:

$$[Y_{ij} = \mu_i + \beta_i I_j + \delta_{ij}].$$

Where Y_{ij} is the variety mean of the i^{th} variety at the j^{th} environment, μ_i is the mean of the i^{th} variety over all environments, β_i is the regression coefficient that measures the response of the i^{th} variety to varying environments, δ_{ij} is the deviation from regression of the i^{th} variety at the j^{th} environment, and I_j is the environmental index obtained as the mean of all varieties at the j^{th} environment minus the grand mean (Eberhart and Russell, 1966).

Environmental stress due to water deficit often negatively impacts cotton production systems (Pettigrew, 2004a). Water is often the most limiting factor in cotton production as it is

essential to promote all growth functions from emergence to harvest (Gerik et al., 1996; Howell, 2001). Water deficit stress will typically reduce the plants ability to establish and retain blooms and fruiting structures causing a direct negative impact on yield (Guinn and Mauney, 1984a; Guinn and Mauney, 1984b; Pettigrew, 2004a; Whitaker et al., 2008). Water stress will also yield a plant that is stunted in growth with reduced leaf area, limiting the transpiration rate of the crop, commonly resulting in the shedding of leaves and fruiting structures (Spooner et al., 1958). Plants grown in water stressed environments have limited vegetative growth and are induced into premature reproductive growth that results in a crop with diminished yield potential.

The null hypothesis of this study is that physiological growth, yield, and yield stability will not alter among included varieties when being produced in differing environments. The objective of this study was to investigate cotton variety responses to environmental conditions by using main-stem node counts, lint yield, lint quality, and yield stability of varieties, while making comparisons among environments.

Materials and Methods

An experiment to investigate cotton plant growth, fiber quality, yield, and yield stability in various environments was conducted in West Tennessee through the University of Tennessee's Extension Service's County Standard Trials (CST), in conjunction with area producers in the 2010 and 2011 growing seasons. Of the sixteen varieties in the CST, six were chosen to evaluate in this research. The following varieties were evaluated: DP 0912 B2RF, DP 0920 B2RF, DP 1034 B2RF, FM 1740B2F, PHY 375 WRF, and ST 4288B2F. Although, all fifteen locations were examined for yield stability, only five county locations were utilized to

examine physiological growth patterns each growing season (Table 4). All production scenarios were either a no-tillage system or conservation tillage system.

This experiment was implemented as a completely randomized design with varieties planted in random strips at each location. Plots ranged in size from four to twelve rows spaced 97 cm apart with various row lengths depending on field size (Table 4). Environmental differences were of importance, as environmental conditions varied with locations. The varying amount of rainfall acquired in these locations proved to be of most importance, as water availability proves to be one of the most limiting factors in cotton production systems (Gerik et al., 1996; Howell, 2001). Amounts of precipitation acquired at locations were categorized as environments receiving more and less than 7.6 cm of rainfall throughout bloom duration. The 7.6 cm level of precipitation was chosen as it allowed for an equal number of observations of environments receiving greater than and less than 7.6 cm of rainfall. All production practices were managed by producers working in conjunction with and following recommendations set forth by the University of Tennessee Extension Service.

Evaluations of physiological growth response in cotton were conducted weekly for five weeks, starting when plots began to bloom. This was accomplished by recording weekly main-stem node counts, including number of nodes, plant height, height of first fruiting branch (HFFB), and nodes above white flower (NAWF). Data was recorded from ten plants selected at random from each plot and replicated three times. Additional measurements of interest include lint yield and fiber quality of varieties. Yield stability is a means to the of consistency or reliability of performance among differing varieties. A regression model, developed by Eberhart and Russell (1966), was used to measure relative yield stability of cotton varieties. In this model, yields of an individual variety are plotted along the y-axis and the mean yields of all

varieties are plotted along the x-axis. The mean lint yield of each CST represents the environment in which it was produced. For each variety, a straight line is fitted to the data points by least squares regression and a linear equation is generated. Varietal yield response across environments is indicated by the slope, y-intercept, and the coefficient of determination (R^2), which is the proportion of variation in a variety's yield that can be attributed to differences in production environment. Yield stability of a variety increases as its R^2 values increase. Yield data of six upland cotton varieties were analyzed from CST trials conducted in 2010 and 2011.

All rows of planted varieties were harvested using a spindle cotton picker that was calibrated and maintained by the producer. Harvested seed cotton weight was obtained using a boll buggy modified with a calibrated scale system. Sub-samples of seedcotton were collected from each plot and weighed prior to ginning. Ginturnout was determined for each sample using a 20-saw gin equipped with a stick machine, incline cleaners and two lint cleaners at the West Tennessee Research and Education Center. Lint yields were calculated using seedcotton weights, gin turnouts, and harvested plot areas. A sub-sample of lint of each entry was analyzed by high volume instrumentation classing procedures at the United States Department of Agriculture Cotton Classing Office in Memphis, TN (Sasser, 1981).

Data were subjected to analysis of variance using the PROC MIXED procedure of SAS (ver. 9.2; SAS Institute; Cary, NC). Means were separated using Fishers Protected LSD procedure at the 0.05 significance level. Additionally, regression analysis was used to determine yield stability. The coefficient of determination, slope, and y-intercept was calculated by linear regression.

Results and Discussion

Year of the study was not significant based on ANOVA results, as both years accumulated adequate heat units and precipitation to produce a high yield potential cotton crop. Therefore, data were pooled across the two years of the study, and each location was considered as an environment. Locations nested within year and interactions of these effects were considered random; whereas variety, amount of precipitation at each location, and interactions of these effects were considered fixed effects.

Cotton Growth and Development

Limited responses to the amount of precipitation received during bloom were observed for plant growth parameters. Differences in plant structure among varieties were noted during the bloom period. HFFB data was similar for all varieties, therefore data is not presented. Node accumulation was not affected by precipitation amount during the bloom period in this study. There was an observed effect on plant height due to differing varieties and environments. The variety that responded by adding the most plant structure during the blooming period was ST 4288B2F, with 22.4 cm of plant growth (Table 6). However, FM 1740B2F only added 17.2 cm of growth during bloom which was the least response of the six varieties evaluated. The variety with the most overall response in growth and plant structure was PHY 375 WRF, with the addition of 3.7 nodes and 21.6 cm of plant height over the documented five weeks. The variety with the least amount of node and plant growth during the blooming period was DP 0912 B2RF, with 2.8 nodes of growth and 17.3 cm of accumulated plant height during the evaluation period. This indicates that PHY 375 WRF is less determinate than DP 0912 B2RF, in these experiments.

A variety that can accumulate more plant structure during the bloom period can potentially achieve higher yields.

Maturity

Cotton maturity was recorded throughout the blooming period by monitoring NAWF (Bourland et al., 2001). Maturity was similar for all varieties included in this study and no effect was present due to differing varieties. There was a NAWF increase of 0.5 nodes at the end of evaluation in areas receiving greater than 7.6 cm of precipitation, indicating that where more precipitation was present during the blooming period maturity was slightly delayed regardless of variety, since there were no differences among evaluated varieties (Table 7). The decline in NAWF represents new fruiting site development and blooming rate. In instances of dryland cotton production in a short season growing environment blooming rate often surpasses the plants ability to develop new fruiting sites. Additionally, fruit shedding due to drought stress, carbohydrate demand, and other nutrient diversion causes short season, dryland cotton to have a rapid reduction of NAWF values.

Lint Yield

Variation in lint yield and fiber quality was determined by variety and amount of precipitation received during the monitored blooming period. All six varieties that were evaluated during the growing season in areas receiving more than 7.6 cm of precipitation during the blooming period displayed an increase in yield compared to the same varieties grown in environments receiving less than 7.6 cm of rainfall, except DP 1034 B2RF. In locations receiving more than 7.6 cm of precipitation during the blooming period, PHY 375 WRF, had the highest yield at 1280 kg ha⁻¹ (Table 8). Whereas DP 0920 B2RF yielded 1140 kg ha⁻¹, the

highest in areas that received less than 7.6 cm of precipitation during bloom. The variety with the highest increase in yield was ST 4288B2F, with a 220 kg ha⁻¹ increase, when grown in areas receiving more than 7.6 cm of precipitation during the blooming period. DP 1034 B2RF showed the least amount of lint yield gain when produced in locations with greater than 7.6 cm of precipitation by yielding 69 kg ha⁻¹ more than the average of the other environments included in the study.

Fiber Quality

Micronaire was decreased for all varieties when greater than 7.6 cm of precipitation was received during the bloom period. Both DP 0912 B2RF and FM 1740B2F micronaire values were reduced in locations with greater than 7.6 cm of precipitation avoiding discounts for high micronaire (Table 8). This indicates that value of the cotton crop can be increased with added moisture by decreasing micronaire (Allen and Lorenzo, 2011). A reduction in fiber strength was observed in all varieties in this study, with the exceptions of PHY 375 WRF and FM 1740B2F, that were grown in locations receiving the higher precipitation value during bloom. As differences in fiber strength are determined by genetic background and not growing environment (Meredith and Bridge, 1973).

Yield Stability

Mean cotton yields of the twelve varieties investigated in the fifteen CST tests conducted in 2010 and 2011 ranged from 980 to 1110 kilograms of lint ha⁻¹, and were averaged across environments and years (Table 9). Thus, all varieties demonstrated high yield potential in these tests. Slopes of the linear regression ranged from 1.17 for DP 1028 B2RF to 0.87 of FM 1740 B2RF, indicating that DP 1028 B2RF has potential to have higher yields in higher yielding

environments than does FM 1740 B2RF. Y-intercept values ranged from 124.91 of DG 2570 B2RF to -207.08 of DP 1028 B2RF, indicating that DG 2570 B2RF has higher yield potential in lower yielding environments (Figure 5.1 and 5.2). Regression analysis found that R^2 values ranged from 0.89 for PHY 375 WRF and DP 0912 B2RF to 0.74 for PHY 367 WRF. This indicates that 89% of the variation in PHY 375 WRF and DP 0912 B2RF yield can be accounted for by differences in environment, but only 74% of the yield variation of PHY 367 WRF is due to differing environmental factors. More than 26% of the variation in yield in PHY 367 WRF is unaccounted for in this model, while only 11% of PHY 375 WRF yield variation was unexplained. These results suggest that the yield of PHY 367 WRF were less stable than those of PHY 375 WRF in the environments included in this study, since less yield variability can be accounted for by growing environment. A comparison of yield and stability rankings show there is little or no correlation between yield and yield stability. When selecting varieties for a production system, it may prove beneficial to look at yield stability as well as other desirable traits, like high yield potential. According to this study, ST 5458B2RF has better yields in both low and high yielding environments than other varieties evaluated. However, PHY 375 WRF and DP 0912 B2RF prove to be the most stable varieties included in this study, regardless of growing conditions, because of high R^2 values and positive slope of the regression line.

After evaluating the results of this study the null hypothesis that physiological growth, yield, and yield stability will not alter among included varieties when being produced in differing environments is accepted in the case of number of nodes, node above white flower, and fiber uniformity. However, the rest of the parameters included in this study will reject the afore stated null hypothesis and accept the alternate hypothesis that states physiological growth, yield, and yield stability will alter among included varieties when being produced in differing

environments. Results from these trials indicate that cotton variety and amount of precipitation accumulated during the blooming period can impact cotton production. Physiological results suggest that once the blooming period is initiated, most vegetative growth is in support of developing bolls. The majority of vegetative growth occurs prior to bloom, thus water during bloom will impact boll development more than vegetative growth. Blooming rate is noticeably more rapid than fruit development as these trials were conducted in dryland scenarios. The combination of dryland production, other stress situations, and the short growing season all caused a rapid decline in NAWF. Varieties grown in environments where greater than 7.6 cm of precipitation received some benefit in plant growth and development, but yield and fiber quality were greatly improved. Five of six varieties evaluated received a boost in yield by being produced in areas where more than 7.6 cm of rainfall was received during the blooming period. Micronaire was reduced for all varieties receiving the higher amount of precipitation, preventing two varieties from being discounted for high micronaire. Variability of yield stability parameters were due to the differences in genotype-environmental interactions, but utilizing stable varieties for a production area. Yield stability parameters can aid in decision making for variety selection and will add economic value to cotton grown in areas of variable rainfall.

Abbreviations Used

B2F, Bollguard 2 Roundup Ready Flex™; B2RF, Bollguard 2 Roundup Ready Flex™; DP, Delta and Pine Land™; FM, Fiber Max™; HFFB, height of first fruiting branch; HNR, height to node ratio; NAWF, nodes above white flower; PHY, Phytogen™; ST, Stoneville™; WRF, Widestrike™ Roundup Ready Flex™.

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Conclusions

The overall objective of this research was to determine the effects that irrigation and environment have on the cotton plants structure, yield, fiber quality, and stability of varieties. These are all important plant and crop parameters to consider in either irrigated or dryland cotton production scenarios. The first part of this study emphasizes on the effects of irrigation in a variable soil on upland cotton. The main concerns with this study were if a beneficial reaction of plant structure, canopy interception, canopy temperature, yield, fiber quality, and water use efficiency from the cotton plant would be observed with the addition of irrigation in a soil varying in depth to a sandy layer. The last part of this research emphasizes on the effect of environment and varietal differences of cotton grown in real world, dryland production scenarios. Concerns of this test were similar to the first, as in was plant structure, yield, and fiber quality going to be effected in a positive manner by being grown in production scenarios where more precipitation was accumulated during the blooming period, but yield stability was also evaluated to observe which varieties were more stable across the locations in this study.

Part I

Results from these trials indicate that irrigation amount and depth to a sand layer in soil can impact cotton production. Soils with a shallow depth to sand benefit greater from supplemental irrigation not only in plant growth in development, but yield, fiber quality, and water use efficiency was well. Increased lint yield and improved fiber quality from efficient water use added economic value to cotton grown on variable soils.

Part II

Results from these trials indicate that cotton variety and amount of precipitation accumulated during the blooming period can impact cotton production. Physiological results suggest that once the blooming period is initiated, most vegetative growth is in support of developing bolls. The majority of vegetative growth occurs prior to bloom, thus water during bloom will impact boll development more than vegetative growth. Blooming rate is noticeably more rapid than fruit development as these trials were conducted in dryland scenarios. The combination of dryland production, other stress situations, and the short growing season all caused a rapid decline in NAWF. Varieties grown in environments where greater than 7.6 cm of precipitation received some benefit in plant growth and development, but yield and fiber quality were greatly improved. Five of six varieties evaluated received a boost in yield by being produced in areas where more than 7.6 cm of rainfall was received during the blooming period. Micronaire was reduced for all varieties receiving the higher amount of precipitation, preventing two varieties from being discounted for high micronaire. Yield stability parameters can aid in decision making for variety selection and will add economic value to cotton grown in areas of variable rainfall.

Appendices

Appendix A

Figures

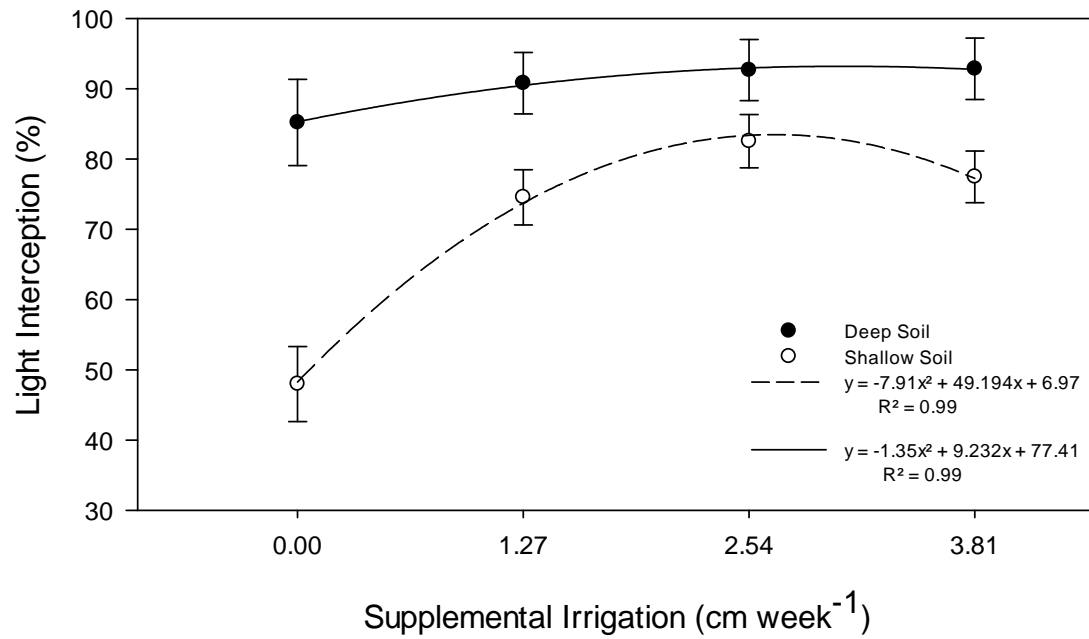


Figure 1. Canopy light interception of a cotton crop grown in a soil varying in depth to a sandy layer and receiving varying amount of irrigation.

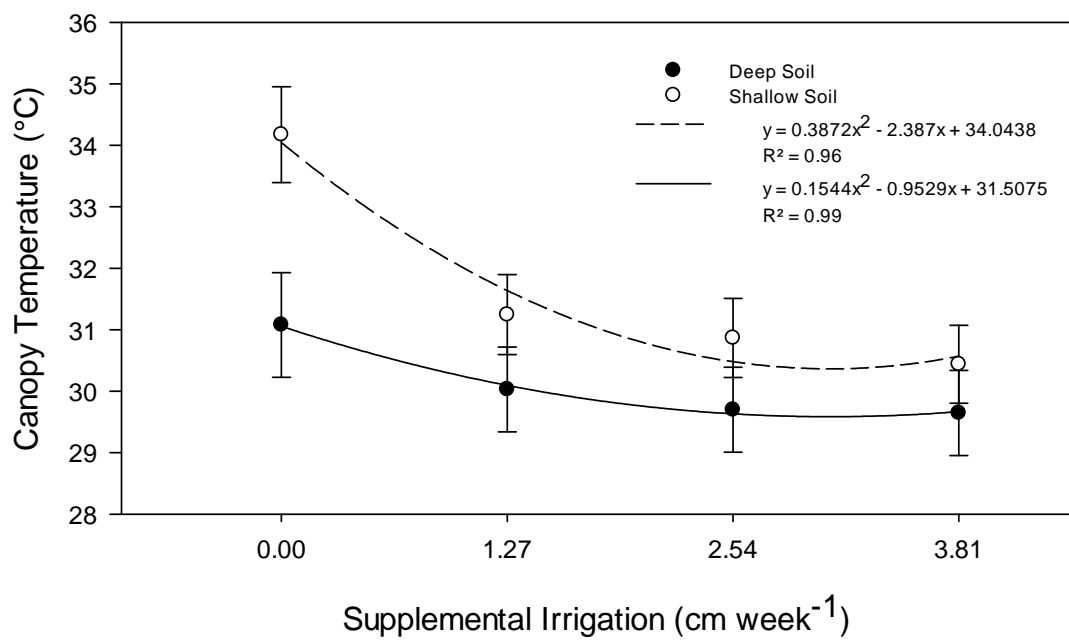


Figure 2. Average canopy temperature of a cotton crop grown in a soil varying in depth to a sandy layer and receiving varying amounts of irrigation.

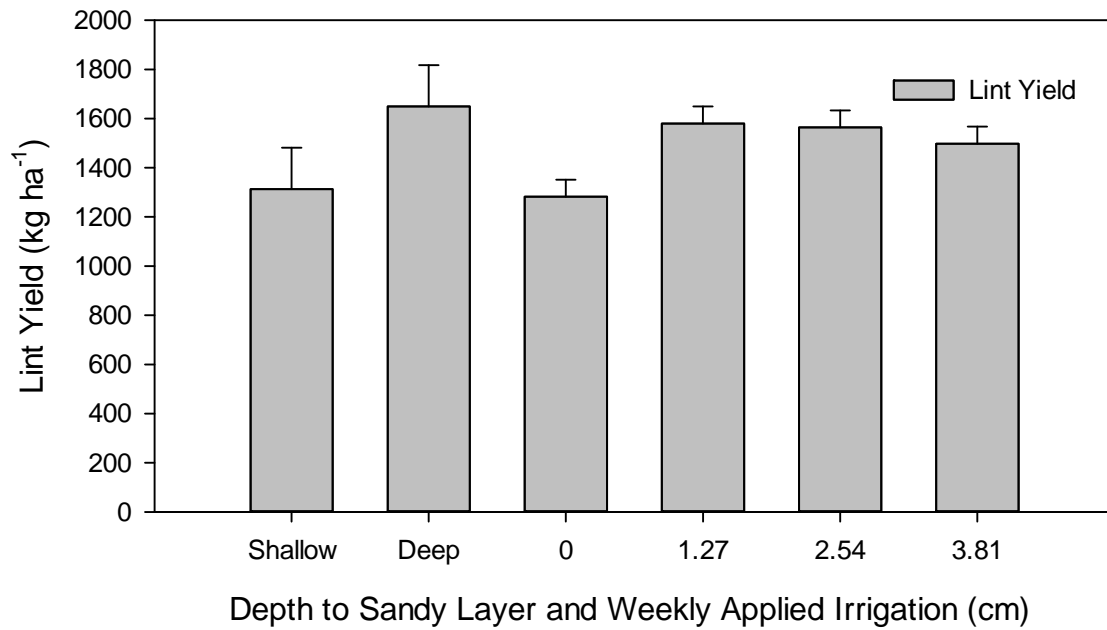


Figure 3. Lint yield of cotton grown a soil varying in depth to a sandy layer and receiving varying amounts of irrigation

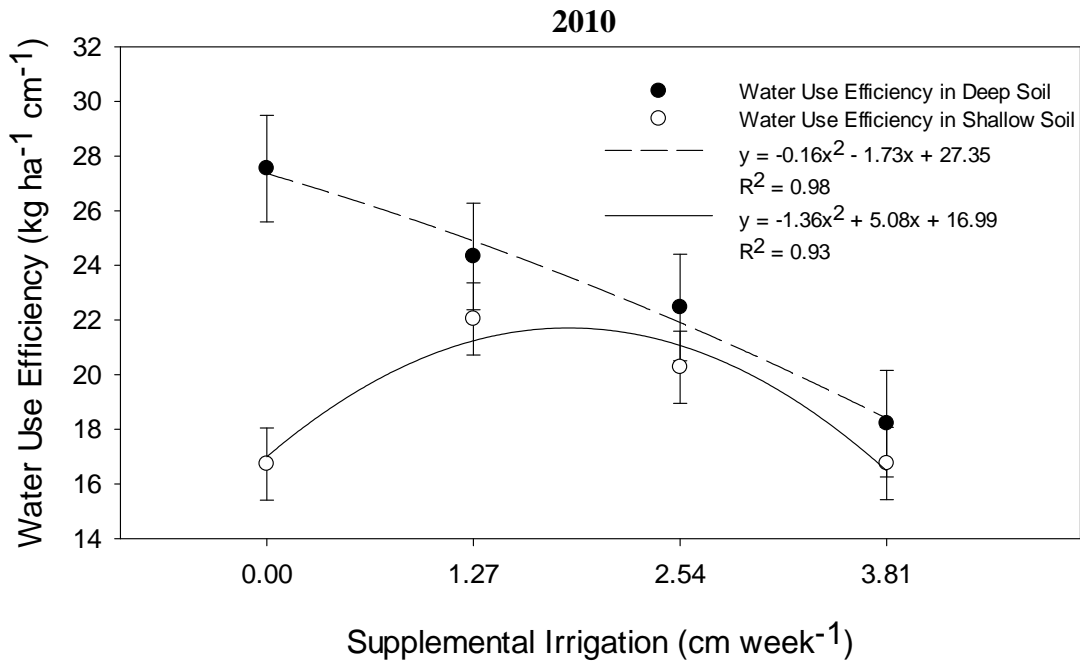


Figure 4.1 Water use efficiency in cotton grown in a soil varying in depth to a sandy layer in 2010.

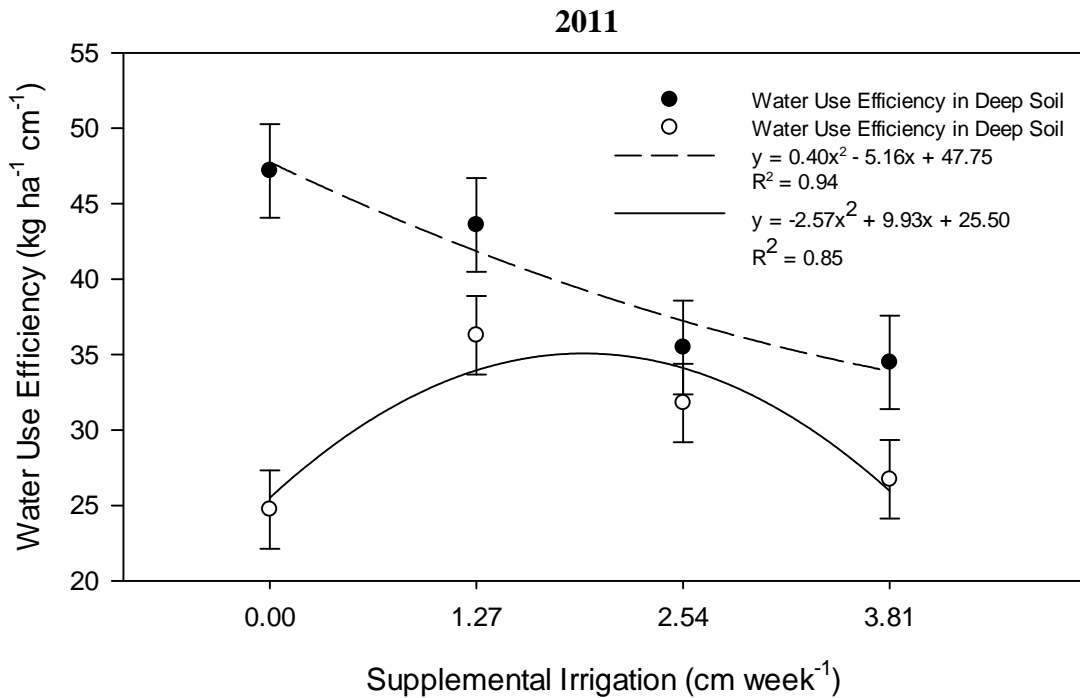


Figure 4.2 Water use efficiency in cotton grown in a soil varying in depth to a sandy layer in 2011.

^z Water use efficiency calculation includes precipitation and supplemental irrigation.

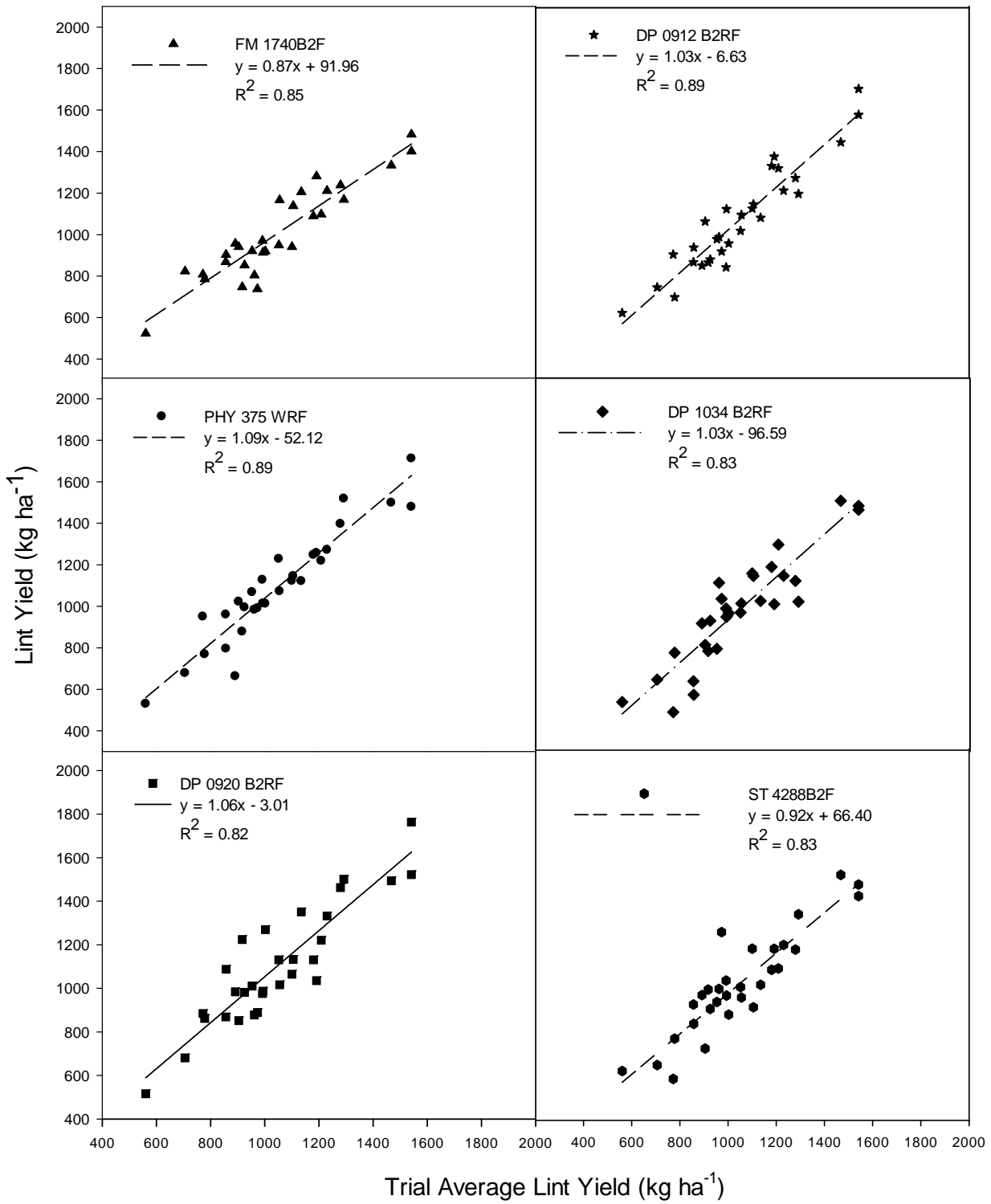


Figure 5.1 Yield stability analysis of six cotton varieties grown at fifteen locations during 2010 and 2011.

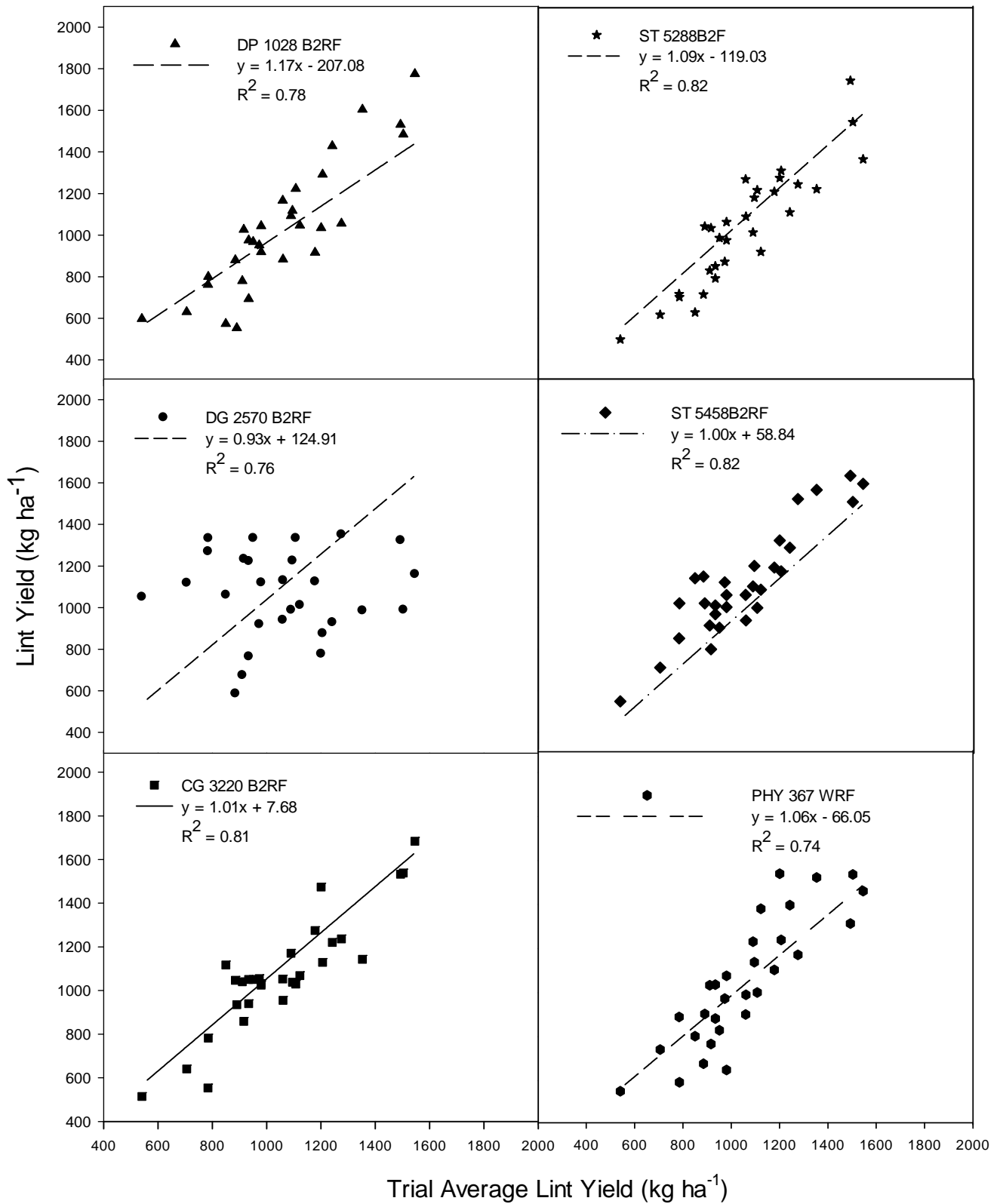


Figure 5.2 Yield stability analysis of six cotton varieties grown at fifteen locations during 2010 and 2011.

Appendix B

Tables

Table 1. Irrigation rates, irrigation totals, total rainfall, and total water for Jackson, TN during 2010 and 2011 growing seasons, along with historical average rainfall.

Irrigation Initiation	2010			2011			Historical Average Rainfall ^Y	
	Irrigation Rate (cm)	Total Irrigation (cm)	Total Rainfall (cm) ^Z	Total Water (cm)	Total Irrigation (cm)	Total Rainfall (cm)		Total Water (cm)
Pinhead Square	1.27	7.04	57.58	64.62	6.93	35.74	42.67	49.78
Pinhead Square	2.54	14.05	57.58	71.63	13.84	35.74	49.58	49.78
Pinhead Square	3.81	21.08	57.58	78.66	20.77	35.74	56.51	49.78
First Bloom	1.27	6.12	57.58	63.7	5.61	35.74	41.35	49.78
First Bloom	2.54	12.27	57.58	69.85	11.23	35.74	46.96	49.78
First Bloom	3.81	18.39	57.58	75.97	16.84	35.74	52.55	49.78
Dryland	0	0	57.58	57.58	0	35.74	35.74	49.78

^Z Total rainfall collected from May to September for 2010 and 2011.

^Y Historical average rainfall from May to September from 1971-2000.

Table 2. Average plant nodes, plant height, and NAWF of a cotton crop grown in a soil varying in depth to a sandy layer and receiving varying amounts of irrigation.

Irrigation (cm)	Soil Depth	Week	Week	Week	Week	Week	Week	Week	Week	Week	Week	Week	Week
		1	2	3	4	1	2	3	4	1	2	3	4
		Plant Nodes (no.)				Plant Height (cm)				NAWF ^Z			
0		13.8	15.7	15.6	16.2	89.0	89.8	94.4	93.8	4.9	2.1	1.2	0.6
1.27		14.9	16.8	16.8	17.6	96.3	104.5	107.3	108.9	5.8	2.9	1.7	1.1
2.54		15.0	17.1	17.3	17.6	98.6	106.1	110.4	110.6	6.1	3.3	2.1	1.3
3.81		14.9	16.9	17.3	17.9	93.5	102.9	106.4	106.7	6.1	3.5	2.1	1.2
LSD (0.05)		0.7	0.7	0.8	0.8	NS	8.6	9.2	9.1	0.7	0.6	0.3	0.4
	Shallow ^Y	14.2	15.9	16.0	16.5	88.2	94.7	96.4	95.6	5.2	2.5	1.4	0.6
	Deep ^X	15.1	17.4	17.5	18.2	100.5	106.9	112.7	114.4	6.2	3.5	2.2	1.5
	LSD(0.05)	0.5	0.5	0.6	0.6	5.8	6.1	6.6	6.5	0.5	0.4	0.2	0.3

^ZNAWF = Main stem Nodes Above White Flower.

^Y Shallow = < 61 cm to sand layer, n = 56

^X Deep = > 89 cm to sand layer, n = 42

Table 3. Cotton fiber quality analysis of a crop grown in a soil varying in depth to a sandy layer and receiving varying amounts of irrigation.

Irrigation (cm)	Soil Depth	Lint Percent		Fiber Length	Fiber Strength	Fiber Uniformity
		(%)	Micronaire	(in.)	(g tex ⁻¹)	(%)
0		40.4	4.6	1.10	30.0	82.2
1.27		39.8	4.5	1.13	30.1	82.8
2.54		39.2	4.4	1.14	30.1	83
3.81		39.1	4.4	1.15	31.4	83.2
LSD (0.05)		0.7	0.1	0.01	0.6	0.4
	Shallow ^Z	39.9	4.4	1.11	30.1	82.3
	Deep ^Y	39.4	4.5	1.15	31.3	83.2
LSD (0.05)		NS	NS	0.01	0.5	0.3

^Z Shallow = < 61 cm to sand layer, n = 56

^Y Deep = > 89 cm to sand layer, n = 42

Table 4. Cotton County Standard Trial locations, soil types, heat accumulation, total precipitation and average yield where physiological measurements were recorded.

Location	Year	Soil Series /Texture	Row Spacing (cm)	Planting Date	Harvest Date	Total DD 15.6 ^Z	Total Precipitation ^Z (cm)	Average Yield (kg ha ⁻¹)
Crockett Co.	2010	Adler ^Y Silt Loam	97	5/25/2010	10/12/2010	1088	35	910
Fayette Co.	2010	Grenada ^X Silt Loam	97	5/7/2010	9/22/2010	1145	28	1350
Gibson Co.	2010	Collins ^W Silt Loam	97	5/13/2010	9/28/2010	1149	25	1240
Lake Co.	2010	Reelfoot ^V Silt Loam	97	5/6/2010	9/21/2010	1083	18	1210
Tipton Co.	2010	DeKoven ^U Silt Loam	97	5/24/2010	10/15/2010	1080	31	1090
Crockett Co.	2011	Grenada Silt Loam	97	5/26/2010	10/18/2010	1062	29	980
Fayette Co.	2011	Grenada Silt Loam	97	5/10/2010	10/16/2010	1076	24	1180
Gibson Co.	2011	Memphis ^T Silt Loam	97	5/19/2010	10/18/2010	1011	21	950
Lake Co.	2011	Reelfoot Silt Loam	97	5/16/2010	10/12/2010	1075	12	1280
Lauderdale Co.	2011	Grenada Silt Loam	97	5/20/2010	10/5/2010	998	21	1100

^Z Climate information recorded from June 1st to August 31st of respective year.

^Y Coarse-Silty, Mixed, Superactive, Thermic Fluvaquentic Eutrudepts

^X Fine-Silty, Mixed, Active, Thermic Oxyaquic Fraglossudalfs

^W Coarse-Silty, Mixed, Active, Acid, Thermic Aquic Udifluvents

^V Fine-Silty, Mixed, Superactive, Thermic Aquic Argiudolls

^U Fine-Silty, Mixed, Superactive, Thermic Typic Endoaquolls

^T Fine- Silty, Mixed, Active, Thermic Typic Hapludalf

Table 5. Average number of nodes for six cotton varieties at ten locations in Tennessee during the blooming period, 2010 and 2011.

Variety	Location Rainfall (cm)	Week1	Week 2	Week 3	Week 4	Week 5
		Plant Nodes (no.)				
DP 0912 B2RF		14.0	15.5	16.1	17.3	16.8
DP 0920 B2RF		14.1	15.5	16.0	16.9	17.3
DP 1034 B2RF		13.7	15.0	15.7	17.0	17.1
FM 1740B2F		13.5	15.1	15.7	16.6	16.7
PHY 375 WRF		13.9	16.0	16.2	17.6	17.5
ST 4288B2F		13.8	15.5	16.1	17.0	17.0
LSD (0.05)		NS	0.5	NS	0.7	NS
	< 7.6	13.6	15.1	15.6	16.6	16.7
	> 7.6	14.1	15.8	16.4	17.6	17.4
	LSD (0.05)	NS	NS	NS	NS	NS

Table 6. Average plant height for six cotton varieties at ten locations in Tennessee during the blooming period, 2010 and 2011.

Variety	Location Rainfall (cm)	Week 1	Week 2	Week 3	Week 4	Week 5
		Plant Height (cm)				
DP 0912 B2RF		81.8	89.9	95.0	98.0	99.1
DP 0920 B2RF		75.9	85.3	92.2	93.5	94.5
DP 1034 B2RF		84.8	94.2	100.6	103.6	104.9
FM 1740B2F		77.0	85.3	91.2	92.7	94.2
PHY 375 WRF		83.3	97.0	100.8	106.2	104.9
ST 4288B2F		80.5	90.2	95.5	98.0	102.9
LSD (0.05)		6.1	6.9	6.4	8.4	7.9
	< 7.6	71.4	80.8	85.9	86.9	87.6
	> 7.6	89.7	99.8	105.9	110.5	112.8
	LSD (0.05)	NS	NS	NS	21.6	NS

Table 7. Average nodes above white flower for six cotton varieties at ten locations in Tennessee during the blooming period, 2010 and 2011.

		Week 1	Week 2	Week 3	Week 4	Week 5
Variety	Rainfall (cm)	NAWF ^Z (no.)				
DP 0912 B2RF		7.3	6.2	4.4	3.2	1.7
DP 0920 B2RF		7.2	6.1	4.1	3.2	1.7
DP 1034 B2RF		7.1	6.2	4.3	3.3	1.8
FM 1740B2F		7.0	5.8	4.1	2.9	1.3
PHY 375 WRF		7.3	6.6	4.6	3.7	1.6
ST 4288B2F		7.1	6.0	4.4	3.3	1.8
LSD (0.05)		NS	NS	NS	NS	NS
	< 7.6	7.1	6.0	4.2	2.7	1.9
	> 7.6	7.2	6.3	4.5	3.8	1.4
	LSD (0.05)	NS	NS	NS	NS	0.5

^ZNAWF = Main stem Nodes Above first fruiting position White Flower

Table 8. Yield and fiber quality analysis of six cotton varieties at ten locations in Tennessee during 2010 and 2011.

Precipitation Amount (cm)	Variety	Yield	Lint Percent	Micronaire	Length	Strength	Uniformity
		(kg ha ⁻¹)	(%)		(in.)	(g tex ⁻¹)	(%)
< 7.6	DP 0912 B2RF	1020	38.1	5.1	1.09	31.0	82.2
	DP 0920 B2RF	1140	39.3	4.9	1.14	31.3	83.1
	DP 1034 B2RF	980	38.9	4.7	1.12	32.2	82.4
	FM 1740B2F	980	38.1	5.0	1.11	32.9	82.3
	PHY 375 WRF	1100	38.9	4.7	1.11	30.9	82.2
	ST 4288B2F	960	34.5	4.8	1.13	32.0	82.2
> 7.6	DP 0912 B2RF	1110	36.4	4.8	1.07	29.6	81.5
	DP 0920 B2RF	1260	40.1	4.7	1.10	28.5	81.3
	DP 1034 B2RF	1050	39.2	4.6	1.14	30.5	82.5
	FM 1740B2F	1120	36.0	4.5	1.10	31.2	82.1
	PHY 375 WRF	1280	38.6	4.5	1.10	29.8	82.1
	ST 4288B2F	1180	35.5	4.6	1.13	30.8	81.6
	LSD (0.05)	110	1.9	0.2	0.03	1.6	NS

Table 9. Yield stability of twelve cotton varieties at fifteen locations in Tennessee during 2010 and 2011.

Stability Rank	Variety	Mean Lint Yield ^Z 2010-2011 (kg ha ⁻¹)	Yield Rank	Regression Parameters		R ²
				y-Intercept	Slope	
1	PHY 375 WRF	1090	4	-52.12	1.09	0.89
2	DP 0912 B2RF	1070	6	-6.63	1.03	0.89
3	FM 1740B2F	1010	11	91.96	0.87	0.85
4	DP 1034 B2RF	980	12	-96.59	1.03	0.83
5	ST 4288B2F	1030	9	66.40	0.92	0.82
6	DP 0920 B2RF	1100	3	-3.01	1.06	0.82
7	ST 5288B2F	1030	8	-119.03	1.09	0.82
8	ST 5458B2RF	1110	1	58.84	1.00	0.82
9	CG 3220 B2RF	1070	5	7.68	1.01	0.81
10	DP 1028 B2RF	1030	10	-207.08	1.17	0.78
11	DG 2570 B2RF	1100	2	124.91	0.93	0.76
12	PHY 367 WRF	1040	7	-66.05	1.06	0.74
	Mean:	1060		0.00	1.02	0.82

^Z Means averaged across fifteen County Standard Trial Locations.

Vita

Matthew S. Wiggins was born August 8, 1988, in Jackson, TN. He is the son of Mr. and Mrs. Jerry Wiggins of Friendship, TN. He attended Crockett County High School and graduated in May 2006. He then enrolled at Tennessee Technological University in August 2006 and received a Bachelor of Science in Agriculture, with an emphasis in Agricultural Engineering Technology in December 2009. Upon graduation, he accepted the position of Graduate Research Assistant in the graduate program at The University of Tennessee working under Dr. Christopher Main, Cotton and Small Grains Extension Specialist, and achieved a Master of Science degree in Plant Sciences in May 2012. After graduation he will be continuing his education and research as he enters the Ph. D. program at The University of Tennessee.