AGRONOMIC EVALUATION OF SUBSURFACE DRIP AND OVERHEAD IRRIGATION FOR COTTON IN GEORGIA

by

Calvin Douglas Meeks

(Under the Direction of Guy Collins)

ABSTRACT

Cotton irrigated acreage is predicted to increase 89 percent in Georgia by 2050 Research was conducted to investigate agronomic and physiological effects of subsurface drip irrigation (SDI) on cotton grown in Georgia in comparison to traditional overhead (OVHD) irrigation. Field experiments were conducted at Stripling Irrigation Research Park (SIRP) near Camilla, GA, and Southeast Georgia Research and Education Center (SEGREC) near Midville, GA during 2011 and 2012. Cotton irrigated with SDI produced similar yields to OVHD irrigation while using less water. Cotton yields were slightly higher (84 kg/ha) when irrigated with SDI with shallow tape (buried 5 cm below the soil surface) compared to SDI with tape buried 30 cm deep. Optimal irrigation methods were found to be matching UGA's weekly water requirement and or by maintain soil moisture potential above -40 kPa for both cultivars.

INDEX WORDS: Cotton, Subsurface Drip, Irrigation, Water, Soil Moisture

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INTRODUCTION AND LITERATURE REVIEW

This literature review summarizes the importance of efficient irrigation for cotton in Georgia, as well as the effects of water stress on cotton growth. Additionally, the differences between cotton irrigated by subsurface drip irrigation (SDI) and overhead irrigation (OVHD) observed in previous research are discussed.

Population growth and episodic drought has greatly increased the demand of groundwater resources in the state of Georgia. Agriculture irrigation accounted for 41% of the total water usage in Georgia for the year ending 2004 (Hutson, 2004). Irrigation of many crops is now seen as a necessity for growers to remain sustainable and profitable. In order to sustain current irrigation practices, water must be conserved by using more efficient irrigation methods. Subsurface drip irrigation has been touted to save up to 37 percent more water compared to other irrigation methods such as OVHD irrigation (Whitaker et al., 2006).

Cotton growth and water stress

The availability and quality of water can affect the physiological processes of all plants. Water is the main component of actively growing plants, ranging from 70-90 percent of fresh plant mass, and is essential to nutrient transport, chemical reactions, cell enlargement, transpiration, and most other plant processes (Gardner et al., 1984). All plants are affected by soil moisture deficit or water stress which causes plant growth and development to be hindered by inhibiting cellular expansion, altering enzyme concentrations, and eventually decreasing respiration, photosynthesis, and assimilate translocation (Loka et al., 2010).

Many ancestors of domestic cotton (*Gossypium hirsutum* L.) were viny perennial plants with an indeterminate growth habit that were native to semi-arid sub-tropical environments that experienced - and adapted to - periodic drought and temperature extremes (Kohel et al., 1974). These wild cotton lines produced abundant vegetative growth under favorable growing conditions, which included adequate water and nutrients (Ritchie et al., 2007). Vegetative growth assists the plant in intercepting sunlight, but excessive vegetative growth can decrease the number of bolls that are produced since resources are diverted away from reproductive growth (Loka et al., 2010). Excessive vegetative growth also diverts energy away from lint and seed production (Ritchie et al., 2009). These characteristics of cotton influence how cotton is managed, as commercial production in the U.S. requires cotton to be produced as an annual crop through maximizing production and retention of harvestable fruit within a single season and before conditions become unfavorable for continued growth and fruit set. In commercially grown cotton, determinate growth habits are desired to limit vegetative growth and enhance fruit production (Jost et al. 2006). Limiting plant growth is achieved through the use of plant growth regulators that are applied to irrigated cotton to suppress vegetative growth (Jost et al., 2006; Vellidis et al., 2009); however irrigation timing, rates, and methods can also affect vegetative growth (Ritchie et al., 2009). Efficient irrigation has been shown to produce high-yielding, high quality cotton without wasting water and with less need for plant growth regulators since wasteful, excessive vegetative growth would be limited and reproductive growth maximized (Whitaker et al., 2008).

Water requirements of cotton

Bednarz et al. (2002) found that cotton grown in South Georgia requires a minimum of 46 cm of water per growing season for maximum yields to be achieved. The state of Georgia received an average of 52.7 cm of rainfall during the typical growing season (1 May - 31 September) during 1971-2000, and more recently, an average of 46.3 cm from 2009-2012 (Georgia Automated Environmental Monitoring Network, 2013), suggesting that average seasonal rainfall should be sufficient for cotton production in this region. However, course-textured, sandy soils with poor water retention comprise the majority of cultivated land in Georgia (Chesworth et al., 2008), which can lead to suboptimal or insufficient soil moisture during periods of critical water demand. Although average seasonal rainfall suggests that cotton water requirements meet the criteria defined by Bednarz et al. (2002), this rainfall usually occurs incrementally, interspersed with dry periods and high temperatures, and does not necessarily align with the critical stages of cotton water demand throughout the season.

Additionally, high temperatures during the growing season create an environment prone to heat stress or increased evaporation of needed water with temperatures during the typical growing season averaging 25.7 °C during 1971-2000 and 26.2 C in more recent years (2009-2012), with average maximum daily temperatures of 32.0 °C (1971-2000) and more recently, an average of 32.6 °C for 2009-2012 (Georgia Automated Environmental Monitoring Network, 2013). Drought has been shown to negatively affect boll retention which ultimately can lead to yield losses and poorer lint quality since a greater number of yield-contributing bolls are located lower in the plant and usually on the first position of each node (Pettigrew, 2004). Cotton growth slows during periods of water deficit, with plant height/terminal growth increasing at a slower rate than when supplemental water is applied via irrigation (Ritchie et al., 2009) or if sufficient rainfall occurs. Additional node formation is also slowed (Ritchie et al., 2009) which can limit upward development of effective fruiting sites. The slowed growth results in hastened maturity, as measured by nodes above the first square and nodes above the uppermost first-position white flower (Bourland et al., 1992; Bourland et al., 2001; Brown and Oosterhuis, 1992), potentially causing plants to prematurely cease upward development of fruiting (premature "cutout") which can adversely affect yields.

However, excessive irrigation also results in increased fruit shed (Cetin and Bilgel, 2002). In some situations, it has been documented that fruit loss due to mild-to-moderate water stress occurring later in the growing season can result in plants that produce and retain fewer upper bolls on nodes near the top of the plant (Cetin and Bilgel, 2002). Irrigating beyond what is required by cotton, on the other hand, often causes excessive vegetative growth and potentially the loss of fruit at the lower nodes, allowing the potential for compensatory growth at the top of the plant later in the growing season (Cetin and Bilgel, 2002) which can be advantageous if optimal fruit set is not achieved on lower nodes. This same effect can be problematic if excessive irrigation causes the loss of critical fruit on lower nodes. Full-season climates with longer periods of suitable heat unit accumulation allows for the possibility for avoidance of adverse yield effects by shifting of boll production to the upper nodes (Cetin and Bilgel, 2002). However, in regions where the growing season is limited by cooler late-season weather, the likelihood of this compensation is reduced as optimal yields are usually observed through the retention and development of bolls on lower node zones (Ritchie et al., 2009). Additionally, OVHD irrigation can also cause pollen rupture in cotton that can lead to fruit loss (Burke 2003). Subsurface Drip Irrigation is currently used in Texas due to its increased efficiency and the problematic issues associated with declining aquifer levels (Bordovsky et al., 2000). In fact, in the areas of Texas where irrigation water is supplied by the Ogallala aquifer, over 100,000 ha of SDI is currently used (Colaizzi et al., 2008). Benefits of SDI systems in this region include yield improvements as well as water savings when compared to OVHD systems (Bordovsky and

Porter, 2003; Colaizzi et al., 2004, 2005, 2006). Climatic differences between Texas and Georgia would require research to ascertain whether the yield advantage over center pivots (OVHD irrigation) would be applicable and consistent in Georgia's climate. The utility of SDI in Texas has been accepted by many growers, however research must be conducted in Georgia due to major differences in seasonal temperature fluctuation (daytime high temperatures and nighttime low temperatures), humidity, heat unit accumulation (length of season), sunlight intensity, cultivar differences, etc. The potential benefits, along with the utility of SDI for smaller, irregular-shaped fields unsuitable for center pivots, have spurred an increased interest in SDI in Georgia. Currently 45% of cotton is irrigated yearly on average (Guillebeau, 2006) but mostly with OVHD systems.

This research was conducted to define optimum irrigation methods for cotton grown in Georgia since Georgia's climate is a full-season environment with greater humidity and relatively frequent rainfall, and less sunlight intensity than the regions of Texas that currently implement SDI. The differences in environment, soil, cultivars, and other aforementioned factors raise many questions of the suitability of SDI in the Southeastern US.

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Chapter 1

Comparison of Subsurface Drip and Overhead Irrigation

Introduction

Overhead (OVHD) irrigation efficiency is affected by temperature, humidity, and wind speed (Smajstrla et al., 2006). Evaporation and drift of water applied via OVHD systems can occur before water droplets make contact with targeted soil (McLean et al., 2000; Ocampo et al., 2003) potentially leading to significant water losses. However, this type of system has been shown to significantly increase cotton yields in Georgia, as shown with the University of Georgia Statewide Variety Testing Program that demonstrates an average yield increase of 46 percent with full-season cultivars compared to the same cultivars in nearby rain-fed environments during 2012 (Day et al. 2012). Additional cotton yield increases resulting from OVHD irrigation have been clearly documented in Georgia (Bednarz et al., 2002; Bordovsky and Porter, 2003; Whitaker et al., 2006). Lint yield increases are associated with higher boll production with reduced boll abortion compared to dryland cotton (Whitaker et al., 2006). However, cotton irrigated with OVHD irrigation has also been shown to decrease the number of bolls near the base of the plant which can delay the maturity of the plant (Ritchie et al., 2009), and could be potentially problematic due to weather-related risks such as late-season rain and adversely cool weather during the fall in some situations. Additionally, OVHD irrigation can also cause pollen rupture in cotton that leads to fruit loss (Burke, 2003).

While most irrigation systems use OVHD in the Coastal Plain of Georgia (Harrison, 2012), subsurface drip irrigation (SDI) offers several potential advantages over OVHD irrigation, including flexibility in the systems size and shape, lower water supply pressure and flow rate requirements, ease of automation due to its fixed position and no mobility, and flow controllers that are readily available (Camp, 1997). Systems in the Coastal Plain of Georgia need to be flexible as fields vary in size and shape, potentially benefitting the several relatively small (lees than 30 ha) and irregularly shaped fields throughout Georgia's cotton belt. Overhead irrigation systems are limited to circular or lateral movement only, potentially leaving significant areas of the field non-irrigated (Camp, 1997). Overhead irrigation systems are therefore best-suited for larger fields, whereas SDI systems are capable of irrigating all areas of fields rendered unreachable by OVHD systems, allowing for dryland cotton corners, and/or small, irregular shaped fields to be irrigated. Subsurface Drip Irrigation systems also do not require time to travel through the field unlike OVHD systems, thereby ensuring that irrigations can be consistently applied in a more timely manner for all areas of the field. Additionally, SDI systems can compensate for rainfall by applying smaller amounts of water periodically over a given time, whereas OVHD systems typically apply larger amounts in fewer, less-frequent, single applications. If rainfall occurs during a particular week of development, application rates in SDI systems can be adjusted or discontinued resulting in water savings, whereas OVHD systems may have already applied a larger amount of water which may not have been needed with the additional rainfall that occurred after irrigation. Also, SDI has been shown to be more efficient since losses associated with OVHD systems, such as water droplet evaporation and drift onto non-target areas, are virtually eliminated since water is delivered underground (Payero et al., 2005).

Cotton production in arid and semi-arid areas using SDI has previously been evaluated and widely adopted by commercial cotton producers throughout the South Plains and Trans

Pecos regions of Texas beginning in the early 1980's (Henggeler, 1995 & 1997; Enciso et al., 2003; Colaizzi et al., 2004). Subsurface Drip Irrigation can have significantly greater initial costs than OVHD systems (O'Brien et al., 1998; Segarra et al., 1999; Colaizzi et al., 2004), but has been shown to produce higher lint yields, higher quality lint and improved water use efficiency when compared to OVHD systems (Segarra et al., 1999; Bordovsky and Porter, 2003; Whitaker et al., 2006). It has also demonstrated potential as a possible alternative to OVHD irrigation for cotton in the southeastern U. S. (Camp et al., 1997, 1999; Whitaker et al., 2006).

In summary, SDI has been shown to be an efficient alternative to OVHD irrigation. While previously considered financially unfeasible to growers, the benefits now outweigh the cost and SDI now has potential of becoming a more popular irrigation method in the future due to its increased efficiency and potential water savings, as well as its proven ability to provide superior cotton yield and quality. These factors reinforce its utility in smaller, odd-shaped fields that would otherwise be non-irrigated or where OVHD systems may be unsuitable. Lastly, recent studies evaluating irrigation methods of cotton in the humid regions of the Southeastern U.S. have shown that cotton irrigated by SDI had fewer nodes above white flower (NAWF) and nodes above cracked boll (NACB) compared to OVHD irrigated methods, which suggests the possibility that time to reach maturity and defoliation/harvest date of the crop could potentially be accelerated (Ritchie et al., 2009).

However, SDI brings new challenges for a cotton producer due to its permanent underground fixture. Tillage, future crop rotations, activation of herbicides, and seed germination are all issues that must be addressed. Subsurface drip irrigation systems are not equipped to apply large amounts of water in a single application, necessitating the evaluation of irrigation methods for optimal yields in Georgia's climate that is typically humid and encounters episodic rainfall and drought. For these reasons, research in Georgia was warranted. The objectives of our research were to compare SDI systems to OVHD irrigation under two scheduling methods with regard to water use, plant growth, and lint yields. Two modern cultivars, that differ in maturity and sensitivity to water stress, were utilized to more fully examine the effect of irrigation method and irrigation system compared to dryland cotton production.

Materials and methods

Research experiments were conducted at the Stripling Irrigation Research Park (SIRP) near Camilla, Georgia during 2011 and 2012. The cultivars evaluated were Delta & Pine Land (DP) 1050 B2RF (Monsanto Company, St. Louis, MO) and FiberMax (FM) 1740 B2F (Bayer CropScience, Research Triangle Park, NC). Deltapine 1050 B2RF is a mid to full-season cultivar touted to perform well in dryland cotton conditions, whereas FM 1740 B2F is an early to mid-season cultivar touted to perform well in conditions where water is sufficient. Both cultivars were planted on May 17, 2011 and May 1, 2012 at a rate of 7.2 sd/m^2 using a two-row vacuum Monosem planter (Monosem Inc, Edwardsville, KS). Cotton was grown in rows spaced 0.91 m apart, and each SDI plot was six rows wide with SDI lines installed in alternate row middles. A two-row buffer was included on each side of each SDI plot to prevent potential influences of adjacent-plot irrigation. Individual plots were 12 m long and three m wide with one m borders. The soil at SIRP was a Lucy loamy sand (loamy, kaolonitic, thermic, Arenic, Kandiudults). To ensure an equal and optimal stand among treatments, all plots were irrigated until emergence with the OVHD system with a drop nozzle spacing of 7.5 ft with Nelson (LR Nelson, Peoria, IL) fixed spray nozzles. Post-planting irrigation for uniform seedling emergence required 5.1 cm in 2011 and 4.6 cm in 2012 (data not shown/reported).

The experimental design was a randomized complete block design, with a factortial arrangement between irrigation treatments and a dryland cotton check added, with five irrigation treatments and six replications. Subsurface drip tape was 0.38 mm thick tape with emitters spaced 45 cm spaced apart (Netafim, Fresno, California) installed at 30.5 cm below the soil surface. Preliminary field tests indicated an actual application rate of 0.25 cm per 113 minutes.

Irrigation methods included water applied with either SDI or the OVHD system in order to maintain soil moisture at two predetermined levels. These levels were maintained by monitoring Watermark moisture potential sensors (MPS) (Model 200SS, Irrometer Company Inc., Riverside, CA) and irrigations were applied to maintain readings below -40 or -70 kPa. Irrigations of 2.54 cm were applied with the OVHD system when MPS reached trigger points. Irrigations of varying amounts were applied by the SDI when trigger points were reached. When MPS indicated that either of the trigger points were reached, the amount of water applied was equal to one third of the UGA weekly water requirement (Table 1.1). Watermark Soil Moisture Sensors with Model 950T radio transmitters and Model 950R receivers (Irrometer Company Inc., Riverside, CA) were used to monitor soil moisture in four replicates in this experiment. Soil moisture data from these Watermark sensors were viewable via Irrometer’s online portal. An illustration of this data is available in the Appendix (A.1). Sensors were installed in the crop row at 30 cm and 45 cm below the soil surface, yet irrigations were triggered based on the 30 cm sensors. Total season-long irrigation rates are noted in Table 1.2 and weekly rates are illustrated in Tables 1.3 and 1.4. All other agronomic practices were conducted according to the University of Georgia Cooperative Extension Service Guidelines (Collins eds., 2013).

Two rows of each plot were reserved for machine harvesting using a two-row John Deere model 9930 spindle cotton harvester (Deere and Company, Moline IA). Seed cotton samples were ginned and weighed at the University of Georgia Micro-gin for lint percentage, and samples were sent to the USDA Classing office in Macon, GA for high volume instrumentation (HVI) fiber quality analysis. Data were subjected to analysis of variance (ANOVA) and means were separated using the Mixed Procedure and Fisher's Protected LSD at $p \leq 0.05$ or 0.1 based upon practicality using SAS version 9.2 (SAS Institute, Cary, NC, USA).

Results

Season-long rainfall and total water applied for each irrigation treatment at SIRP during 2011 and 2012 are listed in Tables 1.2. 1.3, and 1.4. In 2011, 38.9 cm of rainfall occurred throughout the season, and irrigation water applied was greater in 2011 for each treatment, ranging from 6.1 to 12.7 cm, compared to 2012 when 43.1 cm rainfall occurred resulting in irrigation applications ranging from 2.54 to 8.89 cm. For irrigation triggered at -40 kPa, SDI resulted in 18 and 13 percent less water applied than the OVHD system in 2011 and 2012, respectively. For irrigation triggered at -70 kPa, SDI resulted in 20 percent less water applied that the OVHD system in 2011, but 57 percent greater water applied in 2012. The significant rainfall experienced in 2012 allowed the OVHD system to only trigger once for the -70 kPa treatment, therefore resulting in less applied water than would normally be expected.

Table 1.5 illustrates the effects of irrigation system and trigger point on lint yield, lint yield obtained over the dryland cotton treatment, and efficiency parameters including lint yield per cm of total water applied and lint yield obtained over the dryland cotton treatment per cm irrigation water applied, pooled over cultivars. When pooled over years and cultivars, irrigation treatments resulted in 27 to 58 percent higher yields compared to the dryland cotton control. Lint yields were 21 percent greater when irrigation was triggered at -40 kPa compared to when irrigations were triggered at -70 kPa. Most importantly, similar yields were observed between the SDI and OVHD systems for both the -40 and -70 kPa triggers, suggesting that SDI could produce similar yields to OVHD while using less water in some situations, especially when triggering irrigation at a higher soil moisture threshold. Subsurface drip irrigation and OVHD also resulted in similar yield advantage over dryland cotton for both the -40 and -70 kPa triggers, however triggering irrigation at -40 kPa resulted in an average 96 percent greater yield advantage than the -70 kPa trigger. With regard to lint yield per total water applied (irrigation and rainfall), both SDI and OVHD systems triggered at -40 kPa were 21 percent greater than the dryland cotton control, however both systems triggered at -70 kPa were no different from that of either the -40 kPa nor the dryland cotton control. Lint yield advantage over dryland cotton per cm irrigation water applied was similar for all irrigation treatments, suggesting that in this study the efficiency of water application was not significantly different between the SDI and OVHD systems.

Table 1.6 illustrates the cultivar by irrigation system interaction in 2011 and 2012. In 2011, when pooled over trigger points, DP 1050 B2RF resulted in similar yields in both SDI and OVHD. Lint yields of FM 1740 B2F were 8 and 20 percent higher than that of DP 1050 B2RF in the SDI and OVHD system respectively, however the OVHD system resulted in 10 percent higher yields for FM 1740 B2F compared to the SDI system. In 2012, FM 1740 B2F and DP 1050 B2RF had similar yields when irrigated using the SDI system, however yields of DP 1050 B2RF were 21 percent higher than FM 1740 B2F in the OVHD system. These data suggests that OVHD irrigation may result in positive cultivar responses in some years. Table 1.7 illustrates the main effects of irrigation system and trigger point in 2011 and 2012. In 2011, OVHD resulted in 4 percent higher yields than the SDI system, however there was no yield response to irrigation system in 2012. The -40 kPa trigger point resulted in 14 and 36 percent higher yields than the -70 kPa trigger in 2011 and 2012 respectively, suggesting that triggering irrigation at a higher soil moisture threshold may consistently result in higher yields than a lower threshold. There was no significant cultivar x trigger point interaction, suggesting that both drought tolerant and drought sensitive cultivars respond positively to a higher soil moisture threshold for triggering irrigation, and that even a drought tolerant cultivar may experience yield penalties by delaying irrigation until a lower soil moisture threshold is reached.

Conclusions

Results from this experiment suggests that SDI can result in similar yields to the widely adopted OVHD systems in Georgia, therefore similar yield improvements compared to dryland cotton production should be observed if growers were to adopt a SDI system for small or irregulary shaped fields that are currently in dryland cotton production. More importantly, yields similar to that of OVHD can be expected while using less water (13 to 18 percent) in SDI in some years if appropriate irrigation triggers (higher soil moisture thresholds) are used to initiate irrigation. This reduction in water usage while achieving optimal yields could result in significant savings associated with pumping costs and could offset some of the initial costs associated with installing a SDI system. Due to the lack of significant responses of lint yield advantage over dryland cotton per cm irrigation water applied, the efficiency of irrigation water applied through SDI is similar to that of OVHD in Georgia's environment, indicating that OVHD water losses due to physical drift and evaporation as suggested by (Segarra et al., 1999; Bordovsky and Porter, 2003) may not be clearly observed in the southeastern U.S versus more arid climates. Water savings associated with the SDI system in this experiment were therefore the likely result of the ability to cease irrigating and adjusting for episodic rainfall as water is applied incrementally in a SDI system, whereas larger amounts are applied in less frequent applications in an OVHD system. This experiment also clearly demonstrated that irrigation should be initiated at a relatively high soil moisture threshold (-40 kPa trigger point) regardless of the irrigation system used or differences in cultivar sensitivity to water stress. The yield responses of cultivar to various irrigation treatments could provide insight regarding how certain cultivars should be positioned (dryland cotton or irrigated), however these effects were variable from year to year. The response of various plant growth and boll distribution parameters were relatively infrequent and inconclusive, however some data suggested that OVHD may result in subtle delays in maturity compared to SDI, similar to that suggested by (Ritchie et al., 2009). In summary, this experiment demonstrated that SDI is a viable method of irrigating cotton in Georgia if irrigation is initiated using appropriate soil moisture triggers, and similar yields to OVHD could be expected with significant water savings.

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Table 1.1. Weekly suggested irrigation rates (cm per week) rates according to the UGA Checkbook. The rates for application via subsurface drip irrigation are shown as cm per day.

Growth Stage	**100% UGA Checkbook**		**65% UGA Checkbook**	
	cm per week	cm per day applied on M[z], W, F	cm per week	cm per day applied on M, W, F
Prior to Bloom	2.54	0.85	1.65	0.55
First week of bloom	2.54	0.85	1.65	0.55
Second week of bloom	3.81	1.27	2.48	0.83
Third week of bloom	5.08	1.69	3.30	1.10
Fourth week of bloom	5.08	1.69	3.30	1.10
Fifth week of bloom	3.81	1.27	2.48	0.83
Sixth week of bloom	3.81	1.27	2.48	0.83
Seventh weed of bloom	2.54	0.85	1.65	0.55
Eighth week of bloom	2.54	0.85	1.65	0.55
End of bloom – first open boll	1.91	0.64	1.22	0.41

[z] M, W, F denotes day of week: Monday, Wednesday and Friday

Table 1.2. Total season-long irrigation and rainfall for each irrigation treatment at Stripling Irrigation Research Park near Camilla, GA during 2011 and 2012.

Irrigation Treatment	2011	2012
	cm	
Dryland cotton Control	0.00	0.00
Subsurface Drip Irrigation (-40 kPa trigger)	10.41	7.72
Subsurface Drip Irrigation (-70 kPa trigger)	6.10	5.99
Overhead Irrigation of 2.54 cm (-40 kPa trigger)	12.70	8.89
Overhead Irrigation of 2.54 cm (-70 kPa trigger)	7.60	2.54
Rainfall	38.86	43.10

Table 1.3 Total rainfall and irrigation per week in cm at Stripling Irrigation Research Park near Camilla, Ga in 2011

Weeks after planting	Growth Stage	Dryland cotton	Overhead -40 kPa	Overhead -70 kPa	SDI[z] -40 kPa	SDI -70 kPa	Rainfall
1	Pre Bloom	0.0	0.0	0.0	0.0	0.0	0.0
2	Pre Bloom	0.0	0.0	0.0	0.0	0.0	0.0
3	Pre Bloom	0.0	0.0	0.0	0.0	0.0	0.0
4	Pre Bloom	0.0	0.0	0.0	0.0	0.0	3.4
5	Pre Bloom	0.0	0.0	0.0	0.0	0.0	3.2
6	Pre Bloom	0.0	0.0	0.0	0.0	0.0	2.0
7	Pre Bloom	0.0	2.5	2.5	0.0	0.0	1.3
8	First Bloom (FB)	0.0	0.0	0.0	2.4	1.7	5.7
9	FB+1 week	0.0	0.0	0.0	0.0	0.0	2.3
10	FB+2 week	0.0	2.5	0.0	1.7	0.0	2.4
11	FB+3 week	0.0	5.1	2.5	3.0	1.7	4.8
12	FB+4 week	0.0	0.0	0.0	0.0	1.3	0.0
13	FB+5 week	0.0	0.0	0.0	2.0	0.0	0.8
14	FB+6 week	0.0	2.5	2.5	1.4	0.8	0.0
15	FB+7 week	0.0	0.0	0.0	0.0	0.6	0.0

[z] Denotes Subsurface Drip Irrigation

Table 1.4 Total rainfall and irrigation per week in cm at Stripling Irrigation Research Park near Camilla, Ga in 2012

Weeks after planting	Growth Stage	Dryland cotton	Overhead -40 kPa	Overhead -70 kPa	SDI[z] -40 kPa	SDI -70 kPa	Rainfall
1	Pre Bloom	0.0	0.0	0.0	0.0	0.0	1.1
2	Pre Bloom	0.0	0.0	0.0	0.0	0.0	1.5
3	Pre Bloom	0.0	0.0	0.0	0.0	0.0	0.4
4	Pre Bloom	0.0	0.0	0.0	0.0	0.0	1.4
5	Pre Bloom	0.0	0.0	0.0	0.0	0.0	1.1
6	Pre Bloom	0.0	0.0	0.0	0.0	0.0	3.6
7	Pre Bloom	0.0	0.0	0.0	0.0	0.0	1.6
8	First Bloom (FB)	0.0	0.0	0.0	0.0	0.0	2.1
9	FB+1 week	0.0	2.5	2.5	0.0	0.0	2.7
10	FB+2 week	0.0	2.5	0.0	0.0	0.0	1.0
11	FB+3 week	0.0	0.0	0.0	1.7	0.9	1.4
12	FB+4 week	0.0	3.8	0.0	4.7	3.9	2.0
13	FB+5 week	0.0	0.0	0.0	1.3	1.3	5.4
14	FB+6 week	0.0	0.0	0.0	0.0	0.0	8.6
15	FB+7 week	0.0	0.0	0.0	0.0	0.0	5.4

[z] Denotes Subsurface Drip Irrigation

Table 1.5. Lint yield, yield advantage over dryland cotton, yield per 2.54 cm total water applied (irrigation and rainfall), and yield per 2.54 cm of irrigation water applied for each irrigation treatment at Stripling Irrigation Research Park and during 2011 and 2012.^{z}

Irrigation system	Trigger point	Lint Yield	Lint yield advantage over dryland cotton	Lint yield per cm total water applied	Lint yield advantage over dryland cotton per cm irrigation water applied
			——kg ha^{-1}——		
Dryland cotton control	…….	953 c	……	23.8 b	…….
Overhead	-40 kPa	1503 a	461 a	28.7 a	50.7
Overhead	-70 kPa	1212 b	226 b	26 ab	47.2
Subsurface Drip	-40 kPa	1434 a	404 a	28.7 a	52.1
Subsurface Drip	-70 kPa	1207 b	215 b	26 ab	41
	p-value	x	0.0143	0.079	NS

^{z}Data are pooled over cultivars and years. Means within a column followed by dissimilar letters are significantly different based on Fisher’s Protected LSD test at α = 0.05 or 0.1.

Table 1.6. Cultivar yield response to irrigation system at Stripling Irrigation Research Park during 2011 and 2012.[z]

Cultivar	Irrigation system	Lint yield	
		2011	2012
		kg ha^{-1}	
Deltapine 1050 B2RF	Overhead	1528 c	1150 a
Deltapine 1050 B2RF	Subsurface drip	1551 c	1012 ab
FiberMax 1740 B2F	Overhead	1835 a	947 b
FiberMax 1740 B2F	Subsurface drip	1674 b	1085 ab
	p-value	0.0218	0.0267

[z] Data are pooled over trigger points. Means within a column followed by dissimilar letters are significantly different based on Fisher's Protected LSD test at α = 0.05.

Table 1.7. Yield response of cotton to irrigation system and to trigger point at Stripling Irrigation Research Park and during 2011 and 2012.[z]

Irrigation system	Lint yield	
	SIRP[y] 2011	SIRP 2012
	kg ha^{-1}	
Overhead	1681 a	1048
Subsurface drip	1612 b	1049
p-value	0.0802	NS
Trigger point		
-40 kPa	1751 a	1209 a
-70 kPa	1542 b	888 b
p-value	< 0.0001	< 0.0001

[z] Data are pooled over cultivars and irrigation treatments. Means within a column followed by dissimilar letters are significantly different based on Fisher's Protected LSD test at α = 0.1.

[y] SIRP denotes Stripling Irrigation Research Park near Camilla, GA.

CHAPTER 2

COMPARISON OF INSTALLATION DEPTH FOR SUBSURFACE DRIP IRRIGATION TAPE

Introduction

Subsurface Drip Irrigation (SDI) tape could be effectively installed essentially anywhere in the soil column. Subsurface drip irrigation systems differ from overhead (OVHD) irrigation systems in that SDI is a stationary system that is buried in a fixed location within the soil column for a prolonged period of time. Although both OVHD and SDI systems are touted to improve yields when compared to dryland cotton production (Camp et al., 1998), SDI systems are thought to be more efficient as water is applied underground and is not subject to the potential losses that OVHD systems experience. Drip irrigation is commonly installed on the surface in the San Joaquin Valley in California (Hanson et al., 2000). Subsurface drip irrigation systems are also commonly installed in the High Plains area of the Trans Peco regions of Texas. However, in Georgia, crop rotations with crops such as peanut (*Arachis hypogaea* L.) and tillage practices such as disking, cultivation, deep-turning, etc., may affect the utility of surface tape or shallow SDI. Peanut is a crop that is harvested by inverting plants from the soil (Sorensen et al. 2010), thereby limiting the utility of surface or permanent shallow SDI in many areas of Georgia, as peanut is grown on approximately 209,918 ha in Georgia (USDA Census of Agriculture, 2007) and is commonly rotated with cotton.

Previous research at USDA-ARS-National Peanut Research Laboratory in Dawson, GA has been conducted regarding installation of SDI at shallow depths (3.5 – 5 cm) for short periods of time then removing the SDI tape prior to harvest (Sorensen et al., 2010). Their research suggested that installation of a SDI system for one year would require an irrigated peanut yield increase of 1832 kg ha^{-1} at \$0.40 kg over dryland cotton to account for expenses of the SDI system installation, however the removal of the tape was not taken into account for these calculations. The authors observed an increase in yield of 1235 kg ha^{-1} suggesting that it was not cost-effective to install a SDI system for one year in peanut (Sorensen et al., 2010). Additionally, shallow depths may not be preferred for cotton due to the fact that producers would prefer a permanent installation over one that has to be removed prior to harvest. However, the authors also suggested that necessary cotton yield increases should be 643 kg ha^{-1} at \$1.14 kg^{-1} to account for the cost of a shallow SDI system (Sorensen et al., 2010). This research also suggested that in deficit rainfall conditions, shallow SDI irrigation resulted in an average lint yield increase of 1161 kg ha^{-1} over dryland cotton (Sorensen et al., 2010). Therefore, the increased lint yields with SDI in cotton would account for the cost of the system even with tape only used for one year, suggesting that shallow SDI systems are plausible if the producer is willing to remove the drip lines yearly for peanut production (Sorensen et al., 2010). Research comparing deeper (greater than 10 cm) versus shallow SDI have also been conducted. Yield advantages associated with shallow (5 to 6 cm) SDI compared to deep SDI (25 to 30 cm) has also been documented in some situations (Sorensen et al., 2010). Sorensen et al. (2010), noted significant yield responses between tape depths from year to year weather differences dependent on rainfall during the growing season.

Sorensen et al. (2012) used a SDI system installed at 31cm and was utilized in a crop rotation with maize (*Zea mays* L.**),** peanut, and cotton. Results from this work suggested that the aforementioned rotation is an effective system design that increased yields and provided enough flexibility to grow multiple row crops in rotation (Sorensen et al., 2012). The research conducted by Sorensen et al. (2012) was based on evapotranspiration (ET) replacement with crop coefficient adjustments which accounts for demands per cotton growth stage by days after planting and not necessarily actual cotton growth stage, nor did the authors use sensors to trigger irrigations. The research conducted by Sorensen et al. (2010) was utilized multiple irrigation methods for multiple depths. However, research done by Sorensen et al. (2012) was conducted using a single method of engaging irrigation treatments. Cotton is a crop that does not require removal of shallow SDI prior to harvest, unlike peanut, further investigation of shallow and deep SDI using easily adoptable irrigation methods (checkbooks and sensor-based scheduling) is warranted in Georgia. The adoption of high-maintenance or labor-intensive systems by growers of large acreage crops may present a challenge in Georgia, and the annual removal of SDI tape may deter growers from installation of shallow SDI. Therefore more research is needed to evaluate the response of cotton to shallow and deep SDI and determine the most effective depth of SDI.

Materials and methods

Research experiments were conducted at the Stripling Irrigation Research Park (SIRP) near Camilla, Georgia on a Lucy loamy sand (loamy, kaolonitic, thermic, Arenic, Kandiudults). The cultivars evaluated were Delta & Pine Land (DP) 1050 B2RF (Monsanto Company, St. Louis, MO) and FiberMax (FM) 1740 B2F (Bayer CropScience, Research Triangle Park, NC). Deltapine 1050 B2RF is a mid- to full-season cultivar touted to perform well in dryland cotton conditions, whereas FM 1740 B2F is an early- to mid-season cultivar touted to perform well in conditions where water is sufficient. Cotton was grown in rows spaced 0.91 m apart, and each SDI plot was six rows wide with SDI lines installed 45 cm away from the crop row in alternate row middles. A two-row buffer was included on each side of each drip irrigation plot to prevent potential influences of adjacent-plot irrigation. Subsurface drip tape was 0.38 mm thick tape with 45 cm spaced emitters (Netafim, Fresno, California) installed at 5.5 and 30.5 cm below the soil surface. Preliminary field tests indicated an actual application rate of 0.25 cm per 113 minutes. To ensure an optimal stand among treatments, all plots were irrigated until emergence with the OVHD irrigation system. Irrigation for uniform seedling emergence required 5.1 cm in 2011 and 4.6 cm in 2012 (data not shown).

Treatments included the two aforementioned cultivars subjected to four irrigation treatments in both 5.5 cm tape (shallow) and 30.5 cm tape (deep). Two irrigation methods included irrigation applied to maintain soil moisture at two predetermined levels (-40 kPa and -70kPa) determined by Watermark™ moisture potential sensors (Model 200SS (MPS) (Irrometer Company Inc., Riverside, CA) with irrigation amounts based on one third of UGA's weekly water requirements for cotton (CHBK). Two irrigation methods were based on UGA's weekly water requirement where one third of the weekly requirement or 65% of that requirement was applied on Monday, Wednesday, and Friday of each week. Irrigations were adjusted based on the rainfall to ensure that cotton received 100% or 65% of the weekly requirement each week (rainfall was included by reducing irrigations for up to one week ahead but only up to 2.54 cm, any rainfall more than 2.54 was not counted towards weekly requirements) (Table 2.1). For comparison, a non-irrigated dryland cotton check was included in the study. Water was applied simultaneously in both the shallow and deep SDI for each irrigation treatment.

Watermark™ Soil Moisture Sensors, Model 200SS with Model 950T radio transmitters and Model 950R receivers (Irrometer Company Inc., Riverside, CA) were used to monitor soil moisture in four replicates in this experiment. Sensors measured soil moisture potential and data were viewable via Irrometer Company's online portal. An example of this data is illustrated in theAppendix (A.1). Sensors were buried in the crop row at 30 cm and 45 cm deep, however irrigations were triggered based on the 30 cm sensors. Rainfall was also monitored and CHBK irrigations were adjusted accordingly (Table 2.3). All other agronomic practices were conducted according to the University of Georgia Cooperative Extension Service Guidelines (Collins eds., 2013).

The experimental design was a randomized complete block design, with a factorial arrangement between irrigation treatments and a dryland cotton check added, with five irrigation treatments and six replications. Plots were 12 m long and three m wide with one m borders. The number of main-stem nodes was recorded on five plants per plot bi-weekly. Upon anthesis, plant height and main-stem nodes above the highest first-position white flower (NAWF) were recorded on five plants per plot weekly. Two rows of each plot were reserved for machine harvesting using a two-row John Deere model 9930 spindle cotton harvester (Deere and Company, Moline IA). Seed cotton samples were ginned and weighed at the University of Georgia Micro-gin for lint yield, lint percentage, and subsamples were sent to the USDA Classing office in Macon, GA for high volume instrumentation (HVI) fiber quality analysis. Data were subjected to analysis of variance (ANOVA) and means were separated using Fisher's Protected LSD at $p \leq 0.05$ or 0.1 based upon practicality using SAS version 9.2 (SAS Institute, Cary, NC, USA).

Results

Table 2.2 illustrates irrigation rates applied in both shallow and deep SDI for each irrigation treatment. Plots with shallow and deep SDI tape were tied into the same main line, therefore, therefore irrigations were applied simultaneously for each irrigation treatment in both shallow and deep SDI. Rainfall totaled 38.9 cm in 2011 and 43.1 cm in 2012. In both 2011 and 2012, both sensor-based irrigation treatments (triggered at -40 or -70 kPa) required less water than both the 65 and 100 percent Checkbook methods.

Illustrating the main effect of SDI tape depth, averaged over irrigation method and variety on lint yield, lint yield advantage over dryland cotton, lint yield per cm total water applied, and lint yield advantage over dryland cotton per cm irrigation water applied at Stripling Irrigation Research Park in 2011 and 2012 is shown in Table 2.5. When pooled over irrigation treatments and cultivars, irrigation using shallow (5.5 cm) SDI resulted in three and 12 percent higher yields than that of deep (30.5 cm) SDI in 2011 and 2012 respectively. A similar effect was observed in lint yield advantage over dryland cotton in which shallow SDI resulted in a yield advantage of 11 and 39 percent higher than that of deep SDI in 2011 and 2012, respectively. As measure of water use efficiency, lint yield per cm total water (irrigation and rainfall) applied associated with shallow SDI was three and 11 percent higher than that of deep SDI in 2011 and 2012 respectively, and lint yield advantage over dryland cotton per cm irrigation water applied was 13 and 28 percent higher than that of deep SDI in 2011 and 2012 respectively, suggesting that shallow SDI is significantly more efficient than deep SDI when irrigating using similar amounts of water.

The interaction between SDI depth and irrigation treatment for lint yield, yield advantage over dryland cotton, and lint yield advantage over dryland cotton per cm irrigation water applied is shown in Table 2.6. There was no significant interaction of SDI depth and irrigation treatment for any of the aforementioned parameters in 2011. In 2012, lint yields were similar between shallow and deep SDI for irrigation triggered at both -40 and -70 kPa, however irrigating according to the 100 and 65 percent Checkbook methods using shallow SDI resulted in 20 and

24 percent higher yields than that of deep SDI, suggesting that SDI depth has greater impact on yield when greater irrigation rates are used. A similar effect was observed for yield advantage over dryland cotton in 2012, in that the yield advantages of the -40 and -70 kPa trigger methods were similar between shallow and deep SDI, however irrigating according to the 100 and 65 percent Checkbook methods using shallow SDI resulted in 60 and 90 percent higher yield advantages than that of deep SDI, further suggesting that SDI depth has greater impact on yield when higher irrigation rates are used. In 2011, 11.9 and 18.5 cm irrigation water was applied to the 100 and 65 Checkbook methods respectively, whereas 10.4 and 6.1 cm was applied in the -40 and -70 kPa sensor-based trigger irrigation methods respectively. In 2012, 10.8 and 19.4 cm irrigation water was applied to the 100 and 65 Checkbook methods respectively, whereas 7.7 and 6 cm was applied in the -40 and -70 kPa sensor-based trigger irrigation methods respectively. There was no significant interaction of SDI depth and irrigation treatment for lint yield advantage over dryland cotton per cm irrigation water applied in either year. A similar effect was observed for plant height, total nodes per plant, and total bolls per plant (Table 2.7).

Conclusions

Results from this experiment clearly demonstrate that shallow SDI can result in significantly greater yields, yield advantage over dryland cotton, and water efficiency parameters such as lint yield per cm total water applied and yield advantage over dryland cotton per cm irrigation water applied. These data is similar to the findings of (Sorensen et al., 2010, 2012), however in this experiment, the increases in the aforementioned parameters observed in shallow SDI only occurred when using irrigation treatments such as the Checkbook methods that utilized higher rates of irrigation water than sensor-based irrigation. Water was applied at the same rates and times in both shallow and deep SDI for each irrigation treatment in this experiment, thereby suggesting that water usage is more efficient in shallow SDI compared to deep SDI. Some plant mapping parameters suggested that later maturing cultivars may be result in more sufficient growth compared to earlier maturing cultivars when deep SDI is used, however this was unclear. Despite these findings, deep SDI would likely be preferred by growers who commonly produce peanuts in rotation with cotton, due to tillage practices or other restrictions as well as the fact that shallow tape is not as economical due to the fact that deep tape would be used for multiple years..

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Table 2.1. Weekly suggested irrigation rates (cm per week) of recommended rates according to the UGA Checkbook. The rates for application via subsurface drip irrigation are shown as cm per day.

Growth Stage	**100% UGA Checkbook**		**65% UGA Checkbook**	
	cm per week	cm per day applied on M[z], W, F	cm per week	cm per day applied on M, W, F
Prior to Bloom	2.54	0.85	1.65	0.55
First week of bloom	2.54	0.85	1.65	0.55
Second week of bloom	3.81	1.27	2.48	0.83
Third week of bloom	5.08	1.69	3.30	1.10
Fourth week of bloom	5.08	1.69	3.30	1.10
Fifth week of bloom	3.81	1.27	2.48	0.83
Sixth week of bloom	3.81	1.27	2.48	0.83
Seventh weed of bloom	2.54	0.85	1.65	0.55
Eighth week of bloom	2.54	0.85	1.65	0.55
End of bloom – first open boll	1.91	0.64	1.22	0.41

[z] M, W, F denotes day of week: Monday, Wednesday and Friday

Table 2.2. Total season-long irrigation and rainfall for each irrigation treatment at Stripling Irrigation Research Park near Camilla, Georgia.

Irrigation Treatment	2011	2012
	——cm——	
Dryland cotton Control	0.00	0.00
Subsurface Drip Irrigation (-40 kPa trigger)	10.41	7.72
Subsurface Drip Irrigation (-70 kPa trigger)	6.10	5.99
Subsurface Drip Irrigation (100% of Checkbook)	18.54	19.43
Subsurface Drip Irrigation (65% of Checkbook)	11.94	10.78
Rainfall	38.86	43.10

Table 2.3 Total rainfall and irrigation per week in cm at Stripling Irrigation Research Park near Camilla, Ga in 2011

Weeks after planting	Growth Stage	Dryland cotton	Shallow 100%	Shallow 65%	Shallow -40 kPa	Shallow -70 kPa	Deep 100%	Deep 65%	Deep -40 kPa	Deep -70 kPa	Rainfall
1	Pre Bloom	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2	Pre Bloom	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
3	Pre Bloom	0.0	0.762	0.5	0.0	0.0	0.8	0.0	0.762	0.5	0.0
4	Pre Bloom	0.0	0.8	0.5	0.0	0.0	0.8	0.0	0.8	0.5	0.0
5	Pre Bloom	0.0	0.3	0.2	0.0	0.0	0.3	0.0	0.3	0.2	0.0
6	Pre Bloom	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
7	Pre Bloom	0.0	1.0	0.7	0.0	0.0	1.0	0.0	1.0	0.7	0.0
8	First Bloom (FB)	0.0	1.3	0.8	2.4	1.7	1.3	0.0	1.3	0.8	2.4
9	FB+1 week	0.0	2.8	1.8	0.0	0.0	2.8	0.0	2.8	1.8	0.0
10	FB+2 week	0.0	1.2	0.8	1.7	0.0	1.2	0.0	1.2	0.8	1.7
11	FB+3 week	0.0	3.4	2.2	3.0	1.7	3.4	0.0	3.4	2.2	3.0
12	FB+4 week	0.0	1.3	0.8	0.0	1.3	1.3	0.0	1.3	0.8	0.0
13	FB+5 week	0.0	3.3	2.1	2.0	0.0	3.3	0.0	3.3	2.1	2.0
14	FB+6 week	0.0	1.4	0.9	1.4	0.8	1.4	0.0	1.4	0.9	1.4
15	FB+7 week	0.0	1.1	0.6	0.0	0.6	1.1	0.0	1.1	0.6	0.0

Table 2.4 Total rainfall and irrigation per week in cm at Stripling Irrigation Research Park near Camilla, Ga in 2012

Weeks after planting	Growth Stage	Dryland cotton	Shallow 100%	Shallow 65%	Shallow -40 kPa	Shallow -70 kPa	Deep 100%	Deep 65%	Deep -40 kPa	Deep -70 kPa	Rainfall
1	Pre Bloom	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2	Pre Bloom	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
3	Pre Bloom	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
4	Pre Bloom	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
5	Pre Bloom	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
6	Pre Bloom	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
7	Pre Bloom	0.0	1.2	0.7	0.0	0.0	1.2	0.0	1.2	0.7	0.0
8	First Bloom (FB)	0.0	1.8	1.2	0.0	0.0	1.8	0.0	1.8	1.2	0.0
9	FB+1 week	0.0	0.4	0.0	0.0	0.0	0.4	0.0	0.4	0.0	0.0
10	FB+2 week	0.0	1.5	1.0	0.0	0.0	1.5	0.0	1.5	1.0	0.0
11	FB+3 week	0.0	4.1	2.6	1.7	0.9	4.1	0.0	4.1	2.6	1.7
12	FB+4 week	0.0	4.1	2.6	4.7	3.9	4.1	0.0	4.1	2.6	4.7
13	FB+5 week	0.0	1.9	0.4	1.3	1.3	1.9	0.0	1.9	0.4	1.3
14	FB+6 week	0.0	2.3	1.5	0.0	0.0	2.3	0.0	2.3	1.5	0.0
15	FB+7 week	0.0	0.8	0.3	0.0	0.0	0.8	0.0	0.8	0.3	0.0

Table 2.5. The effects of subsurface drip irrigation (SDI) tape depth on lint yield, lint yield advantage over dryland cotton, lint yield per cm total water applied, and lint yield advantage over dryland cotton per cm irrigation water applied at Stripling Irrigation Research Park during 2011 and 2012.[z]

Subsurface Drip Depth	Lint yield		Lint yield advantage over dryland cotton		Lint yield per cm total water applied		Lint yield advantage over dryland cotton per cm irrigation water applied	
	2011	2012	2011	2012	2011	2012	2011	2012
	kg ha^{-1}							
Deep (30.5 cm)	1693 b	1054 b	492 b	211 b	33.5 b	13.2 b	44.6 b	28.2 b
Shallow (5.5 cm)	1744 a	1176 a	545 a	293 a	34.4 a	14.6 a	50.3 a	36.2 a
p-value	0.0589	0.0009	0.0589	0.006	0.0807	0.0031	0.0466	0.0204

[z] Data are pooled over cultivars and irrigation treatments. Means within a column followed by dissimilar letters are significantly different based on Fisher's Protected LSD test at α = 0.05 or 0.1.

Table 2.6. The effects of subsurface drip irrigation (SDI) tape depth and irrigation treatment on lint yield, lint yield advantage over dryland cotton, and lint yield advantage over dryland cotton per cm irrigation water applied at Stripling Irrigation Research Park and during 2011 and 2012.^{z}

Subsurface Drip Depth^{z}	Irrigation Treatment	Lint yield		Yield advantage over dryland cotton		Lint yield advantage over dryland cotton per cm irrigation water applied	
		2011	2012	2011	2012	2011	2012
			kg ha^{-1}				
Deep (30.5 cm)	100% Checkbook	1768	1109 cd	568	248 bcd	30.5	14.6
Deep (30.5 cm)	– 40 kPa trigger	1719	1170 bc	519	288 b	49.4	51.2
Deep (30.5 cm)	65% Checkbook	1777	1008 de	577	181 cde	48.1	20.3
Deep (30.5 cm)	– 70 kPa trigger	1504	928 e	305	127 e	50.7	26.9
Shallow (5.5 cm)	100% Checkbook	1842	1328 a	641	396 a	34.4	25.6
Shallow (5.5 cm)	– 40 kPa trigger	1811	1141 bc	611	270 bc	58.3	47.7
Shallow (5.5 cm)	65% Checkbook	1746	1252 ab	546	343 ab	45.5	43.3
Shallow (5.5 cm)	– 70 kPa trigger	1580	983 e	379	164 de	63.1	28.7
p-value		NS	0.0209	NS	0.0862	NS	NS

[z] Data are pooled over cultivars. Means within a column followed by dissimilar letters are significantly different based on Fisher's Protected LSD test at α = 0.05 or 0.1.

Chapter 3

Comparison of Sensor-Based Irrigation to Weekly Checkbook Irrigation Methods in Subsurface Drip Irrigation

Introduction

Several irrigation scheduling techniques are currently available to cotton producers in the Southeastern US. Such techniques include utilization of wireless moisture sensors that are viewable to the user via online data portals on modern smart phones, using volumetric water sensors that require daily downloads to view data. There is also the University of Georgia's EASY Pan™ that gives a visual representation of evapotranspiration (ET) for most crops in Georgia such as cotton, to simply replacing ET with data from Georgia Automated Environmental Monitoring Network. Research in Georgia conducted by Sorensen et al. (2012) investigated replacement of the estimated water used by the cotton crop. This was achieved by calculating the ET of the local micro-environment and using crop coefficients determined by Harrison and Tyson (1993). The estimated water use in their research was replaced at a rate of 100 percent, 75 percent, and 50 percent to determine optimum irrigation levels for Subsurface Drip Irrigation (SDI). Precipitation was subtracted from the daily ET to account for rainfall amounts (Sorensen et al., 2012). These authors found that replacement of 75 percent of the estimated water utilized by the crop resulted in the highest yields (Sorensen et al., 2012). The replacement of 75 percent of estimated crop water utilization consistently yielded higher than the 100 percent replacement in their research with similar yields, suggesting potential water savings of 25 percent with using a SDI system and triggering irrigation via ET readings as compared to 100 percent ET replacement. This also suggest that simply replacing ET via SDI may be excessive in some situations, therefore other methods of determining cotton water requirements may be needed.

Although ET calculations can be made easily if the tools are available, some producers often encounter time, equipment or information limitations when attempting to calculate estimated water use of cotton, therefore moisture potential sensors may be an economically viable alternative for which to schedule irrigation. Sensors that use gypsum moisture blocks can be economical and user-friendly as they require little maintenance and need not to be calibrated to the specific soil type since moisture potential is measured (Muñoz-Carpena, 2004). Moisture potential sensors, such as Watermark sensors, also have an advantage for producers since they do not have to be calibrated for each specific soil type in a grower's field whereas moisture sensors that use electrical conductance would require calibration (Muñoz-Carpena, 2004). Moisture potential sensors allow users to observe the degree of soil moisture (level of soil wetness or dryness) which provides insight regarding when irrigation should be resumed (Muñoz-Carpena, 2004; Whitaker et al., 2006; Vellidis et al., 2007). Sensors that measure volumetric water content are more dependent on soil type and require calibration, however field observations suggests they often respond more rapidly to changes or fluctuations in soil moisture.

Other techniques such as one from Netafim™ (Netafim, Fresno, CA) currently offers a cotton production manual that provides recommendations but these recommendations are considered to be very general by extension specialists and not specific for the growing conditions often observed in Georgia. These recommendations are based on ET replacement depending on cotton growth stage and are recommended to be evaluated either with tensiometers or moisture potential sensors to observe the amount of useable water from rainfall events (Netafim Cotton Production Manual, 2012).

Originally developed separately for high yield goals and moderate yield goals, tables developed by irrigation engineer, Gene Siegler, and subsequently modified by Bednarz et al. (2002), known as UGA's weekly water requirement for cotton in Georgia, indicate weekly water requirements of cotton produced in Georgia. Irrigation scheduling which utilizes this table is often referred to as a checkbook (CHBK) method and is illustrated in Table 3.1, which provides weekly requirements based on plant growth stage, with water requirements increasing after first bloom, peaking during mid-bloom, and gradually decreasing during late bloom (Collins eds., 2013). This method has been recently modified, as modern cultivars have shown little positive response to the weekly rates described in the higher yield goal scenario (Ritchie eds., 2009). Computer models are also available to producers, including Irrigator Pro™ which is a computerized model designed to manage peanut and cotton irrigation with recommendations based on over 20 years of scientific research data (Irrigator Pro ™, 2013). This program accounts for planting date, cultivar planted, previous crop, soil type, and irrigation capacity, and utilizes digital soil thermometers to collect minimum/maximum soil temperatures as well as rain gauges to account for rainfall. Recommendations for cotton are based upon the physiological needs of the plant at various stages of development and take advantage of soil moisture sensors. This model differs from the peanut model by requiring the use of soil moisture potential sensors installed at depths of 8", 16", and 24". The Irrigator Pro™ model essentially models the irrigation requirements with soil temperature data and moisture sensor data to give the most accurate recommendations for cotton producers.

Many growers in Georgia have little access to timely remote technology, therefore rely on irrigation practices that can be conducted independently of such technology, such as the CHBK method. However, installation of soil moisture sensors could allow for potential water savings, by allowing the producers to cease or resume irrigation as the sensors suggests. These sensors monitor actual soil moisture below the soil surface and allow water savings by helping to irrigate cotton prior to the wilting point is reached, while avoiding irrigation if soil moisture is sufficient due to rainfall. Sensors may also allow users to account for variation in soil type, as some soils may retain water from rainfall for a longer period of time than other soils.

Overhead (OVHD) systems apply water directly to the soil surface whereas SDI systems apply water below the soils surface. Efficiency with SDI has been observed to approach 100 percent (Schneider et al., 2001) whereas OVHD can be as low as 65% (Perlman, 2013). Due to this fact, research is needed to determine optimal application rates for SDI systems or if less water can be applied in SDI systems due to its greater efficiency compared to irrigation methods currently utilized by OVHD systems. Sensor-based irrigation scheduling also must be evaluated and compared to the CHBK method due to the fact that there are varying levels of technology among growers, and to determine if soil moisture thresholds utilized in OVHD systems also apply to SDI systems. The use of sensors would require frequent monitoring by the grower or a consultant; however the potential water savings or decreased pumping costs could offset this additional requirement. Several methods (soil moisture sensor systems such as Watermark sensors, and CHBK scheduling) have been evaluated in Georgia for OHVD systems (Whitaker et al. 2006, Ritchie eds. 2009). Since SDI systems operate using more frequent applications of lower irrigation rates, typically resulting in water savings (Whitaker et al., 2008), the investigation of these techniques in SDI systems is warranted to determine optimal irrigation strategies for an SDI system. The objectives of this research was to determine optimal irrigation strategies for both checkbook and sensor based methods and compare the observed water savings and yield responses.

Materials and methods

Research experiments were conducted at the Stripling Irrigation Research Park (SIRP) near Camilla, Georgia, and Southeast Georgia Research and Education Center (SEGREC) near Midville, GA during 2011 and 2012. The soil at SIRP was a Lucy loamy sand (loamy, kaolonitic, thermic, Arenic, Kandiudults) and the soil at SEGREC was a Dothan loamy sand (loamy, kaolonitic, thermic, Arenic, Kandiudults). The cultivars evaluated were Deltapine (DP) 1050 B2RF and Fibermax (FM) 1740 B2F. Deltapine 1050 B2RF is a mid to full season cultivar touted to perform well in dryland cotton conditions, whereas FM 1740 B2F is an early to mid season cultivar touted to perform well in conditions where water is sufficient. Cotton was grown in rows spaced 0.91 m apart, and each SDI plot was six rows wide with SDI lines installed 45 cm away from the crop row in alternate row middles. A two-row buffer was included on each side of each drip irrigation plot to prevent potential influences of adjacent-plot irrigation. Subsurface drip tape was 0.38 mm thick tape with 45 cm spaced emitters (Netafim, Fresno, California) installed at 30.5 cm below the soil surface. This system had an application rate of 0.25 cm per 75 minutes at SEGREC; however SIRP had an application rate of 0.25 cm per 113 minutes.

Treatments included the two aforementioned cultivars subjected to the following irrigation treatments: Watermark moisture potential sensors (Model 200SS (MPS); (Irrometer Company Inc., Riverside, CA) with water applied at one third of the weekly rates on Monday, Wednesday, and Friday according to 100 percent of UGA Checkbook (CHBK) recommendations only when triggered at -40 kPa and -70 kPa via MPS (Table 3.1); irrigation applied at one third of the weekly rates for three alternate days according to 100 and 65 percent of UGA CHBK recommendations (Table 3.1) without sensor-based triggering, and a dryland cotton control.

Watermark Soil Moisture Sensors, Model 200SS with Model 950T radio transmitters and Model 950R receivers (Irrometer Company Inc., Riverside, CA) were used to monitor soil moisture in four replicates in this experiment. Sensors measured soil moisture potential and data were viewable via Irrometer Company's online portal. An illustration of this data is located in the Appendix (A.1). Sensors were buried in the crop row at 30 cm and 45 cm deep, however irrigations were triggered based on the 30 cm sensors. Rainfall was also monitored and CHBK irrigations were adjusted accordingly (Table 3.4). To ensure an equal stand among treatments, all plots were irrigated until emergence with the OVHD irrigation system. Irrigation for uniform seedling emergence required 5.1 cm in 2011 and 4.6 cm in 2012 (data not shown). All other agronomic practices were conducted according to the University of Georgia Cooperative Extension Service Guidelines (Collins eds., 2013).

The experimental design was a randomized complete block design, with a factortial arrangement between irrigation treatments and a dryland cotton check added, with five irrigation treatments and four replications.. Plots were 12 m long and three m wide with one m borders. The number of main-stem nodes was recorded on five plants per plot bi-weekly. Upon anthesis, plant height and main-stem nodes above the highest first-position white flower (NAWF) were recorded on five plants per plot weekly. Two rows of each plot were reserved for harvesting and machined picked. Seed cotton samples were ginned and weighed at the University of Georgia Micro-gin for lint yield, lint percentage, and subsamples were sent to the USDA Classing office in Macon, GA for high volume instrumentation (HVI) fiber quality analysis. Data were subjected to analysis of variance (ANOVA) and means were separated using Fisher's Protected LSD at $p \leq 0.05$ or 0.1 for practicality using SAS version 9.2 (SAS Institute, Cary, NC, USA).

Results

Illustrated in Table 3.2 are the irrigation rates applied in each irrigation treatment during 2011 and 2012. Rainfall at SIRP was 38.9 cm in 2011 and 43.1 cm in 2012. At SIRP, sensor-based irrigation treatments triggered at -40 or -70 kPa required 44 and 49 percent less water than the 100 and 65 percent Checkbook methods in 2011, and 60 and 44 percent less water than these same treatments in 2012. Rainfall at SEGREC was 18.0 cm in 2011 and 36.6 cm in 2012. At SEGREC, sensor-based irrigation treatments triggered at -40 kPa required 0.8 percent less water than the 100 percent Checkbook method and 15 percent more than the 65 percent Checkbook methods in 2011, and in 2012, irrigation triggered at -40 kPa required 49 percent less water than the 100 and 15 percent more than the 65 percent Checkbook methods.

Table 3.5 illustrates lint yield responses to irrigation treatment at SIRP and SEGREC during 2011 and 2012. At SIRP in 2011, all irrigation treatments resulted in 25 to 48 percent increases in yield compared to the dryland cotton control, although triggering irrigation at -70 kPa resulted in 13 to 15 lower yields compared to both the 100 and 65 percent Checkbook methods and triggering irrigation at a higher soil moisture threshold of -40 kPa. At SIRP in 2012, all irrigation treatments resulted in 26 to 59 percent higher yields than the dryland cotton control, however triggering irrigation at -70 kPa resulted in similar yield to the 65 percent Checkbook method, but had 16 and 20 percent lower yields than the 100 percent Checkbook method and triggering irrigation at -40 kPa, respectively. All irrigation treatments resulted in 153 to 203 percent greater lint yields than the dryland cotton control at SEGREC in 2011, with the 100 percent Checkbook method resulting in 20 percent higher yields than the 65 percent Checkbook method. Yields were similar between the -40 and -70 kPa trigger methods. At SEGREC in 2012, nearly all irrigation treatments resulted in similar yields to the dryland cotton control, due to the significant rainfall that occurred during that year. The 65 percent Checkbook method resulted in 13 percent lower yields than the dryland cotton control during that year.

The effects of irrigation treatment on lint yield advantage over dryland cotton at SIRP and SEGREC during 2011 and 2012 is illustrated in Table 3.6. At SIRP in 2011, triggering irrigation at -70 kPa resulted in 41 to 47 lower yield advantages than all other irrigation treatments. At SIRP in 2012, triggering irrigation at -40 kPa resulted in 56 percent greater yield advantage than irrigation triggered at -70 kPa, however similar yield advantages were observed between the 65 and 100 percent Checkbook methods. At SEGREC in 2011, the 100 percent Checkbook method resulted in 13 to 33 percent greater yield advantages compared to irrigation triggered at -70 kPa and the 65 percent Checkbook method respectively. Yields were similar between both sensor based treatments, and were also similar between the 100 percent Checkbook method and irrigation triggered at -40 kPa. At SEGREC in 2012, all irrigation treatments resulted in negative yield advantages, with the most negative value resulting from the 65 percent Checkbook method. The 100 percent Checkbook method and irrigation triggered at -40 kPa resulted in higher yields and yield advantage over dryland cotton more frequently than the 65 percent Checkbook method and irrigation triggered at -70 kPa.

Table 3.7 illustrates the effect of irrigation treatment on lint yield advantage over dryland cotton per cm irrigation water applied at SIRP and SEGREC during 2011 and 2012. At SIRP in 2011, the 100 percent Checkbook method, which utilized more water than other treatments, resulted in 35 to 38 percent less yield advantage per cm irrigation water applied than all other irrigation treatments. At SIRP in 2012, irrigation triggered at -40 kPa resulted in 75 to 195 percent greater yield advantage per cm irrigation water applied than all other treatments. At SEGREC in 2011, the 65 percent Checkbook method resulted in 26 to 32 percent higher yield advantage per cm irrigation water applied than all other treatments. There was no positive yield advantage per cm irrigation water applied for any irrigation treatment at SEGREC in 2012, likely resulting from the significant rainfall that occurred at SEGREC during that year. In 2011, the 65 percent Checkbook method resulted in greater efficiency than the 100 percent Checkbook method at both locations, although similar values were observed between the sensor-based irrigation trigger methods. At SIRP in 2012, irrigation triggered at -40 kPa resulted in 75 percent greater efficiency than irrigation triggered at -70 kPa.

Lint yields per cm total water (rainfall and irrigation) applied for each irrigation treatment and the dryland cotton control at SIRP and SEGREC during 2011 and 2012 is shown in Table 3.8. At SIRP in 2011, lint yield per total cm water applied was similar between irrigation triggered at both -40 and -70 kPa, however the 65 percent Checkbook resulted in 11 percent greater lint yield per total water applied than the 100 percent Checkbook. Both irrigation triggered at -40 kPa and the 65 percent Checkbook method resulted in 11 percent greater lint yield per total water applied than the 100 percent Checkbook and the dryland cotton control. At SIRP in 2012, irrigation triggered at -40 kPa resulted in 21 to 35 percent greater lint yield per total water applied than all other treatments, and 21 percent greater values than irrigation triggered at -70 kPa. Similar values between the Checkbook methods were observed at that site-year. At SEGREC in 2011, all irrigation treatments resulted in 15 to 38 percent greater lint yield per total water applied than the dryland cotton control, with the 65 percent Checkbook method resulting in 18 percent greater values than that of the 100 percent Checkbook method and similar values between irrigation triggered at -40 and -70 kPa. At SEGREC in 2012, all irrigation treatments resulted in 7 to 24 percent less lint yield per total water applied than the dryland cotton control, however irrigation triggered at -70 kPa (which utilized less irrigation water than other irrigation treatments) resulted in 13 to 21 percent greater lint yield per total water applied than other irrigation treatments.

When pooled over irrigation treatments, FM 1740 B2F resulted in 9 and 4 percent greater yields than DP 1050 B2RF at SIRP and SEGREC respectively during 2011 (Table 3.9). Cultivars yielded similarly at SIRP in 2012, however at SEGREC in 2012, DP 1050 B2RF yielded 17 percent higher than FM 1740 B2F. FiberMax 1740 B2F resulted in 31, 132, and 12 percent greater lint yield advantage over dryland cotton compared to DP 1050 B2RF at SIRP (2011), SIRP (2012) and SEGREC (2011) respectively, however this cultivar resulted in a 496 percent disadvantage over dryland cotton compared to DP 1050 B2RF at SEGREC in 2012, suggesting that it is more responsive to irrigation, both positively and negatively (Table 3.10). This data also suggest that DP 1050 B2RF is less responsive to irrigation and is therefore more stable across environmental factors such as water. A similar cultivar effect was observed for lint yield advantage over dryland cotton per cm irrigation water applied (Table 3.12) with FM 1740 B2F resulting in 28, 147, and 10 percent greater efficiency than DP 1050 B2RF at SIRP (2011), SIRP (2012), and SEGREC (2011) respectively, however this cultivar demonstrated a 277 percent disadvantage over dryland cotton compared to DP 1050 B2RF at SEGREC in 2012. FiberMax 1740 B2F resulted in a 6 percent greater and 14 percent less lint yield per total water (rainfall and irrigation) applied compared to DP 1050 B2RF at SIRP in 2011 and SEGREC 2012 respectively, but cultivars responded similarly at SIRP 2012 and SEGREC 2011 (Table 3.11).

Conclusions

Yield responses to irrigation treatment were variable across site-years, therefore defining an optimal irrigation strategy for SDI may be difficult since no one method was distinctly superior. However, the greatest yield responses and yield advantage over dryland cotton were most consistently observed when irrigating according to the 100 percent Checkbook method and irrigation triggered at -40 kPa. In instances where the two aforementioned treatments resulted in similar yields, significant water savings resulted from the sensor-based method as irrigation was only applied when soil moisture fell below the threshold. With regard to efficiency of water applied, yield advantages over dryland cotton per cm irrigation water applied was also variable across site-years, although the 100 percent Checkbook method, which required the highest rates of irrigation water, was not among the most efficient methods. When observing lint yield per total water (rainfall and irrigation) applied, generally the 65 percent Checkbook and irrigation triggered at -40 kPa resulted in the greatest yields per unit water than most other treatments at most site years. Although Schneider et al., (2001) suggested that SDI efficiency may approach 100 percent, and Perlman (2013) suggested that OVHD efficiency could be as low as 65 percent, our findings suggested that irrigating at 65 percent of normal OVHD irrigation rates (100 percent Checkbook method) could result in suboptimal yields. This experiment also suggested that the earlier maturing cultivar, FM 1740 B2F, was more responsive to applied water (both positively and negatively), whereas the later maturing cultivar, DP 1050 B2RF, appeared to be less responsive, thus more stable across environments. Although responses of plant height, total nodes and bolls per plant were not consistent across environments, these parameters tended to be greater resulting from treatments that utilized more irrigation water.

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Table 3.1. Weekly suggested irrigation rates (cm per week) and 65 percent of recommended rates according to the UGA Checkbook. The rates for application via subsurface drip irrigation are shown as cm per day.

Growth Stage	**100% UGA Checkbook**		**65% UGA Checkbook**	
	cm per week	cm per day applied on M[z], W, F	cm per week	cm per day applied on M, W, F
Prior to Bloom	2.54	0.85	1.65	0.55
First week of bloom	2.54	0.85	1.65	0.55
Second week of bloom	3.81	1.27	2.48	0.83
Third week of bloom	5.08	1.69	3.30	1.10
Fourth week of bloom	5.08	1.69	3.30	1.10
Fifth week of bloom	3.81	1.27	2.48	0.83
Sixth week of bloom	3.81	1.27	2.48	0.83
Seventh weed of bloom	2.54	0.85	1.65	0.55
Eighth week of bloom	2.54	0.85	1.65	0.55
End of bloom – first open boll	1.91	0.64	1.22	0.41

[z] M, W, F denotes day of week: Monday, Wednesday and Friday

Table 3.2. Total season-long irrigation and rainfall for each irrigation treatment at Stripling Irrigation Research Park, Camilla Ga. and Southeast Georgia Research and Education Center, Midville Ga.

	Camilla	Camilla	Midville	Midville
Irrigation Treatment	2011	2012	2011	2012
	cm			
Dryland cotton Control	0.0	0.0	0.0	0.0
Subsurface Drip Irrigation (-40 kPa trigger)	10.4	7.7	29.6926	5.3
Subsurface Drip Irrigation (-70 kPa trigger)	6.1	6.0	15.7	0.8
Subsurface Drip Irrigation (100% of Checkbook)	18.5	19.4	29.9	10.8
Subsurface Drip Irrigation (65% of Checkbook)	11.9	10.8	25.8	4.4
Rainfall	38.9	43.1	18.0	36.6

Table 3.3 Rainfall and irrigation totals in cm for Stripling Irrigation Park near Camilla, Ga and Southeast Georgia Research and Education Center, near Midville Ga for 2011

Weeks after planting	Growth Stage	Midville 100%	Midville 65%	Midville -40 kPa	Midville -70 kPa	Camilla 100%	Camilla 65%	Camilla -40 kPa	Camilla -70 kPa	Midville Rainfall	Camilla Rainfall
1	Pre Bloom	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.14	0.0
2	Pre Bloom	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.3	0.0
3	Pre Bloom	0.8	0.5	0.0	0.0	0.8	0.5	0.0	0.0	0.8	0.0
4	Pre Bloom	0.8	0.5	0.0	0.0	0.8	0.5	0.0	0.0	1.4	3.4
5	Pre Bloom	0.3	0.2	0.0	0.0	0.3	0.2	0.0	0.0	1.8	3.2
6	Pre Bloom	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.1	2.0
7	Pre Bloom	1.0	0.7	0.0	0.0	1.0	0.7	0.0	0.0	2.0	1.3
8	First Bloom (FB)	1.3	0.8	2.4	1.7	1.3	0.8	2.4	1.7	1.3	5.7
9	FB+1 week	2.8	1.8	0.0	0.0	2.8	1.8	0.0	0.0	0.9	2.3
10	FB+2 week	1.2	0.8	1.7	0.0	1.2	0.8	1.7	0.0	0.3	2.4
11	FB+3 week	3.4	2.2	3.0	1.7	3.4	2.2	3.0	1.7	0.0	4.8
12	FB+4 week	1.3	0.8	0.0	1.3	1.3	0.8	0.0	1.3	1.5	0.0
13	FB+5 week	3.3	2.1	2.0	0.0	3.3	2.1	2.0	0.0	0.0	0.8
14	FB+6 week	1.4	0.9	1.4	0.8	1.4	0.9	1.4	0.8	0.7	0.0
15	FB+7 week	1.1	0.6	0.0	0.6	1.1	0.6	0.0	0.6	3.9	0.0

Table 3.4 Rainfall and irrigation totals in cm for Stripling Irrigation Park near Camilla, Ga and Southeast Georgia Research and Education Center, near Midville Ga for 2012

Weeks after planting	Growth Stage	Midville 100%	Midville 65%	Midville -40 kPa	Midville -70 kPa	Camilla 100%	Camilla 65%	Camilla -40 kPa	Camilla -70 kPa	Midville Rainfall	Camilla Rainfall
1	Pre Bloom	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.1
2	Pre Bloom	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.5	1.5
3	Pre Bloom	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.4
4	Pre Bloom	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	6.0	1.4
5	Pre Bloom	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.8	1.1
6	Pre Bloom	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.6
7	Pre Bloom	1.2	0.7	0.0	0.0	1.2	0.7	0.0	0.0	4.5	1.6
8	First Bloom (FB)	1.8	1.2	0.0	0.0	1.8	1.2	0.0	0.0	9.9	2.1
9	FB+1 week	0.4	0.0	0.0	0.0	0.4	0.0	0.0	0.0	3.1	2.7
10	FB+2 week	1.5	1.0	0.0	0.0	1.5	1.0	0.0	0.0	2.2	1.0
11	FB+3 week	4.1	2.6	1.7	0.9	4.1	2.6	1.7	0.9	3.2	1.4
12	FB+4 week	4.1	2.6	4.7	3.9	4.1	2.6	4.7	3.9	2.8	2.0
13	FB+5 week	1.9	0.4	1.3	1.3	1.9	0.4	1.3	1.3	0.0	5.4
14	FB+6 week	2.3	1.5	0.0	0.0	2.3	1.5	0.0	0.0	0.7	8.6
15	FB+7 week	0.8	0.3	0.0	0.0	0.8	0.3	0.0	0.0	1.4	5.4
16	END	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.1

Table 3.5. Lint yield response of cotton to irrigation treatment at Stripling Irrigation Research Park and Southeast Georgia Research and Education Center during 2011 and 2012.[z]

Irrigation Treatment	Lint yield			
	SIRP[y] 2011	SIRP 2012	SEGREC[x] 2011	SEGREC 2012
	kg ha^{-1}			
Dryland cotton control	1201 c	737 d	644 d	1364 a
100% UGA Checkbook	1768 a	1108 ab	1950 a	1358 a
-40 kPa Trigger Point	1720 a	1170 a	1891 ab	1279 a
65% UGA Checkbook	1777 a	1007 bc	1629 c	1187 b
-70 kPa Trigger Point	1505 b	928 c	1803 b	1283 a
p-value	<0.0001	<0.0001	<0.0001	0.0015

[z] Data are pooled over cultivars. Means within a column followed by dissimilar letters are significantly different based on Fisher's Protected LSD test at $\alpha = 0.05$.

[y] SIRP denotes Stripling Irrigation Research Park near Camilla, GA.

[x] SEGREC denotes Southeast Georgia Research and Education Center near Midville, GA.

Table 3.6. Effect of irrigation treatment on lint yield advantage over dryland cotton at Stripling Irrigation Research Park and Southeast Georgia Research and Education Center during 2011 and 2012.[z]

Irrigation Treatment	Lint yield advantage over dryland cotton			
	SIRP[y] 2011	SIRP 2012	SEGREC[x] 2011	SEGREC 2012
	kg ha^{-1}			
Dryland cotton control	…….	…….	…….	…….
100% UGA Checkbook	567 a	247 ab	1305 a	-6 a
-40 kPa Trigger Point	519 a	288 a	1246 ab	-85 a
65% UGA Checkbook	576 a	179 ab	983 c	-176 b
-70 kPa Trigger Point	304 b	127 b	1158 b	-81 a
p-value	<0.0001	0.0666	<0.0001	0.004

[z] Data are pooled over cultivars. Means within a column followed by dissimilar letters are significantly different based on Fisher's Protected LSD test at α = 0.05.

[y] SIRP denotes Stripling Irrigation Research Park near Camilla, GA.

[x] SEGREC denotes Southeast Georgia Research and Education Center near Midville, GA.

Table 3.7. The effect if irrigation treatment on lint yield response over dryland cotton per cm applied irrigation water at Stripling Irrigation Research Park and Southeast Georgia Research and Education Center during 2011 and 2012.[z]

Irrigation Treatment	Lint yield advantage over dryland cotton per cm irrigation water applied			
	SIRP[y] 2011	SIRP 2012	SEGREC[x] 2011	SEGREC 2012
	kg ha^{-1}			
Dryland cotton control	…….	…….	…….	…….
100% UGA Checkbook	31 b	19 b	39 b	-1 a
-40 kPa Trigger Point	49 a	56 a	37 b	-16 a
65% UGA Checkbook	48 a	25 b	49 a	-40 ab
-70 kPa Trigger Point	50 a	32 b	39 b	-107 b
p-value	0.0016	0.0031	<0.0001	0.0291

[z] Data are pooled over cultivars. Means within a column followed by dissimilar letters are significantly different based on Fisher's Protected LSD test at α = 0.05.

[y] SIRP denotes Stripling Irrigation Research Park near Camilla, GA.

[x] SEGREC denotes Southeast Georgia Research and Education Center near Midville, GA.

Table 3.8. The effect if irrigation treatment on lint yield per cm total applied water at Stripling Irrigation Research Park and Southeast Georgia Research and Education Center during 2011 and 2012.[z]

Irrigation Treatment	Lint yield per cm total water applied			
	SIRP[y] 2011	SIRP 2012	SEGREC[x] 2011	SEGREC 2012
	kg ha^{-1}			
Dryland cotton control	31 b	17 b	34 c	38 a
100% UGA Checkbook	31 b	18 b	40 b	29 c
-40 kPa Trigger Point	35 a	23 a	39 b	31 c
65% UGA Checkbook	35 a	19 b	47 a	29 c
-70 kPa Trigger Point	34 ab	19 b	40 b	35 b
p-value	0.0041	0.0046	<0.0001	<0.0001

[z] Data are pooled over cultivars. Means within a column followed by dissimilar letters are significantly different based on Fisher's Protected LSD test at α = 0.05.

[y] SIRP denotes Stripling Irrigation Research Park near Camilla, GA.

[x] SEGREC denotes Southeast Georgia Research and Education Center near Midville, GA.

Table 3.9. Lint yield for each cultivar at Stripling Irrigation Research Park and Southeast Georgia Research and Education Center during 2011 and 2012.[z]

Variety	Lint yield			
	SIRP[y] 2011	SIRP 2012	SEGREC[x] 2011	SEGREC 2012
	kg ha^{-1}			
FiberMax 1740 B2F	1662 a	1014	1611 a	1194 b
Deltapine 1050 B2RF	1526 b	966	1556 b	1395 a
p-value	0.0011	NS	0.0819	<0.0001

[z] Data are pooled over irrigation treatment. Means within a column followed by dissimilar letters are significantly different based on Fisher's Protected LSD test at α = 0.05 and 0.1.

[y] SIRP denotes Stripling Irrigation Research Park near Camilla, GA.

[x] SEGREC denotes Southeast Georgia Research and Education Center near Midville, GA.

Table 3.10. Lint yield advantage over dryland cotton for each cultivar at Stripling Irrigation Research Park and Southeast Georgia Research and Education Center during 2011 and 2012.[z]

Variety	Lint yield advantage over dryland cotton			
	SIRP[y] 2011	SIRP 2012	SEGREC[x] 2011	SEGREC 2012
	kg ha^{-1}			
FiberMax 1740 B2F	558 a	295 a	1240 a	-149 b
Deltapine 1050 B2RF	425 b	127 b	1106 b	-25 a
p-value	0.001	0.0006	0.0007	0.0003

[z] Data are pooled over irrigation treatment. Means within a column followed by dissimilar letters are significantly different based on Fisher's Protected LSD test at $\alpha = 0.05$.

[y] SIRP denotes Stripling Irrigation Research Park near Camilla, GA

[x] SEGREC denotes Southeast Georgia Research and Education Center near Midville, GA.

Table 3.11. Lint yield increase over dryland cotton per cm irrigation water applied at Stripling Irrigation Research Park and Southeast Georgia Research and Education Center during 2011 and 2012.[z]

Variety	Lint yield advantage over dryland cotton per cm irrigation water applied			
	SIRP[y] 2011	SIRP 2012	SEGREC[x] 2011	SEGREC 2012
	kg ha^{-1}			
FiberMax 1740 B2F	50 a	47 a	43 a	-64 a
Deltapine 1050 B2RF	39 b	19 b	39 b	-17 b
p-value	0.0039	0.0002	0.0067	0.0689

[z] Data are pooled over irrigation treatment. Means within a column followed by dissimilar letters are significantly different based on Fisher's Protected LSD test at α = 0.05.

[y] SIRP denotes Stripling Irrigation Research Park near Camilla, GA

[x] SEGREC denotes Southeast Georgia Research and Education Center near Midville, GA.

Table 3.12. Lint yield increase over dryland cotton per cm total water applied at Stripling Irrigation Research Park and Southeast Georgia Research and Education Center during 2011 and 2012.[z]

variety	Lint yield per cm total water applied			
	SIRP[y] 2011	SIRP 2012	SEGREC[x] 2011	SEGREC 2012
	kg ha^{-1}			
FiberMax 1740 B2F	34 a	20	40	30 b
Deltapine 1050 B2RF	32 b	19	40	35 a
p-value	0.0037	NS	NS	<0.0001

[z] Data are pooled over irrigation treatment. Means within a column followed by dissimilar letters are significantly different based on Fisher's Protected LSD test at α = 0.05.

[y] SIRP denotes Stripling Irrigation Research Park near Camilla, GA

[x] SEGREC denotes Southeast Georgia Research and Education Center near Midville, GA.

Appendix

Table A.1- Illustration of moisture sensor data for irrigation triggering.