WATER USE EFFICIENCY AND IRRIGATION RESPONSE OF COTTON CULTIVARS GROWN ON SUB-SURFACE DRIP IN WEST TEXAS

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Abstract

Decreasing water availability has led to research on the water use requirements of most agronomic crops, as well as the yield and quality impacts of deficit irrigation. Some drought-tolerant crops, including cotton (*Gossypium hirsutum* L.) can adapt well to deficit irrigation. The purpose of this study is to determine which cultivars perform better under deficit irrigation. The main objectives for this research include: (i) evaluating water use efficiency (WUE) and boll distribution of cotton cultivars at different rates of sub-surface drip irrigation (SDI); (ii) comparing yield, WUE and boll distribution between cultivars at varying irrigation levels; and (iii) determining the cultivar with best yield stability under deficit irrigation to reduce irrigation water use without affecting yield in West Texas. The experimental design of the project was a split plot design with irrigation as the main plot and cultivar as the sub plot. Yield, WUE and boll distribution data were gathered during 2010 and 2011 and analyzed using proc GLIMMIX in SAS 9.2. In 2010 cultivars DP1044 and FM9160 performed very well under deficit irrigation. In 2011 cultivar DP1044 again was a top performer along with DP0935 and DP0924. Boll distribution patterns where highly variable between cultivars and within irrigation regimes. These results suggest that DP1044 could be a good cultivar selection for the Texas High Plains where water is limited to reduce water use while maintaining good yield stability.

Introduction

The Texas High Plains annually produces 25% of the entire U.S. cotton crop, and cotton is the leading cash crop in Texas. Irrigated cotton yields for Lubbock county and the 25-county area around Lubbock have been increasing since 1986 (Wanjura et al., 2002) and the dependence of crop yields on water supply is becoming a critical issue with the limited water resources in the Lubbock area. The Ogallala aquifer is one of the largest aquifer systems in the world, containing 3.5 billion acre-feet of water and underlying 174,000 square miles across South Dakota, Nebraska, Wyoming, Colorado, Kansas, Oklahoma, New Mexico, and Texas (Torell et al., 1990). Over 90% of withdrawals from the Ogallala in the Texas High Plains are for irrigated agriculture; therefore it is essential that water be used as efficiently as possible to maintain irrigated crop production. The reversion to non-irrigated farming in the West Texas area will result in a significant amount of total cotton production in Texas as well as the United States to be lost.

Irrigation Scheduling with Evapotranspiration Estimates

Determining accurate, efficient, and repeatable rates of irrigation is difficult, because environmental factors and soil type can affect the amount of irrigation that is needed by the crop. One solution to this challenge is the use of a reference measure of evapotranspiration (ET_o), calculated from a standardized reference surface under ambient environmental conditions. Relating ET to a specific surface allows ET to be transferable across different environments. Therefore, the only factors affecting ET_o are climatic parameters, including temperature, solar radiation, relative humidity, and wind speed, which can be computed from weather data using the FAO Penman-Monteith equation (Allen et al., 1998).

A crop coefficient (K_c) can be applied by expressing the difference in ET between a crop (ET_c) and the hypothetical grass surface. This allows correction for specific growth stages to obtain an estimate of crop water use. Howell et al. (2004) used a crop coefficient model based on the accumulation of heat units over the growing season as growing degree days (GDD), instead of a model solely based on days after planting. This procedure has been used to more accurately estimate and relate crop water use over a variety of locations and growing seasons.

Water Use Efficiency (WUE)

WUE is defined physiologically as the unit of dry matter produced per unit of water used. In production, this definition is often summarized as the unit yield per unit of water applied, because yield is easier to measure than in-season biomass changes. Most improvements in WUE have been the result of advances in irrigation methods and management strategies. There are many ways to improve WUE by management practices including: tillage practices, cultivar advances and crop selection for area (Howell et al., 2004). Most of these practices reduce the amount of water used which does not necessarily impact WUE directly. Irrigation methods such as SDI can also be an effective means to improve WUE through increasing crop yields and less evaporative losses, especially in semiarid and arid environments like the Texas High Plains (Howell. 2001). Several studies have proved that WUE increases with yield and irrigation at decreasing marginal returns (Howell et al., 2004; and Grismer. 2002). Contrasting to this, studies by Dagdelen et al. (2009) and Basal et al. (2009) in Turkey found values of WUE to increase as irrigation water applied was reduced from 100% to 75% of soil water depletion. WUE values were also higher for these studies than those produced by Howell et al, (2001).

Yield

Irrigation has proven to increase yields for Lubbock county and the 25-county area around Lubbock which have been increasing since 1986 (Wanjura et al., 2002). Irrigation and total water amounts of 58cm and 74cm respectively described in Wanjura et al. (2002) achieve maximum yield in the West Texas area. Total seasonal water application by DeTar. (2008) for the San Joaquin Valley of California produced similar values to Wanjura et al. (2002) with a critical level of 65.4cm to achieve maximum yield. He also concluded a 5% reduction of water below the critical level would produce a 4.6% reduction in yield. Wanjura and Upchurch. (2000) compared yield reduction differences between corn and cotton and concluded that yield increased only 17% between limited and fully irrigated cotton, while corn yields resulted in a 60% increase from limited to full irrigation. This difference in yield reductions could be attributed to differences between an indeterminate and determinate crop. Harvestable portions of corn decrease more when water deficit stress affects critical growth stages compared to cotton that aborts or produces less fruit. However, Dagdelen et al. (2009) and Basal et al. (2009) found no yield reductions when reducing irrigation from a 100% to 75% of soil water depletion.

Boll Distribution

Irrigation studies have documented how cotton yield and growth are altered by moisture deficit stress. However much less is known on how components of yield such as boll distribution are affected. Changes in fruiting habits can effect in-season plant growth, including plant maturity. Ritchie et al. (2009) concluded that irrigation method has a significant effect on boll distribution. He compared overhead and SDI methods and concluded that SDI produced more bolls at the base of the plant compared to overhead irrigation due to physical damage of pollinating flowers by overhead irrigation. Boll distribution characteristics where also looked in Pettigrew. (2004) between irrigated and dryland cotton on SDI along with differences in eight different cultivars. He concluded that irrigation alters distribution of bolls both vertically and horizontally. Yield reduction by moisture deficit stress was primarily due to reduction in number of bolls produced and reduced amount of lint per seed, while increases in yield by irrigation where due to additional bolls being set at higher nodes and more distal positions on the plant.

Objectives

The purpose of this study is to determine the interaction between cultivar, WUE, and yield among cotton cultivars with different irrigation regimes, and determine which cultivars perform better under deficit irrigation. The main objectives for this research include: (i) evaluating the WUE and boll distribution of cotton cultivars at different rates of SDI; (ii) comparing yield, WUE and boll distribution between cultivars at varying irrigation levels; and (iii) determining the cultivar with best yield stability and fiber quality under deficit irrigation to reduce irrigation water use without reducing yield in West Texas.

Materials and Methods

The research was conducted over a two year period at the Texas Tech Research Farm in New Deal, Texas and the Chapman farm in Lorenzo, Texas. The experimental design at both locations was a split plot design with three replicates, with irrigation as a main plot and cultivar as the split plot. Seven cotton cultivars were examined including: DP 0912 B2RF, DP 0924 B2RF, DP 0935 B2RF, DP 1028 B2RF, DP 1032 B2RF, DP1044 B2RF, and FM 9160 B2F. The irrigation method at both locations was high-frequency SDI. The New Deal location had drip tape under every bed on 40" centers, while Lorenzo had drip tape under every other furrow on 80" centers. The

irrigation regimes for New Deal in 2010 were severe-deficit, moderate-deficit, and fully irrigated. Lorenzo included, severe-, moderate-, mild-deficit, and fully irrigated regimes for 2010. For 2011 the regimes where the same at both locations consisting of: severe-, moderate-, mild-deficit, and fully irrigated regimes. The irrigation treatments where initiated at first square and adjusted weekly based on changes in weekly evapotranspiration readings.

In-season Data Collection
Growth monitoring included collecting weekly plant height and total nodes data for 2010 and 2011. Height and node data was taken in cultivars DP 1044 B2RF and DP 0912 B2RF across all irrigation regimes and replications on five consecutive plants beginning at the 5-6 node growth stage and continuing through cutout. Initial and mid-season height and node measurements were conducted throughout the entire study for inter-cultivar comparisons. Final plant mapping was conducted prior to harvest in 2010 which consisted of taking plant height, total node, node of first fruiting branch, node with cracked boll, and node of uppermost harvestable boll on five consecutive plants from every plot in the trial. In 2011 boll distribution was determined in replace of final mapping. This modification of final plant mapping is a more extensive data collection process in which plant height and total node are measured along with the node and position of every boll on five consecutive plants for every plot throughout the study.

Soil moisture monitoring was done by weekly neutron probe readings for soil volumetric water content beginning at pin-head square and continuing till cutout at the New Deal location only. All plots with cultivars DP 0912 B2RF and DP 1044 B2RF in two replications were measured for soil moisture. Measurements were conducted to a depth of 100cm in 20cm increments.

Yield was determined from the two middle rows of each 4 row plot, and 3-5 lb fiber sub-samples was also collected at time of harvest and sent off for HVI analysis at the Fiber and Biopolymer Research Institute in Lubbock, TX. Data was analyzed using SAS 9.2 statistical software with proc GLIMMIX that handles fixed and random effects for a split plot design.

Results and Discussion

Irrigation
Total applied water for the two years of the study are represented in Figures 1 and 2. In 2010 most of the water applied came as rainfall with 13 inches total of effective rainfall. Each irrigation regime received varying amounts of irrigation including 1.1, 4.8, and 8.1 inches applied to the severe deficit, moderate deficit, and fully irrigated regimes respectively. The severe-deficit regime received 1.1 inches before irrigation treatment where initiated. Once treatments where commenced the severe-deficit regime received no more water by irrigation. The moderate-deficit regime received irrigation at a rate of 0.1 in day^{-1} and the fully irrigated regime received 0.2 in day^{-1}. Actual ET_c replacement for the fully irrigated, moderate-, and severe-deficit regimes were 71%, 60% and 48% respectively.
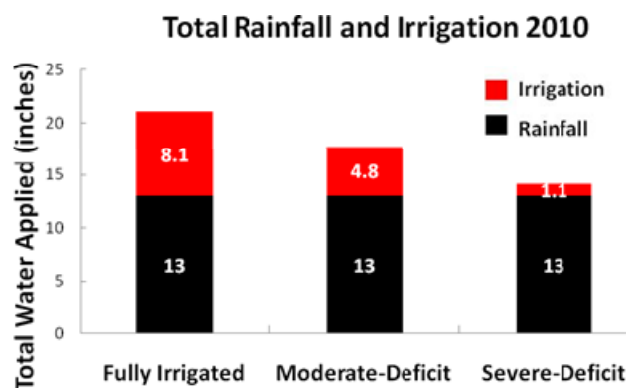

Figure 1. Total water applied in inches for three irrigation regimes in 2010.
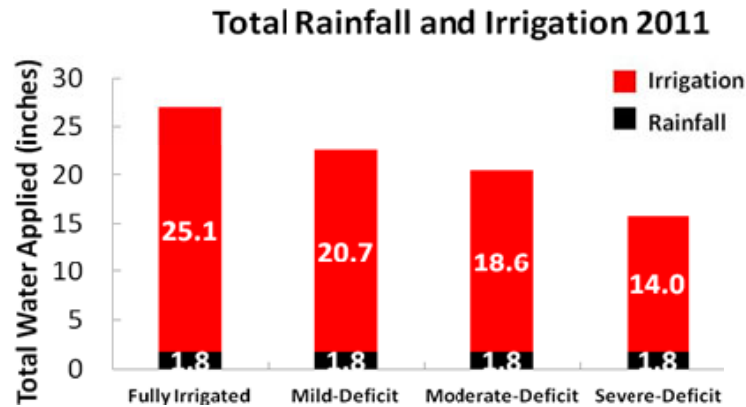
Figure 2. Total water applied in inches to four irrigation regimes in 2011

The 2011 growing season resulted in more total water applied to each irrigation regime than 2010, and most of the water applied was by irrigation compared to rainfall with only 1.8 inches of effective rainfall falling during the growing season. Total irrigation applied to the severe-deficit regime was 14 inches which was supplied before irrigation treatment where initiated. The moderate-, mild-deficit, and fully irrigated regimes received 18.6, 20.7, and 25.1 inches of irrigation respectively. Once treatments where initiated the severe-deficit received no more water by irrigation and the moderate-deficit regime received irrigation at a rate of 0.05 in day^{-1}. The mild-deficit and fully irrigated treatments received irrigation at rates of 0.1 in day^{-1} and 0.15 in day^{-1} respectively. Irrigation rates for the fully irrigated treatment where lower in 2011 due to a max pump time of 4 hours per day. Actual ET_c replacement for the deficit regimes were similar to the three regimes in 2010 with 69%, 62%, and 48%ET replacement. The fully irrigated regime had an ET_c replacement of 83%.

Yield and WUE
Yield and WUE values for 2010 and 2011 are represented in Figures 3 and 4. Lint yield averages over all irrigation regimes ranged from 961 to 1121 lbs acre^{-1}. FM 9160 and DP 1044 had the two highest averages and were significantly different from all other cultivars except DP 0912. Yields increased with increasing water application.
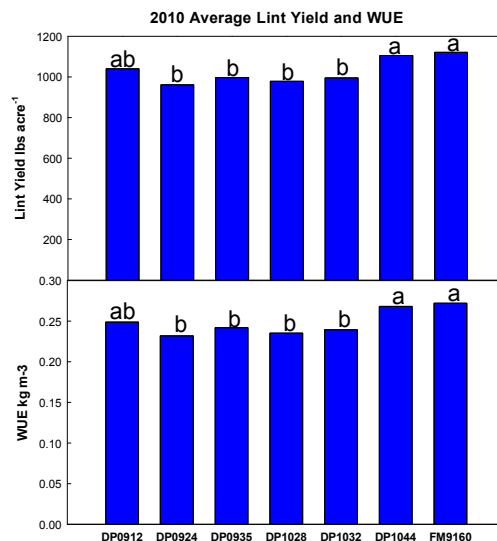

Figure 3. Lint yield expressed in lbs acre^{-1} and WUE expressed as kg m^{-3} for each Cultivar in 2010. Means followed by same letter do not differ significantly ($P_{crit} = 0.05$).
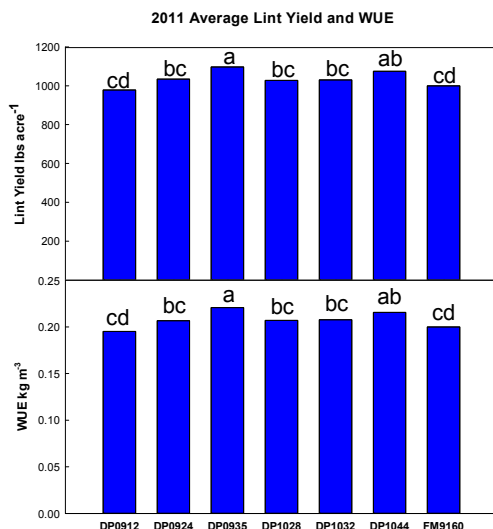
2011 Average Lint Yield and WUE

Figure 4. Lint yield expressed in lbs acre^{-1} and WUE expressed as kg m^{-3} for each Cultivar in 2011. Means followed by same letter do not differ significantly (P$_{crit}$ = 0.05).

In the severe-deficit regime FM 9160 produced the highest yield at 635 lbs acre^{-1} followed by DP 1044 with 585 lbs acre^{-1}. DP 1044 and FM 9160 were also the top performers in the moderate-deficit regime producing 1281 and 1197 lbs acre^{-1} respectively. In the fully irrigated regime DP 0912 was the top performer with 1556 lbs acre^{-1}, which was the highest yield in the study. FM 9160 and DP1044 followed with 1531 and 1447 lbs acre^{-1} respectively.

WUE values for 2010 followed similar patterns to yield in cultivar performance. This is due to the average yield being divided by total water applied which was the same for each cultivar. WUE averages ranged from 0.23 to 0.27 kg m^{-3}. FM 9160 had the highest WUE for the severe-deficit regime, (0.20 kg m^{-3}). DP 1044 had the highest WUE in the moderate deficit regime (0.32 kg m^{-3}), and DP 0912 had the highest WUE in the fully irrigated regime (0.33 kg m^{-3}).

Yield averages in 2011 were similar to 2010 with a range of 978 to 1096 lbs acre^{-1}. The highest averages were produced by DP 0935 and DP 1044 with the DP 0935 average differing significantly from all other cultivars except DP 1044. DP 0935 produced the highest yields in the severe-, mild-deficit, and fully irrigated regimes with 607, 1300, and 1568 lbs acre^{-1} respectively. DP 1032 produced the highest yield in the moderate-deficit regime with 929 lbs acre^{-1}. Yield values for the two years of the study do not differ greatly from those produced in other studies in the area (Wanjura et al., 2002; Howell et al., 2004).

WUE averages were lower in 2011 with a range of 0.20 to 0.22 kg m^{-3}. DP 0935 had the highest WUE in the severe-deficit, mild-deficit, and fully irrigated regimes with 0.17, 0.26 and 0.25 kg m^{-3} respectively. In the moderate-deficit regime DP 1032 had the highest WUE with 0.20 kg m^{-3}. Values for WUE in 2010 are very similar to those produced in Howell et al., (2004); however WUE values for the 2011 season were numerically greater.

Boll Distribution
Patterns for boll distribution were highly variable for first position bolls between cultivars as well as within irrigation regimes. Figures 5a, 5b, and 5c represent three different cultivars with differing boll distribution patterns. Each graph represents the change in boll node^{-1} plant^{-1} as irrigation is increased. Figure 5a represents boll change for DP 0935 where boll production is decreased by 5 to 15% in lower portions of the plant (node 9 and below) for each irrigation regime over severe-deficit. There were significant increases of 10 to 45% in bolls produced at higher portions of the plant (node 10 and above). DP 1044 (Figure 5b) followed a similar pattern, with boll reduction in lower portions (node 7 and below) of 5 to 15% in the moderate- and mild-deficit regimes only. Boll production higher in the plant (node 8 and above) was greater than DP 0935 with increases of 21to 55%. Boll production for FM 9160 (Figure 5c) followed a very unique pattern with no reductions in lower portions of the plant, but rather two peaks in boll produced at nodes 7 and 13 for each irrigation regime.
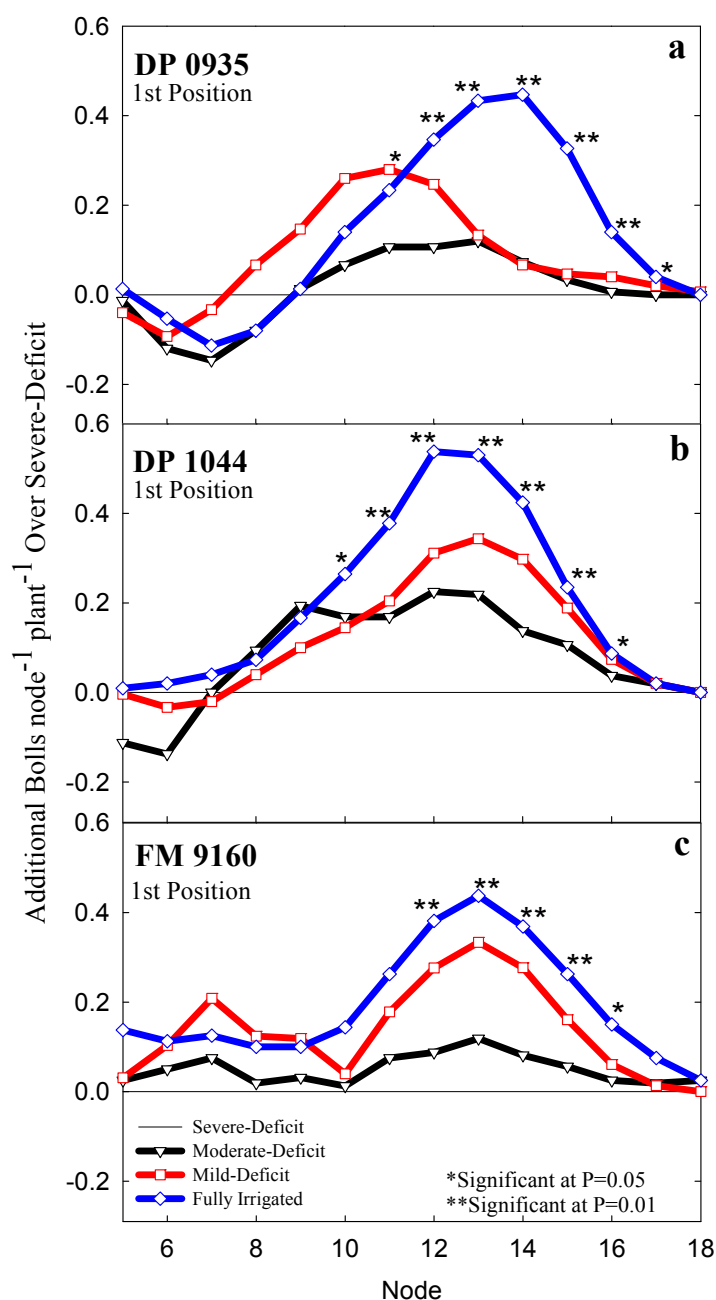
Figure 5. Additional first position bolls node^{-1} plant^{-1} over severe-deficit regime by node for DP0935 (5a), DP1044 (5b), and FM9160 (5c) cultivars.

Summary

There were several notable cultivars for both years of the study. In 2010, FM 9160, DP 1044, and DP 0912 had the highest average yields and WUE. FM 9160 and DP 1044 performed very well in the deficit regimes for 2010. In 2011, DP 0935, DP 1044 and DP 0924 had the highest average yields. DP 0935 and DP 1044 performed very well in the deficit regimes. Boll distribution patterns were highly variable between cultivars and within irrigation regimes, with DP 0935 and DP 1044 having reduced boll production in lower portions of the plant and significant increases in boll production at higher portions of the plant compared to severe-deficit treatments. These results suggest that

DP1044 could be a good cultivar selection for the Texas High Plains, where water is limited to reduce water use while maintaining good yield stability.

Acknowledgements

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