PROFITABILITY AND YIELD OF COTTON CULTIVARS AFFECTED BY IRRIGATION LEVEL AND EPISODIC DROUGHT IN WEST TEXAS

F.R. Simao
Texas Tech University
Lubbock, TX
G.L. Ritchie
J. Johnson
Texas Tech University and Texas A&M Agrilife Research
Lubbock, TX
C.W. Bednarz
Bayer CropScience
Lubbock, TX

Abstract

Water management is a very important factor in irrigated cotton production systems. The field experiments were conducted at the Texas Tech New Deal and Quaker Avenue research farms during the 2010 to 2012 seasons. From sets of 10 and 21 cultivars and experimental lines observed in 2010, 8 cultivars were studied in all the three years. In 2012 cultivars DP0935 and FM9180 were tested on all irrigation and episodic drought regimes in the same location. Episodic drought treatments included a full irrigation throughout the season; non-irrigation from squaring to flowering; 3 weeks of non-irrigation beginning at early flowering; 3 weeks of non-irrigation beginning at peak bloom; and non-irrigation beginning from peak bloom to the crop termination. The studies also included deficit irrigation, mild deficit irrigation, and dry land started after crop establishment. The profitability and break-even price were calculated based on the 2012 costs and prices. In 2012, even if the area of mild deficit irrigation regime was increased to use the same amount of water of a fully irrigated hectare, the profit of a fully irrigated hectare would be higher. These results can be important to the development of more economically efficient water management strategies for cotton in West Texas.

Introduction

Water management is a very important factor in any crop production system. According to Denning et al. (2001), the Texas High Plains accounted for nearly 20% of the total U.S. production during the past decade. In this region almost half of the cotton area is irrigated and it is responsible for the majority of the production. The main source of water to West Texas irrigated cotton is the Ogallala Aquifer that has been depleted in a rate superior to its recharge. As stated by Bordovsky et al. (2000), as water supplies and availability continue to decline in Texas, it is imperative to adopt the most efficient irrigation systems and management techniques. Farm-level yields in the Texas High Plains are significantly influenced by irrigation rates. Improving irrigation management practices can be profitable and may also increase the usable life of the Ogallala Aquifer.

Information about irrigation costs and water response can help growers to improve overall water management and water returns. For cotton irrigation management, it is suggested a lack of knowledge about the effects of water restriction on the irrigated crop profitability. This knowledge will lead to more efficient irrigation strategies for the cotton farmers.

Literature review

Mills (2010) found that cotton had quadratic response to water increases, reaching peak yields with 75 and 65 cm of total water in 2008 and 2009. Irrigation produced variable results with cotton fiber quality due to heavy rainfall late in the 2008 growing season. Economic analysis suggested that profit maximizing yields were lower than the maximum yields observed (Mills, 2010).

Irrigation termination is also an important aspect related to Irrigation management. According to Sneed (2010) in a study about irrigation termination to improve fiber maturity on the Texas High Plains, irrigation termination had a significant impact on yield, fiber maturity, and the overall quality. The earliest irrigation termination matured the earliest and produced the lowest yields. Lint yields were higher in the latest irrigation termination but also used more water and reduced fiber quality in most locations. Excessive rainfall and drought conditions that were observed during this study impacted yield and quality.

In Mills (2010) work, it was also found that loan values, net returns, and returns above seed costs and water costs of \$7.50 and \$12.50 ha-cm resulted in second order polynomials. Denning et al. (2001) concluded cotton had non-linear responses, and Mills (2010) suggested that profit max is before maximum yield. Their conclusion also agrees with the basic concepts of the theory of the firm (Doll and Orazen, 1992).

Mills (2010) results were different for each year due to the amount of rainfall within each growing season. The curvature in all the results suggested that producers can apply too much water thereby decreasing net returns. With this information, Mills (2010) concluded that the need for more irrigation management is apparent and that, in the Texas High Plains, 0.64 cm of water per day probably is an excessive depth for most days and years. Considering West Texas high evaporation rates and low annual rainfall, more conscientious water management would probably increase profit margin (Mills, 2010).

In Sneed's (2010) work, he found that depending on the cost of irrigation water, the most profitable time of terminating irrigation is not always the highest yielding. Depending on the cost of irrigation water and the availability of water, a producer could use less water and have equal or higher profits. Cultivar selection also had an impact on profits.

Wild (2008) in a study about optimal economic combination of irrigation technology and cotton varieties on the Texas High Plains, estimated gross margins and net returns above total variable and fixed irrigation costs for varieties and irrigation systems with different irrigation levels. He found that producers could increase gross margins by adopting new varieties; estimations showed that subsurface drip irrigation (SSI) can produce higher net returns than low energy precision application (LEPA) center pivot systems. He also demonstrated the importance of managing production according to environmental factors. His analysis emphasized the importance for cotton producers to be informed to properly manage their production.

The main conclusion of the Denning et al. (2001) study was that knowledge and consideration of the effect of management decisions on lint quality can substantially increase expected profitability and reduce profit variation. These authors also concluded that better decision-making ability would improve profitability of farm operations. Availability of precise, up-to-date estimates of the quality premiums and discounts, implicit in the observed market lint prices, would be critical for these purposes.

The final note from Denning et al. (2001) was caution about the use of models estimated in his study. Though statistically sound, their models were based on three years of experimental data from Lubbock County. The yield and quality predictions from these models are imperfect due to the usual "random" error, e.g. the effect of factors not included in the models. When applied in farm management decisions, the predictions would also be subject to "extrapolation" error caused by any major difference between the experimental site management and the farm site management. Re-estimating the models based on an expanded data set that includes future-year observations from other Texas High Plains cotton-farming areas can reduce this extrapolation error. We can conclude from these recommendations that it is necessary to research profitability returns on irrigation for more years.

Bordovsky et al. (2000) conducted an economic evaluation of cotton irrigated by LEPA and SSI in the Texas High Plains. These authors explained that the advantages of SSI over LEPA in cotton production are increased cotton lint yield and improved water use efficiencies, particularly at very low irrigation capacities. They also stated that irrigation management economic evaluations are as important as irrigation systems'.

Allen et al. (2007) alerts that improved water use efficiency can cause increased water use, instead of water savings, when more systems are installed. The Texas High Plains exemplifies this situation. In this region, agriculture depends heavily on irrigation at non-sustainable rates of water extraction from the Ogallala aquifer. Today, agriculture uses about 95% of total water withdrawn from this aquifer.

Doorembos and Kassam (1979) suggested that when the cotton water supply is limited, different from other plants such as banana, it is possible to obtain a higher total cotton production increasing the area and providing partially the water needs than fully supplying a limited area. In a banana plantation, for example, a higher total production would be achieved using just the area were there would be available water to completely supply the plant irrigation needs than having a larger area not fully irrigated.

Summarizing, irrigation strategies studies and its economic relevance are extremely important from different standpoints, especially when it is considered a scenario with increased use associated with water shortage such as the cotton production in West Texas.

Conceptual Framework

One of the most important aspects related to an enterprise management is it economic returns, so it is also very important in determining the effects in profitability of improved crop practices, such as new water management strategies. Agricultural Economics applies economic models to agricultural problems, using economic principles in the biological nature of agriculture. It is assumed that the goals of Agricultural Economics are to increase efficiency in agriculture; produce needed products without wasting resources, increase efficiency of farm, and increase efficiency of resource use. Production Economics is the application of the principles of microeconomics in agriculture (Doll and Orazem, 1992). One of the goals of Production Economics is to assist manager in determining the best use of resources, given the changing needs, values, and goals of society. It is often assumed that the objective of the farm manager is to maximize profit and increase the efficiency in the use of resources.

From extension services it is possible to find estimations for enterprise budgets for several conditions (Texas, 2012). For the conditions of this study, the most appropriated budget was selected. Using the budget for West Texas drip irrigated cotton from the Texas A&M AgriLife extension services (Texas, 2012), together with the basic production economics concepts (Doll and Orazem, 1992), we developed an estimate of how lint yields and lint prices will affect income, break-even price and returns above irrigation costs, allowing us to make economic comparisons for different irrigation amounts and the resultant yields.

We concluded that in the proposed scenario, the breakeven yield is 1037 kg ha^{-1} if the price is held at \$1.76 per kg lint. We also calculated the breakeven price of \$1.09 per kg if the lint yield is 1681 kg ha^{-1}.

From the extension services selected budget (Texas, 2012); we assume non-irrigation related costs to be the same (\$ 1,559.06) for all irrigation treatments and a cost of US\$ 1.16 per mm of irrigation per hectare. Therefore, to calculate total cost for each irrigation management strategy (TCt) based on the irrigation depth applied per treatment (IAt) we can use Eq. 1:

$$TCt = 1559.06 + 1.16 * IAt \tag{1}$$

We provided an equation to calculate Total Revenue per treatment (TRt) based on the treatment lint yield (Yt) and cotton seeds produced per treatment (Yst) in kg per hectare:

$$TRt = 0.20 * Yst + 1.76 * Yt \tag{2}$$

We also developed an equation for calculate Profit per treatment (Pt) in dollars as a function of IAt and Yt, the field trials data:

$$Pt = TRt - TCt = 0.20 * Yst + 1.76 * Yt - 1559.06 - 1.16 * IAt \tag{3}$$

Finally, we also provided an equation to calculate a breakeven price for each treatment (BEPt):

$$BEPt = \frac{1559.06 + 1.16\ \mathrm{IAt} - SR}{Yt} - PD \tag{4}$$

Treatments with the highest profit per treatment and the lowest breakeven prices per treatment should also be the most economically beneficial irrigation management strategies. A complete set of parameters must be observed to understand the effects of irrigation management and episodic drought. Episodic drought for this research is defined as a period when the irrigation of an irrigated crop is completely interrupted.

Objectives

The general objective of this paper is to suggest optimum economic water management strategies for cotton.

The specific objectives are:
(i) Determine the effects of episodic water stress and irrigation management strategies on the yield and production economics related variables for selected cotton varieties.
(ii) Suggest if higher total production and profits can be achieved fully irrigating a limited area or by using any of the proposed water saving strategies in a larger area, with the same total water applied.

Methods

Yield, fiber quality, and boll distribution were obtained from a set of Episodic Drought trials and from a set of irrigation field trials that we conducted in the West Texas region from 2010 to 2012.

The field experiments were conducted at the Texas Tech New Deal and Quaker Avenue research farms during the 2010, 2011, and 2012 seasons. These experimental sites are located in the Texas High Plains, considered a semi-arid area. In 2010, both trials were located at New Deal; in 2011, the Episodic trial was located at Quaker and the Irrigation trial at New Deal; and in 2012 the Irrigation trial was located at Quaker while the Episodic trial was repeated at both locations. In these experimental farms, the soil has high clay content and high water holding capacity. The soil at the Quaker Avenue farm is an Amarillo-Acuff sandy clay loam (Fine-loamy, mixed, superactive, thermic Aridic Paleustolls), and the soil at the New Deal farm is a Pullman-Olton clay loam (Fine, mixed, superactive, thermic Aridic and Torrertic Paleustolls).

For both sets of trials, the experimental design was a split-plot with water treatments as the main plot and cultivars as split-plot. Experimental units were two rows, measuring 10.7 m in 2010 and 12.2 m in 2011 and 2012. Row spacing was one meter. SSI system was used. The irrigation tape was placed 0.25 m below the surface under every row.

Agronomical practices followed Texas A&M AgriLife Extension recommendations for the Texas High Plains. Fertilizer in the form of 28-0-0-5 was applied at a rate of 90 kg N ha^{-1}. Weed control included herbicide applications (glyphosate), and mechanical hoeing. A conventional tillage system was used. Plant growth regulators (PGR) were applied in 2010.

The episodic drought treatments included a full irrigation throughout the season; non-irrigation from squaring to flowering; 3 weeks of non-irrigation beginning at early flowering; 3 weeks of non-irrigation beginning at peak bloom; and non-irrigation beginning from peak bloom to the crop termination. At the 2010 season due to the occurrence of precipitation events in the early season the treatments 3 weeks of non-irrigation beginning at early flowering; and 3 weeks of non-irrigation beginning at peak bloom were not present. Besides a fully irrigated treatment, in 2010 the Irrigation trial had a deficit irrigated management, and a treatment with irrigation interrupted after the crop establishment (squaring). In 2011 and 2012 Irrigation trial treatments also included mild deficit irrigation.

From a set of ten cultivars planted for the Episodic Drought trial in 2010, we selected cultivars DP0912, DP0935, FM9170, and FM9180 for the 2011 and 2012 seasons. From a set of 21 cultivars and experimental lines planted for the Irrigation trial in 2010, cultivars ACALA 1517-E2, FM832, SIOKRA24, and ST506 were selected for the 2011 and 2012 seasons. FM9180 was also tested on the 2011 and 2012 Irrigation trials. DP0935 was also tested on the 2012 Irrigation trial.

Weather climate parameters were obtained from automated weather stations located near the experimental fields and include precipitation and other measurements necessary to calculate the irrigation needs. The total irrigation applied was measured with hydrometers.

All plots were harvested with a cotton stripper equipped with load cells. Grab samples were taken during harvest. The grab samples were ginned. During ginning, seed-cotton, lint, and seeds were weighed. Turnout (lint percentage), lint yield, and seed yields were calculated. Lint samples were sent for analysis at the using the High Volume Instrument (HVI) at the Fiber and Biopolymer Research Institute (FBRI) in Lubbock, TX.

Based on information obtained from the Extension Services 2012 budgets (Texas… 2012) and the equations presented on the "Conceptual Framework" section it was possible to calculate Returns, Profits, and Break-even prices. Based on the Plains Cotton Growers Inc. website information (Plains… 2012) it was possible to determinate premiums and discounts based on HVI fiber quality parameters provided by the FBRI. Seed-cotton water use efficiency (WUE) was computed by the division of Seed-cotton yield by the total water received per treatment (irrigation plus rainfall).

For testing the hypothesis of a higher cotton production be achieved partially irrigating a big area, first we calculated for each irrigation level the area that would be irrigated with the volume of water from the full irrigation treatment, then we multiplied the equal water area to the yield to obtain the equal water production to be compared. An equal water profit was also computed by the multiplication of the profit per hectare to the equal water area. A marginal value product (MVP) was obtained by the ratio of the increase in revenue by the increase on water applied.

The statistical analysis was done using the GLIMMIX Procedure in SAS® software (SAS Inst., 2010) with an ANOVA followed by a mean separation at 5% level of probability using the LSMEANS statement. GLIMMIX procedure can properly separate random and fixed effects. SAS programming statements followed the recommendations provided by Littell et al. (1996).

Results

Tables 1 and 2 shows the significance of the seed-cotton yield variable as a function of the water treatment, cultivar selection, and irrigation-cultivar interaction for all year-location environments of the Episodic Drought and Irrigation sets of trials. For all environments and trials statistically significant ($p<0.01$) irrigation effect was observed. A cultivar single main effect was observed for two environments of each set of trials. While the irrigation-cultivar interaction was statistically significant for all environments of the Episodic drought sets of trials, at the Irrigation levels set of trials it was significant just in 2012.

Table 1. Episodic Drought trials. Statistical significance (p-values) for the F test due to effects on Seed-cotton Yield. Qk = Texas Tech Quaker Avenue Research Farm. ND = Texas Tech New Deal Research Farm.

Factor	p-value in 2010	p-value in 2011	p-value in 2012(Qk)	p-value in 2012(ND)
Episodic drought	0.0007 **	< 0.0001 **	< 0.0001 **	< 0.0001 **
Cultivars	0.0013 **	< 0.0025 **	0.9257 n.s.	0.4300 n.s.
Interaction	0.0015 **	0.04117 *	< 0.0001 **	0.0215 *

* = Statistically significant at 0.05 level
** = Statistically significant at 0.01 level
n.s. = Not statistically significant at 0.05 level

Table 2. Irrigation levels trials. Statistical significance (p-values) of the study factors and interaction in the variable cotton seed yield during the 2010, 2011, and 2012 seasons.

Factor	p-value in 2010	p-value in 2011	p-value in 2012
Irrigation	<0.0001 **	< 0.0001 **	< 0.0001 **
Cultivars	<0.0001 **	0.1071 n.s.	< 0.0001 **
Irrigation*Cultivar	0.1297 n.s.	0.5667 n.s.	0.0006 **

* = Statistically significant at 0.05 level
** = Statistically significant at 0.01 level
n.s. = Not statistically significant at 0.05 level

In 2012 both, episodic drought and different levels of irrigation were evaluated for cultivars FM9180 and DP0935 at the Texas Tech Quaker Avenue Research Farm. Table 3 Summarizes the significance of some factors that we can use to compare the effects on different water allocation strategies in cotton yield. For all factors we found extremely significant irrigation effects (p<0.0001). Cultivar selection had statistically significant effect on lint yield, and lint percentage. Irrigation-cultivar interaction was observed for lint percentage. More details of the effect of the treatments on these variables can be observed on figures 1 to 6.

Table 3. Significance (p-values) of the analysis of variance for production variables as affected by the irrigation episodic drought, cultivar or their interaction in 2012.

Factor	Irrigation	Cultivar	Irr*Cult Interaction
Seed-cotton yield	< 0.0001 **	0.6115 n.s.	0.7325 n.s.
Lint yield	< 0.0001 **	0.0008 **	0.1021 n.s.
Lint percentage	< 0.0001 **	< 0.0001 **	0.0163 *
Seed-cotton water use efficiency	< 0.0001 **	0.3756 n.s.	0.3942 n.s.
Equivalent water area production	< 0.0001 **	0.3483 n.s.	0.3663 n.s.

*: significant at P = 0.05; **: significant at P=0.01; n.s.: not significant at P = 0.05

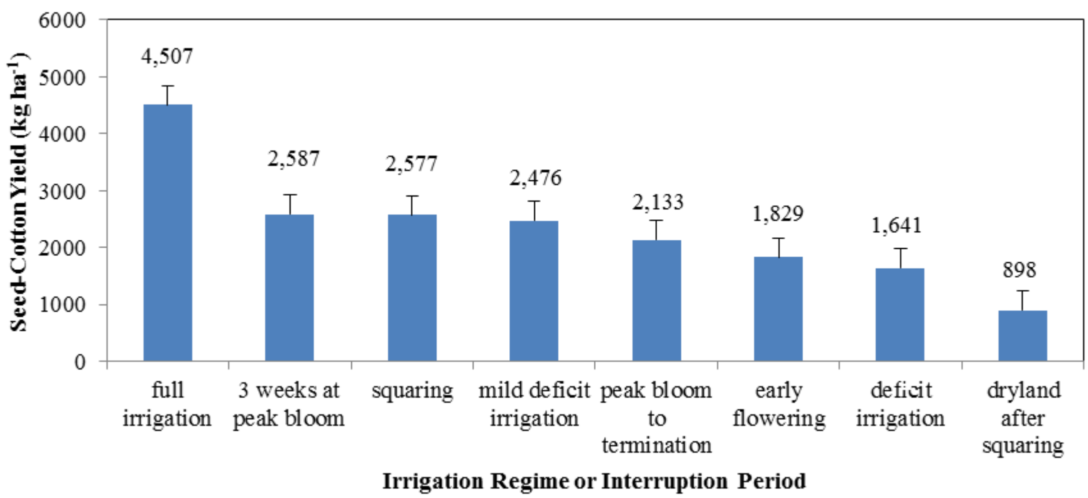

Figure 1. Average Seed-Cotton Yield over cultivars DP0395 and FM9180 subjected to eight different irrigation regimes during the 2012 season at the Texas Tech Quaker Avenue Research Farm. Black bars represent one Least Significant Difference. LSD(0.05) = 338 kg ha^{-1}.

In 2012 seed-cotton yield was more than 3600 kg ha^{-1} higher in the full irrigation treatment (highest yield treatment) when compared to the dryland after irrigation management (Figure 1). The seed-cotton yield when a 3 weeks at peak bloom irrigation interruption occurred was not statistically different of the observed from a squaring stage episodic drough and also didn't differ from the yield from a mild deficit irrigation management. The seed-cotton yield obtained after a early flowering stage irrigation interruption was not statistically different from the obtained from a deficit irrigation management.

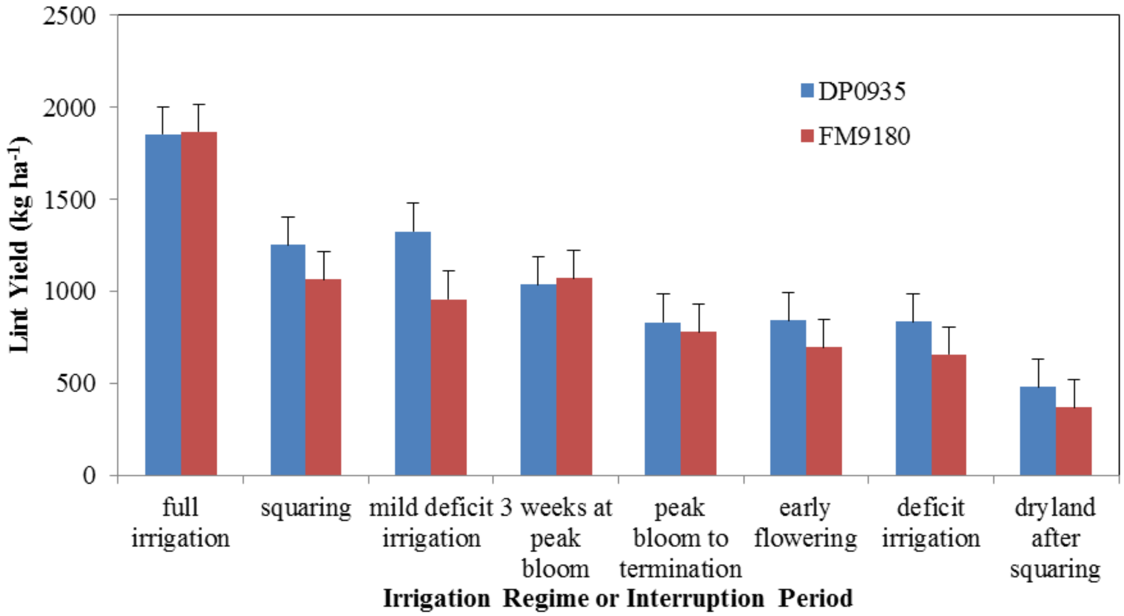

Figure 2. Lint Yield of cultivars DP0395 and FM9180 subjected to eight different irrigation regimes during the 2012 season at the Texas Tech Quaker Avenue Research Farm. Black bars represent one Least Significant Difference. LSD(0.05) = 152 kg ha^{-1}.

In 2012 lint yield was more than 1400 kg ha^{-1} higher in the full irrigation treatment (highest yield treatment) when compared to the dryland irrigation management (Figure 2). Similar to the seed-cotton yield, lint yield when a 3 weeks at peak bloom irrigation interruption occurred was not statistically different of the observed from a squaring stage episodic drough and also didn't differ from the yield from a mild deficit irrigation management. The lint yield obtained after peak bloom to termination and early flowering stage irrigation interruption were not statistically different from the obtained form a deficit irrigation management. The average yield of DP0935 was 125 kg ha^{-1} higher than FM9180.

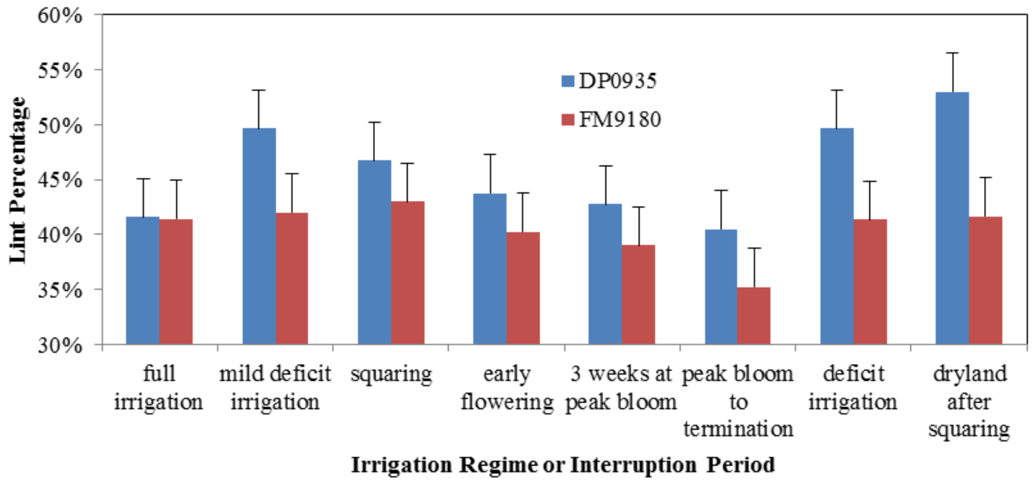

Figure 3. Lint percentage of cultivars DP0395 and FM9180 subjected to eight different irrigation regimes during the 2012 season at the Texas Tech Quaker Avenue Research Farm. Black bars represent one Least Significant Difference. LSD(0.05) = 3.5%.

Figure 3 shows the interaction on the irrigation-cultivar effects on the lint percentage (turnout). While in the dryland treatment DP0935 had the highest of all turnouts (53%) and at the peak bloom to termination the lowest of all turnouts was observed for FM9180 (35%), at the full irrigation both cultivars turnouts were nearly the same (nearly 41%) and so their difference were not statistically significant. At early flowering and fully irrigated regimes, the differences on the cultivars turnout was also not statistically significant.

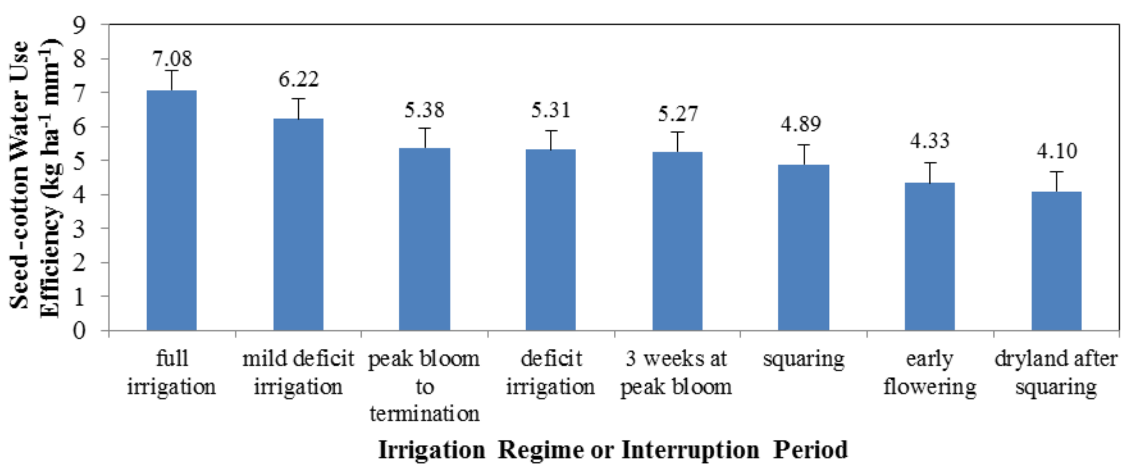

Figure 4. Average Seed-cotton water use efficiency from cultivars DP0395 and FM9180 subjected to eight different irrigation regimes during the 2012 season at the Texas Tech Quaker Avenue Research farm. Black bars represent one Least Significant Difference. LSD(0.05) = 0.58 kg ha^{-1} mm^{-1}. 1 kg ha^{-1} mm^{-1} = 1 g daL^{-1}.

In 2012, seed-cotton water use efficiency (WUE) was higher at full irrigation, followed by the mild deficit irrigation. The two lowest WUE were observed at the early flowering irrigation interruption and at the dryland treatments and were not statistically different. All other irrigation treatments WUE was not statistically different averaging nearly 5 kg ha^{-1} mm^{-1}.

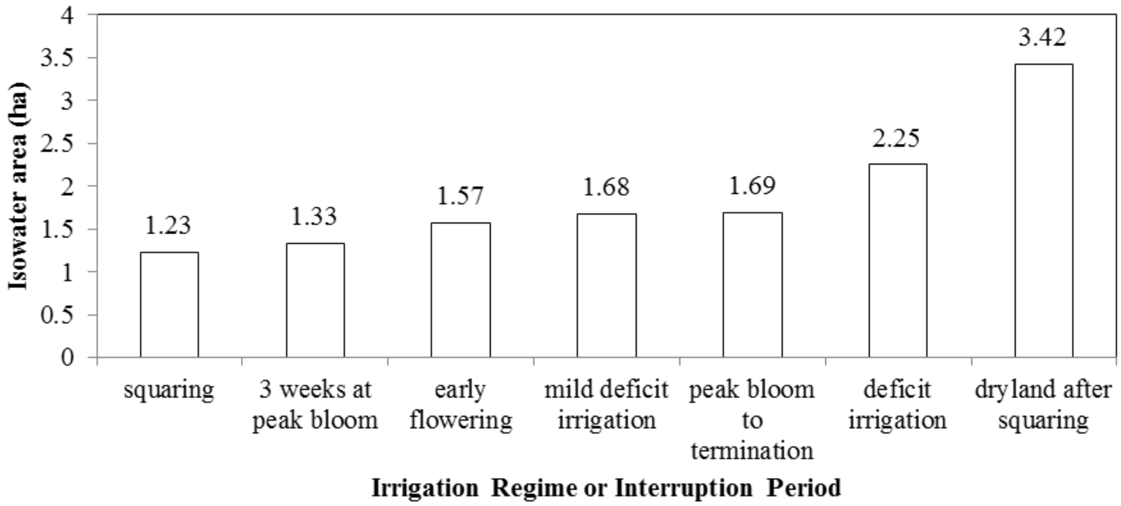

Figure 5. Area equivalent to the use of the water volume in one full irrigated ha for seven different irrigation regimes during the 2012 season at the Texas Tech Quaker Avenue Research Farm.

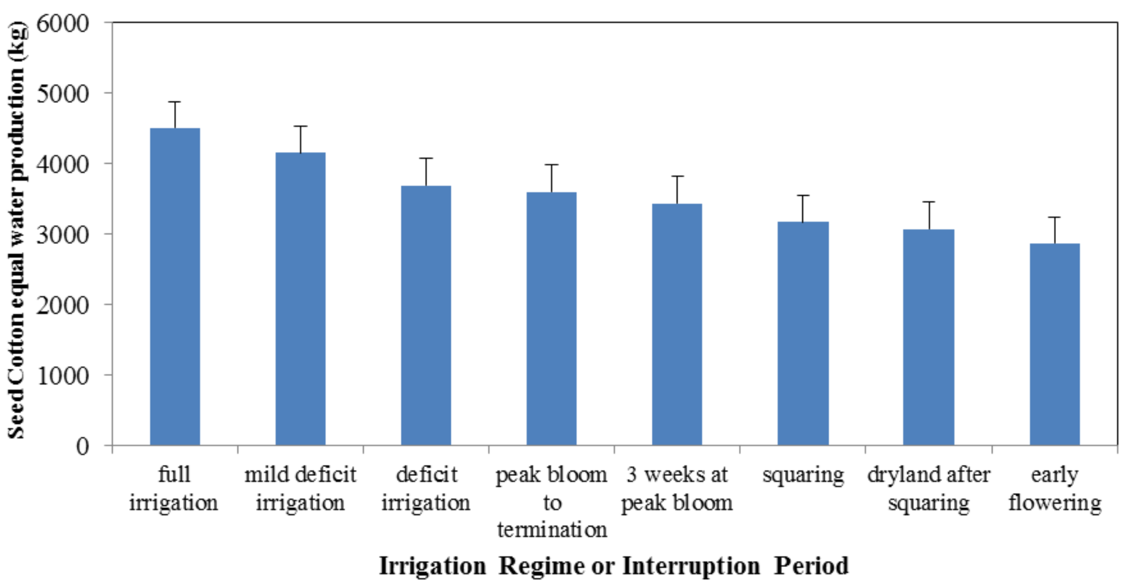

Figure 6. Production of an expanded area for the same total water volume averaged from cultivars DP0395 and FM9180 subjected to eight different irrigation regimes during the 2012 season at the Texas Tech Quaker Avenue Research Farm. Black bars represent one Least Significant Difference. LSD(0.05) = 379 kg.

If the water saved on the several irrigation management strategies tested in 2012 were used to irrigate a larger area with the same total volume of water used in one fully irrigated hectare, the increased area will have the dimensions described on Figure 5. These increased areas would provide the total production described on Figure 6. The highest total production would still be achieved under one fully irrigated hectare, but it was not statistically different from the total production obtained under a mild deficit irrigation management.

On Table 4 the significance for production economics related variables is presented. For all variables shown on Table 4 we had a signficant effect for irrigation ($p<0.0001$), and for cultivar at $p=0.01$. There was also a signficant irrigation-cultivar interaction at $p=0.05$ for premiums, breakeven price, equal water volume profit, and MVP.

Table 4. Significance (p-values) of the analysis of variance for production economics related variables as affected by irrigation management, cultivar or their interaction in 2012.

Factor	Irrigation	Cultivar	Irr*Cult Interaction
Total premiums or discounts	< 0.0001 **	0.0093 **	0.0019 **
Total revenue	< 0.0001 **	0.0076 **	0.2117 n.s.
Total profit	< 0.0001 **	0.0076 **	0.2117 n.s.
Breakeven price	< 0.0001 **	< 0.0001 **	0.0008 **
Equal water volume profit	< 0.0001 **	< 0.0001 **	0.0124 *
Marginal value product	< 0.0001 **	< 0.0001 **	< 0.0001 **

*: significant at p = 0.05; **: significant at p = 0.01; n.s.: not significant at p = 0.05

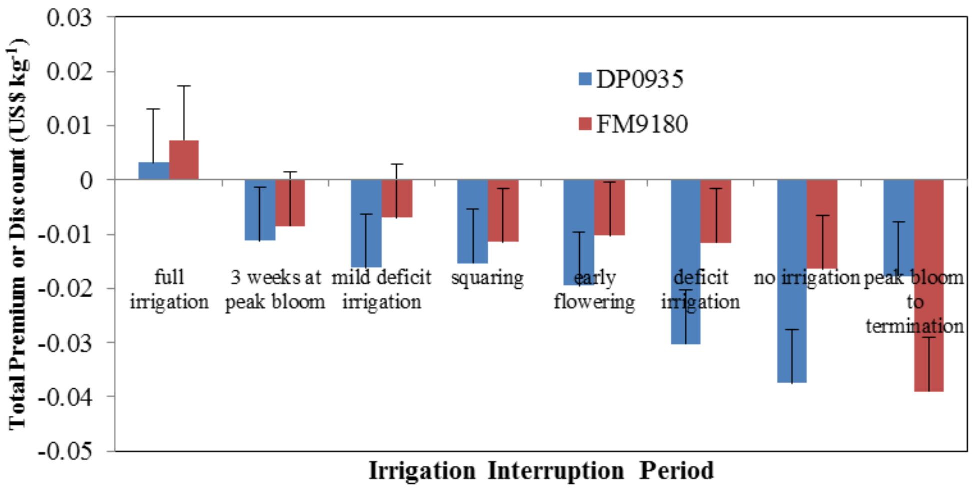

Figure 7. Premium or discount of cultivars DP0395 and FM9180 subjected to eight different irrigation regimes during the 2012 season at the Texas Tech Quaker Avenue Research Farm. LSD ($p=0.05$) = US$ 0.0099 kg^{-1}.

The effects of fiber quality in the price received in each treatment in 2012 is described on Figure 7. While only the full irritation would provide an increased price, or premium, the higher discounts of nearly US$ 0.03 kg^{-1} would be received on the no irrigation after the crop stablishment, and no irrigation from peak bloom to crop termination, these discounts were not statistically different from the received at the deficit irrigation. The single main effect of cultivar provided lower discounts for FM9180, however, an irrigation-cultivar interaction was observed, and when there was an episodic drought from peak bloom to termination the lower discount was obtained by DP0935.

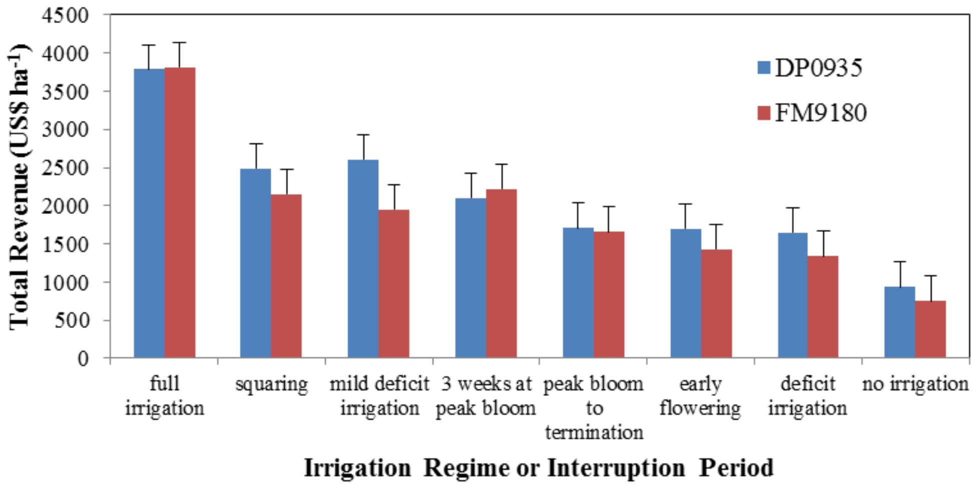

Figure 8. Revenue obtained from cultivars DP0395 and FM9180 subjected to eight different irrigation regimes during the 2012 season at the Texas Tech Quaker Avenue Research Farm. LSD ($p=0.05$) = US$ 326.00 ha^{-1}.

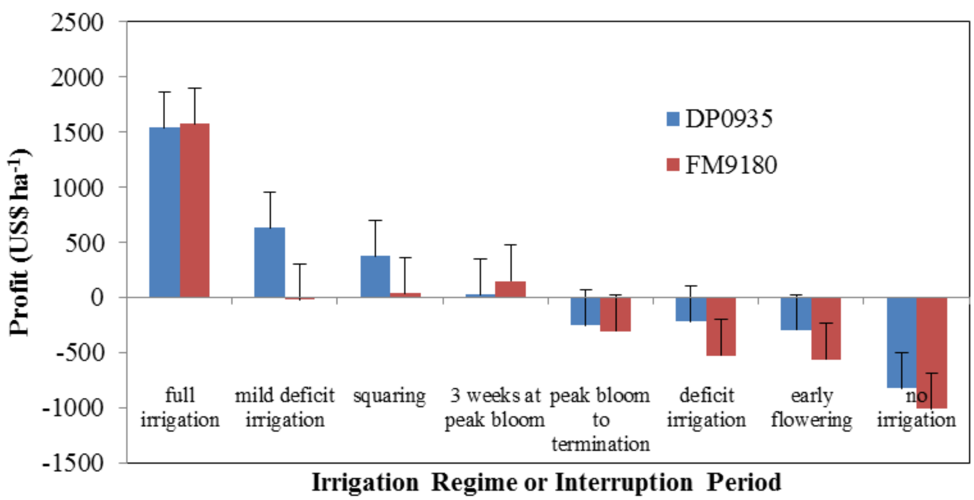

Figure 9. Profit or loss obtained from cultivars DP0395 and FM9180 subjected to eight different irrigation regimes during the 2012 season at the Texas Tech Quaker Avenue Research Farm. LSD ($p=0.05$) = US$ 326.00 ha^{-1}.

The effects of the treatments on the revenues (Figure 8) were very similar to the effect on profit (Figure 9). An average revenue difference of almost US$ 3,000 ha^{-1} (more than US$ 2,400.00 ha^{-1} in profit) was observed between the fully irrigated and dryland water regimes. These were the highest and the lowest revenues and profits and were statistically different from all other treatments. The effects of mild deficit irrigation in revenue and profit were not statistically different from the obtained by irrigation interruptions at the squaring stage and at the peak bloom stage from three weeks. Similarly, the total revenue and profit obtained with a deficit irrigation regime would be similar to the observed when there was an episodic water stress at the early flowering stage and from the peak bloom until the crop termination.

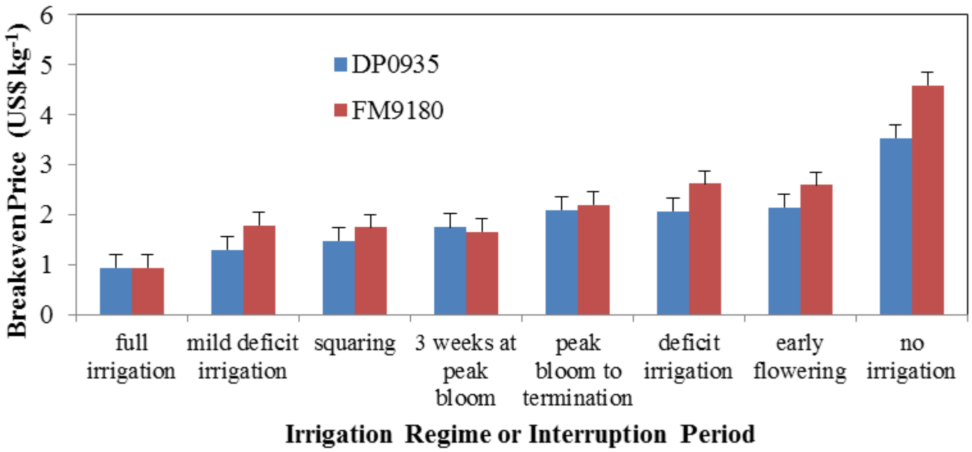

Figure 10. Breakeven price for cultivars DP0395 and FM9180 subjected to eight different irrigation regimes during the 2012 season at the Texas Tech Quaker Avenue Research Farm. LSD (p=0.05) = US$ 0.26 kg^{-1}.

In 2012, the effects of the water treatments on breakeven price (Figure 10) were the opposite of the observed for revenue (Figure 8) and profit (Figure 9). The lowest of all treatments breakeven price was observed for the full irrigation and the highest for the dryland, and they were statistically different from all other irrigation regimes or interruption periods. Similar to the effects of water in revenue and profit, the breakeven price effects of mild deficit irrigation in were not statistically different from the obtained by irrigation interruptions at the squaring stage and at the peak bloom stage from three weeks. Also the breakeven price for a deficit irrigation regime would be similar to the observed when there was an episodic water stress at the early flowering stage and from the peak bloom until the crop termination. An cultivar-irrigation interaction was also observed for breakeven price (p=0.0008), although the single main effect of cultivar would indicate a breakeven price for FM9180 higher than for DP0935, at full irrigation regime the breakeven price for both cultivars would not be statistically different, averaging nearly US$ 0.93 kg^{-1}.

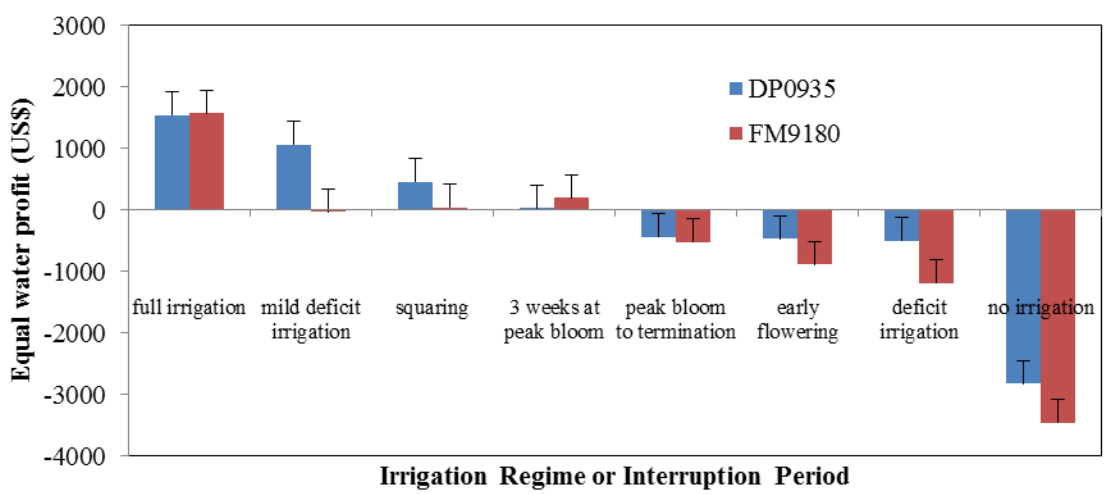

Figure 11. Profit obtained using an equal irrigation volume from cultivars DP0395 and FM9180 subjected to eight different irrigation regimes during the 2012 season at the Texas Tech Quaker Avenue Research Farm. LSD (p=0.05) = US$ 376.98. In 2012, even if the area was increased to use the same amount of water of a fully irrigated hectare the profits obtained in a fully irrigated hectare would still be the highest of all water regimes (Figure 11),

indicating that it is probably more profitable for a farmer, under 2012 similar environmental conditions, to reduce the crop area but keep it fully irrigated, since the profit of a fully irrigated hectare was more than a US$1,000.00 superior than the obtained at an increased area at a mild deficit irrigation regime.

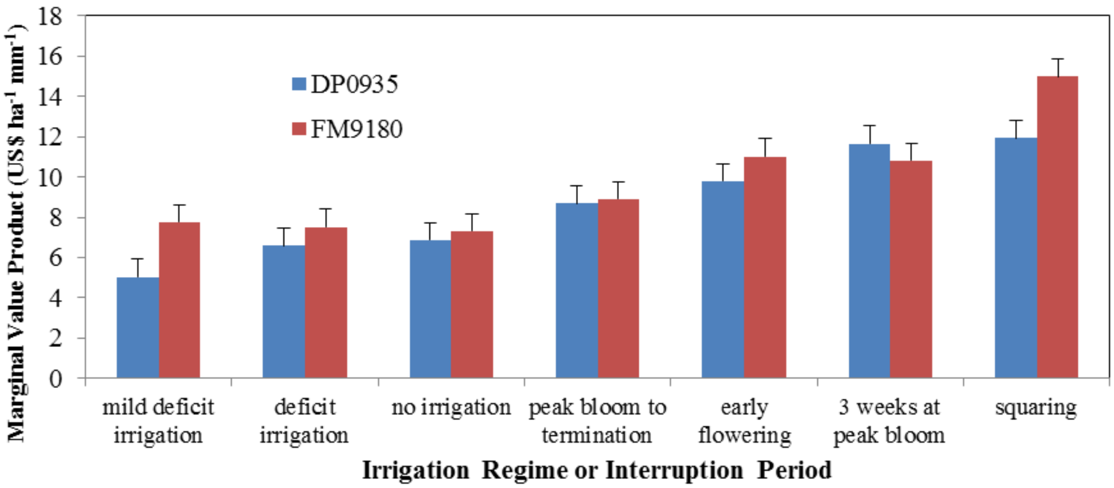

Figure 12. Marginal Value Product to full irrigation of cultivars DP0395 and FM9180 subjected to seven different irrigation regimes during the 2012 season at the Texas Tech Quaker Avenue Research Farm. LSD (p=0.05) = US$ 0.88 ha^{-1} mm^{-1}. US$ 1.00 ha^{-1} mm^{-1} = US$ 0.01 10^{-2} L^{-1}.

Figure 12 shows that in 2012 the highest increase in revenue per aditional milimeter of irrigation depth applied would be obtained from a crop with irrigation interrupted at the squaring stage, more than US$13 ha^{-1} mm^{-1}. The lowest MVP was observed for a crop at a mild deficit, and it would not be statistically different from the MVP for a deficit irrigation nor dryland.

Summary

For all environments and trials statistically significant ($p<0.01$) irrigation or episodic drought effect on seed-cotton yield was observed.

A cultivar single main effect in seed-cotton yield was observed for two environments of each set of trials.

While the seed-cotton irrigation-cultivar interaction was statistically significant for all environments of the Episodic Drought sets of trials, at the Irrigation levels set of trials it was significant just in 2012.

In 2012, the seed-cotton yield when a 3 weeks at peak bloom irrigation interruption occurred was not statistically different of the observed from a squaring stage episodic drough and also didn't differ from the yield from a mild deficit irrigation management.

If the water saved on the several irrigation management strategies tested in 2012 was used to increase the planted area, the highest total production would still be achieved under one fully irrigated hectare, but it was not statistically different from the total production obtained under a mild deficit irrigation management.

2012 effects of the treatments on the revenues were very similar to the effect on profit. An average revenue difference of almost US$ 3,000 ha^{-1} (more than US$ 2,400.00 ha^{-1} in profit) was observed between the fully irrigated and dryland water regimes.

The 2012 effects of mild deficit irrigation in revenue and profit were not statistically different from the obtained by irrigation interruptions at the squaring stage and at the peak bloom stage from three weeks. Similarly, the total revenue and profit obtained with a deficit irrigation regime would be similar to the observed when there was an episodic water stress at the early flowering stage and from the peak bloom until the crop termination.

In 2012, even if the area of mild deficit irrigation regime was increased to use the same amount of water of a fully irrigated hectare the profit of a fully irrigated hectare would be superior in more than a thousant dollars.

References

Allen, V.G., M.T. Baker, E. Segarra, and C.P. Brown. 2007. Integrated Crop-Livestock Systems in Dry Climates. Agronomy Journal 99:346-360.

Bordovsky, J.P., W.M. Lyle, and E. Segarra. 2000. Economic Evaluation of Texas High Plains Cotton Irrigated by LEPA and Subsurface Drip. Texas Journal of Agriculture and Natural Resources 13: 67-73.

Denning, M.L., O.A. Ramirez, and C. Carpio. 2001. Impact of Quality on the Profitability of Irrigated Cotton Production on the Texas High Plains, in: N. C. Council (Ed.), Beltwide Cotton Conference, Memphis, TN. pp. 208-216.

Doll, J.P., and F. Orazen. 1992. Production economics: theory with applications. Second Edition ed. Krieger Publishing Company, Florida.

Littell, R.C., G.A. Milliken, W.W. Stroup, and R.D. Wolfinger. 1996. SAS system for mixed models. SAS Inst., Cary, NC.

Plains. 2012. Plains Cotton Growers Inc. < http://www.plainscotton.org/2012Loan/2012LoanPandD.pdf>

SAS Institute. 2010. The SAS system for Windows. Release 9.3. SAS Inst., Cary, NC.

Sneed, J. 2010. Irrigation Termination to Improve Fiber Maturity on the Texas High Plains, Plant and Soil Science, Texas Tech University, Lubbock - TX. pp. 119. (Master of Science Thesis)

Texas. 2012. West Texas A&M AgriLife Extension Service: Estimated costs and returns per Acre < http://agecoext.tamu.edu/fileadmin/user_upload/Documents/Budgets/District/2/2012/cottondihtir.pdf/>.

Wilde, C. 2008. Optimal economic combination of irrigation technology and cotton varieties on the High Plains of Texas, Agricultural and Applied Economics, Texas Tech University, Lubbock, TX. pp. 158. (Master of Science Thesis)