

REPORT

Title: Cotton-Biofuels Production Systems in a Changing High Plains Environment

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Abstract: Concern in the Texas High Plains over declining water tables has led local water conservation districts to impose increasingly restrictive pumping limits beginning in 2012. This, coupled with the increased need for dedicated crops to supply the region's confined animal feeding operations as well as support the state's push for biofuels production, and the issue of elevated cotton disease pressures will impact future production decisions. Traditionally, crop rotation systems in the region incorporate grain sorghum in rotation with cotton, which has been shown to reduce incidence of cotton disease; however, it has also been shown that such rotations do not compare favorably to continuous cotton either economically or in terms of water use efficiency. In 2011, a cotton-alternative crop rotation study was initiated on a 24-acre (9.7 ha) site at the Texas AgriLIFE Research Center in Halfway, Texas. While the overall objective of the study is to develop field data for eventual water policy and economic analysis; a first year objective was to establish a 2:1 cotton rotation system using two oilseed crops (sunflower and safflower), and two forage sorghum varieties in the rotation with cotton. The complementary objective was to document and compare water use and economic advantages/disadvantages among alternative crop cultivars versus continuous cotton where the primary water resource is rainfall supplemented by three very limited irrigation levels. The results showed that, in cotton, with 152 mm (6 in) of seasonal irrigation (High), yield, seasonal irrigation water use efficiency and irrigation water value was significantly greater than with 76 mm (3 in) of seasonal irrigation (Medium). In forage sorghum, at the High irrigation level, both total biomass and dry matter yield were significantly higher than at the Medium level; however, seasonal irrigation water use efficiency and irrigation water value were statistically ($\alpha = .05$) the same for each variety. For oilseed crops, no statistical differences were observed in any measured parameter between the High and Medium irrigation levels. Seed and oil yield were significantly lower in both sunflower and safflower at the Low (pre-plant only) irrigation level. Based on soil water monitoring, cotton depleted soil water by approximately 42 mm (1.67 in) over the growing season, while the alternative crops resulted in 63.5 mm (2.5 in) of soil water depletion. Among treatments for 2011, irrigation water value was highest where cotton was irrigated at the High level, having a relative value of \$52.00/ac-in.

Problem and Research Objective: The Texas High Plains (THP) region has long faced the reality of declining water availability in the Ogallala and other minor panhandle aquifers. Storage in the southern region of the Ogallala Aquifer has declined from 500 billion m³ in 1990 to approximately 436 billion m³ in 2004, a 12% decline over the 15-year period (Ogallala Aquifer Maps, TTU-CGT); and, according to the 2007 State Water Plan, the volume of Ogallala water available for use in 2010 was 7 billion m³ and will decline annually to 4.2 billion m³ by 2060 (Water for Texas, 2007). The state's water policy is now aimed at reducing the rate of

groundwater withdrawals. The Texas Water Code now requires groundwater conservation districts to develop each aquifer's "desired future conditions" within groundwater management areas to determine management goals for that aquifer, essentially regionalizing water management (TWC §35.004 *et seq.*). The code also requires a target and/or cap for groundwater permitting. To comply with the second requirement, THP water districts have implemented mandatory pumping limits, to be phased in over a four-year period beginning in 2012 (HPUWCD No. 1, 2012).

Also, there is an increased interest in biofuel production (*other than corn-based ethanol*) both at the state and federal levels. In 2009, the state legislature established the Texas Bioenergy Policy Council and Research Committee under the umbrella of the Texas Department of Agriculture. These bodies were charged with the task of developing strategies to further the state's goal of positioning itself as the nation's leader in bioenergy production by "*identifying strategies to the potential transition of agriculture in western regions of Texas to dryland bioenergy crops that are not dependent on groundwater resources*" (TDA, 2011). Meanwhile, federal mandates and incentives are also driving the expectation of major increases in the production of biomass (U.S. DOE, 2009). The federal Renewable Fuels Standard now requires 15.2 billion gallons of renewable fuel be produced in 2012 (U.S. EPA, 2012), and the Energy Independence and Security Act of 2007 sets the long-term production target at 36 billion gallons per year by 2022 (U.S. DOE, 2009).

Further, due to its environmental suitability, the THP has a very high concentration of confined animal feeding operations (CAFO). In 2011, there were 2.57 million head on feed for slaughter (85% of the state's total and 22% of the nation's total) in the THP, and the region is home to 8 of the state's top 10 dairy producing counties, producing 54% of the state's milk (USDA-NASS, 2011). These industries rely heavily on grains shipped from out of state; thus, there is a need for locally grown feeds to stay viable.

Finally, there is the growing issue of disease pressure in cotton monoculture: Verticillium wilt is the most yield-limiting cotton disease in the THP region and can drastically affect water use efficiency by reducing yield (Wheeler, *et al.*, 2009). In field tests at the Helms Research Farm in 2008 and 2009, the incidences of wilt in cotton were reduced from 30% to less than 8% by using sorghum every third year in rotation with cotton (Wheeler, *et al.*, 2009). While cotton crop rotation strategies in this region typically include cotton in rotation with grain sorghum; an 8-year cotton/grain sorghum study showed that rotation with grain sorghum did *not* favorably compare to continuous cotton either economically or from a water use efficiency perspective at current commodity prices (Bordovsky, *et al.*, 2011).

The foregoing issues will require area producers to consider alternatives to the traditional cotton production systems. Several crops have been identified as reasonable alternatives for rotation with cotton due to their adaptability to the region and potential value in the animal feed/bioenergy markets. These include the oilseed crops safflower and sunflower, as well as forage sorghums for animal feed or potential biomass conversion, among others. Each of these crops has been grown with varying levels of success in the region; although there are no known long-term studies documenting detailed water use and crop responses when incorporated in cotton rotation systems at extremely low irrigation levels.

The overall objective of this project is to document total water use and crop response in rotation systems where alternative crops are grown with cotton. Specific objectives are to: 1) establish a 2:1 cotton rotation using biofuels crops in the rotation; 2) begin documenting and comparing water use among rotation sequences versus continuous cotton where the primary water resource is rainfall supplemented by very limited irrigation; and 3) begin documenting crop yield and quality, nutrient use, pest and disease pressures and determining water use efficiency and economic advantages/disadvantages of alternative crops rotated with cotton compared to the traditional continuous cotton system.

Materials/Methodology: In 2011, a 2:1 cotton-alternative (AC) crop rotation study was initiated on a 9.7 ha (24-acre) field at the Texas AgriLIFE Research Center in Halfway, Texas. The study was established under an 8-span center pivot with crops irrigated by LEPA using circular rows oriented perpendicular to the pivot lateral. Rotation treatment plots included: cotton followed by cotton and then the AC treatment (**CCA**); cotton followed by AC and then cotton (**CAC**), and; AC followed by two years of cotton (**ACC**). The rotation treatments will be compared to continuous cotton (**CCC**). Rotation treatment areas were 16 1-m (40") rows wide and arced 180° of the pivot circle. The 180° pivot arc was divided into six pie-shaped wedges containing the irrigation treatments, where in-season irrigation was held to 0 mm or "pre-plant irrigation" only (**Low**); 76 mm (**Med.**), and 152 mm (**High**), respectively in each of two randomly selected wedges. Treatment plots were arranged in a randomized block design within 4 blocks. Plot sizes ranged from ~ 0.05 to 0.2 ha (.15 - .5 acres) allowing 4 alternative crops or varieties to be planted as sub-plots within the AC treatment areas. The field design and crop rotation sequence are shown in Figure 1, below.

The AC treatments consisted of: sunflower (Cruiser Maxx s668); safflower (TTU #1601), and; two sorghum/sudan-hybrid forage sorghum varieties (Maxi Gain BMR & Sugar Graze Ultra, Coffey Seed Co., Plainview, Texas). Sunflower and safflower crops were planted on 20-April at ~ 49,400 plants ha⁻¹ (20,000 ppa) and ~ 226,000 plants ha⁻¹ (91,500 ppa) respectively. Cotton (FM 9160 B2F) was planted 17-May at ~ 116,000 plants ha⁻¹ (47,000 ppa), and the forage sorghum varieties were planted on 31-May at ~ 6.5 kg/ha (5.8 lbs/ac) and ~ 6.2 kg/ha (5.5 lbs/ac) respectively. All treatments were planted using a John Deere® Max Emerge planter.

Figure 2 shows the target and applied seasonal irrigation schedule for each crop. Target irrigation timing and amount were determined based on crop water use curves and known critical development periods for each crop. A Lindsay FieldBasic® programmable irrigation controller with electronic valve was used to pressurize the pivot, set the appropriate pivot speed, and stall/drain the pivot between irrigation treatments (wedges). Access tubes were placed to a depth of ~ 2 m (6.5') in the oilseed treatments, and ~ 1.4 m (4.5') in the forage sorghum and cotton treatments, and volumetric soil water content was monitored throughout the season in four replicates of each crop by the neutron scatter method, beginning 1-June and ending 27-September.

Safflower and Sunflower Sampling Methods

Representative samples (4 rows by ~ 4 m) from plots of the safflower and sunflower were hand-harvested on 25-July and 5-August respectively. Samples of each crop were threshed using a large plot thresher. Seed yield, water use efficiency (WUE), seasonal irrigation water use

efficiency (SIWUE), and seasonal irrigation water value (SIWV) were determined from the resulting seed weights and harvest area for each crop, and oil and moisture content were determined by Nuclear Magnetic Resonance Spectrometry (NMR) analysis at the Texas AgriLIFE Research Seed Laboratory in Lubbock, Texas. Oil yield was determined for each crop based on NMR results.

Forage Sorghum Sampling Methods

Representative samples (4 rows by ~ 4 m) from plots of the two forage sorghum varieties were hand-harvested on 19-September. Whole plants were weighed and chopped in the field using a 2" Cub Cadet® chipper/shredder to determine total biomass yield. Ensilage was hand-mixed and ~ .91 kg (2-lb) sub-samples were placed in a sealed container and immediately frozen. Forage quality for each replication and variety was determined from the frozen sub-samples by Near Infrared (NIR) analysis at an independent laboratory. Wet and dry yield, water use efficiency (WUE), seasonal irrigation water use efficiency (SIWUE), and seasonal irrigation water value (SIWV) were determined from the field weights and NIR results.

Cotton Sampling Methods

Cotton treatments were machine-harvested with a John Deere® 7445 stripper equipped with on-board scales and area calculator (Calc-An-Acre®), which recorded seed cotton weights and harvest distance at each sampling site. In 2011, samples were taken from each crop strip along the pivot lateral, and at each irrigation treatment along the pivot arc for a total of 54 samples. Approximately .45- to .91-kg (1 – 2 lb) sub-samples from each seed cotton sample were ginned at the Texas AgriLife Research and Extension Center's gin in Lubbock, Texas. Lint yield was determined using harvested area, seed cotton harvest weight and lint turnout percentage. Lint quality was determined by HVI analysis performed on all lint samples at the Fiber & Biopolymer Research Institute at Texas Tech University in Lubbock, Texas. Loan values were determined based on HVI results.

Calculations

WUE for each treatment and replicate was calculated by dividing lint yield (cotton), seed yield (oilseed) or dry yield (forage sorghum) by total in-season water (rainfall + in-season irrigation + change in soil water content). SIWUE was calculated by subtracting non-irrigated yield (Y_{DL}) from irrigated yield for each treatment (Y_P) and dividing the product by in-season irrigation (I_S), $[Y_P - Y_{DL}/I_S]$. SIWV (\$/acre-in) was calculated by multiplying the crop price (\$/lb) by SIWUE (lbs/acre-in). Crop prices for sunflower, cotton and forage sorghum (*i.e.* hay) were estimated from USDA-NASS United States/Texas average price received (projected) for November 2011 (USDA-NASS, 2011). The prices used were as follows: Texas average for sunflower (\$18.70/cwt); U.S. average for Upland cotton (\$.817/lb); and, U.S. average for "other" hay (\$122.00/ton). Safflower price was estimated based on 2011 locally contracted price (\$.20/lb). SIWV estimations did not account for input costs, premiums or discounts due to quality, or value-added products (*i.e.* milk production, safflower oil for consumption, or cottonseed value). Lint, seed/oil, and hay yield, cotton loan value, SIWV and SIWUE of the four replicates were averaged by treatment and comparisons made using standard analysis of variance with separation of means by Fisher's least significant difference method.

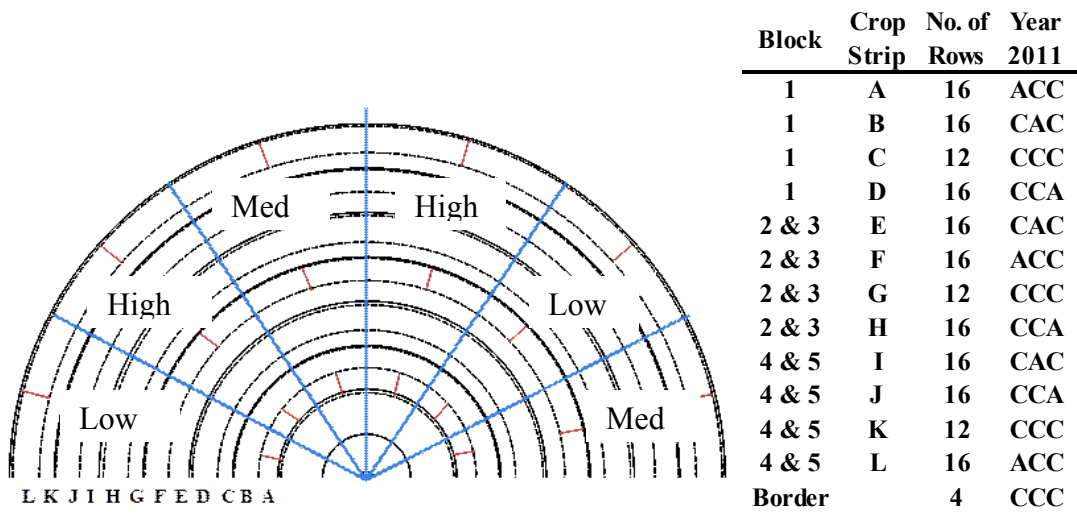


Figure 1. 2011 field design (9.7 ha), showing 3 irrigation treatments, and 12 crop strips (left); and, legend showing cropping sequences by block (right). Texas AgriLIFE Research Center - Halfway.

2011		High (6" In-season Irr.)								Med. (3" In-season Irr.)							
		Sorghum		Cotton		Sunflower		Safflower		Sorghum		Cotton		Sunflower		Safflower	
Irr. Week	Date	Tgt	Appl	Tgt	Appl	Tgt	Appl	Tgt	Appl	Tgt	Appl	Tgt	Appl	Tgt	Appl	Tgt	Appl
1	5-Jun		1			1	1	1	1		1			1	1	1	1
2	12-Jun					1	1	1	1					1	1	1	1
3	19-Jun	1		1	1	1	1	1	1				1	1	1	1	1
4	26-Jun					1	1	1	1					0.5		0.5	
5	3-Jul	1	1	1	1	1	1	1	1	1	1	1	1				
6	10-Jul					1	1	1	1								
7	17-Jul	1	1	1	1					1	1	1	1				
8	24-Jul		1		1						1	1	1				
9	31-Jul	1		1						1							
10	7-Aug	1	1	1	1												
11	14-Aug	1	1	1	1												
12	21-Aug																
13	28-Aug																
Total		6	6	6	6	6	6	6	6	3	4	3	4	3	3.5	3	3.5

Figure 2. Target and applied seasonal irrigation schedule for cotton-alternative crop rotation study at Texas AgriLIFE Research Center-Halfway, 2011.

Principal Findings: Tables 1 through 4, below contain average yield, cotton loan value, WUE, SIWUE and SIWV for cotton and four alternative crops by irrigation level for 2011. In cotton (Table 1) a significant difference ($\alpha=.05$) among irrigation levels was observed for yield, SIWUE and SIWV. In the two varieties of forage sorghum, while a significant difference in yield was observed among irrigation levels; there were no corresponding differences in SIWUE or SIWV (Table 2). In sunflower and safflower (Tables 3 & 4) there were no significant differences in

yield, SIWUE or SIWV in the High versus Med. irrigation levels; however, a statistical difference was observed between the High versus Low irrigation levels in both crops.

Numerical differences were seen in yield, SIWUE and SIWV between the two forage sorghum varieties (Maxi Gain BMR being greater than Sugar Graze Ultra), as well as between the two oilseed crops (sunflower having the greater yield, SIWUE and SIWV compared to safflower). This was unexpected given that the sunflower experienced severe pest pressure from carrot beetle (*Tomarus gibbosus*) infestation, resulting in a high degree of crop loss.

Among all treatments, cotton irrigated at the High level resulted in the highest relative water value at \$52.00/ac-in (Figure 3). Also, the average seasonal change in profile water for cotton was less than the alternative crops. The change in soil volumetric water content (Δ VWC) in cotton from 1-June through 27-September was approximately 1.67 inches (42.4 mm), while the alternative crops approached 2.5 inches (63.5 mm). This value represents the average at all irrigation levels. As shown in the figure, under conditions such as those experienced in 2011, cotton resulted in the highest water value with the least seasonal soil water depletion.

Table 1. Average lint yield (lbs/ac), loan value (\$/lb), SIWUE (lbs/ac-in), SIWV (\$/ac-in), and WUE (lbs/ac-in) in cotton at three irrigation levels. Texas AgriLIFE Research Center at Halfway, Texas, 2011.

Irr. Level	Avg. Lint Yield		Avg. SIWUE (lbs/ac-in.)	Avg. SIWV	Avg. WUE (lbs/ac-in.)
	(lbs/ac)	Avg. Loan Value		(\$/ac-in.) @ .82/lb	
High (6")	504 ^[A]	0.51 ^[A]	64 ^[A]	52 ^[A]	50 ^[A]
Med. (4")	269 ^[B]	0.47 ^[A]	38 ^[B]	31 ^[B]	33 ^[B]
Low (PP)	119 ^[C]	0.51 ^[A]			29 ^[B]

Means with the same letter are not significantly different (Fisher's LSD method; $\alpha=.05$).

Table 2. Average wet yield (lbs/ac), dry yield (lbs/ac), SIWUE (lbs/ac-in), SIWV (\$/ac-in), and WUE (lbs/ac-in) in two forage sorghum varieties at three irrigation levels. Texas AgriLIFE Research Center at Halfway, Texas, 2011.

Irr. Level	Avg. Wet Yield (lbs/ac)	Avg. Dry Yield (lbs/ac)	Avg. SIWUE (lbs/ac-in.)	Avg. SIWV	Avg. WUE (lbs/ac-in.)
				(\$/ac-in.) @ \$122/ton	
Maxi Gain BMR					
High (6")	15594 ^[A]	3854 ^[A]	534 ^[A]	33 ^[A]	321 ^[A]
Med. (4")	9997 ^[B]	2749 ^[B]	525 ^[A]	32 ^[A]	275 ^[AB]
Low (PP)	4480 ^[C]	1335 ^[C]			223 ^[B]
Sugar Graze Ultra					
High (6")	17139 ^[A]	4550 ^[A]	648 ^[A]	40 ^[A]	379 ^[A]
Med. (4")	11487 ^[B]	3251 ^[B]	647 ^[A]	39 ^[A]	325 ^[A]
Low (PP)	4480 ^[C]	1364 ^[C]			228 ^[B]

Means with the same letters are not significantly different (Fisher's LSD method; $\alpha=.05$).

Table 3. Average seed yield (lbs/ac), oil yield (lbs/ac), SIWUE (lbs/ac-in), SIWV (\$/ac-in), and WUE (lbs/ac-in) in sunflower at three irrigation levels. Texas AgriLIFE Research Center at Halfway, Texas, 2011.

Irr. Level	*Avg. Seed Yield (lbs/ac)	Avg. Oil Yield (lbs/ac)	Avg. SIWUE (lbs/ac-in.)	Avg. SIWV (\$/ac-in.) @ \$18.70/cwt	Avg. WUE (lbs/ac-in.)
High (6")	804 ^[A]	327 ^[A]	67 ^[A]	12 ^[A]	78 ^[A]
Med. (3.5")	567 ^[AB]	238 ^[AB]	52 ^[A]	9 ^[A]	73 ^[A]
Low (PP)	334 ^[B]	152 ^[B]			79 ^[A]

*8% moisture.

Means with the same letters are not significantly different (Fisher's LSD method; $\alpha=.05$).

Table 4. Average seed yield (lbs/ac), oil yield (lbs/ac), SIWUE (lbs/ac-in), SIWV (\$/ac-in), and WUE (lbs/ac-in) in safflower at three irrigation levels. Texas AgriLIFE Research Center at Halfway, Texas, 2011.

Irr. Level	*Avg. Seed Yield (lbs/ac)	Avg. Oil Yield (lbs/ac)	Avg. SIWUE (lbs/ac-in.)	Avg. SIWV (\$/ac-in.) @ .20/lb	Avg. WUE (lbs/ac-in.)
High (6")	547 ^[A]	197 ^[A]	33 ^[A]	7 ^[A]	53 ^[A]
Med. (3.5")	480 ^[A]	169 ^[A]	36 ^[A]	6 ^[A]	62 ^[A]
Low (PP)	245 ^[B]	86 ^[B]			58 ^[A]

*4.5% moisture.

Means with the same letters are not significantly different (Fisher's LSD method; $\alpha=.05$).

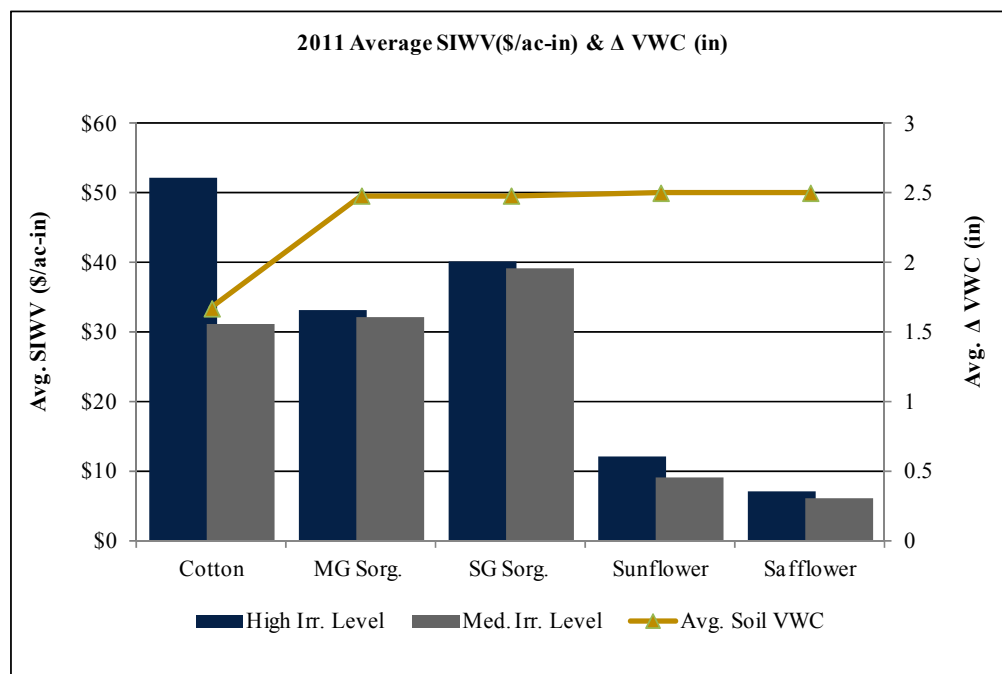


Figure 3. Relative seasonal irrigation water value (\$/ac-in) and average seasonal change in soil volumetric water content (in) in cotton and four alternative crops at High and Med. irrigation levels. Texas AgriLIFE Research Center at Halfway, Texas, 2011.

Significance: While these initial data are useful for a cursory evaluation of the feasibility of cotton-alternative crop systems, the ultimate goal of this study is to develop a dataset for comprehensive economic/policy analysis of Texas High Plains cropping systems under severe irrigation limits. This report describes the first year of the study. The 2011 growing season was characterized by severe drought and unusually high temperatures, with 2011 being both the driest and hottest year on record for the region. These conditions contributed to atypical yield results, even for those crops considered to be drought tolerant. As one would expect in a dry year, yields were significantly increased by increases in irrigation level. The highest seasonal irrigation water value (\$52.00/ac-in) among all crops was in cotton at the High irrigation level. This suggests that when water is severely limited, the better production decision may be to reduce input costs by planting cotton on a smaller area and irrigating at a higher rate compared to other alternatives.

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