LEVERAGING RAINFALL WITH VERY LIMITED IRRIGATION IN TEXAS HIGH PLAINS COTTON ROTATIONS

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Abstract

Declining water tables have led to increased dependence on rainfall for crop production in the Texas High Plains. Also, pest pressures in cotton and increased confined animal feeding have contributed to the need for alternative crops other than cotton. Field evaluations were conducted to compare yield and total water use of the typical continuous cotton system to three-year cotton rotations that replaced cotton every third year with 1) BMR forage sorghum, non-BMR forage sorghum, safflower, and sunflower (test years 2013 to 2016) and 2) corn and grain sorghum at two populations (years 2017 to 2018). Seasonal irrigation volumes were limited to 0, 3 and 6 acre-inches/acre per year. To date, there are no results indicating cotton in rotation with any alternate crop consistently produced higher or lower yields than continuous cotton. Gross crop returns, and therefore gross irrigation water values, were generally higher when irrigations were applied to cotton rather than alternative crops. In all years, increases in water use efficiency (WUE) occurred with each incremental increase in seasonal irrigation volume. The WUE results indicate concentrating limited irrigation on smaller land areas is the more productive use of seasonal rainfall, as well as irrigation, than spreading irrigations over larger areas under the conditions of this experiment.

Introduction

Cotton production will continue to be the foundation of the agricultural economy in the Southern High Plains (SHP) of Texas. However, significant changes such as declining water tables, modifications in water policy, elevated cotton disease pressures and demands of confined feeding operations are occurring and affecting production decisions.

The SHP of Texas is undergoing a transition from irrigated to dryland production. A recent study showed the accelerated annual usage in the Ogallala Aquifer in Texas had increased to 4.3 M ac-ft from 2011 to 2013 compared to the 1950-2011 average of 2.6 M ac-ft with negligible recharge (McGuire, 2014). 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.

Crops other than cotton are grown to address various issues. Verticillium wilt is currently the most yield-limiting cotton disease in the SHP and can drastically affect water use efficiency (WUE) by reducing yield (Wheeler et al., 2012). Rotations of non-host crops with cotton may be part of the solution. Also, confined feeding operations have placed approximately 2.4 M head of cattle, 234 thousand dairy cows, and 865 thousand hogs on feed in the Texas High Plains (USDA-NASS, 2010). This industry depends on local irrigated grain and forage production to stay viable.

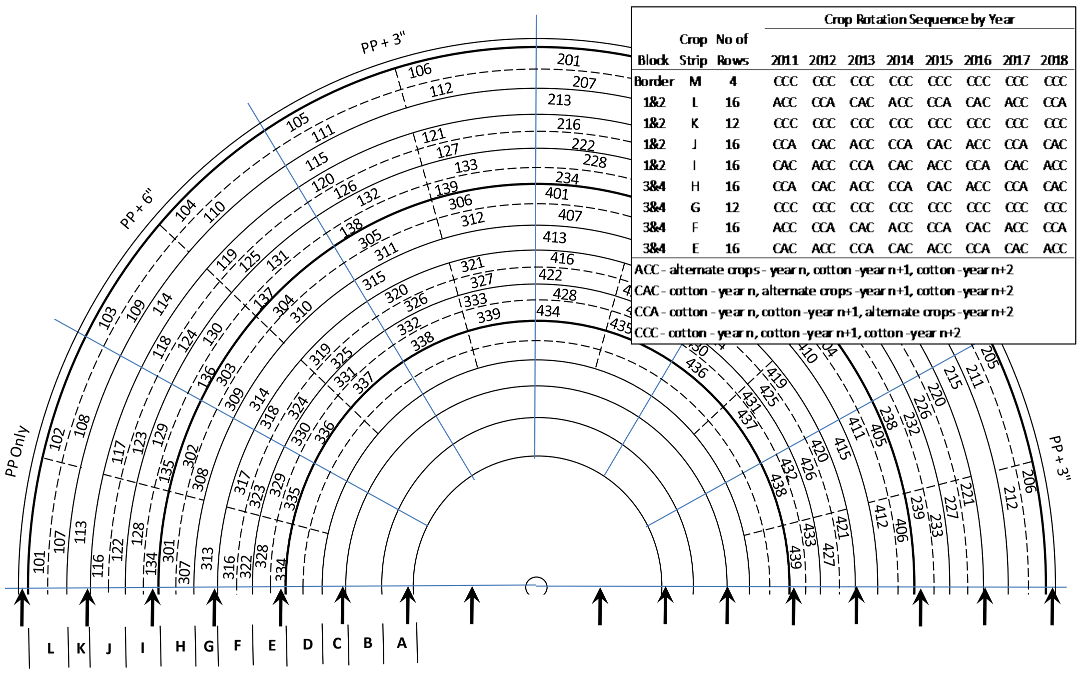
Annual rainfall in the SHP averages approximately 18 inches per year with 12 inches from April to September, sufficient to plant over 1.5 M ac of dryland cotton per year (USDA-NASS, 2010). One semi-arid production strategy uses available irrigation volumes for timely crop establishment or during critical reproductive periods when the lack of timely rain could cause catastrophic yield losses. This strategy leverages seasonal rain with irrigation to maximize rainfall value by ensuring some level of production in dry years and reasonable yields in wet years. Past studies addressed cotton rotations with wheat and grain sorghum at limited irrigation rates (Bordovsky et al., 1994, Bordovsky et al., 2011). There are no known studies documenting water use in cotton rotation systems involving crops such as forage sorghums, safflower, and sunflower under very limited irrigation. Also, new corn and sorghum hybrids are being marketed as "drought-and-heat-tolerant" and, in limited irrigated rotations, may provide additional alternatives while using minimal irrigation in average rainfall years. Questions include whether these alternative crops (ACs) are a reasonable option in rotation with cotton in terms of water use and economics and how do they compare to continuous cotton in this water-short environment. The use of low levels of supplemental irrigation in such rotations may stabilize year to year crop production (compared to dryland production), help reduce disease and pest pressures in cotton, and provide options for confined feeding operations as available irrigation quantities decline.

The objective of this paper is to report the status of an ongoing research project comparing crop yields and water productivity of a continuous cotton production system to those of several cotton rotations with alternative crops planted once every third year and where seasonal irrigation amounts are limited to 0, 3 and 6 inches per year. This information will be used for future economic analysis and incorporated into future decision guides.

Materials and Methods

A three-year crop rotation cycle was initiated in 2011 at the Texas A&M AgriLife Research Center at Halfway, TX on a 24-acre site having a Pullman clay loam soil. The area was divided into 156 plots arranged in a complete block design of three whole plot treatments having preplant plus seasonal irrigation depths of 3 + 0 inches; 3 + 3 inches; and 3 + 6 inches, respectively. Thirteen sub-plot treatments from 2011 through 2016 included four having alternative crops (ACs) in the current year following cotton in yr_{-1} and yr_{-2} (ACC); four treatments having cotton in the current year, an AC in yr_{-1} and cotton in yr_{-2} (CCA); four having cotton in the current year, cotton in yr_{-1} and an AC in yr_{-2} (CAC), and continuous cotton (CCC). The field layout provided four replicates of each rotation treatment x irrigation level. The ACs included two forage sorghum types (BMR and non-BMR), safflower, and sunflower. In 2017 and 2018 the four ACs were replaced with two plant populations of corn and two plant populations of grain sorghum.

Irrigation was by the LEPA method. Treatment plots were either 8 or 12 40-inch wide rows and extended over a 15^0 or 30^0 pivot arc (Fig.1) Irrigation quantities were controlled by adjusting pivot speed or terminating flow using a programmable irrigation controller capable of automatically pressurizing the pivot irrigation system, setting pivot speeds for desired irrigation amounts, and terminating irrigation flow at appropriate locations between irrigation treatments. Following preplant irrigations of no more than 3 inches on all plots, total in-season irrigation depths were limited to 0, 3 or 6 inches per year resulting in total annual irrigation amounts of no more than 3, 6 or 9 inches. Seasonal irrigations of up to 1 inch per event were applied at critical crop growth periods with timing adjusted for rainfall and the crop being irrigated.



Block	Crop Strip	No of Rows	Crop Rotation Sequence by Year 2011	2012	2013	2014	2015	2016	2017	2018
Border	M	4	CCC	CCC	CCC	CCC	CCC	CCC	CCC	CCC
1&2	L	16	ACC	CCA	CAC	ACC	CCA	CAC	ACC	CCA
1&2	K	12	CCC	CCC	CCC	CCC	CCC	CCC	CCC	CCC
1&2	J	16	CCA	CAC	ACC	CCA	CAC	ACC	CCA	CAC
1&2	I	16	CAC	ACC	CCA	CAC	ACC	CCA	CAC	ACC
3&4	H	16	CCA	CAC	ACC	CCA	CAC	ACC	CCA	CAC
3&4	G	12	CCC	CCC	CCC	CCC	CCC	CCC	CCC	CCC
3&4	F	16	ACC	CCA	CAC	ACC	CCA	CAC	ACC	CCA
3&4	E	16	CAC	ACC	CCA	CAC	ACC	CCA	CAC	ACC

ACC - alternate crops - year n, cotton -year n+1, cotton -year n+2
CAC - cotton - year n, alternate crops -year n+1, cotton -year n+2
CCA - cotton - year n, cotton -year n+1, alternate crops -year n+2
CCC - cotton - year n, cotton -year n+1, cotton -year n+2

Figure 1. Field layout and plot map for the crop rotation with limited irrigation experiment, Texas A&M AgriLife Research, Halfway, Texas.

Year to year tillage was minimal consisting of stalk destruction (if applicable), herbicide incorporation while reshaping seedbeds, and furrow diking. Nutrients are injected on the sides of the crop row before planting based on 24-inch soil sampling, N-P-K analysis, and expected yield of the crop at the treatment irrigation level. Preplant irrigations were completed three to five days prior to planting a crop. Safflower and sunflower were generally planted between the 20th and 25th of April; cotton, forage sorghums and grain sorghum were planted on or near the 18th to the 25th of May; and corn planted near May 30. Pests in each crop were monitored weekly over the growing season and appropriate controls were applied at recommended thresholds.

Following planting, changes in volumetric soil water content to soil profile depths of 7 feet were periodically determined using the neutron probe method in two replicates of each treatment. The seasonal change in volumetric water content, along with rain and irrigation amount, were used to determine total water use of crops in respective treatments. From respective plots, forage sorghum, safflower, sunflower, corn and/or grain sorghum samples were hand harvested, while cotton was machine harvested, and yields and yield quality parameters were determined. Total water use and yield were used to calculate water use efficiency (WUE). Differences in yield and WUE among treatments were analyzed using standard statistical methods. The 2013 crop year was the first complete three-year rotation cycle of this experiment, therefore, results presented are from crop years 2013 and later. Yield results from 2015 were compromised due to late season hail and were not included.

Results and Discussion

Seasonal Rainfall

Seasonal rainfall from 2011 to 2018 varied widely over the test years (Fig. 2). From a crop water use stand point, 2011, 2012, 2016 and 2018 were dry to exceptionally dry with virtually no significant soil wetting during rain events in June or July due to either light amounts or extremely short duration rain and runoff. Rain in 2013 was near average for the period; and in 2014, 2015 and 2017, was well above average. With limited irrigation, annual weather conditions greatly affected yields and irrigation water productivity from one year to the next.

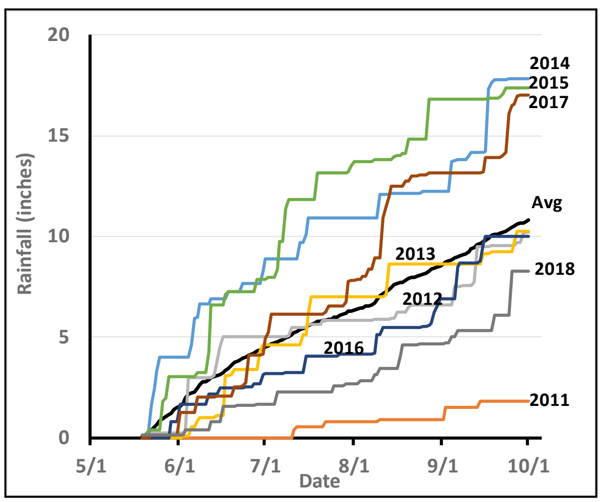


Figure 2. Long-term average and annual cumulative rainfall from May 20 through October 1 at Texas A&M AgriLife Research, Halfway, Texas, 2011-2018.

Yield and Water Use Efficiency

Average seasonal irrigation quantity, total water used, yield, and WUE for the years that included forage sorghums, safflower, and sunflower in rotations are given in Table 1. As expected, average yields increased with increased seasonal irrigation by up to 300%, for example cotton yield increased from 458 lb/ac to 1311 lb lint/ac in the continuous cotton (CCC) treatment with 0” and 6” of seasonal irrigation, respectively. Among the group of nine treatments where cotton was harvested each year and for a given irrigation level, yields were within fairly narrow ranges of 462 to 358 lb/ac at 0” seasonal irrigation; 877 to 762 lb/ac at 3”; and 1368 to 1208 lb/ac at 6”. Cotton lint yields from the CCC treatment were numerically higher than most of those in rotation treatments and significantly

Table 1. Treatment names, total irrigation per year, annual water used, average annual yield and water use efficiency from cotton rotations treatments that included forage sorghums, safflower, and sunflower using limited irriation quantities, Texas A&M AgriLife Reserch, Halfway, Texas 2013, 2014, and 2016.

		3"+ 0" Irrigation				3"+ 3" Irrigation				3" + 6" Irrigation			
	Treat. Name	Irr. Amt (in)	Annual Water Use[1] (in)	Avg. Yield[2] (lb/ac)	WUE[3] (lb/ac-in)	Irr. Amt (in)	Annual Water Use (in)	Avg. Yield (lb/ac)	WUE (lb/ac-in)	Irr. Amt (in)	Annual Water Use (in)	Avg. Yield (lb/ac)	WUE (lb/ac-in)
BMR Sorghum w/ Cot prior two years	ACC-FS1	3	13.2	14428	1082	6	16.7	22139	1331	9	18.4	27938	1515
Non-BMR Sorghum w/ Cot prior two years	ACC-FS2	3	13.1	15909	1200	6	16.6	25525	1535	9	18.4	34015	1838
Safflower w/ Cot prior two years	ACC-Saf	3	12.7	526	44	6	15.6	780	51	9	18.3	789	44
Sunflower w/ Cot prior two years	ACC-Sun	3	12.9	641	55	6	16.6	1685	110	9	18.8	2425	141
Cot w/ BMR two years prior	CAC-FS1	3	13.7	408	30	6	16.6	858	52	9	19.9	1368	69
Cot w/ Non-BMR two years prior	CAC-FS2	3	13.9	422	31	6	16.9	813	47	9	19.8	1366	69
Cot w/ Saf two years prior	CAC-Saf	3	14.0	453	33	6	16.9	809	47	9	19.7	1300	66
Cot w/ Sun two years prior	CAC-Sun	3	14.0	462	33	6	16.4	792	49	9	19.4	1295	67
Cot w/ BMR the prior year	CCA-FS1	3	13.3	385	29	6	16.4	877	53	9	19.4	1245	64
Cot w/ Non-BMR the prior year	CCA-FS2	3	13.6	369	27	6	15.8	803	50	9	19.0	1307	68
Cot w/ Saf the prior year	CCA-Saf	3	13.7	368	27	6	15.8	781	49	9	19.2	1208	63
Cot w/ Sun the prior year	CCA-Sun	3	13.3	358	27	6	16.4	762	46	9	19.3	1272	65
Continuous Cotton	CCC	3	14.1	458	33	6	16.7	824	50	9	19.7	1311	67
Cotton Summary													
	Average	3	13.7	409	30	6	16.4	813	49	9	19.5	1297	66

[1]Annual water use = seasonal irrigation + seasonal effective rainfall + change in seasonal soil water in 7 ft. soil profile.
[2]Moistusre Content - Forage Sorghum @ 65%, Sunflower @ 10%, Safflower @8%
[3]Water use efficiency (WUE) = grain or lint yields divided by annual water use

higher than several treatments in individual years (data not shown). At the 3” + 3” irrigation level, only the cotton treatments preceded by cotton and BMR forage sorghum (CAC-FS1) and those preceded by BMR forage sorghum (CCA-FS1) produced greater three-year yields than those of the CCC treatment, by 4 and 6%, respectively. At the 3” + 6” irrigation level, CAC-FS1 and CAC-FS2 yields were both 4% greater those of CCC. However, from one year to the next, relative cotton yields among these treatments were not consistent.

In 2017 the rotation treatments were altered by replacing past ACs with drought tolerant corn and grain sorghum hybrids, both at two plant populations. Table 2 contains irrigation amounts, estimates of annual water used, yield, and WUE for treatments in 2017 and 2018. Since 2017 and 2018 were the first and second years of having corn and grain sorghum in rotations, reported cotton results from rotation treatments have histories of the previous ACs. As in previous years, continuous cotton (CCC) yields were generally within 5% and exceeded yields from several rotation treatments indicating that previous AC crop histories had little consistent effect on the current years cotton crop compared to the continuous cotton treatment, even at very low irrigation levels. One exception was the 2017 cotton yields from the CCA-Saf treatment where yields exceeded all other treatment yields at all irrigation levels. This effect was attributed to extremely low 2016 safflower yields resulting in higher residual soil water going into 2017. Cotton yield was not reported for the 2017 CCA-Sun treatment due to negative effects of sunflower herbicide carryover.

Water use efficiency (or water productivity) was calculated by dividing crop yields by the total water quantity estimated to produce that yield. Total water used within a treatment was estimated as the sum of seasonal irrigation, seasonal effective rainfall and the change in soil water in the 7-foot soil profile. Relative WUEs for treatments reported in Tables 1 and 2 generally tracked those of yields for respective treatments due to the total water used being near the same for a crop within an irrigation level and year. One significant result was that WUE in each year, including individual years from 2013 to 2016, increased with each increase in seasonal irrigation level. For example, the average WUE of combined cotton treatments from 2013 to 2016 was 30, 49, and 66 lb/ac-in for the 3” + 0”, 3” + 3”, 3” + 6” irrigation levels, respectively (Table 1). Since WUE values included rainfall, the value of seasonal rainfall during these years was also proportionally increased with higher irrigation.

Irrigation Water Value

One way of evaluating optimum production strategies among the thrirteen treatments is by comparing respective irrigation water values (IWVs), or the gross monetary return per unit of irrigation applied to a crop within an

Table 2. Treatment names, total irrigation per year, annual water used, average yield and water use efficiency from cotton rotations treatments that included two populations of corn and grain sorghum using limited irrigation quantities, Texas A&M AgriLife Reserch, Halfway, Texas, 2017 -2018.

			3" + 0" Irrigation				3" + 3" Irrigation				3" + 6" Irrigation			
		Treat. Name	Irr. Amt (in)	Annual Water Use[1] (in)	Yield[2] (lb/ac)	WUE[3] (lb/ac-in)	Irr. Amt (in)	Annual Water Use (in)	Yield (lb/ac)	WUE (lb/ac-in)	Irr. Amt (in)	Annual Water Use (in)	Yield (lb/ac)	WUE (lb/ac-in)
2017	Corn 12k ppa w/Cot prior 2 yrs	ACC-C1	2.2	12.0	0	0	5.0	14.9	3807 A	255 A	8.2	18.1	5600 A	309 A
	Corn 20k ppa w/Cot prior 2 yrs	ACC-C2	2.2	12.1	0	0	5.0	14.7	3240 A	221 A	8.2	17.7	6491 A	366 A
	Grain Sorg 22k ppa w/Cot prior 2 yrs	ACC-S1	2.2	12.8	510 A	40 A	5.0	14.2	4274 A	302 A	8.2	17.1	5302 A	310 A
	Grain Sorg 42k ppa w/Cot prior 2 yrs	ACC-S2	2.2	12.4	467 A	38 A	5.0	14.4	4485 A	311 A	8.2	18.2	5048 A	278 A
	Cot w/ BMR two years prior	CAC-FS1	2.2	14.8	526 b	35 b	4.3	17.7	893 b	51 b	6.8	20.0	1254 a	63 a
	Cot w/ Non-BMR two years prior	CAC-FS2	2.2	15.2	521 b	34 b	4.3	17.6	902 b	51 b	6.8	19.9	1262 a	63 a
	Cot w/ Saf two years prior	CAC-Saf	2.2	15.1	571 b	38 b	4.3	17.7	897 b	51 b	6.8	20.1	1221 a	61 a
	Cot w/ Sun two years prior	CAC-Sun	2.2	15.1	484 b	32 b	4.3	17.1	795 b	46 b	6.8	19.6	1177 a	60 a
	Cot w/ BMR the prior year	CCA-FS1	2.2	15.3	597 b	39 ab	4.3	17.9	939 b	53 b	6.8	20.1	1248 a	62 a
	Cot w/ Non-BMR the prior year	CCA-FS2	2.2	15.7	559 b	36 b	4.3	17.0	886 b	52 b	6.8	20.1	1297 a	65 a
	Cot w/ Saf the prior year	CCA-Saf	2.2	15.9	764 a	48 a	4.3	18.0	1165 a	65 a	6.8	20.5	1418 a	69 a
	Cot w/ Sun the prior year	CCA-Sun	2.2	13.9			4.3	15.6			6.8	18.3		
	Continuous Cotton	CCC	2.2	15.7	588 b	37 b	4.3	17.4	897 b	52 b	6.8	19.5	1239 a	64 a
	Cotton Summary													
		Average	2.2	15.2	576	37	4.3	17.3	922	52	6.8	19.8	1264	63
2018	Corn 12k ppa w/Cot prior 2 yrs	ACC-C1	3.0	9.7	0	0	6.0	13.5	1547 A	115 A	9.0	16.2	3903 A	240 A
	Corn 20k ppa w/Cot prior 2 yrs	ACC-C2	3.0	9.9	0	0	6.0	13.9	1036 A	75 A	9.0	16.4	3756 A	228 A
	Grain Sorg 22k ppa w/Cot prior 2 yrs	ACC-S1	3.0	11.7	0	0	6.5	14.9	1645 A	110 A	9.5	18.2	4353 A	240 A
	Grain Sorg 42k ppa w/Cot prior 2 yrs	ACC-S2	3.0	11.0	0	0	6.5	15.1	1281 A	85 A	9.5	18.1	3237 A	179 A
	Cot w/ BMR two years prior	CAC-FS1	3.0	10.4	202 c	19 d	6.0	13.5	555 b	41 a	9.0	16.3	872 a	53 a
	Cot w/ Non-BMR two years prior	CAC-FS2	3.0	10.4	205 c	20 d	6.0	13.7	595 ab	44 a	9.0	16.5	914 a	55 a
	Cot w/ Saf two years prior	CAC-Saf	3.0	11.1	243 bc	22 bd	6.0	14.4	649 ab	45 a	9.0	17.2	951 a	55 a
	Cot w/ Sun two years prior	CAC-Sun	3.0	12.4	366 a	29 a	6.0	14.4	642 ab	45 a	9.0	18.1	919 a	51 a
	Cot w/ Corn 12k ppa the prior year	CCA-C1	3.0	10.1	289 b	29 ab	6.0	14.0	723 a	52 a	9.0	18.0	971 a	54 a
	Cot w/ Corn 20k ppa the prior year	CCA-C2	3.0	10.7	301 ab	28 ac	6.0	14.1	679 ab	48 a	9.0	17.1	979 a	57 a
	Cot w/ GSorgh 22k ppa the prior year	CCA-S1	3.0	10.0	188 c	19 d	6.0	13.8	627 ab	45 a	9.0	16.5	883 a	54 a
	Cot w/ GSorgh 42k ppa the prior year	CCA-S2	3.0	9.5	206 c	22 cd	6.0	13.8	641 ab	47 a	9.0	16.2	943 a	58 a
	Continuous Cotton	CCC	3.0	10.4	235 bc	23 bd	6.0	13.5	602 ab	45 a	9.0	16.1	965 a	60 a
	Cotton Summary													
		Average	3.0	10.6	248	23	6.0	13.9	635	46	9.0	16.9	933	55

[1]Annual water use = seasonal irrigation + seasonal effective rainfall + change in seasonal soil water in 7 ft. soil profile.
[2]Yields within a column followed by a common letter and letter type are not significantly different (±<0.05, Tukey).
[3]Water use efficiency (WUE) = grain or lint yield divided by annual water use, WUE's for a given crop within a column followed by a common letter and letter type are not significantly different (±<0.05, Tukey).

irrigation level. These values are the product of yields and local commodity prices, divided by the irrigation quantity used. Figures 3 and 4 highlight differences in IWVs of all treatments compared to the continuous cotton treatment from 2013 to 2018. IWVs ranged from near $200/ac-inch in the 2016 CCC cotton treatment (Fig. 3, 3” + 0” irrigation level) where rains prior to planting reduced preplant irrigation below 3 inches; to $0/ac-in in the 2018 ACC treatments (Fig. 4, 3” + 0” irrigation level) where preplant irrigations produced no harvestable corn or grain sorghum in a year of below average rainfall. Although results varied by year, in treatments where cotton was harvested each year, there were no IWVs from rotation treatments that were consistently greater or less than those of the CCC treatments regardless of irrigation level. However, IWVs of alternative crops (ACs) were typically below those of any treatment were cotton was harvested, particularly those of safflower (Fig. 3) and corn and grain sorghum (Fig. 4). Following cotton, sunflower in 2014 and non-BMR forage sorghum in all years resulted in the highest IWVs under the conditions of this experiment. Therefore, in terms of gross return per unit of limited irrigation, continuous cotton production remains as one of the best options in the Texas South Plains.

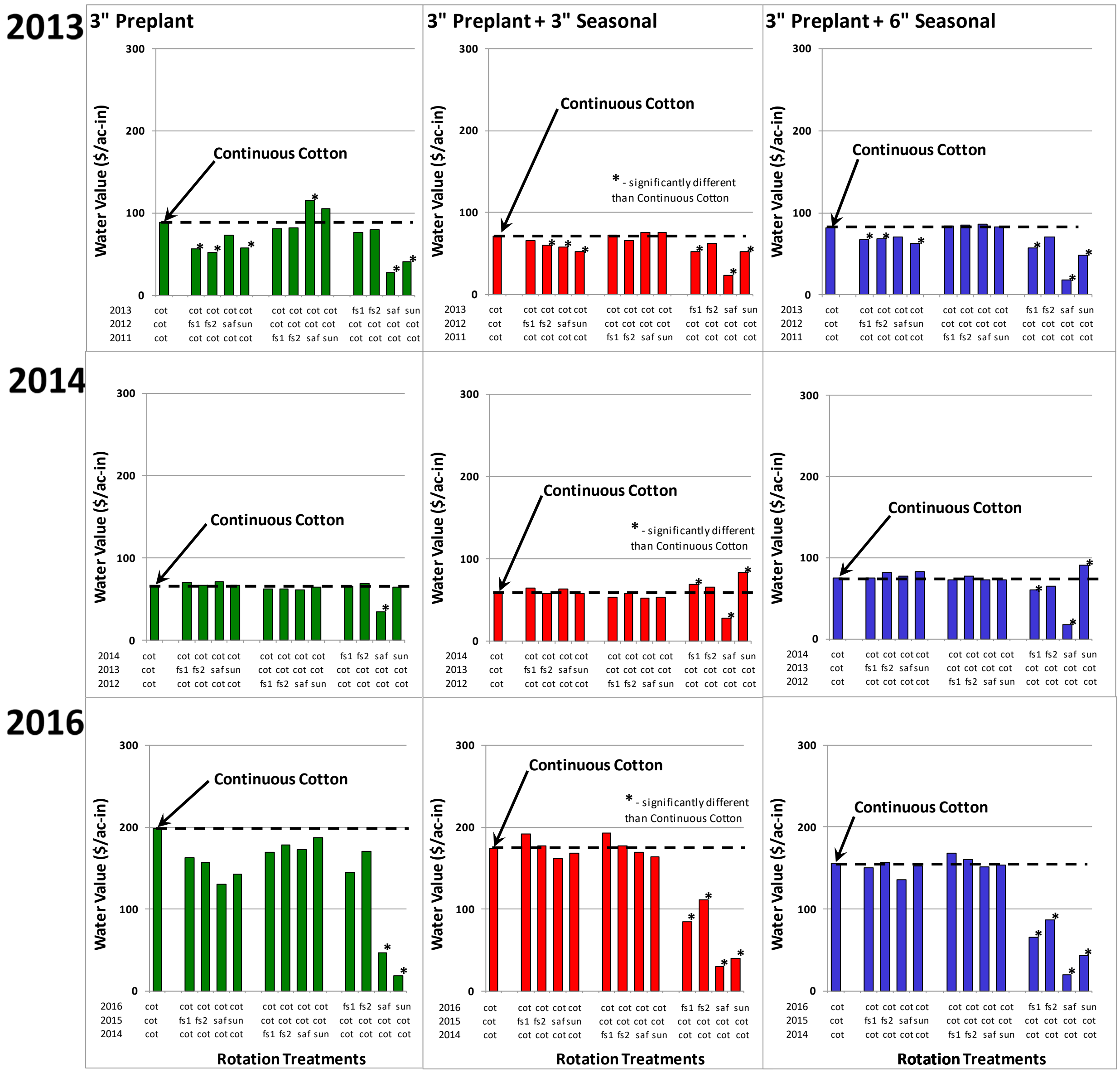


Figure 3. Irrigation water value (IWV) of thirteen treatments with rotation treatments having BMR forage sorghum (fs1), non-BMR-forage sorghum (fs2), safflower (saf), and sunflower (sun) every third year at three irrigation levels at Texas A&M AgriLife Research, Halfway, Texas, 2013, 2014, 2016.

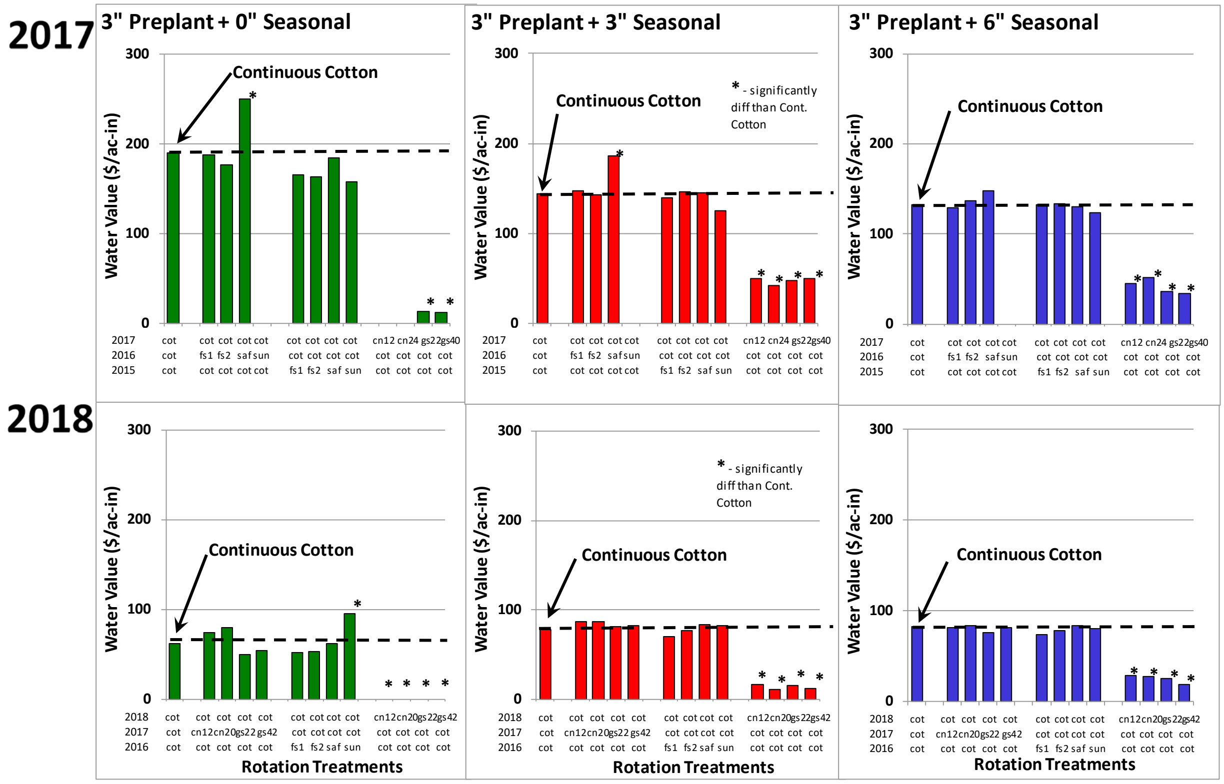


Figure 4. Irrigation water value (IWV) of thirteen treatments with rotation treatments having corn at 12,000 plants per acre (cn12), corn at 20,000 plants per acre (cn20), grain sorghum 22,000 plants per acre (gs22), and grain sorghum at 42,000 plants per acre (gs42) every third year at three irrigation levels at Texas A&M AgriLife Research, Halfway, Texas, 2017-2018.

Summary

Field evaluations were conducted to compare yield and total water use of a continuous cotton cropping system to three-year cotton rotations that replaced every third cotton crop with 1) BMR forage sorghum, non-BMR forage sorghum, safflower, and sunflower (2013 to 2016) and 2) corn and sorghum at two populations (2017 to 2018). Seasonal irrigation volumes were limited to 0, 3 and 6 acre-inches/acre per year. To date there were no results indicating cotton in rotation with an alternate crop produced consistently higher or lower yields than continuous cotton. Gross crop returns, and therefore gross irrigation water values, were generally higher when irrigations were applied to cotton rather than alternative crops. In all years, increases in WUE occurred with each incremental increase in seasonal irrigation volume indicating that concentrating available irrigation on smaller land areas may be the better water use option, of both rainfall and irrigation, than spreading irrigations over larger areas. From a grower's perspective, an optimum rotation compared to continuous cotton will depend on identifying local production parameters that improved water productivity. These might include differences in relative crop production costs, large differences in commodity prices, or significant reductions in crop damage (blowing sand, pests) by rotations with other crops.

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