COTTON YIELD RESPONSE TO VARIABLE IRRIGATION CAPACITY IN THE TEXAS HIGH PLAINS

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Abstract

Within the Ogallala Aquifer Region of Texas, the available irrigation capacity for a given field can change within a single growing season due to declines in well capacity, diverting water to higher value crops in dry years, or pumping volume restrictions. To better manage available water resources in the Texas High Plans, there is a need to determine cotton lint yield and irrigation water productivity as a function of changing irrigation capacities during major cotton growth periods. LEPA irrigated cotton was evaluated at the Texas A&M AgriLife Research Center at Halfway, Texas from 2010 to 2013. The treatment factors included in-season irrigation capacity (maximums of 0 in/d – **L** (low); 0.125 in/d – **M** (medium); and 0.25 in/d – **H** (high)) and irrigation application within cotton growth periods determined by heat unit (hu) accumulation, (early vegetative/juvenile (< 950 hu); reproductive (950-1350 hu); and maturation (>1350 hu)). Combinations of these factor levels resulted in 27 irrigation treatments. A 4-span LEPA pivot was used to irrigate 9.5 acres of this field experiment. The pivot was modified so that each 8-row section (40-inch rows planted in a circular pattern) along the lateral length could automatically provide different irrigation amounts depending on the treatments being irrigated and pivot position. Groups of valves were actuated using signals from a controller with specific "on-off" sequences for each irrigation treatment and treatment location. Inputs to the controller were pivot location (via GPS signal) and irrigation quantity (via application map) at each 8-row x 16-degree section for each irrigation application. Cotton yield and water productivity in all four years indicated that building soil water in the profile, or irrigating in excess of the evapotranspiration rate of the cotton plants early in the growing season, reduced irrigation water value compared to applying irrigation later in the growing season. This was attributed to water loss from excessive evaporation (high wind, low humidity) that often occurs and to the lack of irrigation capacity late in the season to accommodate developed cotton plants.

Introduction

Within the Ogallala Aquifer Region of Texas, the available irrigation capacity for a given field can change within a single growing season. Typically this is due to declining water tables. More recently, it is due to growers diverting irrigation from one crop (cotton) to other crops (corn) which may have higher value, or are at a more critical growth stage than cotton, particularly in a year of low rainfall. Furthermore, groundwater conservation districts in the Texas High Plains have enacted pumping restrictions which may result in changes in late seasonal irrigation management as volume limits are reached. Timing of irrigation applications using limited available water is becoming very critical and is further complicated by erratic rainfall.

Maximum water use efficiency as a function of irrigation volume and timing has been determined by applications at different cotton growth stages using the furrow method (Newman, 1966). This experiment as well as others showed large yield reductions when water deficits occurred during peak flowering periods as compared to earlier or later in the flowering period (Jordan, 1983). More recent deficit irrigation studies, using Low Energy Precision Application (LEPA) and subsurface drip irrigation (SDI) delivery systems, evaluated treatments having somewhat uniform irrigation deficits over the entire growing season, either as a percent of evaporative demand (Bordovsky, et al., 1992) or at uniform, limited irrigation capacities (Bordovsky et al., 2011). Recent research of non-uniform timing of limited irrigation with LEPA and SDI has focused on pre-plant irrigation, diverting water from cotton to grain sorghum, and the timing of irrigation termination. Full pre-plant irrigations significantly increased cotton yield over treatments with limited pre-plant irrigation, however, water value was higher when those pre-plant water units were applied closer to peak consumptive periods (Bordovsky and Porter, 2003). An evaluation of irrigation termination based on physiological cotton development was conducted at the Halfway and New Deal research sites with results showing fiber quality increases and lint yield declines with early irrigation termination (Sneed, 2010). An overall systematic evaluation of cotton response to center pivot irrigation as a function of growth stage at several deficit irrigation capacities has not been available.

The immediate objective of this project is to determine cotton lint yield, irrigation water productivity, and cotton lint quality as a function of combinations of irrigation capacities during three cotton growth periods. The overall objective is to improve water management and water value in a semi-arid environment where proposed regulations may restrict irrigation volume and pumping capacities are declining. This paper presents some of the most significant findings of this project.

Method and Materials

Irrigated cotton was evaluated at the Texas A&M AgriLife Research and Extension Center at Halfway, Texas (3514 ft elev., 34^0 10’ N, 101^0 56’ W). The treatment factors included in-season irrigation capacity (maximums of 0 in/d – **low**, 0.125 in/d – **medium**, and 0.25 in/d – **high**) and irrigation application within specific cotton growth periods. Periods were generally defined by heat unit (hu, dd60) accumulation and were designated as early vegetative/juvenile (< 950 hu), reproductive (950-1350 hu) and maturation (>1350 hu). Combinations of these factor levels resulted in 27 irrigation regimes or treatments (Table 1). The extreme treatments were 0 in/d, or **Low** irrigation capacity, in all growth periods (**LLL**) and 0.25 in/d, or **High** irrigation capacity, in all growth periods (**HHH**) which approached full irrigation in years of average rainfall. Within each treatment, water was applied at designated irrigation capacities in the specific growth periods according to a soil water balance that allowed increases in soil profile water to 80% of field capacity subject to a protocol described by Bordovsky and Lyle (1996). Therefore, rain events reduced or terminated irrigations within a treatment if soil water calculations indicated that profile water was above 80% field capacity.

Table 1. Irrigation treatments having combinations of irrigation capacities (low, medium or high) at each cotton developmental period (vegetative, reproductive or maturation) for experiments at Texas A&M AgriLife Research, Halfway, TX.

Treat. No.	Treatment	Crop Development and Irrigation Periods		
		Preiod 1 - Vegetative	Period 2 - Reproductive	Period 3 - Maturation
1	LLL	Low	Low	Low
2	LLM	Low	Low	Medium
3	LLH	Low	Low	High
4	LML	Low	Medium	Low
5	LMM	Low	Medium	Medium
6	LMH	Low	Medium	High
7	LHL	Low	High	Low
8	LHM	Low	High	Medium
9	LHH	Low	High	High
10	MLL	Medium	Low	Low
11	MLM	Medium	Low	Medium
12	MLH	Medium	Low	High
13	MML	Medium	Medium	Low
14	MMM	Medium	Medium	Medium
15	MMH	Medium	Medium	High
16	MHL	Medium	High	Low
17	MHM	Medium	High	Medium
18	MHH	Medium	High	High
19	HLL	High	Low	Low
20	HLM	High	Low	Medium
21	HLH	High	Low	High
22	HML	High	Medium	Low
23	HMM	High	Medium	Medium
24	HMH	High	Medium	High
25	HHL	High	High	Low
26	HHM	High	High	Medium
27	HHH	High	High	High

The experiment was conducted in a transitional soil changing from a Pullman clay loam (fine, mixed, thermic Torrertic Paleustolls) to an Olton loam (fine, mixed, thermic Aridic Paleustolls). Average annual rain for the site is

18 inches with an average of approximately 11 inches occurring from May to September; however, precipitation amount and occurrence is extremely variable. Limited and unpredictable rainfall, as well as the high evaporative demand in spring and early summer, necessitates supplemental irrigation for consistent crop production in the region.

A 4-span LEPA pivot was used to irrigate 9.5 acres in this test. The pivot was modified so that each 8-row width (40-inch rows planted in a circular pattern) along the lateral length were automatically irrigated at the appropriate amount depending on the treatment and pivot position. Changes in irrigation applications occurred as frequently as every 16 degrees of pivot movement (Bordovsky and Mustian, 2013). Irrigation quantities within 8-row sections were governed by irrigation applicator (nozzle) orifice size and on/off cycling of the applicator. Pivot position was determined by corrected GPS signal located at the distal end of the pivot. Pivot speed was constant for all applications. Each nozzle was controlled by a solenoid valve located in the drop line near the lower cord of the pivot span truss. Groups of four valves (irrigating an 8-row plot) were actuated using signals from a variable-rate irrigation controller (Farmscan 7000, Dothan, Alabama) with specific time sequences for each irrigation treatment and distance from the pivot point. Electrical systems for power distribution and valve control (to signal on/off sequences) were designed and installed along the length of the pivot lateral. Appropriate control and evaluation software was developed for the irrigation controller and flow monitoring systems. Inputs to the controller were pivot location (via GPS signal) and irrigation quantity (via application map) for each 8-row x 16-degree area irrigated by the pivot. The research protocol and field design provided a complete randomized block experimental design with three replications. The pivot modification, pivot evaluation, and software development were conducted in 2009. The field experiment was initiated in 2010 and continued through the 2013growing season.

Prior of each crop year, treatment areas were grouped by potential lint yield with soil nutrient samples obtained from plots of each grouping. Nitrogen, phosphorus and trace elements were applied in a site-specific manner and in amounts to prevent yield reductions from nutrient limitations with average rainfall and expected irrigation. In each year, pre-plant LEPA irrigations were uniformly applied over all plots if profile water was inadequate for seed germination and plant establishment. Due to the high air temperatures and elevated wind speeds at planting, additional applications were made by low elevation spray to insure seed germination in 2011 and 2012. Cotton was planted in early May of each year (Table 2). Seasonal irrigations were started as soon as possible following cotton establishment and soil water monitoring equipment was installed (Table 2). Prior to each in-season irrigation, daily soil water balances were calculated for each treatment using information from the Texas High Plains ET Network (Porter, et al., 2005), local rainfall, irrigation quantity from previous irrigations and a locally derived crop coefficient. The water balance calculations determined irrigation amounts, subject to treatment limitations, for that set of irrigations. Irrigation frequency was generally every 2 to 4 days. Volumetric soil water content and cotton canopy temperatures were monitored in selected treatments during the growing season. The three irrigation periods, rain, and heat unit accumulation for each cotton growth period for each year are specified in Table 2.

Table 2. Planting dates, irrigation periods, and rain and heat unit accumulation during irrigation periods in irrigation timing experiements at Texas A&M AgriLife Research, Halfway, TX., 2010-2013.

	Time Period *	2010	2011	2012	2013
Planting (date)		11-May	11-May	9-May	13-May
Plant Emergence (date)		20-May	25-May	22-May	20-May
Irrigation Periods (date range)	P1	24 Jun-18 Jul	14 Jun-10 Jul	19 Jun- 13 Jul	13 Jun-20 Jul
	P2	19 Jul-7 Aug	11 Jul- 3 Aug	14 Jul- 4 Aug	21 Jul-6 Aug
	P3	8 Aug-7 Sep	4 Aug- 1 Sep	5 Aug- 4 Sep	7 Aug-7 Sep
Rain During Periods (inches)	1 Jan to Emergence	8.32	1.44	1.61	2.50
	Emergence to P1	4.52	0.00	5.43	1.01
	P1	4.01	0.00	0.45	6.00
	P2	1.48	0.80	0.39	0.00
	P3	0.81	0.10	0.74	1.60
	Post P3 to 30 Sept	0.47	0.90	3.59	1.63
	1 Oct to 31 Dec	2.32	2.14	1.49	
	Annual Total	21.93	5.38	13.70	12.74
Heat Unit Accumlation (dd60)	Emergence to P1	584	437	480	344
	Emergence thru P1	957	1026	939	963
	Emergence thru P2	1285	1561	1379	1271
	Emergence thru P3	1754	2196	1899	1757
	Emergence thru 30 Sept	2032	2464	2104	1989

*Irrigation Periods generally occurred during vegetative (P1), reproductive (P2), and maturation (P3) cotton growth periods.

Seed cotton sample weights (4-row x ~ 80 ft) were obtained by using an automated weighing system on a modified 4-row John Deere 7445 cotton stripper. Cotton sub-samples (~2.0 lb) from each harvested sample were ginned to determine lint percentage at the Texas A&M AgriLife Research and Extension Center in Lubbock, Texas. Fiber quality parameters of lint samples were determined by the High Volume Instrument (HVI) system at the Fiber and Biopolymer Research Institute, Texas Tech University in Lubbock. Commodity Credit Corporation (CCC) cotton loan values were determined from fiber quality parameters of lint samples. Cotton lint yield, water productivity, and fiber quality were determined for each treatment. Data analysis was with standard AOV and means separation.

Results

The growing seasons of the four test years were quite different in terms of rain and temperature. Monthly rain is given in Figure 1. In 2010 above average rain occurred with twice the average rainfall from January to April. This provided an excellent soil water base to begin the irrigation season. 2011 was a record setting year in terms of heat, low rain, and high wind speeds, particularly in April through July. The 2012 rain was below average with rains that occurred in June and September being large, but ineffective due to high rain intensity and runoff in June and being too late for yield enhancement in September. Total 2013 rain was below the 18 inch average, however seasonal rains were near average and timely and temperatures were moderate.

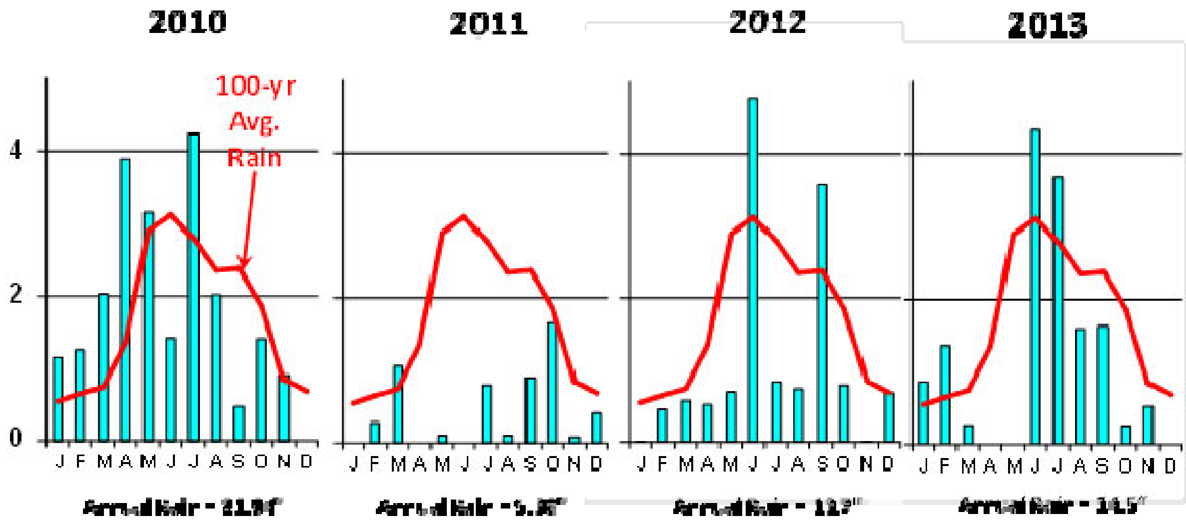

Figure 1. Monthly rain totals and 100-year average rainfall at the Texas A&M AgriLife Research Center at Halfway, TX., 2010-2013.

Table 3 contains irrigation amounts of seven of the 27 irrigation treatments during the three irrigation periods for each year. The seven treatments are grouped having maximum irrigation capacity of 0.25 in/d, equivalent to 600 gpm delivered to a 130 acre pivot (**HHH**, **MHH**, **LHH**, and **LMH**) and 0.125 in/d, equal to 300 gpm supplying a similar area (**MMM**, **LMM**, and **LLL**). The **HHH** and **MMM** treatments represent a traditional strategy of using available irrigation capacity in the vegetative period in an attempt to increase water in the soil profile for later use at the two respective irrigation capacities.

Table 3. Irrigation amounts (inches) during vegetative, reproductive and maturation periods at two maximum irrigation capacities in irrigation timing experiements at at Texas A&M AgriLife Research, Halfway, TX., 2010-2013.

			0.25 in/d				0.125 in/d		
Year	Irrigation Period	Irrigation Interval	HHH	MHH	LHH	LMH	MMM	LMM	LLL
2010									
	P1	24 Jun-18 Jul	2.00	1.25	0.00	0.00	1.25	0.00	0.00
	P2	19 Jul-7 Aug	3.20	3.20	4.00	2.50	2.50	2.50	0.00
	P3	8 Aug-7 Sep	3.95	3.95	3.95	5.00	3.00	3.00	0.00
		Total	9.15	8.40	7.95	7.50	6.75	5.50	0.00
2011									
	P1	14 Jun-10 Jul	6.50	3.50	0.00	0.00	3.50	0.00	0.00
	P2	11 Jul- 3 Aug	5.50	6.00	6.00	3.00	3.00	3.00	0.00
	P3	4 Aug- 1 Sep	5.55	6.10	6.10	6.20	3.50	3.40	0.00
		Total	17.55	15.60	12.10	9.20	10.00	6.40	0.00
2012									
	P1	19 Jun- 13 Jul	4.50	3.00	0.00	0.00	3.00	0.00	0.00
	P2	14 Jul- 4 Aug	4.80	5.25	5.25	2.63	2.63	2.63	0.00
	P3	5 Aug- 4 Sep	5.25	6.25	6.75	6.75	3.75	3.75	0.00
		Total	14.55	14.50	12.00	9.38	9.38	6.38	0.00
2013									
	P1	13 Jun-20 Jul	5.99	3.00	0.00	0.00	3.00	0.00	0.00
	P2	21 Jul-6 Aug	3.96	5.28	5.28	2.64	2.64	2.64	0.00
	P3	7 Aug-7 Sep	5.33	6.33	7.67	7.67	4.33	4.33	0.00
		Total	15.29	14.61	12.95	10.31	9.97	6.97	0.00

Mature boll counts by node and position were made on at least five plants in each replicate of all treatments prior to harvest in 2011, 2012 and 2013. From this, boll addition or loss relative to the traditional treatments, **HHH** or **MMM**, was determined for treatments having reduced irrigation during the vegetative periods (Figure 2). As expected, relative boll loss was high (particularly in nodes 8-10) in **LLL** treatments each year. In the excessively dry year of 2011, the **LHH** and **MHH** treatments resulted in additional bolls at nodes 10 to 12. In 2012, relative boll reduction occurred in all treatments compared to the **HHH** treatment. In the "average" rainfall year of 2013, boll load of all selected treatments were similar to the corresponding **HHH** and **MMM** treatments.

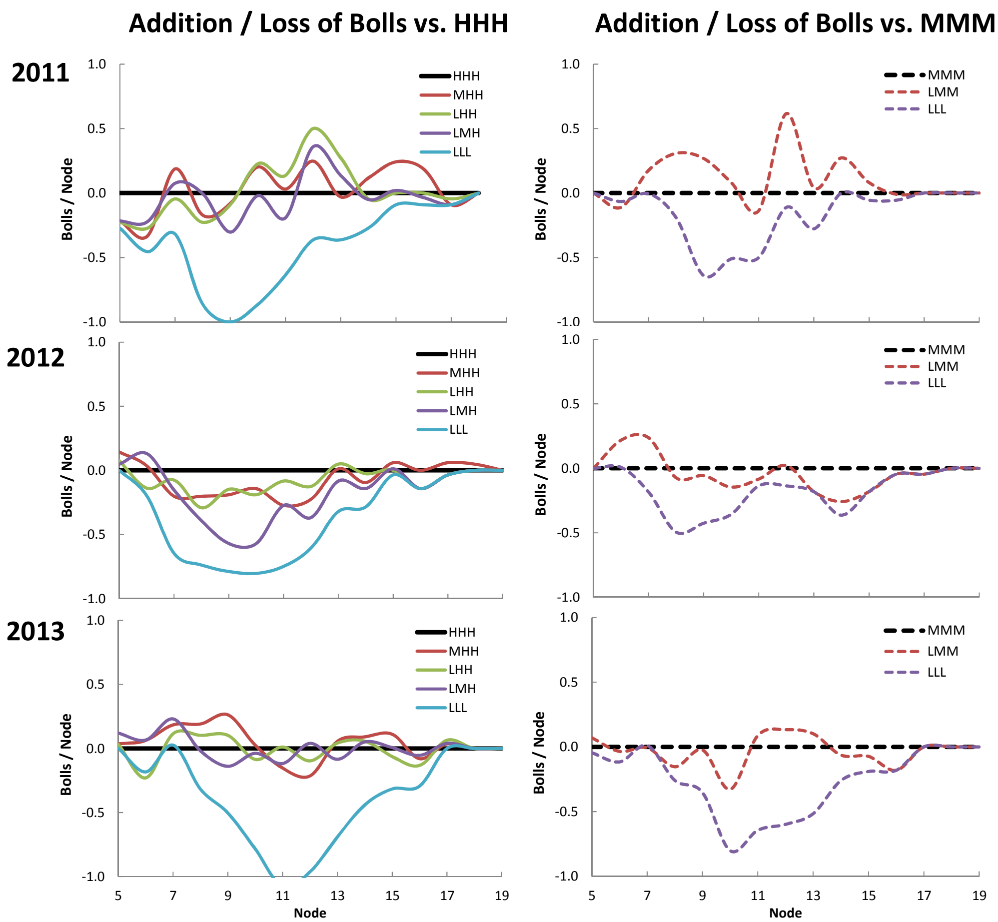

Figure 2. Differences in mature bolls per node of early reduced water treatments from standard irrigation treatments of HHH with maximum daily irrigation capacity of 0.25 in/d and MMM with maximum daily irrigation capacity treatment of 0.125 in/d at Texas A&M AgriLife Research Center, Halfway, TX, 2010-2013.

Total seasonal irrigation, yield, seasonal irrigation water use efficiency (SIWUE) and loan values for highlighted treatments are in Table 4. Averaged over the 4-year period, cotton lint yield ranged from 326 lb/ac/yr in the **LLL** treatment (dryland) to 1319 lb/ac/yr in the **MHH**. SIWUE ranged from 57 lb lint/ac-in in the **MMM** treatment to 79 lb lint/ac-in for the **LMH** treatment. Fiber quality, as indicated by four-year average loan value, ranged from $0.513 in the **LLL** treatment to $0.559 in the **LMH** treatment.

Table 4. Seasonal irrigation, cotton lint yield, seasonal irrigation water use efficiency, and cotton lint loan values at two maximum irrigation capacities in irrigation timing experiments at Texas A&M AgriLife Research, Halfway, TX., 2010-2013.

		0.25 in/d				0.125 in/d		
		HHH	MHH	LHH	LMH	MMM	LMM	LLL
Seasoanal Irr. (inches)	2010	9.15	8.40	7.95	7.50	6.75	5.50	0.00
	2011	17.55	15.60	12.10	9.20	10.00	6.40	0.00
	2012	14.55	14.50	12.00	9.38	9.38	6.38	0.00
	2013	15.29	14.61	12.95	10.31	9.97	6.97	0.00
	Avg[2]	14.14	13.28	11.25	9.10	9.03	6.31	0.00
Yield (lb/ac)	2010	1604 a[1]	1647 a	1590 a	1513 a	1384 a	1388 a	927 b
	2011	860 a	901 a	692 b	567 c	382 d	395 d	28 e
	2012	998 a	1105 a	1081 a	566 b	548 b	504 b	22 c
	2013	1559 a	1625 a	1622 a	1626 a	1173 b	1155 b	485 c
	Avg[2]	1255 a	1319 a	1246 a	1068 b	872 c	860 c	366 d
SIWUE (lb/ac-in)	2010	74 a	86 a	83 a	78 a	68 a	84 a	
	2011	47 ab	56 a	55 a	59 a	35 b	57 a	
	2012	67 ab	75 ab	88 a	58 b	56 b	76 ab	
	2013	70 b	78 b	88 ab	111 a	69 b	96 ab	
	Avg[3]	65 a	74 a	79 a	76 a	57 a	78 a	
Lint Loan Value ($/lb)	2010	0.573 a	0.576 a	0.574 a	0.559 a	0.563 a	0.560 a	0.573 a
	2011	0.566 a	0.564 a	0.550 a	0.572 a	0.528 a	0.542 a	0.47 b
	2012	0.517 a	0.486 a	0.487 a	0.531 a	0.504 a	0.520 a	0.494 a
	2013	0.516 bc	0.499 c	0.531 ab	0.574 a	0.519 ab	0.559 ab	0.515 bc
	Avg[2]	0.543 ab	0.531 ab	0.535 ab	0.559 a	0.528 ab	0.545 ab	0.513 b

[1] For individual years, randomized complete block with means within a row followed by a common letter are not significantly different (Tukey, p<0.05)

[2] For yearly average, split plot analysis with year as main plot and treatments as subplots. Means within a row followed by a common letter are not significantly different (Tukey, p<0.05).

[3] Treatment averages calculated from total yields and irrigations of the four combined years, analysed as randomized complete block (Tukey, p<0.05)

Insight into the strategy of irrigating at full capacity early in the growing season to store water in the soil profile is obtained by comparing the traditional treatments, **HHH** and **MMM**, with those having less early irrigation within a given maximum irrigation capacity. The **HHH** treatment resulted in an average of 1255 lb/ac/yr using 14.1 in/yr compared to **MHH** at 1319 lb/ac using 13.3 in/yr of seasonal irrigation, or a 5% yield increase with 6% less irrigation (Table 4). **HHH** compared to **LHH** resulted in the near-same four-year yield of 1250 lb/ac while **LHH** required 2.9 inches less irrigation than **HHH**, or 20% less seasonal water. At the lower maximum irrigation capacity, the **MMM** four-year yield was 872 lb/ac compared to the **LMM** treatment at 860 lb/ac/yr using 2.7 inches less irrigation, or a 30% decline in seasonal water use. The yields from the traditional irrigation treatments **HHH** and **MMM** were not significantly reduced in any individual year by reducing irrigations during the vegetative period when followed by irrigations at full capacity in the vegetative and reproductive periods, except for the **LHH** treatment in 2012. These results support the hypothesis that a large portion of early season pivot irrigation is lost due to high evaporative demand and higher water productivity occurs when irrigation application is more proportional to crop water demand.

Water productivity in all years was numerically higher (in many cases significantly higher, p<05) in the LHH and LMM treatments than in the HHH and MMM treatments, respectively (Table 4). Also, cotton fiber quality, as determined by loan values, were not reduced in any year by reducing early season irrigation.

Conclusions

Test results were obtained from years representing record breaking extremes - high rainfall in 2010, low and ineffective rainfall in 2011 and 2012, and near average seasonal rain in 2013. In all years, cotton yield and water productivity data indicated that trying to store water in the soil profile, or irrigating in excess of the evapotranspiration rate of the cotton plants, early in the growing season reduced irrigation water value compared to applying irrigation later in the growing season. Field results showed treatments with reductions of seasonal water during the vegetative period use up to 20 percent less irrigation with minor yield loss compared to traditional treatments. This was attributed to the effects of excessive evaporation (high wind, low humidity, and high temperatures) that often occurs in May through June in the Texas High Plains as well as early plant development that could not be supported with available irrigation capacity late in the growing season. These field tests will provide the foundation for in-season irrigation recommendations that optimize lint yield (and water value) based on irrigation pumping and volume restrictions.

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