YIELD AND APPLIED WATER RELATIONSHIPS IN MULTI- YEAR DRIP IRRIGATED COTTON PRODUCTION

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Abstract

Cotton irrigation studies from 1988-1999, which included different irrigation scheduling methods at Lubbock, TX, used amounts of water that ranged from deficit to excessive amounts for maximizing lint yield. Scheduling treatments based on canopy temperature were included each year. Drip irrigation and recommended production practices for the area were used. This 12-year data base was analyzed to estimate the effect of irrigation and growing season temperature on yield. Yields in the irrigation studies were then compared with those for the northwest Texas production region. Maximum yield was estimated to occur at an irrigation input of 58 cm or a total water application of 74 cm. The components of total water supply for the maximum yield treatments averaged 74% irrigation and 26% rain. Lint yield response to irrigation up to the point of maximum yield was approximated as 11.4 kg/ha-cm of irrigation between the limits of 5 cm and 54 cm with observed lint yields ranging from 855 to 1608 kg/ha. The intra-year maximum yield treatments were not limited by water input, and the inter-year range of 300 kg/ha was not correlated with the quantity of applied water. The maximum lint yields were linearly related to monthly and seasonal heat units (DD60s) with regressions for July and August and from May to September being significant. The fluctuation of maximum lint yields and the response to DD60s was similar in the irrigation studies and the production region surrounding Lubbock. The rate of lint yield increase with heat units was slightly higher in the irrigation studies and is attributed to lower water stress in these treatments compared to the irrigated fields in the surrounding area.

Introduction

Viewed from the perspective of water stress, the purpose of irrigation is to keep crop water status at a level that maximizes yield within the constraints of irrigation supply and growing season weather. Irrigation provides varying percentages of total crop water supply depending on the climate. Among US cotton growing regions irrigation ranges from being supplemental to rain to being the primary source of water for production.

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The cotton production region within a 100 mile radius around Lubbock, TX is semi-arid where about one-half of the cotton acreage is non irrigated and yields vary with rainfall. The average lint yield of irrigated and dryland cotton production in the 25 county area around Lubbock was 571 and 332 kg/ha, respectively, from 1977-1998.

Numerous studies of cotton irrigation have focused on irrigation scheduling to optimize yield and efficiency of water use. Over a three year period cotton responded to frequency of irrigation using the low energy precision application (LEPA) system for applying irrigation, Bordovsky, et al. (1992). For irrigation intervals ranging from 3 to 15 days they concluded that the optimum irrigation interval was 3 days, regardless if the water application was deficit or adequate for full soil water use replacement. Radin et al. (1989) found that yield of cotton increased as the interval between water application decreased even if the amount of water was unchanged in the arid climate of Arizona. They concluded that high frequency drip irrigation (1 to 2 day intervals) prevented cyclic water stress and deterioration of the root system compared to low frequency (2-week intervals). Low and high frequency cotton irrigation, determined by allowable soil water depletions of 55 and 30%, respectively, was compared in level basins by Hunsaker, et al. (1998) where the total water application was equal in both frequencies. Lint yields for high frequency were 15 and 20% higher than for low frequency in the first and second years of the study. The question of whether the benefits of high frequency irrigation with a drip system could be achieved with a less expensive delivery system by applying extra irrigations during peak fruiting of cotton was addressed by Radin et al. (1992). One supplement flood irrigation in level basins increased seedcotton yield 15% over a 10 d or 14 d interval control, two supplements increased 25%, and daily drip irrigation by 40%. Doubling the number of irrigations for a short period during peak fruiting achieved much of the benefit of drip irrigation.

We have studied cotton irrigation since 1988 with the combined information being a data set that includes different irrigation quantities and yields produced under weather regimes spanning a 12- year period. Using this data base, the objectives of this report are to (1) estimate the irrigation-yield response of cotton, (2) estimate the relationship of growing season temperature with cotton yield, and (3) compare the irrigation-yield response of the irrigation studies with the yield trends for the northwest Texas production region.

Procedure

Cotton irrigation scheduling was studied from 1988-1999 using canopy temperature as the input information for defining irrigation signals for scheduling. The goal of these studies was the development of an automated method that required a small number of measurements to accomplish irrigation scheduling. Continuous measurement of cotton canopy temperature and the computation of 15-min averages was common across all years. The interval for making irrigation decisions was 15-min through 1994 and from 1995 increased to three days after each irrigation application, based on the daily accumulation of time that canopy temperatures exceeded threshold values. Replication of treatments varied from three to four among years.

Infrared thermometers measured cotton canopy temperatures, usually from a nadir viewing angle 1 to 3 feet above a cotton row. The infrared thermometer viewed the top leaves which were sunlit and the planofile orientation of leaves minimized the observation of shaded leaves.

Fertilizer application each year was based on soil sampling. The studies during 1988-1996 had nitrogen injected into the irrigation system at the rate of 900 g ha cm^{-1} (5.0 lbs. acre in^{-1}). Yield fluctuations among years were primarily in response to amount of irrigation and in-season weather. The irrigation treatments changed over time but in each year there were one or more treatments which applied water in amounts that minimized crop water stress. Descriptions of irrigation treatments used in each year are given below. More detailed results for many of the irrigation studies are provided in by Wanjura et al. (1990), Wanjura et al. (1992), Wanjura, et al. (1995), and Wanjura et al. (1996)

The treatments in 1988 were: (1) 28C-- irrigated when the 15-min average canopy temperature exceeded 28%C, (2) 30C-- irrigated when the 15-min average canopy temperature exceeded 30%C, (3) 32C-- irrigated when the 15-min average canopy temperature exceeded 32%C, (4) SWR-- weekly replacement of soil water extracted from the root zone which was determined from soil moisture measurements with a neutron probe, and (5) Dry-- received only rain after planting. Treatments 1, 2, and 3 were immediately irrigated in 15-min intervals when the canopy temperature criterion were satisfied.

The 1989 treatments were identified as: (1) 26C2-- irrigated when the 15-min average canopy temperature exceeded 26%C and the start of irrigation was delayed until squaring, (2) 28C-- irrigated when the 15-min average canopy temperature exceeded 28%C, (3) 28C2-- irrigated when the 15-min average canopy temperature exceeded 28%C and the start of irrigation was delayed until squaring , (4) SWR-- weekly replacement of soil water extracted from the root zone which was determined from neutron soil moisture measurements, and (5) Dry-- received only rain after planting. Treatments 1, 2, and 3 were immediately irrigated in 15-min intervals when the canopy temperature criterion were satisfied.

The treatments in 1990 were: (1) 26C-- irrigated when the 15-min average canopy temperature exceeded 26%C, (2) 28C-- irrigated when the 15-min average canopy temperature exceeded 28%C, (3) 30C-- irrigated when the 15-min average canopy temperature exceeded 30%C. Treatments 1, 2, and 3 also required the soil moisture tension measured with a tensiometer at 20 cm to be less than -10 cb. (4)SWRF-- weekly replacement of soil water extracted from the root zone which was determined neutron soil moisture measurements, (5) Dry-- received only rain after planting, (6) SWRV-- beginning at first square bi-weekly irrigation replaced soil water extracted from the root zone which was determined neutron soil moisture measurements. The interval between irrigations was adjusted for rainfall, and (7) SPRNK-- applied 1.0 cm irrigations daily when the number of 15-min periods when canopy temperature exceeded 28%C was 10 or greater by 1800 h. The SPRNK treatment was the first irrigation scheduling treatment based on canopy temperature for the entire day time to produce an irrigation signal.

The 1991 treatments included: (1) 28CR-- irrigated when the 15-min average canopy temperature exceeded 28%C. Start of irrigation was delayed until the five main stem node stage and continued until 65% boll maturity, (2) 28C-- irrigated when the 15-min average canopy temperature exceeded 28%C, (3) 2.5 TT-- required 2.5 hours per day above 28%C, (4) 4.0 TT-- required 4 hours per day above 28%C, (5) 5.5 TT-- required 5.5 hours per day above 28%C, (6) 7.0TT-- required 7 hours per day above 28%C. Treatments 3, 4, 5, and 6 accumulated time on a daily basis using a minimum irrigation interval of three days and a 20 mm irrigation was applied in response to each irrigation signal. (7) DRY-- preplant irrigation filled the soil profile and then it received only rain after planting.

The 1992 treatments were: (1) 28C-- irrigated when the 15-min average canopy temperature exceeded 28%C, (2) 28CR-- irrigated when the 15-min average canopy temperature exceeded 28%C. Start of irrigation was delayed until the five main stem node stage and continued until 65% boll maturity, (3) 28CNAD-- irrigated when the 15-min average nadir canopy temperature exceeded 28%C, (4) 2TT-- required 2.0 hours per day above 28%C, (5) 4TT- - required 4.0 hours per day above 28%C, (6) 6TT-- required 6.0 hours per day above 28%C, (7) 8TT-- required 8.0 hours per day above 28%C. Treatments 4, 5, 6, and 7 accumulated time on a daily basis using a minimum irrigation interval of three days and a 20 mm irrigation was applied in response to each irrigation signal. (8) DRY--preplant irrigation and then only rain after planting. All treatments received a preplant irrigation to fill the soil profile.

Treatments in 1993 were all controlled in 15-min intervals triggered by canopy temperature exceeding 28%C. (1) EI-- irrigation started immediately after stand establishment, (2) DI-H-- irrigation initiation was delayed until squaring (7-9 mainstem nodes) and then the first irrigation was equal to the amount applied by EI during the early irrigation period , (3) DI-L-- irrigation initiation was delayed until squaring, (4) DRY-- received a preplant furrow irrigation to fill root zone and only rain after planting. and (5) VTH(30)-- canopy temperature threshold for applying irrigation was 30 %C. All treatments received a preplant irrigation to fill the soil profile.

Treatments in 1994 were (1) EI-- irrigation started immediately after stand establishment, (2) DI-H-- irrigation initiation was delayed until squaring (7-9 main stem nodes) and then the first irrigation was equal to the amount applied by EI during the early irrigation period , (3) DI-L-- irrigation initiation was delayed until squaring, (4) DRY-- received a preplant furrow irrigation and only rain after planting. All treatments received a preplant irrigation to fill the soil profile.

The 1995 study had a total of nine treatments which were established in the following manner. Three irrigation treatments were created by using time accumulations of 4, 6, and 8 hours above a canopy temperature threshold of 28%C to produce irrigation signals. The minimum irrigation interval was 3 days. The normal irrigation rate of 2.1 cm was applied through drip irrigation tubing which was placed on the surface of each bed. Three water levels were established within each irrigation treatment by subdividing each plot into Normal, Drought, and Drought/Excess segments. Irrigation of the N plots in each irrigation treatment began at first square on DOY 179 when plants had 7.8 main stem nodes. The beginning dates for withholding irrigation in the D plots were DOY 192, DOY 209, and DOY 223 in irrigation treatments 8, 6, and 4 h, respectively. The D/E irrigation plots in all irrigation treatments began on DOY 223 and received irrigations at twice the normal rate (2 X 2.1 cm). The D/E irrigation plot in the 4 hour irrigation treatment did not have a D period.

The 1996 study included four dates of planting-- DOY 116, DOY 127, DOY 140, and DOY 154. Irrigation was applied whenever canopy temperatures exceeded 28%C for at least 5 hours with a minimum of three days between irrigation events. An irrigation application of 2.1 cm was applied in response to each irrigation signal.

The 1997 study included four water level treatments which were designated as WL1-dryland, WL2- 1/3 ET, WL3- 2/3 ET, and WL4-1.0 ET. An average ET value of 7 mm d^{-1} was assumed to represent the 1.0*ET water level of each crop based on ET estimates using historical weather information. Irrigations were applied at 3-day intervals unless a rain event of at least 16 mm occurred between irrigations. A total of 5.5 h of canopy temperature above 28%C was required to create an irrigation signal.

There were two water levels in 1998 and 1999. WH was irrigated at the rate of 1.0 *ET where ET was estimated as 7 mm d^{-1}. Irrigations were applied at 3-day intervals unless a rain event of at least 16 mm occurred between irrigations. A total of 5.5 h of canopy temperature above 28%C was required to create an irrigation signal. The WL water level received only rain.

Agronomic data including planting date, growing season DD60s, irrigation periods, cultivars, and row spacing are summarized in Table 1.

Results

Field studies were usually planted during the middle of May, DOY 130-DOY140, which is normally the optimum time for cotton, Table 1. The exceptions were 1992 which was replanted because unfavorable weather damaged seedling stands, and 1996 which had four planting dates between DOY 116 and DOY 154. The DD60s are a method of quantifying seasonal heat input from air temperatures and included the period from planting date through September. Irrigation normally began at first square and continued until early September. Most irrigation treatments did not apply excessive amounts of water and thus plants did not have excessive vegetative growth.

Yield Response to Irrigation

Lint yields of all irrigation treatments with their corresponding irrigation and total water application inputs are summarized in Table 2 for the period 1988-1999. The years 1989 and 1991 were omitted in all yield response analyses because weather damage during the growing season lowered yields. The irrigation treatments in 1995 that included a period of drought (no irrigation) are not normal irrigation practice and were omitted from the data base for analysis. The purpose of the irrigation studies each year varied and this influenced the design of individual treatments. A consistent objective across all years was the use of remotely measured canopy temperature as the source of information for scheduling irrigation, but the criteria for decision-making varied. Thus some irrigation treatments in all years utilized canopy temperature.

The second order polynomial in Figure 1a provides the best approximation of the irrigation-yield response for all years. The low yields for the lowest and highest irrigation amounts indicate that the irrigation treatments spanned the range from deficit to excess water input. The fitted curve estimates maximum yield at an irrigation input of 58 cm. The relationship of lint yield to total water applied during the irrigation period which includes rain is also described by a polynomial in Figure 1b. Here lint yield is estimated to peak at a total water input of 74 cm. Most irrigation treatments applied amounts below the estimated value for maximizing lint yield. The observed yields for water applications less than the quantity for estimated maximum yield show considerable variability about the fitted curves which suggests yields were responding to factors other than water input within and among years.

Yield Response to Irrigation up to Maximum Yield

The treatments which applied seasonal irrigations of less than 60 cm were used to estimate yield response to irrigation input that ranged from deficit to approximately optimum quantities. Lint yield response to increasing amounts of irrigation to the point of maximum yield were examined by including only irrigation treatments which were controlled by canopy temperature and which had similar time distributions of irrigation application. Treatments omitted were those in 1989 and 1991, treatment SWRF in 1988, treatment 26C in 1990, treatment VTH(30) in 1993, the drought and D/E treatments in 1995, and PD3 and PD4 in 1996. These treatments are described in the Procedure section and in Table 2.

In this region a linear approximation describes the lint yield-irrigation relationship, Fig. 2. The average increase in lint yield is 11.4 kg/ha-cm of irrigation between 5 cm and 54 cm where observed yields ranged from 855 to 1608 kg/ha. This yield response to water is not high, but is in the yield range of 2 to 3 bales / acre which is above the level of most efficient lint yield response to water input.

Another important question concerning the lint yield-irrigation response, is what is the relationship between yield and water application at the point of maximum yield in each year where water was not limiting production. This question was examined by looking at only those treatments that produced maximum yields within each year; ie, those treatments with RY=100% in Table 2. Here again the years 1989 and 1991 were not used because of the weather damage effect on yield. The maximum lint yield treatments had values that ranged from 1300 to 1600 kg/ha, but there was no yield trend with quantity of irrigation, Figure 3, or with total applied water (data not shown). The components of total water supply for the maximum yield treatments were 74 % from irrigation and 26% from rain. Yield variability appears to have resulted from other environmental factors among years where water input was not limiting yield response. These are year effects and not irrigation responses. The cause for the variability is important because the range of maximum yield values is 25% of the highest observed maximum value.

Yield Response to Seasonal Heat Input

The thermal energy input for cotton production was computed as DD60s which are commonly used to quantify growing season temperatures for cotton. Heat units from the planting date each year through September units ranged from a low of 1966 DD60s in 1992 to 2836 DD60s in 1998, Table 1. The association of maximum lint yield with monthly and seasonal DD60 values is described as linear regressions in Table 3. Data for 1998 were not used because its accumulation of DD60s was in excess of the heat unit input needed for maximum yield. The equations describe a positive relationship between DD60s and lint yield. Monthly DD60 regressions for July and August and for May-September are significant.

Seasonal heat units from May through September averaged 2302, 2238, and 2194 for the 1988-1999, 1965-1987, and 1965-1999, periods, respectively. The warmest year in the 1965-1999 period was 1998. For the 1965-1999 period either the highest or second highest DD60 accumulation for each month from May through September was recorded between 1988 and 1999. The monthly regressions for the linear relationships in Table 3 are compared in Figure 4 for the range of monthly DD60s values that occurred during 1988-1999. For the individual months, the lint yield response with DD60s was highest for August followed by July. The seasonal accumulation of heat input from May-PD through September, was significantly related with lint yield for the observed range of values from 1966 to 2458 DD60s. May-PD is the period in May from the planting date through the end of the month. Thus in reference to Figure 3 where there was no relation between amount of irrigation and maximum yield, the total heat unit accumulation does positively correlate with lint yield. Peng, et al. (1989) reported cotton growth and development was directly associated with heat units under irrigated conditions

The DD60-maximum yield regressions, which are plotted for the range of observed DD60 values for each month show that heat unit accumulation was lowest from the planting date each year to the end of May, was highest in June, and then decreased in order from July, August, and September. The range of monthly DD60s was highest in June and smallest in August. Average monthly DD60s had the same ranking for the 1965-1999 (data not shown) and 1988-1999 periods. Monthly DD60 means from lowest to highest were May, September, June, August, and July.

Irrigation Studies Compared with Area Yields

In the 25 county area surrounding Lubbock, TX, 54 % of the cotton acreage was irrigated during 1988-1998. Irrigated yield comparisons between Lubbock county and the 25 counties is shown in Figure 5. Since 1986 yields have trended upward with the 25 county area yields being slightly higher than for Lubbock county. The irrigation water supply is groundwater and Lubbock county irrigation wells pump less water than the average for the entire production region. The maximum lint yields from our irrigation studies in Figure 6 have a yield trend between 1988-1998 that is similar to average irrigated Lubbock county yields. The low yields in 1989 and 1991 irrigation studies deviate from the general yield pattern because unfavorable weather events reduced yield. The irrigation study lint yield in 1996 is also relatively low. In that year, which included multiple planting dates, cotton was planted on beds which had wheat stubble which was terminated with herbicide prior to planting. These beds were dry from moisture extracted by the wheat which resulted in nonuniform emergence and slow early growth which contributed to lowered yield.

The lint yield response with seasonal DD60s was analogous for maximum yield treatments in the irrigation studies, Lubbock county, and the 25 counties, Figure 7. The rate of lint yield increase was slightly higher in the irrigation studies as shown by the linear regression lines and coefficient values. The higher sensitivity of the maximum yield treatments in the irrigation studies is likely due to lower water stress in these treatments compared to area irrigated production fields.

Discussion

The irrigation studies were conducted with drip irrigation which uniformly applied water and was precisely metered. Testing during 1988-1990 included different temperature thresholds which scheduled irrigation in 15-min intervals and were compared with weekly irrigation intervals that replaced depleted soil moisture. Automated irrigation based on canopy temperature produced cotton yields that were generally higher than the soil water replacement method. The 1991 and 1992 tests measured water application and yield that resulted from different time thresholds. The 1993-1994 tests compared early versus delayed initiation of irrigation using 15-min irrigation decision intervals. The 1995 study compared different time thresholds for controlling irrigation with the inclusion of secondary factors of drought and excessive irrigation. Studies in 1996-1999 used 5.0 h or 5.5 h time thresholds above 28%C to schedule irrigation. The highest cotton yield in the 12-year study was produced by the DI-L treatment in 1994 which was also significantly different from the other irrigated treatments.

Irrigation quantities applied during the 12 years of scheduling studies at Lubbock, TX ranged from deficit to excessive amounts for maximizing lint yield. A second order polynomial provided the best description of the irrigation-yield response across years and estimated that maximum yield is achieved at an irrigation input of 58 cm. A similar polynomial for the lint yield-total water applied relationship which includes rain during the irrigation period estimates that peak yield occurs at 74 cm. Most irrigation treatments applied water in amounts that were less than the estimated value for maximizing lint yield. The observed yields for irrigation treatments that applied less water than the quantity estimated to produce maximum yield showed considerable variability indicating that yields were influenced by factors other than water input.

Lint yield response to increasing amounts of irrigation up to the point of maximum yield were approximated with a linear relationship. Here the average increase in lint yield was 11.4 kg/ha-cm of irrigation between the limits of 5 cm and 54 cm where observed lint yields ranged from 855 to 1608 kg/ha. This yield response to water is low, but the yield range of 2 to 3 bales/acre is above the level of most efficient lint yield output per unit of water input. The maximum yields each year were not limited by water input, but their inter-year range was from 1300 to 1600 kg/ha, with no yield trend with quantity of applied water. Yield variability among years appeared to result from other environmental factors since water input was not limiting yield. For the maximum yield treatments the components of total water supply were 74 % irrigation and 26% rain.

Seasonal heat units from May through September were higher for the 1988-1999 period, than either the 1965-1987 or 1965-1999 periods. During the 1965-1999 period either the highest or second highest DD60 monthly accumulations from May through September were recorded between 1988 and 1999. Maximum lint yield was linearly associated with monthly and seasonal DD60 values with monthly regressions for July and August and for May-September being significant. The monthly ranking of DD60 means from lowest to highest was May, September, June, August, and July. There was no relation between amount of irrigation and maximum yield, but the total heat unit accumulation positively correlated with lint yield. In most years once the water requirement for cotton is fully satisfied seasonal temperature is a significant determinant of yield level.

Irrigated cotton yields for Lubbock county and for the 25 county area around Lubbock have trended upward since 1986. The maximum lint yields from our irrigation studies had a similar yield trend between 1988-1998. There was an analogous response of lint yield to DD60s in the irrigation studies, Lubbock county, and the 25 county area. The rate of lint yield increase was slightly higher in the irrigation studies and is attributed to lower water stress in these treatments compared to the irrigated fields in the surrounding production region.

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Table 1. Yearly agronomic summary for cotton irrigation studies, 1998-1999.

Year	Planting Date DOY	Rain cm †	Head Units DD60s, ˚F ‡	Irrigation Period Start	End	Cultivar	Row Spacing cm
1988	137	16	2070	162	257	Paymaster 404	75
1989	138	18	2294	171	256	Paymaster 404	75
1990	138	20	2314	159	253	Paymaster 404	75
1991	134	25	2145	157	252	Paymaster HS26	75§
1992	162¶	11	1966	184	281	Paymaster HS26	75
1993	130	17	2329	#	262	Paymaster HS26	75
1994	129	09	2458	† †	258	Paymaster HS26	75
1995	139	08	2229	179	250	Paymaster HS26	100
1996	‡ ‡	‡ ‡	2453	173	235	Paymaster HS26	100
1997	136	23	2199	181	238	Paymaster HS26	100
1998	134	15	2836	152	243	Paymaster HS2326	100
1999	133	04	2290	187	253	Paymaster HS2326	100

† Rainfall amounts for all years are only for the period of irrigation (start to end). This does not include rain before planting or from planting to the start of irrrigation.

‡ Heat units are from planting date through September. Heat units were computed as, DD60s= í (T_{max} + T_{min})/2 - 60, where T_{max} and T_{min} are daily maximum and minimum air temperatures (%F) measured at 2 m.

§ A thunderstorm with hail and high wind on DOY 171 (June 19, 1991) damaged seedlings and reduced plant population. The leaf damage and subsequent weather contributed to infestation by Ascochyta blight which slowed vegetative growth. Later Verticillum Wilt was observed in mid July and continued for the duration of the season. Affected plants averaged 40% of the population on DOY 248. A heavy infestation of aphids in early August persisted for three weeks.

¶ The 1992 study was initially planted on DOY 127 and replanted on DOY 162 because plant population and vigor were lowered by a prolonged period of frequent rain and cool temperatures. In the 25 county area around Lubbock 76 % of the cotton acreage was replanted due to weather damage.

Early irrigation in 1993 began on DOY 159 and delayed irrigation started on DOY 182.

†† Early irrigation in 1994 began on DOY 153 and delayed irrigation started on DOY 173.

‡‡ The 1996 study used four planting dates (DOYs 116, 127, 140, 154) to measure the affect of wind velocity on seedling stand vigor. No wind damage occurred during the seedling growth stage of any planting date. The last date (DOY 154) was converted into a simulated wind damage study on DOY 166 when treatments were imposed. The last irrigation was applied on DOY 235 because 10.7 cm of rain occurred on DOYs 240 and 241. Cumulative rainfall after planting dates DOYs 116, 127, 140, and 154 through DOY 258 was 31 cm, 31 cm, 30 cm, and 26 cm, respectively.

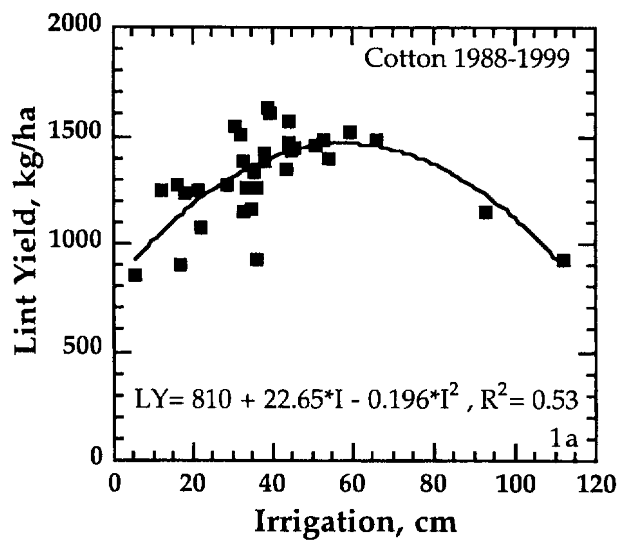
Table 2. Yields and water applications for all treatments in irrigation studies, 1988-1999.

Year	Treatment	Lint Yield kg/ha	Relative Yield %	Irrigation cm	Total Water cm
1988	28C	1431	100	44.4	60.4
1988	30C	1073	75	21.8	37.9
1988	32C	902	63	16.6	32.6
1988	SWRF	1147	80	92.6	108.1
1988	DRY	353	25	0.0	16.1
1989	26C2	595	71	59.4	77.4
1989	28C	839	100	44.9	62.9
1989	28C2	673	80	37.2	55.2
1989	SWRF	554	66	63.1	82.0
1989	DRY	630	75	1.0	18.0
1990	26C	931	63	111.7	131.2
1990	28C	1401	95	53.9	73.4
1990	30C	1389	94	32.8	52.3
1990	SWRF	1485	100	65.8	85.3
1990	DRY	706	47	0.0	19.5
1990	SWRV	1165	78	34.6	54.1
1990	SPRNK	1345	91	43.6	63.1
1991	28CR	1006	100	40.9	65.8
1991	28C	947	94	47.0	71.9
1991	2.5 TT	845	84	45.5	70.4
1991	4.0 TT	879	87	36.5	61.4
1991	5.5 TT	637	63	30.5	55.4
1991	7.0 TT	757	75	28.8	53.7
1991	DRY	481	48	0.0	24.9
1992	28CNAD	1335	100	35.1	46.0
1992	8 TT	1248	93	12.0	22.9
1992	2 TT	1263	95	36.0	46.8
1992	28CR	1263	95	33.4	44.3
1992	4 TT	1270	95	28.4	39.3
1992	28C	1146	86	32.6	43.5
1992	6 TT	1231	92	18.3	29.2
1992	DRY	1060	79	0.0	10.9
1993	EI	1447	93	45.4	62.5
1993	DI-H	1467	95	44.2	61.3
1993	DI-L	1548	100	30.4	47.5
1993	DRY	668	43	0.0	17.1
1993	VTH(30)	1267	82	15.9	33.0
1994	EI	1481	91	52.4	61.6
1994	DI-H	1460	90	50.5	59.7
1994	DI-L	1630	100	38.7	47.9
1994	DRY	609	37	0.0	9.2
1995	4 hr Normal	1572	98	43.9	52.5
1995	4 hr Drought	624	39	28.4	36.8
1995	4 hr D/E	1522	95	59.4	67.7
1995	6 hr Normal	1608	100	39.5	47.9
1995	6 hr Drought	506	31	17.5	25.9
1995	6 hr D/E	1388	86	38.0	46.4
1995	8 hr Normal	1424	89	38.0	46.4
1995	8 hr Drought	435	27	9.0	17.4
1995	8 hr D/E	927	58	35.8	44.2
1996	PD 1	1198	100	33.6	41.6
1996	PD 2	1169	98	33.6	41.6
1996	PD 3	847	71	27.3	32.0
1996	PD 4	864	72	27.3	32.0
1997	WL1	365	24	0.0	22.9
1997	WL2	855	57	5.3	28.2
1997	WL3	1251	83	21.3	44.2
1997	WL4	1510	100	32.0	54.9
1998	WL dryland	262	18	0.0	14.8
1998	WH 1.0 ET	1440	100	44.0	58.8
1999	WL dryland	78	7	0.0	3.8
1999	WH 1.0 ET	1204	100	41.8	45.6

Table 3. Relationships between DD60s and lint yield for nonwater stressed irrigation treatments (RY=100), 1988-1999 _1/

Period	Regression Relationship Linear	R^3
May - PD_2/	LY = 1488 + 0.287*HU	0.04
June	LY = 1315 + 0.363*HU	0.17
July	LY = 936 + 0.952*HU	0.37
August	LY = 599 + 1.733*HU	0.52
September	LY = 1351 + 0.468*HU	0.03
May - September	LY = 325 + 0.532*HU	0.74

_1/ The years omitted are 1989,1991, 1996, and 1998.
_2/ May - PD is the period in May from the planting date through the end of the month.



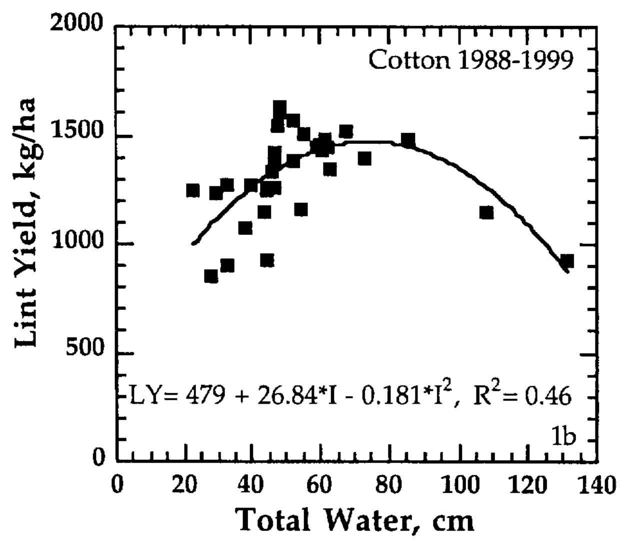


Figure 1. The relationship of irrigation with lint yield is shown in Figure 1a and with total water applied in Figure 1b for cotton irrigation studies, 1988-1999.

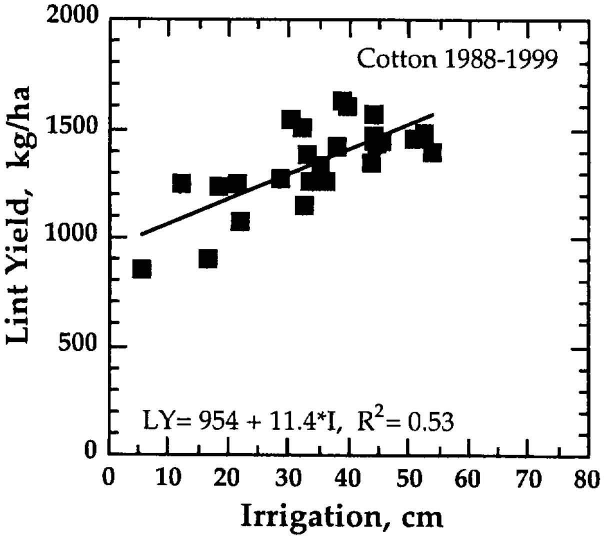


Figure 2. Lint yield response to irrigation for treatments which had similar application intervals and applied less water than the quantity which produced maximum yield in each year, 1988-1999.

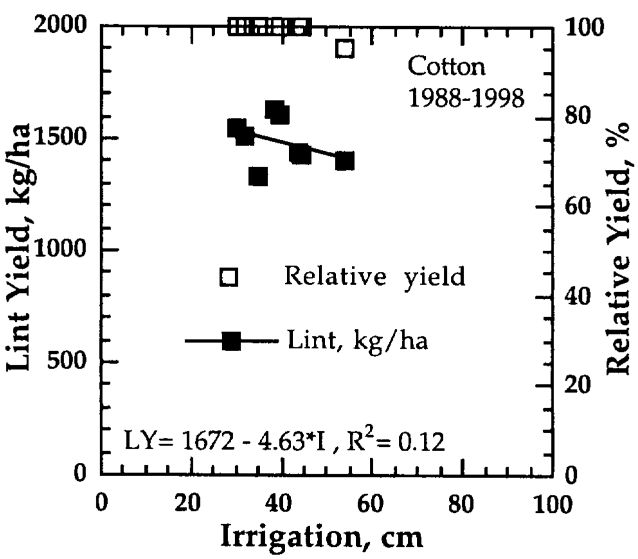


Figure 3. Irrigation amounts applied to maximum lint yield treatments, 1988-1999. Lint yields are variable among years but are not related to irrigation amount.

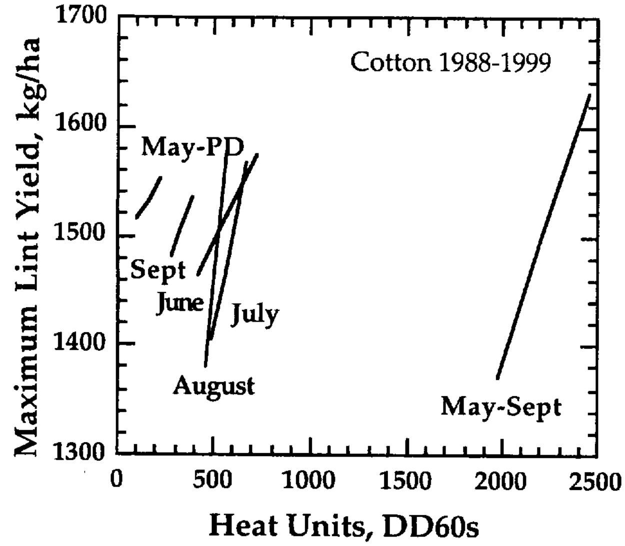


Figure 4. Linear regression lines for DD60s and maximum lint yields for monthly and seasonal periods, 1988-1999. Each regression line is plotted for the range of observed DD60 values. May-PD is period from the planting date through the the end of the May.

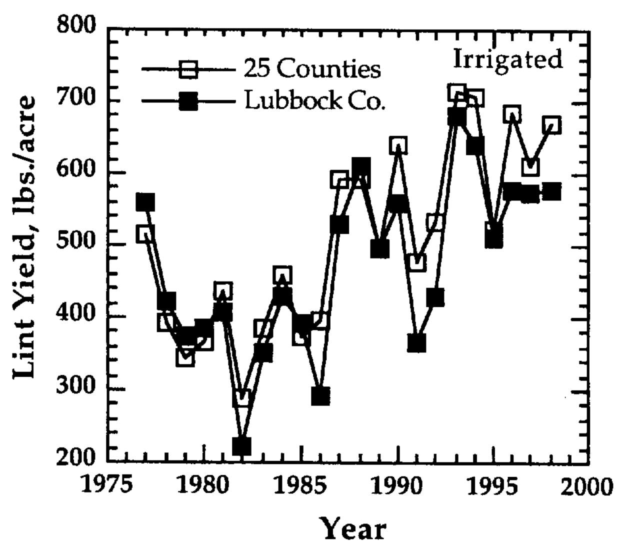


Figure 5. Average irrigated cotton lint yields for Lubbock county and the 25 county area surrounding Lubbock, TX, 1977-1998.

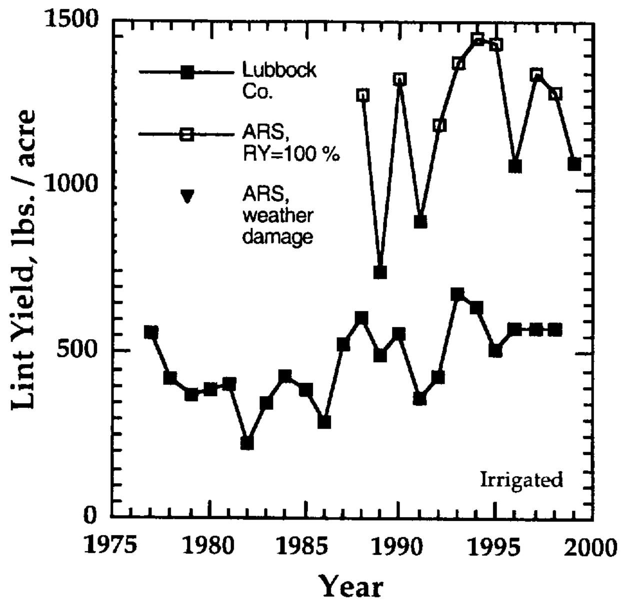


Figure 6. Comparison of average irrigated cotton yields for Lubbock county and yearly maximum lint yields in irrigation studies, 1988-1998.

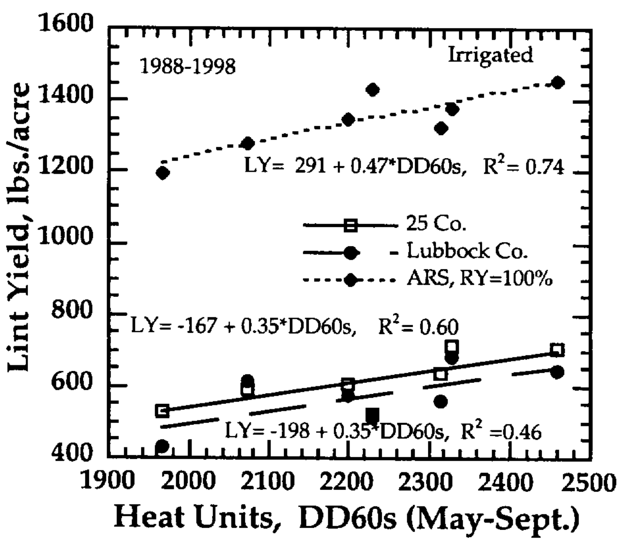


Figure 7. Comparison of irrigated lint yield relationships with seasonal DD60s for maximum lint yield treatments, and average Lubbock county and 25 county yields, 1988-1998.