# Sorghum/Cotton Rotation under Extreme Deficit Irrigation Conditions

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## Abstract

Dryland crop production has been economically viable on the Southern High Plains as over 1 million acres of non-irrigated, row-crops are harvested each year. On the remaining 1.5 million acres of irrigated croplands, growing cotton and grain sorghum using dryland production strategies complemented by very limited irrigation could stabilize crop output for an extended period at the expense of immediate losses in agricultural productivity and related economic activity in the area. A field experiment is underway to develop cropping systems data for economic analysis. The treatments compare a sorghum/cotton (1:2) rotation to continuous cotton, both efficiently irrigated at pumping capacities of 1.25 and 2.5 gpm/ac. The rotation strategy allows movement of limited irrigation resources to the crop providing the highest economic value as a function of growth stage and rainfall events. The results to date show that including sorghum in the rotation consistently increased cotton yield compared to continuous cotton under deficit irrigation. In 2003, the first year of a complete rotation cycle, cotton yields were 9 to 26% higher in rotation treatments than in continuous cotton treatments while using 9 to 19% less irrigation and reducing the number of field operations required to curtail blowing sand. Seasonal irrigation water use efficiency was highest in treatments where cotton followed sorghum at the 1.25 gpm/ac irrigation capacity.

## Introduction

The competition for available water in Texas is increasing. In west Texas, the Llano Estacado Regional Planning Group projects water demand for residential, manufacturing, and livestock segments of the economy to escalate as population increases by 20% over the next 50 years (TWDB, 2001). This demand for water will be at the expense of irrigated agriculture although irrigated production is forecast to remain the cornerstone of the economy. The Ogallala Aquifer is the major water-bearing formation in the region with approximately 90% of the water currently used for irrigation. Recharge of the formation is minimal, estimated at 0.5 to 3 inches/year within the region (TWDB, 2001). Therefore, demand from non-irrigation water needs will reduce availability for irrigation as groundwater supplies diminish. To maintain the agriculturally based economy, the principal strategy of the Llano Estacado Planning Group is to increase irrigation water use efficiency. This can only be achieved by taking full advantage of the region's climate, soils, and rain, and by distributing supplemental water with well-managed, efficient irrigation systems.

Dryland crop production has been economically viable on the Southern High Plains (SHP) as over 1 million acres of non-irrigated, row-crops are harvested each year (TASS, 2003).

Two major economic problems with non-irrigated crop production include extreme year-to-year yield variability and low overall production, with yields averaging less than 25% of yields from irrigated crops. On the 1.5 million acres of SHP irrigated croplands, production of drought tolerant crops such as cotton and grain sorghum is typical with irrigation providing 40 to 80% of estimated crop evapotranspiration (ET). However, water demands on the aquifer could be reduced while maintaining stable crop output by combining the efficient use of very limited irrigation (< 25% ET) with proven dryland production strategies. This overall strategy requires the diligent use of both dryland production practices such as furrow diking, reduced and/or minimum tillage, precise plant populations and varieties, and crop rotations, as well as, the use of very efficient irrigation delivery systems such as LEPA (Bordovsky et al., 1992).

The benefits of conservation-tilled cotton in rotation with grains on the SHP have been documented under furrow-irrigated conditions (Keeling et al., 1989, Bordovsky et al., 1994). Potential economic advantages of rotations in typical irrigated production have also been investigated (Segarra et al., 1991, Blackshear and Johnson, 2003). The question becomes whether an extreme deficit irrigation strategy is economically viable compared to dryland and traditional irrigated production when using efficient irrigation systems, opportunities to redirect available water among crops, and all available rainfall.

The objective of this paper is to describe an ongoing field experiment evaluating a sorghum/cotton rotation system that utilizes rain as its primary water source yet is irrigated at very low to medium levels by the LEPA method. This project will develop production data to answer questions concerning economic allocation of limited irrigation.

## Materials and Methods

The field experiment is being conducted at the Texas Agricultural Experiment Station Research and Extension Center at Halfway, TX (1071 m elev., $34^0$ 11'N, $101^0$ 56' W). The field is located adjacent to a playa in a transitional soil changing from a Pullman clay loam (fine, mixed, thermic Torrertic Paleustolls) at high elevations to an Olton loam (fine, mixed, thermic Aridic Paleustolls) at lower elevations. In 2001, a sorghum/cotton rotation (1:2) was established on a 9-acre area under an 8-span center pivot with the crop irrigated by LEPA using circular rows perpendicular to the pivot lateral. Primary rotation treatments include: CCS – cotton followed by cotton and sorghum, CSC – cotton followed by sorghum and cotton, and SCC – sorghum followed by two years of cotton. Cotton yields from these treatments are compared to a continuous cotton treatment – CCC. Primary treatment plots are 12 40-inch rows wide and arc $70^0$ of the pivot circle. The $70^0$ pivot arc is split into three smaller wedge-shaped areas (three sub-treatments) where irrigation capacity is limited to 0.0 (no seasonal irrigation), 1.25, or 2.5 gpm/ac (~ 0%, 25% and 50% of peak cotton ET). The cropping system treatments were arranged in a complete randomized block design with four replications along the length of the pivot lateral. The three irrigation capacity treatments are imposed perpendicular to the cropping system treatment areas and are approximately 3 acres each (~$24^0$ arcs) in size. This arrangement prevents statistical comparisons of different irrigation capacities, but is required due to physical limitations. The application devices (LEPA socks) along the pivot were located in alternate furrows and all pivot drops were equipped with manual valves to control irrigation of sorghum, cotton, or both during each irrigation event.

Grain sorghum (Golden Acres 1506) was planted at a rate of 5.0 to 7.7 lbs. of seed per acre on 18 May, 14 May, and 14 May of 2001, 2002, and 2003. Seeding rates were dependent on irrigation capacity with lower rates in non-irrigated treatments. Cotton (Paymaster 2326RR) was planted each year at rates of 13 to 13.7 lbs of seed per acre the day prior or the day following grain sorghum plantings. All nutrients (liquid, ground application) were applied prior to planting based on 12-inch soil test analysis at rates corresponding potential yields. Differences in tillage and herbicide applications during the 3-year period for each treatment are given in Table 1. Insect pest control consisted of systemic insecticide at cotton planting for thrips control (4 lb Temik®/ac), one broadcast application per year to control thrips in cotton (3 oz Orthene®/ac) in 2001 and 2003, and a directed spray application for aphids in grain sorghum (16 oz. Lorsban®/ac) in 2001.

Early planted sorghum is irrigated with all available water at the beginning of the growing season in an attempt to fill the soil profile and provide moisture during early critical plant development. The scheduled irrigations for each treatment are given in Table 2. By early to mid July, the irrigation protocol allows diversion of some or all irrigation from sorghum to cotton in the rotation treatments. Additional sorghum irrigations are applied at early dough stage depending upon rain and irrigation capacity. Within crop rotation areas, the total weekly irrigation volume on combined cotton and sorghum plots is limited by irrigation capacity, either 1.25 or 2.5 gpm/ac. Optional weekly irrigation schedules within the irrigation capacity limits are also given in Table 2. Continuous cotton treatments, by contrast, are irrigated at constant irrigation rates, subject to irrigation capacity, throughout the irrigation period.

## Results and Discussion

### Rainfall and Irrigation

Timing and quantity of rainfall have a huge impact on crop production in limited irrigated areas. Figure 1 displays daily rain quantities from May through August of 2001, 2002 and 2003 at Halfway. All three years were very dry during critical growth periods in July and August. Rain from planting through 31 August totaled 3.0, 3.9, and 8.9 inches in 2001, 2002, and 2003, respectively. Heavy rain, hail, and high winds in June 2003 drastically reduced cotton plant populations and caused disease that slowed growth of surviving plants.

Irrigations were initiated in early June of each year and were terminated the last week in August. The low rain amounts during the summers of 2001 and 2002 resulted in slightly more water being diverted from sorghum to cotton within the rotation treatments than originally scheduled. In 2003, the poor cotton yield potential resulted in scheduled quantities being diverted from cotton to sorghum. Cumulative growing season irrigation amounts for rotation and continuous cotton treatments at 1.25 and 2.5 gpm/ac treatments from 2001 to 2003 are in Figure 2. The CCS and CSC treatments were irrigated identically in each year, therefore, irrigation data from the CSC treatments are not shown in Figure 2. The slopes of lines through data points indicate irrigation rates and show periods where water was used on sorghum, cotton, or both in the rotation treatments. Vertical lines indicate dates of irrigation initiation, rate change, or termination.

### Crop Response

In 2001, the dry growing season resulted in sorghum yields in the 0.0 (dryland), 1.25, and 2.5 gpm/ac treatments being lower that expected at 22, 36.5, and 72.2 bu/ac, respectively. Cotton and grain sorghum yields and seasonal irrigation totals for each treatment by year are given in Table 3. Although irrigations in cotton treatments were delivered at different times and slightly different amounts, here were no significant differences in lint yield between continuous cotton (CCC) and rotation cotton (CCS and CSC) at any irrigation level. Considering the dry growing season, cotton lint yields were very high averaging 343, 746, and 1158 lb./ac in the 0.0, 1.25, and 2.50 gpm/ac treatments, respectively.

The lack of rain in 2002 resulted in no sorghum grain yields in the 0.0 gpm/ac treatments and lower that expected yields in the 1.25 and 2.5 gpm/ac treatments. At the 1.25 gpm/ac, proportionally more water was diverted from cotton to sorghum than in 2001. This increased sorghum yield by 30% (36.5 vs. 47.6 bu/ac in 2001 and 2002, respectively). Cotton yields at the 1.25 gpm/ac capacity in 2002 were generally decreased compared with 2001 while using slightly more irrigation. However, the cotton immediately following sorghum (CCS) resulted in a 28% increase in lint yield compared to continuous cotton (585 vs. 749 lb/ac for CCS and CCC, respectively). Similar yield comparisons from 0.0 and 2.5 gpm/ac treatments showed yield increases of 19.8 and 8.8% respectively, but were not significantly different ($P<0.5$, LSD) than continuous cotton. The 0.0 gpm/ac cotton yield was much lower in 2002 compared to 2001 while irrigation at the 2.5 gpm/ac capacity resulted in similar lint yields in both 2001 and 2002.

Following the harsh early season weather in 2003, irrigated cotton benefited from 60 days of hot, dry weather producing good cotton yields with reduced irrigation quantities. For the second year in a row, the lack of July and August rain resulted in zero sorghum grain yield and low cotton yields in all 0.0 gpm/ac treatments. Irrigated cotton treatments following sorghum had significantly higher yields with less irrigation than continuous cotton treatments. In cotton treatments one year following sorghum (CCS) at the 2.5 gpm/ac irrigation capacity, lint yields were significantly increased by 26% with 19% less seasonal irrigation compared to continuous cotton treatments (965 lb/ac with 6.8 in. of irrigation vs. 764 lb/ac with 8.4 in. of irrigation, respectively). At the 1.25 gpm/ac capacity, lint yields were increased by 18% with 15% less irrigation compared to continuous cotton (704 lb/ac with 3.8 in. of irrigation vs. 585 lb/ac with 4.5 inches). In cotton treatments two years following sorghum (CSC), yields were significantly higher by 19 % in 2.5 gpm/ac treatments and 6 % in the 1.25 gpm/ac treatments compared to those of continuous cotton. The benefits of having sorghum in rotation with cotton are particularly pronounced in harsh weather years such as 2003 due to crop residue providing protection from blowing sand and reduced occurrence of diseases. Further direct benefits to cotton are easily realized in the reduction in the number of field operations required to reduce blowing sand following a sorghum crop (Table 1).

Table 3 also contains seasonal irrigation water use efficiency (SIWUE) of treatments in 2003. SIWUE is the quantity of cotton lint produced from each unit of seasonal irrigation applied. At both irrigation capacities, SIWUE in all treatments with a history of sorghum is much higher than that of continuous cotton. SIWUE ranged from 93 to 109 lbs./ac-in of water applied in rotation treatments compared to 56 to 67 lbs/ac-in of water in continuous cotton treatments. Water use efficiency was also numerically higher in the 1.25 gpm/ac irrigation capacity treatments than the 2.5 gpm/ac treatments. In years of very limited rainfall, stretching irrigation resources with efficient delivery systems can result in very efficient water use.

## Conclusions

The results to date document the positive effect of sorghum on cotton yield in a sorghum/cotton rotation where irrigation quantities are limited and irrigation application methods are efficient. The rotation consistently increased cotton yield compared to continuous cotton under deficit irrigation. In the harsh, early growing season of 2003, cotton yields were up to 26% higher in the rotation than in comparable continuous cotton treatments while using 19% less irrigation and reducing the number of field operations required to prevent blowing sand. Seasonal irrigation water use efficiency was highest in treatments where cotton followed sorghum at the 1.25 gpm/ac irrigation capacity. However, the lack of July and August rain in both 2002 and 2003 clearly show the risk of this rotation under purely dryland (0.0 gpm/ac) conditions. No grain was harvested in either of these years and the resulting sorghum residue failed to consistently increase the yield of subsequent cotton crops. Under irrigated conditions, the drawbacks to this rotation are the low crop market value and the high water requirement of sorghum relative to cotton. Additional field data will allow valid economic evaluations.

## Disclaimer

Mention of trade names or commercial products in this paper is solely for providing specific information and does not imply recommendation or endorsement by the Texas Agricultural Experiment Station.

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Table 1. Tillage and herbicide applications of continuous cotton and rotation treatments irrigated at 0.0, 1.25 and 2.5 gpm/ac irrigation capacities from 2001, 2002 and 2003, TAES, Halfway, TX.

| Year | Input | Operation | | CCC | CCS | CSC | SCC |
|---|---|---|---|---|---|---|---|
| 2001 | Tillage | Deep Chisel | 2/27 | X | X | X | X |
| | | Springtooth cultivator | 3/15 | X | X | X | X |
| | | List (disc bedder) | 4/3 | X | X | X | X |
| | | Rolling Cultivator | 4/11 | X | X | X | X |
| | | Dike | 4/28 | X | X | X | X |
| | | Rodweed | 5/16 | X | X | X | |
| | | Rodweed | 5/17 | | | | X |
| | | Rolling Cultivator | 6/6 | | | | X |
| | | Dike | 6/6 | | | | X |
| | | Rolling Cultivator | 6/11 | X | X | X | |
| | | Dike | 6/12 | X | X | X | |
| | Herbicide | Prowl® w/rolling cultivator (oz./ac) | 4/26 | 32 | 32 | 32 | |
| | | Cotton Pro® (oz./ac) | 5/17 | 32 | 32 | 32 | |
| | | Atrazine non-incorporated (oz/ac) | 5/19 | | | | 32 |
| | | Roundup® broadcast (oz./ac) | 6/9 | 26 | 26 | 26 | |
| | | Roundup® directed (oz./ac) | 7/10 | 26 | 26 | 26 | |
| 2002 | Tillage | Stalk cutter | 3/11 | X | | X | X |
| | | Stalk Cutter x 2 | 3/11 | | X | | |
| | | Dike | 4/3 | X | X | X | X |
| | | Rotary Hoe | 5/21 | X | | X | X |
| | | Sweep Cultivator | 6/3 | X | | X | |
| | | Rolling Cultivator | 6/3 | X | | X | |
| | | Dike | 6/3 | X | | X | |
| | Herbicide | Roundup® broadcast (oz./ac) | 5/8 | 26 | 26 | 26 | 26 |
| | | Caparol® non-incorporated (oz/ac) | 5/15 | 32 | 32 | 32 | |
| | | Atrazine non-incorporated (oz/ac) | 5/15 | | | | 32 |
| | | Roundup® broadcast (oz./ac) | 6/6 | 32 | 32 | 32 | |
| 2003 | Tillage | Shred Stalks | 1/18 | X | | X | X |
| | | Shred Stalks | 3/18 | | X | | |
| | | Dike | 3/18 | | X | | |
| | | Stalk Puller | 3/19 | | X | | |
| | | Rotary Hoe | 5/24 | X | | X | |
| | | Rotary Hoe | 5/31 | X | | X | |
| | | Sweep cultivator | 6/2 | | | | X |
| | | Rotary Hoe | 6/3 | X | | X | |
| | | Rotary Hoe | 6/7 | X | | X | |
| | | Sweep cultivator | 6/9 | | | | X |
| | | Barring off disc/cultivator | 6/10 | | | | X |
| | | Dike | 6/10 | | | | X |
| | | Dike | 6/18 | X | | X | |
| | | Rotary Hoe | 6/23 | X | | X | |
| | | Rotary Hoe | 6/25 | X | | X | |
| | | Sweep cultivator | 6/30 | X | X | X | |
| | | Barring off disc/cultivator | 7/1 | X | | X | |
| | | Dike | 7/2 | X | X | X | |
| | Herbicide | Roundup® broadcast (oz./ac) | 3/28 | 26 | | 26 | 26 |
| | | Prowl® broadcast (oz./ac) | 4/5 | 24 | | 24 | |
| | | Cyclone® Max broadcast (oz./ac) | 5/1 | | | | 16 |
| | | Cyclone Max® broadcast (oz./ac) | 5/7 | 16 | 16 | 16 | |
| | | Caparol® non-incorporated (oz/ac) | 5/14 | 16 | 16 | 16 | |
| | | Attrex® non-incorporated (oz/ac) | 5/15 | | | | 16 |
| | | Roundup WM® broadcast (oz./ac) | 6/11 | 20 | 20 | 20 | |
| | | Prowl® directed (oz./ac) | 6/11 | | | | 24 |
| | | Roundup WM® directed (oz./ac) | 8/15 | 20 | 20 | 20 | |

Table 2. Planned and optional weekly irrigation schedules for sorghum/cotton rotation at 1.25 and 2.50 gpm/acre irrigation capacities.

| | Irrigation Amounts (Inches) | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 1.25 gpm/ac | | | | 2.5 gpm/ac | | | |
| Crop Rotation | CCC | CCS | CSC | SCC | CCC | CCS | CSC | SCC |
| Week No. | | | | | | | | |
| 1 | 0.00 | 0.00 | 0.00 | 1.39 | 0.00 | 0.00 | 0.00 | 1.39 |
| 2 | 0.93 | 0.00 | 0.00 | 1.39 | 0.93 | 0.00 | 0.00 | 2.78 |
| 3 | 0.00 | 0.00 | 0.00 | 1.39 | 0.93 | 0.00 | 0.00 | 2.78 |
| 4 | 0.93 | 0.00 | 0.00 | 1.39 | 0.93 | 0.93 | 0.93 | 0.93 |
| 5 | 0.00 | 0.70 | 0.70 | 0.00 | 0.93 | 0.93 | 0.93 | 0.93 |
| 6 | 0.93 | 0.70 | 0.70 | 0.00 | 0.93 | 0.93 | 0.93 | 0.93 |
| 7 | 0.00 | 0.00 | 0.00 | 1.39 | 0.93 | 0.93 | 0.93 | 0.93 |
| 8 | 0.93 | 0.00 | 0.00 | 1.39 | 0.93 | 0.93 | 0.93 | 0.93 |
| 9 | 0.46 | 0.70 | 0.70 | 0.00 | 0.93 | 0.93 | 0.93 | 0.93 |
| 10 | 0.46 | 0.70 | 0.70 | 0.00 | 0.93 | 1.40 | 1.40 | 0.00 |
| 11 | 0.46 | 0.70 | 0.70 | 0.00 | 0.93 | 1.40 | 1.40 | 0.00 |
| 12 | 0.46 | 0.70 | 0.70 | 0.00 | 0.93 | 1.40 | 1.40 | 0.00 |
| 13 | 0.46 | 0.70 | 0.70 | 0.00 | 0.93 | 1.40 | 1.40 | 0.00 |
| 14 | | | | | 0.93 | 1.40 | 1.40 | 0.00 |

Optional

| | CCS | CSC | SCC | CCC | CCS | CSC | SCC |
|---|---|---|---|---|---|---|---|
| Optional weekly irrigation distributions that maintain irrigation capacity limits | 0.00 | 0.00 | 1.39 | 0.93 | 0.00 | 0.00 | 2.87 |
| | 0.30 | 0.30 | 0.78 | 0.93 | 0.40 | 0.40 | 1.99 |
| | 0.46 | 0.46 | 0.46 | 0.93 | 0.70 | 0.70 | 1.39 |
| | 0.70 | 0.70 | 0.00 | 0.93 | 0.93 | 0.93 | 0.93 |
| | | | | 0.93 | 1.10 | 1.10 | 0.59 |
| | | | | 0.93 | 1.40 | 1.40 | 0.00 |

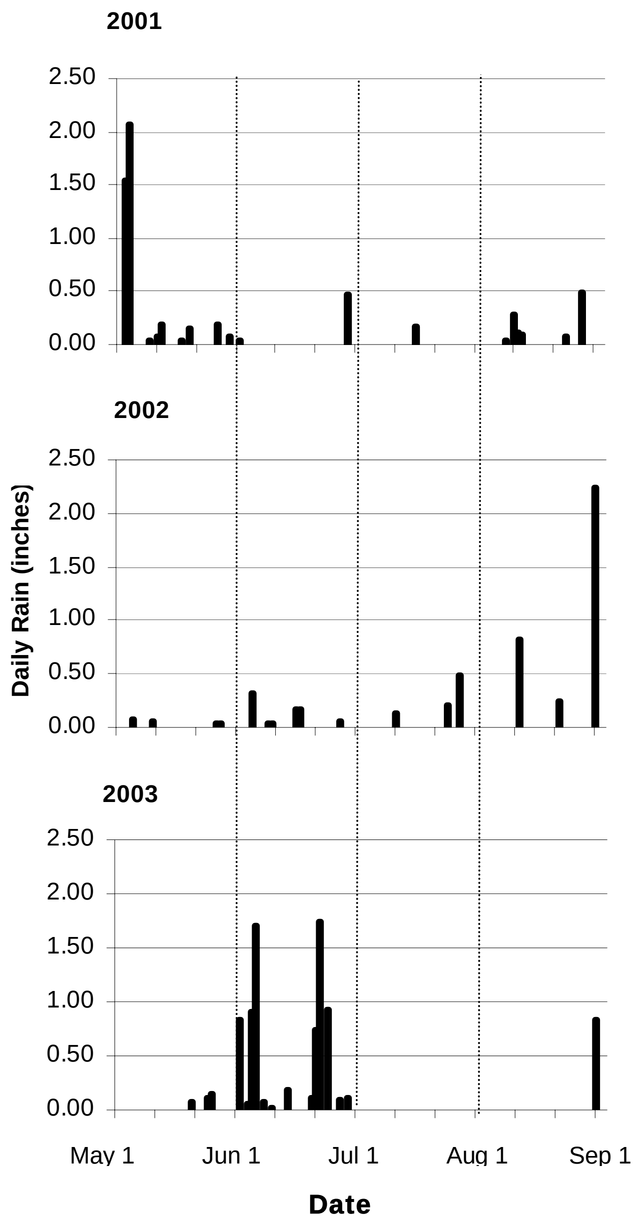


Figure 1. Daily rain amounts during planting and irrigation seasons of 2001, 2002 and 2003, TAES, Halfway, TX.

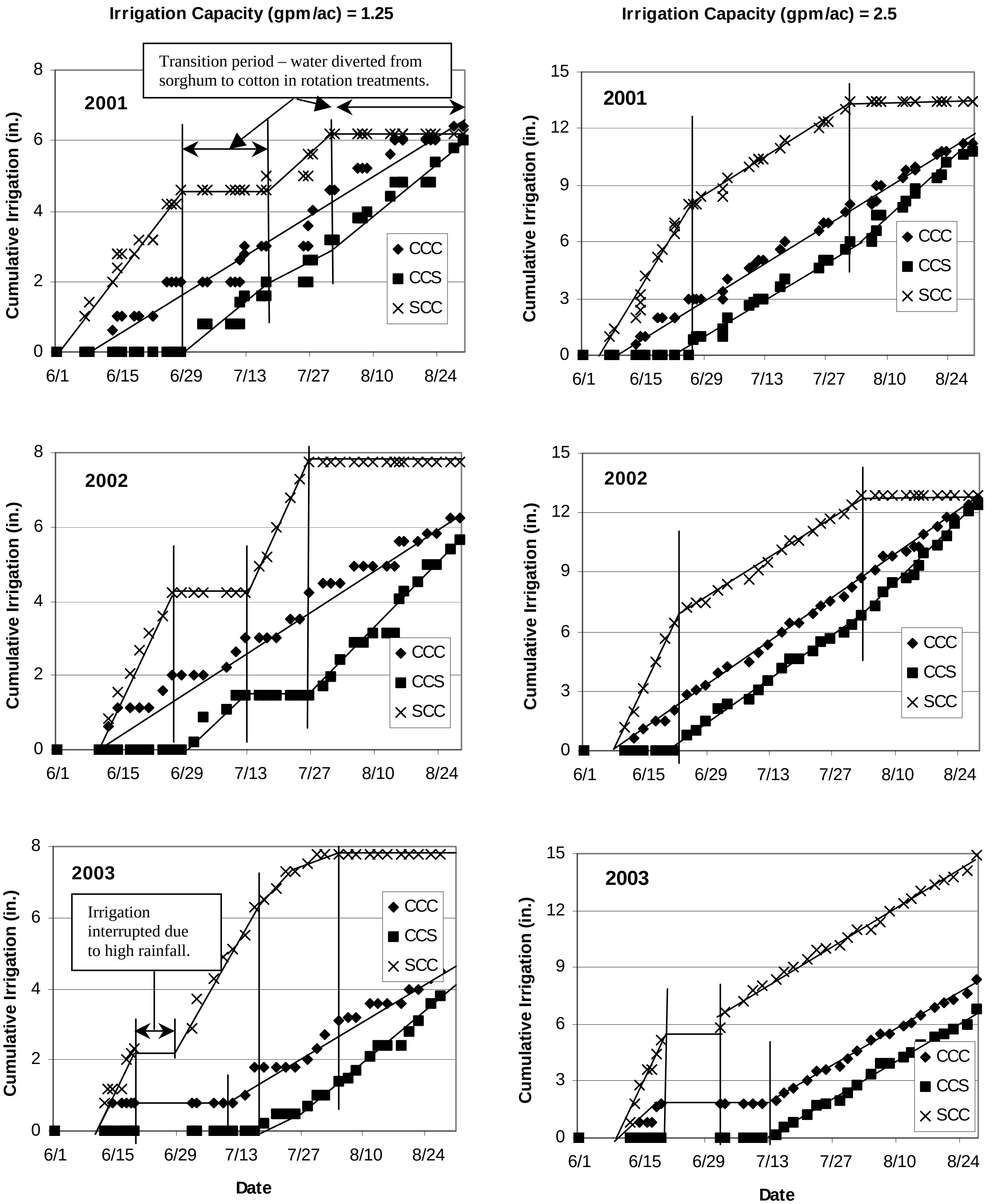


Figure 2. Cumulative seasonal irrigation amounts for rotation and continuous cotton treatments irrigated at 1.25 and 2.5 gpm/ac irrigation capacities in 2001, 2002, and 2003, TAES, Halfway, TX.

Table 3. Sorghum grain, cotton lint yield, seasonal irrigation amounts, and seasonal water use efficiency resulting from rotation and continuous cotton treatments at irrigation capacities of 0.0, 1.25 and 2.5 gpm/ac at TAES, Halfway, 2001, 2002 and 2003.

| Irrigation Capacity | Treat-ment Name[1/] | Crop | Grain Yield (bu/ac) | | | Lint Yield [2/] (lb./ac) | | | Seasonal. Irrigation (in) | | | Seasonal Irrigation WUE[3/] (lbs./ac-in) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | 2001 | 2002 | 2003 | 2001 | 2002 | 2003 | 2001 | 2002 | 2003 | 2003 |
| 0.0 gpm/ac | CCC | Cotton | | | | 333 c | 111 f | 293 e | 0.0 | 0.0 | 0.0 | |
| | CSC | Cotton | | | | 341 c | 100 f | 274 e | 0.0 | 0.0 | 0.0 | |
| | CCS | Cotton | | | | 352 c | 133 e | 288 e | 0.0 | 0.0 | 0.0 | |
| | SCC | Sorghum | 22.0 | 0.0 | 0.0 | | | | 0.0 | 0.0 | 0.0 | |
| 1.25 gpm/ac | CCC | Cotton | | | | 723 b | 585 d | 596 d | 6.0 | 6.3 | 4.5 | 67 |
| | CSC | Cotton | | | | 786 b | 653 c | 632 cd | 5.4 | 5.7 | 3.8 | 94 |
| | CCS | Cotton | | | | 730 b | 749 b | 704 c | 5.4 | 5.7 | 3.8 | 109 |
| | SCC | Sorghum | 36.5 | 47.6 | 53.2 | | | | 6.2 | 7.8 | 7.8 | |
| 2.50 gpm/ac | CCC | Cotton | | | | 1160 a | 1173 a | 764 b | 10.8 | 12.7 | 8.4 | 56 |
| | CSC | Cotton | | | | 1163 a | 1175 a | 903 a | 10.2 | 12.5 | 6.8 | 93 |
| | CCS | Cotton | | | | 1152 a | 1276 a | 965 a | 10.2 | 12.0 | 6.8 | 100 |
| | SCC | Sorghum | 72.2 | 85.0 | 101.1 | | | | 13.4 | 12.8 | 14.9 | |

1/ CCC – Continuous cotton.
CSC – Cotton in current year, 2 years out of sorghum.
CCS – Cotton in current year, 1 year out of sorghum.
SCC – Sorghum in current year, cotton in the previous 2 years.

2/ Yields followed by the same letter in a column within an irrigation capacity treatment are not significantly different (P<0.05, LSD).

3/ Seasonal irrigation water use efficiency = (irrigated yield – 0.0 gpm/ac yield)/seasonal irrigation quantity.