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Cotton and Sorghum Rotation Under Deficit Furrow Irrigation

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Abstract. *Cotton and sorghum were grown in rotation in 2001 and 2002 at Bushland, TX on a Pullman clay loam soil under furrow irrigation. Cotton yields were not different in the rotation compared with continuous sorghum and cotton. Sorghum yield was increased 11% by the rotation following cotton.*

Additional research in seasons with differing climatic patterns will be required before absolute conclusions are developed. The 2002 results definitely indicated an advantage for a rotation of.sorghum with cotton. Future research will examine the crop rotation with limited irrigation of sorghum following irrigated cotton

Keywords. climate, cotton, crop production, furrow irrigation, irrigation, rain, sorghum, tillage, water conservation, yields

Introduction

Cotton (*Gossypium hirsutum* L.) is a major crop produced on the semi-arid Southern Texas High Plains region and has expanded into the Northern Texas High Plains and even into the southwestern Kansas regions. It is produced under both irrigated and dryland cultures. Grain sorghum [*Sorghum bicolor* (L.)] is also widely produced in this region. It is mainly a dryland crop, but a substantial amount of sorghum is irrigated in this region. Table 1 provides the 2001 crop statistics for cotton and sorghum production on the Texas High Plains (TASS, 2002). The High Plains harvested production area represented 40% of the state cotton area in 2001 while the harvested High Plains sorghum production area represented 15% of the state total sorghum production area. The mean annual precipitation is similar from North to South on the Texas High Plains, but irrigation water is generally more available on the Northern Texas Plains (Musick et al., 1990). The cotton production data reported by TASS (Texas Agricultural Statistical Service) for reporting region 1-N (northern 23 counties in the Texas Panhandle; Table 1) occur in the southern most counties in that region with limited production north of Amarillo. Both cotton and sorghum yields increase in the northern region (1-N; Table 1) due to greater irrigation water availability (Musick et al., 1990). Musick et al. (1987) summarized the improved water conservation that has occurred in the Texas High Plains. Despite these improved irrigation technologies, expansion and continued irrigation has perpetuated continued groundwater depletion from the Ogallala aquifer in Texas, due in part to the legal and regulation of groundwater under the doctrine of the "right of capture."

Table 1. Texas High Plains crop production statistics for harvested area and mean yields for cotton and sorghum for the 2001 season (TASS, 2002).

Crop / Culture	Reporting District (1-N)		Reporting District (1-S)		High Plains Region		State	
	Area (ha)	Yield (g m^{-2})	Area (ha)	Yield (g m^{-2})	Area (ha)	Yield (g m^{-2})	Area (Mil. ha)	Yield (g m^{-2})
Cotton / Irrigated	255,870	86.1	427,935	62.6	683,805	71.4		
Cotton / Dryland	46,154	36.3	243,725	22.0	289,879	24.3		
State Sum / Mean Yield							1.721	53.9
Sorghum / Irrigated	97,166	482.2	58,704	318.5	155,870	420.5		
Sorghum / Dryland	139,676	203.5	163,968	155.4	303,644	177.5		
State Sum / Mean Yield							1.053	313.9

Cotton is the predominate crop on the Texas Southern High Plains (see Table 1; 1-S is the 18 southwestern counties in the Texas Panhandle) and is often produced in a monoculture whether irrigated or dryland. Segerra et al. (1991) reported that a cotton-wheat *Triticium aestivium* L.) rotation with or without irrigation was a dominate cultural system using conservation tillage, although a cotton-sorghum rotation was slightly better than continuous cotton with conventional tillage. Previously, Keeling et al. (1989) illustrated the improved cotton production with conservation tillage using a cotton-wheat rotation. Rotations (Francis and Clegg, 1990) provide biodiversity and offer improved sustainable production systems (Parr et al., 1990) that can lead to improved long-term ecological systems. Jones and Johnson (1982) reviewed dryland cropping systems adapted for the Texas High Plains and the Southern High Plains. Limited irrigated cropping system rotations have been studied on the Texas High Plains with cotton and sorghum (Segerra et al., 1991). Schneekloth et al. (1991) evaluated crop rotations in South-Central Nebraska under a range of irrigation.

The objective of this research was to evaluate a cotton-sorghum rotation under graded furrow irrigation in a semi-arid, advective environment to determine mainly if sorghum yields could be enhanced following an irrigated cotton crop.

Materials and Methods

This study was conducted at the USDA-ARS Conservation and Production Research Laboratory at Bushland, Texas (lat. 35E11' N; long. 102E06' W; 1,170 m elevation MSL) during the 2001-2002 growing seasons. The soil at this site is classified as Pullman clay loam (fine, mixed, thermic Torrertic Paleustoll) [Taylor et al., 1963; Unger and Pringle, 1981] which is described as slowly permeable because of a dense B22 horizon about 0.3 to 0.5 m below the surface that makes the soil appropriate for furrow irrigation. The plant available water holding capacity within the top 2.0 m of the profile is approximately 240 mm (~200 mm to 1.5-m) depth). A calcareous layer at about the 1.5 m depth limits significant rooting and water extraction below this depth. This soil is common to more than 1.2 million ha in this region. The field slope is approximately 0.5% or less (W-E mostly).

The plots were arranged in a complete randomized block arrangement with three replications. Each plot was 305 m in length and 12 rows wide. The plots were on beds that were 0.76-m rows in an E-W orientation. Irrigations were applied using 200-mm diameter PVC gated pipe from the west side of the plots, and an in-line propeller water meter from an underground pipeline with 250-mm hydrants was used to measure applications. Irrigations were typically 12-hr sets with "gross" applications of 150-mm applications. Occasionally, smaller applications (75 mm) or larger applications (200 mm) were used depending on soil water depletions. Tailwater runoff was not measured, but irrigation steams were optimized to achieve uniform infiltration opportunity times for at least 80% or greater of the furrow length.

The treatments were

S-C	sorghum-cotton
C-C	continuous cotton
C-S	cotton-sorghum (same as S-C, but different sequence)
S-S	continuous sorghum

The agronomic and cultural details are provided in Table 2. Seasonal irrigation applications are given in Table 3. Irrigation "gross" volumes were greater in 2002 due to slower advance rates that required longer set times at achieve the desired application distribution.
Grain yields were hand harvested from four 10-m^2 samples (two adjacent 6.6-m long row segments) and another 1-m^2 sample was taken for biomass and to determine harvest index. Grain mass was determined from three 500 seed sub-samples from each plot. Yield samples were sampled in the center of each quarter of the furrow length (approximately at 38 m, 114 m, 190 m, and 266 m distances from the west end). All grain yields were converted to 14% wb water contents.

Seed cotton samples were hand harvested similarly from four 10-m^{-2} samples (two adjacent 6.6-m long row segments) in the center of each quarter of the furrow length (approximately at 38 m, 114 m, 190 m, and 266 m distances from the west end). Gin sub-samples (approximately 2-3 kg) were separated from the field samples after drying and weighing for ginning (at the Texas Agricultural Experiment Station plot gin at Lubbock, TX) and fiber sub-samples were sent to the Texas Tech University Textile Laboratory for commercial fiber quality analyses (results not presented here).

Yield data and yield components were analyzed using SigmaStat V. 2.03.0 (SPSS, Inc.) as a two-way ANOVA and variables with significantly different treatment means ($P<0.05$) were compared with the Tukey multi-comparison test. Statistical results were analyzed for individual seasons.

Table 2. Agronomic and cultural data.

Category	Sorghum	Cotton
2001	04/12 Disc plowed 04/17 Applied liquid fertilizer 17g (N) m^{-2} 04/18 Sweep plowed 04/24 Listed 05/17 Applied Dual Magnum II at 0.155 ml (ai) m^{-2} 05/17 Rolling cultivator and culti-packer 05/22 Planted Pioneer 84G62 at 21 seeds m^{-2} 05/30 Emergence 06/26 Cultivated 07/25 Heading 10/01 Hand harvest	04/12 Disc plowed 04/17 Applied liquid fertilizer 17g (N) m^{-2} 04/18 Sweep plowed 04/24 Listed 05/17 Applied Dual Magnum II at 0.155 ml (ai) m^{-2} 05/17 Rolling cultivator and culti-packer 05/23 Planted DPL 2145 at 20 seeds m^{-2} 05/23/01 Applied Roundup at 0.117 ml (ai) m^{-2} 05/30 Emergence 06/14 Applied Acephate for thrips at 0.029 ml (ai) m^{-2} 06/26 Cultivated 07/18 First bloom 10/31 Hand harvest 12/11 Shredded cotton stalks 12/20 Stalk puller and disk bedder
2002	01/11 Shredded sorghum stalks 01/16 Disc plowed 01/16 Listed 04/01 Applied liquid fertilizer 17 g (N) m^{-2} and 5.6 g (P) m^{-2} 04/02 Rolling cultivator 04/16 Disc bedder 05/16 Applied Roundup at 0.117 ml (ai) m^{-2} 05/23 Applied Dual Magnum II at 0.156 ml (ai) m^{-2} 05/23 Rolling cultivator and culti-packer 05/23 Planted Pioneer 84G62 at 21 seeds m^{-2} 05/31 Emergence 06/24 Cultivated 09/30 Hand harvested	04/01 Applied liquid fertilizer 17 g (N) m^{-2} and 5.6 g (P) m^{-2} 04/02 Rolling cultivator 04/16 Disc bedder 05/16 Applied Roundup at 0.117 ml (ai) m^{-2} 05/23 Applied Dual Magnum II at 0.156 ml (ai) m^{-2} 05/23 Rolling cultivator and culti-packer 05/23 Planted DPL 2145 RR at 20 seeds m^{-2} 05/31 Emergence 06/24 Cultivated 12/10 Hand harvested

Table 3. Irrigation “gross” applications.

	Sorghum				Cotton			
Year	Date	Amount (mm)			Date	Amount (mm)		
2001	Sets ➤	N	Mid	S	Sets ➤	N	Mid	S
	06/27	91	0	0	06/27	91	0	0
	06/28	0	165	0	06/28	0	165	0
	06/29	0	0	127	06/29	0	0	127
	07/16	112	0	0	07/16	112	0	0
	07/17	0	124	0	07/17	0	124	0
	07/18	0	0	109	07/18	0	0	109
	08/01	107	0	0	08/08	142	0	0
	08/02	0	132	0	08/07	0	163	0
	08/03	0	0	114	08/09	0	0	147
	08/23	69	0	0				
	08/22	0	53	0				
	08/21	0	0	74				
TOTAL		378	475	424		345	452	384
2002	Sets ➤	N	Mid	S	Sets ➤	N	Mid	S
	04/22	178	0	0	04/21	197		
	04/24	0	0	175	04/24			175
	04/25	0	171	0	04/25		171	
	05/07	193	0	0	05/07	193		
	05/08	0	177	0	05/08		177	
	05/09	0	0	160	05/10			191
	06/25	152	0	0	05/12			
	06/26	0	144	0	06/25	152		
	06/27	0	0	143	06/26		144	
	07/27	183	0	0	06/27			143
	07/28	0	203	0	06/29			
	07/29	0	0	174	07/30			
	08/27	184	0	0	07/31		185	
	08/28	0	0	161	08/01	180		182
	09/10	0	173	0				
TOTAL		890	869	813		723	678	691

Results and Discussion

Climatic Conditions

Both 2001 and 2002 were drought summers and below “normal” summer rainfall. Annual precipitation in 2001 was 18 mm below “normal” while 2002 received 32 mm more than “normal,” yet the summer rainfall was below “normal” (Fig. 1 & Fig. 2). Rainfall in 2001 was near “normal” until July and remained low the remainder of the growing season and 500 to 600 mm below the estimated ET (evapotranspiration) of sorghum and cotton based on a 14 May sowing date using the North Plains ET (evapotranspiration) Network (Marek et al., 1996). Rainfall was below “normal” throughout the summer and fall and was about 500 mm below

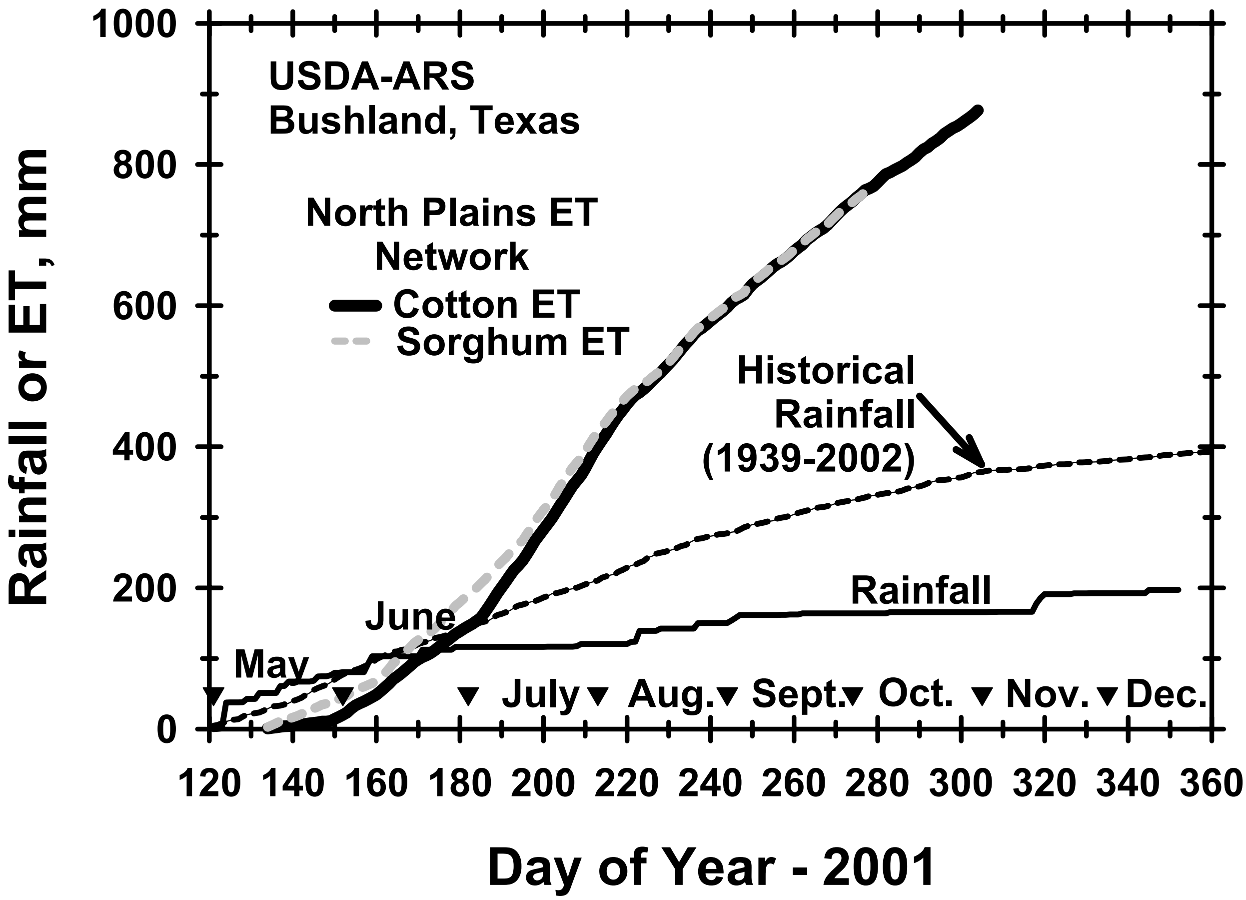

Figure 1. Precipitation received after 14 May and historical May through December precipitation at Bushland, TX in 2001 and the season cotton and sorghum ET (evapotranspiration) based on the North Plains ET Network (Marek et al., 1996).

estimated ET of both sorghum and cotton. Estimated growing season ET was similar for both sorghum and cotton in both years, but estimated sorghum ET forthe NP ET network for Bushland (Marek et al., 1996) led cotton ET until July when the development of cotton caught up to the sorghum.

Crop specific GDD (growing degree days) with differing base temperatures (Marek et al., 1996) and grass reference ET (ET_o) (Walter et al., 2000) are shown in Figs. 3 and 4 for the 2001 and 2002 seasons, respectively. Sorghum matured sooner in 2001 than in the 2002 season. Cotton accumulated approximately 1,200 °C-days for the mid May planting in both seasons, but this cumulative GDD is less than the 1,450 °C-days required for "full season" cotton (Peng et al., 1989) on the Texas High Plains. Reference grass ET (ET_o) (Walter et al., 2000) was slightly greater during mid season in 2002 but was about 1,150 mm at cotton maturity in both seasons.

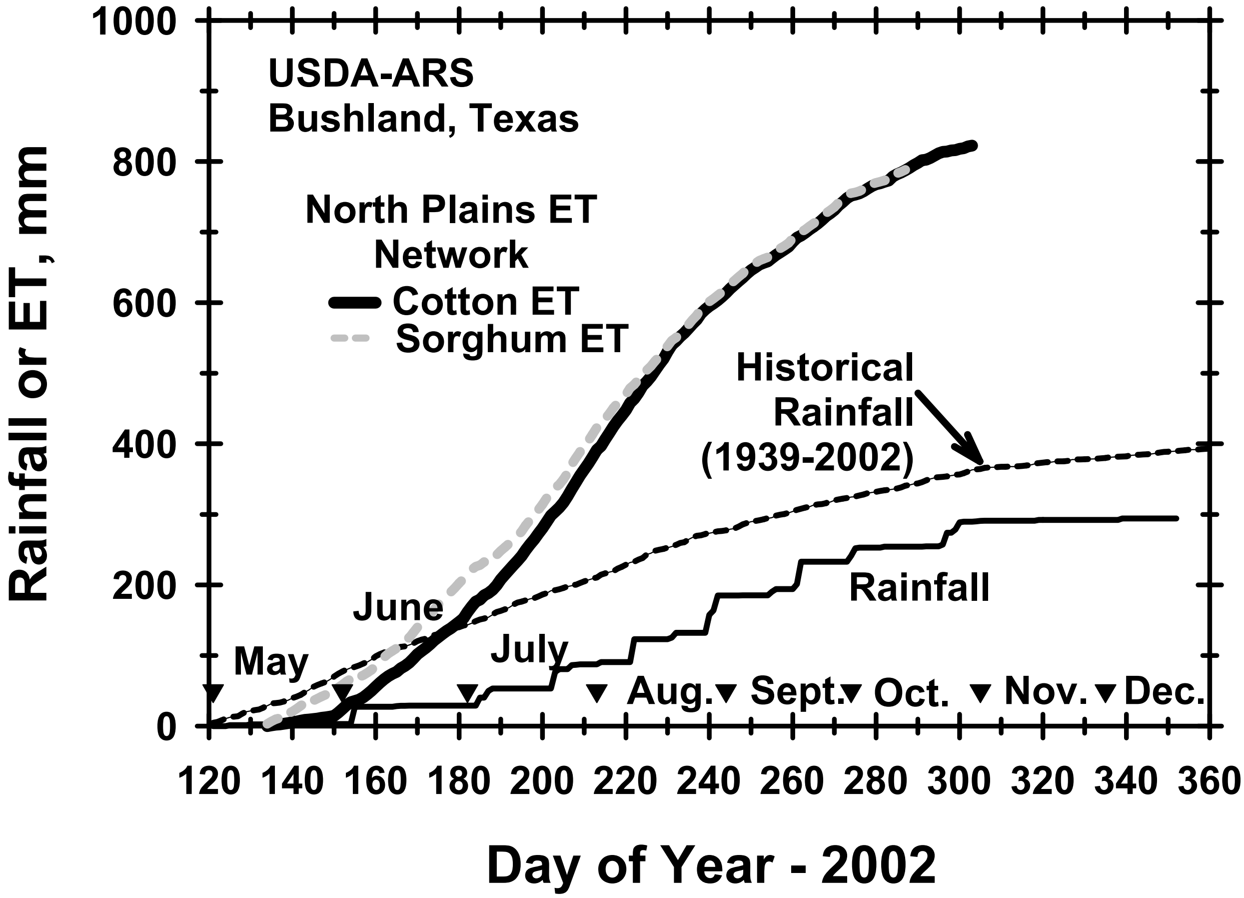

Figure 2. Precipitation received after 14 May and historical May through December precipitation at Bushland, TX in 2002 and the season cotton and sorghum ET (evapotranspiration) based on the North Plains ET Network (Marek et al., 1996).

Crop Yield and Yield Components

Crop yields in 2001 were the first year of the rotation sequence, so they should not be different for the rotation treatments. Table 4 illustrates that both the cotton and sorghum yields and yield components were not statistically different ($P<0.05$) for the rotations.

Cotton yields (Table 4) were greater than regional production in 2001 (Table 1), but much less in 2002 due to an unusual sudden bollworm infestation that greatly reduced the harvestable bolls per plant (Table 4). This likely masked any rotation effect in 2002 although the lint yield was slightly better (but not statistically different) from the continuous cotton yields. Cotton yields are sensitive to early boll sets and their retention, especially in this marginal environment for cotton (Hake et al., 1990). Gin Turn out was greater for the greater lint production in 2001, although the single season ANOVA could not determine if the gin turn outs were different for the two seasons. Future analyses will compare seasonal effects as well as fiber quality differences

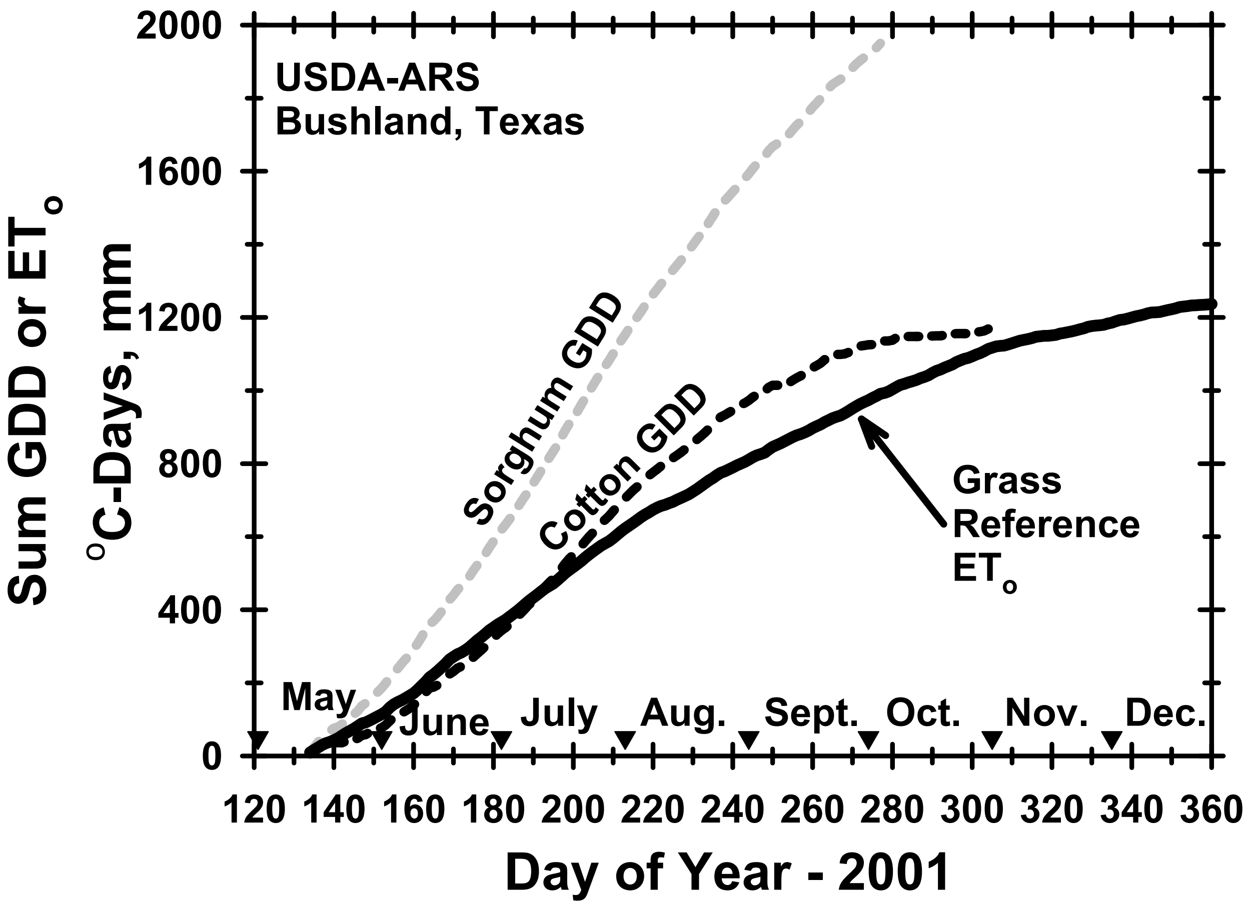

Figure 3. Sorghum and cotton cumulative GDD (growing degree days) (Marek et al., 1996) and reference grass ET_o (Walter et al., 2000) in 2001 for Bushland, TX.

Sorghum yields (Table 4) were more than twice the regional irrigated yields (Table 1) in both seasons. Grain yields in 2002 were greater than in 2001. The rotation had greater yield ($P<0.05$) in 2002 than continuous sorghum (11% increase). The seed mass was not different for the rotations or seasons. Harvest index (dry grain per unit biomass) was statistically greater for the continuous sorghum in both seasons but the rotations had greater yields.

Segerra et al. (1991) reported greater profits for a cotton-wheat rotation yet this requires three years compared with the annual crops for a sorghum-cotton rotation. They did not elaborate how land costs or capital costs were expensed over the three years. The annual cotton-sorghum rotation is an attractive alternative to continuous cotton if improved yields can be achieved by using a rotation that permits differing herbicides, pest control measures while offering greater wind and water erosion from conservation tillage for the higher residue sorghum crop that can possibly improve soil organic matter.

Although our agronomic options were limited, sorghum could likely be produced with acceptable results with much reduced inputs (lower seeding rates, lower fertility, reduced irrigation, etc.).

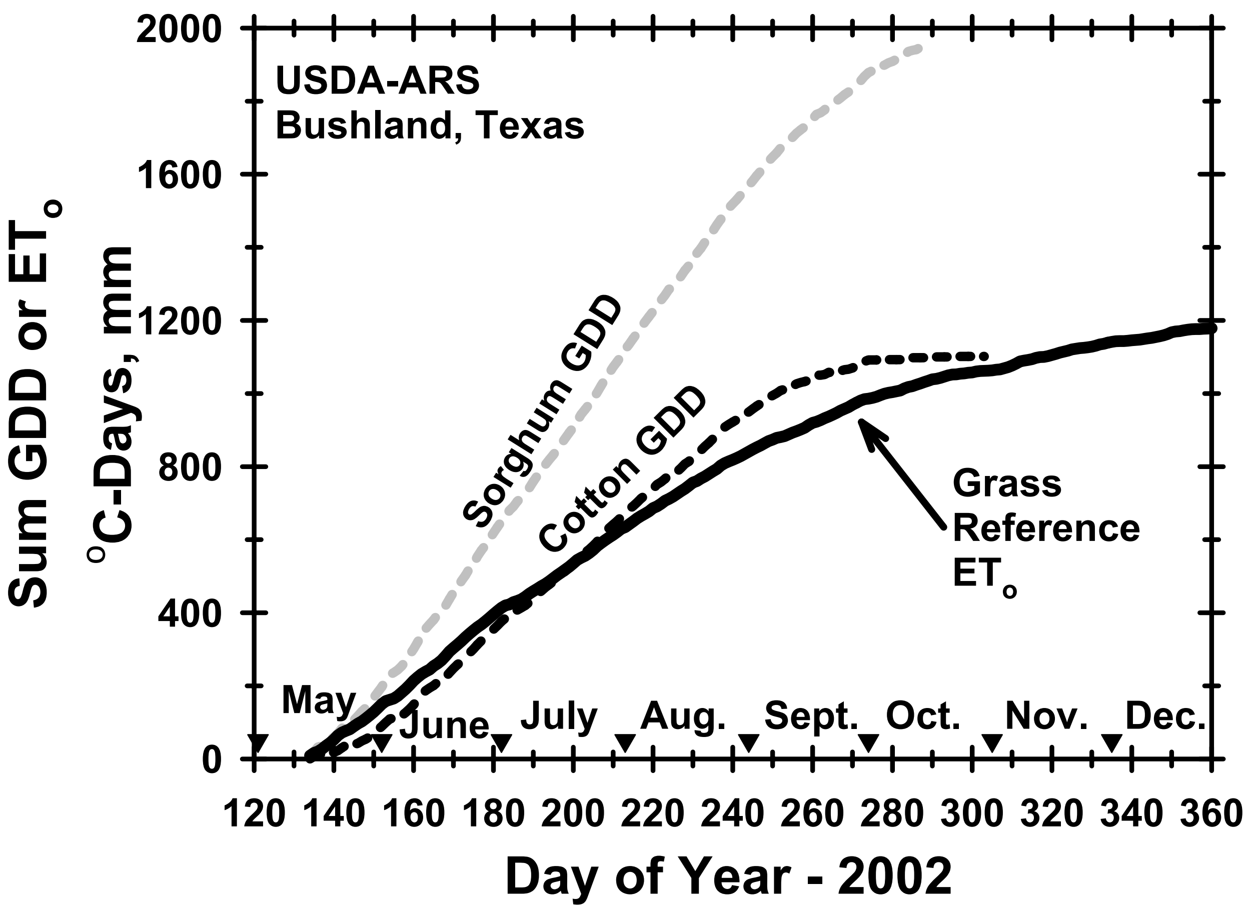

Figure 4. Sorghum and cotton cumulative GDD (growing degree days) (Marek et al., 1996) and reference grass ET_o (Walter et al., 2000) in 2002 for Bushland, TX.

Future Research

This is a progress report on the first year of a rotation experiment that is continuing through 2003 with irrigated sorghum. Beyond 2003, the sorghum will be produced with only one seasonal irrigation and a possible preplant irrigation if needed. In addition, the yield results will be analyzed for all three seasons as well as the lint fiber quality data. Following Segerra et al. (1991) and Keeling et al. (1989), the economics of the rotations will be analyzed.

Summary and Conclusions

Cotton and sorghum were grown in rotation in 2001 and 2002 at Bushland, TX on a Pullman clay loam soil under furrow irrigation. Cotton yields were not different in the rotation compared with continuous sorghum and cotton. The cotton yields in 2002 were greatly reduced by pests, but the 2001 yields were greater than the regional irrigated cotton yields. Sorghum yield was increased 11% by the rotation following cotton. In both years, both the rotation and continuous sorghum yields were more than double regional yields.

Table 4. Yield result means for 10-m^2 samples for the cropping systems.

SORGHUM			
Treatments	Grain Yield ($g\ m^2$)	Seed Mass (mg/seed)	Harvest Index [1/] (---------)
2001			
C-S [2/]	948.2 a [3/]	29.4 a	0.482 b
S-S [2/]	880.3 a	29.1 a	0.513 a
2002			
C-S	1,121.5 A	28.5 A	0.495 B
S-S	1,008.4 B	30.6 A	0.513 A
COTTON			
Treatments	Lint Yield ($g\ m^2$)	Gin Turn Out (fraction)	Bolls/plant (---------)
2001			
S-C [2/]	126.6 a	0.270 a	7.3 a
C-C [2/]	124.2 a	0.276 a	6.6 a
2002			
S-C	36.6 A	0.222 A	1.9 A
C-C	33.0 A	0.218 A	2.0 A

[1/] Based on a 1-m^2 sample size.
[2/] First year of rotation sequence.
[3/] Numerical values within a year, species followed by the same letter are not statistically different ($P<0.05$) based on an ANOVA and Tukey multiple comparison test.

Additional research in seasons with differing climatic patterns will be required before absolute conclusions are developed. The 2002 results definitely indicated an advantage for a rotation of sorghum with cotton. Future research will examine the crop rotation with limited irrigation of sorghum following irrigated cotton.

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