

Delayed Initiation of Fruiting as a Mechanism of Improved Drought Avoidance in Cotton

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ABSTRACT

Delayed fruiting in cotton (*Gossypium hirsutum* L.) may result in enhanced root growth, which could improve the crop's ability to avoid episodic drought events. This study, conducted under a rainout shelter at the University of Georgia Coastal Plain Experiment Station, Tifton, examined the effects of delayed fruiting on cotton root growth and yield under irrigated and water deficit stress conditions. Delayed fruiting was achieved through fruiting branch removal at 35 and 41 d after planting (DAP) in 2000 and 41 and 48 DAP in 2001 such that the first fruiting branch occurred approximately at main stem node 9 in all plants within a plot. Water deficit stress was developed by withholding irrigation and rainfall beginning at first flower for 17 d in 2000 and 16 d in 2001. Root counts were made for six consecutive weeks beginning at first flower using a minirhizotron camera system. At harvest, 3 m of row in each plot was hand picked and boll counts and seed cotton yields were recorded. Delayed fruiting, irrespective of irrigation treatment, resulted in higher root counts. Delayed fruiting also delayed maturity and altered fruit distribution on the plant. Upper main stem nodes contributed more to boll number and seed cotton yield with delayed fruiting. In 2000, delayed fruiting with water deficit stress reduced yield whereas no such differences were detected in 2001. Thus, delayed fruiting resulted in increased root growth but did not enhance drought avoidance as determined by boll number or seed cotton yield.

WATER AVAILABILITY is arguably the most limiting factor to profitable cotton production in the Southeast. Because of the shallow, coarse textured soils of the Coastal Plain and the unreliable rainfall patterns endemic to the region, episodic drought events are commonplace. With proper management, irrigation has been shown to increase lint yield by more than 350 kg ha⁻¹ in Georgia (Bednarz et al., 2003). Pace et al. (1999) suggested cotton cultivars that can endure and recover from drought are needed to minimize fruit loss and reduce the amount of water required for irrigated crop production. Before new cultivar development, however, the physiological mechanisms of drought avoidance for cotton must be more fully understood. One possible mechanism to maintain water uptake during an episodic drought event is through augmented root development.

The initiation of reproductive growth and its timing with respect to vegetative development may have a large effect on root development. Studies have documented enhanced vegetative growth and shift in boll position in response to delayed initiation of fruiting through early season flower bud removal with yields being similar to control (Bednarz and Roberts, 2001; Jones et al., 1996a). Flower bud removal changes the partitioning of plant

resources in favor of vegetative structures, which increases the ability of the crop to acquire carbon, nitrogen, and water (Sadras, 1995; Pettigrew et al., 1992). Sadras (1996) reported under high availability of resources, cotton plants subjected to early season flower bud removal showed increased vegetative growth and increased root/shoot ratio, which enhanced their ability to assimilate carbon and nitrogen with respect to undamaged controls.

To date, no one has examined the impact of delayed initiation of fruiting through early season fruiting branch removal on episodic drought avoidance in cotton. The objective of this study was, therefore, to investigate the impact of delayed initiation of fruiting on cotton root growth and yield under irrigated and water-deficit conditions. We hypothesize that delayed initiation of fruiting will increase root growth, which, in turn, will increase the crop's avoidance to a midseason episodic drought event.

MATERIALS AND METHODS

Field studies were conducted in a tall crop rainout shelter designed by Maw and Stansell (1986) at the University of Georgia Coastal Plain Experiment Station, Tifton, in 2000 and 2001. A single moisture sensor located at the rainout shelter complex detected rainfall, which then activated an electric motor that moved a shelter over the plot area. At the conclusion of the rainfall event, the shelter was automatically moved off the plot area. Eighteen plots under the rainout shelter were isolated from each other by 0.1-m-thick concrete barriers. These concrete barriers were constructed by trenching to an impervious soil layer approximately 1.2 m below the soil surface. Corrugated perforated drain tubing was placed in the trench and covered with 0.025 m of crushed rock to intercept any water immediately above the impervious layer. Wooden forms were built to support the 0.1-m-thick concrete approximately 0.05 m above the soil surface. The trench and forms were filled with reinforced concrete. The raised concrete edges provide walkways between the plots and also prevent movement of soil moisture from one plot to another. The dimensions of each plot were 2.43 by 2.43 m. For the current study, each plot consisted of three rows of cotton spaced 0.76 m apart and 2.43 m long. Watermark sensors (Irrometer, Riverside, CA) were installed between two rows in each plot at 0.13, 0.2, 0.4, 0.6, 0.8, and 1.0 m. The soil in the rainout shelter was a Tifton loamy sand (fine-loamy, kaolinitic, thermic, Plinthic Kandudults). The experimental design was a randomized block design with four treatments and four replications.

Culture Practices

Approximately 3 wk before planting in both years, all plots were fertilized with 672 kg ha⁻¹ of 3-9-18 N-P-K. Cotton (cv.

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Abbreviations: FI-FBR, full irrigation and fruiting branch removal; FI-NFBR, full irrigation and no fruiting branch removal; NI-FBR, no irrigation and fruiting branch removal; NI-NFBR, no irrigation and no fruiting branch removal

Suregrow 501 BR) was planted on 2 June 2000 and 24 April 2001. At 7 d after planting (DAP) 36 kg N ha⁻¹ was applied to all plots as NH₄ NO₃. At 21 DAP in 2000 and 18 DAP in 2001 plant populations were hand-thinned to 13 plants m⁻². At 42 DAP in 2000 and 43 DAP in 2001 56 kg N ha⁻¹ was side-dressed as 28-0-0-5 on every plot. At 38 DAP in 2000 and 43 DAP in 2001 0.7 L ha⁻¹ of mepiquat (1,1-dimethylpiperidinium) chloride was applied to all plots. This application was repeated at 60 DAP in both years. Plots were flood irrigated with 25 mm of water before and after simulation of an episodic drought event when the soil water potential at any depth became more negative than -50 kPa. Also before and after the simulated drought event, the shelter rainfall sensor was not activated to allow the plots to be rain fed. All other culture practices were in accordance with the University of Georgia Cooperative Extension Service guidelines (Brown et al., 2000).

Treatment Establishment

Fruiting branches were hand-removed at 35 and 41 DAP in 2000 and at 41 and 48 DAP in 2001. Fruiting branch removal treatments were continued until the first fruiting branch occurred at approximately main stem node nine in all the plants within a plot, which is three to four main stem nodes higher than the typical node of the first fruiting branch. The treatments were as follows: (i) no fruiting branch removal and full irrigation (FI-NFBR), (ii) no fruiting branch removal and no irrigation or rainfall for approximately 2 wk beginning at first flower (NI-NFBR), (iii) fruiting branch removal and full irrigation (FI-FBR), and (iv) fruiting branch removal and no irrigation or rainfall for approximately 2 wk beginning at first flower (NI-FBR).

At first flower (52 DAP in 2000, 64 DAP in 2001), the water deficit stress treatment was initiated and continued for 17 d in 2000 and 16 d in 2001. During the water stress treatment, plots with full irrigation were given 0.025 m of water twice weekly while supplemental irrigation and rainfall was withheld from the water-stressed plots. Soil-moisture was measured at approximately 0800 h almost daily during the water stress period with watermark sensors (Irrometer, Riverside, CA) buried at 13, 20, 40, 60, 80, and 100 cm. (Fig. 1).

Data Collection

A minirhizotron camera system (Bartz technology, Santa Barbara, CA) was used to record root images weekly for six consecutive weeks beginning at first flower in 2000 and 2001. Before planting, one minirhizotron tube was installed per plot 0.05 m to one side of the drill at a 60° angle to the soil surface. The minirhizotron tubes were 1.8 m long and 0.08 m in diameter. The exterior surface of the minirhizotron tubes protruding above the soil surface was wrapped with black plastic tape to prevent light entry into the rhizosphere and subsequent possible adverse effects on root growth (Pearson, 1974). When not in use, the opening of each minirhizotron tube was covered with an aluminum soda can with the top removed. The portion of each minirhizotron tube above the soil surface was also wrapped with white plastic while not in use to reflect long wave radiation. To record images, the camera's optical system was lowered into each minirhizotron tube. The images sensed were transmitted to a Sony video cassette recorder (model CCD-TRV99) for later playback and analysis. The root counting techniques as described by Upchurch and Ritchie (1984) were used. For making root counts, the video recording was played on a television with a grid (1 cm²) pasted to the monitor. The numbers of roots intersecting grid lines were counted (Taylor et al., 1970). Root counts of only living roots with a white fresh appearance were taken. The total number of main stem nodes and the number of main stem nodes above the uppermost first position white flower (NAWF) were also collected on 10 randomly selected plants per plot during the days on which root recordings were made.

Harvest aids were applied on 5 Oct. 2000 and 31 Aug. 2001 {1.5 L ha⁻¹ ethephon (2-chloroethylphosphonic acid) + 0.5 L ha⁻¹ tribufos (*S,S,S*-tributyl phosphorotrithioate) + 0.14 kg ha⁻¹ thidiazuron [1-phenyl-3-(1,2,3-thiadiazol-5-yl)urea]}. Plants were harvested on 23 Oct. 2000 and 14 Sep. 2001. At harvest, 3 m of row in each plot were hand-harvested as described by Jenkins et al. (1990). Seed cotton, boll number and boll weight at each fruiting site were measured separately. Thus, the contribution to total yield was determined for each fruiting position.

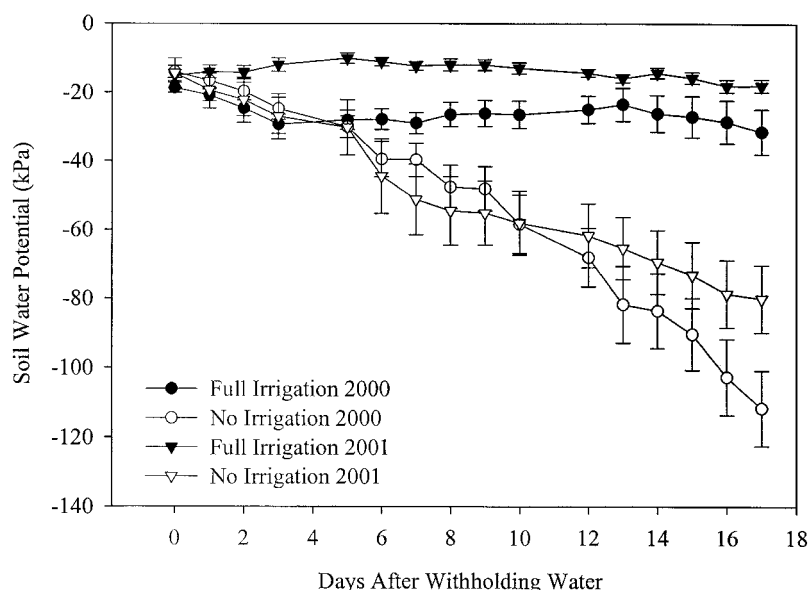


Fig. 1. Soil water potential (kPa + SE) at several days after withholding irrigation and rainfall in studies conducted at the University of Georgia Coastal Plain Experiment Station in 2000 and 2001. Each data point represents the mean of six depths (0.13, 0.2, 0.4, 0.6, 0.8, and 1.0 m and four replications).

Table 1. Effect of irrigation (I) and fruiting branch removal (FBR) on the average number of root intersections across all depths at several weeks after first flower (FF) in rainout shelter studies conducted at the University of Georgia, Coastal Plain Experiment Station in 2000 and 2001.

Weeks after FF	Treatment				Mean	Contrasts		
	Full I, no FBR	Full I, FBR	No I, no FBR	No I, FBR		Full I vs. no I	FBR vs. no FBR	Interaction
	Number of root intersections					Increase in root intersections due to effect		
0	150.89 AZ ab†	150.34 AZ c	114.38 AZ c	83.39 AZ c	124.75 d	51.73 a	-15.77 b	15.22 a
1	173.32 AZ a	197.52 AZ b	121.50 AZ bc	123.50 AZ b	153.96 c	62.92 a	13.10 ab	11.10 a
2	158.79 AZ ab	198.18 AZ b	141.18 AZ abc	179.09 AZ a	169.31 b	18.35 a	38.65 ab	0.74 a
3	141.21 AZ b	222.16 AZ b	149.80 AZ ab	188.55 AZ a	175.43 b	12.51 a	59.85 a	21.10 a
4	148.36 AZ ab	273.71 AY a	161.98 AZ a	200.98 AZ a	196.26 a	29.56 a	82.18 a*	43.18 a
5	75.89 AZ c	167.00 AZ c	66.25 AZ d	111.21 AZ bc	105.09 e	32.71 a	68.04 a	23.07 a
Mean	147.37 AZ	204.62 AY	131.27 AZ	151.11 BZ	158.59	34.80 *	38.55 *	18.70

* Denotes level of significance at $P = 0.05$.

† Within columns, means followed by the same lower case letter are not significantly different. A, B separates the 2 irrigation treatments within each fruiting branch removal treatment; Y, Z separates the 2 fruiting branch removal treatments within each irrigation treatment. LSD (0.05) between weeks after first flower = 30.13; LSD (0.05) between treatments = 101.82; LSD (0.05) between weeks after first flower mean = 12.30; LSD (0.05) between treatment means = 50.91; LSD (0.05) between contrasts = 72; LSD (0.05) between contrast means = 29.39.

Data Analysis

Root count data was aggregated over 0.2-m depth intervals resulting in the creation of seven intervals. Root count data were transformed using the \log_{10} transformation. Root count data were also summed with increasing depth interval. These data were also \log_{10} transformed. The statistical model employed for analysis of root count data, number of main stem nodes, and NAWF was a split-split-split plot in space (depth, node, node), time (date), and time (year) as suggested in Steel and Torrie (1980). The statistical model employed for analysis of yield component data was a split-split plot in space (node) and time (year). The statistical model employed for analysis of yield data was a split plot in time (year). Year is the last split since the plot was the same in both years. All analyses were performed by either Proc GLM or Proc MIXED in SAS (2000).

RESULTS

Roots

The interaction between fruiting branch removal and minirhizotron recording date (weeks after first flower) was significant ($F = 8.57$; $MS = 47\ 712$; $df = 9$) for the number of root intersections. A significant linear trend in the number of root intersections was observed for the fruiting branch removal treatments (FI-FBR and NI-FBR; Table 1). In the no fruiting branch removal treatments (FI-NFBR and NI-NFBR), the linear trend was not observed. Thus delayed fruiting resulted in greater root growth. The number of root intersections for the FI-FBR treatment was greatest at 4 wk after first flower while the number of root intersections for the NI-FBR treatment was greatest at two, three and four weeks after first flower (Table 1). This was followed by a significant reduction in the number of root intersections at the fifth week of flowering in all treatments (Table 1). At the fourth week of flowering, the FI-FBR treatment had a greater number of root intersections (273.71) than the FI-NFBR treatment (148.36). This was due to the fruiting branch removal effect (Table 1). Also, when averaged across all weeks of flowering, the mean number of root intersections was greater in the FI-FBR treatment than the FI-NFBR treatment (204.62 versus 147.37, respectively; Table 1), which was due to the fruiting branch removal effect. Thus, under full

irrigation, delayed fruiting increased the number of root intersections across depths. Additionally, when averaged across all weeks of flowering, the FI-FBR treatment resulted in greater mean number of root intersections than the NI-FBR treatment (204.62 versus 151.11, respectively; Table 1). Thus, when fruiting was delayed, irrigation increased the number of root intersections across depths.

In summary, fruiting branch removal resulted in a greater number of root intersections. The irrigation effect and the interaction between irrigation and fruiting branch removal were not consistent. However, when averaged across all weeks of flowering, the irrigation effect was significant. Thus, fruiting branch removal and irrigation resulted in greater root mass.

A minirhizotron recording date (weeks after first flower) \times depth interval interaction was also found ($F = 3.17$; $MS = 17\ 662$; $df = 54$). The number of root intersections increased across all treatments with depth to 40 to 60 cm and decreased thereafter (Table 2). Root intersections did not differ among treatments except at the 40- to 60-cm depth interval. At this depth interval the FI-FBR treatment had a greater number of root intersections (545.55) than the FI-NFBR treatment (279.41; Table 2). Thus delayed fruiting resulted in greater root intersection means under full irrigation at this depth interval. Additionally at the 40- to 60-cm depth interval the FI-FBR treatment had a greater number of root intersections (545.55) than the NI-FBR treatment (305.95; Table 2). Thus, irrigation resulted in greater root intersection means under delayed fruiting at this depth interval. When averaged across all depth intervals, the number of root intersections was different among treatments (Table 2). Overall, the FI-FBR treatment resulted in more root intersections (204.62) than the FI-NFBR treatment (147.37). Additionally, the FI-FBR treatment resulted in more root intersections than the NI-FBR treatment (151.11).

A minirhizotron recording date (weeks after first flower) by depth interval interaction was also found for cumulative root intersections ($F = 4.79$; $MS = 146\ 240$; $df = 54$). A linear increase in cumulative root intersections for all the treatments was observed (Table 3). Treatment differences were not observed at any depth

Table 2. Effect of irrigation (I) and fruiting branch removal (FBR) on the number of root intersections across all dates at several depth intervals in rainout shelter studies conducted at the University of Georgia, Coastal Plain Experiment Station in 2000 and 2001.

Depth interval (cm)	Treatment				Mean	Contrasts		
	Full I, no FBR	Full I, FBR	No I, no FBR	No I, FBR		Full I vs. no I	FBR vs. no FBR	Interaction
	Number of root intersections					Increase in root intersections due to effect		
0–20	12.93 AZ c†	19.23 AZ d	7.18 AZ c	7.68 AZ c	11.76 e	8.65 a	3.40 b	2.90 bc
20–40	135.68 AZ b	234.43 AZ b	106.95 AZ bc	166.16 AZ b	160.81 c	48.50 a	78.98 a	19.77 bc
40–60	279.41 AZ a	545.55 AY a	369.73 AZ a	305.95 BZ a	375.16 a	74.64 a	101.18 a*	164.96 a*
60–80	248.84 AZ a	227.70 AZ bc	207.64 AZ b	193.11 AZ b	219.32 b	37.90 a	–17.84 b	–3.31 bc
80–100	152.10 AZ b	122.52 AZ cd	102.68 AZ bc	199.36 AZ b	144.17 c	–13.71 a	33.55 ab	–63.13 c
100–120	108.66 AZ bc	134.20 AZ bc	63.18 AZ c	151.68 AZ b	114.43 cd	14.00 a	57.02 ab	–31.48 bc
120–140	93.95 AZ bc	148.70 AZ bc	61.50 AZ c	33.84 AZ c	84.5 d	73.66 a	13.55 ab	41.21 b
Mean	147.37 AZ	204.62 AY	131.27 AZ	151.11 BZ	158.59	34.80	38.55 ab	18.70 bc

* Denotes level of significance at $P = 0.05$.

† Within columns, means followed by the same lower case letter are not significantly different. A, B separates the 2 irrigation treatments within each fruiting branch removal treatment; Y, Z separates the 2 fruiting branch removal treatments within each irrigation treatment. LSD (0.05) between depths = 105.35; LSD (0.05) between treatments = 135.80; LSD (0.05) between depths mean = 52.68; LSD (0.05) between treatment means = 51.33; LSD (0.05) between contrasts = 96.02; LSD (0.05) between contrast means = 36.29.

interval (Table 3). When the means for all treatments across depths were compared, however, differences were observed (Table 3). Overall, the FI-FBR treatment had higher cumulative root intersections (852.06) than the FI-NFBR treatment (580.65). Also, the FI-FBR treatment had higher cumulative root intersections than the NI-FBR treatment (612.61). These differences were due to significant irrigation and fruiting branch removal effects.

Total Number of Main Stem Nodes

Fruiting branch removal and irrigation affected the number of main stem nodes per plant (Table 4). Fruiting branch removal by weeks after first flower and irrigation by weeks after first flower interactions were also found. At 1 wk after first flower, fruiting branch removal resulted in more main stem nodes per plant within both irrigation treatments (Table 4). At 2, 3, and 4 wk after first flower, the two irrigation treatments within each fruiting branch removal treatment differed. In these three plant stages FI-NFBR resulted in more main stem nodes than NI-NFBR and FI-FBR resulted in more main stem nodes than NI-FBR. At 2, 3, and 4 wk after first flower, fruiting branch removal under full irrigation resulted in more main stem nodes than no fruiting branch removal under full irrigation. Similarly at 3, 4,

and 5 wk after first flower, NI-FBR resulted in more main stem nodes than NI-NFBR. When the number of main stem nodes across all weeks after first flower were compared, differences were also observed (Table 4). FI-FBR resulted in more main stem nodes (13.8) than FI-NFBR (13.1). Similarly, NI-FBR resulted in more main stem nodes (13.0) than NI-NFBR (12.3). These differences were due to a significant fruiting branch removal effect. FI-NFBR resulted in more main stem nodes (13.1) than NI-NFBR (12.3) and FI-FBR resulted in more main stem nodes (13.8) than NI-FBR (13.0), which was due to a significant irrigation effect.

Nodes above White Flower

At first flower, FI-NFBR resulted in more nodes above white flower (NAWF) than FI-FBR (Table 5). Similarly NI-NFBR resulted in more NAWF than NI-FBR. These differences were due to a significant fruiting branch removal effect. At 2 wk after first flower, FI-NFBR resulted in more NAWF than NI-NFBR and FI-FBR resulted in more NAWF than NI-FBR treatment. At 3 wk after first flower, FI-FBR resulted in more NAWF than FI-NFBR treatment and NI-FBR resulted in more NAWF than NI-NFBR. These differences were due to a significant fruiting branch removal effect. Additionally at three weeks after first flower, FI-NFBR and

Table 3. Effect of irrigation (I) and fruiting branch removal (FBR) on the number of cumulative root intersections across all dates at several depth intervals in rainout shelter studies conducted at the University of Georgia, Coastal Plain Experiment Station in 2000 and 2001.

Depth interval (cm)	Treatment				Mean	Contrasts		
	Full I, no FBR	Full I, FBR	No I, no FBR	No I, FBR		Full I vs. no I	FBR vs. no FBR	Interaction
	Cumulative root intersections					Increase in root intersections due to effect		
0–20	12.93 d†	19.23 e	7.18 d	7.68 e	11.76 f	8.65	3.40	2.90
20–40	148.61 d	253.66 d	114.14 d	173.84 e	172.56 e	57.15	82.38	22.68
40–60	428.02 d	799.20 c	483.86 c	479.80 d	547.72 d	131.78	183.56	187.62
60–80	676.86 b	1026.91 b	691.50 b	672.90 c	767.04 c	169.69	165.73	184.33
80–100	828.95 b	1149.43 b	794.18 ab	872.27 b	911.21 b	155.97	199.29	121.20
100–120	937.61 ab	1283.64 ab	857.36 ab	1023.95 ab	1025.64 a	169.97	256.31	89.72
120–140	1031.57 a	1432.34 a	918.86 a	1057.80 a	1110.14 a	243.63	269.86	130.92
Mean	580.65 AZ	852.06 AY	552.44 AZ	612.61 BZ	649.44	133.83 *	165.79 *	105.62

* Denotes level of significance at $P = 0.05$.

† Within columns, means followed by the same lower case letter are not significantly different. A, B separates the 2 irrigation treatments within each fruiting branch removal treatment; Y, Z separates the 2 fruiting branch removal treatments within each irrigation treatment. LSD (0.05) between depths = 180.64; LSD (0.05) between treatments = 409.84; LSD (0.05) between depths mean = 90.32; LSD (0.05) between treatment means = 154.91; LSD (0.05) between contrasts = 289.80; LSD (0.05) between contrast means = 109.54.

Table 4. Effect of irrigation (I) and fruiting branch removal (FBR) on the total number of main stem nodes at several weeks after first flower (FF) in rainout shelter studies conducted at the University of Georgia, Coastal Plain Experiment Station in 2000 and 2001.

Weeks after FF	Treatment				Mean	Contrasts		
	Full I, no FBR	Full I, FBR	No I, no FBR	No I, FBR		Full I vs. no I	FBR vs. no FBR	Interaction
	Number of main stem nodes					Increase in root intersections due to effect		
0	11.2 AZ e†	11.6 AZ e	11.2 AZ d	11.5 AZ d	11.4 e	0.0 d	0.3 c	0.0 ab
1	12.0 AZ d	12.8 AY d	11.5 AZ d	12.7 AY c	12.3 d	0.3 c	0.9 ab*	-0.2 b
2	13.1 AZ c	14.0 AY c	12.3 BZ c	12.9 BZ c	13.1 c	0.9 b*	0.8 b*	0.2 ab
3	13.8 AZ b	14.9 AY b	12.5 BZ c	13.5 BY b	13.7 b	1.4 a*	1.1 a*	0.0 ab
4	14.8 AZ a	15.8 AY a	13.2 BZ b	14.6 BY a	14.6 a	1.4 a*	1.3 a*	-0.2 b
5	13.8 AZ b	13.7 AZ c	13.9 AZ a	13.1 AY bc	13.6 b	0.3 c	-0.4 d	0.4 a
Mean	13.1 AZ	13.8 AY	12.3 BZ	13.0 BY	13.1	0.8 *	0.8*	0.0

* Denotes level of significance at $P = 0.05$.

† Within columns, means followed by the same lower case letter are not significantly different. A, B separates the 2 irrigation treatments within each fruiting branch removal treatment; Y, Z separates the 2 fruiting branch removal treatments within each irrigation treatment. LSD (0.05) between weeks after first flower = 0.54; LSD (0.05) between treatments = 0.63; LSD (0.05) between weeks after first flower mean = 0.22; LSD (0.05) between treatment means = 0.32; LSD (0.05) between contrasts = 0.45; LSD (0.05) between contrast means = 0.18.

FI-FBR had more NAWF than the NI-NFBR and NI-FBR treatments, respectively. These differences were due to a significant irrigation effect. At 4 wk after first flower, FI-FBR had more NAWF than FI-NFBR, which was due to the fruiting branch removal effect. Additionally, at 4 wk after first flower, FI-NFBR and FI-FBR had more NAWF than the NI-NFBR and NI-FBR treatments, respectively. These differences were due to a significant irrigation effect. Differences were also observed in the number of nodes above white flower across weeks after first flower (Table 5). FI-NFBR and FI-FBR resulted in more NAWF than the NI-NFBR and NI-FBR treatments, respectively. Thus withholding irrigations and rainfall hastened crop maturity.

Yield

FI-FBR resulted in the greatest number of bolls per square meter (91.3) in 2000 while NI-FBR resulted in the least (67.8), because of a significant irrigation effect (Table 6). Similarly, FI-FBR resulted in the greatest seed cotton yield (464 g m^{-2}) whereas NI-FBR resulted in the lowest seed cotton yield (324 g m^{-2}), because of the significant interaction between irrigation and fruiting branch removal. Thus, a delay in fruiting followed by a subsequent water stress drastically reduced both the number of bolls per square meter as well as seed cotton yield in 2000. In 2001, however, differences in bolls per square meter were not observed. FI-NFBR

resulted in the highest seed cotton yield (488 g m^{-2}), whereas NI-NFBR resulted in the lowest (423 g m^{-2}). This effect was due to the significant interaction between irrigation and fruiting branch removal. Thus, early initiation of fruiting followed by a subsequent water stress reduced seed cotton yield in 2001.

Delayed fruiting reduced the possibility of harvesting a first or second sympodial position boll at lower main stem nodes yet increased the possibility of harvesting a first or second sympodial position boll at upper main stem nodes (data not presented). In general, fruiting branch removal resulted in greater seed cotton yield at upper main stem nodes (main stem nodes 8–13), whereas no fruiting branch removal resulted in greater seed cotton yield at lower main stem nodes (main stem nodes 5–8). These results are in agreement with Bednarz and Roberts (2001), who investigated the redistribution of seed cotton yield after manual removal of early season floral buds.

DISCUSSION

In this study, delayed fruiting resulted in more root intersections. These results are in agreement with previous studies, which have reported that fruit loss changes partitioning of plant resources in favor of vegetative structures (Jones et al., 1996b; Sadras, 1995). Thus, preferential partitioning of photosynthate to root growth

Table 5. Effect of irrigation (I) and fruiting branch removal (FBR) on the number of main stem nodes above white flower (NAWF) at several weeks after first flower (FF) in rainout shelter studies conducted at the University of Georgia, Coastal Plain Experiment Station in 2000 and 2001.

Weeks after FF	Treatment				Mean	Contrasts		
	Full I, no FBR	Full I, FBR	No I, no FBR	No I, FBR		Full I vs. no I	FBR vs. no FBR	Interaction
	Number of nodes above white flower					Increase in root intersections due to effect		
0	5.0 AY a†	4.3 AZ a	5.1 AY a	4.2 AZ a	4.7 a	0.0 d	-0.6 d*	0.1 ab
1	5.0 AZ a	4.6 AZ a	4.8 AZ a	4.3 AZ a	4.7 a	0.3 cd	-0.3 d	0.0 ab
2	4.4 AZ b	4.7 AZ a	3.8 BZ b	4.1 BZ a	4.3 b	0.6 bc*	0.4 bc*	0.0 ab
3	3.0 AZ c	3.6 AY b	2.0 BZ c	2.8 BY b	2.9 c	0.9 b*	0.8 a*	-0.1 ab
4	1.8 AZ d	2.5 AY c	0.6 BZ d	1.0 BZ c	1.5 d	1.4 a*	0.7 ab*	0.2 a
5	0.8 AZ e	0.7 AZ d	0.6 AZ d	0.9 AZ c	0.8 e	0.0 d	0.1 c	-0.2 a
Mean	3.6 AZ	3.6 AZ	3.0 BZ	3.1 BZ	3.3	0.6 *	0.2 *	0.0

* Denotes level of significance at $P = 0.05$.

† Within columns, means followed by the same lower case letter are not significantly different. A, B separates the 2 irrigation treatments within each fruiting branch removal treatment; Y, Z separates the 2 fruiting branch removal treatments within each irrigation treatment. LSD (0.05) between weeks after first flower = 0.48; LSD (0.05) between treatments = 0.53; LSD (0.05) between weeks after first flower mean = 0.20; LSD (0.05) between treatment means = 0.26; LSD (0.05) between contrasts = 0.37; LSD (0.05) between contrast means = 0.15.

Table 6. Boll number and seed cotton yield at harvest as affected by irrigation and fruiting branch removal in rainout shelter studies conducted at the University of Georgia, Coastal Plain Experiment Station in 2000 and 2001.

Treatment		Bolls (m ²)			Seed cotton (g m ⁻²)		
Irrigation	Fruiting branch removal	2001†	2001†	Average	2000	2001	Average
Full	No	85.7 a,z‡	96.2 a,z	91.0	398 a,z	488 a,z	423
None	No	78.6 a,z	87.9 a,z	83.3	364 a,z	423 b,z	394
Full	Yes	91.3 a,z	92.8 a,z	92.0	464 a,z	456 a,z	460
None	Yes	67.8 b,z	91.2 a,z	79.5	324 b,z	457 a,z	391
LSD (0.05)		11.9	14.5	13.3	74.3	51	64
ANOVA							
Source of Variation	df	2000	2001	Combined§ years	2000	2001	Combined years
Rep	3	0.07	0.42	0.00	0.62	1.03	0.00
Fruiting Branch Removal (FBR)	1	0.24	0.01	0.09	0.06	0.01	0.06
Irrigation (I)	1	8.44 *	1.21	5.00	2.72	4.06	4.04
FBR × I	1	2.42	0.55	0.29	5.21*	4.28*	0.11
Field Plot Error	9	110.66	81.18	0.00	2154	10.11	0.00
Year	1			52.43			1782.82
Rep × Year	3			0.00			593.30
FBR × I × Year	3			18.69			1367.27
Field Plot Error × Year	9			88.93			1582.13

* Denotes level of significance at $P = 0.05$.

† Each year: Value for rep is a variance component. Values for FBR, I, and FBR × I are F values. Value for field plot error is the error mean square.

‡ a, b separates the 2 irrigation treatments within each fruiting branch removal treatment; y, z separates the 2 fruiting branch removal treatments within each irrigation treatment.

§ Combined years: Values for rep, field plot error, year, rep × year are variance components. Values for FBR, I, and FBR × I are F values. Value for field plot error × year is the error mean square.

at the expense of reproductive growth may have been responsible for the increased number of root intersections under delayed fruiting conditions. Additionally, a significant linear trend with time (weeks after first flower) occurred when roots were measured under delayed fruiting conditions. This reinforces the above stated conclusion about the effect of delayed fruiting on cotton root growth.

Across all measuring dates, delayed fruiting followed by water deficit stress resulted in more cumulative root intersections than early fruiting followed by water deficit stress. The results from this investigation also show considerable variability in the effect of irrigation on cotton root growth. However, across all measuring dates full irrigation when accompanied by delayed fruiting resulted in the highest root count. These results indicate cotton cultivars that initiate fruiting later in the season may have the potential for increased root growth under irrigation.

Depth interval also significantly affected root mass in this study. The number of root intersections increased across all four treatments with depth to 40 to 60 cm and decreased thereafter. Klepper et al. (1973) described a significant shift in rooting pattern with water stress. In their study, more roots were initially observed in the upper soil horizons. But, as a result of death of old roots in the upper horizons and production of new roots in the lower soil horizons, rooting density increased with depth under water stress. No such distinct pattern was observed in our study. However, at the 40- to 60-cm depth interval, delayed fruiting when accompanied by full irrigation resulted in a greater root mass.

Bednarz and Roberts (2001) and Jones et al. (1996b) reported an increase in the number of main stem nodes with fruit removal. Our data also show an increase in the number of main stem nodes with delayed fruiting. Increased number of main stem nodes under delaying fruiting conditions is indicative of greater vegetative

growth. Additionally, full irrigation, irrespective of fruiting branch removal, resulted in more main stem nodes. Jones et al. (1996a) also reported a delay in maturity associated with manual removal of flowers during the first 3 wk of flowering. In our study, crop maturity as determined by NAWF was significantly affected by both irrigation and fruiting branch removal. The greater NAWF values late in the flowering period with fruiting branch removal indicate vegetative growth above ground was not limited by sink demands of the developing boll load.

Numerous studies have investigated the effects of early season fruiting form removal on yield (Bednarz and Roberts, 2001, Jones et al., 1996a; Kennedy et al., 1986; Kletter and Wallach, 1982; Pettigrew et al., 1992). These studies reported no significant reduction in total lint yield with early season flower bud removal. Considerable year-to-year variation exists in our data for total number of bolls per square meter and total seed cotton yield (g m²). In 2000, no irrigation under delayed fruiting reduced seed cotton yield whereas in 2001 no irrigation under normal fruiting reduced seed cotton yield. Several studies (Bednarz and Roberts., 2001; Kletter and Wallach., 1982; Jones et al., 1996a) have reported cotton compensates for loss of early season fruiting forms through increased boll retention at upper main stem nodes. Our results are in agreement. Additionally, delayed fruiting reduced seed cotton yield and average boll weight at lower main stem nodes, but increased seed cotton yield and average boll weight at upper main stem nodes. This shift in yield distribution is indicative of compensatory growth.

This study examined the efficacy of delayed fruiting on alleviating water stress by comparing the effect of either presence or absence of water stress under either delayed or normal fruiting conditions on cotton root growth, maturity and yield. Delayed fruiting resulted in increased root growth. Delayed fruiting delayed matu-

rity and also altered the contribution among the nodes to boll weight and yield. In 2000, delayed fruiting under water stress reduced yield whereas in 2001 no such differences were detected. Thus, delayed fruiting did result in increased root growth but did not enhance drought avoidance as determined by boll number or seed cotton yield.

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