

COTTON

Analysis of Cotton Yield Stability Across Population Densities

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ABSTRACT

Final lint yield in cotton (*Gossypium hirsutum* L.) is relatively stable across a wide range of population densities. This study was conducted to determine (i) which components of final lint yield impart this yield stability across plant populations and (ii) how yield distribution is influenced by population density. Studies were conducted in 1997 and 1998 on a Tifton loamy sand (Fine-loamy, kaolinitic, thermic Plinthic Kandiuults). Cotton was planted in each study on 91-cm row widths at seeding rates ranging from 3.5 to 25.1 seeds m^{-2} . At harvest, each plot was hand picked and boll numbers and weights were recorded at each monopodial branch and sympodial branch fruiting position. Lower population densities led to plants with more mainstem nodes and monopodial branches with increased fruit retention, resulting in greater fruit production per plant. Boll size was inversely related to population density. Mean net assimilation rate from first flower to peak bloom also was related inversely to population density. The mainstem node of peak boll set increased with population density. Fruit production on a ground area basis was greater in the first sympodial position as population density increased, while fruit production on a ground area basis in third positions and monopodial branches was greater as population density decreased. Accumulative seedcotton from sympodial branches also increased with population density. Total fruit number and seedcotton yield per area were not influenced by population density in these studies. Yield stability across population densities was achieved through manipulation of boll occurrence and weight.

THE reported response of cotton lint yield to population density has been relatively small. Bridge et al. (1973) indicated maximum yields were obtained in the Mississippi Delta within a population range of 7.0 to 12.1 plants m^{-2} . Maximal lint yields in Texas occurred within plant population ranges of 7.9 to 15.5 plants m^{-2} (Fowler and Ray 1977) and 7.0 to 14.0 plants m^{-2} (Hicks et al., 1989). Lint yields in Georgia also were unresponsive to population densities of 9.6 to 14.4 plants m^{-2} (Hawkins and Peacock, 1970).

Other reports have indicated the optimum population density depends upon environment. Hearn (1972) demonstrated that as yield potential increased, the optimal plant density also increased. Kerby et al. (1996) reported the optimal plant density was greater under conditions of severe stress. Heitholt (1994) reported the optimal plant density was higher for okra-leaf (10.0–15.0 plants m^{-2}) than for normal leaf (5.0 plants m^{-2}) isolines of

'DES 24-8ne'. Maximal lint yields in these studies required a maximum leaf area index (LAI) between 4.0 and 5.0, which occurred at a higher population density in the okra-leaf isoline. Kittcock et al. (1986) measured plant height at population densities ranging from 2.0 to 20.0 plants m^{-2} and reported for every 10 cm increase in final plant height the optimal plant density decreased by 1.1 plants m^{-2} . Finally, Micinski et al. (1990) reported that plant populations were a factor in the yield response to varying planting dates.

The published literature is replete with studies designed to determine the optimum cotton plant density with respect to final lint yield. Apparently, final lint yield is relatively stable across a wide range of population densities. None of the published literature, however, attempts to determine which components of final lint yield impart this yield stability across population densities. Therefore, the objectives of this investigation were to determine (i) how yield stability across population densities is achieved and (ii) how plant population influences yield distribution in cotton under growing conditions with high yield potential.

MATERIALS AND METHODS

Studies were conducted in two locations in 1997 and one location in 1998. The 1997 studies were conducted at the Coastal Plain Experiment Station Ponder Farm (CPES '97) and the Rural Development Center–Center Pivot Farm (RDC '97). Both locations are in Tift County Georgia on a Tifton loamy sand (Fine-loamy, kaolinitic, thermic Plinthic Kandiuults). The study was repeated in 1998 at the CPES Ponder Farm (CPES '98).

Cotton (cv. Suregrow 501) was planted on 25 April (RDC '97) and 9 May (CPES '97) 1997 and 4 May (CPES '98) 1998 with a Monosem air planter (Lenexa, KS) on 91-cm row widths. Seeding rates were 3.5, 7.2, 10.8, 14.3, and 21.5 seeds m^{-2} in the RDC '97 and CPES '98 studies and 3.5, 10.8, 18.0, and 25.1 seeds m^{-2} in the CPES '97 study. A planter chart supplied by the manufacturer was utilized to calibrate the planter for each targeted seeding rate. Also during calibration, the planter closing disks were raised such that the seed drill would not close while planting. Precise measurements of seeding rate were then recorded on these open drills. Final plant populations were recorded at harvest.

Water stress was minimized with sprinkler irrigation in all studies. Fertility, weed control, and insect scouting and control measures in all studies were in accordance with the University of Georgia Cooperative Extension Service guidelines. Harvest aids were applied (2.3 L ha^{-1} of ethephon plus cyclanilide and 0.7 kg a.i. ha^{-1} of thidiazuron) in mid-September in all studies.

Growth analyses were conducted at first flower (approx-

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mately 60 d after planting) and peak bloom (approximately 80 d after planting) in each study. For each growth analysis plants from 1 m of row were cut at the soil level and removed from the plot. Total leaf area from each plot was determined with an area meter (LICOR, LI-3100, Lincoln, NE). Total shoot dry weight from each plot was determined after drying to uniformity at 60°C. Mean net assimilation rate from first flower to peak bloom was determined as described by Hunt (1982, p. 14–41).

At harvest, 3 m of row in each plot were hand harvested as described by Jenkins et al. (1990a). Seedcotton, boll number, and boll weight at each fruiting site were maintained separately. Thus, the contribution to total yield was determined for each fruiting position. The following changes to the Jenkins et al. (1990a) methodology were implemented: (i) the cotyledonary node was counted as node 0 and (ii) after recording the number and weight of bolls from each position, lint percentages were determined by combining the seedcotton from each plot prior to ginning.

Forty-seven plots were used in the three studies. Differences in seeding rate and seedling emergence resulted in 31 different plant densities. Therefore, nine population density intervals were established and the 31 plant densities were assigned to an interval. The nine intervals established were: (i) 2.5 to 4.5 plants m^{-2} , (ii) 4.5 to 6.5 plants m^{-2} , (iii) 6.5 to 8.5 plants m^{-2} , (iv) 8.5 to 10.5 plants m^{-2} , (v) 10.5 to 12.5 plants m^{-2} , (vi) 12.5 to 14.5 plants m^{-2} , (vii) 14.5 to 16.5 plants m^{-2} , (viii) 16.5 to 18.5 plants m^{-2} , and (ix) 20.5 to 23.0 plants m^{-2} .

The experimental design used in all studies was a randomized block design with three (RDC '97 and CPES '97) or four (CPES '98) replicates. Each plot was six rows wide and 15 m long. In order to use the plant densities previously described, the three studies and associated replications were considered main plot sampling units. The treatments were the 31 plant densities that were determined from a physical count of the plants harvested in each plot. Sub-plots were the nodes containing harvestable bolls and sub-sub-plots were the positions at each lateral branch. The complete experimental design, based on the 31 plant densities, was used to establish the correct error terms. The whole plant data was analyzed using the Proc MIXED procedure (Littell et al. 1996). Plant density interval, node, and position were fitted to the data where each was represented by a second-order polynomial regression and all interactions. Out of 20 variables analyzed, 11 were reduced to a first-order polynomial regression (linear).

RESULTS AND DISCUSSION

Several reports have shown that population density is inversely related to mainstem node number (Buxton et al., 1977; Fowler and Ray, 1977; Galanopoulou-Sendouka et al., 1980; Heitholt, 1995; Jones and Wells, 1997; Kerby et al., 1990; Wanjura and Bilbro, Jr., 1977). Lower population densities in our experiments also resulted in plants with more mainstem nodes (21.8 nodes $plant^{-1}$) when compared with higher densities (16.5 nodes $plant^{-1}$) (Table 1). Additionally, population density has been shown to be inversely related to monopodial branch number (Buxton et al., 1977; Fowler and Ray, 1977; Jones and Wells, 1997). Our data is in agreement (Table 1). Monopodial branch number in our experiments ranged from 2.8 $plant^{-1}$ in the lowest population density to 0.2 $plant^{-1}$ in the highest. Other reports also have shown that as population density increases so does the node number of the first sympodial branch (Buxton

Table 1. Total mainstem nodes and monopodial branches per plant at harvest as affected by plant density in studies conducted at Tifton, GA in 1997 and 1998.

Density	N	Mainstem nodes	Monopodial branches
Plants m^{-2}		Total $plant^{-1}$	Total $plant^{-1}$
2.5–4.5	9	21.8	2.8
4.5–6.5	8	20.4	1.8
6.5–8.5	3	17.5	1.5
8.5–10.5	7	19.7	1.6
10.5–12.5	5	17.7	1.7
12.5–14.5	7	18.1	1.4
14.5–16.5	3	16.8	0.7
16.5–18.5	2	16.5	0.4
20.5–23.0	3	18.9	0.2
Regression			
Linear		**	**
Quadratic		NS	NS
ANOVA	df		
Study	2	**	NS
Rep(study)	7	NS	NS
Density(I)	8	**	**
Density(R)	22	NS	NS

Density (I) = ANOVA MS associated with the nine intervals listed above; Density (R) = ANOVA MS remaining after Density (I) SS are removed. NS, *, ** denote level of significance for none, $P = 0.05$, and $P = 0.01$, respectively.

et al., 1977; Fowler and Ray, 1977; Jones and Wells, 1997; Kerby et al., 1990). The node of the first sympodial branch was not related to population density in our studies (data not shown), which is in agreement with Galanopoulou-Sendouka et al. (1980). Averaged across population densities the first sympodial branch was at mainstem node 5.7 in our studies. These results show lint yield production in lower population densities is potentially compensated through supplemental fruiting-site production on additional mainstem nodes and monopodial branches. In addition, sympodial branch length (Kerby et al., 1990) and nodes per monopodial branch (Buxton et al., 1977) have been shown to increase with decreasing population density. Therefore, in low population densities, supplemental fruiting site production also may occur through the production of additional fruiting positions on sympodial and monopodial branches.

Boll retention also has been shown to increase with decreasing population density (Galanopoulou-Sendouka et al., 1980; Guinn et al., 1981). In addition, Kerby et al. (1990) indicated the percent of fruiting positions maturing a boll increased as population density decreased. Our results show much of this response occurs from mainstem nodes 6 to 14 (Fig. 1). Our results also show the mainstem node of peak boll set increased with increasing population density. Averaged across sympodial branch positions, peak boll set occurred at mainstem node 7 (73.8%) in the 2.5 to 4.5 plants m^{-2} range, mainstem node 8 (53.1%) in the 4.5 to 6.5 plants m^{-2} range, and mainstem node 9 in the 6.5 to 8.5 (41.9%), 12.5 to 14.5 (28.0%), and 20.5 to 23.0 (22.0%) plants m^{-2} ranges. Jenkins et al. (1990b) reported peak boll set occurred at node 11 for position one, node 9 for position two, and node 8 for position three fruit with a population density of 9.5 plants m^{-2} . Averaged across population densities, our results show the probability of harvesting a mature boll was greatest at node 10 for position one

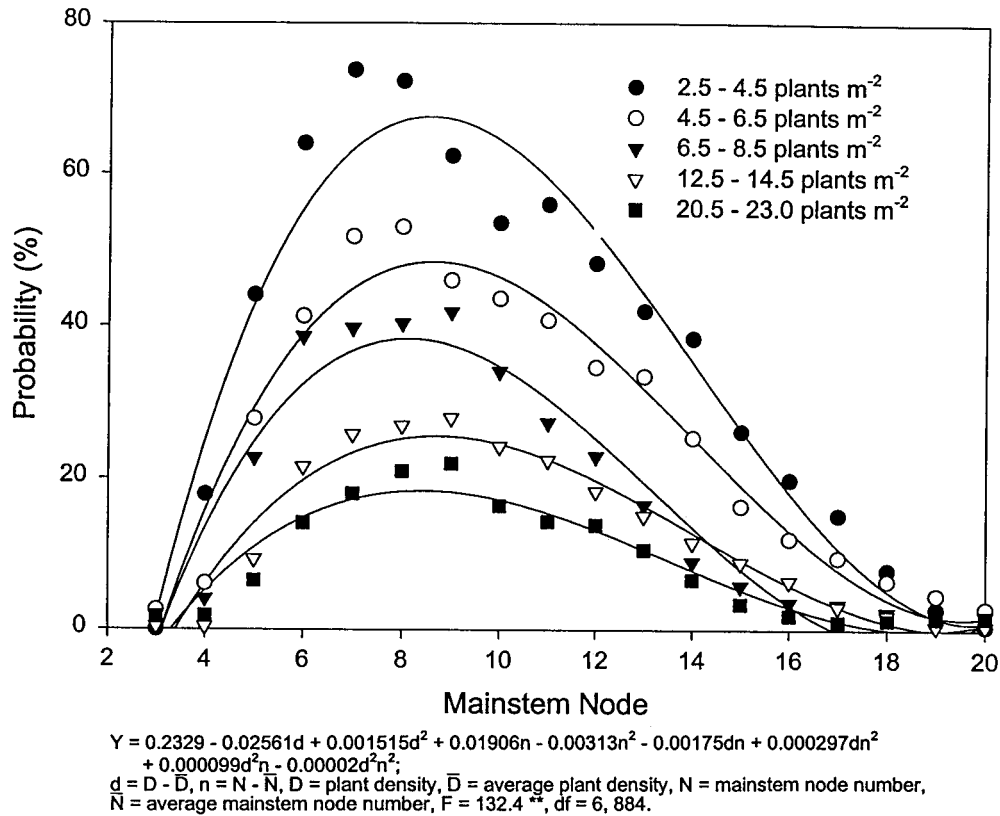


Fig. 1. Effect of plant density on the probability of harvesting a pickable boll at each main stem node in studies conducted at Tifton, GA in 1997 and 1998. Data are averaged across all sympodial branch positions. Only select population densities are shown for clarity.

fruit and node 9 for position two and three fruit (Table 2).

In the first sympodial position, the probability of harvesting a mature boll was influenced greatly by mainstem node and to a lesser extent by population density (Table 2). Conversely, the probability of harvesting a

second position boll was influenced more by population density and to a lesser extent by mainstem node. The probability of harvesting a third position boll was related primarily to population density, while the influence of mainstem node was practically nonexistent. Constable (1986) indicated that the altered light environment re-

Table 2. ANOVA of plant density studies conducted at Tifton, GA in 1997 and 1998.

Variable	Effect	Sympodial position					
		1		2		3	
		F ratios	Point of inflection	F ratios	Point of inflection	F ratios	Point of inflection
Probability	D_L	-80	23 plants m ⁻²	-345	21 plants m ⁻²	-187	13.5 plants m ⁻²
	D_Q	+4		+24		+64	
	N_L	+239	10	+26	9	+3	9
	N_Q	-506		-87		-9	
	$D_L \times N_L$	-25		+6		+13	
	df	739		612		432	
Boll weight	D_L	-20	17 plants m ⁻²	-32	23 plants m ⁻²	-50	19 plants m ⁻²
	D_Q	+4		+0		+2	
	N_L	+152	11	+76	10	+14	9
	N_Q	-226		-133		-25	
	$D_L \times N_L$	-6		-1		+0	
	df	739		612		432	
Boll weight	P_L	+82	53%	+128	50%	+79	60%
	P_Q	-97		-70		-61	
	N_L	+29	11	+51	10	+14	9
	N_Q	-36		-26		-9	
	D_L	-13	21 plants m ⁻²	+0	<1 plants m ⁻²	+1	<1 plants m ⁻²
	D_Q	+2		-0		-0	
	$P_L \times N_L$	-4		+5		+4	
	$P_L \times D_L$	-19		-5		+3	
	$N_L \times D_L$	-1		+1		+3	
	df	736		609		429	

D = plant density (plant m⁻²), N = mainstem node number (unitless), P = probability of harvesting a mature boll (%). L = linear coefficient from regression, Q = quadratic coefficient from regression. The + or - sign indicates slope.

Table 3. Boll weight and total yield on cotton plant sympodia and monopodia at harvest as affected by plant density in studies conducted at Tifton, GA in 1997 and 1998.

Density	N	Sympodial position				Mean	Sympodial position				Total
		1	2	≥3	Monopodia		1	2	≥3	Monopodia	
Plants m⁻²		g seedcotton boll⁻¹					kg seedcotton ha⁻¹				
2.5–4.5	9	5.2	4.8	4.2	4.5	4.7	1300	905	650	1619	4474
4.5–6.5	8	4.7	3.9	3.8	3.9	4.2	1644	898	606	1128	4276
6.5–8.5	3	4.8	4.0	3.9	3.8	4.2	1577	1054	444	665	3740
8.5–10.5	7	4.6	4.1	3.5	3.8	4.3	2513	938	222	494	4167
10.5–12.5	5	4.4	4.1	3.7	4.2	4.3	2623	978	267	277	4145
12.5–14.5	7	5.0	3.7	2.5	3.3	4.6	3733	505	219	205	4662
14.5–16.5	3	4.4	3.9	2.9	4.8	4.2	3234	487	218	105	4044
16.5–18.5	2	4.4	4.0	3.7	3.9	4.3	3250	332	52	87	3721
20.5–23.0	3	4.3	3.7	0.8	1.3	4.2	4010	282	4	5	4301
Regression											
Linear		*	**	**	**	NS	**	*	**	**	NS
Quadratic		–	–	–	–	–	–	–	*	**	–
ANOVA	df										
Study	2	NS	NS	NS	NS	NS	**	NS	NS	NS	NS
Rep(study)	7	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Density(I)	8	NS	**	*	NS	NS	**	NS	NS	**	NS
Density(R)	22	NS	NS	NS	NS	*	**	NS	NS	NS	NS

Density (I) = ANOVA MS associated with the nine intervals listed above; Density (R) = ANOVA MS remaining after Density (I) SS are removed. NS, *, ** denote level of significance for none, $P = 0.05$, and $P = 0.01$, respectively.

sulting from high population densities prevents sympodial branches from producing distal fruiting sites. Therefore, the impact of population density is greater on the probability of harvesting second and third position fruit because these fruiting positions are reduced or eliminated in higher populations.

Several studies have concluded boll size is inversely related to population density (Baker, 1976; Bridge et al., 1973; Buxton et al., 1979; Fowler and Ray, 1977; Galanopoulou-Sendouka et al., 1980; Hawkins and Peacock, 1971, 1973; Jones and Wells, 1997; Rao and Weaver, Jr., 1976; Smith et al., 1979). Our results are in agreement (Table 3). Jenkins et al. (1990b) also reported peak boll weight occurred between mainstem nodes 6 to 12 for position one fruit. Averaged across population densities, our results show peak boll weight occurred at mainstem node 11 for position one fruit, mainstem node 10 for position two fruit, and mainstem node 9 for position three fruit (Table 2).

In the first and second sympodial positions, boll weight was influenced greatly by mainstem node and to a lesser extent by population density (Table 2). Third position boll weight was related primarily to population density. These effects are similar to those observed in the probability of harvesting a mature boll. Boll weight of distal fruiting positions also is influenced more by population density because these fruiting positions are reduced or eliminated in higher populations.

The probability of harvesting a mature boll and boll weight are related (Table 2). These variables do not affect one another but are related because they are both highly sensitive to population density and mainstem node. Across population densities peak boll weight occurred when the probability of harvesting a mature boll was between 50 and 60%. Lower fruit retention may have reduced the size of existing fruit because available photosynthate was directed to vegetative growth. This would be in agreement with Kennedy (et al. 1986) who found that limited fruit removal resulted in increased vegetative growth and reduced boll weight. Higher fruit

retention may have reduced fruit size due to the greater assimilate demand relative to supply.

Several studies have reported increased LAI with increased population density (Buxton et al., 1977; Fowler and Ray, 1977; Galanopoulou-Sendouka et al., 1980; Heitholt, 1994; Jones and Wells 1997; Kerby et al., 1990). Buxton et al. (1977) also reported that the increase in LAI associated with increased population density is exaggerated in the central portion of the plant canopy. The increased LAI associated with high population densities also has been shown to reduce the efficiency of photosynthetic photon flux density (PPFD) interception per unit leaf area (Heitholt, 1994). In our studies mean net assimilation rate (NAR) decreased with increasing population density (Table 4). Mean NAR from first flower to peak bloom was $14.8 \text{ g m}^{-2} \text{ d}^{-1}$ in the lowest population density range and $9.0 \text{ g m}^{-2} \text{ d}^{-1}$ in the highest.

Table 4. Mean net assimilation rate from first flower to peak bloom as affected by plant density in studies conducted at Tifton, GA in 1997 and 1998.

Density	N	Mean net assimilation rate
Plants m⁻²		g m⁻² d⁻¹
2.5–4.5	9	14.8
4.5–6.5	8	11.2
6.5–8.5	3	10.2
8.5–10.5	7	9.9
10.5–12.5	5	11.2
12.5–14.5	7	7.7
14.5–16.5	3	9.5
16.5–18.5	2	8.9
20.5–23.0	3	9.0
Regression		
Linear		**
Quadratic		NS
ANOVA	df	
Study	2	NS
Rep(study)	7	NS
Density(I)	8	NS
Density(R)	22	NS

Density (I) = ANOVA MS associated with the nine intervals listed above; Density (R) = ANOVA MS remaining after Density (I) SS are removed. NS, *, ** denote level of significance for none, $P = 0.05$, and $P = 0.01$, respectively.

Table 5. Number of bolls per square meter and per plant on cotton plant sympodia and monopodia at harvest as affected by plant density in studies conducted at Tifton, GA in 1997 and 1998.

Density	N	Sympodial position				Total	Sympodial position				Total
		1	2	≥3	Monopodia		1	2	≥3	Monopodia	
Plants m⁻²		Bolls m⁻²					Bolls plant⁻¹				
2.5–4.5	9	24.7	18.8	15.7	35.8	95.0	8.1	6.2	5.1	11.6	31.0
4.5–6.5	8	34.7	23.2	15.8	28.8	102.5	6.5	4.3	2.9	5.3	19.0
6.5–8.5	3	32.8	26.3	11.5	17.8	88.4	4.2	3.3	1.5	2.3	11.3
8.5–10.5	7	55.8	22.6	6.4	12.3	97.1	5.7	2.3	0.7	1.3	10.0
10.5–12.5	5	59.8	23.8	7.0	6.7	97.3	5.2	2.1	0.6	0.6	8.5
12.5–14.5	7	73.0	16.2	1.9	7.8	98.9	5.5	1.2	0.1	0.6	7.4
14.5–16.5	3	69.8	17.9	4.1	4.7	96.5	4.5	1.2	0.3	0.3	6.3
16.5–18.5	2	51.1	28.2	5.9	2.2	87.4	2.8	1.6	0.3	0.1	4.8
20.5–23.0	3	92.9	7.2	0.1	0.1	100.3	4.3	0.3	0.0	0.0	4.6
Regression											
Linear		**	NS	**	**	NS	**	**	**	**	**
Quadratic		**	-	*	**	-	-	**	**	**	**
ANOVA	df										
Study	2	*	NS	NS	NS	NS	*	NS	NS	NS	NS
Rep(study)	7	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Density(I)	8	**	NS	NS	**	NS	**	**	*	**	**
Density(R)	22	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

Density (I) = ANOVA MS associated with the nine intervals listed above; Density (R) = ANOVA MS remaining after Density (I) SS are removed. NS, *, ** denote level of significance for none, $P = 0.05$, and $P = 0.01$, respectively.

Decreased boll set and weight from increased population density may result from the combined effects of excessive LAI, reduced PPFD efficiency, and reduced mean NAR.

Fruit production on an individual plant basis also is inversely related to population density. Jones and Wells (1997) and Wanjura and Bilbro, Jr. (1977) advanced this concept with in-season growth analyses that showed plants from lower populations produce more squares and immature and mature bolls. Our at-harvest results show first position open bolls plant⁻¹ ranged from 8.1 in the lowest density to 4.3 in the highest density (Table 5). The additional plant numbers in the higher populations, however, resulted in more first position fruit on an area basis (Table 5). Third position sympodial fruit and monopodial fruit were practically nonexistent in the higher population densities. Total fruit numbers at harvest ranged from 31 fruit plant⁻¹ in the lowest population density to 4.6 fruit plant⁻¹ in the highest. Total fruit m⁻² was not significantly different.

Jenkins et al. (1990a) reported a lint distribution of 71, 20, 3, and 6% across fruiting positions one, two, three, and monopodial branches with a population density of 9.5 plants m⁻². In our studies, seedcotton distribution in the lowest population density range (2.5–4.5 plants m⁻²) was 29, 20, 15, and 36% across fruiting positions one, two, three, and monopodial branches (Table 3). Conversely, in the highest population density range (20.5–23.0 plants m⁻²) lint distribution was 94, 5, <1, <1% across fruiting positions one, two, three, and monopodial branches, respectively. The contribution to final seedcotton yield from first positions increased with increasing population density while contributions from second, third, and monopodial fruit decreased. However, total seedcotton produced ranged from 3721 to 4474 kg seedcotton ha⁻¹ across population densities and was not significantly different.

Jenkins et al. (1990a) showed mainstem nodes 9 through 14 contributed the most to lint yield with a population density of 9.5 plants m⁻² (counting the coty-

ledonary node as 1). In our studies mainstem nodes 6 through 12 contributed the most to seedcotton yield (Fig. 2). Also, as population density increased, the contribution to total seedcotton from the mid-canopy region increased. The probability of harvesting a mature boll decreased in the mid-canopy region as population density increased (Fig. 1), but the additional plant numbers in the higher populations resulted in more seedcotton in this region. The sympodial branch contributing the most to final seedcotton yield increased with population density (Fig. 2). For instance, maximum seedcotton yield in the population density range of 2.5 to 6.5 plants m⁻² occurred at mainstem node 8, while maximum yield in the 7.5 to 23.0 plants m⁻² range occurred at mainstem node 9. This is the same trend observed in boll retention discussed earlier (Fig. 1).

Figure 3 illustrates accumulative seedcotton arising on sympodial branches for the various population densities. Accumulative seedcotton in the lowest populations (2.5–8.5 plants m⁻²) was lower than that of the higher populations (12.5–23.0 plants m⁻²). However, the reduction in seedcotton from sympodial branches in the lower population densities was compensated by additional seedcotton from monopodial branches (Table 3). The rate at which seedcotton is accumulated also is greater from mainstem nodes 8 to 14 in the higher population densities. Early boll retention and weight may have been lower in the higher population densities, but the additional plant numbers in the higher densities compensate for these reductions, resulting in greater accumulative seedcotton.

Increasing plant density has been shown to increase earliness (Rao and Weaver, 1976; Smith et al., 1979). Kerby et al. (1990), however, suggested that increasing plant density will delay maturity of full-season indeterminate cultivars. Baker (1976) and Kostopoulos and Chlichlias (1979) found plant density and earliness were not related. Finally, Galanopoulou-Sendouka et al. (1980) and Fowler and Ray (1977) indicated a medium-range population density is more consistent in earliness.

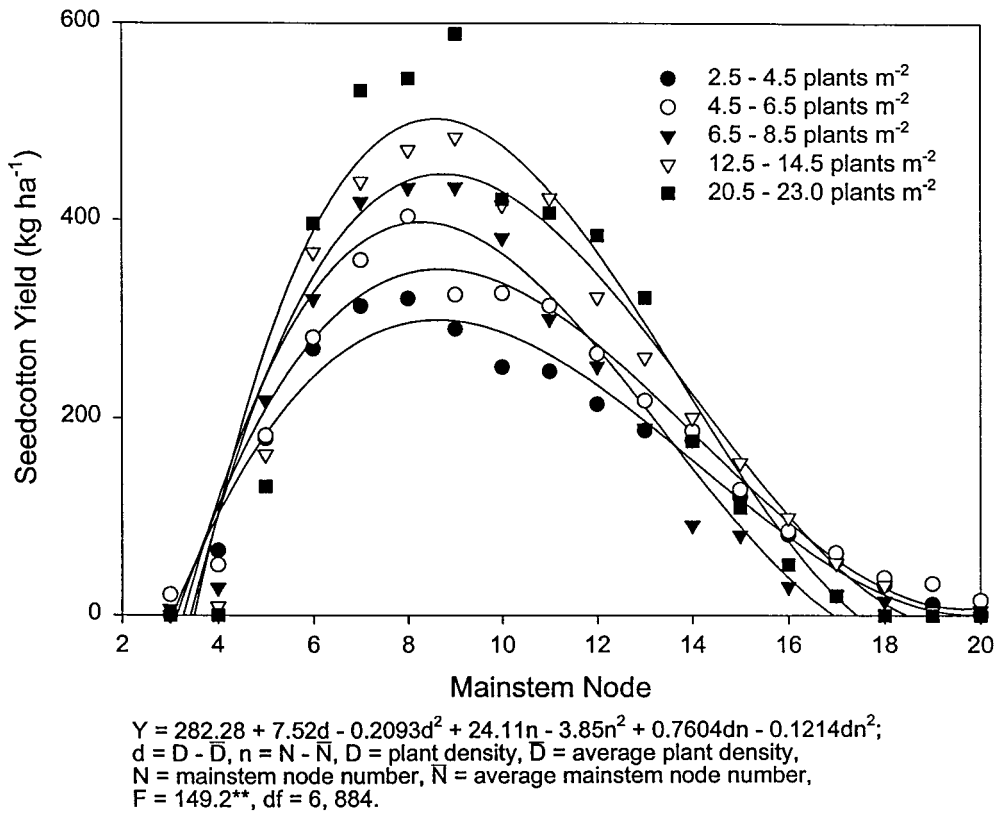


Fig. 2. Effect of plant density on total seedcotton yield at each mainstem node in studies conducted at Tifton, GA in 1997 and 1998. Data are totaled across all sympodial branch positions. Only select population densities are shown for clarity.

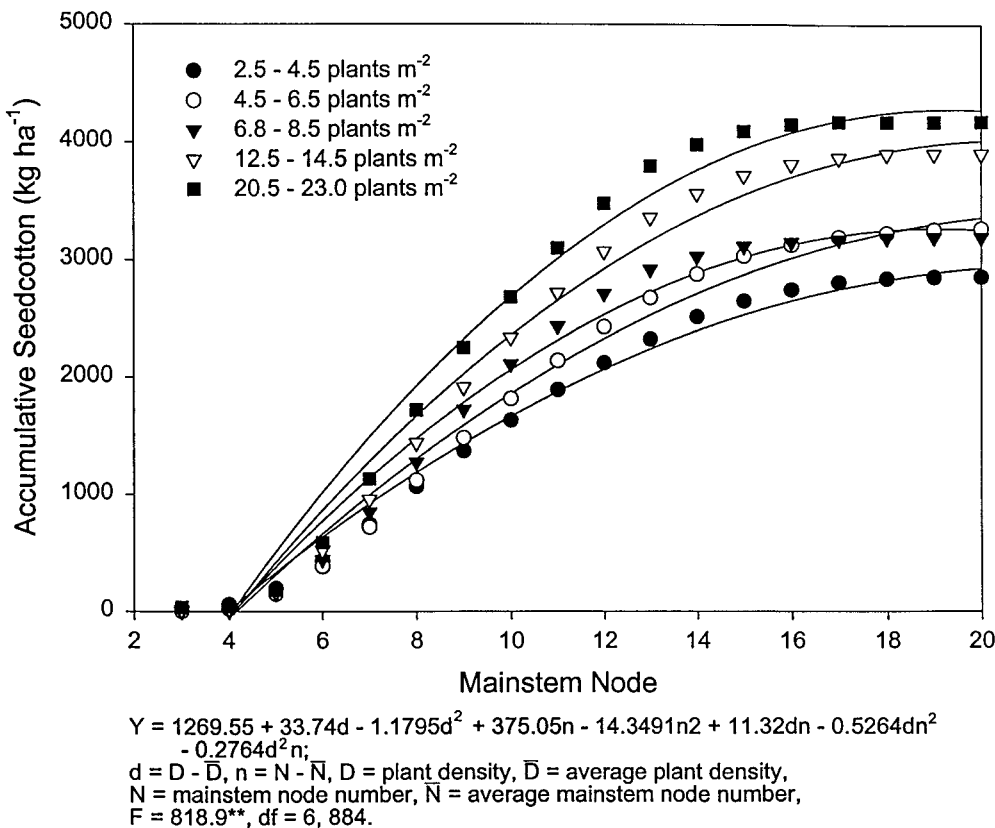


Fig. 3. Effect of plant density on accumulative seedcotton yield at each mainstem node in studies conducted at Tifton, GA in 1997 and 1998. Only select population densities are shown for clarity.

In our studies the rate of seedcotton accumulation was greater from mainstem nodes 8 to 14 in the higher population densities, indicating earliness is enhanced with increasing population density. Since higher population densities produce plants with fewer mainstem nodes and shorter sympodial branches, it could be reasonably concluded that maturity would be enhanced. However, in the higher population densities early boll retention was lower, which will delay maturity (Kerby et al., 1990). In addition, higher population densities will result in longer sympodial and monopodial plastochrons (Kerby and Buxton, 1978) and longer boll maturation periods (Buxton et al., 1979; Galanopoulou-Sendouka et al., 1980) which will also delay maturity. Assessing earliness using a different methodology, however, presents a different view.

The number of sympodial branches required to produce 95% of the harvestable bolls (95% zone) has been described as one method of determining the effective fruiting period or earliness (Kerby, 1996, p. 9–10). In our studies, the number of sympodial branches required for the 95% zone were 10.0 in the 2.5 to 4.5 plants m^{-2} density range, 10.1 in the 4.5 to 6.5 plants m^{-2} density range, 8.4 in the 6.5 to 10.5 plants m^{-2} density range, 9.2 in the 12.5 to 14.5 plants m^{-2} density range, and 9.1 in the 20.5 to 23.0 plants m^{-2} density range. Using this methodology, maturity appears to be maximized in our medium range population density. However, only seedcotton from sympodial branches is used in this determination and to maintain maximum yield potential in our medium range population density, additional monopodial branches were produced, which have been shown to delay maturity (Ray and Richmond, 1966).

The optimum plant density, from the standpoint of earliness, would be one that resulted in reasonably high fruit retention with no monopodial branches. This would most likely occur in some medium range population density, which we did not pinpoint in our studies. In our studies population densities below 8.5 plants m^{-2} produced monopodial branches and higher population densities resulted in greater fruit shed.

CONCLUSIONS

Our results show that decreased population density resulted in greater fruiting site production and fruit retention. Lower population densities also resulted in heavier fruit production. As population density increased, mean NAR decreased, resulting in reduced fruiting site production, fruit retention, and boll weight. These combined effects resulted in fewer bolls and less seedcotton on a per-plant basis. These results show yield potential is a differential function, dependent upon the probability that a boll will occur, the weight of that boll, and the population density. Yield stability is achieved across a range of population densities through manipulation of boll occurrence and boll weight.

As population density decreased, the percent of fruit arising on second and third positions and monopodial branches increased. Third positions and monopodial branches were the greatest contributors to total seedcot-

ton in the lowest population density, while first positions were the greatest contributors in the highest population density. Accumulative seedcotton from sympodial branches increased with population density, indicating a greater percentage of the total seedcotton was produced on monopodial branches in the lower population densities. The rate of seedcotton accumulation also was greater in the higher population densities. While these results indicate earliness is enhanced in higher population densities, they are not conclusive. Finally, the mainstem node of peak boll set and seedcotton yield increased with population density, indicating a reduction in the efficiency of PPFD interception and NAR in the mid-canopy region. Thus, while total seedcotton yield was not influenced by population density in these studies, the distribution of the fruit on the plant was.

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REFERENCES

- Baker, S.H. 1976. Response of cotton to row patterns and plant populations. *Agron. J.* 68:85–88.
- Bridge, R.R., W.R. Meredith, Jr., and J.F. Chism. 1973. Influence of planting method and plant population on cotton (*Gossypium hirsutum* L.) *Agron. J.* 65:104–109.
- Buxton, D.R., R.E. Briggs, L.L. Patterson, and S.D. Watkins. 1977. Canopy characteristics of narrow-row cotton as influenced by plant density. *Agron. J.* 69:929–933.
- Buxton, D.R., L.L. Patterson, and R.E. Briggs. 1979. Fruiting pattern in narrow-row cotton. *Crop Sci.* 19:17–22.
- Constable, G.A. 1986. Growth and light interception by mainstem cotton leaves in relation to plant density in the field. *Agric. For. Meteorol.* 37:279–292.
- Fowler, J.L., and L.L. Ray. 1977. Response of two cotton genotypes to five equidistant spacing patterns. *Agron. J.* 69:733–738.
- Galanopoulou-Sendouka, S., A.G. Sficas, N.A. Fotiadis, A.A. Gagianas, and P.A. Gerakis. 1980. Effect of population density, planting date, and genotype on plant growth and development of cotton. *Agron. J.* 72:347–353.
- Guinn, G., J.R. Mauney, and K.E. Fry. 1981. Irrigation scheduling and plant population effects on growth, bloom rates, boll abscission, and yield of cotton. *Agron. J.* 73:529–534.
- Hawkins, B.S., and H.A. Peacock. 1970. Yield response of upland cotton (*Gossypium hirsutum* L.) to several spacing arrangements. *Agron. J.* 62:578–580.
- Hawkins, B.S., and H.A. Peacock. 1971. Response of 'Atlas' cotton to variations in plants per hill and within-row spacings. *Agron. J.* 63:611–613.
- Hawkins, B.S., and H.A. Peacock. 1973. Influence of row width and population density on yield and fiber characteristics of cotton. *Agron. J.* 65:47–51.
- Hearn, A.B. 1972. Cotton spacing experiments in Uganda. *J. Agric. Sci. (Cambridge)*. 78:13–25.
- Heitholt, J.J. 1994. Canopy characteristics associated with deficient and excessive cotton plant densities. *Crop Sci.* 34:1291–1297.
- Heitholt, J.J. 1995. Cotton flowering and boll retention in different planting configurations and leaf shapes. *Agron. J.* 87:994–998.
- Hicks, S.K., C.W. Wendt, J.R. Gannaway, and R.B. Baker. 1989. Allelopathic effects of wheat straw on cotton germination, emergence, and yield. *Crop Sci.* 29:1057–1061.
- Hunt, R. 1982. Plant growth curves, the functional approach to plant growth analysis. University Park Press, Baltimore, MD.

- Jenkins, J.N., J.C. McCarty, Jr., and W.L. Parrott. 1990a. Effectiveness of fruiting sites in cotton: Yield. *Crop Sci.* 30:365–369.
- Jenkins, J.N., J.C. McCarty, Jr., and W.L. Parrott. 1990b. Fruiting efficiency in cotton: Boll size and boll set percentage. *Crop Sci.* 30:857–860.
- Jones, M.A., and R. Wells. 1997. Dry matter allocation and fruiting patterns of cotton grown at two divergent plant populations. *Crop Sci.* 37:797–802.
- Kennedy, C.W., W.C. Smith, Jr., and J.E. Jones. 1986. Effect of early season square removal on three leaf types of cotton. *Crop Sci.* 26:139–145.
- Kerby, T.A. 1996. Management considerations in cotton production with special emphasis on growing NuCOTN varieties with the Boll-gard gene. Delta and Pine Land Company, Scott, MS.
- Kerby, T.A., and D.R. Buxton. 1978. Effect of leaf shape and plant population on rate of fruiting position appearance in cotton. *Agron. J.* 70:535–538.
- Kerby, T.A., K.G. Cassman, and M. Keeley. 1990. Genotypes and plant densities for narrow-row cotton systems. I. Height, nodes, earliness, and location of yield. *Crop Sci.* 30:644–649.
- Kerby, T.A., S.J. Hake, K.D. Hake, L.M. Carter, and R.H. Garber. 1996. Seed quality and planting environment. p. 203–209. *In* S.J. Hake, T.A. Kerby, and K.D. Hake (eds.) *Cotton production manual*. ANR Publications, University of California, Oakland, CA.
- Kittock, D.L., R.A. Selley, C.J. Cain, and B.B. Taylor. 1986. Plant population and plant height effects on pima cotton lint yield. *Agron. J.* 78:534–538.
- Kostopoulos, S., and A. Chlichlias. 1979. Influence of row spacing and plant population densities on yield, earliness and fiber properties of two Greek cotton cultivars (*Gossypium hirsutum* L.). *J. Agric. Res.* 4:343–355.
- Littell, R.C., G.A. Milliken, W.W. Stroup, and R.D. Wolfinger. 1996. SAS System for Mixed Models. SAS Institute, Cary, NC.
- Mcinski, S., P.D. Colyer, K.T. Nguyen, and K.L. Koonce. 1990. Effects of planting date and early-season pest control on yield in cotton. *J. Prod. Agric.* 3:597–602.
- Rao, M.J., and J.B. Weaver, Jr. 1976. Effect of leaf shape on response of cotton to plant population, N rate, and irrigation. *Agron. J.* 68:599–601.
- Ray, L.L., and T.R. Richmond. 1966. Morphological measures of earliness of crop maturity in cotton. *Crop Sci.* 6:527–531.
- Smith, C.W., B.A. Waddle, and H.H. Ramey, Jr. 1979. Plant spacings with irrigated cotton. *Agron. J.* 71:858–860.
- Wanjura, D.F., and J.D. Bilbro, Jr. 1977. Cotton population dynamics: Influence of the within-the-row spacing and emergence time. *Agron. J.* 69:312–318.

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