

Phenological and Morphological Components of Cotton Crop Maturity

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ABSTRACT

Full season cotton (*Gossypium hirsutum* L.) cultivars may be better adapted to the lower southeastern USA because early maturing cultivars may not recover from the many episodic drought events that annually plague the region. The objective of this investigation was to determine if cotton maturity may be defined on the basis of flowering interval, boll maturation period, or whole plant yield distribution. Studies were conducted at the University of Georgia Coastal Plain Experiment Station in 2001, 2002, and 2003. Nine commercially available cotton cultivars were over seeded and hand thinned to 10.8 plants m⁻². Areas within each plot were reserved for daily white flower and open boll tagging and hand harvest. Mean vertical flowering intervals were 2.1 (2001), 2.7 (2002), and 2.6 (2003) d. Mean vertical flowering intervals increased from main stem node 5 to about main stem node 11 and then began to decline. Mean horizontal flowering intervals were 3.2 (2001), 4.4 (2002), and 3.8 (2003) d and were shorter than those in previous reports. In all years, the earlier maturity cultivars possessed the shortest boll maturation periods while the later maturity cultivars possessed the longest. The earlier maturity cultivars also produced a greater percentage of their total lint yields at lower main stem nodes. Of the many possible pathways to early crop maturity, the ones investigated in this study that appear to have been most useful in breeding programs are shortening of the horizontal flowering interval and boll maturation period and lengthening of sympodial branches at lower main stem nodes.

THE COTTON BOLL WEEVIL (*Anthonomus grandis* Boheman) first appeared in the USA in 1892 near Brownsville, TX (Parenica, 1978, 1–17; 62–68). By the end of 1919, the boll weevil was found across the U.S. Cotton Belt from south Texas to the Carolinas (Newell and Bynum, 1920). Production of an early maturing cotton crop was not considered of special importance until the arrival of this voracious insect pest (Buie, 1928). Buie (1928) indicated the production of cotton in the presence of the boll weevil had become a race between the farmer and the weevil. Thus, the quest for early crop maturity had begun.

More recently, the Boll Weevil Eradication Program has virtually eliminated *A. grandis* as an economic pest in the southeastern region of the U.S. Cotton Belt. In addition, cotton cultivars containing the genes for expression of the δ -endotoxin of *Bacillus thuringiensis* (Bt) for control of *Heliothis virescens* (Fabricius) have become widely utilized. These technological advances have resulted in a decline in insecticide use against *A. grandis* and *H. virescens* (Mann et al., 1997). Even in the

absence of late season insect pressure, however, poorly drained soils and a history of inclement weather patterns during the fall months continue to necessitate management for early crop maturity in some regions of the U.S. Cotton Belt. In the lower southeastern USA, however, more favorable fall weather conditions and well drained soils may not necessitate management for early crop maturity. In fact, management for full season crop maturity may be the more suitable approach.

Water availability is frequently the most limiting factor to profitable cotton production in the southeastern USA. 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 can 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 yield loss. It is suggested that full season cotton cultivars are better adapted to the lower southeastern USA because early maturing cultivars may not recover from the many episodic drought events that plague the region throughout the growing season. To more fully comprehend and possibly capitalize on this phenomenon (i.e., the proposed ability of full season cultivars to recover from episodic drought), the phenology and morphology of cotton crop maturity must be more completely understood.

Agronomic earliness of cotton crop maturity has been defined as the proportion of the total crop that is produced by the first picking (Leffler, 1979; Ray and Richmond, 1966; Richmond and Radwan, 1962). Because of variation among locations and years, however, a more suitable agronomic definition of earliness may simply be achieving an acceptable yield in the shortest time from planting (Munro, 1971).

Phenologically and morphologically, the definition of earliness is much more complex. The time to first square or first flower and the main stem node of the first fruiting branch are some of the measures of earliness (Joham, 1979). Other factors influencing earliness include seedling tolerance to cold (Muramoto et al., 1971), seedling vigor (Leffler, 1979), shorter flowering plastochrons (Hearn 1969; Hesketh et al., 1975), shorter squaring period (Hesketh and Low, 1968), more flowering sites per fruiting branch (Hesketh et al., 1975), and shorter boll maturation periods (Gipson and Ray, 1970).

In reality, early crop maturity is probably a combination of several possible venues. It seems likely the greatest advances in early crop maturity may be made through modifications in flowering intervals, boll filling periods, or whole plant yield distribution. For example, if flowering intervals were shortened by only 1 d, this alone could shorten the growing season by more than 1 wk. Production of a larger proportion of the total crop at

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lower main stem nodes may also lead to earlier crop maturity through greater retention of fruit initiated early in the season and avoidance of extended boll filling periods from fruit initiated later in the growing season at upper main stem nodes. Thus, the objectives of this investigation were to determine if cotton crop maturity may be defined on the basis of flowering interval, boll maturation period, or whole plant yield distribution.

MATERIALS AND METHODS

Cultural Practices

Studies were conducted at the University of Georgia Coastal Plain Experiment Station Ponder Farm in 2001, 2002, and 2003 on a Tifton loamy sand (Fine-loamy, kaolinitic, thermic Plinthic Kandiudults). Nine commercially available cotton cultivars were over seeded on 9 May 2001, 18 June 2002, and 29 April 2003 with a Monosem air planter (Lenexa, KS) on 91-cm-row widths. The cotton cultivars utilized in this study and their respective maturity classifications as provided by their respective planting-seed purveyors are: PhytoGen Seed Company (PSC) 355 (early), Paymaster (PM) 1199R (early), Delta and Pine Land (DPL) 491 (early-mid), Fibermax (FM) 966 (mid-full), Stoneville (STV) 4892BR (mid-full), DPL 33B (mid-full), DPL Pearl (full), DPL 565 (full), and PSC GA161 (full). While planting, 6.7 kg ha⁻¹ aldicarb [2-methyl-2-(methylthio) propionaldehyde *O*-(methylcarbamoyl)oxime] was applied in furrow for insect control. After emergence (approximately 14 d after planting; DAP) all plots were hand thinned to 10.8 plants m⁻². Fertility, weed control, and insect scouting and control measures were in accordance with the University of Georgia Cooperative Extension Service guidelines (Brown et al., 2001). Water deficit stress was minimized with overhead sprinkler irrigation. Harvest aids were applied [2.3 L ha⁻¹ of ethephon, 2-chloroethylphosphonic acid, plus cyclanilide, 1-(2,4-dichloroanilino) carbonyl cyclopropanecarboxylic acid, and 0.7 kg ai ha⁻¹ of thidiazuron, 1-phenyl-3-(1,2,3-thiadiazol-5-yl)urea] when the crop achieved 90% open boll (20 Sep. 2001, 13 Nov. 2002, and 16 Sep. 2003). The experimental design used was a randomized block design with four (2001 and 2003) or three (2002) replicates. Each plot was four rows (0.91-m spacing) wide and 15 m long.

Because of the wide range in planting date among seasons, degree days (heat units with a base of 15°C; DD15) were calculated. In 2001, the number of days elapsed from planting to defoliation was 135 with a total DD15 accumulation of 1391°C d. In 2002, the number of days elapsed from planting to defoliation was 149 with a total DD15 accumulation of 1393°C d. Thus, the later planting date in 2002 resulted in two additional weeks to reach a roughly equivalent number of degree days. In 2003 the number of days elapsed from planting to defoliation was 140 with a total DD15 accumulation of 1394°C d. These day degree sums are about 45% less than the heat unit scale in Fahrenheit (base 60).

Data Collection

A section of 6.1 m from one of the middle two rows in each plot was reserved for hand harvest. After defoliation, plants from this area were removed from the field and harvested by fruiting position. After harvest, the seed cotton from each fruiting position was ginned separately and the contribution to total lint yield at each fruiting position was determined.

A section of 3 m from the other middle row was reserved for white flower and open boll tagging. White flowers were tagged almost daily throughout the flowering period with a

dated jeweler's tag. Likewise, cracked bolls were tagged almost daily until 90% of all bolls were open. After defoliation at 90% open boll, the tagged plants in each plot were harvested one at a time and their flower and cracked boll dates were recorded at each fruiting position. In this manner, the boll maturation period (number of days from white flower to open boll) was determined at each fruiting position. Additionally, horizontal flowering intervals (number of days between successive flowers on a sympodial branch) and vertical flowering intervals (number of days between first position flowers on successive main stem nodes) were determined. A total of 12 742 (2001) 9749 (2002) and 14 970 (2003) tags were recorded (an average of 3186, 3250, and 3742 tags per replication in 2001, 2002, and 2003, respectively). During the growing seasons, the numbers of main stem nodes from the uppermost first sympodial position white flower to the plant apex (i.e., nodes above white flower) were counted on 10 randomly selected plants in each plot weekly.

Data Analysis

Tag data consisting of white flower date, open boll date, and boll maturation period were analyzed using Proc MIXED (SAS, 2000) by boll position. Since each variety did not have the same number of nodes, a preliminary analysis was done to test the cultivar × node interaction as a fixed effect using replication (rep), rep × cultivar, plant (rep cultivar), rep × node, and rep × cultivar × node as random effects. Least square means for each cultivar × node interaction and all pair-wise differences among the cultivar × node means were calculated. Corrected standard errors were determined from the test of significance performed on the pair-wise mean differences. For the second analysis, cultivar and node were considered fixed effects while cultivar × node as well as the previously indicated effects as random effects. This second analysis allowed the main effects of cultivar and node to be tested by their interaction since this term was found to possess a non-zero positive variance component as suggested by Fisher (1990). Since cultivar was associated with plots of land, while node was associated with the morphology of the plant, differential tests were performed using the appropriate error term for each main effect (Steel and Torrie, 1960; Cochran and Cox, 1957).

RESULTS AND DISCUSSION

Flower Date

Across cultivars, flowering began between 57 and 64 DAP and continued flowering for 25 to 30 d (Table 1). Flowering began sparsely at the fifth main stem node and continued through the seventeenth or eighteenth main stem node, resulting in a fruit setting zone of 12 to 13 main stem nodes.

In all years, the weighted mean first sympodial position flower dates were longest for DPL 491, DPL 565, and DPL Pearl and shortest for PM 1199R and PSC 355 (Table 2). This is likely due to the fact that PM 1199R and PSC 355 are earlier maturity cultivars and produced more flowers at lower main stem nodal positions than the other three later maturity cultivars. Cultivar differences within nodes were not consistent. Monopodial branches flowered at about the same time as first sympodial position flowers on main stem node 10 (Table 1).

Table 1. Weighted average first sympodial position flower dates in days after planting (DAP) and vertical flowering intervals (VFI, days) across cultivars at each main-stem node in studies conducted at the University of Georgia Coastal Plain Experiment Station in 2001, 2002, and 2003.

Main-stem node	Flower date			VFI		
	2001	2002	2003	2001	2002	2003
	DAP			d		
17	89.6	89.8	93.9	1.59	1.57	2.75
16	88.0	88.2	91.1	1.84	2.01	2.31
15	86.1	86.2	88.8	1.83	2.54	2.77
14	84.3	83.7	86.0	2.17	3.62	3.28
13	82.1	80.1	82.7	2.27	3.82	2.91
12	79.9	76.3	79.8	2.53	3.07	2.54
11	77.3	73.2	77.3	3.02	3.60	2.67
10	74.3	69.6	74.6	2.62	3.02	2.31
9	71.7	66.6	72.3	2.48	3.04	3.54
8	69.2	63.5	68.8	2.41	2.54	3.19
7	66.8	61.0	65.6	2.30	1.88	2.43
6	64.5	59.1	63.2	0.42	1.88	2.21
5	64.1	57.2	60.9	–	–	–
Veg	73.6	66.5	67.7	–	–	–
Mean	75.2	69.1	75.3	2.12	2.72	2.57
LSD(0.05)	2.1	2.8	3.1	1.4	1.2	1.1

Vertical Flowering Interval

In 2001 and 2002, the mean number of days between first position white flowers on successive main stem nodes (vertical flowering interval) increased from main stem node 6 to main stem node 11 and then began to decline again (Table 1). Hesketh et al. (1975) observed longer vertical flowering intervals in the upper sympodial branches compared with the lower. It seems plausible the vertical flowering interval would increase with increasing sympodial branch number and boll load. It is probable that vertical flowering intervals in the current study were greatest in the mid-canopy region because flowering and the number of developing bolls were greatest in this region. Thus, the source-to-sink ratio in this region was most likely reduced, resulting in extended vertical flowering intervals.

In probably the first paper ever on cotton flowering intervals, McClelland (1916) reported the vertical flowering interval in the cultivar 'Cleveland Big Boll' to be about 3.00 d. In a later study using three other cultivars, McClelland and Neely (1931) found the range to be from 2.00 to 3.00 d. More than four decades later, Hesketh et al. (1975) found the vertical flowering interval to approximate this same range in day/night temperature regimes of 32/29 or 32/33°C. In the current study, the average vertical flowering intervals were 2.12, 2.72 and 2.57 d in 2001, 2002, and 2003, respectively (Table 1). Godoy and Palomo (1999), studying the inheritance of certain phenological and morphological variables contributing to cotton crop maturity, found the vertical flowering interval would not be a suitable plant character for use in selection for early crop maturity. Thus, it appears the vertical flowering interval may not have changed appreciably through the years of breeding for early crop maturity.

Horizontal Flowering Interval

McClelland (1916) was also the first to report about 6.00 d elapsed between successive flowers on a sympo-

Table 2. Weighted average first sympodial position flower dates in days after planting (DAP) across main-stem nodes in nine commercially available cotton cultivars in studies conducted at the University of Georgia Coastal Plain Experiment Station in 2001, 2002, and 2003.

Cultivar	Flower date		
	2001	2002	2003
	DAP		
DPL 33B	74.7	69.4	76.8
DPL 491	76.0	69.6	76.2
DPL 565	76.0	70.8	77.4
DPL Pearl	76.5	70.4	77.4
FM 966	74.8	68.1	74.1
PM 1199R	74.5	67.1	73.1
PSC 355	74.6	67.5	73.1
PSC GA161	75.0	68.5	75.2
STV 4892BR	74.5	69.5	74.8
Mean	75.2	69.1	75.3
LSD(0.05)	1.3	1.9	1.5

dial branch (the horizontal flowering interval). In a more detailed study, McClelland and Neely (1931) reported the horizontal flowering interval to range from 5.33 to 6.25 d. Munro (1971) reported an unusually long horizontal flowering interval of 9.4 d. Working in temperature controlled environments, Hesketh et al. (1975) reported horizontal flowering intervals ranging from 5.0 to 8.9 and from 5.5 to 6.7 d in day/night temperature regimes of 32/29 and 32/33°C, respectively. Mean horizontal flowering intervals in the current study were 3.2, 4.4 and 3.8 d in 2001, 2002, and 2003, respectively (Table 3). Generally, PM 1199R and PSC 355 (the earlier maturity cultivars) exhibited shorter horizontal flowering intervals than the later maturity DPL cultivars (data not presented). Godoy and Palomo (1999) reported the heritability of the horizontal flowering interval was sufficient and suggested the trait could be manipulated in a breeding program. The horizontal flowering intervals reported in the current study are a minimum of two days less than previous reports. Also, horizontal flowering intervals in the current study appear to differ among the earlier and later maturity cultivars, which suggest this trait has been manipulated in the pursuit of early crop maturity.

Boll Maturation Period

The number of days elapsed from white flower to cracked boll (the boll maturation period) has been suggested as a possible means to manipulate crop maturity (Godoy and Palomo, 1999; Hesketh et al., 1972; Morris,

Table 3. Weighted average flower dates at each sympodial position in days after planting (DAP) and horizontal flowering intervals (HFI, days) across cultivars in studies conducted at the University of Georgia Coastal Plain Experiment Station in 2001, 2002, and 2003.

Sympodial position	Flower date			HFI		
	2001	2002	2003	2001	2002	2003
	DAP			d		
1	75.2	69.1	75.3	–	–	–
2	79.0	73.3	79.8	3.9	4.2	4.4
3	81.5	77.9	82.9	2.5	4.6	3.2
Mean	76.6	70.8	77.1	3.2	4.4	3.8
LSD(0.05)	2.6	2.3	2.9	1.5	1.3	1.5

Table 4. Weighted average first sympodial position boll maturation periods in calendar days and degree days (DD15's) across cultivars at each main-stem node in studies conducted at the University of Georgia Coastal Plain Experiment Station in 2001, 2002, and 2003.

Main-stem node	Calendar days			Degree days		
	2001	2002	2003	2001	2002	2003
15	48.6	58.8	50.7	526.7	410.0	578.6
14	48.9	60.4	50.9	534.7	413.1	586.0
13	49.4	60.6	50.7	542.8	420.9	591.1
12	49.3	60.0	51.2	548.0	451.2	600.9
11	49.5	59.1	51.3	552.1	467.2	605.2
10	49.7	59.0	51.6	557.2	488.9	610.7
9	49.7	57.3	51.8	558.8	516.6	612.4
8	49.3	55.3	51.9	555.2	535.1	617.5
7	49.7	53.9	52.8	558.4	550.7	623.1
6	49.4	52.9	53.3	558.7	565.7	628.9
5	49.5	52.2	53.7	559.9	578.2	635.4
Veg	54.7	59.8	–	615.1	544.0	–
Mean	49.5	56.9	51.8	555.6	495.1	608.1
LSD(0.05)	1.7	1.1	1.0	9.5	12.7	5.9

1964). Morris (1964) suggested the boll maturation period may be confounded by the effects of temperature and negate genotypic differences. Gipson and Ray (1970), Hesketh et al. (1972, 1975), and Hesketh and Low (1968) also indicated the boll maturation period is largely temperature dependent. The mean boll maturation period in 2002 (56.9 d) was almost 8 d longer than in 2001 (49.5 d) and almost 6 d longer than in 2003 (51.8 d; Table 4). Also in 2002, the mean boll maturation period increased with increasing main stem node (Table 4). These differences may be attributable to the slower rate of day degree accumulation observed in 2002 during boll filling (Fig. 1). Interestingly, in 2003 mean boll maturation periods decreased with increasing main stem node number (Table 4), which may be attributable to the slightly higher rate of day degree accumulation observed during boll filling in 2003. Thus, first sympodial position boll maturation period in terms of days was either unaf-

ected by main stem node, increased with increasing main stem node or decreased with increasing main stem node.

Oosterhuis et al. (1996) indicated approximately 470 degree days (base 15°C) are needed for boll maturation. The mean number of degree days for boll maturation in the current study was considerably higher (556, 495, and 608°C d in 2001, 2002, and 2003, respectively; Table 4). Additionally, while the number of calendar days needed for boll maturation increased, decreased, or were unaffected by main stem node, the number of degree days needed for boll maturation decreased with increasing main stem node in all years (Table 4). This observation is likely due to the lower rate of degree day accumulation later in the boll maturation period in all years (Fig. 1). Inclusion of an upper temperature threshold of 30°C for degree day calculations in the current study reduced the mean number of degree days needed for boll maturation by 6 to 8% but did not change the relationship of decreasing number of degree days needed for boll maturation with increasing main stem node (data not presented). Thus, our data do not support the hypothesis that boll maturation period may be defined on the basis of degree day calculation.

In all years, FM 966, PM 1199R, PSC 355, and STV 4892BR possessed the shortest boll maturation periods while PSC GA161 possessed the longest (Table 5). In 2001 boll maturation periods on monopodial branches were longer than on sympodial branches (Table 4). Additionally, boll maturation periods of outer sympodial position bolls were not consistently longer than those of inner sympodial position bolls (data not presented).

Yield Distribution

Jenkins et al. (1990) in a study investigating yield distribution of early and full season maturity cotton cultivars, reported earlier maturity cultivars produced

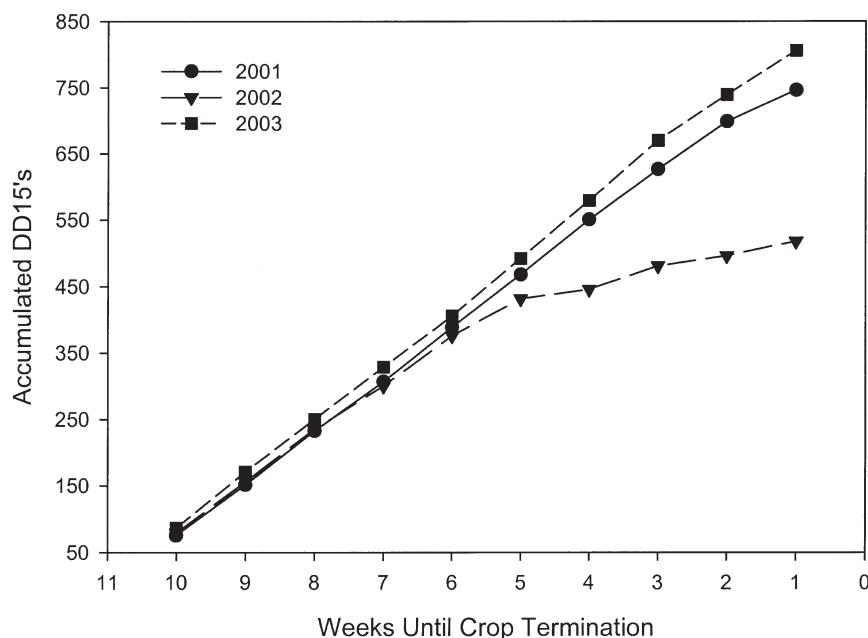


Fig. 1. Heat unit accumulation (DD15) versus weeks until crop termination in studies conducted at the University of Georgia Coastal Plain Experiment Station in 2001 through 2003.

more lint on sympodial branches at main stem nodes 6 through 8 than older, later maturity cultivars. In the current study, the two earlier maturity cultivars (PSC 355 and PM 1199R) also produced a greater percentage of their respective total lint yields at lower main stem nodes than the later maturity cultivars (Fig. 2). Wells and Meredith (1984a, 1984b) have shown modern cultivars transition earlier from vegetative to reproductive development and may have a better coordination of assimilatory capacity with reproductive sink activity. However, if reproductive development is initiated too early in the growing season, vegetative growth (including roots) may become suppressed to the extent that the cultivar cannot tolerate intermittent water deficit or thermal stress events, which are common to the lower southeastern USA.

Physiological Cutout

It has been suggested that effective flowering in cotton (the flowering period contributing to economic yield) is terminated when the uppermost first sympodial position white flower is five main stem nodes from the plant apex, which is defined as physiological cutout (Bourland et al., 1992). Under normal growth conditions, effective flowering will proceed for approximately 20 d and end approximately 80 d after planting. Across cultivars, in 2001 the crop flowered for 25.5 d (3.6 weeks), in 2002 the crop flowered for 32.6 d (4.7 weeks), and in 2003 the crop flowered for 34.8 d (5.0 wk).

Across cultivars, nodes above white flower = 5 occurred at 78, 74, and 80 d after planting in 2001, 2002, and 2003, respectively. Lint produced after these dates totaled 286, 179, and 270 kg ha⁻¹ across cultivars in 2001, 2002, and 2003 (Fig. 3). If effective flowering is terminated at 80 d after planting, physiological cutout

Table 5. Weighted average first sympodial position boll maturation periods in days across main-stem nodes in nine commercially available cotton cultivars in studies conducted at the University of Georgia Coastal Plain Experiment Station in 2001, 2002, and 2003.

Cultivar	Boll maturation period		
	2001	2002	2003
	d		
DPL 33B	50.1	56.5	51.9
DPL 491	49.9	58.0	53.2
DPL 565	50.5	58.8	52.3
DPL Pearl	49.6	57.2	51.5
FM 966	48.2	55.7	50.3
PM 1199R	48.1	53.2	49.6
PSC 355	49.2	56.2	50.6
PSC GA161	51.4	60.4	54.3
STV 4892BR	49.0	56.3	51.9
Mean	49.5	56.9	51.8
LSD(0.05)	0.9	1.1	1.6

across cultivars ended at main stem node 13 in all three years (Table 1). The remainder of the lint produced after these nodes to the plant terminal is approximately 10% (164 kg lint ha⁻¹) of the mean yield in 2001, 6% (59 kg lint ha⁻¹) of the mean yield in 2002 and 21% (270 kg lint ha⁻¹) of the mean yield in 2003. If effective flowering were defined as simply the first 20 d of the flowering period, physiological cutout occurred across cultivars at main stem nodes 14, 12, and 12 in 2001, 2002, and 2003, respectively. The remainder of the lint produced after these nodes to the plant terminal is approximately 5% (78 kg lint ha⁻¹) of the mean yield in 2001, 12% (110 kg lint ha⁻¹) of the mean yield in 2002 and 28% (364 kg lint ha⁻¹) of the mean yield in 2003. It should be noted the Bourland et al. (1992) guidelines were developed in Arkansas under intense late season insect pressure. The extended growing season and lack of severe late season insect pressure in the lower south-

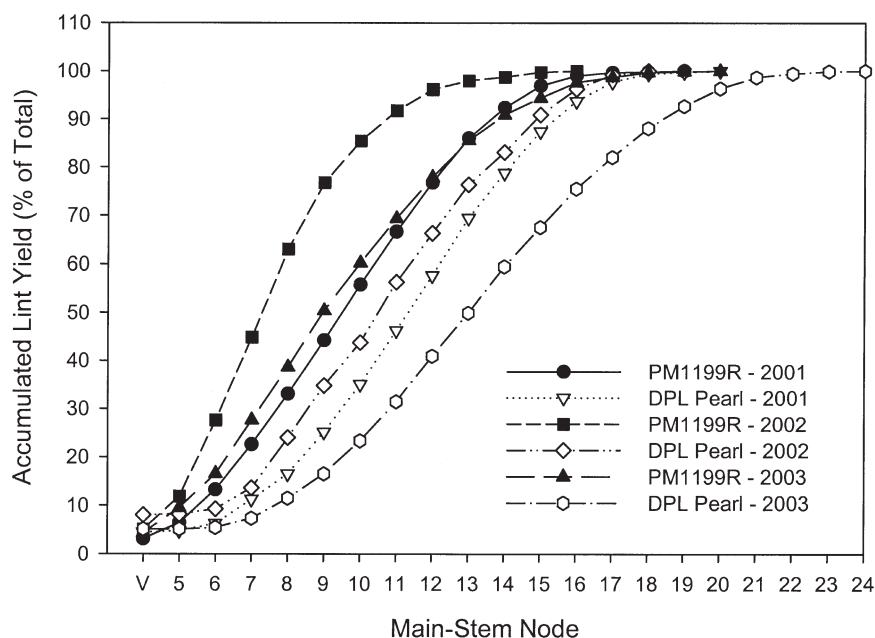


Fig. 2. Accumulated lint yields at each main-stem node expressed as a percentage of the total yield in studies conducted at the University of Georgia Coastal Plain Experiment Station in 2001–2003. Only DPL Pearl and PM 1199R are presented for clarity. LSD(0.05) = 4.0 (2001), 6.5 (2002) and 10.2 (2003). Average lint yields across cultivars was 1680, 920, and 1303 kg ha⁻¹ in 2001, 2002, and 2003, respectively.

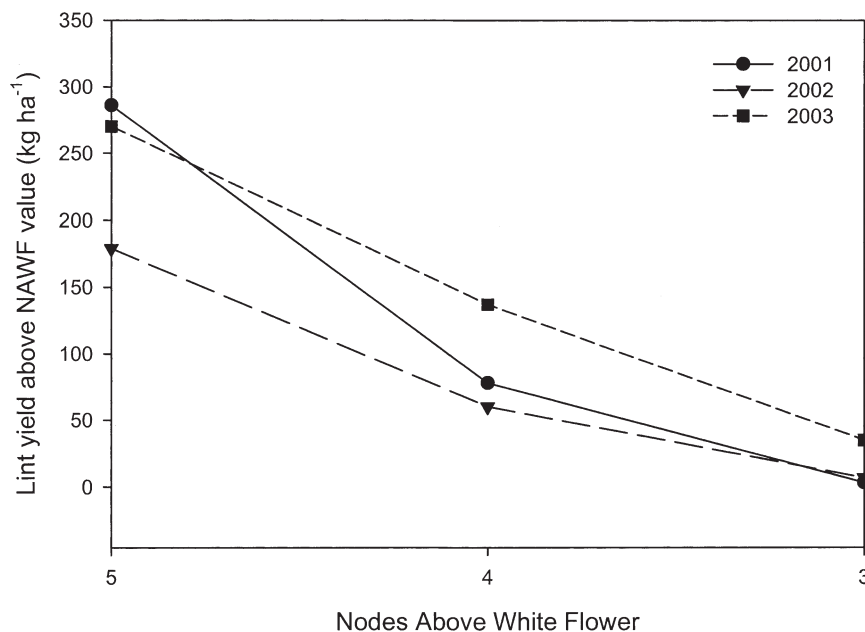


Fig. 3. Lint yield (kg ha^{-1}) above several nodes above white flower (NAWF) values in studies conducted at the University of Georgia Coastal Plain Experiment Station in 2001 through 2003. Values presented are the mean of nine cultivars differing in maturity classification.

eastern USA are more conducive to late season fruit maturation. Kerby (1996) defines the effective fruiting period as the time required to set 95% of all harvestable bolls. Using these guidelines, effective fruiting across cultivars ended at main stem node 15 or approximately 86 d after planting in 2001 and 2002 and main stem node 18 or approximately 96 d after planting in 2003.

Figure 3 illustrates the mean lint yield above several nodes above white flower values for each year. These data indicate as much as 15% of the total lint yield may occur after nodes above white flower = 5. If the lint were valued at $\$1.35 \text{ kg}^{-1}$ and the cost of a typical insecticide application was $\$20 \text{ ha}^{-1}$, fruit produced after nodes above white flower = 3 would be unprofitable to protect. Thus, in the lower Coastal Plain the effective flowering period appears to extend to nodes above white flower = 3.

CONCLUSIONS

In the cotton industry, there are many axioms regarding crop development. One of which pertains to the flowering intervals. McClelland (1916) was the first to report 3- and 6-d vertical and horizontal flowering intervals for cotton. These earliest reported flowering intervals continue to be accepted as true even today. Across cultivars, nodes and years, the average vertical and horizontal flowering intervals in the current study are 2.5 and 3.8 d, respectively. It should be noted, however, that flowering intervals are temperature, node, and cultivar dependent.

Another axiom regarding crop development pertains to the boll maturation period. In the current study, the number of degree days (base 15°C) needed for boll maturation was consistently longer than the generally accepted value of 470°C d (Oosterhuis et al., 1996). In addition, while the number of degree days required for

boll maturation decreased with increasing main stem node the number of calendar days required for boll maturation varied. Thus, these data indicate boll maturation cannot be defined solely on the basis of degree days or calendar days.

Another axiom regarding crop development pertains to physiological cutout. Physiological cutout in the desert Southwest refers to the interval in full season cultivars when flowering ceases completely between the first and top (i.e., earliest and latest matured) crops. In the humid Mid South, Bourland et al. (1992) have proposed physiological cutout occurs at nodes above white flower = 5 because fruit initiated after this point are seldom mature by harvest because of deteriorating fall weather and increasing insect pest pressure. In some regions of the U.S. Cotton Belt late season inclement weather and insect pest pressure may dictate physiological cutout indeed occurs at nodes above white flower = 5. In the lower southeastern USA, however, late season weather patterns and insect pest pressure are not as problematic and effective flowering may proceed to nodes above white flower = 3.

In the current study, the mean vertical flowering interval increased from main stem node 5 to about main stem node 11 and then began to decline, which is likely a matter of source-to-sink relationships. Vertical flowering intervals in the current study are also consistent with those from the earliest reports on this topic (McClelland, 1916). Thus, it appears that selection for early crop maturity has not affected the rate of vertical flowering. It has been suggested that the horizontal flowering interval is a heritable trait and can be manipulated in breeding programs (Godoy and Palomo, 1999). The horizontal flowering intervals reported in the current study are, at a minimum, 2 d shorter than the earliest reports. Thus, this trait may have been manipulated in the selection for earlier maturity cultivars.

Previous reports have also indicated the boll maturation period can be confounded by the effects of temperature and negate genotypic differences (Morris, 1964). In all years of the current study, FM 966 and PM 1199R possessed the shortest boll maturation periods while PSC GA161 possessed the longest. Because of a later planting date in 2002, the crop matured under a slower rate of degree day accumulation, which may be the driving force behind the year differences for boll maturation period (weighted mean of 49.5, 57.4, and 51.7 d in 2001, 2002, and 2003, respectively). Differences in the rate of degree day accumulation are also attributed to the year differences in weighted mean vertical flowering interval (2.12, 2.72, and 2.57 in 2001, 2002, and 2003, respectively) and horizontal flowering interval (3.2, 4.4, and 3.8 in 2001, 2002, and 2003, respectively).

The two early maturity cultivars (PSC 355 and PM 1199R) in the current study produced a greater percentage of their respective total lint yields at lower main stem nodes than the full season cultivars, which is consistent with the findings of others (Jenkins et al., 1990). Of the many possible pathways to earlier crop maturity, those investigated in this study that appear to have been most useful in breeding programs are (i) shortening of the horizontal flowering interval, (ii) shortening of the boll maturation period, and (iii) lengthening of sympodial branches at lower main stem nodes.

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