1277 COTTON WITHIN-BOLL YIELD COMPONENTS

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ABSTRACT

Cotton (*Gossypium hirsutum* L.) within-boll yield components have changed throughout the last thirty years of cultivar development. The question arises, how do within-boll yield components differ in contemporary high yielding cultivars? Nine commercially available cotton cultivars were over seeded and hand thinned to 10.8 plants m^{-2} in 2001, 2002 and 2003. Prior to machine harvest, plants from 6 m of one row were removed from each plot and hand harvested by fruiting position. After hand harvest, seed cotton from each fruiting position was ginned separately. Boll number, lint mass, seed number, seed mass, seed surface area and fiber properties were determined for each fruiting position. These data were then used for within-boll yield component calculations. One of the top yielding cultivars in this investigation (DPL 33 B), characterized by a smaller seed mass, produced greater total seed surface area per unit of land area, but lower lint mass and fiber number per unit of seed surface area. The other two top yielding cultivars in this investigation (DPL 491 and STV 4892 BR), characterized by a larger seed mass, produced lower total seed surface area per unit of land area, but greater lint mass and fiber number per unit of seed surface area. These data indicate fiber number and lint mass per unit of seed surface area are linked to seed size, which should be considered when selecting for increased lint mass or fiber number per unit of seed surface area.

INTRODUCTION

The relationships among cotton lint yield and its components are complex (Worley et al. 1974). Worley et al. (1974) concluded that boll number per unit land area was the largest contributor to lint yield, followed by seed number per boll and lint mass per seed. Culp and Harrell (1975) reported increased lint yield was possible under selection for medium to small bolls with the greatest possible number of small seeds per boll while maintaining a high lint percentage (lint mass relative to seed cotton mass). These authors suggested more seeds per boll may be desirable because of the greater amount of surface area for lint production within the boll (Harrell and Culp 1976). Bridge (1971) discovered a general change to smaller bolls, smaller seed and higher lint percentage in high-yielding Delta cultivars. Miller and Rawlings (1967) also found as yield increased by selection, lint percentage and seeds per boll increased while boll and seed mass decreased. Data from recent field experiments in Georgia showed two contemporary cultivars possessed lower boll and seed mass than any found in the cotton literature (Bednarz et al. 2006).

These findings illustrate within-boll yield components have changed as a result of selection for increased lint yield. The questions arise, how are within-boll yield components related to yield in contemporary high yielding cotton cultivars? Do these characteristics differ from earlier reports? Are small boll and seed mass a common characteristic of contemporary high yielding cultivars? If it is possible to identify common within-boll yield components among high yielding cultivars, selection criteria for future cultivar development may be identified that could capitalize on these most basic yield components. Hence, the objectives of this investigation were to determine how yield components differ in contemporary high yielding cotton cultivars.

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 91cm 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 days 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 stress was minimized with overhead sprinkler irrigation in all studies. Irrigation water was applied (2.54 cm) to all plots when soil water tension at any monitoring location fell below -40 kPa at the 20 cm soil depth or below -50 kPa at the 40 cm soil depth. Harvest aids were applied (2.3 L ha^{-1} of ethephon plus cyclanilide and 0.7 kg ai ha^{-1} of thidiazuron) when the crop achieved 90% open boll (20 September 2001, 13 November 2002 and 16 September 2003). The experimental design used was a randomized block design with four (2001 and 2003) or three (2002) replicates. Each plot was 4 rows (0.91 m spacing) wide and 15 m long.

Data Collection:

Immediately prior to machine harvest, plants from 6 m of one of the center rows were removed from each plot and taken to a field laboratory where they were later hand harvested by fruiting position. After hand harvest, seed cotton from each fruiting position was ginned separately. Boll number, lint mass and seed number, seed mass and seed surface area (after acid delinting) were determined for each fruiting position. Fiber from each fruiting position was delivered to Cotton Incorporated (Cary, NC) for fiber quality analyses. Fiber quality was determined using an Uster Technologies (Charlotte,NC) Advanced Fiber Information System (AFIS) instrument. Fiber fineness and mean fiber lengths from the AFIS data set were used to calculate fiber numbers. Fiber fineness is reported as fiber mass per unit fiber length (i.e. mg km^{-1}). Also, through ginning and acid delinting, lint mass $seed^{-1}$ was determined. Fiber fineness and lint mass $seed^{-1}$ data were used to determine total fiber length $seed^{-1}$. Mean fiber length data from 3,000 individual fiber length measurements, also reported by AFIS, and total fiber length $seed^{-1}$ data were then used to determine fiber number $seed^{-1}$. Seed surface area was determined through alcohol displacement and a series of coefficients described by Hodson (1920). For this analysis, 100 seed were placed in a graduated cylinder and covered with 20 ml of ethanol. The volume of ethanol displaced was then used for determination of seed surface area using the coefficients developed by Hodson (1920). Fiber number $seed^{-1}$ and seed surface area data were then used to determine fiber number cm^{-2} of seed surface area. Data presented in this manuscript are either the sum or weighted mean of all fruiting positions.

Statistical Analyses:

The initial combined data analyses showed interactions with year. Thus, the data are presented for each year (Steel and Torrie, 1980). The data for each year were analyzed as a split plot in time using Proc MIXED (SAS 2000) where the main plots consisted of replications and nine cultivars, and the split plots consisted of the main stem nodes. After analysis, weighted means or sums were found by averaging or summing over the nodes to obtain data for the nine cultivars.

RESULTS

Because of the wide range in planting date among years and its possible effect on yield components between years, degree days (heat units with a base of $15^{o}C$; DD15) were calculated. In 2001 the number of days elapsed from planting to defoliation was 135 with a total DD15 accumulation of 1391 ^{o}C d. In 2002 the number of days elapsed from planting to defoliation was 149 with a total DD15 accumulation of 1393 ^{o}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 ^{o}C d.

The cultivars utilized in this investigation were high-yielding Georgia cultivars, the recurrent parent of a high-yielding Georgia cultivar, or were presented by the seed companies as prime candidates for potential to commercialize. Thus, this collection of cultivars represented the products of commercial breeding that were most highly regarded by the planting seed industry. Across years, the top three cultivars in terms of lint mass (g m^{-2}) were DPL 33 B, DPL 491 and STV 4892 BR. While these cultivars were roughly equivalent in agronomic performance (i.e. lint yield), yield components among them clearly differed. Thus, our results will focus on these three cultivars and data from the other cultivars used in this investigation will not be presented. It would be informative, however, to survey yield components of lower yielding cultivars as well. An attempt was made during protocol development to select commercially available cultivars that were genetically diverse as well as high yielding. Unfortunately, agronomic performance of several of the selected cultivars was unacceptable, which was likely due to several factors other than yield components such as lack of ability to exploit a long season environment while tolerating intermittent periods of heat and drought stress. Thus, yield components of the underperforming (i.e. low yielding) cultivars will not be presented because it is suggested their unacceptable agronomic performance was likely due to their inability to acclimate to the Lower Coastal Plain and inter-relations among yield components under these environmental conditions many not reflect the relationships under more optimal conditions.

Harrell and Culp (1976) suggested breeders should select for increased number of bolls per unit land area with more seeds per boll. Bridge et al. (1971) and Miller and Rawlings (1967) indicated selection for increased lint yield resulted in cultivars with more seeds per boll and smaller boll and seed sizes. Of the top three yielding cultivars, DPL 33 B produced the greatest number of bolls m^{-2} followed by STV 4892 BR and then DPL 491 (Table 1). While DPL 33 B produced the greatest number of bolls m^{-2}, it also produced the least lint mass $boll^{-1}$ in all years (Table 1). In 2002 and 2003, DPL 491 and STV 4892 BR were equally greater in lint mass per boll than DPL 33 B. In two of the three years, DPL 33 B and DPL 491 produced the greatest number of seeds $boll^{-1}$ while STV 4892 BR produced the least (Table 2). Conversely, in all three years, seed mass (mg $seed^{-1}$) was lowest for DPL 33 B (Table 2). In summary, increased boll number per unit land area with more seeds per boll and smaller boll and seed sizes were suggested as desirable selection criteria more than 30 years ago. DPL 33 B more closely matched these criteria than the other top yielding cultivars utilized in this investigation.

Harrell and Culp (1976) indicated the rationale for the increased number of small seeds per boll was increased seed surface area within the boll for fiber development. As previously mentioned, DPL 33 B produced more bolls per unit land area with more seeds per boll (Tables 1 and 2). This also resulted in a greater number of seeds produced per unit land area with this cultivar (Table 2). The lower seed mass (mg seed^{-1}) of DPL 33 B (Table 2) was concomitant with lower seed surface area (cm^{2} seed^{-1}). The additional number of seeds produced with this cultivar per unit land area, however, resulted in a total seed surface area per unit land area (m^{2} m^{-2}) that was greater than any of the other cultivars included in the study (Table 3). Thus, while we did not measure total seed surface area within the boll as suggested by Harrell and Culp (1976), total seed surface area per unit land area, which is arguably one of the most basic components of yield potential, was consistently greater in one (DPL 33 B) of the top three yielding cultivars in this investigation.

While the other two top yielding cultivars included in this investigation (DPL 491 and STV 4892 BR) produced less total seed surface area per unit land area, lint mass produced per seed (mg seed^{-1}) was greater (Table 3). Greater lint mass per seed occurred through production of more fibers per seed with these two cultivars relative to DPL 33 B (Table 4). In 2001 and 2002 the number of fibers produced cm^{-2} of seed surface area and lint mass cm^{-2} of seed surface area was greater in DPL 491 and STV 4892 BR relative to DPL 33 B (Table 4). Thus, while DPL 491 and STV 4892 BR produced less total seed surface area, high lint yield per unit land area was maintained through greater lint production per seed and per unit seed surface area.

DISCUSSION

While we did not test this hypothesis, it is possible that seed size is the primary force driving yield components. DPL 491 and STV 4892 BR are larger seeded cultivars while DPL 33 B is small seeded (Table 2). It is interesting to note, therefore, that yield components in this investigation differed greatly between the cultivars. The larger seeded cultivars in this investigation produced fewer bolls per unit land area, more lint mass per boll, more lint mass and fiber number per seed and fewer seeds with less total seed surface area on a land area basis (Tables 1-4.). Cultivar differences with respect to lint yield, however, did not consistently differ across the three environments (Table 1).

Coyle and Smith (1997) indicated the difficulty associated with their measurement resulted in little selection pressure for within-boll yield components other than lint percent and concomitantly seed size. Harrell and Culp (1976) indicated high lint percentage would continue as the key selection criteria until a method to rapidly and economically determine lint frequency (i.e. lint mass per unit of seed surface area) was available. Culp and Harrell (1975) and Harrell and Culp (1976) conducted yield component studies using commercial cultivars and Pee Dee lines with release dates from 1945 to 1975. During this 30-year period, lint percentage increased from approximately 30% to 39%. Boll and seed size ranged from approximately 6 to 8 g seed cotton boll^{-1} and from approximately 120 to 140 mg seed^{-1}, respectively. The number of seeds boll^{-1} averaged about 36 while lint mass seed^{-1} averaged about 72 mg for medium to small seeded cultivars and 85 to 90 mg for the large seeded cultivars. Finally boll number m^{-2}

for the commercial cultivars and Pee Dee lines released throughout this 30-year period ranged from about 30 to 55. In the current investigation, lint percentage ranged from 38% to 41% across cultivars and years (data not presented). Boll and seed size across cultivars and years was 2.07 g lint boll^{-1} and 77.7 mg seed^{-1}. The number of seeds boll^{-1} across cultivars and years was 29.0 while lint mass seed^{-1} across cultivars and years was 68.5. Boll number across cultivars and years was 72.8 m^{-2}. Thus, it appears selection for increased yields during the last 30 years has resulted in cultivars with increased lint percentage but smaller seed and boll masses with fewer seeds boll^{-1} and more bolls m^{-2}. As reported earlier, Bridge (1971) and Miller and Rawlings (1967) indicated selection for increased lint yield resulted in cultivars during the late sixties and early seventies with more seeds boll^{-1} and smaller boll and seed sizes with more seed surface area within the boll for fiber development (Harrell and Culp 1976). Modern cultivars, however, may be characterized by even smaller seed and boll masses, but also fewer (not more) seeds boll^{-1}. While this may have resulted in less seed surface area within the boll for fiber development, the additional number of bolls on a land area basis combined with smaller seed size may have resulted in a total seed surface area on a land area basis that is even greater today.

As early as 1920 Hodson (1920) suggested breeders should use lint frequency (i.e. lint mass per unit of seed surface area) to improve yield potential. While one single yield component can not be considered alone, the weight of lint and number of fibers per unit seed surface area must be the most basic within-boll yield components (Coyle and Smith 1997). While the smaller seeded cultivar

(DPL 33 B) produced more total seed surface area on a land area basis (Table 3), lint mass on a seed surface area basis was lower (Table 4). The other two top yielding cultivars in this investigation (DPL 491 and STV 4892 BR), however, produced less total seed surface area on a land area basis but more lint mass on a seed surface area. These data indicate fiber number and lint mass per unit seed surface area are linked to seed size, which should be considered when selecting for increased lint frequency.

CONCLUSIONS

Interestingly, a large seeded cultivar by current standards would have been considered small seeded thirty years ago. It appears years of cultivar development for increased lint percentage has also resulted in reduced seed and boll mass. Miller and Rawlings (1967) suggested increased lint yield through selection for increased lint percentage has not only reduced boll and seed mass, but also fiber length and fiber strength. Stewart and Kerr (1974) also indicated selecting for lint percentage alone to increase yield could compromise fiber length and seed mass. It has been suggested fiber length varies by fiber location on the seed, seed location within the boll and boll location on the plant (Bradow and Davidonis 2000). Our data suggest cultivars with small seeds compensate for production of small bolls with less mass of fibers per seed through production of more bolls and seeds per unit land area. Thus, if a particular location on the seed or within the boll is a source of short fibers, the problem could become exacerbated when inadvertently selecting for small seeds.

Throughout the last sixty years of cultivar development it appears lint percentage has increased by as much as ten percent. The question arises, how much more can lint percentage increase? If fiber quality becomes less desirable with increased lint percentage/decreased seed mass then further increases in lint percentage are not advisable. Thus, selection for increased lint mass per unit seed surface area may be the next reasonable selection criteria. Across cultivars and years, if lint mass were increased 2 mg cm^{-2} of seed surface area, lint yield would increase by approximately 35 kg ha^{-1}.

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Table 1. Boll number per unit ground area and lint mass per boll and per unit ground area in studies conducted at the University of Georgia in 2001, 2002 and 2003.

Cultivar	2001	2002	2003	2001	2002	2003	2001	2002	2003
	Boll Number (m^{-2})			Lint Mass (g $boll^{-1}$)			Lint Mass (g m^{-2})		
DPL 33 B	108 a	78.0 a	86.9 a	1.79 c	1.75 b	1.91 b	182.8 a	120.8 a	109.2 a
DPL 491	81.4 c	58.3 c	71.9 b	2.40 a	2.17 a	2.27 a	172.7 a	95.88 a	91.11 ab
STV 4892 BR	94.2 b	63.1 bc	72.5 a	2.02 b	2.14 a	2.26 a	165.8 a	110.6 a	76.69 b
Mean	90.3	60.8	67.3	2.07	2.03	2.10	165.0	95.28	78.82
SE	6.02	5.12	7.04	0.05	0.08	0.10	13.34	14.27	15.74
P>F	0.0002	<.0001	0.0018	<.0001	0.0003	<.0001	0.5427	0.0208	0.0085

df = 24 in 2001 and 2003 and 18 in 2002.

Table 2. Seed number per boll and per unit ground area and individual seed mass in studies conducted at the University of Georgia in 2001, 2002 and 2003.

	2001	2002	2003	2001	2002	2003	2001	2002	2003
Cultivar	--------Seed Number ($boll^{-1}$)--------			-------Seed Mass (mg $seed^{-1}$)-------			---------Seed Number (m^{-2})---------		
DPL 33 B	29.22 b	28.31 a	30.62 ab	69.01 a	66.46 c	67.07 c	3118 a	1936 a	1818 a
DPL 491	30.93 a	29.89 a	31.78 a	75.73 b	73.59 b	74.15 b	2357 b	1302 b	1362 b
STV 4892 BR	25.68 c	30.91 a	27.88 b	80.20 c	78.89 ab	81.19 a	2312 b	1337 b	1010 c
Mean	28.6	28.6	29.7	77.8	78.3	76.9	2445	1325	1104
SE	0.7426	2.5358	0.7113	0.930	4.600	2.207	170.7	146.7	211.4
P>F	<.0001	0.6504	<.0001	<.0001	0.0313	<.0001	<.0001	0.0001	0.0005

df = 24 in 2001 and 2003 and 18 in 2002.

Table 3. Seed surface area per seed and per unit ground area and lint mass per seed in studies conducted at the University of Georgia in 2001, 2002 and 2003.

Cultivar	2001	2002	2003	2001	2002	2003	2001	2002	2003
	Seed Surface Area (cm^2 $seed^{-1}$)			Total Seed Surface Area (m^2 m^{-2})			-------Lint Mass (mg $seed^{-1}$)-------		
DPL 33 B	1.063 c	0.984 b	1.000 b	0.3315 a	0.1888 a	0.1808 a	56.32 b	54.01 c	54.46 c
DPL 491	1.108 b	1.014 a	1.115 a	0.2612 b	0.1317 b	0.1515 a	74.05 a	86.44 b	65.83 b
STV 4892 BR	1.133 a	1.050 a	1.111 a	0.2621 b	0.1395 b	0.1119 b	72.40 a	98.44 a	72.14 a
Mean	1.115	1.036	1.096	0.2717	0.1362	0.1195	67.94	72.20	65.28
SE	0.0096	0.0281	0.0319	0.0140	0.0130	0.0155	1.2167	1.175	1.8072
P>F	<.0001	<.0001	0.0004	0.0047	0.0003	0.0014	<.0001	0.0317	<.0001

df = 24 in 2001 and 2003 and 18 in 2002.

Table 4. Fiber numbers per seed and per unit seed surface area (SSA) and lint mass per unit seed surface area in studies conducted at the University of Georgia in 2001, 2002 and 2003.

	2001	2002	2003	2001	2002	2003	2001	2002	2003
Cultivar	-------Fiber Number ($seed^{-1}$)-------			-----Fiber Number (cm^{-2} SSA)-----			------Lint Mass (mg cm^{-2} SSA)------		
DPL 33 B	18507 c	15841 c	19719 b	17418 c	16135 c	19789 a	53.01 c	55.04 c	54.56 a
DPL 491	23909 a	28264 a	22388 a	21583 a	27959 a	20109 a	66.87 a	85.53 b	59.13 a
STV 4892 BR	21641 b	27447 b	23800 a	19120 b	26267 b	21428 a	63.94 b	94.21 a	64.96 a
Mean	21464	21059	22199	19253	20378	20319	60.92	69.78	59.66
SE	503.88	313.64	862.42	465.95	312.54	1066.3	1.0700	1.1500	2.5256
P>F	<.0001	0.0123	0.0004	<.0001	0.01451	0.4413	<.0001	0.0354	0.1037

df = 24 in 2001 and 2003 and 18 in 2002.