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Comparative Growth of Obsolete and Modern Cotton Cultivars. III. Relationship of Yield to Observed Growth Characteristics[1]

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ABSTRACT

Yield differences among cotton (*Gossypium hirsutum* L.) lines have been used as the measure of cultivar suitability in this century. The result has been a steady increase in yields as progressively newer cultivars have been developed, while little or no information pertaining to the alterations in growth responsible for the enhanced performance has been collected. To assess the association of growth response to lint yield, 12 cotton cultivars representing release years since 1900 were examined for yield, yield components, and their relationship to seasonal vegetative and reproductive growth patterns resulting from two planting dates during 1982. The observed yield of lint exhibited a linear increase in association with the increased year of cultivar release. The largest contributor to yield variation was the number of bolls produced. The modern cultivars (since 1950) produced a greater proportion of their total lint and boll number before 135 days after planting. The early lint production of these cultivars is associated with smaller vegetative plant canopies and an earlier transition to reproductive growth. The modern cultivars exhibited smaller boll weights and a greater lint percentage. Fiber quality, with the exception of micronaire, showed little improvement due to plant breeding. Micronaire tended to increase in the newer cultivars. The data indicate that breeding efforts have altered the number of harvestable bolls to a greater extent than any other characteristic.

***Additional index words:* *Gossypium hirsutum* L., Harvestable boll number, Fiber properties, Total lint.**

SEVERAL traits associated with cotton (*Gossypium hirsutum* L.) boll growth have undergone alterations as a result of selection for lint yield. The percentage of lint has been increased as a result of lint selection cycles (13) and with the development of more modern cultivars (2). Scholl and Miller (13) found that expected progress in lint yield increase was the same whether increased lint or lint percentage was the selection criterion. In contrast, selection for both greater seed per boll and larger seed would produce a reduction in lint yield. Further, cultivars with larger lint yields generally display seed that are smaller in size (2). The largest alteration in yield components concomitant with yield increases has been the increase in the number of bolls produced per unit land area (2,12,13). Bridge et al. (2) showed that the number of bolls per m^2 doubled when the lowest yielding cultivar was compared with the highest yielding cultivar. The simple correlation coefficient computed for the relationship between the mean values of lint yield and bolls per m^2 was 0.85.

Generally, a negative relationship exists between lint yield and fiber quality properties. Scholl and Miller (13) found that both 2.5% span length and fiber strength were negatively correlated with lint yield. Although Meredith and Bridge (11) and Verhalen et al. (14) found that cultivars are the largest source of variation in fiber properties, the timing of the lint harvest will affect lint quality during a season.

This study was pursued to 1) identify what differences in yield components and fiber quality have occurred in the development of cotton cultivars and 2) determine if a relationship exists between yield and growth parameters measured throughout the season.

MATERIALS AND METHODS

Twelve cotton cultivars representing lines developed since 1900 in both the Stoneville (STV) and Deltapine (DPL) backgrounds were grown during 1982 in Stoneville, MS. Two environments were provided by two planting dates, 26 April and 12 May. The plants were grown in 1 m wide rows which were 7.5 m long. The rows were thinned to 10 plants/m at 29 and 27 days after planting (DAP) for the 26 April and 12 May planting dates, respectively. Other cultural practices were described previously (15).

The experimental design was a randomized complete block with six replications. Seed cotton harvest occurring on different dates was considered a split of the whole plot in statistical analyses. Each plot consisted of 5 rows with one completely bordered row used for seed cotton harvest. Harvests occurred at 121, 136, 151, and 189 DAP for the 26 April planting, and at 120, 135, 163, and 173 DAP for the 12 May planting. At each harvest, to avoid selectivity in sampling, the first 50 open bolls in the harvest row were harvested for determination of yield components and fiber properties. After collection of the subsample, the remaining seed cotton from the 7.5 m row was harvested and yields recorded. The total seed cotton per row was the sum of the subsample and the remaining seed cotton of the 7.5 m row.

The weight per boll was determined for each harvest by dividing the weight of seed cotton subsample by the number of bolls collected, usually 50. The total number of bolls per plot per harvest was determined by dividing the total plot seed cotton (subsample plus harvested yield) by the weight per boll determined from the subsample. Lint percentage was determined on the boll subsample, and total lint was determined by multiplying the percent lint $\times$ seed cotton weight collected. Fiber properties were determined by Clemson Cotton Laboratory, Cotton Division, AMS, USDA, Clemson, SC 29631. The harvest at 173 days after

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Table 1. Cumulative lint yield at successive harvest dates of 12 cotton cultivars planted either 26 Apr. or 12 May 1982.

Cultivar	Year of release	Planting date: 26 Apr. Harvest date 121	136	151	189	12 May Harvest date 120	135	163‡
		kg/ha						
STV 825	1978	317	936	1082	1114	376	648	920
STV 213	1962	361	1046	1196	1234	427	713	1001
STV 2B	1938	151	535	684	742	182	380	606
STV 5A	1938	167	636	826	915	155	329	555
STV 2	1933	70	456	630	675	53	187	440
Lone Star	1905	53	287	420	650	59	144	465
DPL 41	1976	372	1059	1242	1283	504	840	1094
DPL 16	1965	232	848	1052	1111	314	556	884
DPL 14	1941	174	702	895	976	245	433	777
DPL 11	1932	153	667	874	955	213	380	820
Dixie Triumph	1914	125	513	650	701	143	306	552
Lightning Express	1905	225	710	847	884	265	461	707
$LSD_{0.05}$		56†	78	41	36	66	51	104

† $LSD_{0.05}$ for the difference among the cultivars in the amount of lint produced since the preceding harvest.
‡ 163 DAP or later.

the May planting was small and was combined with the harvest at 163 DAP. Replications 1 and 2, 3 and 4, and 5 and 6 were combined at all harvests for analysis of the yield components and fiber properties.

RESULTS

The greatest lint yields were exhibited by the modern cultivars regardless of the planting date (Table 1). Generally, there was a linear increase in total lint yield with later cultivar release date; significant correlation coefficients of 0.72 and 0.69 were computed for the relationships of the April and May plantings, respectively. For the April planting all cultivars had produced their maximal single harvest lint yields between 121 and 136 DAP. Following this time, decreasing amounts of lint were harvested. In contrast, the May planting resulted in a differential cultivar response in regard to the date of maximal harvested lint. 'STV 825', 'STV 213', 'DPL 41', and 'Lightning Express' had a single harvest maximum at 120 DAP with 376, 427, 504 and 314 kg lint/ha, respectively. The harvests at 135 and 163 DAP or later resulted in considerably smaller quantities of lint. The remaining cultivars exhibited maxima in harvested lint at 163 DAP or later. As a result, the cultivars with the earlier occurring lint yields produced a greater percentage of their total lint on or before 135 DAP of the May planting.

The earlier trend in lint production was evident in the April planting with STV 825, STV 213, DPL 41, and Lightning Express exhibiting 84.0, 84.8, 82.5, and 80.4% of their total lint production on or before 136 DAP, respectively. On the other hand, 'STV 5A', 'STV 2', 'DPL 11', and 'Lone Star' had 69.5, 67.5, 69.8, and 44.2% of their total lint by that time. The remaining cultivars were intermediate in response. The largest effect of the planting date was that the May planted cultivars consistently produced a smaller portion of their total yield before about 136 DAP than that observed in the April planting. This response was in spite of the generally greater quantity of lint produced before 120 DAP for the May planting vs. that produced by 121 DAP for the April planting date.

Table 2. Cumulative number of harvestable bolls at successive harvest dates of 12 cotton cultivars planted either 26 Apr. or 12 May 1982.

Cultivar	Year of release	Planting date: 26 Apr. Harvest date 121	136	151	189	12 May Harvest date 120	135	163‡
		Bolls/m²						
STV 825	1978	19.5	55.8	66.4	68.6	27.1	44.5	60.6
STV 213	1962	23.9	65.1	74.1	76.8	25.1	42.5	58.8
STV 2B	1938	9.5	31.3	40.2	43.7	12.4	24.8	37.8
STV 5A	1938	10.6	38.2	51.0	56.7	9.6	21.5	38.0
STV 2	1933	5.5	35.8	47.9	53.6	4.2	15.5	30.8
Lone Star	1905	3.0	14.5	24.1	35.5	3.3	7.6	22.5
DLP 41	1976	23.8	62.0	73.4	76.1	30.1	49.3	65.4
DPL 16	1965	12.4	49.5	62.2	65.5	18.1	30.5	50.3
DPL 14	1941	11.1	42.8	53.3	57.9	15.2	26.9	45.3
DPL 11	1932	8.7	38.1	50.3	54.7	12.9	22.4	48.4
Dixie Triumph	1914	9.5	35.6	46.2	50.0	10.8	20.9	37.4
Lightning Express	1905	13.5	51.9	63.8	67.2	22.0	38.4	60.6
$LSD_{0.05}$		3.1†	5.1	2.9	2.0	6.6	4.1	11.7

† $LSD_{0.05}$ for the difference among the cultivars at the same or different harvest dates in the number of bolls which have matured since the preceding harvest.
‡ 163 DAP or later.

Table 3. Simple correlation coefficients of the relationships between lint per m² and yield components for each harvest date and both planting dates.

Variable	Planting date: 26 Apr. Harvest date 121	136	151	189	12 May Harvest date 120	135	165†
Bolls/m²	0.88**	0.75**	0.66**	0.83**	0.91**	0.76**	0.67**
Weight/boll	−0.16	−0.13	0.33**	0.14	−0.16	0.01	0.20
Lint %	0.56**	0.64**	0.03	0.19	0.68**	0.54**	0.04
Seed cotton	0.98**	0.94**	0.94**	0.99**	0.98**	0.95**	0.97**

*,** Significant at the 0.05 and 0.01 levels, respectively.
† 165 DAP or later.

The number of bolls produced closely follow the trends in the amount of lint harvested over time (Table 2). Except for 'DPL 16' at the May planting, cultivars developed since 1950 produced the largest percentage of their bolls before 136 and 135 DAP for the April and May planting, respectively. Of the older cultivars, Lightning Express also produced a comparable percentage of its total boll number by this time. There was a significant positive correlation for the relationship of bolls per m² to lint yield at all harvests of both planting dates (Table 3).

The correlations of the total number of harvested bolls per m² from the seed cotton harvest to the parameters of vegetative and reproductive growth reported earlier (15, 16) for the 26 April planting date are presented in Table 4. At 96 DAP there were significant negative relationships between total vegetative, stem and leaf dry weights, and the total number of harvested bolls. The leaf dry weight and leaf area index at 142 DAP were also negatively correlated with the final boll number. Conversely, the parameters of reproductive growth were for the most part positively correlated with the harvested bolls per

Table 4. Simple correlation coefficients for the relationships between the total number of harvested bolls per m² from the seed cotton harvest and various parameters of growth measured at different dates for the 26 Apr. planting date.

Variable	38	52	69	96	117	142
	Days after planting					
	r					
Total dry weight†	−0.05	−0.06	0.05	−0.09	0.24*	0.18
Vegetative dry weight	−0.05	−0.08	0.03	−0.31**	−0.13	−0.16
Stem dry weight	−0.14	−0.09	0.03	−0.32**	−0.12	−0.11
Leaf dry weight	0.00	−0.06	0.02	−0.26**	−0.14	−0.43**
Leaf area index	0.14	0.01	0.01	−0.09	−0.01	−0.30**
Square number‡	0.42**	0.35**	0.47**	−0.14	−0.17	0.06
Immature boll number	--	--	0.37**	0.38**	0.52**	−0.13
Mature boll number	--	--	--	--	0.35**	0.65**
Square dry weight	--	0.30**	0.42**	−0.26*	0.03	0.06
Immature boll dry weight	--	--	0.16	0.40**	0.46**	−0.31**
Mature boll dry weight	--	--	--	--	0.31**	0.65**
RVR§	--	0.35**	0.46**	0.54**	0.49**	0.61**

*,** Significant at the 0.05 and 0.01 levels, respectively.
† Vegetative data from a previous report (15).
‡ Reproductive data from a previous report (16).
§ Reproductive to vegetative ratio.

Table 5. Simple correlation coefficients for the relationships between the total number of harvested bolls per m² from the seed cotton harvest and various parameters of growth measured at different dates for the 12 May planting date.

Variable	36	53	80	101	126	139
	Days after planting					
	r					
Total dry weight†	−0.15	0.00	−0.14	0.22	−0.05	−0.07
Vegetative dry weight	−0.15	0.01	−0.23*	−0.03	−0.27*	−0.31**
Stem dry weight	−0.15	−0.01	−0.22	−0.05	−0.25*	−0.27*
Leaf dry weight	−0.15	−0.01	−0.22	0.02	−0.33**	−0.42**
Leaf area index	−0.04	−0.07	−0.19	−0.02	−0.27*	−0.42**
Square number‡	0.11	0.34**	0.21	−0.14	--	--
Immature boll number	--	−0.07	0.41**	0.55**	0.18	−0.01
Mature boll number	--	--	--	--	0.48**	0.49**
Square dry weight	--	0.21	0.06	0.13	--	--
Immature boll dry weight	--	−0.09	0.36**	0.51**	−0.02	−0.05
Mature boll dry weight	--	--	--	--	0.41**	0.39**
RVR§	--	0.25*	0.48**	0.46**	0.48**	0.52**

*,** Significant at the 0.05 and 0.01 levels, respectively.
† Vegetative data from a previous report (15).
‡ Reprodutive data from a previous report (16).
§ Reproductive to vegetative ratio.

m². The relationships of the various reproductive structures to the harvested boll number show trends which correspond to the sequential maturing process of the structures. The number of squares, immature bolls, and mature bolls are significantly correlated with total harvested bolls per m² at 38 to 69, 69 to 117, and 117 to 142 DAP, respectively. The dry weights of these organs show similar trends with the exception of significant negative relationships of square dry weight and immature boll dry weight at 96 and 142 DAP, respectively. The reproductive to vegetative ratio was positively correlated with the number of harvested bolls, with coefficients of 0.35, 0.46, 0.54, 0.49, and 0.61 at each of the last five dates measured, respectively.

Table 6. Average weight per boll and lint percentage of 12 cotton cultivars planted on either 26 Apr. or 12 May 1982.

Cultivar	Year of release	Boll weight† 26 Apr.	Boll weight† 12 May	Lint percentage† 26 Apr.	Lint percentage† 12 May
		Planting date		Planting date	
		g/boll		%	
STV 825	1978	3.99	4.33	38.6	36.3
STV 213	1962	4.13	4.48	38.7	37.6
STV 2B	1938	5.17	5.22	32.3	31.2
STV 5A	1938	4.17	4.46	37.0	35.2
STV 2	1933	4.74	5.17	30.0	27.5
Lone Star	1905	5.37	5.86	35.2	33.4
DPL 41	1976	3.84	4.13	42.3	41.3
DPL 16	1965	4.59	5.01	37.7	36.1
DPL 14	1941	4.48	4.54	37.7	36.9
DPL 11	1932	4.60	4.66	38.1	36.8
Dixie Triumph	1914	4.35	4.73	31.6	30.4
Lightning Express	1905	4.36	4.51	30.2	29.8
$LSD_{0.05}$		0.47	0.40	1.2	0.9

† Average of all harvests.

The correlations of harvestable bolls with the growth parameters of the May planting showed similar trends (Table 5). The largest exceptions were the later occurrence of negative correlations concerning parameters of vegetative growth and a less prevalent association with the number and dry weight of the squares.

There were no significant harvest date × cultivar interactions for either the weight per boll or lint percentage. The smallest bolls formed on DPL 41 and STV 825, the newest of the cultivars, while largest bolls were produced by 'STV 2B', STV 2, Lone Star, and DPL 16 (Table 6). Bolls from the May planting were heavier than those from the April planting. A reciprocal effect was found in the percent lint with respect to the planting date. The April planting produced a higher lint percentage than did the May planting. STV 213 and DPL 41 produced the highest lint percentages, regardless of planting date, while STV 2, 'Dixie Triumph', and Lightning Express produced the lowest. The percent lint was significantly correlated with lint yield with correlation coefficients of 0.56 and 0.64 at 121 and 136 DAP for the April planting, and 0.68 and 0.54 at 120 and 135 DAP for the May planting.

There were no significant cultivar × harvest date or cultivar × planting date interactions for fiber properties. The cultivar main effect means from the April planting date are in Table 7. There was no noticeable trend in span length with respect to cultivar release year. Dixie Triumph, STV 5A, and DPL 11 produced the shortest fibers of both 2.5 and 50.0% span lengths. The longest fibers (2.5% span length) were produced by STV 2, DPL 16, and STV 825 with 29.46, 28.45, and 27.69 mm, respectively. The longest values of 50.0% span length exhibited by STV 2, DPL 41, and STV 825 were all 13.21 mm. On the other hand, the three most recent entries from Deltapine displayed the largest values of strength with DPL 14, DPL 16, and DPL 41 exhibiting 191.30, 189.23, and 187.96 kN m/kg, respectively. The newest Stoneville cultivars were intermediate in strength while STV 5A, Dixie Triumph, and DPL 11 were lowest with 160.69, 162.65, and 169.03 kN m/kg, respectively.

Table 7. Fiber properties of 12 cotton cultivars planted on 26 Apr. 1982.

Cultivar	Year of release	2.5% span length	50.0% span length	Strength	Elongation	Micronaire
		mm	mm	kN m/kg	%	reading
STV 825	1978	27.69	13.21	179.81	4.97	4.16
STV 213	1962	27.18	12.95	175.60	6.06	4.23
STV 2B	1938	27.18	12.45	169.32	4.98	3.65
STV 5A	1938	24.89	12.19	160.69	4.89	4.02
STV 2	1933	29.46	13.21	186.78	5.33	3.37
Lone Star	1905	26.92	12.95	181.68	7.84	3.53
DPL 41	1976	27.43	13.21	187.96	5.59	4.08
DPL 16	1965	28.45	12.95	189.23	7.12	3.81
DPL 14	1941	27.18	12.95	191.30	6.70	3.53
DPL 11	1932	25.65	12.19	169.03	7.01	3.92
Dixie Triumph	1914	22.61	11.18	162.65	7.05	3.69
Lightning Express	1905	26.67	12.95	178.15	7.37	3.67
$LSD_{0.05}$		0.51	0.51	6.67	0.35	0.19

Elongation was quite variable with values ranging from a low of 4.89 for STV 5A to a high of 7.84 for Lone Star. All cultivars developed before 1920 exhibited elongation values above 7.00. There was a reciprocal response in micronaire with three of the modern cultivars, STV 825, STV 213, and DPL 41, displaying the largest values. Values lower than these tended to be variable regarding the relative year of the cultivar release.

DISCUSSION

The total lint production by the cultivars supports the estimation of Meredith (10) that breeding efforts have resulted in a linear increase in the genetic yield potential of cotton over time. Conversely, changes in fiber properties are variable and do not exhibit trends of change associated with the relative age of the cultivars. This response is due to the major emphasis placed on increasing the yield of lint by both commercial and state plant breeders (9).

In this study, correlations between final harvested boll numbers and parameters of vegetative and reproductive growth from both planting dates indicate that the differences in dry weight partitioning play a large role in determining final boll number (Tables 5 and 6). Vegetative parameters are negatively correlated to final boll number late in the season indicating that continued growth of these plant parts after boll initiation decreases the number of bolls. This suggestion is supported by the positive correlations between the harvestable boll number and the reproductive to vegetative ratios found throughout reproductive development of both planting dates. Similarly, Meredith and Bridge (11) and Ewing (3) emphasized the importance of a greater proportion of lint production before or shortly after 'cut-out'. In this study, both the percentage of final bolls and lint produced before about 135 DAP demonstrate the greater boll development at earlier stages of growth. An increased amount of boll growth at an earlier stage would mean that coincidental assimilatory activity would be greater due to the presence of relatively younger vegetative organs. The cultivar Lightning Express is exceptional because of its profuse flowering and subsequent high boll number combined with a mediocre lint yield. This apparent anomaly is associated with the low lint percentage characteristic of this cultivar.

The number of bolls harvested from the April planting is smaller than the potential indicated by the number of mature and immature bolls found at 142 DAP (16). Aside from sampling variances, there are at least three reasons why the counts of mature and immature bolls are usually completely translated into harvestable bolls. First, while care to control pests was taken, there were no doubt some losses of immature bolls due to insects. Second, boll rot occurs frequently in the Mississippi Delta at all stages of boll development, but especially if high humidity is present at first boll opening. Third, abscission of immature bolls can occur when fruit loads are high and when temperature and light are limiting growth and reproduction (4).

Meredith and Bridge (11) found a reduction in weight of bolls maturing near the end of the growing season when temperature and solar radiation were well below the optimum. The reduction in weight per boll is largely at the expense of the seed weight and not due to lower seed number per boll or less lint per boll. This response indicates that under stressful and competitive conditions, the weight per boll will be smaller than under optimum or noncompetitive conditions. The weight per boll is also influenced by the genotypic potential of a particular cultivar as is evident of the cultivar differences in intraboll dry matter partitioning. While the deteriorating environment results in a reduction in the weight per boll, we did not detect any major cultivar × harvest date interactions for weight per boll. Although the late season environment reduced the weight per boll overall, there was no change in the relative ranking among the cultivars.

The response in weight per boll observed among the cultivars may be in part due to the number of bolls initiated by a cultivar. Modern cultivars have greater numbers of initiated bolls than obsolete cultivars (2), and the greater number may enhance the interboll competition for photosynthate, thus resulting in smaller bolls. This competition for photosynthate has resulted in inadvertent selections by cotton breeders for modern cultivars with smaller seed (2), thus most of the increased competition results in compensation at the expense of seed weight per boll and not lint per boll. While the correlations between the various yield components and yield (Table 4) have part-whole relationships as expressed by the yield model of: lint yield/m^2 = bolls/m^2 $\times$ boll weight $\times$ lint percentage, the relationships indicate which components of yield contribute the most to lint yield. This study and others (7, 12) show that the number of bolls produced is more important as a contributor to lint yield than boll weight or lint percentage.

While boll abscission can be induced by restricted assimilatory activity, older bolls tend to have priority over younger bolls for photosynthate (4). Therefore, there may be a stage in boll development after which abscission is not likely to occur. Abscission would be most likely during the first 3 weeks, or the enlargement phase of boll development, when the boll and its constituents reach their final volumes. After this time interboll competition for assimilates would occur during boll filling when the fiber and seed undergo the majority of their dry weight accumulation (6). The increases in fiber dry weight coincide with the incorporation of ^{14}C-assimilates into fibers (1).

Carbon dioxide enrichment studies in soybeans have shown that only those components of yield which are determined during the enrichment period were affected (5). High CO_2 concentrations during flowering increased the number of pods initiated but did not increase the yield indicating that there was not sufficient photosynthate available to complete seed development. If an analogous situation exists in cotton, early assimilatory capacity would alter boll initiation and retention while later season photosynthate production would induce responses in boll weight and internal boll partitioning. Mauney et al. (8) found that enrichment with 650 ppm (v/v) CO_2 during the entire reproductive period increased all reproductive parameters monitored. This indicates that reproductive growth may be limited by photosynthate production, yet little information is available pertaining to the particular processes that are affected by enhanced assimilatory activity at varied development periods.

From the patterns in yield, yield components and earlier measured parameters of vegetative (15) and reproductive (16) growth, several conclusions can be made concerning differences among old and new cultivars.

1. Modern cultivars make an earlier, more complete transition from vegetative to reproductive dry matter partitioning.
2. Modern cultivars partition more dry matter into reproductive structures. These same cultivars do not produce a larger amount of total dry matter, indicating that assimilatory activity is not greater in these cultivars.
3. Modern cultivars have a greater proportion of their reproductive development at an earlier stage, thus resulting in a greater amount of reproductive growth occurring when maximal leaf area and mass are present.
4. Modern cultivars generally produce more, smaller bolls with a higher lint percentage.
5. The changes in fiber properties, other than micronaire, brought about since 1900 seem small and show little association with period of cultivar development. Micronaire is higher in cultivars released since 1950.

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