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Growth Analysis of American Upland Cotton, *Gossypim hirsutum* L., with Different Leaf Shapes and Colors[1]

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ABSTRACT

Analysis of plant growth and development of biotypes of American Upland cotton (*Gossypium hirsutum* L.) with nine different combinations of leaf shape and color were made at two plant populations. The nine combinations of leaf shape and color were obtained by crossing Okra Leaf 'Stoneville 7A' BC_4 with Red Leaf Stoneville 7A BC_4 and then selecting the various leaf shapes and color combinations within the F_2 population.

Okra Leaf (L° L°) was associated with low incidence of boll rot, number of vegetative branches, node number of first-fruiting branch, dry weight of vegetative parts, leaf area, and with a shorter plant compared with normal leaf type. Okra Leaf also resulted in earlier maturity, higher harvest index, and higher seed cotton yield compared with normal leaf cotton. Okra Leaf had no effect on fiber length or fiber length uniformity, but caused a slight reduction in fineness and a slight increase in fiber strength.

The homozygous red color resulted in a significant reduction in seed cotton yield in an experiment with 45-cm spacing within the row. There were no significant interactions between leaf shape and leaf color.

All measurements for intermediate (heterozygous) leaf shape were between the values found for Okra Leaf and normal leaf cotton.

Additional index words: **Okra Leaf, Economic yield, Harvest index, Sympodium, Monopodium, Red Plant Body, Boll rot, Earliness.**

MANY factors are recognized as limiting to crop growth. Some factors, such as water, nutrients, insects, and diseases, are subject to control. When these factors are not limiting, the maximum productivity of crop plants depends principally on the amount of light interception and rate of CO_2 assimilation by the crop leaf surface (9).

To assess the influence of factors that might be limiting to productivity, it is useful to have an estimate of the ability of crop plants to accumulate dry matter. That portion of the dry matter that is economically useful is an important factor in determining overall agricultural efficiency (11).

It appears that major breakthroughs in the yield barrier can be obtained by changing plant shape to improve light interception without changing the fundamental processes of photosynthesis (3). To improve crop production scientists (3, 6) have constructed models showing that a leaf area index (LAI) sufficient to intercept 95% of sunlight is essential. When the LAI of plants with ordinary horizontal leaves is increased by planting more plants per unit area, the lower leaves are shaded. Instead of contributing to economic yield production, these shaded lower leaves may actually be parasitic, using more carbohydrate for respiration than the amount produced by photosynthesis (3).

Increasing density of cotton (*Gossypium hirsutum* L.) plants leads to increased LAI and decreased net assimilation rate (11). It appears that in order to obtain a highly effective LAI, a change in the shape, size, and orientation of the cotton leaf is necessary. The Okra Leaf mutant (L° L°) in cotton is characterized by deeply cleft and narrowly lobed leaves with less surface area per leaf and greater vertical orientation of leaves than normal leaf cotton. This type of orientation allows greater penetration of solar radiation to lower leaves, which results in the exposure of a high percentage of the leaves to a light intensity that will allow near-maximum net photosynthesis (1, 5).

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There is evidence that crop maturity in cotton is related to leaf type. Okra Leaf strains bloomed at a 50% higher rate in early season and reached optimum harvest about 7 days earlier than normal leaf varieties (1, 8). The morphological or structural indicators of earliness that are determinants of time and amount of fruiting have been recognized in cotton plants. In general, the lower the node (main-stem) at which the first sympodium is initiated, the earlier the crop matures (12, 13).

Andries et al. (1) found that the Okra Leaf type had no effect on fiber strength, fiber length, and fiber uniformity. It has been shown that the Okra Leaf was associated with up to 50% reduction in the average incidence of boll rot compared with normal leaf under the same conditions (1, 4, 8). The Okra Leaf character resulted in a more open type of plant canopy and could be expected to provide a microclimate less favorable for the development of boll rot than normal leaf plant. Okra Leaf plants were also associated with 41% reduction in leaf surface area and higher lint percentage compared with normal leaf cotton (1).

The present investigation was part of a comprehensive study designed to evaluate the growth and yield of American Upland cotton with different leaf shapes and color and to determine the relationship of these factors to maturity and certain agronomic characters in two plant populations.

MATERIALS AND METHODS

To produce materials for this study crosses were made during the summer of 1968 between plants with Red Plant Body ($R_1 R_1$)-normal leaf shape, 'Stoneville 7A BC_4,' and green leaf color-Okra Leaf shape, Stoneville 7A BC_4, of American Upland cotton. F_1 seeds were grown at Iguala, Mexico during the winter of 1968-69 to produce F_2 seeds. The F_2 of the above crosses were seeded in paper cups in the greenhouse on April 15, 1969 and April 10, 1970. The seedlings were transplanted to the Plant Science Farm, University of Georgia, around June 1 in both years.

The experimental design was a split-plot randomized block with four replications. For each leaf color three leaf shape treatments were established: (i) a population of Okra Leaf plants; (ii) a population of normal leaf plants; and (iii) a population of intermediate (heterozygous) leaf plants. The three leaf colors — red, intermediate red, and green — were assigned to main plots and three leaf shapes to subplots. Experiment A consisted of one-row plots 1 m apart and 9 m long. Hills were spaced at 90-cm intervals, with one seedling per hill. Experiment B contained one-row plots 1 m apart and 4.5 m long. One seedling was planted in each hill, with hills spaced at 45-cm intervals. The wide spacing in Experiment A was used to minimize competition effects and to provide a relatively large number of bolls per plant for the earliness estimates. Experiments were irrigated five times during the growing season each year. Weeds were adequately controlled in both experiments by a combination of mechanical cultivation and application of preemergence herbicides. Insects were controlled with regular application of insecticides.

Plant characters that are associated with earliness, such as rate of flower bud production (squaring), rate of blooming, rate of boll opening, and number of vegetative branches, were measured in both experiments in 1969 and 1970. These measurements were made according to the methods suggested by several investigators (10, 13). To measure the growth and fruiting characteristics of biotypes in both experiments the aboveground portions of four plants of each type were removed from the plots 2 weeks before the first harvest. Leaf area was measured by the disc method described by Johnson (7). Ratio of seed cotton (economic yield) to the total aboveground dry matter production (biological yield) was calculated at maturity and was expressed as harvest index (11).

Measurements of fiber fineness, fiber length, and fiber strength were made from each weekly harvest. These fiber property measurements were made by the Georgia Institute of Technology, Fiber Testing Laboratory. The incidence of boll rot was measured by methods described by Andries et al. (1).

Harvests were made at weekly intervals during the boll maturation period, starting September 5, 1969 and September 10, 1970 in both experiments. The number of bolls harvested at each picking was counted and the weight of seed cotton from each picking was recorded. The measurements, expressed as percentage, were transformed to angles prior to analysis to obviate the bias frequently encountered when percentage data are subjected to variance analysis. However, the values reported are in percentage.

The data collected were subjected to an appropriate analysis of variance on each test and to a combined analysis for 2 years. Duncan's Multiple Range Test was used to test for significant differences among treatment means. Arithmetic means and standard errors were calculated for some time-event characters. Correlation and linear regression methods were used for studies of interrelations among various characters.

RESULTS AND DISCUSSION

The initiation of squares occurred 8 and 10 days earlier in Okra Leaf than in normal leaf type in Experiment A and B, respectively (Table 1). These differences in fruiting period resulted in the Okra Leaf opening bolls 9 and 12 days earlier than normal leaf in Experiment A and B, respectively. These results are in agreement with those obtained by Andries et al. (1) and Jones and Andries (8), who reported that Okra Leaf type matured about 6 to 8 days earlier than normal leaf. The mean values for the intermediate leaf shape were between the other two leaf shapes. These results suggest that the Okra Leaf genotype may be used in developing early maturing varieties. In both experiments cotton with green leaf color had a longer squaring and boll opening period than cotton with red and intermediate leaf color (heterozygous red).

Richmond and Radwan (12) and Richmond and Ray (13) considered the mean maturity date (MMD) as one of the best methods of measuring earliness. They also reported that MMD has the highest heritability and is the most reliable measure of earliness

Table 1. Effect of cotton leaf shape and leaf color on the mean number of days from transplanting to squaring and boll opening, number of flowers during the first 2 weeks of blooming, and mean maturity date.

		Plant spacing							
		45 cm (Experiment A)				90 cm (Experiment B)			
		No. of days to		No. of open flowers/day	Mean maturity date†	No. of days to		No. of open flowers/day	Mean maturity date†
Biotypes		Squaring	Boll opening			Squaring	Boll opening		
Leaf shape	Okra	49.87 ± .17	134.23 ± .19	4.6 a*	20.4 b	51.11 ± .18	138.61 ± .25	3.9 a	19.8 b
	Intermediate	55.89 ± .25	140.73 ± .16	3.5 ab	24.4 ab	55.84 ± .21	142.30 ± .35	3.1 ab	21.4 a
	Normal	57.89 ± .14	143.58 ± .22	2.2 b	26.2 a	61.16 ± .16	150.78 ± .13	1.8 b	24.4 a
Leaf color	Red	54.53 ± .23	140.11 ± .22	3.1 a	23.7 a	54.89 ± .14	144.92 ± .16	3.1 a	21.5 a
	Intermediate	53.67 ± .13	136.80 ± .21	3.9 a	22.4 a	56.53 ± .15	143.75 ± .27	2.8 a	21.6 a
	Green	55.68 ± .19	141.62 ± .17	3.3 a	24.9 a	57.69 ± .27	147.02 ± .29	2.9 a	22.6 a

* Means followed by the same letter in each experiment do not differ significantly at the 5% level. † The mean maturity date expressed in days from September 2.

Table 2. Effect of leaf shape of cotton on plant characteristics.

	Plant spacing					
	45 cm (Experiment A)			90 cm (Experiment B)		
Character	Okra	Intermediate	Normal	Okra	Intermediate	Normal
Node number of first fruiting branches	5.34 b*	6.21 b	7.40 a	4.58 b	5.25 b	6.42 a
Number of vegetative branches	2.37 b	2.95 b	4.22 a	1.83 b	2.06 b	3.41 a
Percent of crop on vegetative branches	10.92 b	14.08 ab	25.67 a	4.24 b	6.84 b	8.94 a
Percent of crop harvested through 3rd week	48.47 a	39.47 b	32.43 b	50.97 a	45.36 b	38.89 b
Plant height, cm†	103.5 b	124.3 a	138.8 a	85.2 c	102.9 b	117.5 a
Number of green bolls/plant†	37.3 a	29.4 ab	20.0 b	26.5 a	19.5 ab	14.9 b
Number of flowers & squares/plant†	14.5 b	27.4 b	36.5 a	8.7 b	13.1 b	23.2 a
Dry wt fruiting parts/plant, g†	305.5 a	241.6 a	156.8 b	211.7 a	157.2 ab	122.3 b
Dry wt vegetative parts/plant, g†	181.1 b	256.4 a	310.6 a	118.2 b	216.8 a	196.7 a
Leaf area/plant, dm^2†	143.2 c	175.3 b	220.4 a	97.2 b	107.9 b	142.8 a
Percent of dry wt. stalk and leaves	64.59 b	74.90 a	77.11 a	61.78 b	69.62 b	76.06 a
Percent of unopened bolls	4.41 b	11.50 b	21.44 a	2.25 b	4.70 b	8.78 a
Percent of boll rot loss	8.47 b	11.55 b	15.49 a	2.76 b	7.01 ab	8.44 a
Final seed cotton yield, kg/ha	1,223 a	1,105 ab	960 b	1,642 a	1,571 a	1,323 b
Harvest index	35.27 a	24.98 b	22.65 b	38.06 a	30.15 ab	23.04 b

* Means for each characteristic within each spacing followed by the same letter do not differ significantly at the 5% level. † Measured when first bolls began to open.

in genetic studies. There were differences between leaf shapes for MMD (Table 1). The Okra Leaf shape cotton matured 5 to 6 days earlier than normal leaf cotton in both experiments. The rate of production of early flowers differed between Okra Leaf and normal leaf. However, there were no significant differences between Okra Leaf and intermediate leaf or between normal leaf and intermediate leaf in either experiment. No statistical differences associated with leaf color were found in earliness.

Morphological measurements of earliness have been shown to be associated with the amount of fruit (crop) produced at certain specified times (13). The percentage of crop harvested through the 3rd week of harvest and percentage of crop on vegetative branches were used as standards of comparison with two of the morphological measures, node number of first-fruiting branch (NNFB) and number of vegetative branches (NVB). There were significant differences between morphological characters associated with leaf shapes (Table 2). In both experiments NNFB and NVB were higher in normal leaf types than Okra Leaf and intermediate leaf. No significant differences were found between Okra and intermediate leaf shape in either experiment.

The Okra Leaf was earlier at each harvest than the normal and intermediate leaf (Fig. 1). The data showed that if first harvest is delayed until approximately 70% of the total bolls are open, as is generally recommended, the Okra Leaf treatment could have been harvested 6 days earlier than the normal leaf treatment. Similar results were reported by other investigators comparing Okra Leaf vs normal leaf (1, 2, 8). Data in Fig. 1 also indicated that after the fifth harvest there were 2% unopended bolls on Okra Leaf type compared with 14% unopened bolls on normal leaf type. These results show clearly the relative earliness of the Okra Leaf. The percentage of unopened bolls was lower in the higher plant population than in the low plant population, which may be attributed to fewer vegetative branches in the close row spacing (Table 2).

There were significant differences due to leaf shape for product-quantity measurements. The percentage of crop on vegetative branches was significantly higher in normal leaf than in Okra Leaf. In both experiments the percentage of crop harvested through the 3rd week was significantly higher in the Okra Leaf than normal and intermediate leaf. The differences between normal leaf and intermediate leaf were not

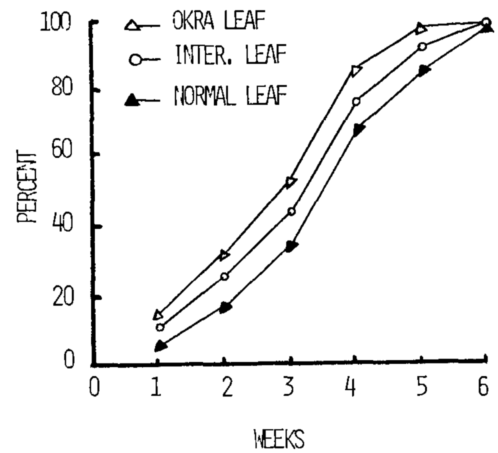

Fig. 1. Effect of leaf shape on weekly harvest of seed cotton as a percentage of total yield.

significant (Table 2). The morphological and product-quantity characters tested in both plant populations did not show any association with leaf color.

There was a negative correlation (—0.86) between NNFB and percent crop harvested through the 3rd week. There was a positive correlation (0.82) between NVB and the percentage of seed cotton yield on the vegetative branches. Similar results were obtained by other investigators (12, 13) in reference to NNFB and NVB.

The quantitative characterizations of plant height, number of green bolls, number of flowers and squares, dry weight of fruiting parts, dry weight of vegetative parts, and leaf area per plant were measured 2 weeks before the first harvest (Table 2). The Okra Leaf plants were shorter than plants with the other two leaf shapes. Two weeks before the first harvest the number of green bolls was significantly higher and the number of squares and flowers per plant was significantly lower in the Okra Leaf. These findings may be considered as an indication for relative earliness of crop maturity and a shorter fruiting period in Okra Leaf plants compared with normal leaf plants. A significantly higher dry weight of fruiting parts and lower dry weight of vegetative parts were found in Okra Leaf compared with normal leaf. The higher plant population (Experiment B) resulted in shorter plants and less total dry weight per plant compared with the lower plant population (Experiment A).

There were significant differences in leaf area per plant due to leaf shape (Table 2). The normal leaf plant had significantly higher leaf area per plant than did the Okra Leaf. The significantly higher dry weight of fruiting parts in Okra Leaf may indicate a better distribution of assimilate to the economically important parts of the plant in Okra Leaf compared with the other two leaf types. The higher light penetration to lower leaves would increase the effectiveness of Okra Leaf to produce higher economic yield with a relatively low leaf area. The mean values for the intermediate leaf were between normal and Okra Leaf. The differences between leaf color and leaf shape $\times$ leaf color interactions were not significant in either experiment.

Few references have been made in the literature to growth and fruiting analysis, comparing Okra Leaf with normal leaf cotton. Andries et al. (1) found that Okra Leaf plants had only 59% as much total leaf surface area as the normal leaf plants. They also reported significant increases in yield and earliness and 50% reduction in boll rot loss in Okra Leaf vs normal leaf cotton. The results of this study regarding growth and development of Okra Leaf plants vs normal leaf plants and findings of other investigators (1, 2, 8) indicate that it may be practical to use Okra Leaf type for a specific high plant population density cultural system.

There were significant differences among product-quantity characters due to leaf shape (Table 2). The Okra Leaf biotype had a lower percent dry weight in stalks and leaves, unopened bolls, and boll rot loss than did the normal leaf cotton. A distinction must be made between the economic yield of a crop (e.g., grain, tuber, seed cotton, etc.) and the total dry-matter yield or biological yield because the economic yield is more important to the producer than the biological yield. The Okra Leaf showed 13 and 15% higher harvest index in Experiments A and B, respectively, than normal leaf. The relative increase in harvest index value in Okra Leaf indicated a better distribution of dry matter to economic yield than with normal leaf cotton.

The harvest index values were slightly higher in the high plant population (Experiment B) compared with low plant population (Experiment A) for the three leaf shapes. These differences may be due to low development of vegetative branches in close row spacing. The relatively low vegetative growth in Experiment B was associated with low incidence of boll rot and low percentage of unopened bolls. There were significantly higher percentages of boll rot loss in normal leaf compared with Okra Leaf in both experiments. These findings were similar to those obtained by Andries et al. (1) and Jones and Andries (8).

There were significant differences in seed cotton yield due to leaf shape (Table 2). The Okra Leaf produced a higher seed cotton yield than normal leaf. All three leaf shapes yielded more seed cotton under high plant population than under low plant population. These differences may be due to high harvest index and less vegetative growth in high plant population. The values for intermediate leaf shape were between the other two leaf shapes for most quantitative characters. The only significant effect of leaf color in these experiments was a reduction in total yield for the homozygous red leaf plants in the high plant population. No significant interaction was found between leaf color and leaf shape. There was a highly significant negative correlation (—0.98) between harvest index and dry weight of leaves and stalks. These findings suggest the advantage of using harvest index along with yield in selecting plants for high economic yield.

The Okra Leaf character in cotton, which was associated with high harvest index, short plant, open type of plant canopy, and other relatively suitable agronomic characters, may be used as an efficient character in selecting plants for maximum net photosynthesis. It may also be of significant value in selecting strains better adapted for a high plant population, narrow row cultural system.

The Okra Leaf type had no effect on fiber length or fiber length uniformity, but caused a slight increase in fiber strength and a slight reduction in micronaire value (fineness). Percent seed germination was slightly higher in Okra Leaf compared with the other two leaf types. The fiber quality values and percent germination were not affected by leaf color.

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