THE EFFECT OF POPULATION DENSITY ON CERTAIN AGRONOMIC AND MORPHOLOGICAL CHARACTERISTICS OF COTTON

by

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CHAPTER I

INTRODUCTION

The potential for production of high quality cotton fiber on the Southern High Plains of Texas is limited by the environment. With the short growing season and relatively cool night temperatures, varieties generally do not develop their full potentials of yield and fiber quality in many seasons.

Predominantly in this area, cotton is harvested by the "once-over" method with the mechanical stripper. Before the crop is harvested, the plants must be killed by frost or with a chemical. Usually a part of the crop is still immature when the plants are killed. Therefore, harvesting in a single operation mixes the immature with the mature fibers; and the over-all fiber quality may be poor, especially if the crop contains a large percentage of immature bolls. The cotton in open bolls is also exposed to weather for a longer period of time with a single harvest than when several selective harvests are used. However, "once-over" stripper harvesting is the most economical method and has been the most profitable method in this area (31).

Two approaches to this problem are conceivable. First, plant characters which affect earliness and fiber maturity may be altered by changing the environment through cultural procedures; or secondly, these characters may be changed through plant breeding. Recent research indicates that a combination of these two approaches will be needed (16, 17, 18, 19).

One of the most promising approaches to the cultural modification of the cotton crop to improve earliness and fiber maturity is that of close-spaced row plantings with high plant population levels. This type of cotton culture has the potential of increasing lint yields, improving fiber quality, and reducing production costs (30, 41, 42).

Most problems which have limited the use of this type of cotton culture have been solved. Weeds can be controlled effectively with pre-emergence herbicides. Broadcast, fingertype strippers have been developed by workers in Texas and Arkansas which have proven to be efficient in harvesting narrow-row cotton (21, 23). However, none of the present commercial varieties are suitable for this type of culture. Research has indicated that an early, short growing, determinate fruiting plant is best suited to high populations (18). A plant of this type has been developed and tested at the South Plains Research and Extension Center, Lubbock, Texas. However, this experimental strain lacks certain attributes which must be corrected

before it will be acceptable as a variety.

Further investigations are also needed to provide a more complete and detailed analysis of how close-spacing affects plant characteristics, fruiting habits, yield and fiber qualities and other factors affecting plant growth and development.

The primary objective of this work was to provide initial information on the effect of population density on the growth and development of the plant, yield, maturity, and fiber qualities and to determine relationships which may exist between certain measures of plant growth and development and yield of lint and seed.

CHAPTER II

REVIEW OF LITERATURE

Competition in crops planted in close-rows at high population levels is almost entirely between plants of similar genotype, all planted at the same time and each growing under similar environmental conditions. McDougall (25) states that "Competition is an extremely important consideration in the growing of crop plants since if too many plants are grown on a given area, the actual yield will be reduced because of too much competition while if too few plants are present, the yield again will be reduced because the available water, light and nutrients will not be used to the greatest advantage." Clements, after years of experimentation and keen observation, was able to analyze and define plant competition as a purely physical process. Clements, et al. (6), stated, "With few exceptions, an actual struggle between competing plants never occurs. Competition arises from the reaction of one plant upon the physical factors about it, and the effect of the modified factors upon its competitors. Two plants, no matter how close, do not compete with each other so long as the water content, the nutrient material, the light and the heat are in excess of the needs of both. When the immediate supply of a single necessary factor falls below the combined demands of the plants, competition begins."

Plants show extreme plasticity in response to varying population density and the resulting environmental conditions. The cotton plant is no exception and has been shown to adapt to a wide range of population levels with only slight effect on total crop yield, although modification of certain individual plant characters does occur (13, 28, 29, 38). The study of cotton plant density is primarily an investigation of the cotton plant's reaction to the environmental changes resulting from variation in spacing of adjoining cotton plants.

Many investigators (7, 13, 20, 28, 29, 35, 37, 38) have measured these reactions, placing particular emphasis on those characters which influence yield and machine harvesting efficiency as affected by various plant population levels within conventionally spaced rows. These results generally indicate that as plant density increases, stalk diameter, plant height, size of branches, size of bolls, number of branches per plant, bolls per plant and nodes per plant decrease in a linear manner. The height of the first branch above the ground and the total plant weight per unit land area increase as plant population increases.

Stansel (37) noted that the number of vegetative branches were decreased more than the fruiting branches in the closer spacings and at spacings as close as 3 inches, no vegetative branches were formed.

Ray (28) found that the mean dry weight of the total plant and its parts increased as the plant population decreased; however, there were no significant differences on a per acre basis except for stalk weight within population levels of 11,900 to 55,600 plants per acre.

Yield data from population levels of 4,500 to 97,000 plants per acre have been inconclusive. Cotton and Brown (7) working with plant densities ranging from 4,500 to 55,000 plants per acre noted a yield reduction at the higher populations while other workers (13, 20, 29, 38) reported no significant yield differences at population levels ranging from 12,000 to 78,000 plants per acre. Smith and Miller (35), however, reported a varietal interaction to a population of 97,000 plants per acre on yield when compared to a population of 35,000 plants per acre. Yields were decreased at the high population when Deltapine was the variety, but no significant decrease was noted with Stormproof Number 1.

Ray, et al. (29), in a five year study, found that populations ranging from 18,800 to 77,400 plants per acre had no consistent affect on earliness nor fiber properties. There was a trend toward lower Micronaire at the higher populations, but it was slight for the plant densities studied.

For several years close-row spacing of cotton with high population levels has been studied in various parts of the Cotton Belt on

a limited scale. Wanjura and Hudspeth (41) in a five year study at Lubbock, Texas, found that cotton yields averaged ten percent higher on closely spaced rows than on conventional 40-inch rows. Fiber data were inconclusive, but indications were that very high plant populations can lower Micronaire. In another study by these investigators (42), an increase in yield of 258 pounds was obtained over 40-inch row cotton with Gregg cotton. The plant population for the narrow-row culture was approximately 240,000 plants per acre in the seedling stage and 75,000 plants per acre in the 40-inch rows. The narrow-row plants were shorter in height, narrower in spread and had bolls set higher on the plants than the conventionally spaced cotton.

As a part of the Regional Cotton Mechanization Project (16, 17, 19), a comprehensive study of cotton plant population and spacing patterns has been made. Population levels ranged from 15,000 to over a million plants per acre in single rows of 5, 10, 20, 30 and 40-inch rows and 50,000 to 200,000 plants per acre in two rows per 40-inch bed at four row spacings. The highest yields were generally made in the 5 and 10-inch single row spacings at the approximate population levels of an equidistant spacing pattern. There were no pronounced differences in lint yields in the two-rows per bed study, although the lower plant populations tended to produce higher yields.

The narrow-row spacings in the single row study and the two rows per bed generally produced higher bur cotton yields earlier than the 40-inch row pattern. However, because the narrow-rows generally had higher yields, the percentage of the crop that had reached maturity on a given date was slightly lower than that of the 40-inch rows. The effect of increasing plant population on plant characters was generally the same as that found in spacing studies of conventionally planted cotton. Plant height, weight, stem diameter, total nodes, leaf weight, branch length and weight, and weight and number of bolls per plant decreased linearly to an increase in plant density. The height to the first fruiting branch, number of nodes to the first fruiting branch and percentage of barren plants increased with an increase in population. The number of bolls per acre and the per acre weight of plant parts such as leaves, stems, and branches increased as plant population increased. The fruiting-vegetative ratio tended to decrease as plant population increased; however, in 1963 this trend was not readily apparent. The classer's data indicated that Micronaire index decreased as plant density within-a-row increased. This was the only classer's evaluation with an observable difference due to treatments.

In approaching the problem of variation in yield and factors related to crop quality, many researchers (1, 2, 3, 15, 26, 27, 33,

34, 40, 48, 49, 50) have begun to look more closely at some relationships that may be established between crop yield and variations in the environment, especially those variations that can be modified by cultural practices or by modifying characteristics of the plant through plant breeding.

Pioneers (4, 5, 14, 43, 44, 45, 48) in growth analysis have suggested such empirical relationships as relative growth rate, leaf area ratio, net assimilation rate, crop growth rate and leaf area index as useful measurements of plant response to variation in environment. These various estimates can be derived from primary growth data. Certain of these relationships may be useful in determining variation in economic yield.

Ashley, et al. (1) found that the relationship between leaf area index (LAI) and fruiting indicated that flower bud initiation and growth of young fruit on the cotton plant is dependent on concurrent vegetative growth. Late season boll set increased as long as LAI was at or above 5.0. When LAI fell below 5.0, the number of bolls was not increased further. The data also indicated the importance of producing a large plant early in the growing season for production of maximum yields under these conditions.

Muramoto, et al. (26) investigated the relationships among rate of leaf area development, photosynthetic rate and rate of dry

matter production among certain cottons. Their findings indicated a large amount of variation in photosynthetic rate within any one plant. Net assimilation rate of dry matter did not differ greatly among these same plants. Differences in rate of leaf area development were measurable and associated with differences in rates of dry matter produced among cottons and between cottons.

Several investigations have been made on various field and pasture crops where the effect of various population levels and spacing patterns on net assimilation rate, crop growth rate, and leaf area index have been studied (3, 30, 33, 34, 40, 49, 50).

Baker and Meyer (3) working with cotton concluded that regardless of plant size, sun angle or planting pattern, the crop growth rate is directly proportional to the amount of light intercepted. In this study, direct measurement of light interception was used rather than calculating light interception from leaf area measurements.

Williams, et al. (49, 50) demonstrated that dry matter production of corn was a direct function of solar radiation intercepted by the foliage canopy. It was also noted that crop growth rate usually approaches asymptotic values at high leaf-area indices, and that net assimilation rate declined as a curvilinear function of leaf-area index.

Wallace and Munger (40) working with dry bean varieties used relative growth rate, net assimilation rate, and leaf-area ratio to evaluate the relationship of these factors to seed yields. They concluded that the higher over-all relative growth rate and leaf growth rate of certain varieties was accompanied by a much higher leaf-area ratio, suggesting that leaf-area ratio may be the factor chiefly responsible for these differences in growth rates.

Shibles and Weber (33, 34) reported that the rate of dry matter production of soybeans was linearly related to the percentage of radiation intercepted. They also found that high population or close-spacing in any given direction will result in a longer period of vegetative production; thus, the vegetative production period encrouches upon the seed production period. Competition within the plant for the available carbohydrate results with less carbohydrate being available for seed production.

CHAPTER III

MATERIALS AND METHODS

This test was conducted at the South Plains Research and Extension Center of the Texas Agricultural Experiment Station, Texas A&M University, Lubbock, Texas, as a part of Project S-1384, financed in part by the Cotton Producer's Institute of the National Cotton Council. The primary objective of Project S-1384 is the modification of the cotton plant through genetic, cultural, and chemical means for adaptation to minimal maturation temperatures. The purpose of the experiment discussed in this paper was to study cultural means of circumventing the effects of minimal maturation temperatures.

This irrigated field experiment was conducted during the 1965 season on Amarillo loam soil. Growing conditions were nearly ideal with warm clear weather and with no insect or disease problems. Cultural practices currently considered best for production of irrigated cotton in narrow-row culture were used throughout the test. Uniform and highly precise stands of the desired plant population levels and spacings were obtained by planting to the desired row widths and thinning by hand.

Treatments. -- The treatments consisted of five plant population levels with equidistant plant spacings; that is, the spacing

within rows was equal to the spacing between rows. Table 1 shows the five spacing treatments, the plant population for each, and the ground area occupied by one plant.

A John Deere flex planter was used to obtain the desired row widths. The rate of planting was high enough to insure sufficient plants to obtain the desired spacings by thinning.

Table 1. Treatment designation.

Treatment designation 1/	Spacing (inches)	Plants per acre	Area per plant (sq. in.)
1A, 1B	5 x 5	250,900	25
2A, 2B	7 x 7	128,000	49
3A, 3B	10 x 10	62,700	100
4A, 4B	14 x 14	32,000	196
5A, 5B	20 x 20	15,700	400

1/ A-C.A. 491; B-Paymaster 101A

The thinning operation consisted of two steps: At 20 days after planting, the cotton in each plot was thinned to 2-3 plants per hill. Ten days later, each hill was thinned to one plant to obtain the designed spacings and population levels.

Test design. -- A split-plot design was used with varieties as main plots and spacings as subplots. Each plot was 38 feet by 14 feet and was replicated three times. (See field plan, Table 2, for arrangement of plots).

Table 2. Split-plot arrangement of plots.

Replication	Border	Blocks 1/				
		1	2	3	4	5
I	1	5B	2B	3B	1B	4B
	2	4A	5A	2A	3A	1A
II	3	1B	3B	4B	5B	2B
	4	3A	1A	5A	2A	4A
III	5	2A	3A	4A	5A	1A
	6	1B	5B	2B	4B	3B

1/ See Table 1 for treatment designation.

Varieties. -- Two varieties of different growth and fruiting habits were used -- Paymaster 101A, a commercial variety and C.A. 491, an experimental, dwarf-type cotton developed at the South Plains Research and Extension Center. These two varieties were chosen for this study for several reasons. Paymaster 101A is representative of commercial varieties of this area and is relatively early with good performance. Paymaster 101A differs somewhat from the C.A. 491 in fruiting and vegetative characteristics. The C.A. 491 is a dwarf-type plant, fruiting approximately two nodes lower and having shorter nodes, fewer vegetative branches, and a more compact structure than the Paymaster variety. The experimental variety is thought to be better adapted to the narrow-row culture, primarily due to its earliness, its dwarf character, and its fruiting habits.

The seed of both varieties used in this test were acid delinted. The Paymaster 101A seed was of 1963 Foundation Seed stock while the C.A. 491 seed was of a 1964 seed increase lot grown at the Center.

Cultural practices. -- The land area used for this test had been previously prepared for 40-inch row planting by chiseling, listing and preplant furrow irrigating. Fertilizer was applied in February at the rate of 120 pounds of ammonium nitrate per acre. Treflan, a pre-emergence type chemical herbicide, was applied in March at the rate of one-half pound per acre and worked into the soil.

After this site was chosen for the narrow-row cotton study, the beds were disked and leveled. Borders were constructed at 15 foot intervals across the test area, creating six main plots, 14 feet by 190 feet. The area between the borders was leveled again and plowed with a rotary tiller to a depth of 3 to 4 inches as final seedbed preparation.

The test was planted on May 27, 28, and 29. Treatment 1B of the 3rd replication was planted by hand, and the remaining plots were planted with a John Deere flex planter. (See Table 3 for planting rates).

Table 3. Planting rates.

Treatment designation	Pounds of seed planted per acre
1	224
2	160
3	112
4	80
5	56

On May 31, 0.89 of an inch of rain was received on the test plots which furnished sufficient moisture to bring the cotton up to a stand. Irrigation water was applied when the soil moisture level in the top twelve inches dropped to approximately two inches. Table 4 lists the irrigation schedule.

Climatic conditions. -- The effective rainfall is given in Table 5.

The heavy rains which occurred in September replenished soil moisture and may have retarded fiber development and boll maturation. The first killing frost occurred on November 22 with a low of 32 degrees Fahrenheit.

Table 4. Irrigation schedule.

Date irrigated	Acre inches of water applied
April 7 (preplant)	9.00
July 7	5.82
July 26	5.93
August 27	6.00
Total	26.75

Table 5. Effective rainfall during growing season 1/

Date	Rainfall, inches
May 31	0.89
June 15	0.48
September 18	1.06
September 19	2.55
September 20	0.98
October 17	0.94
Total	6.90

1/ Over 0.40 inches.

Vegetative samples. -- Five vegetative samples were planned but due to the large amount of labor and time involved, this number was reduced to four. The dates of the vegetative harvests were June 18, June 28, August 17 and October 25.

The first vegetative sample (June 18) was taken at the time of the first thinning operation. One hundred plants were collected from each plot and fractionated into leaves and stems. Discs were cut from leaves to make leaf area determinations. The designed spacings and population levels had not been achieved at this date; therefore, the plants sampled were subjected to much higher plant densities than the designed levels. The data collected at this date are of value only to determine relative size of the plants in each plant community at this period of the test.

The second vegetative sample (June 28) was taken at the time

of the second and final thinning operation. A hundred plants per plot were collected and the same determinations were made as for the first sample. The population levels at this time were 2 to 3 times that of the designed levels. However, the plants sampled at this date were representative of the plants remaining at the time the desired plant spacings were accomplished.

The third vegetative sample (August 17) was made 80 days after planting at approximately the peak bloom period. The sampling method used involved the removing of the number of plants from each plot that would occupy an area of 129 square decimeters. Every other plant was left in the sampling area so as not to disturb the environment of the surrounding plants more than necessary. The plants were pulled from the soil along with a portion of the tap root, taken to the laboratory, and fractionated into fruiting and vegetative components.

The fourth vegetative sample (October 25) was made at 149 days after planting. This sample date was somewhat later than desired but was sufficient to determine the final dimensions of the plant structures. The sampling technique was the same as that for the third sample.

Morphological measurements. -- The following morphological measurements and determinations were made from the August 17th

and October 25th sampling dates:

1. Plant height. The plant height was measured in centimeters from the point of the cotyledonary scars to the tip of the growing point of the central axis.
2. Stem diameter. The stem diameter was measured in centimeters at a point midway between the cotyledonary scars and the first true leaf node. This measurement was made on the plant samples harvested on October 25th only.
3. Number of nodes. The total number of nodes on the central axis of each plant was counted beginning with the node immediately above the cotyledonary scars.
4. Nodes to the first fruiting branch. The nodes on the main axis to the point at which the first fruiting branch arises from the main axis were numbered in ascending order, with the node immediately above the cotyledonary scars designated as node number one.
5. Number of fruiting forms. The number of open blooms, squares, and bolls was combined as the total number of fruiting forms. This determination was made on a unit area of land basis and on a per plant basis.
6. Number of vegetative branches. A determination of the

number of vegetative branches produced on the central axis was made for each plant.

7. Number of fruiting branches. A determination of the number of fruiting branches produced on the central axis was made for each plant.

8. Weight of fruiting and vegetative components. The oven dry weights of leaves, stems, vegetative branches, fruiting branches, and fruiting forms were expressed in grams per square meter of land area.

9. Leaf area index (LAI). The leaf area index is defined as the ratio of leaf area to area of land occupied by the crop. Leaf area was measured by the dry-weight method as described by Rhoads and Bloodworth (32). Leaves were removed from the plants. A circular cork cutter was used to cut discs of leaf tissue from the approximate center of a representative number of leaves from each plot sample. The area of the cork cutter was determined, and the combined area of the leaf discs of each plot was calculated. These discs were oven dried and weighed to determine leaf area per unit of weight. The total leaf area per plot was calculated from this figure. The leaf area index was then computed using this leaf area. Leaf area and leaf

area index were computed on all treatments and all vegetative samples.

10. Fruiting-vegetative ratio. This is defined as the ratio of dry weight of fruiting forms to the total dry weight of vegetative components.

Other determinations made from the vegetative samples include net assimilation rate, crop growth rate, relative growth rate, and leaf-area ratio. These data were computed for the 50 day period between the June 28th sampling date and the August 17th sampling dates only.

1. Net assimilation rate (NAR). The net assimilation rate as conventionally expressed is a measure of the net gain of dry matter of a community of plants relative to their leaf area and is usually used as an indicator of mean photosynthetic efficiency (44). In this study, NAR was expressed as grams of dry weight accumulated per square meter of leaf area per day. Mean net assimilation rate calculations were based on an exponential relationship between crop-dry-matter production (W) and leaf area (L) and were computed for a time interval t_1 - t_2 as follows from the formula given by Whitehead and Myerscough (47):

$$NAR = \frac{(W_2-W_1)\,(L_2^{a-1}-L_1^{a-1})a}{(L_2^{a}-L_1^{a})(a-1)}$$

The exponent "a" is the ratio of the mean relative growth rate in leaf area over a time interval t_1-t_2, and is calculated from the formula:

$$a = (\log W_2 - \log W_1)/(\log L_2 - \log L_1)$$

2. Crop growth rate (CGR). The crop growth rate is defined by Watson (45) as the time rate of dry matter accumulation referred to a unit of land area or the yield of dry matter per unit land area. In this experiment, CGR was expressed as grams of dry matter accumulated per square meter of land surface per day. It is calculated from the following formula

$$CGR = \frac{W_2 - W_1}{t_2 - t_1}$$

where W_1 and W_2 are the initial and final total dry weight yields, respectively, per square meter of land surface; and t_2-t_1 is the length of the experimental period in days.

3. Relative growth rate (RGR). This was computed as the ratio of the final dry weight of plants to the initial dry weight of plants per unit area of land for the experimental

period, expressed as a logarithm. Relative growth rate as defined by Blackman (4) is the efficiency index of the plant (crop) and represents the efficiency of the plant (crop) as a producer of new material. Following Fisher (14), mean relative growth rate for the experimental period was calculated from the formula

$$RGR = \log_e W_2 - \log_e W_1$$

where W_1 and W_2 are the initial and final total dry weights, respectively, for the experimental period.

4. Leaf area ratio (LAR). This is defined as the ratio of leaf area expressed in square decimeters per square meter of land area to plant weight expressed in grams per square meter of land area. This may be regarded as an index of the amount of "growing material" per unit dry weight of the plants (44).

Agronomic measurements. -- An area of 6.194 square meters was staked out in the central portion of each plot for the purpose of collecting yield data. Mature bolls were harvested by hand at weekly intervals beginning October 4 and continuing to frost. A final harvest was made on December 17. Determinations that were made from the yield plots included the following:

1. Rate of crop maturation (earliness). The cumulative

weight of lint through a specified date, expressed as a percentage of the total crop.

2. Cumulative yield of lint. The weight of lint harvested through a specified date.

3. Boll size. The average weight in grams of seed cotton per boll.

4. Lint percentage of seed cotton. The ratio of lint weight to seed weight expressed as a percentage.

5. Lint percentage of bur cotton. The ratio of lint weight to seed and bur weight expressed as a percentage.

6. Seed index. The weight in grams of 100 seeds.

7. Lint index. The weight in grams of lint from 100 seeds.

The lint index was not determined directly but calculated from the formula:

$$\text{Lint index} = \frac{\text{Lint percentage} \times \text{seed index}}{100 - \text{Lint percentage}}$$

8. Seeds per boll. The average number of seed per boll.

This was calculated from the formula:

$$\text{No. of seed per boll} = \frac{\text{Seed wt. (gms) per plot} \times 100}{\text{Seed index} \times \text{No. bolls per plot}}$$

9. Fiber properties. The fiber properties of length, strength, and fineness were measured for lint taken from the yield

plots of replications 2 and 3 only. These determinations were made by the laboratories of the Cotton Research Committee at Texas Technological College and include the following as defined by the Cotton Testing Service of the Agricultural Marketing Service (39):

a. 2.5% Span length-- The length in inches that is exceeded by 2.5 percent of the fibers. This value approximates the classer's staple length.

b. 50% Span length-- The length in inches that is exceeded by 50 percent of the fibers.

c. Fiber strength (PSI)-- The fiber strength of a bundle of fiber as measured by the Pressley tester and expressed in thousands of pounds per square inch.

d. Micronaire -- The fineness of the fiber expressed in micronaire units.

Statistical procedures. -- The data were subjected to analyses of variance and in some cases regression and correlation analyses, as outlined by Snedecor (36). Duncan's New Multiple Range Test (24) was used to test significance of differences among means.

CHAPTER IV

RESULTS AND DISCUSSION

The effect of plant density on the growth, development, maturity, yield, and fiber properties of cotton was determined from data collected on four vegetative harvest dates at 20, 30, 80 and 149 days after planting and from weekly harvests of bur cotton beginning October 4 and continuing to frost. Tables 6 through 20 summarize the results of this test. The means of spacing treatments of each variety, the means of both varieties, and the significant differences among treatments at the 5 percent level as determined by the Duncan's New Multiple Range Test (24) are given. Table 21 lists the standard errors, coefficients of variation, and "F" values of the data tested.

Plant Characters

Tables 6 through 9 summarize the effect of plant density on the vegetative growth and development of cotton.

Dry weight per plant and leaf area per plant did not show any significant differences due to spacings at 20 days after planting (Table 6). Therefore, vegetative weight per acre was directly related to the number of plants per acre (Table 7). This was essentially true at 30 days after planting, although there were significant differences among treatments in dry weight per plant and leaf area

Table 6. The effect of plant density on total weight per plant and leaf area per plant of two cotton varieties at two vegetative harvest dates.

Plant spacing inches	Weight per plant-grams Harvest date 1/ 6/18	6/28	Leaf area per plant-sq. dec. Harvest date 1/ 6/18	6/28
		C.A. 491		
5	.176	.453 c 2/	.308	.456 d
7	.188	.536 b	.322	.532 c
10	.193	.661 a	.334	.674 a
14	.183	.640 a	.326	.663 ab
20	.189	.565 b	.330	.607 b
		Paymaster 101A		
5	.195	.484 d	.317	.475 d
7	.197	.596 c	.317	.594 c
10	.206	.634 bc	.334	.628 bc
14	.202	.682 ab	.343	.690 ab
20	.212	.729 a	.349	.735 a
		Mean of both varieties		
5	.185	.468 c	.313	.466 c
7	.193	.566 b	.319	.563 b
10	.200	.648 a	.334	.651 a
14	.193	.661 a	.334	.676 a
20	.201	.647 a	.339	.671 a

1/ Harvest dates: 6/18 - 20 days after planting;
6/28 - 30 days after planting.

2/ Any two means followed by the same letter are not significantly different at the 5% level as determined by the Duncan's New Multiple Range Test.

Table 7. Effect of plant density on total weight of two cotton varieties at four vegetative harvest dates.

Plant spacing inches	Dry weight - grams per square meter Harvest dates - days after planting 6/18 20 days	6/28 30 days	8/17 80 days	10/25 149 days
		C.A. 491		
5	10.9 a 1/	28.1 a	694 a	1578 a
7	6.0 b	16.9 b	581 b	1344 b
10	3.0 c	10.2 c	509 c	1102 c
14	1.4 d	5.0 d	464 c	971 c
20	0.7 d	2.3 e	357 d	714 d
		Paymaster 101A		
5	12.1 a	30.0 a	746 a	1403 a
7	6.2 b	18.9 b	608 b	1315 a
10	3.2 c	9.8 c	514 c	1066 b
14	1.6 d	5.3 d	456 cd	1024 b
20	0.8 d	2.8 e	399 d	833 c
		Mean of both varieties		
5	11.5 a	29.0 a	720 a	1490 a
7	6.1 b	17.9 b	595 b	1329 b
10	3.1 c	10.0 c	473 c	1084 c
14	1.5 d	5.1 d	460 c	997 c
20	0.8 d	2.6 e	378 d	773 d

1/ Any two means followed by the same letter are not significantly different at the 5% level as determined by the Duncan's New Multiple Range Test.

per plant and a general trend to larger plants with larger leaf areas in the lower population levels.

At 80 days after planting, the total plant weight per unit land area was still positively correlated to plant density (Table 7). However, total plant weight in the 5" x 5" spacing was only about twice that of the 20" x 20" spacing. The total plant weight of Paymaster 101A was not significantly higher than that of C.A. 491.

Total plant weight per unit land area continued to be directly related to plant density at 149 days after planting, as shown by Figure 1. The relationship was geometrical with the total plant weight increasing at an average rate of 228 grams per square meter of land area with each doubling of the population. The stem diameter, plant height, and the number of nodes per main stem significantly decreased as the number of plants per acre increased (Table 8). However, the weight of stems and leaves per unit area of land (Table 9) was positively correlated to plant density and increased at an average rate of 70 and 39 grams, respectively, per square meter of land area each time the population doubled (Figures 2 and 3). The reduction in plant height was significantly more pronounced in the C.A. 491 than the Paymaster 101A (Figure 4), while stem diameter was affected similarly in both varieties (Figure 5).

LUBBOCK, TEXAS

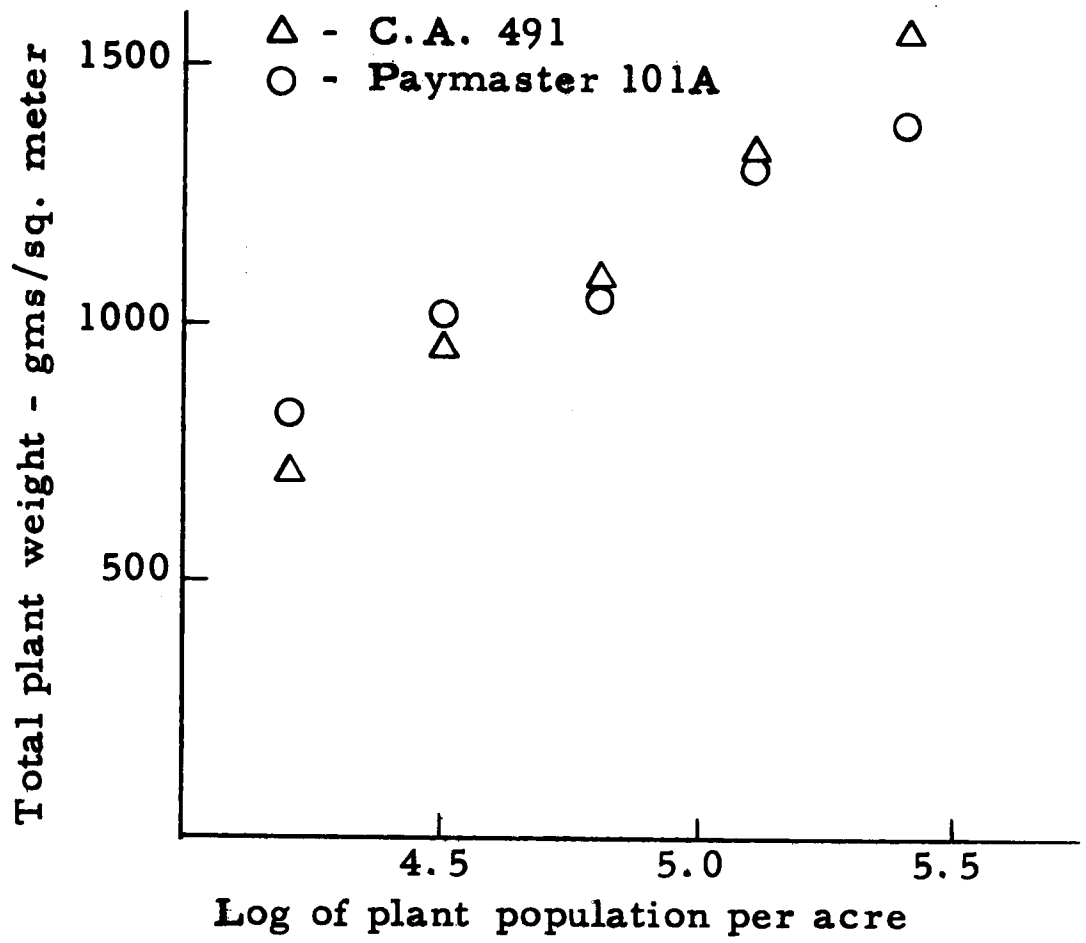

Figure 1. The effect of plant density on the total dry plant weight per unit area of land of two cotton varieties at 149 days after planting.

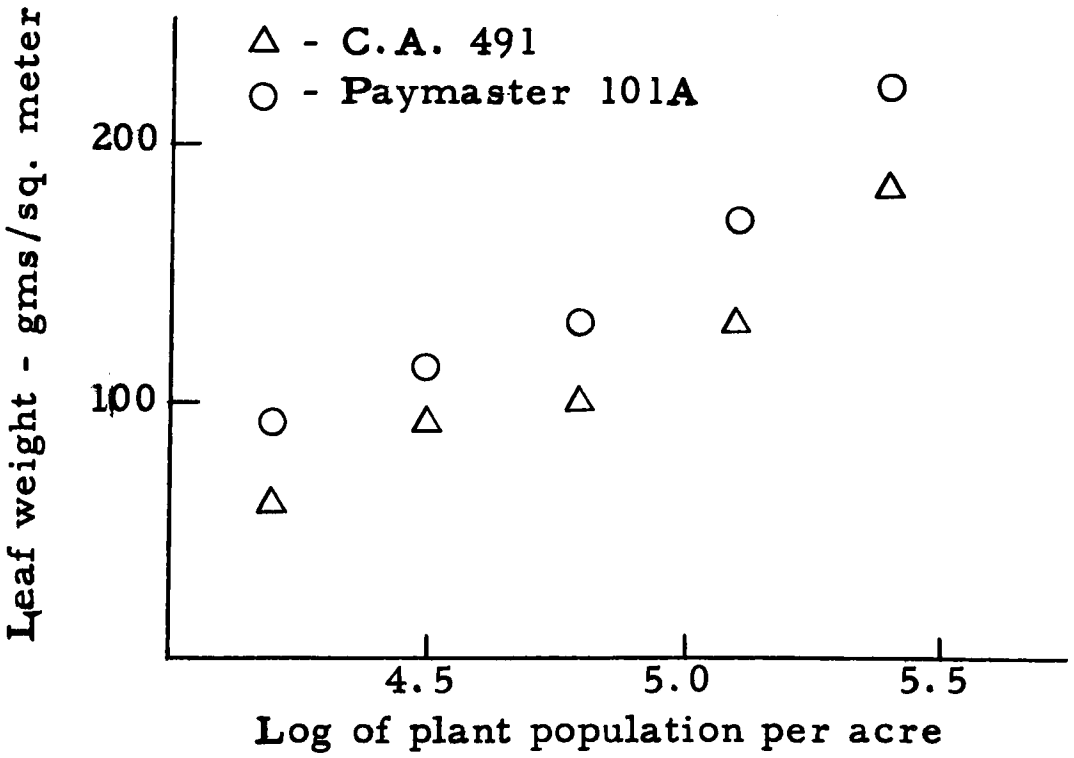

Figure 2. The effect of plant density on the dry weight of leaves per unit area of land of two cotton varieties at 149 days after planting.

Table 8. Effect of plant density on certain vegetative characteristics of two cotton varieties at 149 days after planting.

Plant spacing inches	Vegetative Characteristics					
	Stem diameter cm.	Plant height cm.	No. of nodes per plant	No. of nodes to first fruit. branch	No. of vegetative branches	No. of fruiting branches
			C.A. 491			
5	.503 e 1/	58.55 c	16.69 c	6.19 a	0.19 c	8.93 c
7	.579 d	58.94 c	17.47 c	5.05 bc	0.24 c	10.56 c
10	.711 c	67.72 bc	19.57 b	5.33 b	0.77 b	12.60 b
14	.836 b	70.28 ab	20.57 ab	4.40 d	0.80 b	14.33 b
20	.965 a	78.36 a	21.80 a	4.53 cd	1.27 a	16.33 a
			Paymaster 101A			
5	.508 e	67.46 b	14.96 d	6.65 a	0.31 e	7.21 c
7	.612 d	75.99 ab	17.09 c	6.72 a	1.01 d	9.38 b
10	.712 c	73.08 ab	18.35 bc	6.42 ab	1.78 c	11.07 b
14	.876 b	81.43 a	19.57 ab	6.00 b	3.30 b	12.97 a
20	1.074 a	80.17 a	21.00 a	6.33 ab	4.40 a	14.00 a
			Mean of both varieties			
5	.505 e	63.01 d	15.83 e	6.42 a	0.25 e	8.07 e
7	.596 d	67.47 cd	17.28 d	5.89 b	0.63 d	9.97 d
10	.714 c	70.41 bc	18.96 c	5.88 b	1.27 c	11.83 c
14	.856 b	75.86 ab	20.07 b	5.20 c	2.05 b	13.65 b
20	1.020 a	79.27 a	21.40 a	5.43 c	2.83 a	15.17 a

1/ Any two means followed by the same letter are not significantly different at the 5% level as determined by the Duncan's New Multiple Range Test.

Table 9. Effect of plant density on the weight of certain vegetative plant components of two cotton varieties at 149 days after planting.

Plant spacing inches	Dry weight - grams per square meter (land)			
	Leaves	Stems	Vegetative branches	Fruiting branches
		C.A. 491		
5	184 a 1/	273 a	1.6 c	68 a
7	129 b	178 b	5.1 bc	60 ab
10	99 c	136 c	9.9 ab	77 ab
14	91 c	89 d	13.4 a	54 bc
20	61 d	59 e	12.1 ab	43 c
		Paymaster 101A		
5	222 a	292 a	2.1 d	61 ab
7	169 b	226 b	10.7 c	74 a
10	129 c	143 c	17.2 c	56 b
14	112 cd	109 d	36.8 b	58 b
20	91 d	66 e	46.1 a	40 c
		Mean of both varieties		
5	203 a	283 a	1.9 d	65 a
7	149 b	202 b	7.9 c	67 ab
10	114 c	140 c	13.5 b	59 ab
14	101 c	99 d	25.1 a	56 b
20	76 d	62 e	29.1 a	41 c

1/ Any two means followed by the same letter are not significantly different at the 5% level as determined by the Duncan's New Multiple Range Test.

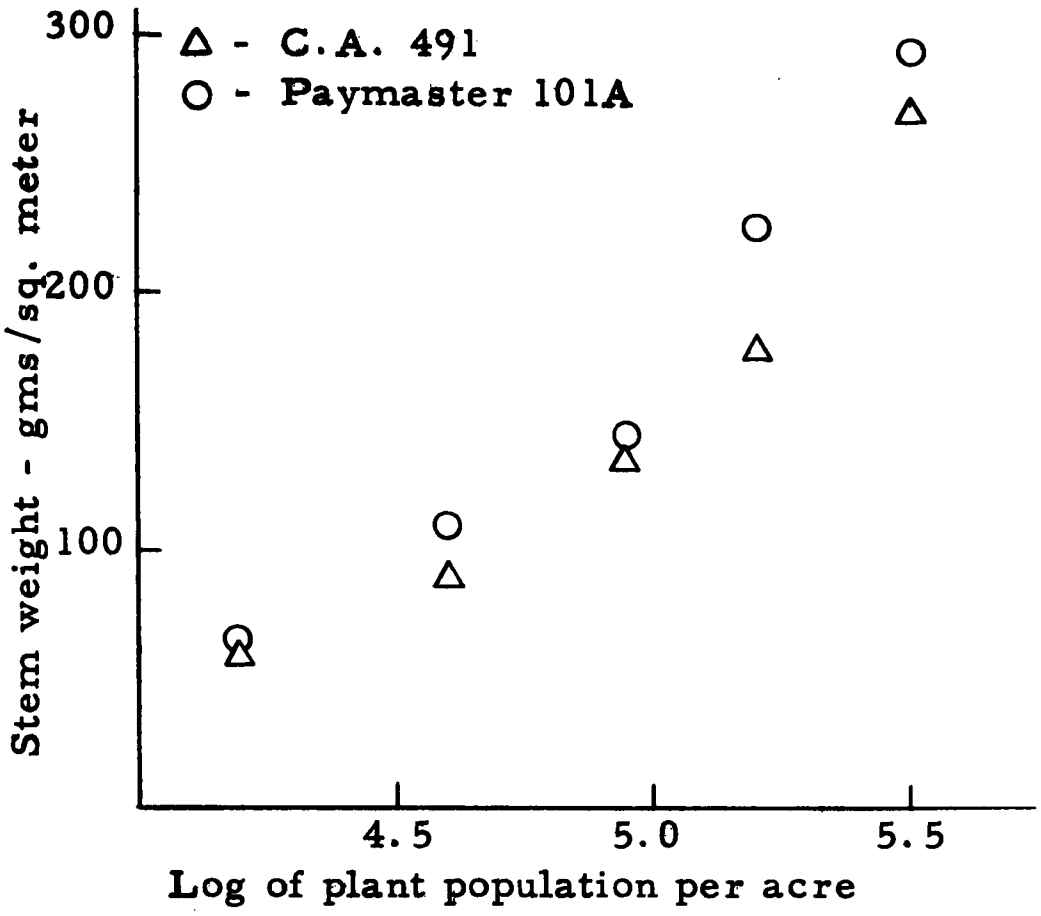

Figure 3. The effect of plant density on the dry weight of stems per unit area of land of two cotton varieties.

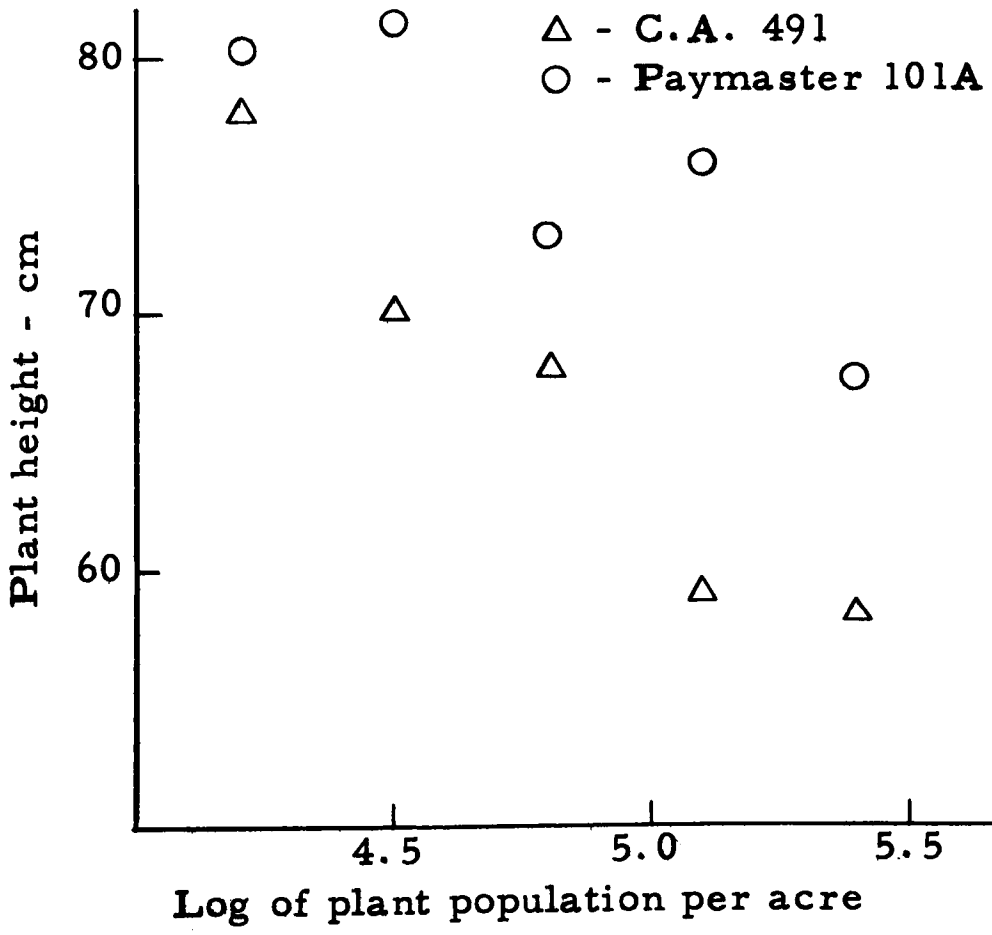

Figure 4. The effect of plant density on the plant height of two cotton varieties.

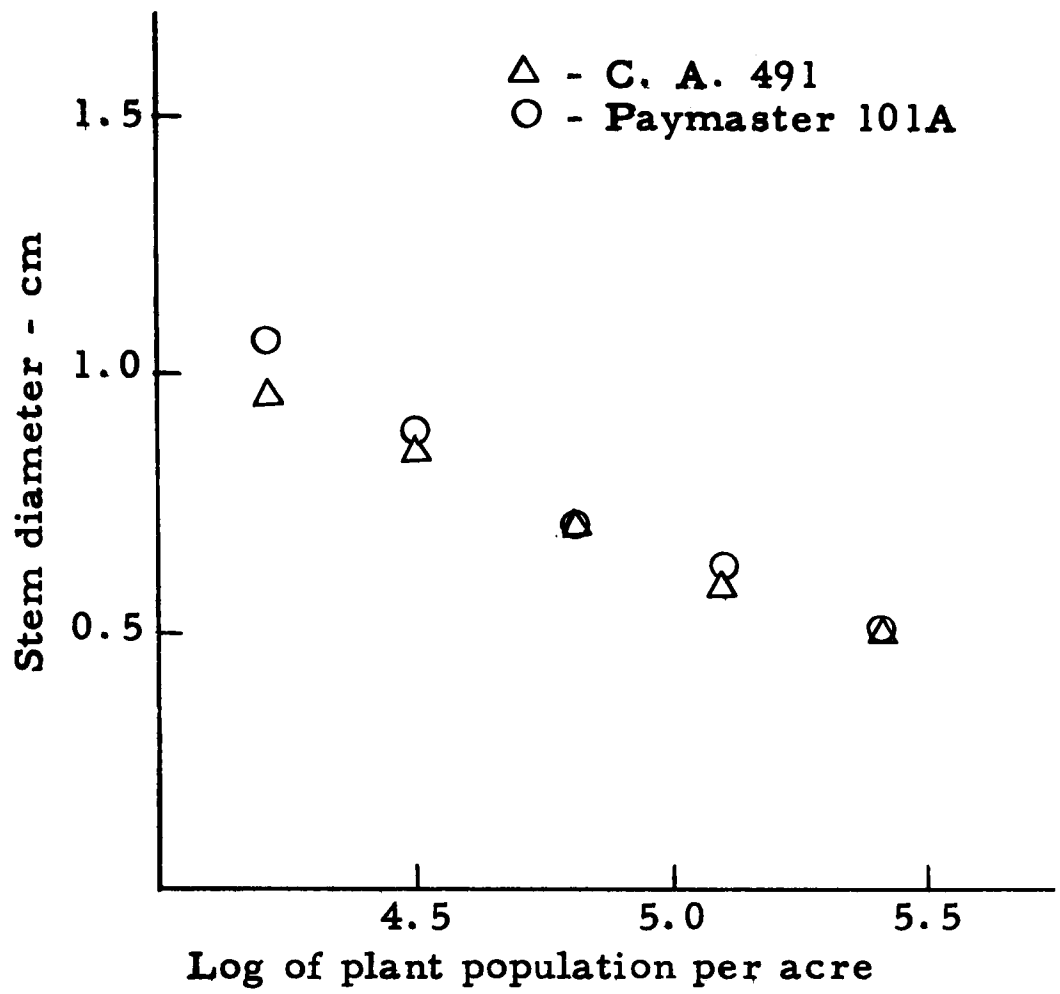

Figure 5. The effect of plant density on the stem diameter of two cotton varieties.

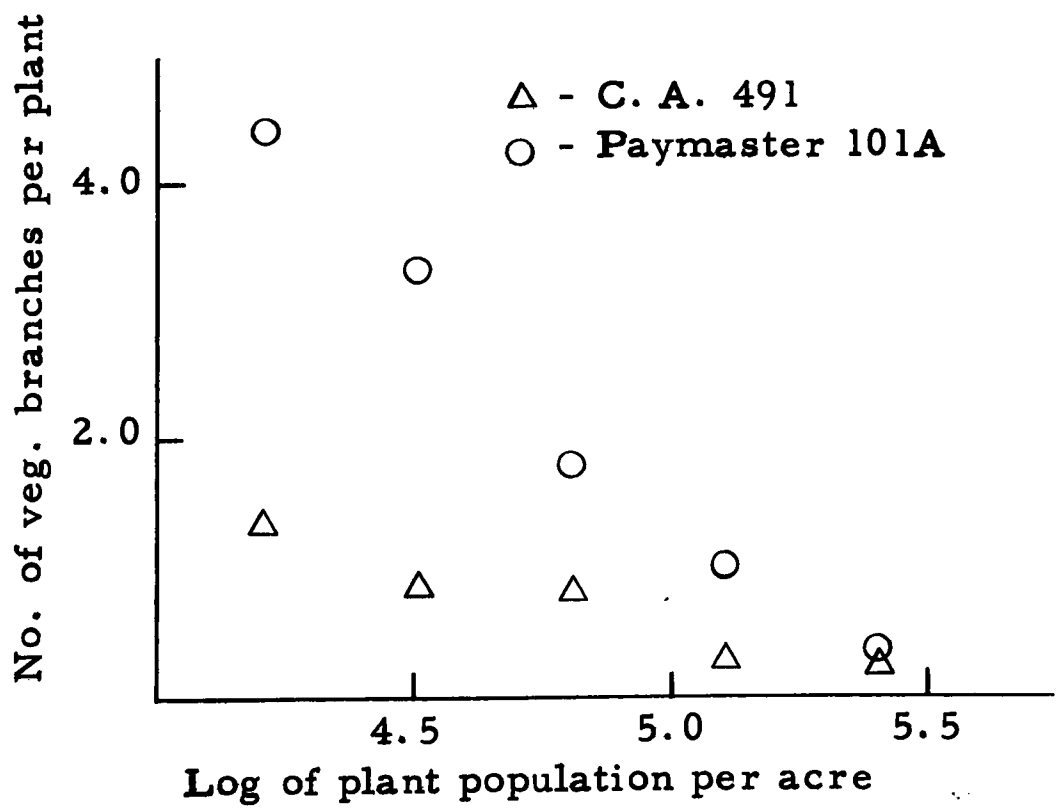

Figure 6. The effect of plant density on the number of vegetative branches per plant of two cotton varieties.

Generally, the number of nodes to the first fruiting branch was greater in the higher population levels (Table 8). Significant differences were noted among spacing treatment means and between variety means, and there was a significant interaction between varieties and spacings.

The weight of vegetative branches per unit land area of both varieties increased with decreased plant population (Table 9). Highly significant differences were obtained between variety means with a significant variety-spacing interaction for both the number of vegetative branches per plant and the weight of vegetative branches per unit land area (Figure 6). The weight of fruiting branches per unit land area was generally positively correlated to the number of plants per acre for the C.A. 491, but the Paymaster variety did not develop any trend in relation to this factor. Both the number of vegetative branches and number of fruiting branches per plant were negatively correlated with plant population (Figures 6 and 7). The C.A. 491 had fewer vegetative branches and more fruiting branches at all population levels than Paymaster 101A.

Leaf area was determined at all sampling dates. The leaf area index (LAI), or ratio of unit leaf area to unit land area, was computed from these data (Table 10). At all dates, LAI was directly related to plant density. On August 17th, 80 days after planting, C.A. 491

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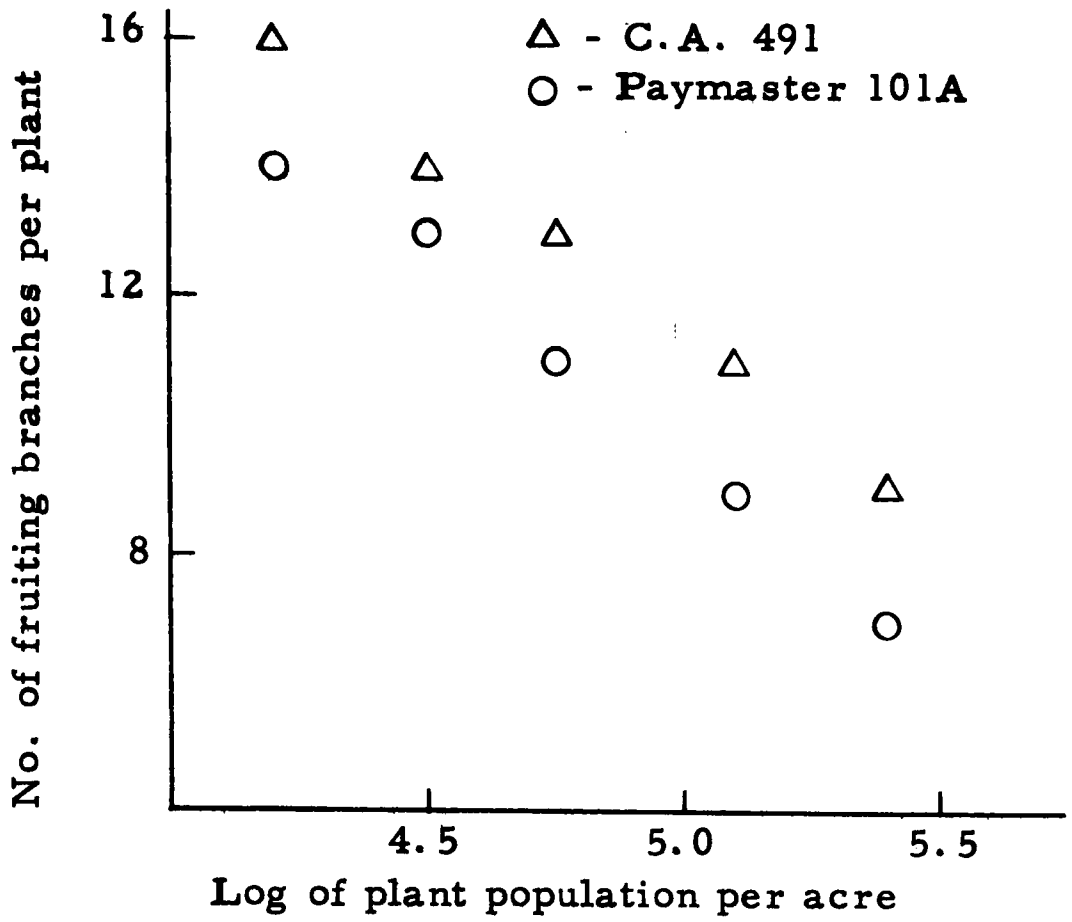

Figure 7. The effect of plant density on the number of fruiting branches per plant of two cotton varieties.

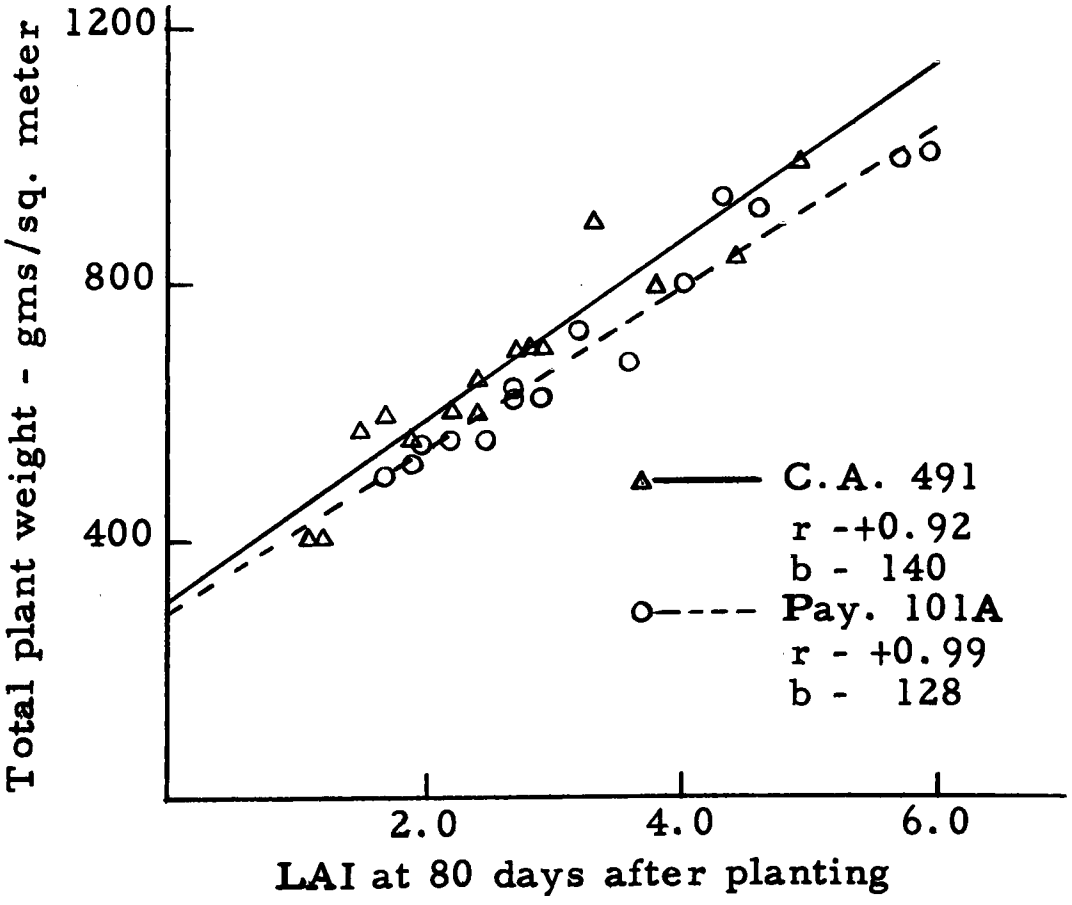

Figure 8. The relationship between total dry plant weight per unit area of land and LAI.

Table 10. Effect of plant density on leaf area index of two cotton varieties at four vegetative harvest dates.

Plant spacing inches	Leaf area index Harvest dates - days after planting 6/18 20 days	6/28 30 days	8/17 80 days	10/25 149 days
		C.A. 491		
5	.191 a 1/	.283 a	4.01 a	2.70 a
7	.102 b	.168 b	3.39 a	1.89 b
10	.052 c	.104 c	2.48 b	1.46 c
14	.026 d	.052 d	1.91 bc	1.33 c
20	.013 d	.024 e	1.27 c	0.89 d
		Paymaster 101A		
5	.197 a	.295 a	5.41 a	3.64 a
7	.100 b	.188 b	3.97 b	2.76 b
10	.052 c	.097 c	2.96 c	2.11 c
14	.027 d	.055 d	2.46 cd	1.83 cd
20	.014 d	.028 e	1.84 d	1.49 d
		Mean of both varieties		
5	.190 a	.289 a	4.71 a	3.17 a
7	.101 b	.178 b	3.68 b	2.33 b
10	.052 c	.101 c	2.72 c	1.78 c
14	.026 d	.053 d	2.19 d	1.58 c
20	.013 e	.026 e	1.56 e	1.19 d

1/ Any two means followed by the same letter are not significantly different at the 5% level as determined by the Duncan's New Multiple Range Test.

had an LAI of 4.0 in the 5" x 5" spacing and only 1.3 in the 20" x 20" spacing. The Paymaster 101A had an LAI of 5.4 in the 5" x 5" spacing and 1.8 in the 20" x 20" spacing. Thus, the higher populations had a much greater leaf area available for photosynthesis than the low populations. Also, the total dry weight per unit land area at the August 17th sampling date was directly related to leaf area index (Figure 8). Highly significant correlation coefficients, +0.92 for C. A. 491 and +0.99 for Paymaster 101A, were found between the LAI and total dry weight.

A reduction in leaf area, hence, leaf area index, occurred between the August 17th and October 25th sampling dates. This is to be expected when plants near senescence and after the rate of leaf area increase departs from the exponential as leaf shed exceeds leaf area expansion. Hutchinson, et al. (22) reported that this occurs somewhere between the 11th and 18th week after emergence, depending on many variables, and that little development of either vegetative or fruiting structures occurs after this point is reached. The reduction in LAI between the August 17th and October 25th sampling dates was approximately the same in all plots; therefore, it was assumed that leaf shed and plant senescence had similar patterns in all treatments (Figure 9).

LUBBOCK, TEXAS

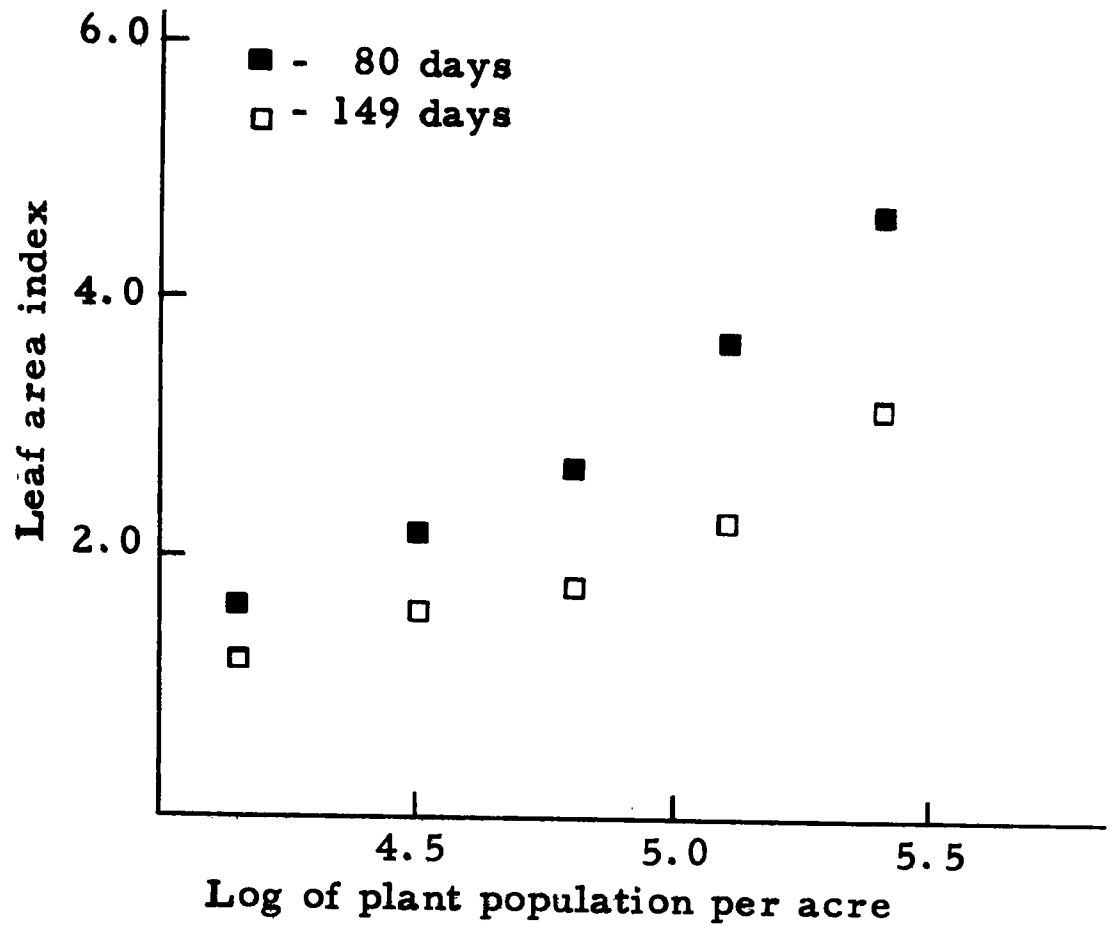

Figure 9. The effect of plant density on the LAI mean of two cotton varieties at 80 days and at 149 days after planting.

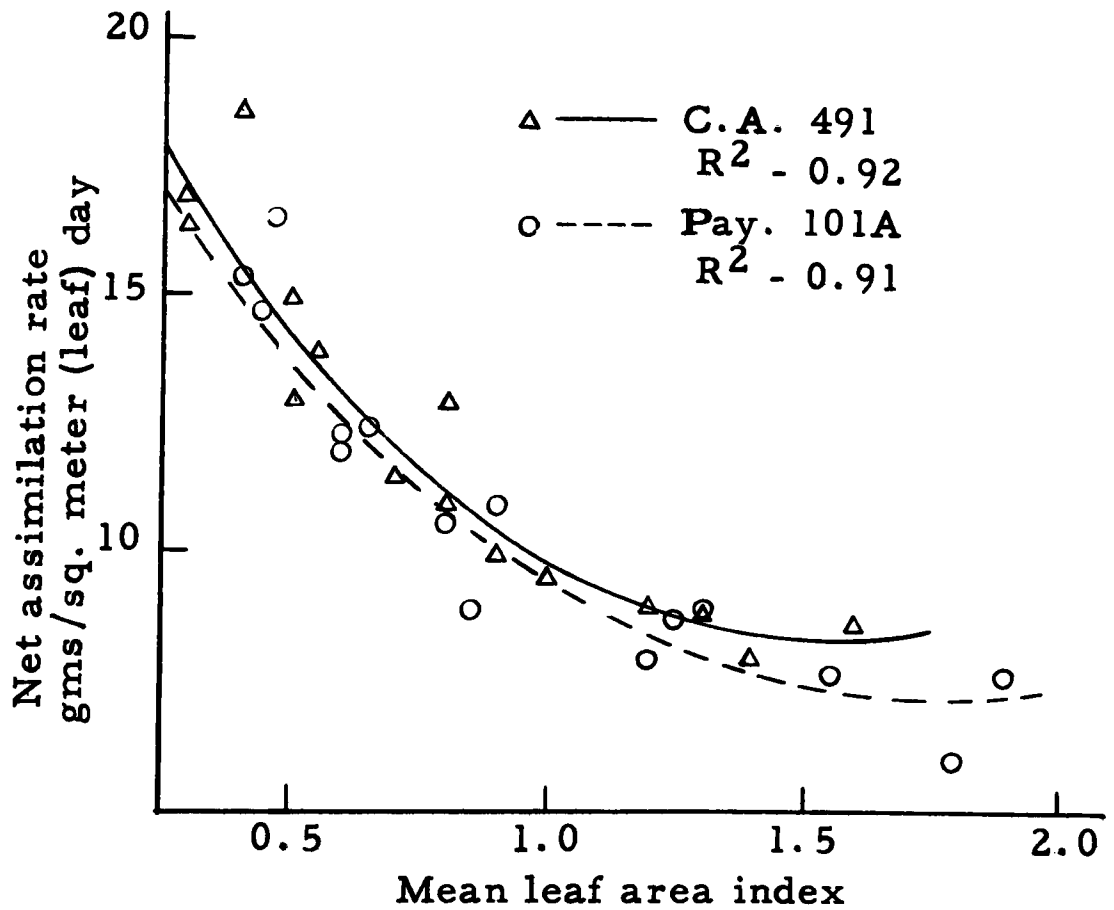

Figure 10. The relation between net assimilation rate and mean leaf area index of two cotton varieties during vegetative harvest interval 2-3.

Growth Relationships

The effect of plant density on such growth relationships as net assimilation rate (NAR), crop growth rate (CGR), leaf area ratio (LAR), and relative growth rate (RGR) was determined for the growth period of 50 days between 30 and 80 days after planting. These data are summarized in Table 11.

Net assimilation rate is generally expressed as a measure of photosynthetic efficiency of the leaf canopy. The net assimilation rate of both varieties significantly decreased at an average rate of 2.2 grams of dry matter per day per square meter of leaf surface each time the plant population was doubled. That is, as plant density increased, the photosynthetic efficiency of the leaf surface decreased. Furthermore, the decrease in NAR as plant density increased was definitely related to the corresponding increase in LAI, as shown by Figure 10. The very high R^2 values of 0.92 for C.A. 491 and 0.91 for the Paymaster variety strongly suggest that a major part of the variation in NAR is associated with the variation in LAI. The reduced photosynthetic efficiency at high leaf area indices may be the result of the shading of lower leaves. This is only an assumption as other factors such as CO_2 concentration, temperature, and water deficit which were not measured in this study could contribute greatly to this loss of efficiency (2, 8, 9, 11). Dunlap (10) found

Table 11. Effect of plant density on certain growth relationships of two cotton varieties for the experimental period of 30 through 80 days after planting.

Plant spacing inches	Net assimilation rate 1/	Crop growth rate 2/	Leaf area ratio	Relative growth rate
		C.A. 491		
5	8.6 d 3/	13.3 a	.675 a	3.20 c
7	9.5 d	11.3 b	.667 a	3.54 bc
10	11.9 c	10.0 bc	.586 b	3.90 b
14	14.1 b	9.2 c	.521 c	4.61 a
20	17.4 a	7.1 d	.451 d	5.02 a
		Paymaster 101A		
5	7.0 e	14.3 a	.789 a	3.21 d
7	8.7 d	11.8 b	.731 a	3.47 cd
10	10.2 c	10.1 c	.657 b	3.96 bc
14	12.2 b	9.0 cd	.624 b	4.44 ab
20	15.6 a	8.3 d	.521 c	4.95 a
		Mean of both varieties		
5	7.8 e	13.82 a	.732 a	3.21 d
7	9.1 d	11.54 b	.699 a	3.50 d
10	11.1 c	10.04 c	.622 b	3.93 c
14	13.2 b	9.10 c	.573 c	4.52 b
20	16.5 a	7.69 d	.486 d	4.99 a

1/ Grams of dry matter per square meter of leaf area per day.

2/ Grams of dry matter per square meter of land area per day.

3/ Any two means followed by the same letter are not significantly different at the 5% level as determined by the Duncan's New Multiple Range Test.

that light intensity readings taken among the lower leaves of closely spaced cotton plants were as low as 600 foot-candles as compared to direct sunlight intensity above the plants at 11,000 foot-candles. The carbohydrate content of leaves grown under comparable light intensities was reported to be 1.8 percent for shaded leaves and 7.7 percent for leaves grown under full sunlight. This suggests that the shading of lower leaves at high leaf area indices is at least partially responsible for the decrease in net assimilation rate.

The effect of plant density on crop growth rate was the reverse of that on net assimilation rate. As plant density doubled, crop growth rate increased at the average rate of 1.47 grams of dry matter per square meter of land surface per day. Figure 11 indicates that crop growth rate is a linear function of leaf area index. Correlation coefficients of + 0.99 for Paymaster 101A and + 0.97 for C.A. 491 are both highly significant and imply that the increase in crop growth rate with an increase in plant density is directly related to the increase in leaf area index.

The efficiency of the crop as a producer of new material, which is referred to as the efficiency index or the relative growth rate (4, 44), was significantly reduced as plant population increased. Blackman (4) pointed out that relative growth rate can be considered as the rate of interest of growth; that is, the increase in dry weight

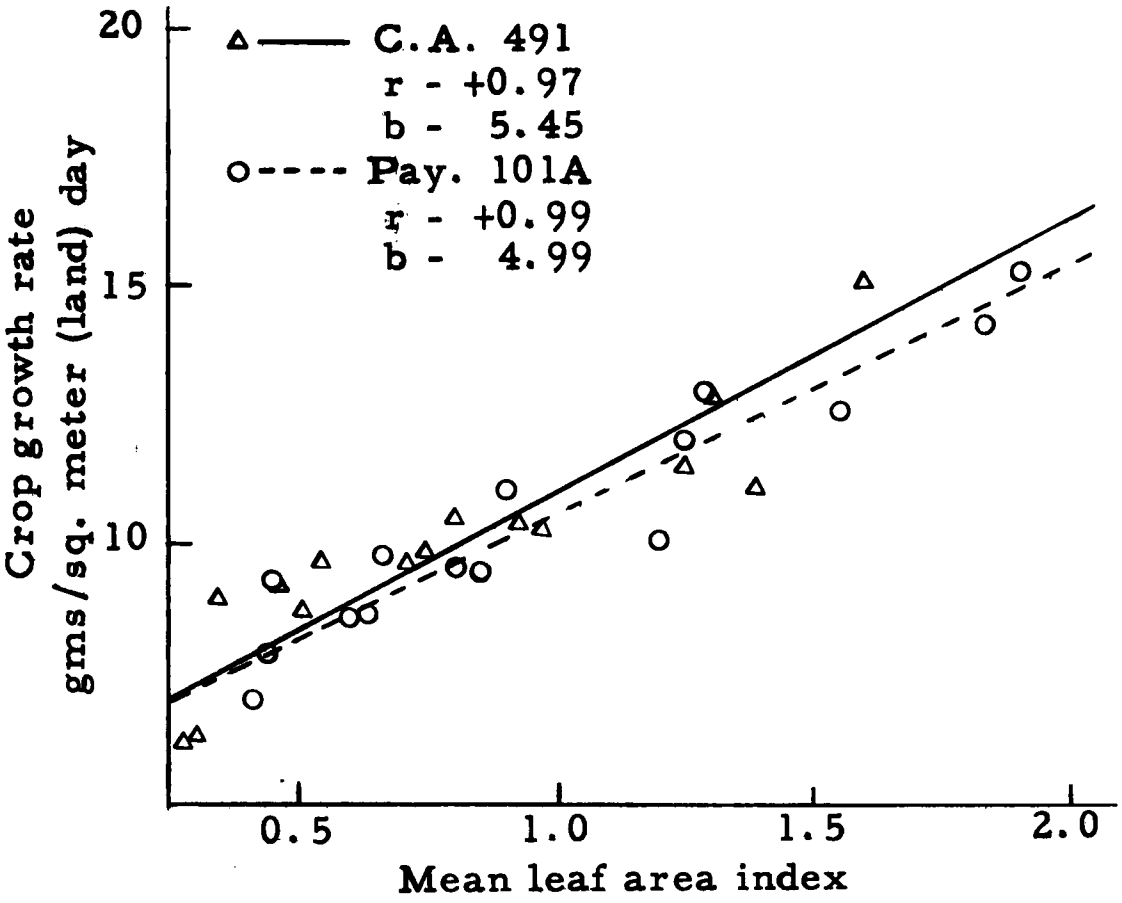

Figure 11. The relationship between crop growth rate and mean leaf area index of two cotton varieties during vegetative harvest interval 2-3.

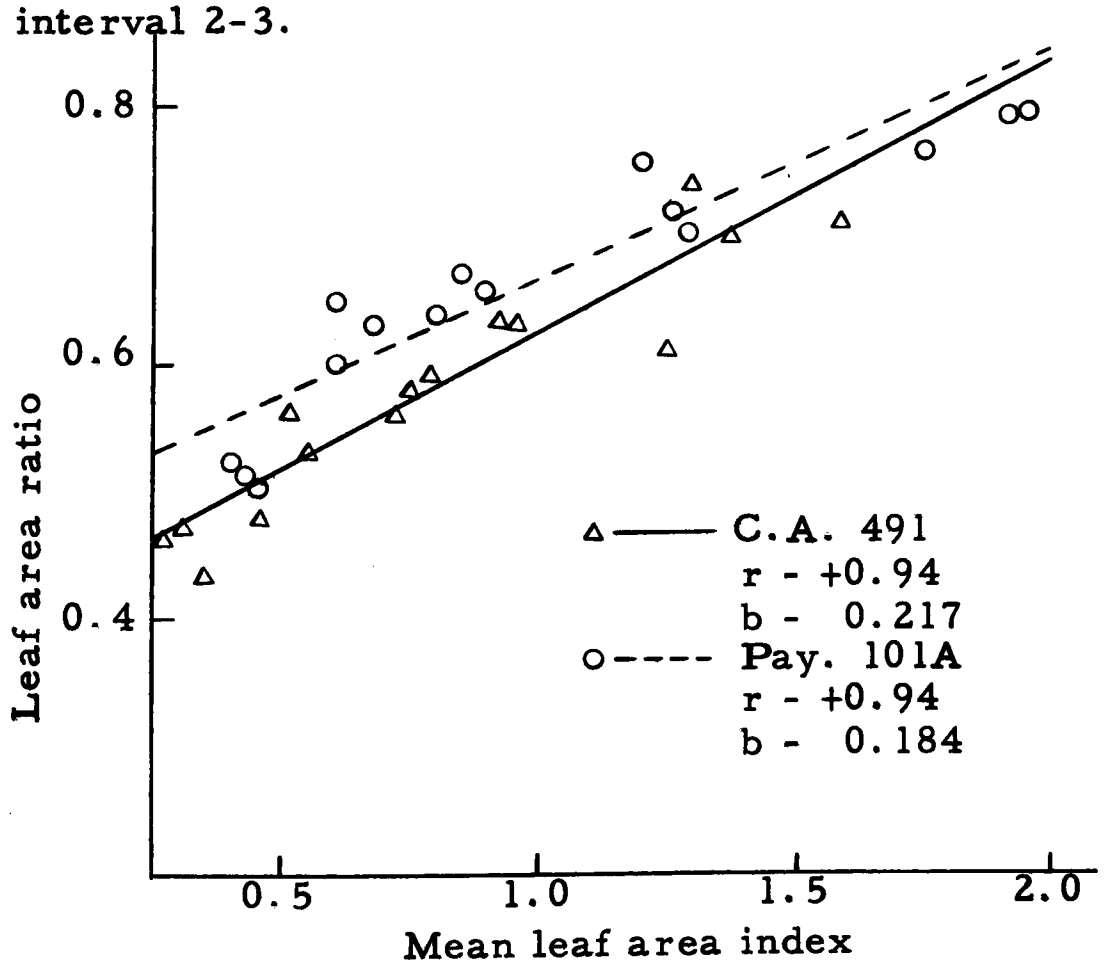

Figure 12. The relationship between leaf area ratio and mean leaf area index of two cotton varieties during vegetative harvest interval 2-3.

can be regarded as a process of continuous compound interest with the amount produced during any time period adding to the "capital" for growth in subsequent periods. Therefore, as Watson (44) pointed out, the dry matter yield of a crop is dependent on three factors: (1) seed weight or initial capital, (2) relative growth rate, and (3) the length of the growing period. The initial seed weight of the 5" x 5" spacing was approximately 16 times as great as that of the 20" x 20" spacing. As the 20" x 20" spacing had a higher "rate of interest" than the 5" x 5" spacing, the length of the growing period becomes an important consideration. If the differences in relative growth rate between treatments remain near or above the initial levels, and the growth period is long enough, the low population levels would overtake, in time, the high population levels in total dry matter production. However, there is no evidence that this occurs during the short growing season of the Southern High Plains of Texas.

Leaf area ratio or the index of the amount of "growing material" per unit dry weight of plants was larger at the higher plant densities and directly related to the population level. There was a significant difference between varieties with the Paymaster 101A having a higher LAR at all levels than the C.A. 491. LAR increased in a linear manner as LAI increased as shown by Figure 12. Correlation

coefficients between LAR and population were highly significant for both varieties.

Fruit Development

The fruiting-vegetative ratio at the August 17th vegetative harvest date generally decreased as population increased (Table 12). However, the highest ratio in the C.A. 491 was in the 14" x 14" spacing. It was significantly higher for C.A. 491 than for the Paymaster variety. At the October 25th sampling date, the fruiting-vegetative ratio remained inversely correlated to plant density with a decrease in the ratio of 0.244 each time the number of plants per acre was doubled (Figure 13). The ratio of the Paymaster 101A was only about 70 percent of that of the C.A. 491 throughout the range of the population levels. These data indicate that the lower population levels tend to convert a greater portion of assimilates into the production of fruiting forms, and that C.A. 491 is a more efficient producer of fruit at all population levels studied than Paymaster 101A.

The weight of fruiting forms per unit land area was significantly different between spacing treatments at the August 17th sampling date, however, no trends were evident at this time (Table 12). At the October 25th sampling date, a definite trend was evident in the C.A. 491 as fruit weight increased with an increase in plant density at an average rate of 91 grams per square meter of land surface

Table 12. Effect of plant density on weight of fruiting forms and fruiting - vegetative ratio of two cotton varieties at 80 and 149 days after planting.

Plant spacing inches	Weight of fruiting forms 1/ 80 days	149 days	Fruiting-vegetative ratio 80 days	149 days
		C.A. 491		
5	111 a 2/	835 a	.236 b	1.50 c
7	124 a	824 a	.325 a	2.09 b
10	124 a	680 b	.377 a	2.10 b
14	121 a	624 b	.406 a	2.39 a
20	78 b	480 c	.333 a	2.58 a
		Paymaster 101A		
5	50 a	608 ab	.086 c	0.98 d
7	66 a	670 a	.141 bc	1.31 c
10	71 a	575 ab	.186 ab	1.55 bc
14	60 a	606 ab	.174 ab	1.81 ab
20	67 a	510 b	.230 a	1.94 a
		Mean of both varieties		
5	81 bc	722 a	.161 b	1.24 c
7	95 ab	747 a	.233 a	1.70 b
10	97 a	628 b	.281 a	1.83 b
14	90 ab	615 b	.290 a	2.10 a
20	73 c	494 c	.281 a	2.26 a

1/ Grams of dry weight per square meter of land area.

2/ Any two means followed by the same letter are not significantly different at the 5% level as determined by the Duncan's New Multiple Range Test.

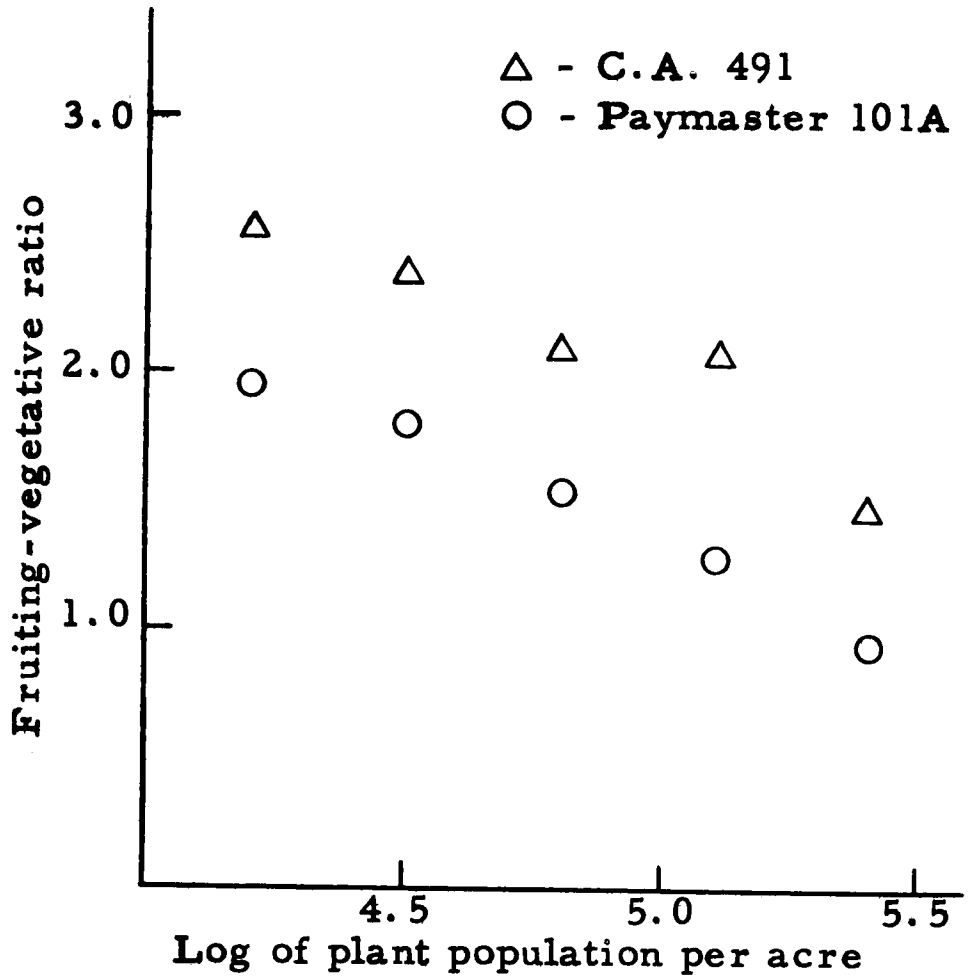

Figure 13. The effect of plant density on the fruiting-vegetative ratio of two cotton varieties at 149 days after planting.

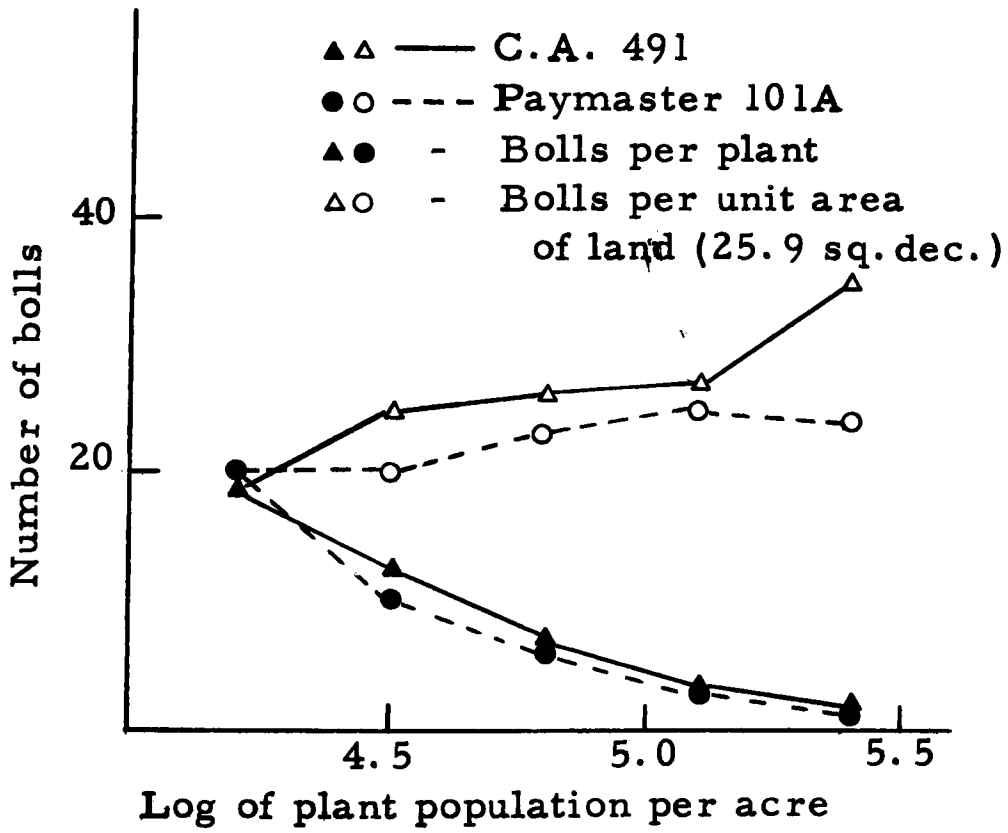

Figure 14. The effect of plant density on the number of bolls per plant and per unit area of land of two cotton varieties at final harvest.

each time the population was doubled.

The number of fruit per unit land area was positively correlated to an increase in population level; that is, as plant population increased, the number of fruit per unit land area increased (Table 13). The reverse is true when considering the number of fruit per plant (Table 14). This is graphically illustrated by Figure 14. It should be noted in Table 14 that when a comparison is made of the number of fruit per plant at 149 days after planting and at final harvest, a lower percentage of fruit was retained at the higher population levels; and this percentage increased as plant density decreased.

Lint Yields and Earliness

The highest total lint yields were obtained with both varieties in the 14" x 14" spacing (Table 15). However, the yield in the 10" x 10" spacing was not significantly lower in either variety, nor was the yield in the 20" x 20" spacing in Paymaster 101A. In the C.A. 491, the 20" x 20" spacing yielded slightly less than the 5" x 5" spacing, but in Paymaster 101A the yield in the 5" x 5" spacing was significantly lower than that of any other spacing. Thus, there is an indication that C.A. 491 is better adapted to high plant densities than is Paymaster 101A. The variety-spacing interaction mean square was significant for total yield.

With the C.A. 491 the highest cumulative lint yields at all harvest dates were obtained in the 14" x 14" spacing (Figure 15).

Table 13. Effect of plant density on the number of fruit per square meter of land area of two cotton varieties at 80 and 149 days after planting and at final harvest.

Plant spacing inches	No. of fruit per square meter of land area		
	80 days	149 days	Final harvest
	C.A. 491		
5	364 a [1/]	233 a	136 a
7	322 a	174 b	105 b
10	289 b	134 c	101 b
14	228 bc	115 cd	96 b
20	169 c	88 d	74 c
	Paymaster 101A		
5	312 a	167 a	93 a
7	272 ab	145 a	98 a
10	219 bc	104 b	88 ab
14	159 c	94 b	79 bc
20	171 c	88 b	77 c
	Mean of both varieties		
5	338 a	200 a	118 a
7	298 ab	160 b	102 b
10	253 b	119 c	95 bc
14	194 c	105 cd	88 c
20	170 c	88 d	76 d

[1/] Any two means followed by the same letter are not significantly different at the 5% level of probability as determined by the Duncan's New Multiple Range Test.

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Table 14. Effect of plant density on the number of fruit per plant of two cotton varieties at 80 and 149 days after planting and at final harvest.

Plant spacing inches	Number of fruit per plant			Percentage 1/ retained
	80 days	149 days	Final harvest	
		C.A. 491		
5	5.9 e 2/	3.8 d	2.2 e	57.9
7	10.2 d	5.5 d	3.3 d	60.0
10	18.6 c	8.6 c	6.5 c	75.6
14	28.8 b	14.5 b	12.2 b	84.1
20	43.6 a	22.6 a	19.1 a	84.5
		Paymaster 101A		
5	5.0 e	2.7 d	1.5 e	55.6
7	8.6 d	4.6 cd	3.1 d	67.4
10	14.1 c	6.7 c	5.7 c	85.1
14	20.1 b	9.8 b	10.1 b	103.1
20	44.0 a	22.5 a	19.8 a	88.0
		Mean of both varieties		
5	5.5 e	3.2 d	1.9 e	59.4
7	9.4 d	5.0 d	3.2 d	64.0
10	16.4 c	7.7 c	6.1 c	79.2
14	24.4 b	12.2 b	11.1 b	90.1
20	43.8 a	22.6 a	19.5 a	86.3

1/ Percentage of fruit per plant at 149 days after planting retained at final harvest.

2/ Any two means followed by the same letter are not significantly different at the 5% level of probability as determined by the Duncan's New Multiple Range Test.

Table 15. Effect of plant density on cumulative lint yields and rate of crop maturation of two cotton varieties.

Plant spacing inches	Cumulative lint yield - 4 harvest dates				Rate of crop maturation	
	Pounds of lint per acre				Percent of total	
	Date 1 10-4	Date 4 10-25	Date 7 11-15	Date 10 12-17 Final harvest	Date 4 10-25	Date 7 11-15
C.A. 491						
5	15	272 d	672 c	1241 c	21.9	54.1
7	11	441 cd	839 bc	1319 bc	33.4	63.6
10	57	718 ab	1148 a	1470 ab	48.8	78.1
14	102	769 a	1179 a	1532 a	50.2	77.0
20	69	582 bc	939 b	1175 c	49.5	79.9
Paymaster 101A						
5	0	8 b	137 d	906 c	0.9	15.1
7	0	54 b	389 c	1287 b	4.2	30.2
10	0	185 b	646 b	1441 ab	12.8	44.8
14	10	371 a	912 a	1522 a	24.4	59.9
20	29	436 a	899 a	1363 ab	32.0	66.0
Mean of both varieties						
5	7	140 b	405 d	1073 c	13.0	37.7
7	5	248 b	614 c	1303 b	19.0	47.1
10	28	452 a	897 b	1456 a	31.0	61.6
14	56	570 a	1045 a	1527 a	37.3	68.4
20	49	509 a	919 ab	1269 b	40.1	72.4

1/ Any two means followed by the same letter are not significantly different at the 5% level as determined by the Duncan's New Multiple Range Test.

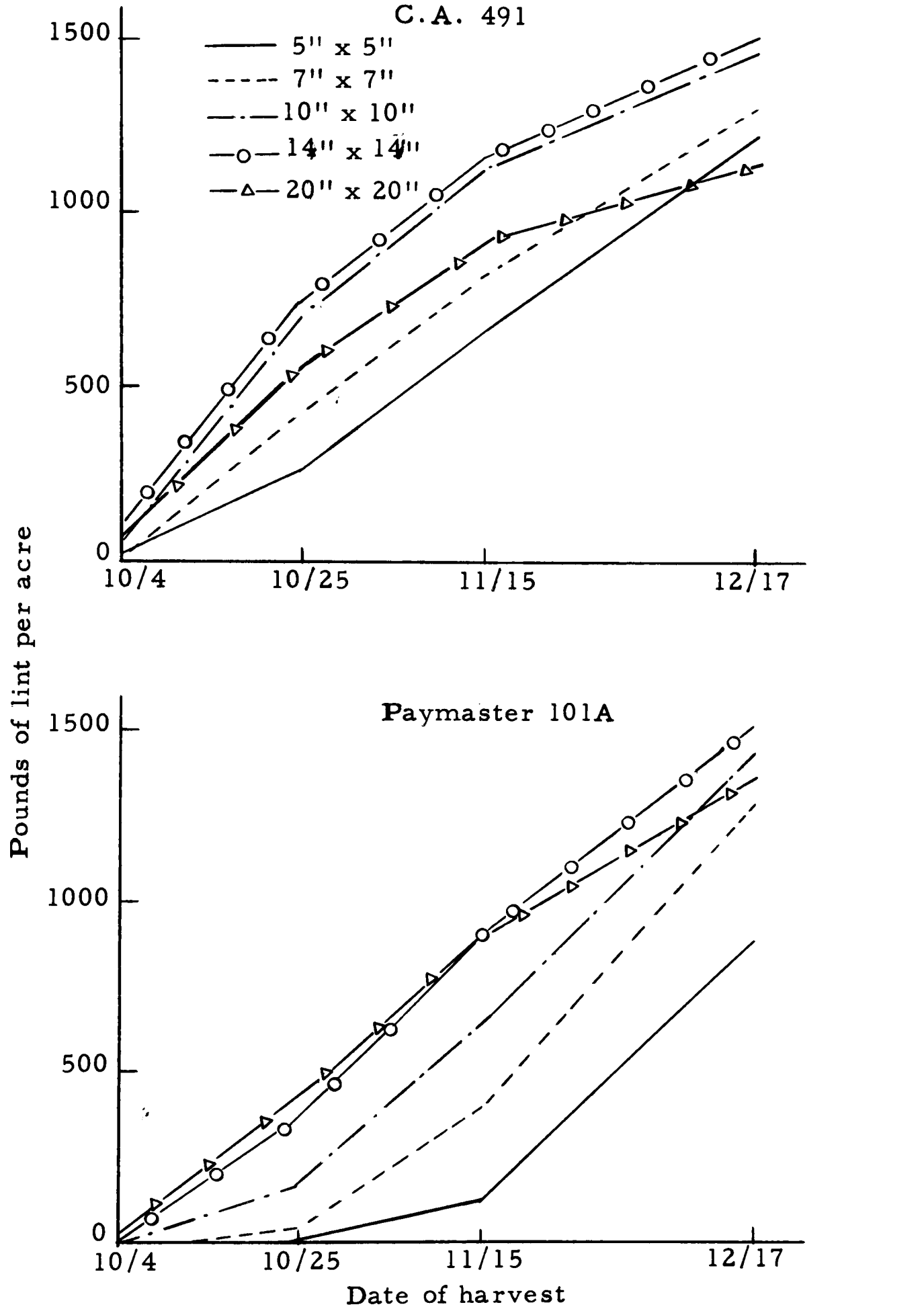

Figure 15. The effect of plant density on the cumulative lint yields of two cotton varieties.

However, when earliness was expressed as a percentage of the total crop harvested (rate of crop maturation) the highest percentage of the crop open was obtained in the 20" x 20" spacing, with the 14" x 14" spacing only slightly lower. The highest cumulative lint yields in the Paymaster 101A were in the 20" x 20" spacing through November 8 and in the 14" x 14" spacing for the remainder of the harvest period. When based on the rate of crop maturation, earliness of the Paymaster variety was inversely correlated to plant density.

Boll Sample Data

Boll sample data are summarized in Table 16. Lint percentage of seed cotton and bur cotton showed significant differences between spacing treatments. There were no definite trends in the C.A. 491 for lint percentage of seed cotton or bur cotton; however, the highest populations did have the lowest lint percentages. The Paymaster 101A tended to have the lowest lint percentages at the highest population levels, and these generally increased as plant density decreased. The lint percentage of seed cotton of the Paymaster variety was significantly higher at all population levels than that of the C.A. 491.

Boll size generally decreased as plant population increased in both varieties. However, a significant interaction between varieties and spacings was noted as the boll size of the Paymaster variety was

Table 16. Effect of plant density on boll sample data of two cotton varieties.

Plant spacing inches	Lint percentage		Seed index	Lint index	Boll size 1/	No. of seed per boll
	Bur cotton	Seed cotton				
			C.A. 491			
5	23.95 c 2/	34.66 a	10.27 b	5.56 b	3.59 b	22.4 c
7	24.08 bc	33.67 a	11.37 a	6.22 a	4.20 a	25.5 bc
10	26.61 a	35.42 a	11.56 a	6.30 a	4.44 a	27.4 ab
14	25.80 ab	35.10 a	10.84 ab	5.93 ab	4.74 a	28.4 a
20	25.32 abc	35.47 a	11.42 a	6.02 a	4.69 a	29.2 a
			Paymaster 101A			
5	23.72 c	36.61 b	10.30 c	5.70 c	3.29 d	22.9 c
7	24.82 bc	36.62 b	10.86 bc	6.26 b	4.25 c	27.0 b
10	26.05 ab	37.44 ab	11.10 bc	6.43 b	4.97 b	29.8 a
14	26.26 ab	37.56 ab	11.73 ab	7.10 a	5.61 a	30.2 a
20	27.26 a	38.72 a	12.11 a	7.16 a	5.37 ab	30.0 a
			Mean of both varieties			
5	23.84 b	35.64 b	10.28 b	5.63 c	3.44 d	22.7 c
7	24.45 b	35.14 b	11.12 a	6.24 b	4.22 c	26.3 b
10	26.33 a	36.43 ab	11.33 a	6.37 ab	4.71 b	28.6 a
14	26.03 a	36.33 ab	11.29 a	6.51 ab	5.18 a	29.3 a
20	26.29 a	37.09 a	11.77 a	6.59 a	5.03 ab	29.6 a

1/ Grams of seed cotton per boll.
2/ Any two means followed by the same letter are not significantly different at the 5% level as determined by the Duncan's New Multiple Range Test.

affected to a greater extent than the C.A. 491. The number of seed per boll also generally decreased as population increased. Little difference was noted between varieties for this factor.

A decrease in plant density generally resulted in an increase in seed index and lint index. C.A. 491 did not react in a definite pattern in regard to either of these factors, although there were significant differences between treatments. The lint index and seed index of Paymaster 101A, on the other hand, tended to decrease as plant density increased. A significant varietal response between varieties and spacings was noted for the lint index.

Fiber Properties

The effects of plant density on the fiber properties of length, strength, and fineness are given in Tables 17, 18, 19 and 20. No clear inferences can be drawn from these data as there was little consistency in the results from the various harvest dates tested. There is some indication that Micronaire is reduced by increasing plant population (Figure 16). Significant differences in the Micronaire readings among treatments (spacings) were noted at Date 5 (November 1) and in the boll samples (December 17) which represent the average for the crop. A varietal response between varieties and spacings was obtained at Date 5 with the C.A. 491 having significantly higher readings at all population levels. Both

Table 17. Effect of plant density on the 2.5 percent span length of two cotton varieties at four harvest dates.

Plant spacing inches	Harvest dates 1/ Date 2 10-11	Date 5 11-1	Date 8 11-22	Boll samples 2/
		C.A. 491		
5	.97	.91	.93 a 3/	.94
7	.98	.94	.90 a	.96
10	1.01	.94	.93 a	.96
14	1.00	.92	.93 a	.96
20	.98	.92	.93 a	.97
		Paymaster 101A		
5	-	.93	.98 a	.96
7	-	.92	.92 a	.98
10	.96	.93	.94 ab	.97
14	.99	.91	.96 a	.99
20	.98	.94	.95 ab	.95
		Mean of both varieties		
5	-	.92	.96 a	.95
7	-	.93	.91 b	.97
10	.99	.94	.94 a	.97
14	1.00	.92	.95 a	.98
20	.98	.93	.94 a	.96

1/ Bolls harvested at these dates opened during the previous week.

2/ Boll samples represent the average for the total crop.

3/ Any two means followed by the same letter are not significantly different at the 5% level as determined by the Duncan's New Multiple Range Test.

Table 18. Effect of plant density on the 50 percent span length of two cotton varieties at four harvest dates.

Plant spacing inches	Harvest dates 1/ Date 2 10-11	Date 5 11-1	Date 8 11-22	Boll samples 2/
		C.A. 491		
5	.46	.44	.43	.44 c 3/
7	.47	.46	.42	.45 bc
10	.48	.45	.44	.47 a
14	.50	.45	.43	.46 ab
20	.47	.43	.43	.46 ab
		Paymaster 101A		
5	-	.44	.43	.43 b
7	-	.44	.44	.46 a
10	.45	.43	.43	.45 a
14	.47	.43	.43	.46 a
20	.46	.45	.42	.46 a
		Mean of both varieties		
5	-	.44	.43	.44 b
7	-	.45	.43	.46 a
10	.47	.44	.44	.46 a
14	.49	.44	.43	.46 a
20	.47	.44	.43	.46 a

1/ Bolls harvested at these dates opened during the previous week.

2/ Boll samples represent the average for the total crop.

3/ Any two means followed by the same letter are not significantly different at the 5% level as determined by the Duncan's New Multiple Range Test.

Table 19. Effect of plant density on the fiber strength (P.S.I.) of two cotton varieties at four harvest dates.

Plant spacing inches	Harvest dates 1/ Date 2 10-11	Date 5 11-1	Date 8 11-22	Boll samples 2/
		C.A. 491		
5	79.4	72.5 a 3/	80.9	76.0
7	76.5	75.2 a	80.1	74.9
10	77.6	77.2 a	79.4	75.2
14	75.8	76.9 a	79.3	76.6
20	82.3	77.5 a	80.1	77.6
		Paymaster 101A		
5	-	75.9 b	74.3	71.7
7	-	76.6 b	75.3	74.5
10	75.0	76.2 b	76.9	74.1
14	81.4	79.2 ab	81.6	77.3
20	81.1	81.5 a	76.9	78.2
		Mean of both varieties		
5	-	73.4 b	77.6	73.9
7	-	75.9 b	77.7	74.7
10	76.3	76.7 ab	78.2	74.7
14	78.6	78.1 a	80.5	77.0
20	81.7	79.5 a	78.5	77.9

1/ Bolls harvested at these dates opened during the previous week.

2/ Boll samples represent the average for the total crop.

3/ Any two means followed by the same letter are not significantly different at the 5% level as determined by the Duncan's New Multiple Range Test.

Table 20. Effect of plant density on micronaire of two cotton varieties at four harvest dates.

Plant spacing inches	Harvest dates 1/ Date 2 10-11	Date 5 11-1	Date 8 11-22	Boll samples 2/
		C.A. 491		
5	4.6	4.3 bc 3/	3.4	3.5 b
7	4.7	4.5 b	2.9	4.1 ab
10	4.8	4.0 c	2.9	4.4 a
14	4.9	4.3 bc	3.0	4.0 ab
20	5.2	5.0 a	2.6	4.2 ab
		Paymaster 101A		
5	-	2.7 c	2.6	2.9 c
7	-	3.2 b	2.7	3.3 bc
10	4.0	3.5 ab	2.5	3.7 ab
14	4.1	3.8 a	2.7	4.1 a
20	4.3	3.9 a	2.6	4.2 a
		Mean of both varieties		
5	-	3.5 c	3.0	3.2 b
7	-	3.9 b	2.8	3.7 ab
10	4.4	3.8 bc	2.7	4.1 a
14	4.5	4.1 b	2.9	4.1 a
20	4.8	4.5 a	2.6	4.2 a

1/ Bolls harvested at these dates opened during the previous week.

2/ Boll samples represent the average for the total crop.

3/ Any two means followed by the same letter are not significantly different at the 5% level as determined by the Duncan's New Multiple Range Test.

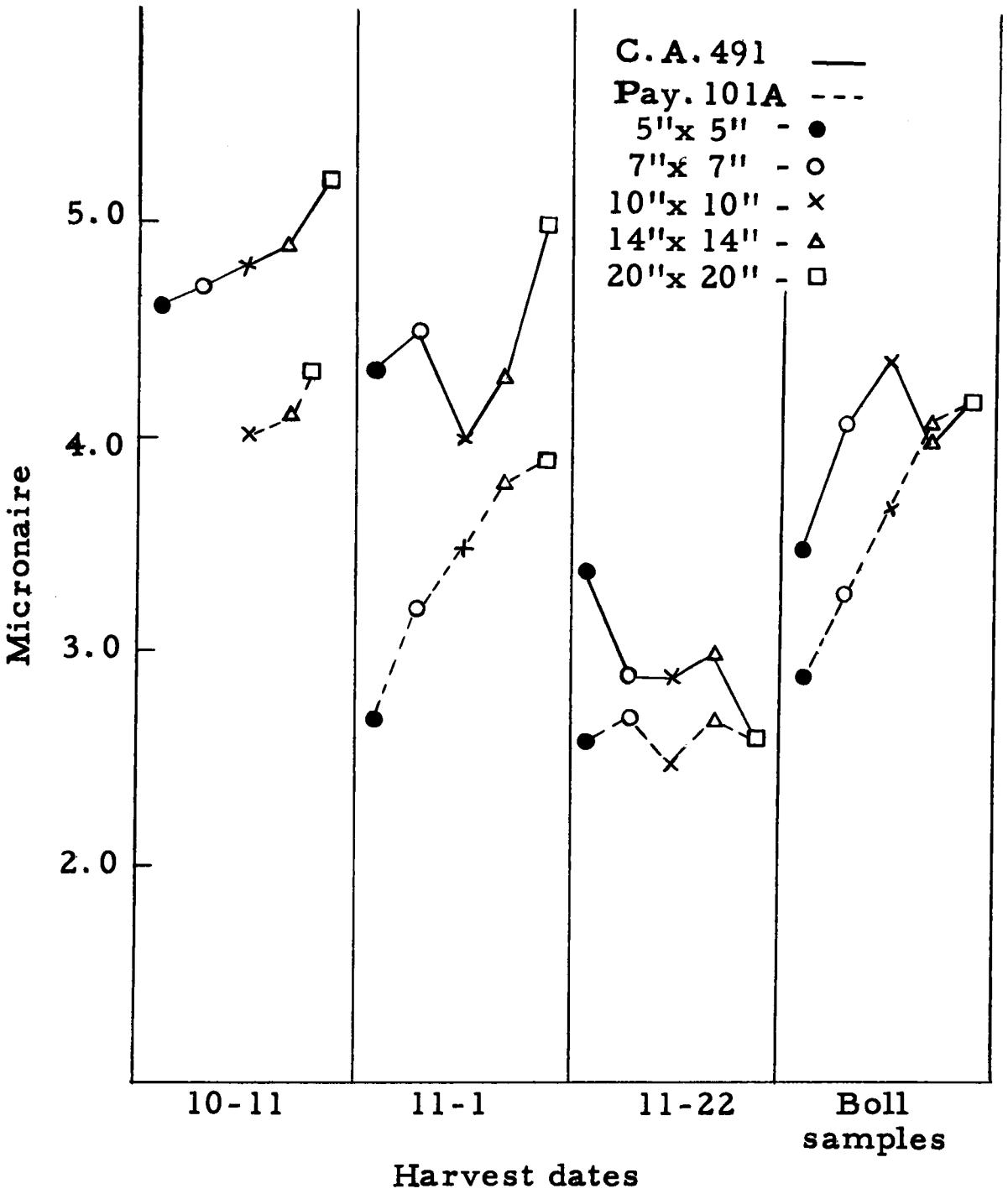

Figure 16. The effect of plant density on the Micronaire of two cotton varieties at three harvest dates and for boll samples.

varieties show a definite trend at Date 2, although differences between treatments were not significant. The Micronaire at this date was inversely related to plant density. A similar trend is evident at Date 5 and in the boll samples of Paymaster 101A, while the results from C.A. 491 were irratic at these dates.

Table 21. Standard errors, coefficients of variation, and "F" values for all measurements and determinations tested.

Measurements and determinations		Standard of error		Coefficient of variation		"F" values		
		Variety	Spacing	Variety	Spacing	Variety	Spacing	Interaction
Total pl. wt.	(6-18)	0.5890	0.2657	22.22	14.18	1.04	269.26**	0.72
"	(6-28)	0.1813	0.4037	2.43	7.64	54.85*	706.83**	1.66
"	(8-17)	15.82	17.095	5.14	7.86	5.67	25.96**	33.18**
"	(10-25)	107.38	35.77	16.38	7.72	0.40	6.19**	2.38
Total wt. per pl.	(6-18)	0.1297	0.0064	11.58	8.12	4.13	0.95	0.18
"	(6-28)	0.0152	0.0149	4.40	6.10	31.46*	30.10**	5.53**
Wt. of leaves	(10-25)	19.24	5.785	25.88	11.00	6.81	72.70**	0.42
Wt. of stems	(10-25)	11.72	7.113	12.93	11.10	7.38	150.36**	1.39
Wt. of fruiting br.	(10-25)	8.61	3.151	25.93	13.42	0.02	10.93**	1.11
Wt. of veg. br.	(10-25)	5.78	1.637	64.58	25.87	15.06	48.83**	18.36
No. nodes 1st fr. br.	(10-25)	0.2903	0.1275	8.73	5.42	51.95*	13.70**	4.47*
No. nodes per pl.	(10-25)	0.1550	0.3339	1.44	4.37	109.36**	43.73**	0.57
No. veg. br.	(10-25)	0.1775	0.0856	21.80	14.88	180.48**	150.31**	54.06**
No. fruit. br.	(10-25)	0.9519	0.4234	14.04	8.83	7.30	44.64**	0.27
Plant height	(10-25)	2.46	2.144	5.99	7.38	32.37*	9.16**	1.82
Stem diameter	(10-25)	0.0096	0.0040	5.74	3.33	6.10	414.91**	4.37**
Leaf area per pl.	(6-18)	0.2935	0.1573	10.00	7.58	0.42	1.25	0.27
"	(6-28)	0.4067	0.2516	7.51	6.57	5.22	31.06**	3.80*
Leaf area index	(6-18)	0.0090	0.0034	20.17	10.82	0.04	461.67**	0.19
"	(6-28)	0.0052	0.0039	6.93	7.43	2.17	729.40**	1.99
"	(8-17)	0.2069	0.1738	12.06	14.33	30.18*	51.40**	12.11**
"	(10-25)	0.2980	0.0878	25.68	10.70	14.15	76.23**	1.10

*Significant at the 5% level.
**Significant at the 1% level.

Table 21. continued

Measurements and determinations		Standard of error		Coefficient of variation		"F" values		
		Variety	Spacing	Variety	Spacing	Variety	Spacing	Interaction
Net assimilation rate	(6-28 to 8-17)	0.3243	0.3521	4.88	7.49	57.11*	95.99**	0.37
Crop growth rate	(")	0.2105	0.3351	3.49	7.86	16.05	49.28**	0.73
Relative growth rate	(")	0.0245	0.1277	10.53	7.76	9.33	32.67**	0.12
Leaf area ratio	(")	0.1732	0.0152	4.82	5.97	59.18*	42.43**	0.43
Fruit-veg. ratio	(8-17)	0.0607	0.0196	42.14	19.22	20.15*	7.70**	1.52
"	(10-25)	0.1175	0.0672	11.18	9.05	68.30*	34.52**	0.58
No.fr. per plant	(8-17)	0.9604	0.6182	8.36	7.61	25.38*	605.11**	8.73**
"	(10-25)	1.7734	0.7172	30.32	17.34	2.37	115.88**	1.52
"	(12-17)	0.5745	0.2116	11.93	6.22	2.92	1416.19**	5.75**
No.fruit/plot	(8-17)	8.94	15.18	6.18	14.84	72.03*	21.27**	0.93
"	(10-25)	13.95	7.555	18.02	13.80	10.83	36.17**	2.44
"	(Final)	21.83	15.09	8.54	8.35	34.49*	8.77**	1.68
Wt. fruit/plot	(8-17)	4.48	4.894	8.91	13.76	293.58**	4.48*	4.84**
"	(10-25)	51.56	26.41	13.92	10.09	8.38	14.31**	3.81*
Cumulative lint yld.	(10-4)	5.4341	10.003	46.43	120.87	75.30*	2.59	1.33
"	(10-25)	83.66	41.95	54.41	38.58	20.60*	9.09**	1.47
"	(11-15)	101.63	47.13	32.67	21.43	15.03	14.73**	2.30
"	(12-17)	70.847	36.08	13.33	9.60	0.40	11.50**	3.20*
Lint percentage bur cotton	(Total)	0.1985	0.4141	1.35	3.99	13.86	7.89**	1.38
" seed cotton	(")	0.0787	0.1061	0.38	0.72	256.74**	5.07**	0.72
Seed index	(")	0.0589	0.2199	0.91	4.83	12.06	6.14**	2.16
Lint index	(")	0.594	0.0924	16.41	3.61	1.94	16.94**	4.90**
Boll size	(")	0.2052	0.1254	7.86	6.79	7.75	31.63**	3.71*
No. seed per boll	(")	1.2622	0.6819	8.01	6.12	3.01	17.96**	0.30

Table 21. continued

Measurements and determinations	Standard of error		Coefficient of variation		"F" values		
	Variety	Spacing	Variety	Spacing	Variety	Spacing	Interaction
2.5% span length (10-11)	-	0.0149	-	2.13	-	0.86	-
" (11-1)	0.01174	0.0086	2.55	1.86	0.02	0.62	1.68
" (11-22)	0.0081	0.0081	1.73	1.74	11.15	4.33*	0.71
" (Boll samples)	0	0.0113	0.00	2.36	**	0.67	0.89
50% span length (10-11)	-	0.0105	-	3.09	-	1.27	-
" (11-1)	0.0078	0.0049	3.56	2.22	1.00	0.97	2.18
" (11-22)	0.0071	0.0063	3.29	2.92	0.06	0.59	0.52
" (Boll samples)	0.0022	0.0040	0.99	1.76	1.00	5.72*	1.72
Fiber strength(P.S.I)(10-11)	-	2.298	-	4.20	-	2.60	-
" (11-1)	0.0671	1.0199	0.17	2.66	1521.44*	5.31*	1.28
" (11-22)	1.1453	0.6042	3.70	1.54	5.19	3.57	15.13**
" (Boll samples)	0.7918	1.1549	2.10	3.06	0.48	3.05	0.30
Micronaire (10-11)	-	0.1512	-	4.36	-	2.36	-
" (11-1)	0.0793	0.1086	4.07	5.57	207.00*	13.49**	5.61*
" (11-22)	0.0767	0.0873	5.47	6.24	21.79	2.22	2.71
" (Boll samples)	0.2013	0.1755	10.59	9.24	4.69	5.74*	1.64

CHAPTER V

SUMMARY AND CONCLUSIONS

This investigation was conducted in 1965 at the South Plains Research and Extension Center, Lubbock, Texas, and was designed to evaluate the reaction of two cotton varieties of different growth and fruiting habits to five plant population levels with equidistant plant spacing. The primary objectives were to determine the effect of plant density on certain aspects of the morphology of the cotton plant with particular emphasis on those characters which influence yield, earliness of maturity, and fiber quality.

Maximum yields were not obtained at the highest population levels in this test but in the range of 30,000 to 60,000 plants per acre. These results generally agree with those of investigations of cotton spacing in 40-inch rows (13, 20, 28, 29, 38). There is some disagreement, however, with the findings of Hudspeth, et al. (16, 17, 19) as they obtained highest yields at very high population levels. Lint yield was relatively high in all population levels considering the late planting date. This may indicate that the equidistant spacing pattern has some advantages over conventional row cultures. Among the population levels investigated, the lower levels were generally earlier on the basis of cumulative lint yields and percentage of total crop open. Prior research at the Center has indicated the opposite, as higher plant populations have generally

resulted in earlier crop maturity (16, 17, 19). However, the test reported herein covered only one year's results; and under different conditions, different results may be obtained.

Lint percentages, seed index, and lint index were only slightly affected by plant density. These factors generally decreased, however, as plant population increased.

Fiber properties were not greatly affected by the spacing treatments in this test, although there was some indication that Micronaire is reduced as plant density increases. If high yields can be achieved in high plant populations, there are no indications that fiber properties will be adversely affected as the yield was affected much more by plant density than were the fiber properties.

Growth of the leaf surface was much more rapid at the higher plant densities. This gave these treatments a decided advantage in total dry matter produced, as total plant weight per unit of land was directly related to leaf area index. However, the net assimilation rate or efficiency of the leaf surface in producing dry matter was reduced as plant population increased. This was apparently the result of less favorable light relationships or perhaps some other modification of the microenvironment of the crop as a result of the moderating effect of the leaf canopy in the closer spacings. Relative growth rate, like net assimilation rate, was more favorable

for production of plant material in the lower population levels. Crop growth rate, on the other hand, was significantly higher in the high plant densities. Relative growth rate expresses growth as a ratio to plant size during the experimental period (t_2-t_1); whereas crop growth rate is simply the amount of dry matter produced per unit area of land. These factors can be indirectly related to yield if the fruiting-vegetative ratios are considered. The fruiting-vegetative ratio was significantly lower at the high population levels indicating that a greater portion of assimilates is directed to vegetative growth at these levels than at lower plant densities. Undoubtedly, other factors such as boll shed were also involved as indicated by the high weight of fruiting forms in the high population levels and the low percentage of these forms matured.

Morphological modification of the individual cotton plants was extensive; and a smaller, more compact plant developed as plant density increased. The resulting decrease in plant height, stem diameter, and size and number of branches as population increases would be conducive to increased mechanical harvesting efficiency with the finger-type stripper. Weight of plant components per unit area of land increased as plant population increased. The dry weight of the various vegetative parts was generally directly

related to plant density.

Several significant variety-spacing interactions strongly suggest that the experimental strain, C.A. 491, is much better adapted to close spacing than Paymaster 101A. C.A. 491 had a more efficient leaf canopy at all population levels and converted a greater portion of assimilates to fruit production than the Paymaster variety. The boll size was affected much more by plant density in Paymaster 101A than in C.A. 491, although boll size was significantly reduced at the highest population level in the C.A. 491. The experimental strain also responded more favorably to plant density in relation to lint yields as the 5" x 5" spacing had slightly higher yields than the 20" x 20" spacing in the C.A. 491 while the 5" x 5" spacing was significantly lower than any other treatment in the Paymaster variety. The reduction in plant height was significantly greater in C.A. 491, and this strain had fewer vegetative branches and more fruiting branches at all population levels than the Paymaster 101A.

The results of this investigation clearly indicate that equidistant plant spacing of cotton plants, within the range of population levels studied, modifies the morphological and physiological characteristics of the plant and crop in such a manner as to affect

yield and earliness of maturity. The need for further investigation is apparent, especially in the area of crop growth relationships and their effect on variations in economic yield as related to plant density. It is also quite evident that the use of an adapted variety for close-row cotton culture is extremely important; and that a compact, early maturing, determinate type plant is best suited for this purpose.

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