GROWTH PARAMETER VARIATIONS AMONG FOUR TETRAPLOID COTTON CULTIVARS (*GOSSYPIUM BARBADENSE* L. AND *GOSSYPIUM HIRSUTUM* L.)

by

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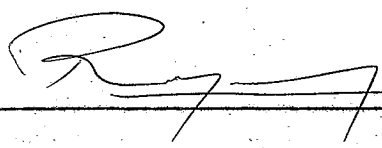
SIGNED: 

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ABSTRACT

Growth analysis techniques were used to compare growth variations and differences in partitioning dry matter (DM) into the above ground plant parts of three G. barbadense L. cultivars, 'Cluster', 'PS-4', 'PS-5' and one G. hirsutum L. cultivar 'DPL-16'. Samples were taken on five dates. Plant height, number of bolls, squares, and dry weight of different plant parts were determined from the bi-weekly sampling. Derived growth analysis indexes were computed from accumulated data.

G. barbadense L. cultivars were significantly taller than the G. hirsutum L. cultivar. Plant height, however, was not indicative of potential DM accumulation. Number of bolls per plant was higher for DPL-16 at 21 July and 4 Aug. and tended to be lower at the last sampling dates. The G. hirsutum L. cultivar accumulated more DM into reproductive organs. The G. barbadense L. cultivars, particularly Cluster, accumulated large amounts of DM into stems and leaves. No significant differences were found for $\overline{LAI}$, $\overline{CGR}$, $\overline{RGR}$, $\overline{NAR}$, and $\overline{LAR}$. Significant differences, however, were found for $\overline{BGR}$, $\overline{NAR_B}$ and $\overline{LAR_B}$. A high $\overline{BGR}$ and $\overline{RBGR}$ were associated with high $\overline{CGR}$ and high and longer $\overline{NAR}$ and $\overline{NAR_B}$ were useful in magnifying differences in partitioning assimilates among the tested genotypes, not detected by other parameters, indicating the importance of having a strong reproductive sink early in the growing season. Results suggest that for further improvement of the cotton genotypes, regarding partitioning of DM into harvestable parts, the earliness of the crop as determined by growth analysis indexes should be considered.

INTRODUCTION

The problem of obtaining high yields in cotton farming is of vital practical importance, and of considerable interest from purely theoretical points of view since its solution has many bearings on fundamental principles in plant physiology and other biological sciences. Our knowledge on the theory of obtaining high yields is, in fact, still undergoing constant revision. Current research is conducted with the aim of studying some relevant physiological processes and their possible influence on the yielding properties of the tested plants.

Analysis of certain agronomic yield characteristics gives valuable information on evolutionary trends and changes in the morphology of plants due to interaction between genotypic variability induced by systematic plant breeding, and natural selection due to environment. This, however, does not say anything about the physiological and biochemical processes lying behind these differences in development. The question immediately arises as to which primary processes may possibly limit the growth of the plants, and which may limit their yielding ability. It is easy to imagine various kinds of "bottlenecks" in plant growth, each of which may limit the magnitude of production. Many of these "bottlenecks" may be widened or removed by proper agricultural practices -- fertilization, irrigation, growth regulators, etc., but one remains which cannot be altered significantly under field conditions -- the amount of incident light falling on the plants. There

may be many reasons to assume that the magnitude of incident light together with the efficiency of the plant canopy to intercept, convert and utilize this energy for growth and differentiation will set the definite upper limit for plant production.

Recognition of major differences in yield depends to a large extent on demonstrating the association of each characteristic with yield in growth analysis experiments. Thus, a complete analysis of the agricultural yield performance would examine variations in the distribution of dry matter between organs and tissues as well as in the total weight of dry matter of the crop.

The objective of the present experiment was to compare growth characteristics among four tetraploid cotton cultivars through plant growth analysis. The investigation was designed to test differences in efficiency, and the partitioning of dry matter among distinct organs of the above ground portion of the cotton plants.

LITERATURE REVIEW

Plant physiologists have produced much information on many aspects involving the effects of external factors on all physiological processes of crop plants. Special attention has been devoted to yield and its relationship to factors limiting photosynthesis. A review of the literature shows relatively few studies conducted in areas analyzing the dependence of yield on the partitioning efficiency of the produced dry matter.

Growth Analysis Techniques

Growth analysis has been used in physiological research as a method of following the dynamics of photosynthetic production measured by production of dry matter. It can also be used to investigate ecological phenomena such as the success of species in various habitats, competition among species, genetic differences in yielding capacity, and effects of agriculture treatments on crop growth. The information obtained makes it possible to follow the formation and accumulation of plant biomass as determined by either environmental or genetic factors. The dependence of plant growth on both kinds of factors is considered specific, and determined by genotype response (Kvet et al., 1971).

Watson (1952) reported the 1915 work of Balls and Holton and later Balls, 1917, who made one of the first attempts to analyze yield of

terms of antecedent growth on the cotton crop in Egypt. They made measurements of the daily growth in height of the mainstem, daily rate of flowering, and the weekly rate of ripe boll production throughout the later part of the growing period. The flowering and bolling curves were used to interpret variations in yield induced by differences in spacing and sowing date, water supply, climatic factor and boll-worm attack.

Ten years following Ball's work, there was a rapid development of the methods of growth and yield analysis by a galaxy of investigators in England as may be seen from the proceedings of the Imperial Botanical Congress held in London in 1924. "The Physiology of Crop Yield: A Survey of Modern Method of Attack" was reviewed by W. L. Balls, V. H. Blackman, F. G. Gregory, G. E. Briggs, R. A. Fisher, E. J. Maskell and F. L. Engledow among others (Evans, 1976).

Williams (1946) and Watson (1952) reviewed growth analysis procedures. Physiological and ecological interpretations were fortified by Blackman and Wilson (1951a) and Blackman and Wilson (1951b). More recently, Radford (1967), Buttery and Buzzel (1974), Hughes and Freeman (1967), Kvet et al. (1971) and Eagles (1971) reviewed the mathematics assumptions and acceptable usage.

Relative Importance of Leaf Area as a Determinant of Growth and Yield

Although the lamina is the only significant organ of photosynthesis in land plants, under certain conditions other organs can contribute major proportions to the total photosynthesis which may

sometimes account for an appreciable fraction of the total dry matter production (Zelitch, 1971). Most authors, however, usually assume that the area of a leaf is the size-attribute that best measures the capacity for photosynthesis of a plant.

In growth analysis literature the total leaf area of a canopy is expressed as "leaf area index" (LAI), i.e., the number of units of leaf area per unit area of ground surface. Since leaves are considered to be the chief organs of photosynthesis, the LAI can be taken as a measure of the size of the photosynthetic system of a crop canopy that best indicates its capacity for photosynthesis.

The total annual photosynthesis of a crop depends not only on the size of the photosynthetic system but also on its efficiency and the length of time during which it is active.

It seems reasonable that the main criterion of success in improving crop yield is the efficiency with which radiant energy is used. Formulating the problem, the leaf area of a crop should expand to reach its optimum as rapidly as possible. The leaves should maintain activity for a prolonged period, and during senescence they should maintain a supply of assimilates to the reproductive and storage organs (Nichiporovich, 1967).

The optimum LAI is determined by rates of CO_2 assimilation and respiration as well as the relation of the leaf architecture, and the manner in which the light interception affects photosynthetic and respiratory capacities of the leaves within the canopy (Zelitch, 1971).

Donald, quoted by McCloud, Bola and Shaw (1964, p.23), presented a hypothetical example to portray the development of an idealized leaf canopy through three successive stages. First the optimum LAI was defined as the amount of leafage necessary to maximize net assimilation. At this stage all leaves are making a positive contribution to dry weight increase though the contribution by the lowest leaves may be quite small. Second, as the leafage continue to increase above the optimum, the LAI ceiling or maximum leaf area index is reached. At this point the rate of death of leaves, at the base of the canopy, as a result of aging or low light intensity equals the rate of appearance of new young leaves. The net assimilation rate by the foliage at the ceiling LAI is below that at optimum LAI. Third, as the plant canopy continues to develop, a ceiling yield is reaching where the nonphotosynthetic tissues have increased until the respiratory losses by the crop equal the photosynthetic gain. At this stage, the dry weight of living material per unit area is static and total net assimilation is zero. If the crop canopy continued to develop, respiration losses would exceed photosynthetic gains and the total yield would diminish below the ceiling yield.

Duncan (1971) predicted by computer simulation that for LAI less than 3.0, differences in leaf angle have only small effects on canopy photosynthetic rates. For higher LAI values Duncan postulated that layers of vertical and horizontal leaves can be arranged to give both the highest and lowest possible rates of canopy photosynthesis for the conditions assumed. It was found that the ratio of highest

to lowest photosynthetic rate varied from 1.14 at LAI 3.0 to 2.0 at LAI 10.0.

Experiments conducted by Watson and French (1962) showed that dry matter production from a heavy kale (Brassica oleracea L.) crop could be increased by keeping LAI close to the optimum. It was pointed out that this can be frustrating if thinning operations are practiced, because optimum LAI vary from place to place. Hence, the change required is presumably a morphological one that will lead to more efficient disposition of the leaves in space, so that their mutual interference is diminished.

In field trials conducted by Berdahl, Rasmusson and Moss (1972) large-leaf lines of barley (Hordeum vulgare L.) exceeded small-leaf lines in flag leaf area by 70% and in LAI by 25%. Lines with small leaves were found to produce more heads and higher grain yields than lines with large leaves when plants did not lodge. Where lodging occurred, however, large-leaf lines had higher kernel weights and were higher yielding. It was concluded that large leaves favor higher kernel weights and that small leaves favor production of more culms.

Fowler (1976) used growth analysis techniques to determine growth and development of conventional and short season cotton cultivars, using an experimental upland cotton (G. hirsutum L.) and three between row spacing configurations. His results showed that during the initial growth of the crop through the tenth week after planting, LAI was closely correlated with population density. A mean crop

growth rate ($\overline{CGR}$) of 8.1 g/m^2 land area/day was maintained up to 19 weeks after planting, thereafter declining in a manner similar to that of LAI.

Ashley, Doss and Bennett (1963) conducted an experiment to describe the seasonal growth of a cotton plant community in terms of leaf area and determine the relation between leaf area and yield characters. Results showed a definite relation between leaf area and total fruiting occurred from LAI of 2.0 to 5.0. When LAI reached 5.0, however, total number of fruits on the plant remained about constant until late season and then declined.

Ashley, Doss and Bennett (1965) made measurements of LAI, fruiting, and other plant factors on an irrigated cotton community and evaluated the relationships among the various growth and fruiting characters. Their results showed that LAI of cotton plants reached 1.0 approximately 6 to 8 weeks after planting, followed by a period in which LAI increased rapidly from 1.0 to 5.0 at about 12 to 14 weeks after planting. After LAI reached 5.0, the growth pattern varied between the 2 years the study was conducted, and between treatments within years. The data indicated that this variation in the late season LAI was associated with the number and maturity of fruit on the plants. The relationships between flower bud initiation and growth of young fruit on the cotton plant were 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 that it is important to develop a

large plant early in the growing season for maximum yields. The yield of seed cotton was directly related to early development of plants.

Bhatt (1974) conducted a study on morphologically contrasting varieties of cotton. Results showed that the normal plant type with monopodial and sympodial branches had a higher leaf area index (LAI) than a short branch variety with only two leaves per node (a sympodial leaf and a mainstem leaf) but that these expanded more quickly. The seed cotton yield of these varieties was the same, so the LAI was not correlated with yield. More sunlight penetrated to the lower nodes of the short branch type and it appeared that a smaller but effective leaf area may result in greater plant efficiency.

Shibles and Weber (1965) studied the dependence of solar radiation interception on LAI and its relation to dry matter production. They found that percent solar radiation interception increased with increasing leaf area development, reached a maximum, and remained constant with further increase in LAI. Rate of dry matter (DM) production was linearly related to percent interception. Since rate of DM production did not decline at LAI greater than required for full solar radiation interception, it was concluded that the lower, shaded leaves of the soybean (Glycine max (L.) Merr.) canopy are not "parasitic" upon the productive portion of the canopy.

LAI certainly influences the efficiency of solar radiation interception of a crop canopy; and it seems that to secure maximal dry matter production, the high values of LAI should occur when seasonal weather conditions are most favorable for photosynthesis.

Relationship Between Leaf Area and Net Assimilation Rate

Net assimilation rate (NAR) is defined in growth analysis literature as the rate of increase of dry weight per unit leaf area, and can provide a measure of the parameter of efficiency of the photosynthetic system. The NAR thus measures the excess of dry matter gained over loss by respiration. Not all changes in net assimilation rate are determined by variations in the rate of photosynthesis.

It has been pointed out by Watson (1956) that if NAR were independent of LAI, the rate of increase of dry matter per unit area of land, the crop growth rate (CGR = NAR x LAI), would increase indefinitely with increase of LAI. He pointed out, however, that as LAI increases, mutual shading of the leaves must eventually begin to decrease the rate of photosynthesis, thus decreasing NAR. Hence, it is to be expected that in higher ranges of LAI there will be an inverse relation between NAR and LAI.

NAR varies between and within species, with mineral nutrition, water supply, and with seasonal climatic conditions. However the significance of this variation in relation to dry matter accumulation and yield depends on its magnitude in comparison with the variation in leaf area (Watson, 1952).

Although within species the variation in NAR is linked primarily with light intensity and secondarily with temperature, there is evidence that between species factors may operate differently. When conditions for growth are optimal, however, even though there

may be differences between species, the NAR are of the same order. These conclusions were reached by Blackman and Wilson (1951a) who worked with 10 species over a period of 5 years studying the relationship between NAR and light intensity.

In a later publication, Blackman and Wilson (1951b) stated that for all species included in their studies, both the changes in NAR and leaf area ratio (LAR) are linearly related to the logarithm of light intensity. Consequently the relationship between the logarithm of light intensity (X) and relative growth rate (Y) should be curvilinear, i.e., $Y = ax^2 + bx + c$. It is therefore possible to determine the light intensity at which growth rate is maximal with new precision.

Auckland and Lambert (1974) selected for high and specific leaf weight on F_2 plants of five soybean crosses in 1972. The F_3 was grown in 1973, and analyzed for various morphological characters thought to be related to physiological processes. It was found that selection for high specific leaf weight resulted in genotypes having high NAR, but in only one cross was NAR associated with yield. It was concluded that NAR appears to be negatively correlated with leaf blade size, petiole size and length. The cross that showed a positive association between yield and NAR had the highest specific petiole weight.

Heath and Gregory (1938) compared the mean net assimilation rate ($\overline{NAR}$) for various species grown in different environments by reviewing the results of several investigators around the world. For

cotton and other species it was concluded that there is little variation ($\overline{NAR}$) for the early vegetative phase of the life cycle even in the most diverse environments.

The effects of age on NAR and relative growth rate (RGR) in cotton plants were studied by Heath (1937). Results indicated no differential effects of age up to flowering for NAR calculated by Gregory's method. This constancy of rate confirms the findings of other investigators working on barley and other species in which vegetative phase NAR remains constant. On the other hand Heath (1937) found that RGR and relative leaf growth rate (RLGR) had a slight downward trend in time.

The results of Crowther (1934) studying cotton in the Sudan, also appear to show no drift of NAR with time until after flowering has begun.

Translocation and Partitioning of Assimilates

Wallace and Munger (1966) compared the extent of variation in distribution of accumulated dry matter among aerial organs at maturity for 11 varieties of dry beans (Phaseolus vulgaris L.). Results obtained supported conclusions of a previous paper (Wallace and Munger, 1965) and indicated distinct varietal and therefore genetic differences for both biological and economic yield, and harvest index. Leaf area (A), LAR, RGR, and RLGR were also found to vary among the dry bean varieties studied. High leaf area (A) and high LAR were found associated with higher seed yield only for some comparisons.

Hesketh, Lane and Thompson (1976) conducted an experiment to determine how the cotton plant partitioned photosynthate into bark, wood, roots, leaves, and petioles. Parameters like weights and sizes of specific leaves or internodes were used, because they vary little among plants avoiding, as they remarked, problems of plant variability and associated large errors that make standard growth analysis procedures difficult. It was found that when greater fractions of dry matter were found in the stem this corresponded to larger values of leaf area.

Koller (1971) found that the amount of dry matter (DM) accumulated varied among segments of the soybean (Glycine max (L.) Merr.) canopy. Partitioning of dry matter followed a similar pattern in each segment. Lower and middle main-stem accumulated the most dry matter but partitioned only 36% of this into the seed component. Branch and upper main stem partitioned 47% of total dry matter into seed. The contribution of environmental factors to this differential partitioning of DM is unknown.

For cereals and soybeans several authors have concluded that differences in time period, (filling period, during which dry matter accumulates) accounts for more yield variation among cultivars than do differences in accumulation rate. Danyard, Tanner and Duncan (1971) attributed less than 16% of the grain yield variation among corn (Zea mays L.) hybrids to differences in the average rate of dry matter accumulation in the ears. They accounted for 71 to 80% of the yield variation with a relative measure of the filling period.

Egli and Leggett (1973) comparing determinate and indeterminate soybean genotypes found that the growth rate of soybean fruit (pod walls plus seed) differed among genotypes from year to year. The suggested that differences in the rate of dry matter accumulation in the fruit of soybeans can exist.

Karami and Weaver (1972) found that okra-leaf lines of cotton have a lower percentage of dry weight in stalks and leaves than normal-leaf lines. Okra lines had 15% higher harvest index than normal-leaf lines, which was interpretated as a better distribution of dry matter to economic yield.

Muramoto, Hesketh and El-Sharkawy (1965) found differences in leaf area development among cottons, G. barbadense L., G. hirsutum L., their hybrids, and other species. Differences in leaf area development were associated with differences in rates of dry matter production. Mu'Allem (1976) found no differences between tetraploid (G. hirsutum L.) and hexaploid experimental lines in average dry weight per plant. Tetraploids, however, accumulated higher amounts of dry matter in the fruiting parts. He reported the efficiency of the tetraploids (G. hirsutum L.) in partitioning assimilates to the reproductive parts of the plant.

Results of Elmore and Hacskaylo (1973) studying source and sink relationships in cotton, indicated that the sinks supplied by monopodial or sympodial leaves are different; and that the sinks supplied by particular leaves change with age and physiological development of the plant.

Number of Bolls as Affected by Growth Patterns

Since cotton has an indeterminate growth habit, vegetative growth competes with bolls for assimilates. Upper young active leaves are near the vegetative sink, and older shaded leaves are near the reproductive sink. This relationship tends to promote inefficient use of assimilates. Thus total photosynthetic activity of the crop canopy may not relate closely to boll yield (Kerby, 1976).

Buxton and Saleem (1976) found that cotton plants total available carbohydrates (TAC) depression coincides with a rapid increase in weight of fruiting forms when lint yields were high, and with a rapid increase in rank vegetative growth when lint yields were low. It was concluded that excessive vegetative growth lowers TAC levels which is associated with depressed lint and seed yield. Buxton remarked that restructuring of the crop canopy to allow greater penetration of solar radiation to leaves near developing bolls may increase yield in narrow-row plantings.

Saleem and Buxton (1976) suggested that assimilates are inefficiently translocated down the main stem axis when TAC level in the central portion of the stem, which contained 48% of the boll load, was only 50% of that in the lower or upper stem portions.

Johnson and Addicott (1967) studied the effect of leaf area and gibberelic acid (GA) on boll retention of cotton plants growing in nutrient culture. Leaf area was reduced using two dipping methods. Results indicated that boll retention depends on the presence of

sufficient number of developing seed to mobilize the assimilates required for continuous growth, and upon the availability of assimilates as governed by the vegetative-reproductive status of the plant.

Maner et al. (1971) developed yield models for selected upland cotton (G. hirsutum L.) genotypes. Bolls per square meter (X) were found to have the greatest influence on yield when compared to seeds per boll (Y) and seed cotton per seed (Z). They pointed out that the greatest amount of yield improvement can be made by exerting selection pressure for more bolls per unit area due to similarity of Y and Z of most of the present successful varieties.

Plant Height

Among cultivated species of cotton, plant height is usually found correlated with amount of dry matter production, and with the indeterminate growth patterns of both cultivated and wild species.

Mu'Allem (1976) found no significant differences in plant height among tetraploids (G. hirsutum L.) and experimental hexaploids lines. The rapid increase in plant height of hexaploids plants, 111 days from planting, suggested less competition from fruit load. In cotton growth studies conducted by Gerald and Cowley (1962) plant height was assumed responsive to imposed treatments or variables. Cotton plants showed fluctuations in height with increasing soil moisture, stress, and plant population. Fluctuations of height due to plant density was also reported by de Oliveira (1974). Little effect of plant leaf type on height was found by Kerby (1976).

Heath (1937) reported that from height of 10 cm up to time of flowering the growth of the main axis of cotton plants is approximately exponential. From germination up to a height of 10 cm, growth does not follow the same exponential curve, but showed a higher growth rate due to a rapid extension of the hypocotyl. Growth in dry weight on the other hand approximated an exponential curve from germination until flowering. Anderson (1971) conducted an experiment using five varieties and two soil temperatures at germination to compare measures of emergence, early growth and earliness of maturity in the field. He concluded that plant height was easy to measure and showed least variability as an indicator of early growth.

Evidence for variation in leaf area, leaf angle, light interception, and photosynthetic rate has been reported; and a vast literature is available on their genetics and heritability. In the long run, the most effective approach to breeding for high yield would be to identify those physiological components causing varietal differences in economic yield and acquire understanding of their genetic control (Wallace, Ozbun and Munger, 1972). In this sense, if the physiological genetic data we have been dealing with herein are used in selecting parents, it should be possible to select directly for yield, using standard selection and breeding procedures. Knowledge of the physiological genetics of those factors affected ecologically and those that affect yield will of course greatly improve the plant breeders understanding of desirable plant type, habit, and appropriate selection procedures to pursue.

MATERIALS AND METHODS

Location and Materials

Three G. barbadense L. cultivars, 'Cluster' (no simpodial branches), 'Pima S-4' (PS-4), and 'Pima S-5' (PS-5) and one G. hirsutum L. cultivar, 'Deltapine 16' were planted on 21 April, 1977 in north-south rows 100 cm apart at The University of Arizona Campbell Avenue Farm in Tucson, Arizona at 1850 feet elevation. Soil type was a coarse-loamy member of the Gila series, a typical torifluvent alluvial. Plots were hand thinned on 23 May to populations of approximately 65,000 plans/ha (26,000 plants/acre). A Latin Square experimental design was used. The plot size was four rows each of 9 m long (9 m^2). The experimental area was treated with the herbicides, Treflan (a-a-a,-Trifluro-z-6 dinitro-N, N-dipropyl-P-toluidene) and Caparol (2,4 bis (isopropilamino)-6-6(-methylthio)-s-s-trazine) in pre-emergence application at the rate of 0.6 liters/ha and 1.4 kg active ingredient/ha., respectively and incorporated by discing. Additional hand weeding was done as needed throughout the growing season. Urea at the rate of 112 kg/ha, was applied preplant in all plots. All other cultural practices were the same as those used for conventional irrigated cotton in Arizona. Plant growth was normal for most of the growing period.

Sampling Techniques and Methods

Samples for dry matter and leaf area determinations were taken on five dates, 7 July, 21 July, 4 August, 18 August, and 2 September.

Four plants per plot were chosen at random from the two central rows in each plot at each sampling date. Plant organs were separated, and measurements of plant height, counting of bolls and squares were made. Plant organs were oven-dried, and dry weight of leaves, stems, petioles, and bolls and squares determined.

A total of eight leaves were randomly subsampled, two from each of the four sampled plants. An automatic leaf area meter, type AAM-5[1] was utilized for the determination of leaf area. Subsampled leaves were oven-dried and leaf area to leaf weight ratio (A/WL) determined. A value for total leaf area of the four plants was obtained by multiplying A/WL by the total dry weight of the leaves of the four sampled plants.

The following growth indexes were calculated from the data:

LEAF AREA INDEX (LAI): Calculated by dividing the total leaf area of the four plants by the ground area covered (Kvet et al., 1971).

$$LAI = \frac{A}{P} \text{ (area - area}^{-1})$$

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1. Hayashi Denko Co., Ltd., Tokyo, Japan.

CROP GROWTH RATE (CGR): Calculated as the mean increase of plant material per unit of time (Kvet et al., 1971).

$$\overline{CGR} = \frac{W_2 - W_1}{T_2 - T_1} \quad (\text{weight.time}^{-1})$$

Results were expressed in $g/m^2/day$

RELATIVE GROWTH RATE (RGR): Calculated as the mean increase of plant material per unit material present per unit of time (Kvet et al., 1971).

$$\overline{RGR} = \frac{\ln W_2 - \ln W_1}{T_2 - T_1} \quad (\text{weight.weight}^{-1}.\text{time}^{-1})$$

Results were expressed in g/100 g/day.

NET ASSIMILATION RATE (NAR): Calculated as mean increase of plant material per unit of assimilatory material per unit of time (Radford, 1967).

$$\overline{NAR} = \frac{W_2 - W_1}{A_2 - A_1} \cdot \frac{\ln W_2 - \ln W_1}{T_2 - T_1} \quad (\text{weight-area}^{-1}.\text{time}^{-1})$$

Results were expressed in $g/dm^2/day$.

LEAF AREA RATIO (LAR): Calculated as mean ratio of the assimilatory material per unit of plant material present (Radford, 1967).

$$\overline{LAR} = \frac{A_2 - A_1}{W_2 - W_1} \cdot \frac{\ln W_2 - \ln W_1}{\ln A_2 - \ln A_1} \quad (\text{area}^2.\text{weight}^{-1})$$

Results were expressed in dm^2/g.

RESULTS AND DISCUSSION

Plant Height

Plant height at five sampling dates is reported in Table 1. No significant differences were found among the four genotypes for plant height on 7 July. Significant differences were observed at the 21 July measurement and thereafter plants reached an age of 91 days from planting. The Gossypium barbadense L. cultivars, were significantly taller than DPL-16. The Cluster cultivar was significantly taller than PS-5 and PS-4. No significant differences in plant height were found between Pima S-4 and S-5 at any sampling dates.

De Oliveira (1974) reported similar averages of plant heights for DPL-16 as those reported here for plants of the same age and of similar planting date. He also reported no effect of leaf type on plant height among G. hirsutum L. cultivars. Results of de Oliveira and other investigators suggest no strong environmental effects on plant height among G. hirsutum L. cultivars. Mu'Allem found no significant differences among tetraploid G. hirsutum L. cultivars. His findings for plant height were similar for DPL-16 as those reported here.

Results on plant height were not indicative of the trend for total dry matter accumulation. This was probably due to the structural differences and the partitioning pattern of the genotypes.

Table 1. Average plant height of four genotypes at five sampling dates.

Genotypes	Sampling Dates				
	7 July	21 July	4 Aug.	18 Aug.	2 Sept.
	cm				
Cluster	52.6 a*	88.3 a	121.6 a	137.4 a	162.8 a
PS-5	51.9 a	78.7 b	97.8 b	109.0 b	108.4 b
DPL-16	54.7 a	69.9 c	82.8 c	83.0 c	87.0 c
PS-4	49.6 a	79.7 b	94.7 bc	105.0 b	109.8 b
C.V. (%)	7.0	4.7	2.3	8.6	8.7

*Means followed by the same letter for a date are not different at the 5% level in the Duncan's multiple range test.

Number of Bolls Per Plant

Table 2 presents the average number of bolls per plant for four genotypes at 5 sampling dates. At the 7 July sampling, DPL-16, Cluster, and PS-4 did not differ significantly, but all three set bolls significantly earlier than PS-5. At 21 July and 4 Aug., DPL-16 had the highest number of bolls per plant and was significantly greater than the G. barbadense L. cultivars. At 18 Aug. and 2 Sept., PS-5 and PS-4 showed an increase in boll number, with PS-5 showing significant increase over Cluster and DPL-16. DPL-16 did not show further increase in number of bolls per plant after 18 Aug., however bolls were greater in size and heavier compared to those of the other G. barbadense L. cultivars. DPL-16 was early in boll set and showed rapid boll development.

Results obtained for number of bolls per plant indicated better efficiency of the G. hirsutum L. cultivar in the early distribution of the assimilates to the development of the already formed reproductive forms. Differences observed at 2 Sept. on the PS-5 and PS-4 cultivars are indicative of the excessive fruiting points formed late in the growing season.

Davis (1974), reported that UKA, an early Semi-dwarf, G. hirsutum L. line of Yugoslavian origin, and Ktechi, an Acala cotton crossed with PS-4 (G. barbadense L.) produced hybrids which showed an advantage in boll set over 'Acala 1571-70'. He found that the shorter boll period, plus the large boll size of the Acala nullified the advantage gained by the hybrid due to early set.

Table 2. Average bolls per plant of four genotypes at five sampling dates.

Genotypes	Sampling Dates				
	7 July	21 July	4 Aug.	18 Aug.	2 Sept.
Cluster	1.0 a*	6.2 b	11.8 c	22.0 b	25.9 b
PS-5	0.1 b	8.5 b	18.0 b	33.6 a	41.3 a
DLP-16	1.0 a	15.4 a	24.5 a	26.6 b	24.5 b
PS-4	0.2 a	6.4 b	17.0 b	28.4 ab	34.3 ab
C.V. (%)	6.9	26.1	12.1	14.4	18.3

*Means followed with the same letter for a date are not different at the 5% level in the Duncan's multiple range test.

It seems reasonable that further improvement of the G. barbadense L. cultivars studied here must come through an effort to induce earliness in boll set, and a possible reduction of the boll period.

It is widely accepted that in the G. barbadense L. varieties studied here, a certain amount of fruit shedding is inevitable adjunct to the indeterminate fruiting habit. It seems clear from the evidence available that shedding may cause significant reduction of yield under certain circumstances. Yield loss may be greatest when early season shedding is highest, since the successful performance of a late crop depends upon favorable conditions obtained in the later part of the season -- a situation that cannot be guaranteed under Arizona conditions.

Although plant sampling techniques included representative plants from each plot, high values for coefficient of variations (C.V.) are reported for number of bolls and other characteristics in this study. This is probably due to the small size of the sample and the variability among plants between species and within each genotype. Hesketh et al. (1976) reported that insect damage, weather changes, emergence date differences and previous growing history all affect plant growth creating considerable variation among plants. They suggested that if such differences could be categorized it would be possible to avoid gross variabilities among plants and the associated large errors that limits standard growth analysis procedures.

Bolls and Squares

Averages of total number of fruiting forms (bolls plus squares) are given in Table 3. No significant differences were found at 7 July and 4 Aug., among the four cultivars. At 21 July, Cluster showed a significantly lower number of bolls compared to the other three cultivars. This probably is attributable to a low CGR during this period. Fruiting load of DPL-16 at 7 July, 21 July, and 4 Aug. was not significantly higher than the three G. barbadense L., however, it was significantly lower in the last sampling dates, 18 Aug. and 2 Sept.

High late fruit load was also associated with high amount of dry matter directed to these organs as shown in Table 4, which involves a relatively large investment of assimilates.

High, late fruit load seems to be associated with low boll retention. Higher rates of flowering have been found associated with high abortion rates of young bolls (Bhardwaj and Sharna, 1968). Shedding of fruiting forms associated with high flowering has been reported by Kerby and Buxton (1976), Johnson and Addicott (1967), Ibrahim (1974), and Ehlig and LeMert (1973).

Dry Weight of Bolls and Squares

Fruit (bolls plus squares) dry weight of four genotypes at 5 sampling dates is reported in Table 4. DPL-16 had significantly greater dry weight of bolls and squares than the G. barbadense L. cultivars at 21 July, 4 Aug. and 18 Aug. The Cluster cultivar accumulated the lowest dry weight of reproductive forms in all sampling dates.

Table 3. Average number of bolls and squares per plant of four genotypes at five sampling dates.

Genotypes	Sampling Dates				
	7 July	21 July	4 Aug.	18 Aug.	2 Sept.
Cluster	13.2 a*	22.8 b	32.7 a	42.4 a	47.5 a
PS-5	16.2 a	34.5 a	47.7 a	49.2 a	45.9 a
DPL-16	21.1 a	36.9 a	37.7 a	28.6 b	25.5 b
PS-4	26.4 a	34.4 a	38.2 a	42.2 a	41.9 a
C.V. (%)	29.1	13.5	23.0	16.0	18.3

*Means followed with the same letter for a date are not different at the 5% level in the Duncan's multiple range test.

Table 4. Average dry weight of bolls and squares per plant of four genotypes at five sampling dates.

Genotypes	Sampling Dates				
	7 July	21 July	4 Aug.	18 Aug.	2 Sept.
	g				
Cluster	2.0 a*	8.3 c	19.0 b	41.3 c	61.0 b
PS-5	3.7 a	14.4 b	29.0 ab	63.9 b	108.9 a
DPL-16	3.8 a	19.1 a	40.8 a	86.8 a	104.1 a
PS-4	4.1 a	12.6 b	23.5 b	54.7 b	100.7 a
C.V. (%)	41.0	15.6	29.0	12.4	21.4

*Means followed by the same letter for a date are not different at the 5% level in the Duncan's multiple range test.

No significant differences were obtained between PS-4 and PS-5 at all sampling dates. At 2 Sept., DLP-16, PS-4 and PS-5 accumulated similar amounts of dry matter which were significantly greater than the Cluster cultivar. The efficiency of DPL-16 on the distribution of assimilates to the already formed fruit are in agreement with results previously discussed in Tables 2 and 3.

Dry Weight of Stems

As shown in Table 5 the four genotypes showed no significant differences in total dry weight of stems per plant at any of the first four sampling dates, 7 July, 21 July, 4 Aug. and 18 Aug. Significant differences were found only at the last sampling date, 2 Sept. with DLP-16 having the lowest dry weight of stems per plant. Dry weight of stems in PS-5 and PS-4 cultivars were similar on 2 Sept. with the Cluster cultivar showing the greatest amount of dry matter directed to the stems.

Although no significant growth of the cotton plant was observed after the last sampling date, Mu'Allen (1976) obtained greater stem dry weights for DLP-16 than those reported here, for cotton of similar age, indicating that environmental factors may have influenced the partitioning patterns of dry matter.

The small increase in stem dry weight of DPL-16 compared to the G. barbadense L. cultivars suggests evolutionary changes occurred to the G. hirsutum L. cultivar to more efficiently direct the assimilates to heavy early flowering, and rapid fruit development.

Table 5. Average dry weight of stems per plant of four genotypes at five sampling dates.

Genotypes	Sampling Dates				
	7 July	21 July	4 Aug.	18 Aug.	2 Sept.
	g				
Cluster	9.4 a*	21.8 a	41.2 a	54.5 a	75.5 a
PS-5	11.6 a	22.8 a	35.7 a	52.9 a	57.8 b
DLP-16	13.7 a	21.9 a	32.0 a	33.9 a	38.4 c
PS-4	11.2 a	27.8 a	36.8 a	49.5 a	56.3 bc
C.V. (%)	28.4	21.4	29.4	20.2	18.8

*Means followed by the same letter for a date are not different at the 5% level in the Duncan's multiple range test.

Dry Weight of Petioles

The mean dry weight of petioles among the four cultivars did not differ significantly at any of the sampling dates (Table 6). Among the G. barbadense L. genotypes, Cluster tended to have larger petioles which may help explain its higher dry weight of petioles even though it had a smaller number of leaves per plant.

Dry Weight of Leaves

Average dry weight of leaves per plant of the four genotypes is reported in Table 7. Significant differences were found only at the 21 July sampling when PS-5 and PS-4 accumulated a greater amount of leaf dry matter than DPL-16 and Cluster cultivars. DPL-16 accumulated less dry matter in the leaves than the G. barbadense L. cultivars. In all sampling dates, differences in dry matter accumulated in the leaves were associated with differences in leaf area per plant and leaf area index (LAI). Results suggested that the ratio A/LW was a useful tool in the calculation of total leaf area and that possible differences in A/LW do not alter total leaf area. Hence, the ratio A/LW deserve special statistical considerations when determining differences in leaf lamina thickness.

Morey, Quiesenberry and Roark (1974) reported differences in leaf anatomy among different species and races of Gossypium. Differences in thickness were determined by quantitative measurements of interveinal leaf tissue, i.e., length of the upper to lower cuticular surface.

Table 6. Average dry weight of petioles per plant of four genotypes at five sampling dates.

Genotypes	Sampling Dates				
	7 July	21 July	4 Aug.	18 Aug.	2 Sept.
	g				
Cluster	3.2 a*	5.5 a	9.1 a	9.3 a	9.6 a
PS-5	3.3 a	6.8 a	7.9 a	8.5 a	8.8 a
DLP-16	3.8 a	6.0 a	6.7 a	8.0 a	7.4 a
PS-4	3.2 a	5.9 a	6.9 a	8.0 a	8.6 a
C.V. (%)	23.0%	8.4	14.8	22.7	15.9

*Means followed by the same letter for a date are not different at the 5% level in the Duncan's multiple range test.

Table 7. Average dry weight of leaves per plant of four genotypes at five sampling dates.

Genotypes	Sampling Dates				
	7 July	21 July	4 Aug.	18 Aug.	2 Sept.
	g				
Cluster	15.6 a*	24.8 b	42.0 a	47.2 a	49.6 a
PS-5	19.8 a	34.4 a	42.5 a	50.4 a	51.8 a
DLP-16	19.1 a	26.9 b	39.3 a	41.2 a	40.5 a
PS-4	19.3 a	31.7 a	40.7 a	46.1 a	50.8 a
C.V. (%)	22.0	8.2	13.8	16.2	16.3

*Means followed by the same letter for a date are not different at the 5% level in the Duncan's multiple range test.

Total Dry Weight Per Plant

Means for total dry weight per plant of four genotypes at five sampling dates are reported in Table 8. The four genotypes did not differ significantly in total dry matter accumulated at 7 July, 4 Aug., 18 Aug. and 2 Sept. The Cluster cultivar had significantly lower dry weight at 21 July than PS-5, PS-4, and Cluster.

When comparing tetraploids and hexaploid cottons, Mu'Allen (1976) found no differences in dry matter accumulation among tetraploid cottons. An average of 251 g. per plant was reported for plants approximately 110 days old.

Leaf Area Index

Leaf area index (LAI) did not differ significantly among the four cotton genotypes at 7 July, 4 Aug., 18 Aug. and 2 Sept., as shown in Table 9. There were significant differences for LAI at 21 July with DPL-16 and Cluster having significantly less leaf area per unit of ground area (LAI) than PS-4 and PS-5.

Results for LAI were consistent with the findings on dry matter accumulated on the leaves, total dry matter per plant and other characteristics as discussed previously. A maximum LAI value of 6.6 found on PS-5 was the highest average of total dry matter per plant in the experiment.

Maximum LAI occurred in the late sampling dates for G. barbadense L. cultivars. The G. hirsutum L. cultivar had lower values of LAI, and reached a maximum LAI of 5.4 at 18 Aug. which dropped later as bolls started to open.

Table 8. Total dry weight per plant of four genotypes at five sampling dates.

Genotypes	Sampling Dates				
	7 July	21 July	4 Aug.	18 Aug.	2 Sept.
	g				
Cluster	30.1 a*	60.3 b	110.4 a	152.2 a	181.0 a
PS-5	383. a	78.4 a	114.8 a	175.8 a	227.2 a
DLP-16	36.2 a	73.8 a	118.9 a	169.8 a	190.4 a
PS-4	37.7 a	77.8 a	107.8 a	158.2 a	216.3 a
C.V. (%)	23	8.5	17.8	14.2	16.0

*Mean followed by the same letter for a date are not different at the 5% level in the Duncan's multiple range test.

Table 9. Leaf area index (LAI) determination of four genotypes at five sampling dates.

Genotypes	Sampling Dates				
	7 July	21 July	4 Aug.	18 Aug.	2 Sept.
Cluster	1.7 a*	2.9 b	4.9 a	6.3 a	6.4 a
PS-5	2.0 a	3.9 a	5.5 a	6.6 a	6.2 a
DLP-16	2.0 a	2.9 b	4.3 a	5.4 a	4.1 a
PS-4	2.1 a	4.0 a	4.8 a	5.9 a	6.3 a
C.V. (%)	22.9	14.6	14.3	22.4	18.0

*Means followed by the same letter for a date are not different at the 5% level in the Duncan's multiple range test.

Mean Crop Growth Rate ($\overline{CGR}$)

As shown in Table 10 the four genotypes did not differ significantly in the mean crop growth rate ($\overline{CGR}$) at any of the sampling periods. $\overline{CGR}$ showed a particular pattern of variation for each cultivar through the sampling periods. The Cluster cultivar reached a $\overline{CGR}$ of 6.6 g/m^2/day between 21 July and 4 Aug. and then decreased as LAI increased in the late season. Pima S-5 reached its maximum $\overline{CGR}$ of 8.1 g/m^2/day between 4 Aug. and 18 Aug. and decreased slowly thereafter. Similar $\overline{CGR}$ of 8.1 g/m^2/day was reported by Fowler (1976) working with an experimental upland cotton (*G. hirsutum* L.). A maximum $\overline{CGR}$ of 6.7 was found for DPL-16 between 4 Aug. to 18 Aug. which dropped rapidly between 18 Aug. and 2 Sept. The highest $\overline{CGR}$ for PS-4 were registered at the last sampling date with a $\overline{CGR}$ of 7.8 g/m^2/day.

Results obtained for $\overline{CGR}$ were in agreement with the findings of Fowler (1976) who reported a decline of LAI and CGR late in the growing season, and those of Watson (1956) on the effects of mutual shading of leaves at high LAI which influence $\overline{CGR}$.

Results obtained herein suggest that differences in growth intensity characterized the genotypes used in this study although they were not statistica/ly significant.

Mean Relative Growth Rate ($\overline{RGR}$)

No significant differences were found among the four genotypes on the $\overline{RGR}$ as shown in Table 11. The highest $\overline{RGR}$ occurred at the 7 July to 21 July sampling period for all tested genotypes indicating that growth intensity of the cotton plants is particularly

Table 10. Mean crop growth rate ($\overline{CGR}$) of four genotypes for four periods.

Genotypes	Sampling periods			
	7 July - 21 July	21 July - 4 Aug.	4 Aug. - 18 Aug.	18 Aug. - 2 Sept.
	$g/m^2/day$			
Cluster	4.0 a*	6.6 a	5.5 a	3.9 a
PS-5	5.3 a	4.8 a	8.1 a	6.8 a
DLP-16	5.0 a	6.0 a	6.7 a	3.7 a
PS-4	5.3 a	4.0 a	6.6 a	7.8 a
C.V. (%)	26.9	36.2	30.9	32.0

*Means followed by the same letter for a period are not different at the 5% level in the Duncan's multiple range test.

Table 11. Mean relative growth rate ($\overline{RGR}$) of four genotypes for four periods.

Genotypes	Sampling periods			
	7 July - 21 July	21 July - 4 Aug.	4 Aug. - 18 Aug.	18 Aug. - 2 Sept.
	g/100 g/day			
Cluster	5.2 a*	4.4 a	2.1 a	1.4 a
PS-5	5.2 a	2.7 a	3.1 a	1.8 a
DLP-16	5.1 a	3.3 a	2.7 a	1.0 a
PS-4	5.2 a	2.3 a	2.7 a	2.3 a
C.V. (%)	34.2	32.2	32.0	31.0

*Means followed by the same letter for a period are not different at the 5% level in the Duncan's multiple range test.

important at this time, (77 to 91 days from planting). $\overline{RGR}$ was higher at low LAI early in the growth periods and declined as the plants were older. These results are in agreement with the findings of Mu'Allen (1976) and Buttery (1970), who found the $\overline{RGR}$ to decline with plant age.

Results obtained in this study indicated that in cotton, both G. hirsutum L. and G. barbadense L. cultivars, the efficiency of the assimilatory apparatus diminish with age and high LAI, as the former occurs late in the growing season.

Mean Net Assimilation Rate ($\overline{NAR}$)

Mean net assimilation rates ($\overline{NAR}$) of four genotypes at four sampling periods are presented in Table 12. There were no significant differences found among the cotton genotypes for $\overline{NAR}$ at any of the sampling periods. $\overline{NAR}$ was higher at early sampling periods and decreased as plants grew older. $\overline{NAR}$ also decreased as LAI increased. This inverse relation suggested a drift on the rate of canopy photosynthesis possibly due to mutual shading of leaves in a crowded canopy. LAI as reported in Table 9 for DPL-16 was low at the last three sampling dates compared to PS-5, PS-4, and Cluster cultivars, which allowed better utilization of the incoming solar energy within the canopy. A similar tendency for a drift of $\overline{NAR}$ on cotton has been reported by Heath (1937), Watson (1952), Watson (1956) and Fowler (1976). Wallace and Munger (1965) considered it possible that an initially larger NAR contributed to the higher $\overline{RGR}$ of their tested pea bean (Phaseolus vulgaris L.) varieties and that excess of leaf area caused reduction on NAR.

Table 12. Mean net assimilation rate ($\overline{NAR}$) of four genotypes for four periods.

Genotypes	Sampling periods			
	7 July - 21 July	21 July - 4 Aug.	4 Aug. - 18 Aug.	4 Aug. - 2 Sept.
	$g/dm^2/day$			
Cluster	0.07 a*	0.07 a	0.03 a	0.02 a
PS-5	0.07 a	0.04 a	0.05 a	0.04 a
DLP-16	0.08 a	0.06 a	0.06 a	0.05 a
PS-4	0.07 a	0.03 a	0.05 a	0.05 a
C.V. (%)	38.1	43.5	34.5	36.2

*Means followed by the same letter for a period are not different at the 5% level in the Duncan's multiple range test.

Mean Leaf Area Ratio ($\overline{LAR}$)

As shown in Table 13, no significant differences were found for $\overline{LAR}$ among the four cotton genotypes Cluster, PS-5, PS-4, and DPL-16 at the first and last sampling periods. The G. barbadense L. cultivars had significantly greater $\overline{LAR}$ on the second and third sampling periods than DPL-16. In general, $\overline{LAR}$ was higher at early sampling periods and decreased as age and LAI increased. $\overline{LAR}$ tended to be greater for the G. barbadense L. cultivars in all sampling periods. Previous discussion on factors affecting $\overline{NAR}$, $\overline{CGR}$, and $\overline{RGR}$ are applicable in explaining changes in $\overline{LAR}$.

In general $\overline{LAR}$ showed less variability among the cultivars. It could serve as a good indicator of the growth intensities, however, based on the relative size of the assimilatory apparatus, and another useful tool in finding of genotypes of rapid growth.

Mean Boll Growth Rate ($\overline{BGR}$)

Mean boll growth rates ($\overline{BGR}$) for four genotypes at four sampling periods are presented in Table 14. There were significant differences in the $\overline{BGR}$ among the genotypes at the period between 7 July and 21 July and 4 Aug. to 18 Aug. All genotypes had a different rate of accumulation of dry matter in the bolls ($\overline{BGR}$). DPL-16 had the highest and Cluster the lowest $\overline{BGR}$. PS-5 had a superior $\overline{BGR}$ than Cluster at this sampling date. No significant differences were found at the second and last sampling periods.

Table 13. Mean leaf area ratio ($\overline{LAR}$) of four genotypes for four periods.

Genotypes	Sampling periods			
	7 July - 21 July	21 July - 4 Aug.	4 Aug. - 18 Aug.	18 Aug. - 2 Sept.
	dm^2/g			
Cluster	0.68 a*	0.62 a	0.58 a	0.51 a
PS-5	0.68 a	0.64 a	0.56 a	0.43 a
DLP-16	0.62 a	0.50 b	0.45 b	0.37 a
PS-4	0.72 a	0.64 a	0.54 a	0.44 a
C.V. (%)	10.0	7.2	10.2	15.1

*Means followed by the same letter for a period are not different at the 5% level in the Duncan's multiple range test.

Table 14. Mean boll growth rate ($\overline{BGR}$) of four genotypes for four periods.

Genotypes	Sampling periods			
	7 July - 21 July	21 July - 4 Aug.	4 Aug. - 18 Aug.	18 Aug. - 2 Sept.
	$g/m^2/day$			
Cluster	0.8 c*	1.4 a	3.0 c	2.6 a
PS-5	1.4 b	1.9 a	4.6 ab	5.9 a
DLP-16	2.0 a	2.9 a	6.0 a	2.3 a
PS-4	1.1 bc	1.4 a	4.1 bc	6.1 a
C.V. (%)	23.6	45.4	21.1	38.0

*Means followed by the same letter for a period are not different at the 5% level in the Duncan's multiple range test.

In general $\overline{BGR}$ increased as the reproductive phase progressed and was greater at high LAI. It also increased with a peak in fruit set and with the initiation of the boll period. DPL-16 showed a trend to accumulate dry matter into the fruits at higher rates than the G. barbadense L. cultivars. A maximum $\overline{BGR}$ of 6.0 g/m^2 (90% of $\overline{CGR}$) occurred for DPL-16 in the period between 4 Aug. and 18 Aug., suggesting that fruit forms of the G. hirsutum L. cultivar intensify their sink strength greatly as soon as fertilization occurs to use almost all the assimilates available for growth.

Findings of Hearn (1968) in Uganda are in agreement with those reported here. He stated among other considerations that when $\overline{BGR}$ equalled $\overline{CGR}$, bolls were shed which prevented the size of the sink to increase beyond the limit of the plant to supply it with assimilates. This probably explains the response of the G. barbadense L. cultivars tested here to heavy flowering. At the last sampling date, PS-4 reached a $\overline{BGR}$ of 6.1 (91% of total $\overline{CGR}$) totally overpassing the vegetative growth. The size of the sink inevitably increased, out of phase with the supply of assimilates, and thus increased shedding.

The results also suggest that the rate at which dry matter accumulates in the bolls may be a useful tool in the measurement of crop earliness and crop maturity; an aspect considered important in Arizona to avoid frost damage, insects, and disease build up, and weathering of the open cotton. The $\overline{BGR}$ is a useful tool in magnifying the differences in efficiency of partitioning assimilates among the tested genotypes which are not easily detected by simple weight comparisons.

Mean Relative Growth Rate of Bolls ($\overline{RGRB}$)

Mean relative growth rates of bolls of four genotypes at four sampling periods are presented in Table 15. There were no significant differences among the four cultivars at any of the sampling periods. $\overline{RGRB}$ decreased as the growing season progressed. Results suggested that early high $\overline{RGRB}$ would be useful in determining genetic differences in crop maturation.

Mean Net Assimilation Rate of Bolls ($\overline{NAR}_B$)

The mean net assimilation rate of bolls ($\overline{NAR}_B$) is interpretated as the rate of dry matter accumulation in the bolls per unit of leaf area per day. Table 16 shows the $\overline{NAR}_B$ of four genotypes for four periods. There were significant differences among the tested cultivars at the periods between 7 July to 21 July, and 8 Aug. to 18 Aug. No significant differences were found at the third and last sampling periods.

In contrast with $\overline{NAR}$ of the plant, $\overline{NAR}_B$ increased as plants grew older and had two characteristic drifts: one after the period of initial flowering, and another late in the growing season due to senescence. In contrast with $\overline{NAR}$ of plants $\overline{NAR}_B$ also increased as LAI increased for each genotype and then decreased as LAI started to drop. Higher LAI, however, did not affect high $\overline{NAR}_B$.

DPL-16 had a higher $\overline{NAR}_B$ both at initial flowering and at boll maturation.

Table 15. Mean relative growth rate of bolls ($\overline{RGRB}$) of four genotypes for four periods.

Genotypes	Sampling periods			
	7 July - 21 July	21 July - 4 Aug.	4 Aug. - 18 Aug.	18 Aug. - 2 Sept.
	g/100 g/day			
Cluster	10.6 a	5.8 a	5.2 a	2.9 a
PS-5	10.0 a	4.8 a	5.8 a	3.8 a
DLP-16	12.0 a	5.3 a	5.6 a	1.3 a
PS-4	8.0 a	4.2 a	6.3 a	4.1 a
C.V. (%)	33.0	45.7	28.4	42.0

*Means followed by the same letter for a period are not different at the 5% level in the Duncan's multiple range test.

Table 16. Mean net assimilation rate of bolls ($\overline{NAR}_B$) of four genotypes for four periods.

Genotypes	Sampling periods			
	7 July - 21 July	21 July - 4 Aug.	4 Aug. - 18 Aug.	18 Aug. - 2 Sept.
	$g/dm^2/day$			
Cluster	0.01 b*	0.01 a	0.02 b	0.01 a
PS-5	0.02 b	0.01 a	0.03 b	0.03 a
DPL-16	0.03 a	0.03 a	0.05 a	0.02 a
PS-4	0.01 b	0.01 a	0.03 b	0.04 a
C.V. (%)	26.0	43.0	38.0	43.0

*Means followed by the same letter for a period are not different at the 5% level in the Duncan's multiple range test.

The results suggest the importance of having high NAR_B which may be considered as indicator of sink strength, especially early in the growing season.

Mean Leaf Area Ratio of Bolls ($\overline{LAR_B}$)

Mean leaf area ratios of bolls ($\overline{LAR_B}$) of four genotypes for four periods are reported in Table 17. In contrast with $\overline{LAR}$, differences on $\overline{LAR_B}$ were significant at all sampling periods. Each genotype had a significantly different $\overline{LAR_B}$ in all sampling periods.

In general $\overline{LAR_B}$ for each genotype decreased with plant age as LAI increased during the growing season. At each sampling period, and among each genotype, high LAI did not lead to high $\overline{LAR_B}$. DPL-16 showed the lowest $\overline{LAR_B}$ and Cluster cultivar the highest $\overline{LAR_B}$.

$\overline{LAR_B}$ intensified the differences among the genotypes, and showed the importance of the relative amount of leaf area supporting a unit of weight of boll. The results suggest that for high $\overline{RGRB}$ ($\overline{RGRB} = NAR_B \times LAR_B$) less and better distribution of leaf area would probably be more efficient, and that the efficiency of the assimilatory apparatus (NAR) is important in determining the efficiency in the partitioning of dry matter of the cotton plant.

Partitioning of Dry Matter

The partitioning of dry matter in the four genotypes into various vegetative and reproductive forms is reported in Table 18. At early reproductive phase i.e., initial flowering, dry matter was accumulated mostly in the vegetative parts. The accumulation of dry

Table 17. Mean leaf area ratio of boll ($\overline{LAR_B}$) of four genotypes for four periods.

Genotypes	Sampling periods			
	7 July - 21 July	21 July - 4 Aug.	4 Aug. - 18 Aug.	18 Aug. - 2 Sept.
	dm^2/g			
Cluster	6.8 a*	4.0 a	2.8 a	1.9 a
PS-5	5.0 b	3.0 b	1.9 b	1.0 b
DPL-16	3.6 c	1.7 c	1.0 c	.6 b
PS-4	5.4 ab	3.5 ab	2.0 b	1.1 b
C.V. (%)	15.7	9.9	18.4	22.2

*Means followed by the same letter for a period are not different at the 5% level in the Duncan's multiple range test.

Table 18. Partitioning of dry matter of four genotypes.

Genotype	Leaves	Petioles	Stems	Bolls and squares	Total
Date: 7 July			%		
Cluster	51.8	10.6	31.0	6.6	100
PS-5	51.6	8.6	30.1	9.7	100
DPL-16	52.0	10.5	27.0	10.5	100
PS-4	51.0	8.5	29.0	10.9	100
Date: 21 July					
Cluster	41.0	9.0	36.2	13.8	100
PS-5	43.8	8.7	29.1	18.4	100
DPL-16	36.4	8.0	29.7	25.9	100
PS-4	40.7	7.6	35.6	16.1	100
Date: 14 Aug.					
Cluster	38.0	8.0	37.0	17.0	100
PS-5	37.0	6.9	31.1	25.0	100
DPL-16	33.0	5.6	27.0	34.4	100
PS-4	37.7	6.4	34.1	21.8	100
Date: 18 Aug.					
Cluster	31.1	6.1	35.8	27.0	100
PS-5	28.2	4.8	30.2	36.3	100
DPL-16	24.2	4.7	20.0	51.1	100
PS-4	29.0	5.1	31.3	34.6	100
Date: 2 Sept.					
Cluster	27.4	5.3	34.3	33.0	100
PS-5	22.8	3.9	25.4	47.9	100
DPL-16	21.2	3.9	20.2	54.7	100
PS-4	23.4	4.0	26.0	46.6	100

matter into the reproductive parts varied greatly and was significantly different among the tested cultivars in almost all sampling periods (Fig. 1). At 7 July, PS-4 accumulated more dry matter (10.9%) into the reproductive parts than DPL-16, PS-5 and Cluster (10.5, 9.7, and 6.6%, respectively). Two weeks later, at 21 July, DPL-16 had the highest (25.9%) and Cluster the lowest (13.8%) partitioning efficiencies for dry matter accumulated in the fruit form. At the fourth and last sampling periods DPL-16 maintained its high rates in accumulating dry matter into reproductive forms compared to the G. barbadense L. cultivars. The amount of dry matter accumulated in bolls and squares surpassed that which was partitioned into vegetative parts (leaves, petioles, and stems). PS-4 and PS-5 (47.9% and 46.6%, respectively) showed to be more efficient than Cluster (33%) at the last sampling period.

The fraction of dry matter accumulated in the leaves differed among the genotypes studied, and the efficiency in partitioning dry matter into leaves decreased with plant age as shown in Table 18 and Fig. 1. DPL-16 accumulated less dry matter in leaves compared to the G. barbadense L. cultivars.

The amount of dry matter accumulated in the petioles was not significantly different among the genotypes at all sampling periods. There were differences, particularly in the Cluster cultivar which had larger and heavier petioles.

Considering the results for the last sampling period only, it was found that stems did accumulate a significant portion of the total

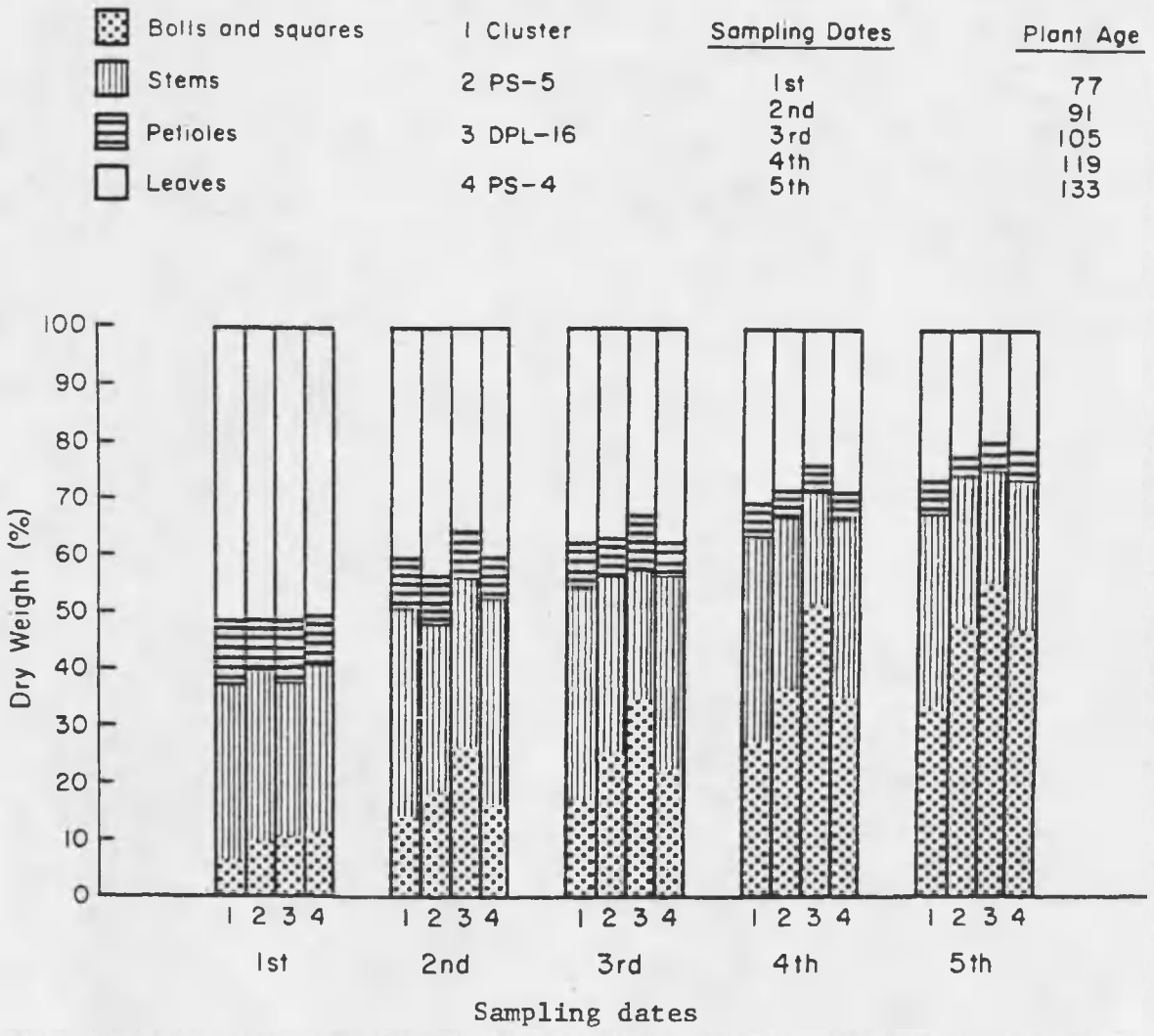

Fig. 1. Partitioning of dry matter of four genotypes for five dates.

dry matter which differed significantly among the genotypes. Partitioning of dry matter into stems was high for Cluster (34%) and low for DPL-16 (20%). These fractions were high for PS-5 and PS-4 (25% and 26% respectively).

There are definitely different patterns among genotypes in partitioning of dry matter into the different parts of the plant. As previously discussed, patterns in partitioning of dry matter into the reproductive parts were strongly influenced by the rate of growth of the crop, $\overline{LAI}$, the efficiency of the assimilatory apparatus as measured by $\overline{NAR}$, and the size of the reproductive part as a sink. A high $\overline{BGR}$ and $\overline{RBGR}$ were associated with high $\overline{CGR}$ and a high and longer $\overline{NAR}$ and $\overline{NAR}_B$ during the fruiting and boll periods. The results obtained, suggest that for improvement of cotton genotypes, the efficiency in partitioning of dry matter into the harvestable parts as determined by growth analysis indexes, could be used to great advantage in influencing genetic gains.

SUMMARY AND CONCLUSIONS

To compare growth variations and differences in partitioning dry matter into plant parts, three G. barbadense L. cultivars and one G. hirsutum L. cultivar were planted at The University of Arizona Campbell Avenue Experimental Farm in Tucson, Arizona in 1977. A Latin Square experimental design was used. Plots were thinned to a population of 65,000 plants/ha. Samples were taken on five dates: 7 July, 21 July, 4 Aug., 18 Aug., and 2 Sept. Plant height, number of bolls, number of squares, dry weight of leaves, petioles, stems, and bolls plus squares were determined. Derived growth analysis indexes: $\overline{CGR}$, $\overline{RGR}$, $\overline{NAR}$, $\overline{LAR}$, $\overline{BGR}$, $\overline{RGRB}$, $\overline{NAR}_B$, and $\overline{LAR}_B$ were calculated.

G. barbadense L. cultivars were significantly taller than the G. hirsutum L. cultivar. Among G. barbadense L. cultivars, Cluster was significantly taller than PS-5 and PS-4. Plant height, however, was not indicative of the potential for dry matter accumulation.

Significant differences were found in boll set. Number of bolls per plant was higher for DPL-16 at two early sampling dates, 21 July and 4 Aug., but was significantly lower at the last sampling dates -- compared to PS-5, PS-4. The total number of fruit forms per plant tended to be similar for all genotypes, and high late fruit load was associated with the high number of total bolls found at the two last sampling dates.

At initial flowering, dry matter accumulated mostly into the vegetative parts of the cotton plants. Accumulation into reproductive forms increased as plants grew older and the rate of increase was dependent on the genotypes. The G. hirsutum L. cultivar accumulated more dry matter into reproductive organs. The G. barbadense L. cultivars, particularly Cluster, accumulated large amounts of dry matter into stems and leaves.

No significant differences were found for $\overline{LAI}$, $\overline{CGR}$, $\overline{RGR}$, $\overline{NAR}$, and $\overline{LAR}$. Patterns in partitioning dry matter into the reproductive sink, however, were strongly influenced by the rate of crop growth ($\overline{CGR}$), $\overline{LAI}$, the efficiency of the assimilatory apparatus as measured by $\overline{NAR}$, and the size of the reproductive sink (bolls and bolls + squares). A high $\overline{BGR}$ and RBGR was associated with high $\overline{CGR}$ and with a high and longer $\overline{NAR}$ and $\overline{NAR}_B$ along the fruiting and boll periods.

$\overline{BGR}$, $\overline{RBGR}$, $\overline{NAR}_B$ and $\overline{LAR}_B$ were useful in magnifying the differences in partitioning assimilates among the tested genotypes that were not detected by other parameters.

Genotypes studied showed different patterns in partitioning dry matter into the different parts of the cotton plant. This suggests that for further improvement of the cotton genotypes, regarding partitioning of dry matter into harvestable parts, the earliness of the crop as determined by growth analysis indexes, should be considered.

This study shows that (1) structural and growth differences among cotton genotypes can be measured, (2) relationship between growth parameters, yield potential, and crop maturity can be

demonstrated, (3) the importance of having a strong reproductive sink early in the growing season to maximize yields is essential, and (4) the potential for further genetic improvement of genotypes can be evaluated through growth analysis.

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