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Carbohydrate Status of Narrow Row Cotton as Related to Vegetative and Fruit Development[1]

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ABSTRACT

Narrow row, high population culture is a promising system for cotton (*Gossypium hirsutum* L.) production; but with improper management the dynamic balance between vegetative and fruit development can be upset, resulting in low lint yields. This study was conducted to investigate the relationship of plant carbohydrate status to vegetative and fruit development. Plant dry weights and total available carbohydrates (TAC) were compared during two seasons in narrow row cotton planted at population densities of 7.4, 14.8, and 22.2 plants/m^2. Although large differences occurred in plant size, TAC levels among the three populations were similar during the various sampling dates. TAC had a cyclic pattern with low levels during mid-season. This depression coincided with a rapid increase in fruiting form weight when lint yields were high and with a rapid increase in vegetative weight when lint yields were low. This excessive vegetative growth can effectively compete with fruiting forms for TAC. In a related experiment, TAC levels along plant axes were lowest near the central part of the plant where developing bolls were located. This shows that the TAC depression can be relatively localized within plants suggesting that photosynthates are not effectively translocated from the top to the central part of the plant. Restructuring of the plant canopy to allow more solar radiation penetration to leaves near developing bolls and/or selecting for more efficient translocation from upper leaves to developing bolls should help increase yields.

Additional index words: **Total available carbohydrates, Boll development, Rank growth, Narrow row cotton, *Gossypium hirsutum*.**

NARROW row culture is a practice recently advocated for cotton (*Gossypium hirsutum* L.) production, especially in the Southwestern USA. Early leaf development, greater solar radiation interception, and high productivity in short seasons are some potential advantages of this practice (15, 16). The cultural system can also reduce production costs and evade some insect damage late in the season (22). With improper management, however, predicted yield increases have not been realized because of excessive vegetative growth and associated high rates of fruiting form (squares and bolls) shedding. This undesirable pattern of growth is more common when unadapted cultivars are used.

In addition to high rates of fruiting form abortion, intense mutual shading and associated low photosynthetic rate per plant, with high population densities in narrow rows, result in a reduction in size and number of plant parts (15, 20). This relationship suggests that cotton plants grown at high densities may have internal carbohydrate deficiencies. The association between fruit abortion and plant carbohydrate levels has been the subject of considerable research while the relationship with vegetative development has received little attention.

Several studies have shown that artificial shading of cotton or exposure to low illumination induces high rates of boll shedding (5, 10, 12). Eaton and Rigler (10) found that abortion of fruiting forms was negligible under both low and high illumination when plants were previously debudded. Higher carbohydrate levels were found in debudded than control plants and in plants grown under high than plants grown under low illumination. Guinn (13) reported that environmental conditions that enhanced photosynthesis, such as high atmospheric CO_2, long photoperiod, and high irradiance, were associated with low rates of fruit abortion. Conversely, increasing night respiration, with high temperatures, enhanced shedding.

These and other studies (1, 14) support the classical nutritional balance theory of shedding by Mason (18) which establishes a close relationship between carbohydrate production and the number of bolls retained by plants. Others have questioned the adequacy of this theory (7, 8). This has led to the development of alternate hypothesis, such as the hormone balance theory or combinations of these two theories.

The primary source of photosynthate for developing fruiting forms in cotton is the subtending leaf with some contribution from bracts (2, 11). Maximal rate of photosynthate utilization occurs when bolls are 8 to 10 days of age (3).

The objectives of this investigation were to determine if carbohydrate status is associated with reduc-

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tion in plant part size and number in narrow row, high density cotton and if carbohydrate deficiency during periods of peak boll load may limit yield potential and influence the balance between vegetative and fruit development.

MATERIALS AND METHODS

The field portion of this investigation was conducted at the Marana Experimental Farm and the Campbell Avenue Farm in Tucson. The experiments at Marana were designed to study the relationship among seasonal changes in plant carbohydrate status, vegetative growth, and fruiting form development as influenced by plant density. The distribution of carbohydrate levels along plant axes when bolls were developing was studied at Tucson.

At Marana 'Stoneville 213' was planted on 100-cm beds in double rows 5-cm apart on 12 May 1971 and 11 Apr. 1972. Preplant applications of N at the rate of 90 and 112 kg/ha were made in 1971 and 1972, respectively. The plants were hand thinned to densities of 7.4, 14.8, and 22.2 plants/m² with four replications in a randomized block design. Each plot consisted of four beds, 15-m long divided into two sections. Six meters were used for lint yield determination and 9 m for subsampling to determine carbohydrate levels and plant part weights. The center two beds were used for all observations and data collection.

Samples for carbohydrate analysis and plant weights were taken at approximately 2-week intervals starting on 1 July 1971 and 19 June 1972. For dry weight (dry wt) determinations, five plants were cut at ground level and separated into stems, leaves, and fruiting forms. For carbohydrate analysis, two plants were uprooted and from each plant five fully expanded top leaves with petioles were collected. These were taken from the stem beginning about four to six nodes below the plant apex. About 8 to 10 cm of the top of the tap root were also sampled. At the final sampling each year, plants were collected for carbohydrate analysis but not for weight determinations.

Flowers were tagged weekly with the date of anthesis starting with the first harvest date. Approximately five bolls from each tagging date, beginning with the third harvest date, were collected for carbohydrate analysis. In 1971, up to 40-day-old bolls were sampled, while in 1972 only bolls up to 21 days old were taken.

'Stoneville 7A' was planted in rows 50-cm apart at Tucson on 22 April 1974 and hand thinned to 10 plants/m². Plants were uprooted on 12 August and separated into stems and roots. Branches and lateral roots were trimmed and discarded. The stems were cut into six segments. The first five segments, starting from the base of the stem, included four nodes each and the sixth segment was composed of the remaining nodes near the apex, which ranged from two to four nodes excluding the apex. Leaves were collected from the top four segments of the main stem and separated into leaf blades and petioles. Tap roots were cut into two sections, a 7.5-cm top part and a 12.5 to 15-cm bottom part. Data for stems and roots were analyzed in a randomized block design and leaves and petioles in a split-plot design replicated five times with two plants per replication.

Samples for total available carbohydrates (TAC) analysis were prepared following the procedure outlined by others using takadiastase (Clarase 900) enzyme (21, 23). Optical densities were determined colorimetrically at 620 nm using the anthrone-reagent technique (24).

For the Marana experiments, harvest dates of 1 July, 15 July, 29 July, 12 Aug., 30 Aug., and 12 Oct. in 1971 will be designated as H_1 to H_6, respectively. In 1972 the harvest dates were 19 June, 3 July, 17 July, 31 July, 14 Aug., 29 Aug., and 11 Oct. which will be referred to as H_1 to H_7, respectively.

RESULTS AND DISCUSSION

TAC in Relation to Plant Growth

The general effect of population density on dry wt per plant was similar to that reported by others (15, 20). During early growth (H_1 and H_2), plant population had only negligible effects on plant dry wt. Significant population effects were generally evident by H_3 when plant canopies were approaching closure. By 110 days after planting, plants from the low density treatment were nearly three times heavier than plants from the high density treatment.

Table 1. Effect of plant population on leaf TAC level averaged over harvest dates.

Plants/m²	mg TAC/g tissue 1971	mg TAC/g tissue 1972
7.4	92.6 a*	88.8 a
14.8	94.3 a	78.7 b
22.2	84.9 a	75.1 b

* Values followed by the same letter in a column are not significantly different at the 0.05 level according to the Student-Newman-Keuls Test.

Although population density had a marked effect on plant size, there was little consistent effect on TAC level of the plant parts. Some tendency existed for low TAC levels in leaves from the high plant population. The effect was not significant for any given harvest in either year but averaged over harvest dates, it was significant in 1972 (Table 1). The low TAC levels probably resulted from greater mutual shading in the high than in the low population, and the resulting effect on photosynthesis. The generally small effect of plant density on TAC level suggests that, as such, TAC is not a major factor determining differences in plant growth rates among the population densities. Other factors, such as free sugars, which were not investigated may have a more important effect.

Stems, roots, and leaves generally displayed a seasonal pattern of intermediate levels early, low levels at mid-season, and high levels at the end of the season; except for leaves which did not accumulate TAC at the end of the season. Except for early in 1971, roots generally had the highest TAC level throughout the sampling period while leaves had the lowest level. TAC levels of stems averaged over the three populations for 1971 and 1972 are shown in Fig. 1 and 2, respectively.

High TAC levels at the end of the season probably reflect a reduction in growth rate and translocation of photosynthates to the roots and stems for active accumulation of carborydrate reserves. Reduction in TAC levels at mid-season is related to the development of a strong sink for TAC by developing cotton bolls in 1971 and in 1972 by rank vegetative growth, which will be discussed.

In agreement with other work, boll TAC levels increased with age until a maximum of about 400 mg/g tissue was reached by about the 15th day, then dropped to a minimum of about 50 mg/g by day 40 (data not presented) (4).

The 1972 experiment received excessive irrigation water because of its location at the far end of the field where water accumulated which resulted in rank vegetative growth. By 110 days after planting, total above ground dry wt per unit ground area did not differ significantly among the three population densities and averaged 788 g/m² in 1971 and 1,062 g/m² in 1972. Stem dry wt at this time averaged 256 g/m² in 1971 compared to 370 g/m² in 1972. In addition the percentage of total dry wt in fruit by 110 days was 29% in 1971 and only 11% with the rank growth of 1972. Mature plant height was 97 cm in 1971 and

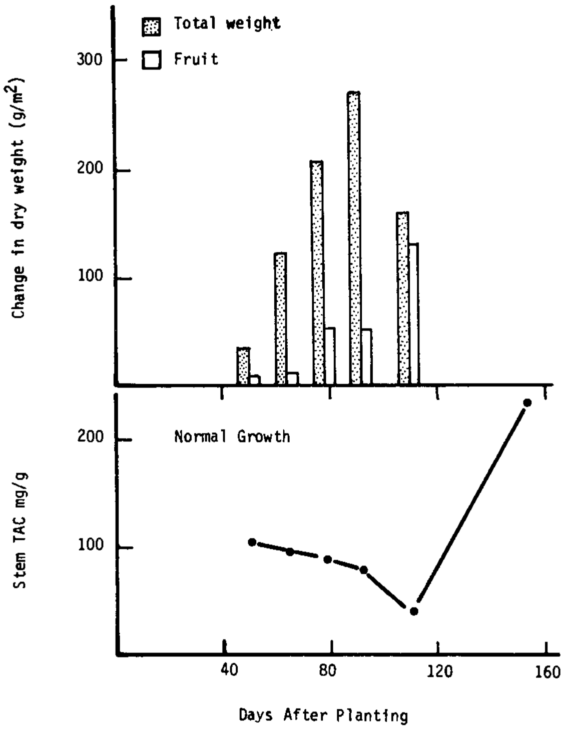

Fig. 1. Increment change in dry weight between harvest dates and stem total available carbohydrates (TAC) levels of plants grown in 1971.

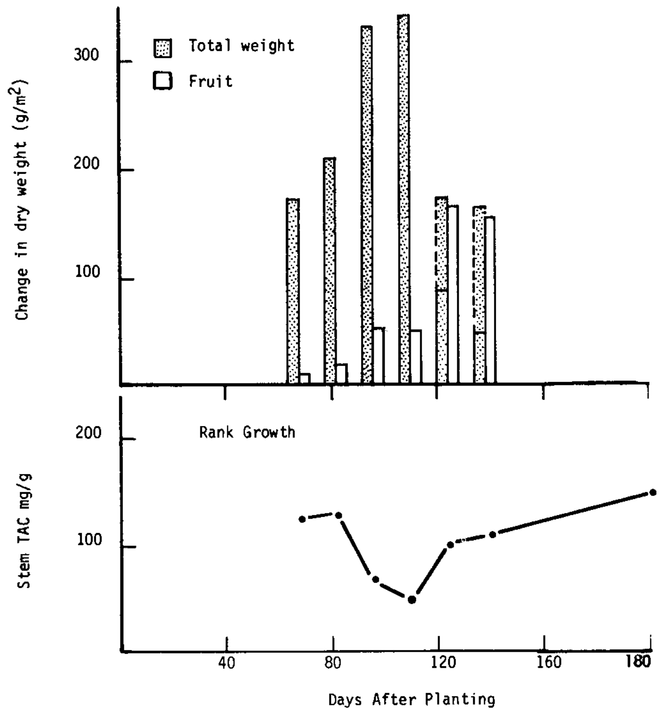

Fig. 2. Increment change in dry weight between harvest dates and stem TAC levels of plants grown in 1972. Dashed area is estimated weight of leaf drop. Rank growth refers to excessive vegetative growth with suppressed fruit development.

118 cm in 1972. Lint yields were not significantly affected by plant density and averaged 1,222 kg/ha in 1971 and 835 kg/ha in 1972.

Increment changes in plant dry wt and dry wt of fruiting forms after the previous harvest date, averaged for the three populations, are also shown in Fig. 1 and 2. For H_1 the increment is dry wt accumulation after planting. Maximum dry wt increment changes were associated with minimum TAC levels during both years. In 1971 the largest increase in increment plant dry wt occurred between H_3 and H_4 (78 and 92 days after planting) and the largest increase in dry wt increment of fruiting forms occurred between H_4 and H_5 (92 and 110 days) (Fig. 1). The increase in fruiting form dry wt coincides with the sharp decrease in TAC levels that occurred at H_5, indicating that the fruiting forms were acting as a strong sink.

In 1972 similar results were obtained except that minimal TAC levels were more closely associated with maximum increase in total plant weight rather than with increase in weight of fruiting forms. The greatest increase in increment dry wt of the plants occurred between H_2 and H_4 (83 and 110 days), while that of the fruiting forms occurred between H_4 and H_6 (110 and 139 days) (Fig. 2). Minimal levels of TAC occurred during H_3 and H_4. Thus rank vegetative growth in 1972 was more important in reducing TAC levels than development of a strong reproductive sink. The lower yield of 1972 can be explained in part by depressed assimilates for translocation to fruiting forms following the period of vigorous vegetative growth. This likely induced a high rate of shedding of fruiting forms.

Eaton and Joham (9) attributed the decline in mineral uptake by roots and the reduction in vegetative expansion during heavy fruiting to depletion of carbohydrates by developing bolls which resulted in reduced movement of assimilates to roots. They found a three fold increase in carbohydrate concentration and a 60% increase in bromide uptake by roots of defruited compared to fruited cotton plants. In an earlier study, Eaton (6) found stimulation of growth and flowering of plants following removal of all previously set bolls. This work supports the 1971 observations where developing bolls effectively reduced plant TAC levels and slowed subsequent growth of the plants.

The effect of rank vegetative growth in reducing TAC levels in 1972 and limiting subsequent reproductive growth is in agreement with the suggestion of Guinn (13) that rank growth can seriously affect fruiting form shedding, especially in high population culture.

TAC Levels Along Plant Axes

The effect of developing bolls on TAC levels of plants suggests that depletion of TAC levels should be greatest near the portion of plant axes where the boll load is developing. To test this hypothesis, TAC along stems, tap roots, and main-stem leaves of cotton plants were investigated in plants harvested from Tucson.

The large variability in TAC level with plant height is shown in Fig. 3. Plant axes had a marked decrease

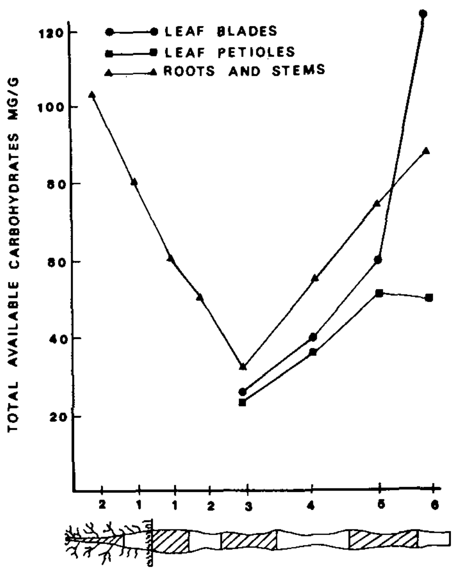

Fig. 3. TAC levels along plant axis. The numbers along the abscissa refer to stem and root sections.

in TAC near the mid section with highest levels at the top of the plant and in the root.

High levels at the plant top reflect the favorable position of leaves for solar radiation interception and high photosynthetic activity, with a relatively low sink demand by developing fruiting forms for these carbohydrates. Low levels near the middle of the stem probably results from the effect of shading and effective utilization of carbohydrates by rapidly developing bolls in this region. Calculations from adjacent plots showed that branches attached to nodes 9 to 12, which correspond to segment 3, carried 48% of the boll load at this time (17).

The rise in TAC level at the base of the stem and in the tap root indicates that this is a region where active accumulation of carbohydrates occurs in this perennial species. Mason and Maskell (19) found a similar gradient in carbohydrate concentration of cotton stems and leaves. TAC variability was more pronounced in leaf blades than in petioles. This seems logical since leaf blades are major photosynthetic structures while petioles are primarily conducting channels.

In agreement with previous work (2), the localized depletion of TAC by developing bolls indicates that photosynthates are not effectively translocated from the top to the central part of the plant. This suggests that the cotton canopy should be designed to allow greater penetration of solar radiation to leaves near developing bolls to increase their photosynthetic activity, and/or plants should be selected for more efficient translocation from upper leaves to developing bolls.

REFERENCES

1. Addicott, F. T., and R. S. Lynch. 1955. Physiology of abscission. Ann. Rev. Plant Physiol. 6:211-237.
2. Ashley, D. A. 1972. ^{14}C-labeled photosynthate translocation and utilization in cotton plants. Crop Sci. 12:69-74.
3. Benedict, C. R., R. H. Smith, and R. J. Kohel. 1973. Incorporation of ^{14}C-photosynthate into developing cotton bolls, *Gossypium hirsutum* L. Crop Sci. 13:88-91.
4. Conner, J. W., D. R. Kreig, and J. R. Gipson. 1972. Accumulation of simple sugars in developing cotton bolls as influenced by night temperatures. Crop Sci. 12:752-754.
5. Dunlap, A. A. 1945. Fruiting and shedding of cotton in relation to light and other limiting factors. Texas Agric. Exp. Stn. Bull. 677.
6. Eaton, F. M. 1931. Early defoliation as a method of increasing cotton yields and the relation of fruitfulness of fiber and boll characteristics. J. Agric. Res. 42:447-462.
7. ———, and D. R. Ergle. 1953. Relationship of seasonal trends in carbohydrate and nitrogen levels and effect of girdling and spraying with sucrose and urea to the nutritional interpretation of boll shedding in cotton. Plant Physiol. 28:503-520.
8. ———, and ———. 1957. Mineral nutrition of the cotton plant. Plant Physiol. 32:175-196.
9. ———, and H. E. Joham. 1944. Sugar movement to roots, mineral uptake and the growth cycle of the cotton plant. Plant Physiol. 19:507-517.
10. ———, and N. E. Rigler. 1945. Effect of light intensity, nitrogen supply and fruiting on carbohydrate utilization by the cotton plant. Plant Physiol. 20:380-411.
11. Elmore, C. D. 1973. Contributions of the capsule wall and bracts to the developing cotton fruit. Crop Sci. 13:751-752.
12. Goodman, A. 1955. Correlation between cloud shade and shedding in cotton. Nature 176:39.
13. Guinn, G. 1974. Abscission of cotton floral buds and bolls as influenced by factors affecting photosynthesis and respiration. Crop Sci. 14:291-293.
14. Johnson, R. E. 1966. Influence of leaf area on fruiting and yield of cotton. Proc. Beltwide Cotton Prod. Res. Conf. National Cotton Council, Memphis, Tenn. p. 236-237.
15. ———. 1969. Spacing effect on growth of cotton. Proc. Beltwide Cotton Prod. Res. Conf. National Cotton Council, Memphis, Tenn. p. 105-108.
16. ———, and V. T. Walhood. 1970. Narrow-row cotton in the San Joaquin Valley. Proc. Beltwide Cotton Prod. Res. Conf. National Cotton Council, Memphis, Tenn. p. 40-42.
17. Kerby, T. A., and D. R. Buxton. 1976. Fruiting in cotton as affected by leaf type and plant population. Proc. Beltwide Cotton Prod. Res. Conf. National Cotton Council, Memphis, Tenn.
18. Mason, T. G. 1922. Growth and abscission in Sea Island Cotton. Ann. Bot. 36:457-483.
19. ———, and E. J. Maskell. 1928. Studies on the transport of carbohydrates in the cotton plant. II. The factors determining the rate and the direction of movement of sugars. Ann. Bot. 42:571-636.
20. Ray, L. L. and J. L. Fowler. 1971. Effects of population density on growth and development of cotton. Proc. Western Cotton Prod. Conf. National Cotton Council, Memphis, Tenn. p. 38-39.
21. Smith, D. 1969. Removing and analyzing total non-structural carbohydrates from plant tissue. Res. Report No. 41. College of Agric. Life Sciences. Univ. of Wisconsin, Madison.
22. Taylor, B. B. 1971. Economics of narrow-row cotton in Arizona. Proc. Western Cotton Prod. Conf. National Cotton Council, Memphis, Tenn. p. 11-12.
23. Weinmann, H. 1947. Determination of total available carbohydrates in plants. Plant Physiol. 22:279-290.
24. Yemmn, E. W. and A. J. Willis. 1954. The estimation of carbohydrates in plant extracts by anthrone. Biochem. J. 57:508-514.