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# Taproot Restriction Effects on Growth, Earliness, and Dry Weight Partitioning of Cotton

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## ABSTRACT

**Cotton (*Gossypium hirsutum* L.) is an indeterminate, woody perennial, whose primary axis remains vegetative throughout the life of the plant. During the boll-filling period, the growing mainstem and taproot compete with reproductive organs for limited supplies of assimilates. In a series of experiments, the effects of taproot restrictions on growth and development of drip irrigated cotton plants were explored. Cotton ('Stoneville 825') plants were grown outdoors and in sunlit growth chambers. Taproots were restricted to various degrees by using different pot sizes (1, 2.5, 7, 12, and 18 L) during the years 1982 to 1983. The pots were arranged in a row crop configuration (10 plants $m^{-1}$ of row, 1 m between rows). Dry matter distribution was measured destructively. The restriction of the taproot apical dominance by small pots (1 or 2.5 L) accelerated the formation of secondary and tertiary roots compared to roots in larger pots (7 L or more). Taproot-restricted plants started to flower earlier and they flowered faster. Their heavier load of developing bolls caused a greater slowing of vegetative growth of the main axis. As a result, taproot-restricted plants were more compact due to shorter internodes on fruiting branches and at the top of the plant. Taproot-restricted plants were earlier and higher yielding in short seasons because of better partitioning of assimilates into fruit rather than into storage organs.**


IN COTTON, a large amount of assimilates is invested in the primary axis, which remains vegetative throughout the life of the plant. The mainstem and the taproot are very efficient sinks that compete successfully for photosynthates with the bolls (Eaton and Rigler, 1945; Saleem and Buxton, 1976; Mauney, 1986). This competition between vegetative and reproductive organs is typical of many perennial trees. On the other hand, in determinate annual plants, vegetative growth is followed by the reproductive stage and there is no direct competition for carbohydrates. Moreover, many determinate annual crops are capable of mobilizing significant reserves into the maturing seeds. When the cotton plant contains a heavy load of developing bolls, the reserves in large woody structures of the main axis are not redistributed (Eaton and Ergle, 1953). Since cotton is grown as an annual field crop, most of these structural reserves are lost from an agronomic point of view. Therefore, restriction of the natural tendency of the cotton plant to store carbohydrates in the primary axis may divert more assimilates to the fruit. One approach to restrict vegetative growth is to modify the root system.

The technique of root modification to control shoot growth and to induce earliness has been practiced in trees for hundreds of years. The common methods of root modification are root pruning and the use of dwarfing rootstocks. Recently, with the use of high frequency drip irrigation, which can modify the root morphology around the dripper, similar effects of compactness, earliness, better quality of fruit, and higher yields have been found in various woody perennial plants. The results of drip irrigation experiments in apple (*Pyrus malus*) (Proebsting et al., 1977), peach [*Prunus persica* (L.) Batch] (Chalmers et al., 1981), grapevine (*Vitis vinifera*) (Richards, 1983), and cotton (Carmi and Shalhevet, 1983; Levin et al., 1983) indicate that there is a common effect of root modification. Since the root tips are a major source of cytokinins and gibberellins, that effect could be hormone-mediated (Skene, 1975; Torrey, 1976).

Under dryland conditions, a deep root system is essential to extract soil-stored water. Taproot-restricted cotton plants that grow on soils containing hardpans are vulnerable to drought. Most experiments with taproot-restricted cotton plants have been done without irrigation, and in many cases those plants were exposed to nutritional and water stresses that reduced yields (Lowery et al., 1970; Taylor and Burnett, 1964). Obviously, the benefits of root modification can only be expressed in an optimal root environment with minimal stresses.

The objective of this paper was to study the effects of taproot restriction per se as a means of inducing earliness, compactness, and fruitfulness in drip-fertigated cotton plants.

## MATERIALS AND METHODS

### *Pot Experiments*

Cotton plants (Stoneville 825) were grown outdoors, in pots of various sizes, at the nursery site of the Crop Simulation Research Unit at Mississippi State, MS, in the summers of 1982 and 1983. The pots were made from 10- and 15-cm-diam. polyvinyl chloride pipes of various lengths. They were arranged in rows according to their size. Taproot growth was restricted more by the depth of the pot than by its volume. During the 2 yr, several sizes of pots (treatments) were used. There were three treatments in 1982 (pot sizes of 18.0, 7.0, and 2.5 L) and four treatments in 1983 (pot sizes of 12.0, 7.0, 2.5, and 1.0 L). Pot depth was 100, 66, 38, 13, and 13 cm for pot volumes of 18.0, 12.0, 7.0, 2.5, and 1.0 L, respectively. Henceforth, the pot treatments will be referred as A, B, C, D, and E in order of descending size.

Planting dates were 3 June 1982 and 27 Apr. 1983. Two seeds were planted in each pot. Germination occurred within 4 d. Two weeks after emergence, the seedlings were thinned to one plant per pot. The plants were arranged in a common field stand of 10 plants $m^{-2}$ (one in a pot, 10 pots in 1 m of row, 1 m between rows). The seeds were planted at the edges of the 15-cm-diam. pots, and the pots were arranged in a zig-zag pattern to allow 10 pots $m^{-1}$ of row. The effect of extra light at the ends of the potlines in the nursery was minimized by the use of graded shade screens.

At the bottom of each pot, 2 cm of washed gravel and an outlet pipe maintained good drainage. The growing medium was a mixture of 3:1 sand and vermiculite (v/v) in 1982 and pure sand in 1983. The plants were irrigated to excess with nutrients (Hoagland solution modified to 50 mg $kg^{-1}$ N until

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flowering, then to 100 mg $kg^{-1}$ N). There were five and 12 applications per day from the drip irrigation system (NETAFIM In-Line drippers with an output of 1 L $h^{-1}$, one dripper per pot) during 1982 and 1983, respectively. The frequency and the amount of water in the applications were controlled by computer. The daily amount of water applied (0.2–0.8 L per pot) was based on pan evaporation data measured at a nearby site. The pots were covered with black polyethylene to keep out rain. In the beginning of the season, when the plants were small, the larger pots received more water than the smaller ones in order to keep the whole profile of sand wet. Soil water potential in the pots was measured by gypsum blocks and tensiometers and maintained throughout the experiments in the range of 0.0 to 0.04 MPa.

Biweekly measurements of plant growth and dry weight distribution in various plant organs were made in destructive samplings. Each sample consisted of 10 adjacent plants from the end of the pot line (1.0 m of row). The final harvest in each year consisted of 2 m of row. The sampling unit in 1982 was a single plant, while that in 1983 was a group of five adjacent plants (0.5 m of row). The total number of harvested plants from each treatment was 60 and 100 in 1982 and 1983, respectively.

At the destructive harvests, mainstem height and number of nodes were recorded. Then, the shoots were divided into blades, petioles, stems, squares, and small and large green bolls. The number of leaves and the leaf area of the sample were recorded. Then, all plant parts were oven-dried at 80 °C and weighed. At the final harvest of each year, the leaf area was estimated by measuring specific leaf area on a subsample of leaves (10 leaves per plant) and multiplying by the dry weight of all the leaves of the sample. The roots were carefully washed on 3.2-mm hardware cloth and then floated in a water bath for final separation from the sandy medium. After that, the roots were grouped into two categories:

1. Taproots—the main woody frame of the root system, including taproot and root branches.
2. Small roots—fine and flexible (unsuberized) roots, which could be separated easily from the main woody frame.

Nondestructive measurements were made on a group of 20 plants in each treatment. Plant height and number of mainstem nodes were recorded weekly, and flowering was observed over a period of 50 d (by counting the number of new flowers that opened daily).

### *Experiments in SPAR Units*

In 1983, two successive SPAR (Soil Plant Atmosphere Research) experiments were conducted to obtain data on plant growth in a constant environment. Detailed descriptions of SPAR units have been published by Phene et al. (1978), McKinion and Baker (1982), and Acock et al. (1985). Ten randomly selected plants from each treatment (B, C, and D) were grown together in each SPAR unit for several weeks under controlled conditions (32/20 °C day/night and 340 $\mu L\ L^{-1}$ [$CO_2$]). Irrigation was continued as in the nursery. Observations were not replicated, since there was only one chamber for each treatment. Therefore, these data are presented without statistical analyses.

The first 30 plants were transferred at 47 d after emergence and harvested at the age of 90 d. Two days later, 30 plants from the three pot sizes, 92 d of age, were transferred from the pot nursery to the three SPAR units. These plants, in the second experiment, were harvested at the age of 122 d.

At the end of each SPAR experiment, destructive harvests of the plants were made to measure growth and dry matter distribution. In order to analyze the effect of temperature on plant growth in the various pot volumes, observations from the SPAR units were compared to those made on nursery plants of the same age. Since the plants that grew in the SPAR units were randomly selected from the nursery, they were considered as additional treatments. Data were analyzed as a completely randomized design using SAS software (Goodnight, 1982).

## RESULTS AND DISCUSSION

### *Plant Growth and Development*

The environmental conditions in 1982 and 1983 were greatly different. The 1982 season was brief and hot from the late planting date until the first frost (25 October). The 1983 season was long and cold from the early planting date until the first frost (6 November). In spite of the great differences between years, the basic plant response to taproot restriction was similar.

In the large pots (volumes of 7.0 L or more, depths of 38 cm or more), typical taproot systems were developed. On the other hand, in the small pots of 13-cm depth, the primary root had reached the bottom of the pot at the time of emergence, and then a flush of growth of secondary roots occurred and formed a lateral root system. There appeared to be two morphological responses to taproot restriction:

1. Early branching of secondary roots at the seedling stage.
2. Early initiation of flowering.

The 1982 seasonal progression of plant height and dry weight of various plant organs is shown in Table 1 and in Fig. 1. From the results, it is clear that the pot volume itself did not limit plant early growth. The vegetative growth of taproot-restricted plants was limited after bloom, probably because of the early, heavy load of developing bolls and not because of the rooting volume per se. Frequent fertigations made it possible for plants grown in small pots to develop a very dense system of fine roots that supported a vigorous shoot.

A primary effect of taproot restriction was to accelerate branching of secondary and tertiary roots. Visual observations, as well as root dry weight data of 40- and 51-d-old plants, showed that in small pots a different root system was formed (Table 1). Later on, from the age of 51 d to midbloom, the small roots in Treatments A and C reached the same dry weight as in Treatment D and the plants from the different pot sizes did not differ significantly from each other. In the boll fill period (107–140 d), the plants that grew in the small pots (Treatment D) maintained this essential system of small roots, while plants in larger pots (Treatments A and C) appeared to lose 7 to 11% of the dry weight of the small roots (Table 1).

Until flowering, there was not much difference in shoot growth among the treatments. The harvest at Day 82 was the first one in which D plants differed significantly from A and C plants in most growth components of shoot and taproot (Table 1, Fig. 1). As the season progressed, these differences in all plant components became larger. In taproot-restricted plants, vegetative growth during the boll fill period was slowed more than in unrestricted plants.

From Day 82 to 140, A and C plants increased the weight of their stems by factors of 3.6 and 3.3, respectively, while D plants increased the weight of their

stems by a factor of only 2.3 (Table 1). In the period of boll filling, from Day 107 to 140, the dry weight of storage organs (stems and large roots) hardly changed in D plants.

The storage of carbohydrates in stem and thickened root is typical of many woody perennial plants. In the cotton plant during the peak demand for carbohydrates (boll filling period), taproot and stem are strong sinks and important competitors with the developing bolls for the available photosynthate. During the boll filling period (plant age 107 to 140 d), A and C plant frames accumulated 107.9 and 169.9 g $m^{-2}$, respectively, while D plant frames accumulated only 27.4 g $m^{-2}$. At the same time, A and C plants increased their fruit dry weight by 386.3 and 297.0 g $m^{-2}$, respectively, while D plants increased their boll dry weight by 235.4 g $m^{-2}$ (Table 1). In other words, A and C plants diverted about 20 to 35% of the photosynthate produced during the boll filling period into their frames, while D plants diverted only 10% (this is only an estimate, since dry weight of fallen leaves and fruit was not recorded).

Eaton and Ergle (1953) showed that the bark of the cotton plant is a very efficient sink from which the carbohydrates are not remobilized. Plants that accumulate more storage carbohydrates do not have better fruit retention than plants with small frames, so from an agronomic point of view those storage carbohydrates are useless.

When the experiment was terminated 140 d after emergence, the total dry weight of A and C plants was 53.9 and 17.7% more than that of D plants, respectively (Table 1). Most of the difference in plant dry weight between the treatments was in the frame components (taproot, stem, and branches).

In 1983, cool weather was the main factor that limited plant growth in the beginning of the season, and the plants were smaller than in 1982. Plant height at harvest was about 61% of that in 1982. Maximum LAI (leaf area index) was 42 to 49% of that in 1982 (Fig. 2). The number of mainstem nodes was about the same (27 to 28) in both years in all the treatments. Although the responses of taproot-restricted plants were not as strong as in 1982, they were of the same type, i.e., early initiation of flowers and restriction of top canopy growth after bloom. Plants that grew in small pots (1.0 and 2.5 L) did not differ significantly from plants that grew in large pots until flowering (Table 2). The main differences among the nursery treatments were in earliness, yield of seed cotton at 189 d

**Table 1. Effects of pot size on dry weight of cotton plant components in 1982.**

| Treatment code and pot volume | | Plant age (Days from emergence) 40 | 51 | 65 | 82 | 107 | 140 |
|---|---|---|---|---|---|---|---|
| | L | | | Leaf blade (g $m^{-2}$) | | | |
| A | 18.0 | 16.1a* | 44.1a | 93.1a | 174.1a | 437.1a | 392.8a |
| C | 7.0 | 12.2b | 45.7a | 78.9a | 151.1ab | 303.7b | 259.0b |
| D | 2.5 | 10.2b | 34.4b | 83.3a | 129.6b | 262.0c | 233.0c |
| LSD (0.05) | | 2.2 | 5.6 | 12.0 | 25.7 | 41.4 | 40.7 |
| | | | | Stem and petiole (g $m^{-2}$) | | | |
| A | 18.0 | 6.2a | 17.2c | 79.9a | 227.1a | 716.2a | 818.0a |
| C | 7.0 | 4.8b | 22.9b | 62.2b | 196.9a | 507.6b | 655.5b |
| D | 2.5 | 4.8b | 29.1a | 86.4a | 195.1a | 424.3c | 455.6c |
| LSD (0.05) | | 0.8 | 3.3 | 10.8 | 32.7 | 68.1 | 92.8 |
| | | | | Large root (g $m^{-2}$) | | | |
| A | 18.0 | 7.3a | 10.5b | 39.6a | 59.1a | 127.9a | 134.0a |
| C | 7.0 | 6.3b | 14.0a | 28.2b | 52.9a | 78.0b | 99.7b |
| D | 2.5 | 6.8ab | 13.5a | 32.4ab | 42.6b | 68.3b | 64.4c |
| LSD (0.05) | | 0.7 | 2.7 | 7.2 | 7.2 | 16.0 | 14.7 |
| | | | | Small root (g $m^{-2}$) | | | |
| A | 18.0 | 4.8b | 8.2b | 28.7a | 38.8a | 68.9a | 60.9a |
| C | 7.0 | 5.1b | 15.0a | 22.6a | 42.4a | 51.1b | 47.6b |
| D | 2.5 | 6.8a | 16.9a | 27.8a | 38.1a | 51.8b | 53.6ab |
| LSD (0.05) | | 0.8 | 1.9 | 7.0 | 9.4 | 10.9 | 10.9 |
| | | | | Total fruit (g $m^{-2}$) | | | |
| A | 18.0 | 0.0 | 0.9a | 7.2b | 33.2b | 296.6a | 682.9a |
| C | 7.0 | 0.0 | 1.1b | 4.3c | 33.9b | 238.0a | 535.0b |
| D | 2.5 | 0.0 | 1.5a | 10.4a | 80.2a | 325.4a | 560.8b |
| LSD (0.05) | | – | 0.3 | 2.7 | 21.9 | 83.4 | 106.0 |
| | | | | Total plant (g $m^{-2}$) | | | |
| A | 18.0 | 34.4a | 71.1b | 240.2a | 532.2a | 1646.6a | 2088.7a |
| C | 7.0 | 28.5b | 98.7a | 196.3b | 477.3a | 1178.4b | 1596.8b |
| D | 2.5 | 28.6b | 105.1a | 248.4a | 485.5a | 1131.8b | 1357.3c |
| LSD (0.05) | | 3.7 | 11.2 | 35.0 | 77.3 | 162.5 | 194.4 |

* Means in the same column not followed by the same letter differ at the 0.05 probability level as determined by SNK range test.

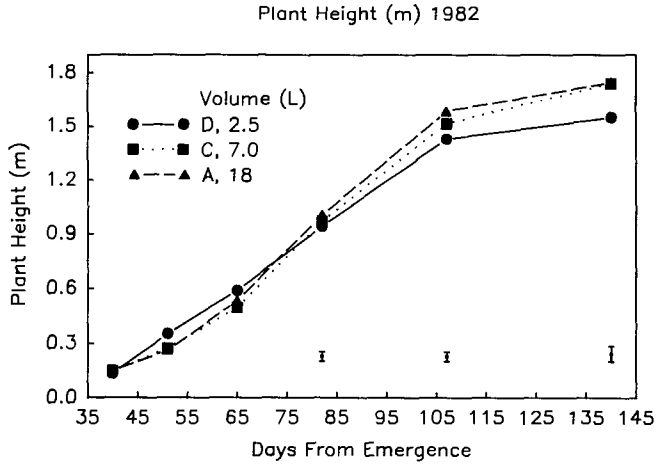


Fig. 1. 1982 seasonal time courses of plant height with three root volumes. Vertical bars indicate LSD (0.05) for pot volume comparisons.

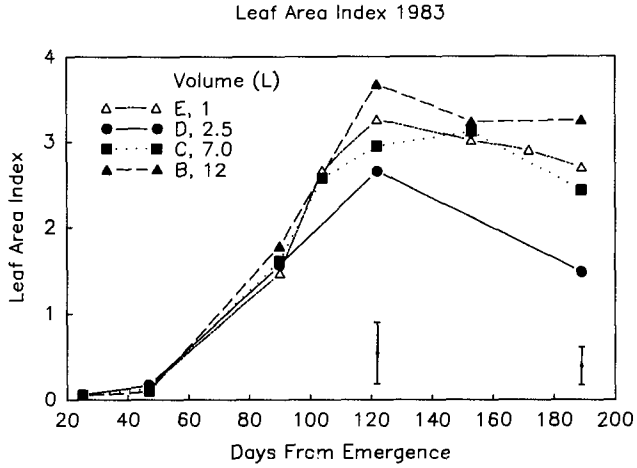


Fig. 2. 1983 seasonal time courses of leaf area index with four root volumes. Vertical bars indicate LSD (0.05) for pot volume comparisons.

**Table 2. Effects of pot size and temperature (location) on dry weight of cotton plant components in 1983.**

| Treatment code and pot volume | | Location | Plant age (Days from emergence) 90 | 122 | 189 |
|---|---|---|---|---|---|
| L | | | | Leaf blade (g m$^{-2}$) | |
| B | 12.0 | Nursery† | 99.6c* | 194.1ab | 169.0a |
| C | 7.0 | Nursery | 95.1c | 194.1ab | 126.6b |
| D | 2.5 | Nursery | 100.4c | 153.2b | 76.4c |
| E | 1.0 | Nursery | 91.3c | 175.4ab | 133.8b |
| B | 12.0 | SPAR‡ | 116.2c | 210.5a | – |
| C | 7.0 | SPAR | 170.9b | 169.7ab | – |
| D | 2.5 | SPAR | 202.9a | 177.4ab | – |
| LSD (0.05) | | | 20.8 | 32.1 | 20.2 |
| | | | | Stem and petiole (g m$^{-2}$) | |
| B | 12.0 | Nursery | 109.6c | 255.1a | 378.3a |
| C | 7.0 | Nursery | 98.2c | 206.9bc | 273.2b |
| D | 2.5 | Nursery | 86.0c | 193.3bc | 209.5c |
| E | 1.0 | Nursery | 84.1c | 195.2bc | 228.7bc |
| B | 12.0 | SPAR | 109.5c | 231.5ab | – |
| C | 7.0 | SPAR | 149.8b | 165.5c | – |
| D | 2.5 | SPAR | 198.2a | 166.8c | – |
| LSD (0.05) | | | 19.2 | 29.0 | 45.6 |
| | | | | Large root (g m$^{-2}$) | |
| B | 12.0 | Nursery | 32.3b | 71.7a | 87.6a |
| C | 7.0 | Nursery | 27.9b | 63.4ab | 64.7b |
| D | 2.5 | Nursery | 29.5b | 41.3c | 48.6b |
| E | 1.0 | Nursery | 24.6b | 39.2c | 52.3b |
| B | 12.0 | SPAR | 26.2b | 53.4bc | – |
| C | 7.0 | SPAR | 28.3b | 47.8c | – |
| D | 2.5 | SPAR | 37.5a | 39.6c | – |
| LSD (0.05) | | | 4.9 | 12.3 | 13.9 |
| | | | | Small root (g m$^{-2}$) | |
| B | 12.0 | Nursery | 14.9c | 45.2a | 34.9b |
| C | 7.0 | Nursery | 20.3bc | 37.0a | 27.5b |
| D | 2.5 | Nursery | 24.4b | 37.2a | 35.7b |
| E | 1.0 | Nursery | 23.3b | 35.5a | 49.0a |
| B | 12.0 | SPAR | 21.0bc | 50.8a | – |
| C | 7.0 | SPAR | 24.1b | 52.4a | – |
| D | 2.5 | SPAR | 70.5a | 48.7a | – |
| LSD (0.05) | | | 5.2 | 12.6 | 9.0 |
| | | | | Total fruit (g m$^{-2}$) | |
| B | 12.0 | Nursery | 21.5c | 244.1e | 676.5a |
| C | 7.0 | Nursery | 27.2c | 263.9de | 707.3a |
| D | 2.5 | Nursery | 26.6c | 347.2c | 612.7a |
| E | 1.0 | Nursery | 45.8b | 441.4a | 758.1a |
| B | 12.0 | SPAR | 18.1c | 280.3de | – |
| C | 7.0 | SPAR | 54.4b | 302.5d | – |
| D | 2.5 | SPAR | 85.9a | 389.2b | – |
| LSD (0.05) | | | 9.0 | 33.7 | 115.4 |
| | | | | Total plant (g m$^{-2}$) | |
| B | 12.0 | Nursery | 277.8c | 810.2a | 1346.3a |
| C | 7.0 | Nursery | 268.7c | 765.2a | 1199.2a |
| D | 2.5 | Nursery | 266.8c | 772.5a | 982.8b |
| E | 1.0 | Nursery | 268.9c | 886.6a | 1221.8a |
| B | 12.0 | SPAR | 277.8c | 826.5a | – |
| C | 7.0 | SPAR | 427.7b | 738.0a | – |
| D | 2.5 | SPAR | 595.1a | 821.7a | – |
| LSD (0.05) | | | 22.7 | 92.1 | 150.3 |

* Means in the same column not followed by the same letter differ at the 0.05 probability level as determined by the SNK range test.
† In the SPAR units (32/20°C) the plants grew from age 47 to 90 d.
‡ In the SPAR Units (32/20°C) the plants grew from age 92 to 122 d.

from emergence, and dry weight of the large root. As the season progressed, the yield differences tended to decrease (cf. Day 122 vs. Day 189 in Table 2).

When plants were transferred at 47 d into the optimal temperature regime in the SPAR units, the higher temperature significantly enhanced the effects of taproot restriction (Table 2). Under the 32/20 °C temperature regime, the effect of pot size was greater than in the nursery. Among the plants of the first SPAR experiment, the dry weight of the small roots

**Table 3. Physiological age of plants and cumulative numbers of flowers in various temperature regimes in 1982 and 1983.**

| | Temperature combination | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | 1982 outdoors | | | 1983 outdoors | | | 1983 planted outdoors and transferred into SPAR units at 45 d. | | |
| trt. code† | A | C | D | B | C | D | B | C | D |
| pot volume (L) | 18.0 | 7.0 | 2.5 | 12.0 | 7.0 | 2.5 | 12.0 | 7.0 | 2.5 |
| Plant age | | | | | | | | | |
| | First flowering day (5 m$^2$) | | | | | | | | |
| DFE‡ | 71 | 70 | 66 | 90 | 89 | 87 | 82 | 79 | 78 |
| PA§ | 44.4 | 43.8 | 41.5 | 45.0 | 44.4 | 43.1 | 45.7 | 43.9 | 43.2 |
| | First 30 flowers m$^2$ | | | | | | | | |
| DFE | 79 | 79 | 72 | 100 | 99 | 98 | – | 87 | 84 |
| PA | 50.1 | 50.1 | 45.6 | 51.3 | 50.7 | 50.1 | – | 50.9 | 48.8 |
| | First 60 flowers m$^2$ | | | | | | | | |
| DFE | 93 | 93 | 88 | 104 | 104 | 103 | – | – | 88 |
| PA | 57.2 | 57.2 | 55.3 | 55.9 | 54.1 | 53.5 | – | – | 53.8 |

† Trt. = treatment.
‡ DFE = Days from Emergence
§ PA = Physiological age or the sum of Physiological days (a Physiological day is 14 degree-days above 12°C).

of D plants was about three times larger than that of B and C plants (Table 2). In order to compare the plant growth in different years and locations, physiological days were calculated for each temperature regime. A physiological day was defined as the time needed for accumulation of 14 degree-days above the threshold of 12 °C.

In the first experiment, the plants grown 43 d in the SPAR units during June and July 1983 received 36.6 physiological days. In the same period, the plants in the nursery received only 27.7 physiological days. In the second SPAR experiment, the advantage of 30 d in SPAR environment over the nursery during August was much smaller than that of June to July. During that period, the plants in the SPAR units received only 4.2 physiological days more than those in the nursery, and no significant interaction between temperature and taproot restriction was found. Another factor that must be considered is the developmental stage of the plants in which the temperature treatment was imposed. In the second experiment, the plants were in the boll filling period, and the temperature effect was expressed in increasing fruit dry weight instead of small root dry weight of D plants in the SPAR (Table 2).

### *Earliness and Yield*

The major differences between the treatments in the first growing phase were the early initiation of squares and the high rate of flowering in plants that had their taproot growth restricted. That response was found in three different observations (Table 3 and Fig. 3). In no case was there a significant difference among the treatments in nodal position of the first fruiting branch. The population that we checked (20 plants from each treatment) was probably too small to detect this. The higher blooming rate of the taproot-restricted plants was due to better square retention and not to more fruiting sites. Drip irrigation (to some extent equivalent to root restriction) increases the blooming rate in many woody species, including cot-

**Table 4. Final harvest of the nursery in 1982 and 1983, dry weights, and numbers of green and open cotton bolls.**

| | | 1982 | 1983 |
|---|---|---|---|
| Plant age at harvest (DFE)† | | 140 | 189 |
| Physiological Age at harvest (PA)‡ | | 71.2 | 85.0 |
| Sample size (no. of plants from each treatment) | | 10 | 20 |

| Treatment code and pot volume | | 1982 Green bolls | 1982 Open bolls | 1983 Green bolls | 1983 Open bolls |
|---|---|---|---|---|---|
| | L | Dry wt. of bolls (g m$^{-2}$) | | | |
| A | 18.0 | 534.8a* | 142.8b | – | – |
| B | 12.0 | – | – | 246.1a | 410.9b |
| C | 7.0 | 427.8b | 98.1b | 288.7a | 413.6b |
| D | 2.5 | 301.4c | 254.9a | 102.3b | 503.3a |
| E | 1.0 | – | – | 236.4a | 511.8a |
| LSD (0.05) | | 87.7 | 90.2 | 106.5 | 41.9 |
| | | No. of bolls per m$^2$ | | | |
| A | 18.0 | 203.3a | 25.6ab | – | – |
| B | 12.0 | – | – | 84.5a | 74.0b |
| C | 7.0 | 164.4b | 15.6b | 60.5a | 73.0b |
| D | 2.5 | 127.8b | 37.8a | 27.5b | 97.0a |
| E | 1.0 | – | – | 84.5a | 96.0a |
| LSD (0.05) | | 38.3 | 12.2 | 20.0 | 7.0 |
| | | Dry weight of an average boll (g) | | | |
| A | 18.0 | 2.7a | 5.9a | – | – |
| B | 12.0 | – | – | 2.9c | 5.6a |
| C | 7.0 | 2.6a | 6.2a | 4.8a | 5.7a |
| D | 2.5 | 2.4a | 6.6a | 3.7b | 5.2a |
| E | 1.0 | – | – | 2.8c | 5.3a |
| LSD (0.05) | | 0.5 | 2.0 | 0.4 | 0.2 |

* Means in the same column not followed by the same letter differ at the 0.05 probability level as determined by SNK range test.
† DFE = Days From Emergence
‡ PA = Physiological Age or the sum of Physiological Days (a Physiological day is 14 Degree-Days above 12°C).

ton (Briggs et al., 1983; Elfving, 1982; Mitchell and Chalmers, 1983; Proebsting et al., 1977). The improved fruit set is consistent with the concept of physiological stress elaborated in the GOSSYM model (Baker et al., 1986). This theory suggests that a limitation to growth that is not stress related, e.g., moderately lower temperature or (as in the present case) mechanical restriction, will reduce sink strength, reduce source: sink imbalance, and enhance fruit retention.

The observations of growth and flowering in different environments (Tables 2 and 3) indicate that there was a large interaction between plant responses to taproot restriction and to temperature. With more favorable temperatures in the SPAR experiment, taproot restriction resulted in much more biomass in all plant parts and especially in fine roots. The advantage of early development of the secondary root system is experienced only when root temperatures are favorable. With more favorable temperature conditions in the SPAR units, taproot-restricted plants flowered earlier and exhibited a higher blooming rate than in the nursery (Table 3).

In both years, the taproot-restricted plants had a significant advantage in earliness and in dry weight partitioning into fruit in the final yield. In 1982, plants were harvested at 140 d of age. At that time, D plants had more open bolls than A and C plants (Table 4). In 1983, weekly harvests of open bolls were made at the nursery on 20 plants (2 m of row) from each treatment. The results are shown in Fig. 4. At the final harvest at 189 d, B and C plants still had about 40%

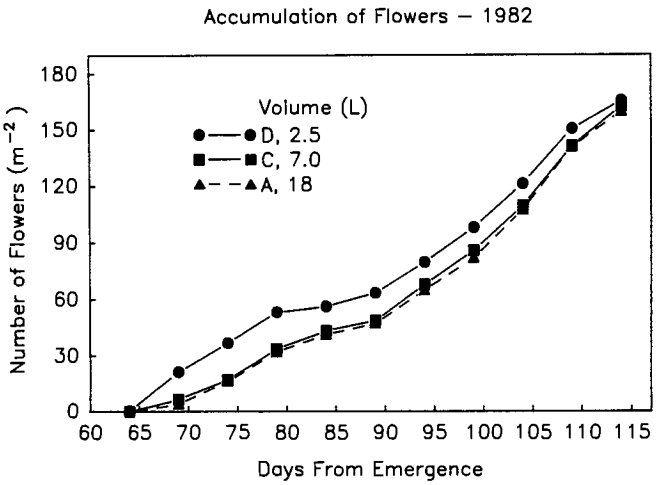


Fig. 3. 1982 cumulative flower formation vs. days from emergence.

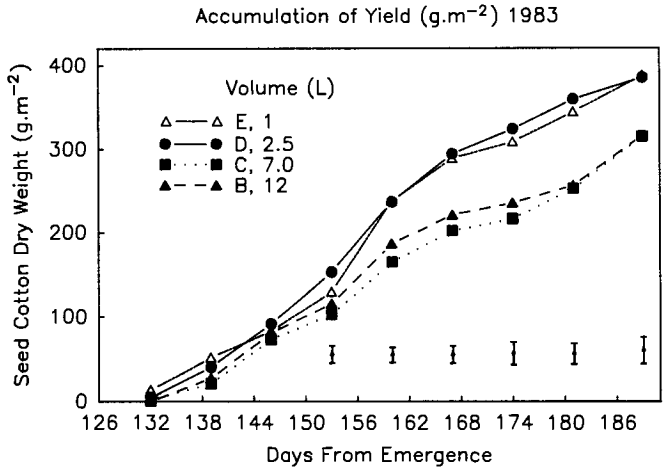


Fig. 4. 1983 cumulative seed cotton dry matter accretion vs. days from emergence.

of the boll dry weight in green bolls, while D and E plants (grown in 1.0- and 2.5-L pots) had only 17 to 31% of the boll dry weight in green bolls (Table 4).

In the long season of 1983, the yield response of the plants to root restriction treatments was directly associated with earliness. In Fig. 4, there are two distinct populations with respect to both earliness and final yield. The D and E plants matured earlier and had significantly higher yield (open bolls at age of 189 d) than B and C plants. In neither year did the average dry weight of an open boll differ significantly among the treatments (Table 4). Moreover, in both years there was little difference among the treatments in the total number of bolls (green and open bolls together) or in the total dry weight of bolls (Table 4). Taproot-restricted plants initiated flowers slightly earlier, set fruit at a rapid rate early in the season, and later nearly stopped their vegetative growth. They were much more determinate. On the other hand, the unrestricted plants (B and C plants) needed a long season to express their yield potential.

The reductions in taproot and woody root branches in D plants were accompanied by a relatively small reduction of the shoot frame. This coordinated reduction is shown in Table 1. At the age of 82 d, the

large root weight in D plants was 72% of that in A plants, while the dry weight of stem and petioles in D plants was 86% of that in A plants. Later, the frames of D plants were further reduced in comparison to those of A plants. At the age of 107 d, large roots and stem in D plants were 53 and 59% of those in A plants, respectively. At the age of 140 d, large roots and stem in D plants were 48 and 56% of those in A plants, respectively. On the other hand, stems and petioles were reduced more than the taproot, since the dry weight of the stem was about four to seven times more than that of the taproot (Table 1). That may indicate the potential of taproot restriction as a means of shifting the partitioning of assimilates in the shoot from stem and branches to fruit.

The reproductive:vegetative balance of the plant is usually expressed as the fruit: shoot ratio, or, whenever root data are available, as the fruit: total plant ratio. Data from Table 1 show that in the final harvest of 1982, the fruit represented 41.2, 33.2, and 32.7% of the plant dry weight in D, C, and A plants, respectively. The same trend was evident in 1983 (from data in Table 2), although ratios of fruit: total plant weight were higher than in 1982 because of the effect of leaf shedding.

## CONCLUSIONS

In a 2-yr study of cotton plants grown in different pot sizes, taproot-restricted plants had a better partitioning of assimilates into yield components than the nonrestricted plants. The production of early yield in the taproot-restricted plants occurred at the expense of the frame. The results indicate the potential for agronomic improvement of drip-irrigated cotton via taproot restriction. Such a system could be useful for dense canopies (narrow-row cotton), especially where a more determinate type of growth is desirable.

## REFERENCES

Acock, B., V.R. Reddy, H.F. Hodges, D.N. Baker, and J.M. McKinion. 1985. Photosynthetic response of soybean canopies to full season carbon dioxide enrichment. Agron. J. 77:942–947.

Baker, D.N., J.R. Lambert, and J.M. McKinion. 1986. GOSSYM: Simulator of cotton crop growth and yield. South Carolina Agric. Exp. Stn. Bull. 1089.

Briggs, R.E., M.A. Maatoug, and W.C. Hoffmann. 1983. Flowering, boll set, and yield in drip irrigated cotton in Arizona. p. 43–45. *In* J.M. Brown (ed.) Proc. Beltwide Cotton Prod. Conf. San Antonio, TX. 2-6 January. Natl. Cotton Council, Memphis, TN.

Carmi, A., and J. Shalhevet. 1983. Root effects on cotton growth and yield. Crop Sci. 23:875–878.

Chalmers, D.J., P.D. Mitchell, and L. van Heek. 1981. Control of peach tree growth and productivity by regulated water supply, tree density, and summer pruning. J. Am. Soc. Hortic. Sci. 106:307–312.

Eaton, F.M., and D.R. Ergle. 1953. Relationship of seasonal trends in carbohydrate and nitrogen levels and effects of girdling and spraying with sucrose and urea to the nutritional interpretation of boll shedding in cotton. Plant Physiol. 28:503–520.

Eaton, F.M., and N.E. Rigler. 1945. Effects of light intensity, nitrogen supply, and fruiting on carbohydrate utilization by the cotton plant. Plant Physiol. 20:380–411.

Elfving, D.C. 1982. Crop response to trickle irrigation. Hortic. Rev. 4:1–48.

Goodnight, J.H. 1982. Analysis of variance. p. 113–119. *In* A.A. Ray (ed.) SAS user's guide. Statistics, SAS Inst., Cary, NC.

Levin, I., D. Kahana, and D. Levi. 1983. Cotton response to irrigation with tricklers and linear movement system. ("Intensive method"). (In Hebrew) Tel-Hay Agronomic Res. Inst. Tel Aviv, Israel (As cited by Avi Ben Porath doctoral dissertation, Mississippi State Univ.)

Lowery, F.E., H.M. Taylor, and M.G. Huck. 1970. Growth rate and yield of cotton as influenced by depth and bulk density of soil pans. Soil Sci. Soc. Am. Proc. 34:306–309.

Mauney, J.R. 1986. Carbohydrate production and distribution in cotton canopies. p. 181–191. *In* J.R. Mauney and J.M. Stewart (ed.) Cotton physiology. The Cotton Foundation, Memphis, TN.

McKinion, J.M., and D.N. Baker. 1982. Modeling, experimentation, verification and validation: closing the feedback loop. Trans. ASAE 25:647–653.

Mitchell, P.D., and D.J. Chalmers. 1983. A comparison of microjet and point emiter (trickle) irrigation in the establishment of high-density peach orchard. HortSci. 18:472–474.

Phene, C.J., D.N. Baker, J.R. Lambert, J.E. Parsons, and J.M. McKinion. 1978. SPAR—A soil-plant-atmosphere research system. Trans. ASAE 21:924–930.

Proebsting, E.L., J.E. Middleton, and S. Roberts. 1977. Altered fruiting and growth characteristics of 'Delicious' apple associated with irrigation method. Hortic. Sci. 12:349–350.

Richards, D. 1983. The grape root system. Hortic. Rev. 5:127–168.

Saleem, M.B., and D.R. Buxton. 1976. Carbohydrate status of narrow row cotton as related to vegetative and fruit development. Crop Sci. 16:523–526.

Skene, K.G.M. 1975. Cytokinin production by roots as a factor in control of plant growth. p. 365–396. *In* J.G. Torrey and D.T. Clarkson (eds.) The development and function of roots. Academic Press, New York.

Taylor, H.M., and E. Burnett. 1964. Influence of soil strength on the root-growth habits of plants. Soil Sci. 98:174–180.

Torrey, J.G. 1976. Root hormones and plant growth. Annu. Rev. Plant Physiol. 27:435–459.