Published September, 1983

Root Effects on Cotton Growth and Yield[1]

Avner Carmi and Joseph Shalhevet[2]

ABSTRACT

The growth of cotton (*Gossypium hirsutum* L.) plants and the distribution of assimilates between their vegetative and reproductive organs were strongly affected by their root zone volume. Reduction of root growth resulting from growing the plants in small pots was accompanied by a considerable decrease in vegetative growth and an increase in the proportional accumulation of dry weight in the reproductive organs. The rate of vegetative growth, characterized by shoot weight and stem length, was positively correlated to the root zone volume which was limited by using pots of 2, 5, 10, or 25 L capacity. The ratio in dry weight of seed cotton to vegetative organs increased as the shoot growth decreased. Restriction of the root growth led to the development of a compact plant, characterized by short internodes, fewer leaves, and high ratios in dry weight of bolls to vegetative organs. Such a plant may be useful in increasing yields in dense canopies. Analyses of N, P, and K in the shoot, as well as measurements of water potential and stomatal resistance in the leaves, showed no significant differences between plants grown in different root zone volumes. It was concluded that the differences in growth rate were not caused mainly by N, P, K deficiency or by water stress, but were due to the differences in development of the root system as affected by the pot capacity.

Additional index words: Root zone, *Gossypium hirsutum* L., Plant density, Root quantity.

COTTON (*Gossypium hirsutum* L.) yield is strongly affected by the competition for assimilates between the vegetative and reproductive organs of the plant (13, 21). An enhanced vegetative growth may decrease yield either by reducing the amount of assimilates available for boll development (13), or by increasing the abscission of fruiting bodies (2). Reduction of vegetative growth through selecting dwarf plants has improved wheat yields. In such plants a higher proportion of assimilates is translocated to the reproductive organs. To obtain similar effects in cotton the plants were sprayed with growth retardants, whereupon both decreased (2, 21) and increased (20) yields were obtained. Cotton growth may be restricted as a result of water (7, 18), salinity (5, 9), or nutrition (8, 14) stress. Reduction of vegetative growth under such conditions is not beneficial since an increased abscission of fruiting bodies may occur (10, 14, 17) and reduce yield. A reduction in root growth may restrain shoot development (1, 12, 16). The role of roots in regulating shoot growth is connected to their function as suppliers of growth substances such as cytokinins (1, 6) or gibberellins (1, 11). These materials are translocated to the shoot and affect its growth. A restricted root system may create a deficiency in the level of such growth substances in the shoot, thus restraining its growth.

The present study investigates the interrelationship between root growth, reproductive and vegetative development, the distribution of assimilate between the vegetative and reproductive organs, and yield of cotton plants grown in restricted root zone volumes.

MATERIAL AND METHODS

Cotton seeds ('Acala SJ-2') were planted in Bet Dagan, Israel in May. The plants were grown in plastic pots of 2, 5, 10, or 25 L capacity, filled with soil composed of 80% sand and 20% silt (V/V). The pots were buried to the height of the soil surface. Rows were spaced 2 m apart, with 1.5 m between plants in each row. The plants were irrigated to excess in pulses by drippers with a full nutrient solution that included microelements and 100 mg/L of N, P, and K. Nitrogen was supplied as NH_4NO_3. The frequency of the pulses and the amount of water supplied by them were automatically controlled and changed throughout the growth period. The water tension in the pots was measured by tensiometers and maintained in the range of 0 to 1.5 MPa. The bottoms of the pots were open and covered with strong netting whose openings were 0.1 mm in diameter. Good drainage was thus achieved while penetration of the roots to the underlying soil was prevented. The frequent irrigation pulses with nutrient solution enabled an efficient washing of the soil, while preventing an accumulation of salts on the one hand and a deficiency of nutrients on the other hand. Xylem water potentials in leaves were measured by a pressure bomb according to Scholander et al. (15). Stomatal resistance was measured using an L1-60 diffusive resistance meter (Lambda Instruments Co.). The effect of the pot capacity on vegetative growth was studied through measurements of shoot weights, root weight, and stem length in plants sampled at random 65 or 145 days

[1] Contribution from the Agricultural Research Organization, The Volcani Ctr., Bet Dagan, Israel. Series No. E-156. Received 8 Feb. 1982.

[2] Plant Physiologists, Inst. of Soils and Water, Agric. Research Organization, The Volcani Ctr., Bet Dagan, Israel.

after sowing. Each sample included 20 plants. Flowering was observed over a period of 35 days by measuring the number of new flowers which opened daily. The soil was separated from the roots by a very delicate and careful washing with water until the roots were totally clean. Yield was picked 145 days post sowing and seed cotton was weighed just from open bolls. Nitrogen, P, and K contents in plant organs were determined in plant dry matter after wet ashing with concentrated sulfuric acid. Nitrogen and P were determined using a Technicon auto-analyzer and K was determined with an Evans electroselenium flame photometer.

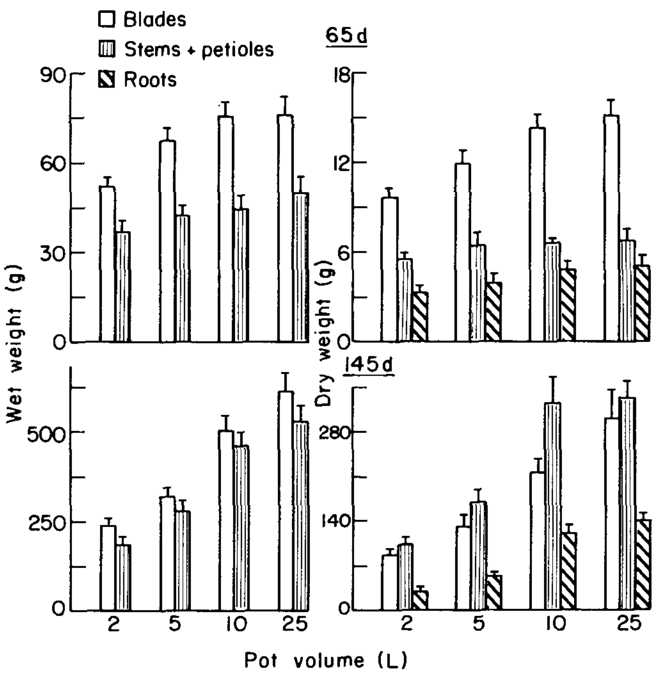

Fig. 1. Fresh and dry weight of cotton organs per plant when grown in pots of different capacities. Plants were sampled 65 or 145 days after sowing. One SE shown at top of each bar.

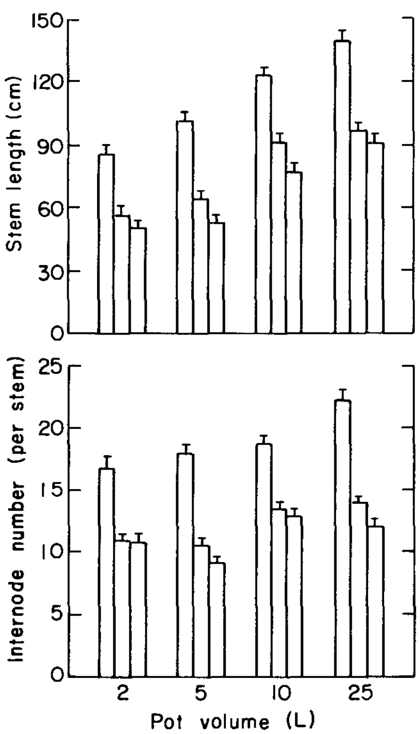

Fig. 2. Length and number of internodes of the three longest stems in cotton plants grown in pots of different capacities. Measurements were made 145 days after sowing. One SE shown at top of each bar.

RESULTS

The vegetative growth of the cotton plants was strongly affected by the root zone volume (i.e. the pot capacity). Wet and dry weight of the shoot (Fig. 1) and its stem length (Fig. 2) increased with increasing root zone. Differences in stem length were due mainly to differences in elongation of the internodes and only slightly to their number (Fig. 2). The growth of the roots, characterized by their dry weight, increased with increasing root zone volume (Fig. 3). The differences in shoot or root growth between plants grown in pots of 10 and 25 L were slight in comparison to the differences seen in plants grown in pots of 2, 5, and 10 L. The morphological development of the roots was also influenced by the root

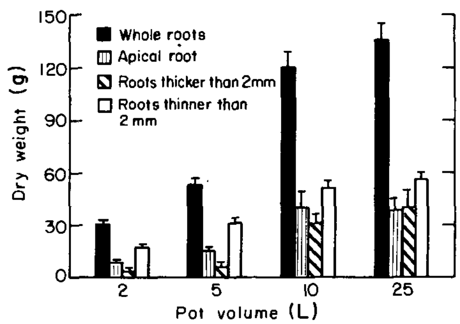

Fig. 3. Dry weight of cotton roots grown in pots of different capacities. Measurements were made 145 days after sowing. One SE shown at top of each bar.

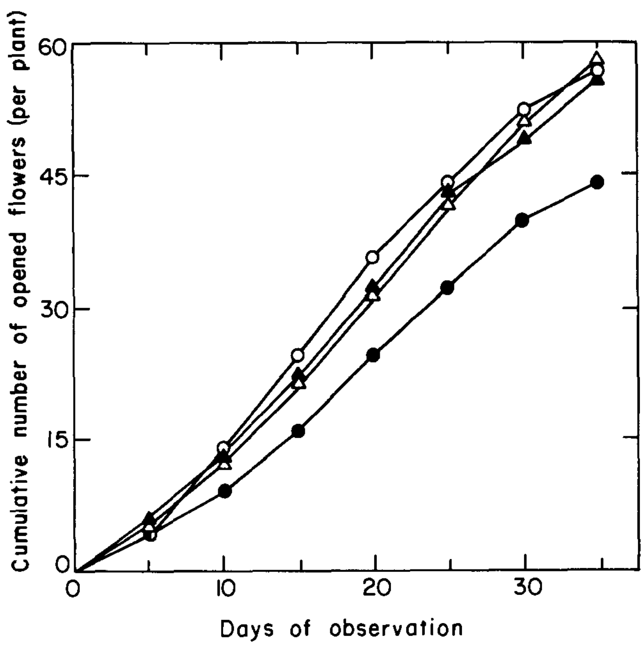

Fig. 4. Cumulative number of flowers per plant opened in cotton plants, beginning 85 days after sowing and ending 35 days later. The plants were grown in pots of 2 (solid circles), 5 (solid triangles), 10 (open triangles) and 25 (open circles) L capacity.

zone volume. Thin roots (less than 2 mm in diameter) accounted for more than 50% of the total root system (on a dry weight basis) in plants grown in pots of 2 or 5 L, and the proportion decreased significantly as the root zone volume increased (Fig. 3). The average number of flowers per plant which opened over a period of 35 days was similar in plants grown in root zones of 5, 10, and 25 L (Fig. 4), in spite of the fact that the plants grown in 5 L pots were considerably smaller than in the other two treatments. In the smallest root zone volume (2 L), flowering was significantly reduced. The flowering in plants grown in pots of 2 and 5 L stopped in mid-September, but continued in the 10 and 25 L pots until the end of September. The average yield per plant of cotton increased with increasing root zone volume in the range of 2 to 10 L (Table 1). No significant difference in yield was found between plants grown in pots of 10 and 25 L.

The difference in yield between the treatments was reflected in the different number of mature bolls per plant, and not in a difference in boll weight (Table 1). It therefore seems that the reduction in growth caused by restricting the root zone volume was specific to the vegetative organs, and did not affect the bolls.

The distribution of assimilates between the vegetative and reproductive organs was influenced by the root zone volume. The smaller the root zone and the less the vegetative growth, the larger the relative quantity of assimilates translocated to the bolls (Fig. 5). The dry matter of the seed cotton expressed as a percentage of the whole plant dry weight was 31, 28, 22, and 20 in the pots of 2, 5, 10, and 25 L capacity, respectively, as can be calculated from Fig. 5.

Analyses of N, P, and K in the leaves and stem (Table 2) revealed no significant differences between the plants grown in pots of different capacities. There was no significant difference in xylem water potential 90 d after sowing between the plants grown in 2 L pots and those in 5 L pots (Table 3). The water potentials of these treatments were similar to those of the plants grown in 10 or 25 L pots in the morning, but slightly lower at noon. Leaf resistances of all treatments were similar (Table 3).

DISCUSSION

The reduced growth of cotton plants as a result of restriction in root zone volume (Fig. 1 and 2) may be attributed either to a decreased absorption of water and nutrients by the limited root system or to a change in the level or of activity of endogenous factors which are influenced by the roots and affect the growth of the plant. There is no indication that the shoot growth reduction was caused by a nutrient deficiency, since no differences in N, P, and K concentration in the stem or leaves were observed between the different treatments (Table 2). It is not clear whether water stress conditions were created in the plants grown in the small pots causing growth reduction. Water stress in cotton is generally accompanied by a decrease in xylem water potential. However, that does not appear to be the cause of the considerable difference in growth rate between the plants in the 2 and 5 L

Table 1. The effect of pot capacity on cotton yield and number of bolls per plant. Measurements were made 145 days after sowing.

Pot capacity	Seed cotton† yield	Seed cotton† weight	Number of bolls‡ per plant
L	g/plant	g/boll	
2	209 ± 15	7.4 ± 0.5	31.0 ± 1.8
5	243 ± 20	7.4 ± 0.6	35.5 ± 2.9
10	304 ± 30	7.4 ± 0.7	46.6 ± 4.6
25	316 ± 30	7.5 ± 0.5	50.9 ± 3.5

† Seed cotton = lint + seeds, mean ± SE.
‡ Bolls longer than 20 mm, mean ± SE.

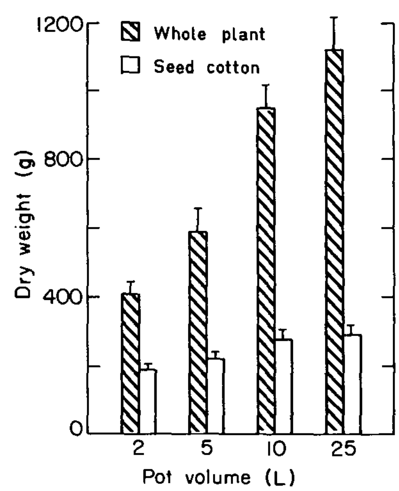

Fig. 5. **Dry weight of seed cotton and of the whole plant when grown in pots of different capacities. Measurements were made 145 days after sowing. One SE shown at top of each bar.**

Table 2. Nutrient concentrations in organs of cotton plants growing in different root zone volumes. Plants were sampled 145 days after sowing. A composite sample of all leaves was analyzed.

Pot capacity	Organ	Nutrient N	P	K
L			mg/g DW†	
2	Blades	23.0 ± 1.8‡	3.2 ± 0.3	11.0 ± 0.9
5	Blades	22.0 ± 1.5	3.0 ± 0.2	10.2 ± 1.0
10	Blades	21.8 ± 1.0	2.6 ± 0.2	10.7 ± 0.8
25	Blades	23.3 ± 1.0	2.6 ± 0.2	10.2 ± 0.8
2	Stems + petioles	9.4 ± 1.4	1.9 ± 0.2	11.5 ± 1.8
5	Stems + petioles	9.4 ± 1.0	1.8 ± 0.2	12.9 ± 1.4
10	Stems + petioles	8.7 ± 0.9	1.6 ± 0.1	10.5 ± 1.4
25	Stems + petioles	9.2 ± 0.9	1.9 ± 0.2	11.5 ± 1.2

† Dry weight.
‡ Means ± SE.

Table 3. Xylem water potential and stomatal resistance of cotton leaves from plants grown in pots of different capacities. Measurements were made at 90 days after sowing.

Pot capacity	Time of day	Leaf resistance	Water potential
L		sec cm^{-1}	MPa
2	0900h†	3.3 ± 0.2‡	−1.10 ± 0.11‡
5	0900h	3.6 ± 0.6	−1.26 ± 0.14
10	0900h	3.4 ± 0.5	−1.13 ± 0.09
25	0900h	3.4 ± 0.3	−1.10 ± 0.06
2	1230h†	3.5 ± 0.1	−1.47 ± 0.08
5	1230h	3.4 ± 0.2	−1.45 ± 0.05
10	1230h	3.5 ± 0.1	−1.30 ± 0.06
25	1230h	3.5 ± 0.1	−1.30 ± 0.04

† Local time.
‡ Mean ± SE.

pots (Fig. 1) as their xylem water potential are similar (Table 3). The xylem water potential of the plants grown in the largest pots reached −1.3 MPa at noon in comparison to a value of −1.47 MPa measured in the plants grown in the smallest pots (Table 3). This water potential range does not generally characterize water stress conditions in cotton leaves under field conditions in the summer. Therefore, it is doubtful whether this small difference in water potential is responsible for the very considerable difference in growth rate.

Carmi and Heuer (1) reported that dwarfishness of beans observed in plants grown in small pots was not caused by water or nutrient deficiency, but by a deficiency in growth substances including cytokinins and gibberellins. No information is yet available about the involvement of growth substances in the growth response of cotton to the small root zone volume.

The ability to affect the distribution of assimilates between the vegetative and reproductive organs in cotton is very important, since the cotton yield is considerably influenced by the competition for assimilates between these organs (13, 20). In the present study it was found that as the root quantity was smaller (in accordance with the limitation in root zone volume), the reduction of vegetative growth was greater on the one hand (Fig. 1 and 2) and the relative quantity of assimilates accumulated in the reproductive organs was increased on the other hand (Fig. 5), as seen from the ratio of the dry weight of seed cotton to that of vegetative organs.

Carmi and Heuer (1) found that in dwarf bean plants developed under conditions of root growth restriction, a large quantity of starch accumulated in the stem and leaves. It was concluded that as a result of reduced vegetative growth an excess of assimilates was produced which could not be used for growth, and thus accumulated in the form of starch in tissues which could store it. It is possible that a similar process occurs in cotton under conditions that restrict root and shoot growth, but that in this crop the excess of assimilates can be used for boll growth. This might affect the dry weight ratio between the vegetative and reproductive organs.

The growth of a compact plant characterized by short internodes and a high ratio of dry weight of bolls to that of vegetative organs, as was obtained in the present work, may be very useful in increasing yields in cotton canopies. Introducing additional plants per unit area may result in decreased penetration of light into the canopy, leading to boll abscission (4, 19) and yield decrease (3, 19) due to the less favorable radiation conditions. Dwarf plants may allow the use of dense canopies without creating worse light conditions than in less dense canopies consisting of non-dwarf plants. A basic question which has yet to be answered is whether under dense canopy conditions the effect of root development on the morphological development of cotton plants and on the distribution of assimilates will be similar to those obtained in the present work, in which the plants were spaced as single units in the field, without mutual shading. There is also the question of how to create conditions in the field which will restrict root growth without causing stresses of drought, aeration, etc. A possible way may be to irrigate with drippers very close to the plant axis, using frequent but limited quantities of water, thus enabling control of the wetted soil volume in the root zone. Development of the roots should be limited to the wetted zone, thus in effect creating a pot of soil without a physical barrier. It has still to be determined whether in such a pot the physiology of the root and the shoot will be the same as in a solid pot.

In conclusion, it is assumed that growth conditions which are able to restrict root growth without causing severe stresses of water, nutrients, salinity, aeration, etc. may be useful in beneficially influencing the boll productivity of cotton plants.

REFERENCES

1. Carmi, A., and B. Heuer. 1981. The role of roots in the control of shoot growth in bean (*Phaseolus vulgaris* L.). Ann. Bot. 48:519–527.
2. De Silva, W.H. 1971. Some effects of the growth retardant chemical CCC on cotton in Uganda. Cotton Grow. Rev. 48:131–135.
3. Fowler, J.L., and L.L. Ray. 1977. Response of two cotton genotypes to five equidistant spacing patterns. Agron. J. 69:733–738.
4. Guinn, G. 1974. Abscission of cotton floral buds and bolls as influenced by factors affecting photosynthesis and respiration. Crop Sci. 14:291–293.
5. Hoffman, G.J., S.L. Rawlins, M.J. Garber, and M. Cullen. 1971. Water relations and growth of cotton as influenced by salinity and relative humidity. Agron. J. 48:822–826.
6. Kende, H. 1965. Kinetin-like factors in the root exudate of sunflowers. Proc. Natl. Acad. Sci. USA 53:1302–1307.
7. Klepper, B., H.M. Taylor, M.G. Huck, and E.L. Fiscus. 1973. Water relations and growth of cotton in drying soil. Agron. J. 65:307–310.
8. Mackenzie, A.J., and P.H. van Schaik. 1963. Effect of nitrogen on yield, boll, and fiber properties of four varieties of irrigated cotton. Agron. J. 55:345–347.
9. Nieman, R.H., and L.L. Poulsen. 1967. Interaction effects of salinity and atmospheric humidity on the growth of bean and cotton plants. Bot. Gaz. 128:69–73.
10. Osborne, O. 1974. Hormones and the shedding of leaves and bolls. Cotton Grow. Rev. 51:256–265.
11. Reid, D.M., and A. Crozier. 1971. Effect of waterlogging on the gibberellin content and growth of tomato plants. J. Exp. Bot. 22:39–48.
12. Saini, G.R. 1979. Root elongation and plant growth in a basal till compact soil treated with 3.5-diodo-4-hydroxybenzoic acid and gibberellic acid. Agron. J. 71:1067–1070.
13. 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.
14. Scarsbrook, C.E., O.L. Bennett, and R.W. Pearson. 1959. The interaction of nitrogen and moisture on cotton yields and other characteristics. Agron. J. 51:718–721.
15. Scholander, P.F., H.T. Hammel, E.D. Bradstreet, and E.A. Hemmingsen. 1965. Sap pressure in vascular sap. Science 148:339–346.
16. Schuurman, J.J. 1965. Influence of soil density on root development and growth of oats. Plant Soil 22:352–374.
17. Spooner, A.C., C.E. Caviness, and W.I. Spurgeon. 1958. Influence of timing of irrigation on yield, quality and fruiting of upland cotton. Agron. J. 50:74–77.
18. Taylor, H.M., and B. Klepper. 1974. Water relation of cotton. I. Root growth and water as related to top growth and soil water content. Agron. J. 66:584–588.
19. Wanjura, D.F. 1977. Cotton population dynamics: Influence of the within-the-row spacing and emergence time. Agron. J. 69:312–318.
20. Zur, M., A. Marani, and R. Carmeli. 1970. Effect of CMH (N-dimethyl-N) (B-chloroethyl-hydrazonium chloride) as compared with that of CCC (2-chloroethyl trimethylammonium chloride) on height, earliness and yield of cotton. Isr. J. Agric. Res. 20:133–134.
21. ----, ----, and B. Karadavid. 1972. Effect of growth retardants CCC and CMH on cotton. Cotton Grow. Rev. 49:250–257.