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**Enhancement of Cotton Development and
Productivity by Means of Controlled
Root Growth**

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C. Abstract

The consequences of implementing a new drip irrigation concept on cotton physiology, growth and productivity were studied. The method was characterized by the build-up of a restricted root zone volume (RRZV) in an otherwise dry soil profile. Daily drip irrigations with small amounts of water which started soon after germination encouraged the plants to develop a shallow root system around the drippers with no root growth below 20-30 cm depth. An increase in irrigation and soil wetting promoted additional growth of roots in the RRZV rather than root penetration to deeper wetted layers. No correlation was found therefore between the wetted soil volume and that volume of the soil in which the roots developed. The proximity of the roots to the drippers and the limited reservoir of available water in the root zone created a high sensitivity and rapid response of the plants to minor changes in irrigation rates. Daily differences in irrigation of less than 1 mm H₂O which correspond to a total of 30-40 mm for the whole growth period considerably affected internode elongation, assimilate production, boll abscission and yield earliness and amount.

Three years of field experiments showed that the irrigation management of RRZV made it possible to obtain high cotton yields from very late sowing due to the acceleration in growth and reproductive processes and the continuation of boll growth late in the season. In double-cropping systems in which cotton was sown after wheat harvest, yields of 5000-6500

kg of seed cotton per hectare were achieved with a total irrigation amount of 420-450 mm H₂O. No additional pre-sowing saturating irrigation were needed. Fiber quality was not affected by the development of bolls late in the summer.

The usefulness of using different methods of determining irrigation amount and timing in the RRZV system was tested. Irrigation according to constants of pan A evaporation rates was inefficient and led to water deficits in critical growth periods. The use of leaf water potential measurements as a criterion for irrigation was practical since minor changes in the daily irrigation rates led to considerable changes in leaf water potential.

The effects of plant row and dripper line spacing on plant water status, growth and yield were investigated. An increase in yield resulted from the decrease of row spacing from 100 to 50 cm, especially under supra optimal irrigation amounts. With denser row spacing the negative effects of high irrigation rates on excessive vegetative growth and consequently yield decrease were decreased. The productive processes were also affected and acceleration of flowering and boll opening were caused by the increase in row density. The increase in dripper line density from one for two adjacent plant row to one line for each row accelerated the vegetative growth early in the growth period but did not significantly affect the yield. In supra optimal irrigation amounts the effect on yield was sometimes negative.

The research conducted in Arizona compared agronomical and physiological aspects of cotton grown in deep wetted root zone, as represented by furrow irrigated plants (FIP) and plants grown under

restricted root zone volume (RRZV) as was previously described. The FIP were irrigated only 14 days and the RRZV daily. The water use efficiency of the RRZV plots was considerably greater than that of the FIP and the water consumption of the RRZV was almost half that of the FIP for achieving similar yields. The RRZV plants succeeded in keeping a better plant water status than the FIP plants as indicated by leaf water potential measurements and stomatal conductance. The RRZV plants were less water stressed in spite of the fact that their irrigation amounts were smaller. The fluctuations in values of leaf water potential and stomatal conductance between subsequent irrigations was considerably greater in FIP treatments as compared to RRZV plants. The hydraulic conductance of the RRZV plants was significantly greater than that of the FIP plants. This reflects a better ability of water transport from the roots to the shoot. The results in both countries show that the RRZV management has the potential of increasing water use efficiency and productivity of cotton and achieving it by a significant saving of water.

D. Objectives

The following were the objectives of the research:

- 1) The development of a new drip irrigation agrotechnique with the aim of obtaining an efficient control of growth and consequently productivity.
- 2) An improvement of water use efficiency.
- 3) Achieving a shortening of cotton growth period as a precondition for the implementation of a double-cropping system cotton-wheat.
- 4) Studying the effects on cotton growth and productivity of using the daily drip irrigation management and RRZV in Arizona, as compared to the conventional furrow irrigation management.

Specific targets for study included:

- 1) The effects of irrigation amount on plant water status of RRZV plants.
- 2) The distribution of water in the soil profile under RRZV irrigation management and its effect on root growth and location.
- 3) The response of cotton with shallow and restricted root zone to prolonged interruption in irrigation.
- 4) The effects of plant row and dripper line spacing on cotton development and productivity.
- 5) The usefulness of measuring pan A evaporation or leaf water potential as criteria for determining irrigation amount in RRZV system.
- 6) The vegetative and reproductive development of a very late sowed cotton as a constituent of a double cropping system.

E. RESEARCH REPORT

Introduction

Cotton yield is strongly affected by assimilate partitioning between vegetative and reproductive organs. Under certain environmental conditions competition for assimilate between the bolls and the vegetative organs exists. An increase in dry materials production caused by a better fertigation management will improve yield only if a significant fraction of the added assimilate will be diverted to the bolls. Carmi (8) and Carmi and Shalhevet (11) reported that physical restriction of root zone volume restrained the vegetative growth and increased the proportional allocation of dry materials to the bolls. Under such conditions a compact plant developed, characterized by short internodes and high boll density on the shoot. Roots affect shoot growth and morphology due to their role as a source of growth substances, especially cytokinins (12,19,30). Root zone volume may determine root growth rate (11,21) and consequently shoot development. The regulation of vegetative growth may therefore be achieved by controlling root zone volume. Restraint of shoot growth which occurs in response to root growth restriction is not necessarily accompanied by a reduction in photosynthetic activity. Carmi et al. (9) reported on an enhancement of photosynthesis per unit leaf area in root restricted plants. Such plants have a high potential of assimilate production and limited ability to use these products for vegetative growth. In cotton, root growth restriction may promote yield earliness (11) which is a critical factor in double-cropping systems.

Application of water in the vicinity of the plants axis by means of a trickle irrigation system will affect the establishment of a root zone

volume whose sizes will be a function of the amount of water supply, evapotranspiration, and infiltration rate of the soil. If water is applied frequently at a rate similar to the evapotranspiration, a restricted wetted soil volume around the drippers may be kept. Due to the frequent fertigation, water tension in the restricted root zone may be kept low and nutrients availability will not be limiting. Consequently the plant will not develop a deep root system and both metabolic energy and dry materials needed for deep root growth will be saved. The above suggested irrigation method will minimize losses of water out of the root zone. Presowing irrigation which is common in Israel may be excluded from the routine irrigation management and save quantities of 80-150 mmH₂O (10). Another advantage of growing plants under RRZV conditions is that it gives a quick and efficient tool of controlling plant development. By a minor change in water supply a considerable effect on phenomena such as growth, senescence, abscission, etc. may be obtained. The buffering ability of the wetted zone is very limited in regard to irrigation rates since the amount of available water in the root zone is small. It is easy to change and reverse the water and nutrient status in the root zone and get the expected effects on the plants.

The implementation of double-cropping cotton and wheat for grains in Israel may significantly improve the farmer's income. It depends on the possibility postponing cotton sowing post-wheat harvest and get high yields in shorter growth period. As was stated previously the control of the RRZV water content may affect developmental processes which will contribute to the achievement of yield earliness and enable double cropping. Delay of

cotton sowing to warmer growth period will accelerate seedling development and may also contribute to the above-stated target.

RESEARCH IN ISRAEL

Materials and Methods

Cotton seeds (*Gossypium hirsutum* L. "Acala SJ-2") were planted in the southern region in Nir-am and Bror-Hail for three successive years following wheat which was harvested till mid-May. the cotton was sowed in the different years between the 20th May and the 6th June. the soil (Loess type) was pre-dried by the winter crop and no saturation irrigation was given. An irrigation of 30-50 mm was given in the process of soil tillage and another 20-30 mm applied by sprinklers for germination.

Plant stand was 100,000-130,000 per hectare, grown in row spacing of 50 or 100 cm. The trickle irrigation network consisted of drippers (capacity 1.4 liters per hour) in lines, 40 or 100 cm apart. The dripper line density was one per row or one per two adjacent rows. Trickle irrigation started 10-20 days after seedlings emergence. Nutrients were supplied continuously in the irrigation system. Evaporation measurements of Class A pan were routinely taken. Moisture content at depths of 0-80 cm was measured weekly during the growth period using a neutron probe. The measurement sites were located 10 cm away from the dripper towards the plant row, between plants in the row and in half the distance between two adjacent rows without a dripper line. Study of root distribution in the soil was done either by careful soil excavations and visual observation of the root distribution or by the isolation, cleanup and weighting of root from soil

samples taken in different locations. Leaf water potential was measured at midday using a Scholander pressure cell.

RESULTS AND DISCUSSION

1. The profile of soil wetting under the RRZV irrigation management

The present work hypothesized that the establishment of a soil humidity gradient in which the wetted soil will be limited to a small volume will encourage the development of a restricted root system. Such a soil moisture regime was to be achieved by the specific drip irrigation management characterized by daily irrigations with small amounts of water starting soon after germination on a dried soil profile (27). Irrigation amounts and management for the three years of experiments is shown in Tables 1 - 3. Measurements of soil water content are presented in Tables 4 and 5 and Figure 1. In the first year of the field experiments the irrigation management caused the accumulation of available water mostly in the 0-30 cm depth, throughout all the growth period (Table 4). The increase of daily irrigation amount led to wetting of deeper soil layers. In the lowest irrigation treatment (A total irrigation of 460 mm H_2O), significant amounts of available water were measured in the 30 - 60 cm soil layer, but almost none was measured below the 50 cm depth. In the highest irrigation treatment (A total irrigation of 550 mm H_2O), a considerable amount of available water was accumulated at least down to 80 cm depth. The much deeper wetting to the soil profile which characterized the higher irrigation treatment (Table 4) was caused by a moderate increase in the daily irrigation rate (see Table 1). Two main conclusions were drawn from these data: a) It is possible, by the specific daily drip

irrigation management, to limit the accumulation of available water to shallow depth of 0-30 cm. b) It is possible, by using the RRZV irrigation management to deepen the soil wetting by moderate addition in the daily irrigation amount. The ability to maintain, under daily irrigation, a very shallow soil wetting may contribute to a considerable increase in water use efficiency. Water saving will be achieved by eliminating the wetting below the root zone. On the other hand, the possibility of deepening the soil wetting by moderate additions of water enables farmers to increase the reservoir of water in the RRZV during sensitive growth stages and decrease the potential negative effects of unexpected difficulties in water supply.

In the third year, soil moisture measurements were taken inside the plant rows and 100 cm from each dripper line, in addition to the dripper zone. As is shown in Table 6, the horizontal spreading of the water is small and no significant amounts of available water were found in depths of 0-80 cm, within or between the plant rows without drippers. It can be concluded that the RRZV (Restricted Root Zone Volume) irrigation management not only restricts soil wetting to shallow depths but also prevents horizontal expansion away of water from the dripper location. These conditions of soil wetting will affect both the location of root growth and absorption of water as will be discussed in the following chapters.

2. Growth and location of roots

The shallow soil wetting which started soon after germination had a dramatic effect on root development and morphology. Careful soil excavations did show that the growth of the tap-root stopped at a depth of 20-40 cm. The tap-root changed growth direction toward the drippers or

stopped growing. Most of the additional root growth was carried out by shallow axillary roots in the direction of the drippers (Fig. 2). It is not known whether the root reorientation occurred in response to the drying of the soil profile in the vertical direction, or in response to the increase in soil wetting towards the drippers.

The data on root distribution in the soil are shown in Tables 7 - 9. In treatments which were irrigated with 414 or 538 mm H₂O (Table 7) more than 50% of the total root biomass was found in the depth of 0-20 cm and additional 40% in the subsequent 20 - 40 cm layer. One of the main working assumptions in the proposal was that irrigation amount will strongly affect the wetted soil volume and consequently the soil volume in which roots will grow (i.e. the root zone). The practical situation disproved this assumption. Increase in irrigation amount from a total of 414 to a total of 538 mm promoted a considerable increase in root biomass weight (Table 7) but didn't lead to the deepening of the root system. It was concluded that the expansion of the wetted soil zone either in response to excessive irrigation or in response to rainfall (in regions with summer rains) does not mean necessarily the elimination of the restricted root zone. The interpretation of these data was that under frequent wetting at the upper soil zone, roots will prefer growing in that zone irrespective of water availability in deeper layers. It seems that under the RRZV irrigation management the better soil aeration in the upper zone becomes the dominant factor in determining root growth location, on condition that water availability is not the limiting factor.

Root distribution in different locations in the field can be studied from Table 8. The root system grew mainly close to the drippers.

Throughout the growth period no significant quantity of root was found below the plant rows or 100 cm aside from the dripper line, to a depth of 80 cm. The measurements of water distribution in the soil of these plots (Table 6) indicate that the soil profile below the plant rows or 100 cm aside from the drippers was dry. This may explain the disappearance of roots from these zones. Measurements of root distribution in treatment in which each plant row has its own dripper line are shown in Table 9. The phenomenon of root concentrating in the vicinity of the drippers and at depth of 0-20 cm was observed again. It was concluded that under the RRZV irrigation management the spacing of the dripper line density did not significantly affect the distribution of roots in the soil, at least at late growth period. The possible advantage of a denser drip irrigation system as described earlier is therefore questionable.

Measurements of root separation to thin and thick fractions are shown in Table 10. In the layer of 0-20 cm and close to the drippers more than 80% of the root biomass (on weight basis) were thinner than 1 mm. It indicates that the RRZV system is characterized by a preferable development of thin roots on behalf of the tap-root and the thick roots which are much less efficient in absorption of water and nutrients. This may explain the potential of quick absorption of water as described in Section 3.

In view of the above-stated data it was concluded that the root zone which was established under the RRZV irrigation management is a shallow and a small one. Under other irrigation managements, such as furrow or sprinkler irrigations, the root systems are much deeper compared to the RRZV system and penetrate to soil layers below 150 cm (20, 32).

3) Water absorption by RRZV systems

The information which was presented in the former sections gave a description of the soil wetting on the one hand and the distribution of roots on the other hand. The absorption of water in specific soil zones is supposed to be determined by the integrated effect of soil humidity and root density. Measurements of changes in soil water content in different soil locations between two subsequent irrigations were conducted for studying these interrelationships. Such a measurement was done on the 28/18 in Treatment No. 3 (see Tables 3a,b), a period in which the daily irrigation was given in two equal shares. The data in Table 11 show that the main reduction in soil water content during the day was in the depth of 0-40 cm, close to the drippers. No significant absorption of water was detected either below the plant rows or 100 cm aside of the dripper line. The content of water in these zones was near or below the wilting point of the specific soil. The zones of water absorption are in full agreement with the data on root distribution, as presented in Table 8.

In the RRZV system a very quick plant response to the daily irrigations was characterized by detection of changes in leaf water potential (Table 12). A supply of 0.5 mm H_2O over a period of 15 minutes increased leaf water potential from -1.64 to -1.56 MPa. The leaf water potential values of plants whose daily irrigation was delayed were decreased during the 15 minutes period from -1.72 to -1.82 MPa. It was concluded that the reservoir of available water in the root zone of the RRZV plants was very limited. Consequently, a minor amount of less than 0.5 mm was sufficient to change the root zone humidity, the root water absorption and the plant water status. It indicates what a strong control

of plant water status can be achieved by small changes in root zone wetting and the effect may be quickly reversed. For affecting plant water status and leaf water potential under other irrigation methods much larger amounts of H_2O has to be added or reduced.

4) Plant responses to basic changes in the profile of soil wetting

As was stated in Section 2, the RRZV plants develop a shallow root system irrespective of water availability in deeper soil layers. It was asked whether the roots will succeed to grow quickly to deep layers and use the available water, under conditions in which the daily irrigations will be stopped unexpectedly. Such an interruption occurs either by a temporary shortage of irrigation water or by technical difficulties. If water is available in deep soil layers a temporary interruption in irrigation may force the plants to use that reservoir and consequently enable water saving by decreasing the irrigation amounts. If such a process occurs it will help to plan the irrigation management at the end of the growth period taking into consideration the use of water which was accumulated below the root zone. For studying this, plants were exposed to heavy irrigation which saturated the soil below the depth of 120 cm, followed either by irrigation termination or by a continuation in the routine daily irrigation management. The experiment was carried out after mid-August, a period in which the late sown cotton has the maximal irrigation consumption. Table 13 includes the changes in soil humidity gradient during a 3-week period, and the distribution of roots in the soil at the end of this period. It can be seen that the major reduction in soil humidity in the unirrigated treatment was in the 0-30 cm soil layer. In the depth of 30-60 cm a drying process

of the soil also did occur but in a much slower rate. The root measurements showed that roots didn't grow in the deeper and more humid layer of 30-60 cm in spite of the quick drying of the upper zone. It indicates that at least at the phenological stage which was studied (i.e. 82 days after sowing) the shallow root system is very slow in its ability to regrow and penetrate to deeper soil layers in response to dramatic changes in soil wetting. The decrease in water content in the 30-60 cm depth was attributed to movement of water in the soil towards the drying root zone. Since such process is slow as compared to the dynamic response of root regrowth, the plants suffer from water stress as will be described later. In the treatment in which irrigation continued as usual no roots were found in deep soil layers in spite of the considerable availability of water. These findings are in good agreement with the data presented in section 2 which indicated that under frequent wetting of the upper soil zone roots will avoid growing to the depth irrespective of the water content in the deeper layers. Measurements of leaf water potential are shown in Table 14. Six days after the irrigation was stopped the leaf water potential reached values of -1.82 MPa as compared to -1.46 in the irrigated control. No additional reduction in leaf water potential was observed in spite of the continuation of soil drying in the upper layers. The interpretation of these findings is that the plants succeeded to absorb water which arrived from deeper layers and partially compensated for the quick decrease in water availability in the shallow and restricted root zone.

5) Effects of temporary interruptions in irrigation on leaf water potential and yield

A major risk of using the RRZV management is the possible exposure of plants to severe water stress following an unexpected interruption of irrigation. Such a stress may lead to abscission of fruit bodies and young bolls (12,16,24,31), decrease in photosynthesis and assimilate production (19,20) and consequently, yield reduction (6,26). For the study of such effects an experiment in which irrigation was delayed for 48 h to 90-day-old plants was carried out. The treatments were formerly irrigated with three levels as presented in Table 1. The effects of 24 or 48h delay in irrigation on leaf water potential are presented in Table 15. The leaf water potential values of the lowest irrigated treatment decreased from -1.44 MPa to -2.42 MPa after the first 24h of irrigation delay, an effect which was caused by a reduction of only 5.7 mm in the water supply (i.e., the daily irrigation amount). The effect on the treatments of the higher irrigation amount was much less. It is understandable in the light of the differences in soil water content of the three treatments as shown in Table 4. After 48 h, stress effects were observed also in the highly irrigated treatments as expressed by their decrease in leaf water potential values. These findings demonstrate a very strong dependence of the RRZV plants on the daily supply of water. The daily amount of irrigation may play key role in controlling processes which are affected by plant water status. On the other hand such a system has a very limited buffering ability to effects of even a short period of irrigation interruption. The severe water stress of 72h after which irrigation was resumed led to a 20% reduction of yield in the low irrigated plots as shown

in Table 16, accompanied with yield earliness. Such effects were not observed in the highly irrigated treatments which showed moderate water stress symptoms. It is possible that elimination of the risk of water stress damage in critical growth stages may be achieved by a temporary increase of root zone water content.

6. The effects of irrigation amount on vegetative development

Cotton is a crop in which the vegetative growth rate plays an important role in determining yield. Excessive irrigation management may enhance vegetative growth to the detriment of reproductive development (15, 18). A reduction in yield can be due to a decreased allocation of assimilates to the reproductive organs. It was shown in the present work that irrigation management of restricted root zone volume (RRZV), gives a very efficient tool for controlling the vegetative growth rate, and thereby avoid the risk of excessive vegetative growth. Considerable effects on growth can be achieved by minor changes in irrigation amount and the effects can be easily reversed. The effects of irrigation amount on vegetative growth of cotton grown under the RRZV management are shown in Tables 17-20. A difference of 30-40 mm H_2O in the total irrigation amount strongly affected shoot growth as expressed by plant height and dry matter accumulation in leaves and stems. These effects were caused by differences of less than 1 mm H_2O in the daily irrigation. In addition to growth parameters leaf water potential was also considerably affected by these irrigation differences as will be presented later. Under the RRZV management a total difference in irrigation of 5-8 mm, which was established over a period of 10-12 days, is sufficient to change shoot

growth rate. Such effects on growth caused by such minimal changes in water supply can not be achieved by any other irrigation management of cotton.

7. The effects of irrigation amount on yield, earliness and fiber quality

Irrigation amount may affect three main reproductive processes which can determine yield amount and earliness: a) Abscission of squares, flowers and young bolls. b) Flowering rate and c) Boll maturation and opening. The effects of irrigation amount on flowering were studied in the first year and the results are shown in Table 21. In spite of the considerable effect of irrigation amount on growth (see Table 17) flowering amount was much less affected. In certain treatments an increase in irrigation enhanced flowering mainly between the low and mid-range levels but not up to the highest irrigation level. In all treatments the addition of irrigation amount increased the amount of boll abscission (Table 21). It increased from 48% abscission in the low irrigation level to 64% in the highest one. It was concluded that the lowest irrigation did not expose the plants to severe water stress which can promote boll abscission.

Yield earliness was significantly affected by irrigation amount (Table 22). Data on the length of the growth period from flowering till boll opening are presented in Table 23. Irrigation amount didn't affect the time needed for boll maturation and opening, either of the early or of the later flowering wave. It took about 60 days from flowering to boll opening. It was concluded therefore that the later harvest of the highly irrigated treatments resulted from a survival of late flowers and not from a slower rate of boll maturation.

Yield rate was strongly affected by irrigation as shown in Tables 16, 19, 22, 24. In the first year the restraintment of vegetative growth in the lowest irrigation treatment (see Table 17) was followed by a yield increase (Table 16). A high yield of 6230 kg/hectare as compared to 4920 kg/hectare was achieved by reducing irrigation rate from 550 to 460 mm H₂O. In the second year the decrease of irrigation from 521 to 463 mm decreased moderately the vegetative growth but significantly enhanced yield (Table 19). In the third year (Table 24) irrigation rate didn't significantly affect the yield. It was concluded that the decrease in yield resulting from high irrigation rates (above 500 mm) is connected to an enhanced vegetative growth and the effect of similar amounts of water supply may be considerably different in different years. The agrometeorological conditions may play a dominant role in determining the effect of irrigation on yield.

There has been different results about the effects of soil moisture stress on fiber quality. According to Brown and Ware (5) cotton grown under various moisture conditions can have different fiber properties. On the other hand, other works didn't find any effects of prolonged soil moisture stress (3, 23).

Effects of irrigation rates on fiber quality are shown in Tables 25, 26. Both fiber fineness (micronaire) and strength were worse quality in the high irrigation treatments. It was concluded that supra optimal vegetative growth (as a consequence of excessive irrigation) may negatively affect yield by decreasing yield amount, delaying maturation, and lowering fiber quality.

8. Effects of irrigation amount on leaf water potential

The change in leaf water potential is widely used as a criterion to characterize the effects of environmental conditions on plant water status. Measurements of leaf water potential in treatments which were irrigated with different amounts of water are shown in Tables 27,28. Considerable differences in leaf water potential between treatments of different irrigation amounts were detected during the growth period. Measurements at 70 days post-sowing (Table 27) showed that an addition of 0.5 mm in the daily irrigation amount (see Table 1) was sufficient to cause a large difference in leaf water potential between the two treatments. The range was between -2.06 MPa at the lowest irrigation treatment and -1.52 at the highest one.

The average evaporation rate according to class A pan (see Table 29) was 6.7 mm H₂O/day. The irrigation constants for the low and high irrigation treatments were 0.78 and 0.85 percent of Class A pan evaporation rates, respectively. Such amounts of irrigation under the conventional drip or sprinkler irrigation are not supposed to establish such differences in leaf water potential. It was concluded that under conditions of RRZV management plants are easily exposed to water stress in response to moderate reductions in irrigation amount, and it may be indicated by the values of their leaf water potential.

9. Criteria for the determination of irrigation management

Further advances in applying the RRZV system is dependent on the improvement of irrigation management which plays a major role in determining the commercial success or failure of the crop. Efficient

criteria for the determination of irrigation timing and amount are essential for intensive irrigation systems. It necessitates choosing reliable parameters which can be easily measured in the field. Two widely used methods of determining irrigation management in cotton were studied: a) Irrigation according to the average daily evaporation rates of Class A pan: b) Irrigation according to leaf water potential values. It was found that the use of Pan A evaporation constants (PAEC) which were optimal in the first year of the research resulted in insufficient irrigation in specific and crucial growth periods during the second year. The use of PAEC in a system of restricted root zone may be useful as an additional parameter in determining irrigation management but not an exclusive one.

Determination of irrigation management according to leaf water potential measurements (LWPM) was found to be an efficient method resulting in preferable growth responses when using the proposed irrigation agrotechnique. Moderate changes in the amount of the daily irrigations resulted in considerable changes in leaf water potential as can be seen from the data in Tables 27-28. The values of leaf water potential that were measured in the field were sometimes out of the planned ranges. A more precise determination of irrigation amounts will require more frequent LWPM than was carried out during the second year (5-6 day intervals). The possibility of carrying out daily, moderate and reversible changes in irrigation amounts create optimal conditions for using LWPM as the basis for irrigation management planning.

10. Effects of irrigation management on growth and yield

The effects of elongated and considerable changes in irrigation amount on growth and yield were studied. Two treatments were carried out. In the first one, plants were irrigated at a low amount for the first 88 days following germination, and then irrigation management was altered to a higher amount. In the second treatment the management was exactly the opposite. Detailed information on the irrigation management is presented in Table 2. The basic assumption was that a low irrigation level till the period of peak flowering will restrict the vegetative growth and prevent the negative results of excessive vegetative growth. A considerable increase in irrigation rate later on will not strongly affect vegetative growth but may decrease boll abscission, encourage boll growth and consequently increase yield. The data presented in Table 30 show that leaf water potential was strongly affected by the changes in the irrigation management. The treatment whose irrigation level was altered from low to high showed higher leaf water potential compared to the treatment which was continuously irrigated at the high level. The other treatment in which irrigation amounts were altered from high to low showed leaf water potential values smaller than those of treatments which were continuously irrigated at the low level (Table 30). These results can be explained by the fact that in each treatment which was irrigated after mid-August with the same amount of water, the plants were significantly different in their shoot size according to the irrigation management of the former period. The difference in shoot size and possibly different conductance of stomata could affect water consumption, shoot water status and consequently leaf water potential.

The increase in irrigation level after mid-August of the lowest irrigated treatment significantly increased yield amount (Table 19) in comparison to the treatment which continued to be irrigated at the low level. The addition in yield was from 436 to 524 kg/dunam while the additional amount of water was only 52 mm. The water use efficiency of the added amount of water was 1.76 kg seed cotton per m³ water which is very high. The other treatment whose water management was changed after mid-August from the high to the low level did not show significant acceleration of boll opening, but also did not respond with significant reduction of yield. It can be concluded in relay on the above-stated findings that a significant increase in irrigation amount late in the growth season may increase yield, while a reduction in irrigation level will not necessarily decrease yield. The responses depended on the former irrigation management. It was assumed that the present results were a consequence of a specific complex of soil water reservoir amount, plant stage of development and agro-meteorological factors in the period when the change in irrigation management took place.

11. The effects of plant row spacing on growth and yield

The rate of coverage of the soil by the foliage plays a major role in determining the potential of light absorption by the canopy, and consequently assimilate production. The acceleration of the soil coverage may be promoted either by the enhancement of shoot growth rate or by increasing plant stand and/or row density. In cotton, both enhanced vegetative growth, or overpopulated canopies, may lead to yield reduction. The mutual shading between adjacent plants reduces light penetration into

the foliage (1) and may result in a reduction of flowering rate and an increase in abscission of young bolls (28, 33). Yield may also be reduced as a result of preferential growth of the main stem over that of the fruiting branches (7, 13). The negative results of enhanced mutual shading in a dense canopy might be overcome by the development of smaller plants, which could be achieved genetically or by the use of growth regulators. However, Wynne et al. (34) concluded that a reduction in plant size in peanuts by genetic or chemical methods would not necessarily result in increased productivity with the use of higher plant populations. Carmi and Shalhevet (11) found that restricted growth resulting from growing cotton plants in a restricted root zone volume was accompanied by a considerable decrease in vegetative growth and an increase in the harvest index. The plants were compact with short internodes and high boll density. Such a morphology may be very useful under conditions of high plant density or dense plant row spacing. It has been previously shown that under the irrigation management of RRZV (10) compactization of plants may be achieved. A study was, therefore, undertaken to determine whether the integrated effect of growth restriction and dense plant row spacing may be profitable. Parameters of vegetative growth, boll maturation, fiber quality and plant water status were compared in treatments of the conventional 100 cm row spacing and a spacing of 50 cm. Plant density in both treatments was 10,000 plants per dunam. Measurements of plant height and internodes number are presented in Table 17. Treatments in which the dripper line spacing was 100 cm were characterized by a restriction of stem elongation for the plots with the denser plant row spacing. No significant

difference in internode number was observed and it was concluded that row spacing affected internode elongation and not their initiation rate.

The effects of row spacing and irrigation amount on the production of dry matter are presented in Table 18. No significant difference in dry matter accumulation per plant was found between the row spacing of 50 and 100 cm, irrespective of the irrigation level. These results are unexpected. It was assumed that the denser spacing would enable better light absorption and consequently greater assimilate production.

A considerable increase in the flowering amount was promoted by decreasing the row spacing from 100 to 50 cm. The effect was pronounced under different levels of irrigation (Table 21). Boll abscission was not affected by row spacing and it amounted to about 50% (Table 21).

The increase of plant row density caused a significant increase in yield, especially at the moderate and high irrigation levels (Table 22). Yields of 600 and 524 kg seed cotton per dunam were achieved in treatments of 50 cm row spacing as compared to 500 and 445 in the treatments of 100 cm spacing. A considerable acceleration of boll maturation and opening was obtained in the denser plant row treatment, especially under the low irrigation level (Table 22).

Measurements of leaf water potential (Table 27) indicate that under low irrigation level the increase in plant row density led to a decrease in leaf water potential. It was assumed that a denser plant row spacing enabled an enhanced transpiration rate and led to a greater water deficit in the leaves. Under the high irrigation level such a difference in leaf water potential was detailed in July but disappeared in August. It was

concluded that such differences do exist until the canopy foliage gets a full coverage of the field.

12. The effects of dripper line spacing on growth and yield

RRZV irrigation management is characterized by a shallow and restricted wetting of the soil. As can be observed from Table 6, most of the soil volume is almost dry during the growth period. Under such conditions the distance between the sites of water application (i.e., the drippers) and the plant location may determine the efficiency of water absorption by the plants. It may be especially important during the early growth period when the root system is still small and not close to the drippers. It was found that in the early growth stages a denser dripper system may promote enhanced vegetative growth without additional irrigation. A considerable enhancement of vegetative growth, as expressed by plant height and dry matter accumulation, was achieved by the increase in dripper line density from one per two adjacent rows to one per each row (Tables 17-18). The effect on growth was significant under the three irrigation levels which were examined. A different phenomenon was observed in plots of 50 cm plant row spacing. Under low irrigation level a dripper line spacing of 50 cm led to greater growth restriction as compared to a line spacing of 100 cm (Table 17). It was interpreted that over-optimal dripper density may increase the amount of water evaporation to such an extent that water stress occurs and the growth rate is affected. No significant increase in yield was obtained in response to the decrease of dripper line spacing from 200 to 100 cm (Table 22). In certain treatments even a slight decrease of yield did occur. It was assumed that under high

irrigation levels a denser dripper system may promote excessive vegetative growth which would be followed by yield reduction.

13. Reproductive processes of late sowed cotton

A major objective of the present study was to develop a double-cropping system cotton-wheat in which cotton will be sown after wheat harvest. This means a delay of 30-50 days in cotton sowing as compared to the conventional sowing period for mono-cropping. A considerable fraction of the bolls of such a late sown crop is supposed to grow and mature during the end of the summer and the beginning of autumn. The colder day and night temperatures during this period may slow boll growth and maturation and reduce the production and allocation of assimilate to the bolls. The effect of the climatic conditions on reproductive development is therefore critical. The growth period of cotton in a double-cropping system is short as a result of the late sowing period. The possibility of getting yield from late flowers is, therefore, highly important. It was found that in late sown cotton, high numbers of young bolls were measured at the end of August (Table 31). The amount ranged from approximately 30 to 65 bolls per m^2 . A considerable fraction of these bolls matured and opened till the end of October (Table 32). It is concluded that the overall agrotechnique during September has to be continued to establish growth conditions which will enable normal development of this fraction of young bolls. The amount of young bolls as measured at the end of August was greater in treatments which were highly irrigated, in comparison to the rest (Table 31). Since the percentage of boll abscission from the late periods of flowering was greater

in the highly irrigated treatments (Table 32) it may be concluded that their greater number resulted from greater late flowering. Measurements of boll survival showed that 45 to 50% of the overall flowers which flowered from the end of July till the end of August set fruits which were harvested. The differences in irrigation level did not affect the percentage of abscission as seen in Table 32. A low amount of irrigation does not necessarily increase abscission. The percentage of boll abscission was affected by the flowering period. Approximately 80% of the flowers which opened between 26.7 to 2.8 set fruits which survived to harvest (Table 32). From flowering of the 3.8 to 17.8 period, only 30% to 40% of the flower produced harvested bolls. Later on in August the survival percentage increased again. These results indicate once again the necessity of using a water management regime which will take into consideration the curve of bolls survived and their period of development.

Data on the length of the growth period from flowering till boll opening are presented in Table 23. In all treatments it took about 60 days till boll opening, irrespective of the flowering date. The maturation of the late bolls was not slowed in spite of the fact that their main growth period was September, a month in which the day length was shortened and the temperatures were lower in comparison to the conditions in August, a month in which the former wave of bolls developed. The increase in irrigation amount rate did not delay boll maturation and opening of either the early or the late flowering wave (Table 23). It was concluded, therefore, that the delay in harvest date of the treatments which were highly irrigated, resulted from a development and survival of late flowers and not from a slower maturation of the bolls.

A selective harvest of bolls which were marked according to their flowering period made it possible to study the relative contribution of different flowering periods to the overall yield in the different treatments. It was found that the flowering wave which set fruits between 19.7 to 10.8 contributes 72% to 80% of the overall yield, while that which flowered between 10.8 to 23.8 contributed 20% to 28% (Table 33). The changes in irrigation level did not significantly affect the relative contribution to the overall yield of different flowering periods (Table 34). This result was unexpected since it was assumed that in the highly irrigated treatments, the relative contribution of the late bolls would be increased.

The irrigation amounts significantly affected the specific boll growth on specific internodes. The seed cotton weight of bolls that grew on internodes 5-8 was similar in all treatments and was about 5.8 gm per boll (Table 34). The average weight of seed cotton in bolls on internodes 9-14 was 6.3 gm in treatments of low irrigation rate in comparison to 5.3-5.7 gm in the highly irrigated treatments. On internodes 15-17, which developed later, the weight of seed cotton in bolls of low irrigated cotton was significantly smaller than that in highly irrigated plants. The distribution of open bolls on the plant internodes was also affected by the irrigation management. The percent of open bolls on the lower internodes (5-11) was considerably higher in low irrigated treatments than in the highly irrigated ones (Table 34). The fractions of open bolls on internodes 5-11 was 55/5-63% of the total boll population. Internodes younger than the 16th one didn't contribute open bolls to the yield, in all treatments. It seems that the continuation of vegetative growth in late

sown cotton after the development of 17-18 internodes is unnecessary and should be prevented by appropriate agrotechniques.

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Tables and Figures

Table 1: Average daily amounts of water supplied by drip irrigation, and overall* amounts of irrigation. Cotton was sown on 6th June.

Period	Average daily irrigation (mm)		
	a	b	c
23/6 - 29/6	2.6	2.6	2.6
30/6 - 5/7	2.9	2.9	2.9
6/7 - 12/7	3.8	3.8	3.8
13/7 - 19/7	4.0	4.7	5.2
20/7 - 26/7	4.2	4.9	5.9
27/7 - 3/8	4.2	4.9	5.9
4/8 - 10/8	4.8	5.5	6.2
11/8 - 17/8	5.2	5.7	6.3
18/8 - 24/8	5.7	6.6	7.3
25/8 - 31/8	5.7	6.6	7.3
1/9 - 6/9	5.5	6.0	6.5
7/9 - 13/9	5.0	5.6	5.6
14/9 - 21/9	3.4	4.0	4.0
22/9 - 28/9	2.0	2.0	2.0
Overall amount (mm)	460	511	550

* Including tillage and germination irrigations.

Table 2(a): Average daily amounts of water supplied by drip irrigation and overall* amounts of irrigation including tillage and germination. Cotton was sown on 19th May.

Period	Average daily irrigation (mm) to treatment no. **								
	1	2	3	4	5	6	7	8	9
18/6-24/6	4.35	4.35	4.35	4.35	4.35	4.35	4.35	4.35	4.35
25/6- 1/7	2.14	2.14	2.14	2.14	2.14	2.14	2.14	2.14	2.14
2/7- 8/7	2.25	2.60	2.25	2.60	2.00	2.34	2.68	2.00	2.68
9/7-15/7	2.94	3.42	2.94	3.42	2.12	2.65	3.14	2.12	3.14
16/7-22/7	3.78	4.42	3.78	4.42	2.60	3.51	4.11	2.60	4.11
23/7-29/7	4.77	5.51	4.77	5.51	3.72	4.92	5.91	3.72	5.91
30/7- 5/8	5.82	6.62	5.82	6.62	4.91	6.42	7.02	4.91	7.02
6/8-12/8	6.00	6.80	6.00	6.80	5.70	6.40	7.20	5.70	7.20
13/8-19/8	6.00	6.80	6.00	6.80	5.37	6.71	7.02	5.88	6.51
20/8-26/8	4.90	5.80	4.90	5.80	4.60	6.17	6.71	6.71	4.60
27/8- 2/9	3.48	4.42	3.48	4.42	3.28	4.28	4.88	4.88	3.28
3/9- 9/9	2.97	3.54	2.97	3.54	2.65	3.14	3.62	3.62	2.65
10/9-16/9	2.80	3.20	2.80	3.20	2.40	2.80	3.20	3.20	2.40
17/9-23/9	2.00	2.80	2.00	2.80	1.50	2.20	2.60	2.60	1.50
24/9-25/9	0.00	1.50	0.00	1.50	0.00	1.20	1.60	1.60	0.00
Overall amount (mm)	463	521	463	521	414	492	538	466	486

* Including tillage and germination irrigations.

** Description of the treatments is presented in Table 2(b).

Table 2(b): Description of the treatments whose irrigation management is presented in Table 2a.

Treatment No.	Distance between adjacent dripper lines (m)	Irrigation level*	Criterion for determining irrigation management
1	1	low	Constant of pan evaporation measurement
2	"	high	"
3	2	low	"
4	2	high	"
5	2	low	Leaf water potential measurements
6	2	moderate	"
7	2	high	"
8	2	till the 17.8 low and later on high	"
9	2	till the 17.8 high and later on low	"

* The irrigation rates of treatments 1 to 4 are different from those of treatments 5 to 9.

Table 3(a): Average daily amounts of water supplied by drip irrigation and overall* amounts of irrigation. Cotton was sown on 28th May.

Period	Average daily irrigation (mm) to treatment**						
	1	2	3	4	5	6	7
6/6-12/6	2.34	1.99	1.99	1.99	1.99	1.99	1.99
13/9-19/6	2.34	2.34	2.34	2.34	2.34	2.34	2.34
20/6-26/6	2.34	2.34	2.52	2.34	2.34	2.34	2.34
27/6- 3/7	2.25	0.95	1.05	0.95	0.95	0.95	0.95
4/7-10/7	2.52	1.60	1.76	1.60	1.60	1.60	1.60
11/7-17/7	2.79	2.52	2.83	2.52	2.52	2.52	2.52
18/7-24/7	3.06	3.12	3.48	3.12	3.12	3.12	3.12
25/7-31/7	3.57	7.88	4.50	3.88	3.88	3.88	3.88
1/8-7/8	4.11	4.55	5.13	4.55	4.55	5.13	4.55
8/8-14/8	4.91	5.10	5.47	5.10	5.10	5.47	5.10
15/8-21/8	5.62	4.91	5.33	4.91	4.91	5.33	4.91
22/8-28/8	5.44	4.51	4.91	4.51	4.51	4.91	4.51
29/8- 4/9	4.73	3.97	4.50	3.97	3.97	4.50	4.50
5/9-11/9	4.02	3.57	3.88	3.57	3.57	3.88	3.88
12/9-18/9	3.75	3.12	3.44	3.12	3.12	3.44	3.44
19/9-25/9	2.32	1.80	2.00	1.80	1.80	2.00	2.00
Overall	446.7	416.9	445.1	416.9	416.9	434.3	423.1

* Including tillage and germination irrigations.

** Description of the treatments is presented in Table 3b.

Table 3b: Description of the treatments whose irrigation management is presented in Table 3a.

Treatment No.	Distance between adjacent dripper lines (m)	Irrigation level	Criterion for determining irrigation management
1	2	-	* *
2	2	low	leaf water potential
3	2	moderate	"
4	1	low	identical to treatment no. 2
5	1*	low	" "
6	2	till the 31/7 low and later on high	identical to treatment no. 2 or 3 according to the growth period
7	2	till the 31/7 high and later on low	" "

* The distance between subsequent drippers was 50 cm in treatment no. 5 and 100 cm in all the rest.

* * The irrigation management was determined in advance according to optimal treatments in previous years. No changes were done in an adjustment to the environmental conditions.

Table 4: ^{*} Content of available water in the soil profile as calculated from neutron probe measurements. Plants were irrigated with overall amounts of 460(a), 510(b) and 550(c) mm H₂O. Irrigation was carried out as presented in Table 1. Cotton was sown on 6th June.

Irrig. rate	Distance between plant dripper rows lines (cm) (cm)		Depth of soil layer (cm)											
			0 - 30				30 - 60				50 - 80			
			21.7	8.8	31.8	21.9	21.7	8.8	31.8	21.9	21.7	8.8	31.8	21.9
a	100	100	36	23	39	37	20	1	14	27	0	0	0	15
a	100	200	27	44	61	72	21	13	29	56	4	0	4	20
a	50	50	39	15	32	47	15	5	14	32	2	0	5	8
a	50	100	36	23	39	37	20	1	14	27	0	0	0	15
b	100	100	38	39	63	48	20	21	41	38	21	8	34	27
b	100	200	58	35	77	80	32	6	44	64	21	0	29	32
b	50	50	54	38	52	49	15	7	38	44	1	0	7	5
b	50	100	39	39	63	48	20	21	41	38	21	8	34	27
c	100	100	71	63	69	55	62	38	59	54	36	23	48	37
c	100	200	44	61	44	65	38	26	36	44	26	15	26	20
c	50	50	57	47	57	74	26	8	50	60	21	0	14	32
c	50	100	71	63	69	55	62	38	59	54	36	23	48	37

* Available water was calculated on the basis of range humidity between wilting point and field capacity.

Table 5: Soil water content (in % of dry weight) in the soil profile as calculated from neutron probe measurements. Cotton was sown on 28th May.

Treatment * No.	Depth of soil layer (cm)																													
	0-30										30-60										50-80									
	24/6	1/7	8/8	14/7	23/7	29/7	4/8	13/8	19/8	25/8	24/6	1/7	8/7	14/7	23/7	29/7	4/8	13/8	19/8	25/8	24/6	1/7	8/7	14/7	23/7	29/7	4/8	13/8	19/8	25/8
1	22.3	21.9	18.9	15.4	14.3	14.0	13.6	14.1	15.5	18.0	21.6	21.4	19.6	16.7	14.5	14.0	14.0	13.6	14.7	15.4	15.8	15.8	15.5	14.5	12.1	11.5	11.4	12.5	11.3	11.8
2	23.0	21.7	14.5	13.5	12.7	13.4	13.0	17.0	13.5	12.5	22.6	21.8	18.1	15.9	14.4	14.6	14.3	14.4	14.0	13.9	16.3	15.8	14.9	14.3	12.5	12.3	12.2	10.4	11.9	10.8
3	21.0	20.0	14.8	13.7	13.0	13.0	13.1	16.7	15.5	13.4	21.1	20.9	17.8	15.1	13.6	13.4	13.1	15.3	15.3	13.6	16.2	16.5	16.6	15.5	13.5	12.7	12.6	9.9	12.6	13.0
4	24.1	23.6	18.5	17.0	15.6	15.8	15.8	17.0	16.0	16.1	23.2	22.7	20.4	17.5	15.0	15.1	14.8	14.2	14.8	15.2	15.6	15.0	14.2	13.7	10.8	10.4	9.8	11.2	11.5	9.6
5	23.5	23.5	19.2	17.9	16.9	16.8	16.4	22.0	22.0	19.9	22.7	22.3	20.0	18.2	16.3	15.7	15.7	17.0	18.2	16.0	15.4	15.2	14.7	13.9	12.3	11.5	11.0	12.6	11.6	10.7
6	22.2	20.1	15.1	14.2	13.7	15.6	14.4	17.0	15.7	15.7	22.0	21.2	18.1	15.5	14.2	14.2	13.9	15.5	14.1	14.3	14.6	14.3	13.6	12.7	11.3	10.6	10.3	12.0	9.7	10.6
7	22.9	21.2	16.8	15.7	-	16.9	15.7	22.7	22.3	15.6	21.8	21.0	18.4	16.1	-	14.6	14.4	20.0	21.8	13.8	14.9	13.8	13.2	12.2	-	10.3	9.7	14.4	14.7	9.3

* Description of the treatments is presented in Tables 3a,b.

Wilting point = 11%. Field capacity = 24%.

Table 6: Content of water in the soil profile throughout the growth period as calculated from gravimetric measurements.

Location	Soil layer depth (cm)	Soil water content (%) at:			
		23/7	28/8	10/9	26/9
Adjacent to the dripper	0 - 20	22.5 $\pm$ 0.4	19.8 $\pm$ 0.6	20.0 $\pm$ 0.4	18.8 $\pm$ 0.3
	20 - 40	19.6 $\pm$ 0.5	16.1 $\pm$ 0.5	16.0 $\pm$ 0.3	14.8 $\pm$ 0.5
	40 - 60	18.0 $\pm$ 0.3	13.6 $\pm$ 0.2	16.0 $\pm$ 0.4	15.5 $\pm$ 0.3
Below the plant row	0 - 20	13.1 $\pm$ 0.9	10.7 $\pm$ 0.4	Dry**	Dry**
	20 - 40	15.5 $\pm$ 0.6	12.0 $\pm$ 0.3	"	"
	40 - 60	16.6 $\pm$ 0.4	12.3 $\pm$ 0.5	"	"
100 cm aside of the dripper line	0 - 20	11.4 $\pm$ 0.5	9.2 $\pm$ 0.2	Dry**	Dry**
	20 - 40	13.6 $\pm$ 0.4	12.0 $\pm$ 0.3	"	"
	40 - 60	16.3 $\pm$ 0.4	12.2 $\pm$ 0.5	"	"

The measurements were done in treatment no. 3 (see Tables 3a,b).

Field capacity and wilting point are around 25% and 13% water content, respectively.

** Below the wilting point.

Table 7: The distribution of the roots in the soil profile as affected by irrigation amount. Roots from different soil depths were sampled on 25th August.

Total irrigation (mm)	Root dry matter weight in depth of 0 - 60 cm (gr)	Root fraction (in percent of total) located in depth of:		
		0-20	20-40	40-60
		cm	cm	cm
414	8.1	52.5	40.6	6.9
538	18.0	49.0	44.1	6.3

* The root dry matter includes the fractions that were separately isolated from the three soil depths.

Irrigation amounts and soil moisture content are presented in Table 2a and Fig. 1.

Table 8: The changes in root distribution in the soil profile throughout the growth period.

Location	Soil layer depth (cm)	Root* density (gr dry matter/1000 ml soil) at:	
		23/7	10/9
Adjacent to the dripper	0 - 20	0.212 $\pm$ 0.020	0.337 $\pm$ 0.050
	20 - 40	0.039 $\pm$ 0.007	0.212 $\pm$ 0.020
	40 - 60	0.007 $\pm$ 0.001	0.081 $\pm$ 0.010
Below the plant row	0 - 20	0.081 $\pm$ 0.005	None
	20 - 40	0.026 $\pm$ 0.001	"
	40 - 60	0.094 $\pm$ 0.002	"
100 cm aside of the dripper line	0 - 20	0.112 $\pm$ 0.010	None
	20 - 40	0.032 $\pm$ 0.006	"
	40 - 60	0.005 $\pm$ 0.001	"

* Only roots less than 1 mm diameter were analyzed. Roots were sampled in treatment no. 3 (see Tables 3a,b, and Table 6).

Table 9: The distribution of roots in the soil profile in treatments in which dripper line density was 1 m.

Location	Soil layer depth (cm)	Root density (g dry matter / 1000 ml soil) at:	
		23/7	15/9
Adjacent to the dripper	0 - 20	0.143 ± 0.014	0.243 ± 0.025
	20 - 40	0.012 ± 0.001	0.040 ± 0.006
	40 - 60	0.003 ± 0.001	0.012 ± 0.004
50 cm aside of the dripper line	0 - 20	0.077 ± 0.011	0.095 ± 0.005
	20 - 40	0.019 ± 0.008	0.026 ± 0.004
	40 - 60	0.005 ± 0.001	0.010 ± 0.002

Only roots of less than 1 mm diameter were sampled. Roots were sampled in treatment no. 5 (see Tables 3a,b; 6).

Table 10: The quantitative ratio between thin (less than 1 mm diameter) and thicker roots in different depths. Measurements were carried out on 15/9.

Location	Soil layer depth (cm)	Dry matter ratio of thin to thick roots
Adjacent to the dripper	0 - 20	7.5
	20 - 40	2.1
	40 - 60	0.3
50 cm aside from the dripper line	0 - 20	1.1
	20 - 40	0.6
	40 - 60	0.8

The analysis was done on the same treatment presented in Table 9.

Table 11: Changes in soil moisture between subsequent irrigations.*
Measurements were carried out on August 28th.

Location	Soil layer depth (cm)	Soil content (%) at:	
		08:00 h	16:00 h
Adjacent to the dripper	0 - 20	19.2	15.6
	20 - 40	16.0	14.0
	40 - 60	13.6	14.4
	60 - 80	13.3	13.7
Below the plant row	0 - 20	10.6	10.5
	20 - 40	12.0	12.3
	40 - 60	12.3	12.3
	60 - 80	12.4	12.6
100 cm aside from the dripper line	0 - 20	10.6	10.5
	20 - 40	12.0	12.3
	40 - 60	12.6	12.7
	60 - 80	13.0	12.5
Adjacent to the dripper in control** row	0 - 20	20.5	18.9
	20 - 40	17.4	17.0
	40 - 60	16.2	16.6
	60 - 80	15.0	15.2

* The daily amount of irrigation was supplied in two pulses at 04:00 and 16:00 h.

** In the control row the shoots were excised and the soil was covered with plastic surface to prevent evaproation. Measurements were done in treatment 3 (see Tables 3a,b).

Table 12: Changes in leaf water potential following the daily irrigation. Measurements were carried out on 31st July. The second daily irrigation pulse started at 14:00 h.

Leaf water potential (MPa)			
Time	Cumulative amount of irrigation (mm)	Irrigated	Nonirrigated
14:00	-	-1.64 $\pm$ 0.05	-1.72 $\pm$ 0.07
14:15	0.5	-1.56 $\pm$ 0.04	-1.82 $\pm$ 0.03
14:20	1.0	-1.32 $\pm$ 0.05	-1.83 $\pm$ 0.08
14:35	1.5	-1.34 $\pm$ 0.07	-1.84 $\pm$ 0.04

The dripper line spacing was 100 cm (one line per plant row).

The nonirrigated plants did not get the second daily irrigation pulse on just this specific date.

Table 13: The integrated effect of deep soil wetting and irrigation interruption on soil moisture profile and root development.

Treatment*	Soil layer depth (cm)	Soil moisture content (%) at:			Root**density (gr dry matter /1000 ml soil)
		21/8	28/8	10/9	
Irrigation stopped	0-30	21.4 $\pm$ 0.2	16.4 $\pm$ 0.4	14.3 $\pm$ 0.4	0.108 $\pm$ 0.010
	30-60	21.1 $\pm$ 0.4	18.4 $\pm$ 0.4	16.7 $\pm$ 0.7	0.004 $\pm$ 0.001
Irrigation continued	0-30	23.2 $\pm$ 0.7	21.7 $\pm$ 0.5	20.0 $\pm$ 0.5	0.430 $\pm$ 0.020
	30-60	22.3 $\pm$ 0.6	21.8 $\pm$ 0.6	20.5 $\pm$ 0.4	0.033 $\pm$ 0.016

* The experiment was carried out in treatment 3 (see Tabs. 3a, b).

** Roots of less than 1 mm diameter.

In the 20/8 the soil was irrigated to the depth by additional irrigation of 80mm, following by either stop or continued irrigation.

The wilting point of the local soil is soil moisture content of around 13%.

Table 14: The integrated effect of deep soil wetting and irrigation interruption on leaf water potential

Treatment*	Leaf water potential (ψ_a)				
	Number of days following irrigation stop				
	2	4	6	8	14
Irrigation stopping	-1.6 $\pm$ 0.02	-1.6 $\pm$ 0.05	-1.82 $\pm$ 0.03	-1.81 $\pm$ 0.03	-1.94 $\pm$ 0.04
Irrigation continued	-1.4 $\pm$ 0.01	-1.31 $\pm$ 0.06	-1.46 $\pm$ 0.03	-1. 50 $\pm$ 0.02	-1.49 $\pm$ 0.04

*See Table 13.

Table 15: Effect of irrigation interruption to 24 or 48h on water potential in leaves of plants grown in plant row and dripper line spacing of 100 cm. Irrigation interruption started 80 days after sowing, on August 23rd.

Irrigation* amount (mm)	Treatment	Water potential in blades (MPa)	
		After 24h	After 48h
460	Control	-1.41±0.04	-1.40±0.05
510	"	-1.36±0.03	-1.29±0.05
550	"	-1.37±0.05	-1.32±0.04
460	Irrigation stopped	-2.42±0.19	-2.23±0.04
510	"	-1.67±0.08	-1.84±0.05
550	"	-1.67±0.13	-1.80±0.04

* Irrigation management is presented in Table 1.

Table 16. Effects of irrigation interruption to 72h on yield and earliness.

Plants were grown in plant row and dripper line spacing of 100 cm. Irrigation interruption started 80 days after sowing, on August, 23rd.

Irrigation amount (mm)	Treatment	Seed cotton yield (kg/dunam)	<u>Cumulative yield (in % of the total yield)</u>			
			19/10	26/10	2/11	8/11
460	Control	617 17	52	76	88	98
510	"	550 29	39	63	82	92
550	"	445 24	35	55	84	93
460	Irrigation stopped	513 22	62	80	94	99
510	"	468 28	44	65	80	93
550	"	480 42	34	52	82	90

Table 17: Effects of irrigation rate, plant rows spacing and dripper density on vegetative growth. Plants were irrigated with 460(a), 510 (b) or 550(c) mm H₂O. Cotton was sown on June 6th.

Irrigation rate	Distance between plant rows (cm)	Distance between dripper lines (cm)	6.7*		14.8		14.9	
			Average plant height (cm)	Average number of plant internodes	Average plant height	Average number of plant internodes	Average plant height (cm)	Average number of plant internodes
a	50	50	21.4±0.7	6.8±0.2	84.0±1.8	14.5±0.1	91.9±3.8	17.1±0.4
a	50	100	22.3±0.8	7.0±0.0	95.0±2.0	15.0±2.0	112.1±4.2	17.6±0.7
a	100	100	21.7±0.2	6.8±0.2	109.5±2.0	15.8±0.5	128.7±9.2	18.7±0.8
a	100	200	22.7±0.5	6.8±0.2	94.1±2.8	14.5±0.4	105.0±4.5	17.5±1.0
b	50	50			110.5±5.0	16.7±1.0	130.3±6.2	19.7±0.4
b	50	100			106.6±1.9	15.5±0.5	124.6±5.5	19.6±0.5
b	100	100			119.6±1.7	15.5±0.4	135.4±7.8	19.9±1.1
b	100	200			100.5±1.8	14.5±0.6	130.3±3.8	19.7±0.9
c	50	50			118.3±1.9	16.8±0.4	154.1±9.2	22.3±0.5
c	50	100			108.3±2.1	15.8±0.5	135.5±4.5	20.7±0.6
c	100	100			132.3±2.9	17.1±0.4	166.7±5.3	21.1±0.4
c	100	200			124.9±5.8	17.0±0.6	158.7±2.8	20.7±1.5

* Until July 6th all treatments received the same quantity of water

Table 18. Effects of irrigation amount, plant row spacing and drippers density on dry material accumulation in plant shoot. Plants were sampled 95 days after sowing.

Irrigation rate (mm)	Distance between plant rows (cm)	Distance between dripper lines (cm)	Average dry matter weight per plant (gr.)		
			stems and petioles	blades	Total
460	50	50	29.0	24.9	53.9
"	50	100	42.4	30.8	73.2
"	100	100	40.5	36.6	77.1
"	100	200	40.6	35.4	76.0
510	50	50	55.3	34.5	89.8
"	50	100	56.7	42.5	99.2
"	100	100	58.0	45.0	103.0
	100	200	58.1	44.5	102.6
550	50	50	67.2	40.9	108.1
"	50	100	65.0	39.2	104.2
"	100	100	74.0	46.5	120.5
"	100	200	68.2	50.1	118.3

* Irrigation management is presented in Table 1.

Table 19. Effects of irrigation amount, management, and dripper line density on cotton growth and yield.

Treatment* No.	Overall irrig. (mm)	Distance between dripper lines (m)	Criterion to determine irrigation	Average** plant height (cm)	Seed cotton yield (kg/dunam)
1	463	1	Constants of Pan A evaporation rates	105	509
2	521	1	"	111	517
3	463	2	"	104	444
4	521	2	"	117	452
5	414	2	leaf water potential values	95	436
6	492	2	"	106	522
7	538	2	"	113	534
8	466	2	"	100	524
9	486	2	"	103	519

* Description of the treatments is presented in Tables 2a,b.

**Plant height was measured on the 2/11.

Table 20: Effects of irrigation amount on the vegetative and reproductive development. Plants were sampled 85 d post-sowing.

Treatment*	Shoot height (cm)	Internodes number per plant	Foliage dry matter (gr/m ²)	Stem + petioles dry matter (gr/m ²)	Number of organs per m ²			Bolls dry matter (gr/m ²)
					Fruit bodies	Flowers	Small bolls**	
2	95.9±7.6	16.7±2.0	186.0±13.0	277.2±19.4	98.0±7.8	17.3±2.4	39.3±4.3	48.6±3.8
3	108.7±6.3	18.4±1.7	247.9±20.8	318.7±13.0	109.2±22.4	15.5±2.1	51.5±4.3	53.2±4.2
6	104.0±5.4	17.7±2.0	208.2±16.6	332.0±30.0	71.7±10.1	17.5±3.1	45.7±5.5	64.5±6.3
								181.0±26.2

* Treatments no. 2, 3 and 6 represent irrigation management of low, moderate and change from low to high in the late growth stage, respectively, as described in Tables 2a, b.

** Bolls shorter than 20 mm.

Table 21. Effects of irrigation amount, plant row spacing and dripper density on flowering, and boll abscission.

Irrigation [*] amount (mm)	Distance between Plant rows (cm)	Distance between dripper lines (cm)	Flowering amount (flowers/m ²)	Boll abscission (%)
460	50	50	200	51
"	50	100	188	46
"	100	100	154	41
"	100	200	183	51
510	50	50	250	60
"	50	100	243	54
"	100	100	206	56
"	100	200	143	37
550	50	50	215	67
"	50	100	230	63
"	100	100	189	65
"	100	200	150	59

* Irrigation management is described in Table 1.

Table 22: Effects of irrigation amount, plant row spacing and drippers density on yield amount and earliness. Cotton sown on 6th June.

Distance between plant rows (cm)	Distance between dripper lines (cm)	Irrigation * amount (mm)	Seed cotton yield (kg/dunam)	Cumulative yield (in % of the total yield)			
				19.10	26.10	2.11	8.11
50	50	460	662±10	72	84	93	99
50	100	"	624±22	62	81	91	97
100	100	"	617±17	52	76	88	98
100	200	"	623±18	56	76	91	98
50	50	510	531±20	39	62	81	94
50	100	"	601±40	44	60	84	96
100	100	"	505±29	39	63	82	93
100	200	"	556±32	46	68	82	92
50	20	550	565±5	40	64	82	94
50	100	"	524±23	37	60	83	96
100	100	"	445±24	35	55	84	93
100	200	"	492±28	39	62	76	92

* Irrigation management is presented in Table 1.

Table 23: Effects of irrigation rate and the period of flowering on the timing of boll opening. Plants were irrigated with overall amount of 414 (a), 492 (b) and 538 (c) mm H₂O.

Treatment* No.	Irrig. level	Flowering period	Cumulative percentage of bolls which were opened up to:							
			16/9	20/9	23/9	25/9	3/10	8/10	15/10	21/10
5	a	19/7-29/7	29.1	74.8	90.9	97.6	100	-	-	-
6	b	"	35.7	72.3	89.5	97.5	100	-	-	-
7	c	"	18.0	53.9	83.2	92.4	100	-	-	-
5	a	26/7-2/8	-	0.6	10.9	20.6	97.0	100	-	-
6	b	"	-	1.1	12.4	31.0	95.1	100	-	-
7	c	"	-	1.4	15.9	36.3	94.8	100	-	-
5	a	3/8-9/8	-	-	-	-	50.5	86.8	100	-
6	b	"	-	-	-	-	63.6	73.3	100	-
7	c	"	-	-	-	-	22.3	90.0	100	-
5	a	10/8-16/8	-	-	-	-	-	36.4	80.5	100
6	b	"	-	-	-	-	-	28.9	86.7	100
7	c	"	-	-	-	-	-	9.2	85.1	100
5	a	17/8-23/8	-	-	-	-	-	-	32.0	96.8
6	b	"	-	-	-	-	-	5.2	33.7	100
7	c	"	-	-	-	-	-	4.0	46.0	96.7

* Irrigation management is presented in Tables 2a, b.

Table 24. The effects of irrigation management on yield amount and maturation. Cotton was sowed on May 27.

Treatment*	Cumulative Seed Cotton				Total seed cotton yield	
	<u>yield (kg/dunam)</u>				(kg/Dunam)	
	2/10		22/10			
1	376.9	16.2	133.9	8.9	518	11
2	321.6	16.7	177.0	17.2	479	16
3	314.8	18.8	157	8.7	458	24
4	373.6	29.2	134.7	13.7	506	6
5	323.8	20.0	177.4	22.5	489	9
6	330.7	28.3	183.1	18.8	475	21
7	294.8	26.9	153.1	11.8	504	10

* Description of treatments and their irrigation management are brought in tabs. 3a, b.

Table 25. Effect of irrigation amount on fiber quality. Plants were grown in plant row and dripper line spacing of 100 cm.

Irrigation amount (mm)	Fiber strength (Lb x 106/sq.inch)	Fiber fineness (micronaire)
460	92.0	44.5
550	92.3	35.3

Table 26. Effects of irrigation amount, management and dripper line density on fiber quality

Treatment* no.	Fiber fineness (Micronaire) No.				
	Plot No.				
	1	2	3	4	5
1	32.8	39.1	39.0	-	-
2	36.0	39.7	43.2	48.5	-
3	31.4	37.9	39.5	43.5	50.2
4	35.0	41.7	40.8	44.9	-
5	31.4	32.4	36.7	44.0	45.5
6	32.6	34.6	36.3	38.2	-
7	29.6	30.8	34.4	45.8	47.0
8	38.8	40.0	41.4	46.4	-
9	35.3	36.0	38.3	38.4	42.3

*Description of the treatments is presented in Table 2 a,b.

Table 27: Effects of irrigation amount, plant row spacing and dripper density on leaf water potential.
Cotton was sown on 6th June.

Distance between plant rows (cm)	Distance between dripper lines (cm)	Total * irrigation amount (mm)	Leaf water potential (MPa)			
			21/7	28/7	17/3	6/9
50	50	460	-2.06±0.05	-1.70±0.05	-1.64±0.05	-1.63±0.05
50	100	"	-1.70±0.06	-1.94±0.04	-2.20±0.03	-1.30±0.04
100	100	"	-1.72±0.07	-1.45±0.05	-2.06±0.02	-1.37±0.02
100	200	"	-1.87±0.08	-1.65±0.03	-2.34±0.02	-1.68±0.05
50	50	510	-1.65±0.04	-1.59±0.04	-1.41±0.01	-1.15±0.04
50	100	"	-1.29±0.02	-1.40±0.05	-1.66±0.05	-1.20±0.02
100	100	"	-1.36±0.03	-1.32±0.04	-1.64±0.07	-1.24±0.03
100	200	"	-1.50±0.02	-1.21±0.02	-1.37±0.05	-1.47±0.02
50	50	550	-1.33±0.02	-1.34±0.06	-1.41±0.02	-1.41±0.01
50	100	"	-1.51±0.10	-1.48±0.10	-1.60±0.01	-1.27±0.04
100	100	"	-1.12±0.01	-1.11±0.010	-1.63±0.02	-1.19±0.02
100	200	"	-1.28±0.03	-1.36±0.02	-1.56±0.04	-1.27±0.06

* Irrigation management is presented in Tables 1.

Table 28: Effect of irrigation amount on leaf water potential. Plants were irrigated with overall amounts of 414(a), 492(b) and 538(c) mm H₂O.

		Leaf water potential (-MPa)													
Treat-*	Irrig.														
ment	rate	3/7	11/7	16/7	19/7	24/7	26.7	31/7	5/8	12/8	16/8	21/8	27/8	5/9	9/9
No.															
5	a	1.55	1.88	1.77	2.11	2.08	1.96	2.20	1.84	1.86	1.78	1.48	1.54	1.69	1.86
															2.15
6	b	1.55	1.70	1.70	2.05	1.72	1.79	1.88	1.48	1.75	1.77	1.65	1.76	1.57	1.80
															1.67
7	c	1.55	1.67	1.46	1.65	1.56	1.59	1.53	1.48	1.67	1.67	1.68	1.49	1.53	1.72
															1.71
															2.01

* Description of the treatments is presented in Tables 2a,b.

Table 29. Daily evaporation of pan A type and irrigation amounts*
calculated as percentage of the evaporation rate.
Cotton was sowed on June 6.

Period	Average Daily evaporation (mm)	Irrigation amount (Relative to the evaporation)		
		Low	Moderate	High
26/6- 3/7	6.4	0.42	0.42	0.42
3/7 -10/7	6.4	0.52	0.52	0.52
10/7-18/7	7.0	0.56	0.61	0.64
18/7-28/7	6.5	0.65	0.76	0.88
28/7- 4/8	6.9	0.61	0.71	0.85
4/8-10/8	6.0	0.80	0.92	1.03
10/8-17/8	6.7	0.78	0.85	0.95
17/8-24/8	6.1	0.93	1.07	1.19
24/8-31/8	6.2	0.92	1.06	1.19
31/8- 6/9	5.0	1.10	1.20	1.30

*See Table 1.

Table 30. The effects of considerable changes in irrigation management in the late growth period on leaf water potential.

Date	Treatment*	Daily irrigation (mm)	Leaf water potential (MPa)
27/8	5	4.2	-1.54
"	9	4.2	-1.54
"	7	6.6	-1.49
"	8	6.6	-1.39
5/9	5	3.0	-1.69
"	9	3.0	-1.95
"	7	4.2	-1.53
"	8	4.2	-1.27
9/9	5	2.4	-1.86
"	9	2.4	-2.26
"	7	3.2	-1.72
"	8	3.2	-1.41
18/9	5	2.2	-1.82
"	9	2.2	-2.10
"	7	2.6	-1.71
"	8	2.6	-1.55
25/9	5	0	-2.15
"	9	0	-2.39
"	7	1.6	-2.01
	8	1.6	-1.90

*Description of the treatments is presented in Tables 2a, b.

Table 31. Effects of irrigation amount and dripper line density on boll number and size. The boll population was divided according to their length to small (less than 1 cm) mid-size (1-2.5cm), and large (longer than 2.5cm). Measurement was carried out on 27/8.

Treat- ment No.	Irrigation level	Distance between dripper lines (m)	Average boll number per m ²			
			small	mid-size	large	Total
1	low	1	60.5	24.5	44.0	129.0
2	high	1	65.7	22.7	33.6	122.0
3	low	2	31.5	25.2	65.2	121.9
4	high	2	46.2	31.0	41.2	118.4
5	low	2	32.0	22.0	64.0	118.0
6	moderate	2	38.5	29.7	63.7	131.9
7	high	2	62.7	31.2	78.2	172.1

* Description of the treatments is presented in Tables 2a, b.

Table 32: Percentage of bolls which survived and arrived to maturation from the overall flowering of the following periods.

Treat- ment No.	Irrig. level	Period of flowering					Total percentage of boll survival
		26/7-2/8	3/8-9/8	10/8-16/8	16/8-22/8	22/8-28/8	
5	low	82.7	33.6	34.5	54.5	43.3	55.4
6	moderate	74.0	29.7	26.5	25.3	29.8	49.9
7	high	80.8	29.8	41.0	48.8	35.2	53.0

* Description of the treatments is presented in Tables 2a,b.

Table 33: The relative contribution to yield (in percent of total yield) of differing flowering periods

Treat- ment No.	Irrig. level	Flowering period	Relative yield (%)	Flowering period	Relative yield (%)	Flowering period	Relative yield (%)	Flowering period	Relative yield (%)	Flowering period	Relative yield (%)
5	low	19/7-25/7	28.4	26/7-2/8	29.2	3/8-9/8	17.5	10/8-16/8	11.4	17/8-23/8	13.5
6	moderate	"	29.0	"	37.0	"	13.9	"	9.5	"	10.6
7	high	"	25.8	"	27.4	"	18.0	"	15.8	"	13.0

Description of the treatments is presented in Tables 2a,b.

Table 34: The effects on irrigation amount on the distribution of open bolls on the different internodes along the plant stem.

- a) The relative number of bolls (in percent of total).
- b) The average weight of seed cotton per boll (gr.).

Treat- ment No.	Irrig. level	Internodes order along the main stem							
		5-8		9-11		12-14		15-17	
		a	b	a	b	a	b	a	b
5	low	32.2	5.8	31.4	6.3	23.3	6.3	13.1	5.3
6	moderate	37.0	6.0	29.9	5.9	20.5	5.6	12.6	5.5
7	high	26.8	5.8	27.7	5.3	25.9	5.7	19.6	5.7

* Description of the treatments is presented in Tables 2a, b.
Measurements were carried out on the 5th November.

Figure 1. Content of available water* in the soil profile as calculated from neutron prob measurements. Plants were irrigated with overall amount of 463 (○—○), 492 (○—○), and 538 (Δ—Δ) mm H₂O, as presented in Table 2.

* Available water was calculated on the basis of range humidity between wilting point and field capacity. Water content between field capacity and wilting point was determined as 100%.

Figure 2. Photograph of plant root system 120 days after sowing.
Arrow = direction of dripper line. 0=soil surface

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EFFECT OF LIMITED ROOT VOLUME ON GROWTH AND PRODUCTIVITY
OF FIELD-GROWN COTTON IN ARIZONA

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In 1984, 1985, and 1986 comparisons of drip irrigated and furrow irrigated cotton were made in Maricopa (1984, 1985) and Phoenix (1986), Arizona. The studies were designed to use growth analysis to discover the source of any possible improved crop efficiency due limited root volume induced by drip irrigation.

Methods

The plots for the 1984 and 1985 experiments were in cooperation with Dr. T. C. Tucker and Dr. D. C. Fangmeier, University of Arizona, Tucson. The plots were designed to test the interaction of N-fertility and volume of irrigation water. The plots used for the 1986 observations were those of the Western Cotton Research Lab., Phoenix.

1984 - Cotton (cv. DPL-62) was replanted at the Maricopa Ag. Center on April 23 on beds with drip tubing placed 20 cm below the surface. The drip tubing was Chapin Twin Wall III 14 mil. Water was applied equally to all plots for germination and early seedling growth, after which the irrigation rate variables were imposed to approximate 0.6, 0.95, and 1.2 of the estimated evapotranspiration (ET) or consumptive use. The total water applied including rainfall was 69, 94, and 122 cm, respectively. The furrow irrigated plots were in an adjacent field. They received pre-planting irrigation of 15 cm water and a flood irrigation of 15 cm every 14 days beginning May 20. Total irrigation for these plots was approximately 140 cm.

The nitrogen treatments of the drip plots were according to the schedule in Table 1. All N was applied through the drip system as N-phuric (28-0-0-9). The initial $\text{NO}_3\text{-N}$ level was approximately 20 ppm in the surface 30 cm. There was approximately 4 ppm $\text{NO}_3\text{-N}$ in the irrigation water.

Table 1. Nitrogen Treatments and Yields of Machine-picked Seed Cotton.

Plant Growth Stage	Treatment (amount N applied, lbs/A)					
	1	2	3	4	5	6
Late vegetative to first flower (May 28 - June 18)	25	25	50	50	100	0
First flower to heavy flowering (June 18 - July 9)	25	50	50	100	100	0
Peak flower to late flower (July 9 - July 30)	25	25	50	50	100	0
Late flower - large bolls (July 30 - August 20)	25	0	50	0	100	0
Total N applied per acre	100	100	200	200	400	0

Seed cotton yields (Table 2) were not significantly affected by N treatment. The initial soil $\text{NO}_3\text{-N}$ level was adequate for the maximum yields possible under existing conditions. Although the seed cotton yields for the

high water level (1.2 ET) appear larger than for the medium level, the apparent differences were not significant statistically. Differences between the low (0.6 ET) and higher water levels were highly significant.

Flowering and boll data were collected from each plot. Flowering data show differences in water and N treatments at the high water level. However, boll retention was reduced by N treatments resulting in approximately the same total boll load and yield. Petiole $\text{NO}_3\text{-N}$ values varied considerably with different N treatments and appear to show agreement between flowering data and N treatments.

Table 2 . Seed cotton yields in drip and furrow irrigated plots at Maricopa, Arizona in 1984.

Drip Irrigation Yields seed cotton, lbs/Ac	N-Treatment					
	1	2	3	4	5	6
0.6 ET	3483	3174	2946	3483	3345	3037
0.95 ET	4619	4644	4751	4862	4943	4467
1.2 ET	5369	5263	5182	5035	4949	5085
Furrow Irrigated	4550					

Because there was no effect on yield of the nitrogen treatments, the growth analysis data for treatment 3 and 6 were averaged to describe 0.6 ET, treatments 1, 3 and 6 used to describe 0.95 ET and treatment 5 used to represent 1.2 ET in comparison with Furrow irrigated which received 200 hg/ha nitrogen.

1985 - After initial stand failure the crop (cv. DPL-62) was replanted on May 6, 1985. Equal amounts of water were applied to all plots prior to June 10. At that time irrigation variables were imposed according to the schedule of Table 3. Tubing placement, N injection and irrigation frequency were the same as in 1984. Initial N level was 8 ppm in the surface 20 cm. Water quality was similar to 1984.

Table 3. Nitrogen treatment for each three-week period.

Plant Growth Stage	Treatment (amount N applied, Kg/ha)					
	1	2	3	4	5	6
Late vegetative to first flower (June 10-24)	16.6	33.3	33.5	66.6	100	0
First flower to heavy flowering (July 1-15)	16.6	33.3	33.5	66.6	100	0
Peak flower to late flower (July 22-Aug 5)	16.7	33.4	0	66.7	100	0
Total N Applied	50	100	67	200	300	0

As in 1984 the furrow irrigated plots were in the adjacent field and received the typical flood irrigation of 15 cm every 14 days. The 0.7, 1.0,

and 1.2 ET drip-irrigated plots received 73, 103, and 124 cm water, respectively, for the season and the furrow-irrigated plots 144 cm in 1985.

Seed cotton yields for these treatments are shown in Table 4. Contrary to the 1984 experience, there was an increase in yield due to nitrogen treatment at the 1.0 ET and 1.2 ET levels of irrigation. However, because of the lateness of the planting the drip-irrigated plots were lower in yield than in 1984 and lower than the furrow-irrigated rows.

Table 4 . Seed Cotton Yields, 1985. (Kg/ha)

Water level	Rep	N rate, Kg/ha					
		0	50	67	100	200	300
0.6 CU	1	2300	2700	1960	2700	2360	2360
	2	2950	2270	2560	2630	2260	2590
	3	<u>2720</u>	<u>2550</u>	<u>3110</u>	<u>2710</u>	<u>2660</u>	<u>2520</u>
	mean	2570	2510	2540	2680	2430	2470
1.0 CU	1	3490	4200	3830	4330	3290	4160
	2	3580	4190	4320	4200	3745	4370
	3	<u>3650</u>	<u>3390</u>	<u>3990</u>	<u>3680</u>	<u>4000</u>	<u>4200</u>
	mean	3570	3920	4050	4070	3680	4250
1.3 CU	1	3770	4370	4600	4400	4200	4910
	2	4350	4470	4620	4480	4700	4780
	3	<u>3490</u>	<u>5210</u>	<u>4710</u>	<u>4340</u>	<u>4040</u>	<u>4330</u>
	mean	3870	4680	4650	4410	4310	4670

The increase of dry weights of the standing crop in 1985 is shown in Figure 1. While the furrow plot germinated and grew more rapidly for the first 30 days, the 100 ET and 120 ET drip plots grew faster in July so that all plots had the same weight by mid-July. The pattern of growth was the same in 1984. After mid-July the 100 ET plots reduced rate of gain in weight, while the 120 ET and furrow continued rapid weight gain until early September.

A parallel pattern of growth can be seen in the increase in LAI (Figure 2). While the initial LAI of the furrow was greater than either of the drip plots, the rate of increase was less, and, therefore, by early July the drip plots had greater LAI. By mid-July, however, the 100 ET treatment ceased LAI expansion while 120 ET and furrow continued to increase. The cessation of LA expansion by 100 ET coincided with the reduction of dry weight increase (Fig. 1).

Boll loading of these plots is shown in Figure 3. It follows the same pattern as the gain in crop weight and LAI. Furrow loaded earliest due to the more rapid seedling growth. The drip treatments began boll loading about the same time and increased at the same rate. The 100 ET plots ceased loading about August 1 and the 120 ET continued to load for an additional week, as did the furrow. The additional time of loading accounted for the difference in yield.

Boll carrying-capacity per unit of leaf area is a sensitive means of evaluating the efficiency of carbohydrate production and partitioning. To do this I used the ratio (LA/B) of leaf area/ m^2 to the number of "active" bolls in that square meter at each harvest date. "Active" bolls were defined as those 40 days old and younger. The derived curves for these calculations are shown in Figure 4. From other studies we have found that 300 cm^2 of leaf per

active boll is the minimum value obtained by very efficient cotton plantings. Such as was the case with the furrow and 100 ET plots.

The earliness of the furrow plots is seen in this analysis, which also shows a degree of earliness on the part of 100 ET. The increase in LA/B after mid-August was due to maturation of the boll load as well as the continued increase in LAI. The higher LA/B of the 120 ET plots shows that the crop continued to expand leaf area at the same time as load with bolls. This strategy for maximum productive yield can be successful with drip irrigation because the leaf water stress is kept low by the frequent irrigations.

The pattern of leaf area development and boll loading was somewhat different in 1986 than in the two previous years. In 1986 the limited-root-volume, drip irrigated crop (100ET) was slightly slower in leaf area development than in 1985 (Fig. 5) but somewhat more rapid in boll loading (Fig. 6). This lead to a crop in which the LA/B was below 200 in the 100ET treatment and was never lower than 350 in the furrow irrigated treatment (Fig. 1). In 1986 the 100ET treatment had a reduced rate of boll loading during mid-season, due probably to the cut-out induced by the low LA/B. Late season boll loading was more rapid in the 100ET treatment. This enabled the limited-root-volume treatment to achieve the same final yield as the conventional, furrow-irrigated crop.

Conclusions: The data from this study point toward water status as the key factor in the greater yield and higher WUE of the limited root volume - drip irrigated plots. Apparently the calculated ET values used to set the 100 ET irrigation schedule in 1985 were not fully adequate for the crop. In that year the 120 ET was the fully sufficient volume of water. It is possible that somewhat more water than the 120 ET would have given additional yield, though with reduced WUE similar to the furrow.

In 1986, experiments were conducted in Phoenix, at the Western Cotton Research Laboratory. Eight plots, arranged in a randomized complete block design, were leveled for flood irrigation. Each plot was 4 rows wide, with all measurements being taken on plants from the center two rows. Four plots were given 150 lb./acre N as urea on JD 148, whereas the other four plots received no added N. Irrigations were on a standard schedule (6 inches of water every two weeks) during the period of measurements, except for one period in July when irrigation was delayed one week. Although rainfall compensated somewhat for the delay, the plants experienced rather severe stress as a result.

The drip-irrigated plants were in the control treatment of the 1986 free-air CO₂ release experiment. This experiment, in an adjacent field, was grown using a surface drip line with orifices spaced at intervals of 46 cm. Irrigation was given daily in an amount calculated to equal to the ET. Nitrogen was supplied in the irrigation water as urea. The total supplied for the season was 150 kg/ha.

In both the drip irrigated and furrow irrigated fields, plants were sampled weekly for leaf area, boll number, biomass, etc. Final seed cotton yield for the season was 2800 kg/ha for the drip irrigated and 2650 kg/ha for the furrow irrigated, N-fertilized plots. The N-stressed plots yielded 1900 kg/ha.

Findings: Final harvest yields are shown in Table 2 and 4. The WUE was improved by the efficient delivery system of underground irrigation, but total crop productivity was greatest in the furrow and 120 ET treatments. Because the range of values was typical of all treatments the remaining discussion will concentrate on the high-N (300 kg/ha) treatment of the 100 ET, 120 ET and furrow plots.

Only in 1986 were there indications in these data that the plants had more efficient carbohydrate partitioning due to the reduced root volume expected from drip irrigation. In that year the LA/B ratio was lower in the limited root volume treatment. However, that treatment could not sustain boll loading for as long a period of time due to lack of vegetative growth. This further emphasizes the need for simultaneous vegetative and reproductive growth in order to achieve maximum production.

Figure 1 . Crop dry weight (gm/m^2) of the developing cotton crop in Maricopa, AZ in 1985. The Furrow treatment was irrigated each 14 days and the 100ET and 120 ET treatments were irrigated daily by drip tubing to create limited root volume.

Figure 2 . Leaf area index (LAI) of the developing cotton crop in Maricopa, AZ in 1985. The treatments were the same as described in Fig. .

Figure 3 . Boll load present on the standing crop (Bolls/m²) in Maricopa, AZ in 1985. The treatments were the same as described in Fig. .

Figure 4 . Leaf area per active boll (LA/B) on the developing crop in Maricopa, AZ in 1985. Active bolls were those 40 days old or younger. Treatments are the same as described in Fig. .

Figure 5 . . Leaf area index (LAI) of the developing cotton crop at Phoenix, AZ in 1986. The treatments are the same as described in Fig. . .

Figure 6 . Boll load (Boll/m²) of the developing cotton crop at Phoenix, AZ in 1986. The Furrow treatment was irrigated each 14 days and the 100ET treatment was irrigated daily by drip tubing with an amount of water calculated to equal the ET loss for that day.

Figure 7 . Leaf area per active boll (LA/B) on the developing crop in Phoenix, AZ in 1986. Active bolls were those 40 days old or younger. Treatments are the same as described in Fig. .

Physiological Studies of Limited Root Volume Cotton

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Methods:

In 1984, studies of plant water relations were carried out at the Maricopa Farm in cooperation with Dr. C. Tucker and Dr. D. Fangmeier. Details of plant growth, petiole analyses, etc., are presented elsewhere. Plant water potentials were assessed with a pressure chamber, using the youngest fully-expanded mainstem leaf. Leaves were shaded, bagged, excised, and stored in a humidified styrofoam chest for transport back to the room housing the pressure chamber. Treatments studied included three levels of water application, 60% (I), 95% (II), and 120% (III) of ET; and two rates of N application, 0 (treatment 6) and 200 lb./acre (treatment 3, Table 1). In addition, furrow-irrigated cotton in an adjacent field was included in the comparisons. The furrow-irrigated cotton was grown using standard cultural practices. All measurements were made on two healthy plants selected from each of three replications. Most measurements of water status were made in the early afternoon (1200 - 1400 hours) on clear sunny days. On one occasion measurements were made at 2-hour intervals beginning at 0500 hours (predawn). Comparisons between furrow- and drip-irrigated cotton were based upon the treatment given 120% ET to preclude the possibility of stress for insufficient water application.

Stomatal conductances were assessed using the LiCor LI-1600 steady state porometer. Measurements were made just prior to excision on the same leaves

used for water potential determinations. Results are expressed as leaf conductances (sums of abaxial and adaxial conductances).

In 1985, experiments were repeated on the same plots, after a winter grain crop had been grown and harvested. In this year measurements were confined to the furrow-irrigated plots and to the 60% and 100% ET water levels in the drip-irrigated treatments. No stomatal conductance measurements were taken.

The 1986 experiments were conducted in Phoenix as described in the previous section. Hydraulic conductances were estimated from the relationship between transpiration and water potential. Beginning before dawn, transpiration rates of the youngest fully-expanded leaves were determined using the LiCor LI-1600 steady-state porometer. Rates were not corrected for the effect of the cuvette's boundary-layer resistance. Immediately after measurement, the same leaves were excised using standard techniques and transported back to the laboratory for measurement of water potentials using a pressure chamber. Measurements were made approximately every 105 minutes until midday. Regression analysis was used to estimate the linear relationship between transpiration rate and leaf water potential, and the water potential at zero transpiration. Hydraulic conductances were always measured on the flood-irrigated plants 3 to 5 days after an irrigation, to make sure that the soil profile would be fully recharged and to give the plants sufficient time to recover from any stress effects.

Results: A. Comparison of drip-irrigated and furrow-irrigated cotton.

Comparisons of cotton plants grown under drip irrigation (daily application) and furrow or flood irrigation (biweekly application) were carried out in 1984, 1985, and 1986. The 1984 and 1985 trials were at the

Maricopa Experiment Station Farm in cooperation with Drs. C. Tucker and D. Fangmeier. The 1986 trial was at the USDA-ARS Western Cotton Research Laboratory, Phoenix. In 1984, there was little difference in midday leaf water potentials throughout most of the growing season, with the notable exception of a period beginning at JD 215 and lasting about two weeks (Fig. 1A). A similar pattern developed in 1985, with leaf water potentials diverging after JD 220. In this case, though, the period in which drip-irrigated plants were less stressed was considerably longer than in 1984 (Fig. 1A).

Stomatal conductances were determined on the cotton plants in 1984 (Fig. 2A). As expected, the leaf conductance of the furrow-irrigated plants cycled more than that of the drip-irrigated plants. Nonetheless, two points are important. First, the maximum conductance of the two groups of plants was equal, and thus the drip-irrigated plants did not have an inherently greater ability to transpire during most of the season. Second, the conductance of the furrow-irrigated plants was much less than that of the drip-irrigated plants for a 20-day period beginning at JD 215. These data show that the difference in transpiration was not the source of the difference in leaf water potential. Rather, the cause-and-effect was probably reversed, with water stress on the tops causing the partial stomatal closure.

Experiments in 1986, although at a different location, reproduced a similar pattern of leaf water potentials as in the previous years (Fig. 3A). In this case the biweekly irrigations were by flooding of level basins. Again, though, except for the periodic stress at the end of each irrigation cycle, the only difference between the treatments occurred around JD 220. This pattern could not have resulted simply from lack of available soil moisture, because it spanned a considerable period (about 2 weeks) after water was resupplied.

In 1986, attempts were made to estimate the plant hydraulic conductance. Leaf water potentials and transpiration rates were recorded beginning before dawn and ending at midday on several days throughout the season. The resulting relationships were estimated by linear regression, and the regression coefficient (slope) was taken as the hydraulic conductance of the plant. In the drip-irrigated plants, hydraulic conductance decreased from 10.9 to $6.2 \mu\text{g cm}^{-2}\text{s}^{-1}\text{bar}^{-1}$ from JD 183 to JD 245 (Fig4A). This means that the ability of the plant to transport water efficiently decreased slightly during the course of the season. In the flood-irrigated plants, the pattern was much more complex. The conductance was always $6.3 \mu\text{g cm}^{-2}\text{s}^{-1}\text{bar}^{-1}$ or higher except on JD 218 and 218, when it was half that value or less (Fig. 4A). Interestingly, the predawn water potential (X axis intercepts in Fig4A) was lowest on JD 217 and 218 as well, regardless of irrigation treatment.

Assuming that the single-leaf transpiration rates presented in Figure 4 are representative of the entire canopy, the total evaporation rate can be calculated as $E = T \times \text{LAI}$ where E is canopy evaporation rate, T is single-leaf transpiration rate, and LAI is the leaf area index. When the hydraulic conductances are "adjusted" by this correction factor (to account for differences in plant leaf area), the treatment effect is accentuated rather than diminished (Table5A). The data indicate that the difference in efficiency of water transport is real whether expressed on the basis of transpiration per unit leaf area or ground area.

Discussion

We have documented that drip-irrigated plants have a higher (less negative) water potential than furrow- or flood-irrigated plants during a period commencing around the beginning of August. This pattern was observed in trials over three years and two locations. The period of less stress in

the drip-irrigated plants seems to coincide with the occurrence of cutout. This stage of crop development is characterized by slowing of growth and failure to set new bolls. Cutout is believed to be caused by the diversion of the plant's carbon into the growth of bolls, leaving little surplus for other activities. Although very few studies have addressed the function of the root system during cutout, Browning et al. (1974) and Taylor and Klepper (1974) reported that total root length per plant declines during that period, with the severity of the decline depending upon the degree to which the plant is stressed. These authors also found a very low predawn water potential during that period and they pointed out that this phenomenon may reflect a lower conductance for water. Our experiments (Fig 4A) have produced very similar evidence that the root system is unable to function efficiently during cutout, but only in the flood-irrigated or furrow-irrigated plants. It is unclear whether this impairment results directly from cutout, or represents an inability of the plant to recover from water stress (from the previous irrigation cycle). In either cases, the greater hydraulic efficiency of the drip-irrigated plants must result from the altered schedule of application or the altered volume of wetted soil. Taylor and Klepper (1971) concluded that deep roots of cotton were as effective as shallow roots in extracting water, so the distribution of water in the soil may not be a factor in determining efficiency of water uptake. Therefore it seems likely that the root system of the drip-irrigated plants is receiving more nutrients (photosynthate) during cutout, or its requirement is less. There is no obvious reason why partitioning of carbon into the root system during cutout would increase in drip-irrigated plants compared to furrow-irrigated plants. However, it is entirely possible that the total root length of drip-irrigated plants is less than for furrow-irrigated plants, because the roots are all concentrated in

moist soil and therefore a smaller root system is capable of delivering adequate water for the tops. If this be the case, then the basal respiration rate of the root system may well be decreased proportionally to total root length.

Results: B. Comparison of N-fertilized and N-stressed cotton.

In both 1984 and 1985, water relations parameters were assessed on drip-irrigated cotton with or without applied N. In 1984, the midday leaf water potential was essentially unchanged by N when the plants were irrigated 60% ET. At 95% ET, though, the N-fertilized plants had a substantially lower (more negative) water potential than the unfertilized plants (Fig 5A). At 95% ET, stomatal conductances were essentially unchanged by N (Fig 6A), indicating that the difference in water potential did not arise as a result of differing transpiration rates per unit leaf area.

Leaf water potentials and stomatal conductances were followed from predawn to midday on one day during the season. The water potential of the two treatments was identical before dawn, but the difference due to N developed rapidly as the day progressed, and was maximal at 1330 hours when measurements ceased (Fig 7A). Comparisons of data obtained at 1100 hours and 1330 hours reveal some interesting facts, i.e. stomatal response to leaf water potential differed between the two treatments. In the -N treatment, stomatal closure occurred during that 2 1/2 hour period even though the water potential never decreased below -16 bars (Fig 7A). In contrast, in the +N treatment stomatal closure occurred only below -16 bars (Fig 7).

In 1985, results were similar to 1984 except that the effect of N on leaf water potentials was larger (Fig 8A). In this year N decreased water potentials of plants at both 60% ET and 100% ET throughout the season. At

times the difference was as large as 6 to 8 bars in the 60% ET treatment (Fig. 8A).

Discussion

These results are consistent with the earlier report (Radin et al. 1985) that N stress makes stomata of cotton more responsive to water stress. In 1984, the only year in which stomatal conductances were measured, N did not alter conductance despite causing large decreases in water potential. The diurnal course of stomatal conductance shows that decreasing water potential does cause stomatal closure within each treatment; therefore we conclude that N stress increases the stomatal response to decreasing water potential.

The reasons for the large difference in plant water potential are uncertain. Several explanations are possible: (1) the added N in the irrigation water decreased its osmotic potential and thereby caused water stress; (2) the increased N greatly increased transpiring leaf area, with the resulting increased water flow through the plant decreasing the water potential; (3) N fertilization decreased the plant's ability to take up water; (4) N fertilization decreased root hydraulic conductance; (5) the N-fertilized plants had a higher rate of water loss per unit leaf area. The first explanation seems unlikely because the rate of N fertilization was not high enough to cause such problems normally. The second possibility is refuted by leaf area measurements, which revealed very little differences due to N, especially in 1984. The fifth explanation is excluded by the failure to detect differences in stomatal conductances (assuming that the youngest fully-expanded leaf is representative of the canopy as a whole). The third and fourth explanations cannot be separated, tested from these data; however, N fertilization is commonly observed to decrease the overall root:shoot ratio. In controlled-environment experiments, N fertilization also increased root

hydraulic conductivity to compensate for this change in root:shoot ratio (Radin and Boyer, 1982). In any event, there is no evidence from these experiments that N fertilization increases hydraulic conductivity under these cultural conditions.

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Table 5. Hydraulic conductances of cotton plants grown with either daily drip irrigation or biweekly flood irrigation. The term $\Delta T/\Delta \Psi$ represents the slope of the line relating transpiration rate of a recently matured leaf to its water potential. When adjusted by the LAI, this slope yields a quantity proportional to whole-plant hydraulic conductance (assuming that the properties of the measured leaf can be extended to the entire canopy).

Julian	$\Delta T/\Delta \Psi$				"Adjusted" $\Delta T/\Delta \Psi$	
Date	$(\text{mg cm}^{-2}\text{s}^{-1}\text{bars}^{-1})$		LAI		$(\text{mg cm}^{-2}\text{s}^{-1}\text{bars}^{-1})$	
	Drip	Fluid	Drip	Fluid	Drip	Fluid
183	10.94	6.34	1.94	1.50	21.2	9.5
190	-	6.91	-	2.71	-	18.7
217	-	3.52	-	1.86	-	6.5
218	9.61	2.61	2.70	1.87	25.9	4.9
245	6.20	7.24	3.82	1.59	23.7	11.5

Legends for figures.

Fig.1A. Leaf water potentials at midday of drip-irrigated and furrow-irrigated cotton plants during two seasons. Values shown $\pm$ standard errors of the mean.

Fig.2A. Stomatal conductances of drip-irrigated and furrow-irrigated cotton plants during 1984. Values shown $\pm$ standard errors of the mean.

Fig.3A. Leaf water potentials at midday of drip-irrigated and flood-irrigated cotton plants during 1986. Values shown $\pm$ standard errors of the mean.

Fig.4A. Relationships between single-leaf transpiration rate and leaf water potential in drip-irrigated and flood-irrigated cotton during 1986. The dates and correlation coefficients for each regression are indicated.

Fig.5A. Water potentials of drip-irrigated plants with and without added N during 1984. Irrigation rates were either 60% or 95% of estimated ET. Values shown $\pm$ standard errors of the mean.

Fig.6A. Stomatal conductances of drip-irrigated plants grown with or without added N during 1984. The irrigation rate was 95% of estimated ET. Values shown $\pm$ standard errors of the mean.

Fig.7A. Diurnal course of leaf water potential and stomatal conductance on 2 Aug. 1984 (JD 215). The irrigation rate was 95% of estimated ET. Values shown $\pm$ standard errors of the mean.

Fig.8A. Water potentials of drip-irrigated plants with or without added N during 1985. Irrigation rates were either 60% or 100% of estimated ET. Values shown $\pm$ standard errors of the mean.

Fig.1A. Leaf water potentials at midday of drip-irrigated and furrow-irrigated cotton plants during two seasons. Values shown $\pm$ standard errors of the mean.

Fig. 2A. Stomatal conductances of drip-irrigated and furrow-irrigated cotton plants during 1984. Values shown $\pm$ standard errors of the mean.

Fig.3A. Leaf water potentials at midday of drip-irrigated and flood-irrigated cotton plants during 1986. Values shown $\pm$ standard errors of the mean.

Fig.4A. Relationships between single-leaf transpiration rate and leaf water potential in drip-irrigated and flood-irrigated cotton during 1986. The dates and correlation coefficients for each regression are indicated.

Fig. 5A. Water potentials of drip-irrigated plants with and without added N during 1984. Irrigation rates were either 60% or 95% of estimated ET. Values shown $\pm$ standard errors of the mean.

Fig. 6A. Stomatal conductances of drip-irrigated plants grown with or without added N during 1984. The irrigation rate was 95% of estimated ET. Values shown $\pm$ standard errors of the mean.

Fig.7A. Diurnal course of leaf water potential and stomatal conductance on 2 Aug. 1984 (JD 215). The irrigation rate was 95% of estimated ET. Values shown $\pm$ standard errors of the mean.

Fig.8A. Water potentials of drip-irrigated plants with or without added N during 1985. Irrigation rates were either 60% or 100% of estimated ET. Values shown $\pm$ standard errors of the mean.

Effect of Limited Root Volume on Growth and Productivity
of Cotton in Large Containers in a Glasshouse

Peter Marchand

A large-pot (56 liter) greenhouse experiment was undertaken in order to compare root development of cotton in an unrestricted soil environment, under drip and flood irrigation regimes. It was hypothesized in this study that the "feast or famine" character of flood irrigation would lead to extensive root exploration as long as the soil profile remained wet, but that this would be followed by substantial dieback of fine roots when the soil later dried. The resulting increase in root turnover, it was thought, would divert carbohydrate away from shoot development, thus leading to lower boll production. In contrast, the drip irrigation regime was expected to maintain sufficient water supply locally to obviate the need for extensive soil exploration by roots, thus making more carbohydrate available for above ground production and increasing the yield of drip-irrigated plants.

The results of the study, summarized in Figure 1B and Table 6, did not support our working hypothesis. Even though soils under drip irrigation remained extremely dry at depth, the roots of these plants explored well beyond the soil volume wetted daily by the drip emitters. In fact, total root production in the first 10 weeks of the experiment was essentially the same in the drip and flood treatments. Furthermore, because the drip plants were exploring drier soils, they experienced considerably higher levels of water stress throughout their active growth phase. These plants were consistently earlier in flowering, possibly related to the higher water stress, but in the end the drip plants produced far fewer flowering sites than did the flood plants.

After 10 weeks, root production under drip irrigation leveled off and for the next 6 weeks remained essentially constant while above ground biomass doubled. During this same period the root mass of flood plants increased by another 100%, while the above ground mass nearly quadrupled....this even though leaf water potentials for flood plants at the end of the drying cycle were exceeding -3.0 MPa (-30 bars) or nearly twice that of the drip plants under the same atmospheric demand (Figure 13). Though the proportions of above ground biomass in shoots, leaves, and bolls at final harvest were essentially the same for both treatments (Table 5), the much larger flood plants yielded 58% more bolls (by weight) than the drip plants.

These results suggest two problems with our earlier reasoning: (1) Our initial perceptions of a "wetted ball" encompassing the root mass of plants grown under drip irrigation was naive. Though there appeared to be a fairly well defined wetted perimeter at the soil surface where the water was received, there was no such boundary between wet and dry soils in vertical profile. In retrospect, it seems more reasonable to expect an even soil moisture gradient from point source to the driest reaches of the pots. (2) The roots of these plants are apparently "programmed" to explore the entire soil profile, even though water was more readily available at the base of the plant. Roots were found probing into soil so dry that it could easily be blown away from root tips, and there were no obvious differences in architecture of root systems developed under the two different watering regimes.

The above conclusions are now being tested in another controlled environment study where plants are being grown in horizontal plexiglas cylinders to eliminate any geotropic response in root growth and limit soil exploration to that which might be induced by water potential gradients alone.

This time, soil water potentials under simulated drip treatments are being measured using the thermocouple psychrometers while the soil is insulated against temperature changes (a problem which plagues greenhouse and field measurements using psychrometers). The use of plexiglas cylinders also affords an opportunity to study architectural aspects of root development in wet versus dry soils, as root growth can be observed and measured without disturbance.

Table 6 .

Pooled Means, Reps 1 and 2, 1st Harvest		
	<u>Drip (n=8)</u>	<u>Flood (n=8)</u>
Plant HT (cm)	36.76 $\pm$ 3.10 S.D.	36.56 $\pm$ 2.53 S.D.
Above-Ground Dry Wt (g)	9.414 $\pm$ 2.40	8.549 $\pm$ 2.10
% Shoots	43.09 $\pm$ 4.14 S.D.	38.55 $\pm$ 3.58 S.D.
Leaves	52.28 $\pm$ 5.03	59.63 $\pm$ 4.03
Flowers/Fruits	4.69 $\pm$ 1.52	1.82 $\pm$ 1.00
Total Wt. - Flowers/Fruits (g)	.468 $\pm$.250	.164 $\pm$.126
Root Dry Wt. (g)*	3.061 $\pm$ 0.31	2.650 $\pm$ 0.48
Root/Shoot Ratio	.326 $\pm$ 0.25	.309 $\pm$.018

* n=4 samples of paired roots - 2

Pooled Means, Reps 1 and 2, 2nd Harvest:

	<u>Drip (n=8)</u>	<u>Flood (n=8)</u>
Plant HT (cm)	35.89 ±5.06 S.D.	46.14 ±6.72 S.D.
Above-Ground Dry Wt (g)	16.265±3.47	20.988±8.61
% Shoots	30.31 ±5.75 S.D.	38.70 ±6.07 S.D.
Leaves	32.02 ±3.48	37.62 ±4.91
Flowers/Fruits	37.67 ±6.86	23.68 ±9.45
Total Wt. - Flowers/Fruits (g)	6.201±2.95 S.D.	5.309±3.89 S.D.
Root Dry Wt. (g)	3.942± .60	5.529± .36
Root/Shoot Ratio	.242± .03	.267± .04

Pooled Means, Reps 1 and 2, 3rd Harvest:

	<u>Drip (n=8)</u>	<u>Flood (n=8)</u>
Plant HT (cm)	34.69 ±5.86 S.D.	45.76 ± 4.90 S.D.
Above-Ground Dry Wt (g)	21.723±8.49	34.570±11.13
% Shoots	18.29 ±5.35 S.D.	21.24 ± 2.86 S.D.
Leaves	26.69 ±6.49	24.20 ± 4.16
Flowers/Fruits	55.01 ±11.50	54.48 ± 6.41
Total Wt. - Flowers/Fruits (g)	12.40 ±5.67	19.27 ± 7.30
Root Dry Wt. (g)	3.138± .48 S.D.	5.043± .71 S.D.
Root/Shoot Ratio	.145± .021	.152± .049

Figure 1B . Growth parameters and leaf water potential (ψ) of cotton plants grown with limited root zones (drip) within full-volume root zones (Flood) in 60L pots in a glasshouse in Tucson, AZ.

F. Cooperation

The cooperation between the two research groups was based on an exchange of information and ideas on the one hand, and on independent work of each group on the other hand. The experiments were not complimentary and consequently the activities of each group could be carried out without any dependence on the advancement of the other group. The priorities of the research activities of each group were designed to exploit the expertise and experience of the local team and to promote the specific agricultural interests in each country. In addition to the regular correspondence, the periodical reports enabled us to summarize together the research activities and to study the significance and application to the achievements of each group to that of the other. During the three years of the project Dr. Carmi and Dr. Plaut visited the Phoenix Laboratory and carried out fruitful discussions with the American group. It seems to us that the cooperative activity in the framework of the BARD project established the basis for further cooperation in the future to the interests of both countries.

G. Benefit to Agriculture

The present research promoted the application of a new irrigation agrotechnique for cotton which has the potential of reducing water consumption and increasing yield. The possibility of getting high yields from late sowed cotton enabled farmers to practice double-cropping system - cotton and wheat - for grains. Thereby, a more intensive use of soil, which otherwise was dedicated only to raise the summer crop, was achieved. The management of restricted root zone irrigation abolished the necessity

northern regions of Israel and was proven to be practically possible.

The information which was obtained on root development and location in regard to irrigation management and the density and orientation of the drip irrigation system is very important from an agronomical point of view. It contributes vital information which has to be taken into consideration in determining the optimal irrigation management. It will help reduce losses of water out of the functional root zone.

The findings on the reproductive development of very late sowed cotton are meaningful. They might change the conventional attitude as concerned to be optimal irrigation management in September in Israel. It was concluded that the continuation of irrigation may result in a considerable increase in yield due to the development and maturation of very late grown bolls.