MORPHOLOGICAL AND PHYSIOLOGICAL DEVELOPMENT OF COTTON UNDER VARIOUS REGIMES OF DRIP IRRIGATION

by

Ramadjita Tabo

A Dissertation submitted to the Faculty of the

DEPARTMENT OF PLANT SCIENCES

In Partial Fulfillment of the Requirements
For the Degree of

DOCTOR OF PHILOSOPHY
WITH A MAJOR IN AGRONOMY AND PLANT GENETICS

In the Graduate College

THE UNIVERSITY OF ARIZONA

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As members of the Final Examination Committee, we certify that we have read

the dissertation prepared by Ramadjita Tabo

entitled Morphological and Physiological Development of Cotton Under Various Regimes of Drop Irrigation

and recommend that it be accepted as fulfilling the dissertation requirement

for the Degree of Doctor of Philosophy.

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B. B. Taylor	18 July 85 Date
Albert K. Dobrenz	18 July 1985 Date
Kyle L. Cox	18 July 85 Date
James Smith	18 July 85 Date

Final approval and acceptance of this dissertation is contingent upon the candidate's submission of the final copy of the dissertation to the Graduate College.

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DEDICATION

This dissertation is dedicated to my late grandmother, Mrs. Mairo Nguessinda, my dear brother, the late Yandjimadji Tabo, my dear mother, the late Marie N'Dodjam and to my suffering father, Tabo Nguessinda and the whole family.

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ABSTRACT

Cotton (*Gossypium hirsutum* L.) grown under drip irrigation was evaluated over a two year period for physiological and morphological responses. Three water levels representing, 103, 93 and 87% of estimated consumptive use (63.6 ha-cm) were used in Marana, AZ. in 1983. In 1984, cotton was grown under eight drip irrigation treatments corresponding to 120, 100, 80 and 60% of the estimated consumptive use (79.5 ha-cm) in Stanfield, AZ. These volumes of water were applied as small daily amounts and larger weekly amounts for a total of eight irrigation treatments. The experimental design was a randomized complete block with four replications.

Mean leaf area ratio ($\overline{LAR}$), leaf area index (LAI), mean net assimilation rate ($\overline{NAR}$), mean relative growth rate ($\overline{RGR}$), mean crop growth rate ($\overline{CGR}$), plant height and the number of mainstem nodes were determined using the growth analysis method. Transpiration, diffusive resistance, leaf and ambient temperatures were measured with a steady state porometer. Apparent photosynthesis (APS) was determined in 1983 with an infrared gas analyzer which measured CO_2 concentrations.

In 1983, the cotton plants from the 103% irrigation treatment had greater transpiration, lower diffusive resistance and lower APS than the 93% treatment plants. In 1984, no significant differences were observed between the seasonal transpiration rates from the eight irrigation treatments. Cotton plants grown under the 120% treatment

showed superior diffusive resistance responses than those from the 60% treatment. Temperature differentials were higher in the 120% treatments than in the 60% treatments. No significant differences were found between $\overline{LAR}$, $\overline{NAR}$, $\overline{RGR}$ and $\overline{CGR}$ during 1983 and 1984.

Even though there were no differences between the total number of flowers produced in the three treatments in 1983, the 93 and 87% treatment plants produced more seed cotton than the 103% treatment plants. In 1984, the seed cotton yield from the 60% daily treatment was significantly the lowest.

Due to the problems related to the late initiation of treatments and excessive rainfall, the physiological and morphological responses of cotton were inconsistent across the various water levels in 1983. Regression analysis confirmed the erratic responses of cotton plants from the weekly treatments across the wide range of environmental conditions in 1984.

CHAPTER 1

INTRODUCTION

Throughout the world, cotton (Gossypium hirsutum L.) is considered to be the most important fiber crop for the textile industry. Not only is the fiber in high demand, but also the seed. Processed cottonseed provide oil, meal, and hulls for food and chemical industries and these products are a good source of protein and vegetablec oil for human and animal consumption.

Cotton which is grown in more hectares in Arizona than any other crop has one of the highest consumptive water use (approximately 104.7 ha-cm), thus making the existing water problems very serious (Erie et al., 1982). Irrigated cotton in Arizona depends largely on groundwater supplies which are getting scarce and expensive. Because of the rising water and energy costs and scarcity of water, water conservation becomes a necessity from the economical as well as the legal standpoint. In Arizona, the "Groundwater Management Law of 1980" limits new well development and water use (Arizona State Legislation, 1980).

In the semi-arid regions of the Southwest in general, and in Arizona in particular, increased water costs and water conservation are of primary concern to growers. Drip irrigation may partially alleviate these problems by enabling water conservation. Drip irrigation has proven to considerably reduce water use as compared with conventional irrigation methods and yet allows for high levels of cotton production (Davis et al., 1980). If used properly, drip irrigation maximizes crop transpiration and minimizes soil-water evaporation; consequently, both high yield and water conservation can be obtained (Matthias et al., 1983). Fangmeir (1977) determined the maximum application efficiency of drip irrigation to be 90% as compared to the 70% of furrow irrigation.

Other drip irrigation benefits include: (1) uniform and continuous supply of moisture creating a favorable condition for plant growth and development (Hofmann and Taylor, 1983); (2) the frequent, uniform and efficient application of water which provides a very effective vehicle for application of nitrogen and for salinity management (Pennington and Briggs, 1983).

Being a new development, drip irrigation should be studied carefully and extensively in order to be used properly and efficiently for maximum water conservation and increased cotton yields. The environment under which any plant is grown has a direct influence on its growth and its development. Namken (1964) reported that soil moisture and air temperature account for 84% of variation in measurements of plant growth. The objective of this study is to evaluate the effects of different water levels applied by drip irrigation on the physiological and morphological development of cotton.

CHAPTER 2

LITERATURE REVIEW

Water supplies for irrigated cotton in Arizona and other semi-arid regions of the world are becoming scarce and expensive (Arizona Land and People, 1982). Because of the increased water costs and its limited availability, farmers need to conserve water while maintaining high yields.

Research dealing with plant growth under various environmental conditions has been extensively documented. Particular attention has been devoted to yield and its relationship with factors limiting photosynthesis. The literature indicates that very little work has been done to investigate the dependence of yield on the partitioning efficiency of the dry matter produced. In contrast, a great deal of information on the effects of environmental factors on physiological processes of plants has been reported in many studies. This review of literature pertains to growth analysis and the effects of water stress on the physiology and morphology of cotton. Because of limited research on drip irrigation, the various concepts presented in this review of literature may help to better investigate and understand cotton growth under drip irrigation.

Characteristics and Importance of Drip Irrigation

Agriculture uses over 85% of all water consumed in Arizona and in the arid west regions (Wilson et al., 1984). In pump irrigated areas of the main agricultural regions, water represents about 22 to 49% of the total variable costs of producing cotton.

In the semi-arid regions where increased water costs and water conservation are of primary concern to growers, drip irrigation is potentially an answer to many of the problems (Briggs et al., 1983). By using drip irrigation, farmers can reduce their water needs by 30 to 50% over conventional furrow methods in the Arid Southwest (Wilson et al., 1984). The operating costs of surface and subsurface drip irrigation systems are within 5% of those of conventional furrow-irrigated cotton, about $1778 per hectare in Arizona (Wilson et al., 1984). However, the annual fixed costs of equipment for drip irrigation systems are considerably greater. Annual fixed costs per hectare were about $864.50 per hectare for drip systems and about $370.50 per hectare for furrow in 1983 (Wilson et al., 1984). If used properly, drip irrigation maximizes crop transpiration and minimizes soil-water evaporation. Consequently both high yield and water conservation can be obtained (Davis et al., 1980).

Tollefson (1982) reported many advantages of drip irrigation system over the conventional furrow irrigation. Some of these advantages are uniform soil moisture distribution, reduced tillage, reduced weed control, enhanced fertility management, reduced water and energy use and increased yields. In 1982, near Casa Grande Deltapine 90 produced 2919.3 Kg of lint ha^{-1} with drip irrigation (Briggs et al., 1983). It was the first time a yield surpassed 2794.1 Kg of lint ha^{-1} in Arizona.

Drip irrigation has some disadvantages including its requirement of more intensive management and technical expertise, clogging of the tubes and emitters, and its high costs (Tollefson, 1982). Tollefson (1982) reported that there are usually no water savings over efficient furrow irrigation when drip systems are used on level, clay loam fields. The system must be maintained and serviced regularly.

Because drip irrigation is a new development in Arizona cotton, lack of data concerning crop coefficients for use in scheduling irrigation is a major problem. Thus, a study of cotton growth under drip irrigation would help to fully understand and properly manage the system for maximum water conservation and increased yields.

Growth Analysis Techniques

Growth analysis has been a valuable tool for the quantitative analysis of plant and crop growth since Blackman in 1919 found that growth generally follows the compound interest law. It has many uses in physiological research. It has been used to follow the dynamics of photosynthetic production of dry matter. Growth analysis can also be used to investigate species survival in different habitats, competition among species, genetic differences in yielding capacity and effects of environmental variables on crop growth.

Net Assimilation rates (g $dm^{-2}day^{-1}$), relative growth rate (g 100 $g^{-1}day^{-1}$), leaf area ratio (m^2 Kg^{-1}), crop growth rate (g $m^{-2}day^{-1}$)

are all growth functions which describe plant growth. The purpose of calculating a growth function is generally to describe or explain how one or more plant species respond to a given environmental situation. Comparisons of growth functions within and among different experiments would be less ambiguous if sources of variation other than imposed treatments could be eliminated.

The growth rate of a plant depends to a large extent on the amount of leaf area present and the rate of dry matter increase per unit of leaf area (net assimilation rate, g $dm^{-2}day^{-1}$) (Whitehead and Myerscough, 1962). Net assimilation rate was originally defined by Gregory (1917) as the rate of increase in total plant weight per unit of assimilating material. Subsequently Briggs et al. (1920) reported that the relative growth rate was the product of the net assimilation rate and the ratio of total leaf area to total plant weight, which they called 'leaf area ratio'. Blackman (1919) referred to the rate of interest as the efficiency of the plant as a producer of new material, and as a measure of the plant's economy in working. That rate of interest may be termed the efficiency index of dry weight production. The rate of interest is in the formula developed by Blackman (1919):

$$w_1 = w_0 e^{rt}$$

where w_1 = final weight

w_0 = initial weight

r = rate of interest

t = time

e = base of natural logarithm

Blackman (1919) stated that the growth of an annual plant, at least in its early stages approximately follows the compound interest law. The dry weight accumulated by a plant at the end of any period depends on the weight of the seed, the average rate at which the plant makes use of the material already present to build up new material and the period of growth.

According to Fisher (1920), the methods of calculation formulated by Briggs et al. (1920) for the analysis of plant growth are inaccurate because they introduce a large exaggeration when the plant is increasing in mass and they apply to periods of varying length. Fisher (1920) stated that the correct measure for the mean value of the relative growth rate over any period, long or short, is Blackman's (1919) "efficiency index".

Further contributions to the concept of growth analysis have followed this form of analysis, but other bases have been used for the resolution of relative growth rate. Thus, Crowther (1934), Ballard and Petrie (1936), Williams (1936), Heath (1937) and others have substituted leaf weight, usually because the accurate measurement of leaf area proved impracticable. Williams (1939), Tiver (1942), Tiver and Williams (1943), and Petrie and Arthur (1943) used leaf protein-nitrogen as an alternative measure of the active growing material.

Leaf Area as a Factor Determining Growth and Yield

Leaf area is commonly used in growth analysis because many scientists believe it is the best measure of the capacity for photosynthesis. However, in addition to the lamina, other organs can contribute to photosynthetic activity of plants. These contributions to total photosynthesis of the plant may sometimes account for a considerable fraction of the total dry matter production (Zelitch, 1971).

In growth analysis, the total leaf area of a canopy is expressed as "leaf area index" (LAI). Leaf area index is defined as the unit leaf area per unit area of ground surface (Kvet et al., 1971). Leaf area index is considered to be a measure of the capacity for photosynthesis.

The leaf area present in a canopy should be important in determining the potential for carbon dioxide exchange rate (CER) of plants regardless of size or shape of individual leaves (Pegelow et al., 1977). Canopy apparent photosynthesis in artificial communities of cotton plants increases with leaf area index (LAI) until a LAI of about 3, after which it either stabilized with additional LAI (at 20°C) or declined (at 30°C and 40°C). Carbon dioxide exchange rate increases with LAI values up to about 8 with soybeans (Glycine max (L.) Merrill) (Pegelow et al., 1977).

Milthorpe (1956) suggested that the rate of leaf area development is an important factor affecting growth rate and he minimized the importance of leaf photosynthetic rate. Stoy (1963) and Murata (1961) however, stressed the importance of leaf photosynthetic rate as a factor determining growth rate. Milthorpe (1956) argued that differences in rate of leaf area development were measurable and were associated with differences in rates of dry matter production among cottons and between cottons and other species. Buxton and Stapleton (1970) reported that LAI, rather than leaf type per se is the major determinant of CER per ground area.

Ashley et al. (1965) conducted an experiment to examine the seasonal growth of a cotton plant community in terms of leaf area and determine the relation between leaf area and yield characteristics. They found a definite relation between leaf area and total fruiting with an LAI of 2 to 5. When LAI reached 5, the total number of fruit on the plant remained constant until late season and then declined.

The total seasonal photosynthesis of a crop depends on the size of the photosynthetic machinery, its efficiency and the length of time during which it is active. An ideal situation results when the leaf area of a crop expands rapidly to attain its optimum LAI, thus making efficient use of radiant energy. The organs of photosynthesis (leaves, bracts) should remain active for a prolonged period of time and provide a good supply of assimilates to the reproductive and storage organs even during senescence (Nichiporovich, 1967).

According to Ashley et al. (1965), late season boll set increased as long as LAI was at or above 5. When LAI fell below 5, the number of bolls was not increased further. These studies showed that it is necessary to develop large plants early in the growing season for maximum yields. The yield of seed cotton was directly related to early development of plants.

LAI influences the efficiency of solar radiation interception by a crop canopy and it appears that maximal dry matter production is directly proportional to high values of LAI under weather conditions which are most favorable for photosynthesis (Shibles and Weber, 1965). Shibles and Weber (1965) reported that solar radiation interception increased with increasing leaf area development, reached a maximum, and remained constant with increase in LAI. The rate of dry matter production was found to be linearly related to percent interception.

Interaction Between Leaf Area and Net Assimilation Rates (NAR)

Another growth function used in growth analysis is NAR. The relative importance of NAR and leaf area in determining growth is still an open question because there are conflicting results from various studies. Watson (1952) reported that differences in leaf area production were more important than differences in NAR in determining growth. Thornley and Hurd (1974) stated that when tomatoes (*Lycopersicon lycopersicum* L.) were grown under various combinations of irradiance, day length, and CO_2 concentrations, differences in relative growth rate (RGR) could best be accounted for by differences in NAR. In contrast, Potter and Jones (1977) in comparing RGR of nine species of weeds and crop plants grown in three different temperature regimes, concluded that differences in RGR were not well correlated with differences in NAR. They included LAP (partitioning of daily weight gain into new leaf area) a new growth function and showed that RGR was closely related with LAP.

Net assimilation (NAR) is the rate of of dry weight increase per unit leaf area, and is a measure of photosynthetic efficiency (Radford, 1967). NAR is a measure of net carbon uptake after respiration. Not all changes in net assimilation rate are determined by variations in the rate of photosynthesis. NAR varies between and within plant species, with mineral nutrition, water supply, and with seasonal climatic conditions (Heath, 1937). However, Heath and Gregory (1938) found in their studies with cotton and other plant species that there is little variation in mean net assimilation rate for the early vegetative phase of the life cycle even in the most diverse environmental conditions.

For many plant species, it has been established that both the changes in net assimilation rate and leaf area ratio are linearly related to the logarithm of light intensity (λ); consequently the relationship between the logarithm of light intensity and relative growth rate should be curvilinear (Blackman and Wilson, 1951).

Heath (1937) working in South Africa found that in the cotton plant the net assimilation rate had no general trend during the vegetative phase but fluctuated about a mean rate. Crowther (1934) reported in his studies with cotton in the Sudan that there was no drift of net assimilation rate with time until flowering had begun. Working with oats (Avena sativa L.) Williams (1936) showed that NAR has no drift in time for the first four to six weeks. In contrast, experiments with Sudan grass (Sorghum sudanense (Piper) Staph) by Ballard and Petrie (1936) indicated a decrease in NAR 2 weeks after the first observation.

Yield analysis requires consideration of dry matter distribution between different plant parts as well as total dry matter accumulated. The factors controlling NAR are independent of the age of the plant during the vegetative phase. Potatoes (Solanum tuberosum L.) attained their maximum leaf area per plant in August and like the cereals showed rapid decrease in the rate of increase of leaf area in the later stages of growth (Watson, 1947). In general, variation in leaf area was the main factor determining differences in yield and variation in NAR was of minor importance (Watson, 1947). He also found that the net assimilation rate of sugar beet was slightly increased by later sowing. This implies that NAR declines with age, independent of change in external factors, but other explanations are possible.

Dry Matter Production and Partitioning

One of the major factors used in growth analysis is dry matter production and partitioning. The total amount of dry matter accumulated by a plant when growing is a function of its photosynthetic and respiratory activity (Patterson et al., 1978). However what is more important is how the products or assimilates are distributed to different parts of the plant. In cotton, the sinks which are of greatest concern are the bolls and seeds.

Average dry-matter distribution in mature cotton plant parts reported by McBryde and Beale (1896) was: roots, 14.6g; stems, 38.3g; leaves, 33.5g; Bolls, 23.5g; seed, 30.1g; and lint, 17.4g. White (1914) found that 12.2% of total seasonal production of dry matter was accumulated by first square, 28.8% by first bloom, and 48.5% by first open boll. White (1915) reported that deficiencies of any of the major nutrients lowered total dry-matter production. Deletion of nitrogen from the fertilizer delayed early-season growth, while deletion of phosphorus and potassium reduced dry-matter production subsequent to first square. Christidis and Harrison (1955) indicated that, in general, the higher the yield, the higher the ratio of lint to dry matter. Bassett et al. (1970) found that approximately two-thirds of the total seasonal dry matter was produced during a 6-week period. He also reported that with the earliest planting date, one-third of the dry-matter was produced during July, and another one-third during the first 2 weeks of August. The period of peak growth was delayed for about 5 days by each month of delay in planting (Bassett et al., 1970).

For cereals and soybeans, Danyard et al. (1971) concluded that differences in the grain filling period during which dry-matter accumulates account for more yield variation among cultivars than do differences in accumulation rate. Differences in the average rate of dry matter accumulation in the ears accounted for less than 16% of the grain yield variation in corn (Zea mays L.).

Karami and Weaver (1972) reported that normal-leaf lines of cotton have a higher percentage of dry weight in stalks and leaves than okra-leaf lines. As a result of better distribution of dry matter to economic yield, okra-leaf lines had 15% higher harvest index (economic yield biological yield^{-1}) than normal-leaf lines. Mu'Allem (1976) found that tetraploids are more efficient than hexaploids in partitioning assimilates to the reproductive parts of the plant.

The indeterminate growth habit of cotton results in a competition for assimilates between vegetative and reproductive growth. There is an inefficient and uneven distribution of assimilates due to the distribution of younger and older leaves. Young active leaves are located next to the vegetative sink whereas older shaded leaves are near the reproductive sink. Consequently, boll yield is not necessarily proportionally related to total photosynthetic activity (Kerby, 1976). Saleem and Buxton (1976) reported that assimilates are inefficiently translocated down the main stem axis when total available carbohydrates in the central portion of the stem, which carried 48% of the boll load was only 50% of that in the lower or upper stem portions.

Plant Height

Plant height is often considered in growth analysis. It is sometimes used to determine the trend of dry matter accumulation. Saxena (1963) noted that a positive correlation exists between dry matter accumulation, yield of seed cotton and height in the '216 F' cotton cultivar. He found that differences in plant height and dry matter accumulation accounted for 83% of the variation in the yield of seed cotton.

Heath (1937) reported that from a height of 10 cm until flowering the growth of the main axis of cotton plants is approximately exponential. From germination up to a height of 10 cm, growth does not follow the same exponential curve, but showed a higher growth rate due to a rapid extension of the hypocotyl. In contrast the dry weight increase is exponential from germination until flowering.

Andries et al. (1971) found that as the row width was reduced, plants got shorter. This could be due to the considerable competition between plants growing closer to each other. They noted that on shorter plants bolls were produced on the upper portion of the stem. Brown (1966) reported that tall plants had longer and greater number of main stem nodes.

Physiological and Morphological Development of Cotton As Affected by Water Stress

The optimization of cotton growth, lint yield, and water-use efficiency requires a knowledge of plant physiology, soil science, and agricultural metereology, as well as their integration with the technology and economics of soil, crop, and water management on the farm. The irrigation schedule is particularly important, not only because of the water needs in arid areas, but also because of the required balance between vegetative and fruiting development in cotton. This balance is obtained by a proper timing of irrigation at sowing, fruiting, and harvesting periods of growth.

Water deficits affect many physiological processes of plants (Hsiao, 1973). The major affects of water deficits on productivity are a reduction in carbon fixation (stomatal closure) and a reduction in leaf expansion.

Moisture stress causes boll shedding in cotton (Ewing, 1918; Lloyd, 1920; Hawkins et al., 1933). Quisenberry and Roark (1976) concluded that less determinate cotton cultivars are better adapted to limited moisture environments. Some cotton species such as *G. thurberi*, survive drought by shedding leaves, others by developing photoplasmic resistance (e.g., *G. hirsutum*) (Hawkins et al., 1933).

Shedding is increased by factors such as deficient or excessive soil moisture, inadequate number of fertilized ovules, improper nutrient supply, excessive heat or cold, damage from insects, diseases or a combination of these factors (Lloyd, 1920). Both ethylene production and boll abscission increased to maximum values just before each irrigation, except early in the season when sensitivity to stress appeared to be relatively low (Guinn et al., 1976). The loss of potential yield due to lower bloom production was almost four times as great as the loss due to increased boll abscission in water-stressed plants (Guinn et al., 1976).

In investigations with sea island cotton (Gossypium barbadense L.), Mason (1922) cited cloudy days and daytime rain as conditions retarding boll growth and augmenting boll shedding. Dunlap (1945) reported low irradiance and short days were more important causes of shedding than higher temperatures or low available moisture. Goodman (1955) also correlated cloud cover with increased shedding and noted some varieties were more susceptible than others. Rain may also increase shedding by rupturing pollen in open flowers (Goodman, 1955).

When irrigation water is limited, it is extremely important to know at what stage of development the crop can best tolerate a water deficit. Grimes et al. (1970) reported that cotton plants should not be stressed for water before the bloom stage. They studied the effects of water stress at different times during the growing season. They found that early stress (on June) caused square shedding and a subsequent depression in flowering. Midseason stress (late July) decreased boll retention and hastened cutout (temporary cessation of growth and blooming). Late stress (late August) induced abscission of almost all young bolls but not of older bolls. Grimes et al. (1978) stated that the optimum time for first irrigation was influenced by water retention capacity of the soil; the greater the water retention capacity, the later the optimum time.

The current trend toward short-season production of cotton potentially could decrease water requirements, as well as the need for insecticides and fertilizer. However, to obtain acceptable yields in a short season, cotton plants should fruit as early as possible and rapidly. Delays and interruptions in boll production could either reduce yields or lengthen the time required to produce the crop; consequently loss of squares (floral buds) and young bolls is more important with short-season than with full-season culture (Guinn et al., 1981).

Longenecker and Erie (1968) stated that plants should never be allowed to develop moisture stress before flowering. But for maximum seasonal production in Arizona, short staple varieties should be permitted to develop mild moisture stress during the major fruiting period with moderate leaf wilt showing about midday.

Stomatal activity, photosynthesis, and nitrate reduction activity are generally considered to be important in affecting yield. Bielorai and Hopmans (1975) reported that photosynthesis and transpiration of cotton were considerably reduced by induced water stress. Jordan and Ritchie (1971) observed that the stomata of field grown cotton did not close at -27 bars leaf water potential, whereas, stomata of greenhouse grown plants closed at -16 bars water potential. Boyer (1965), however, did not observe any increase in diffusive resistance in cotton leaves when water stress was imposed by salinity, but observed a reduction in photosynthesis.

Ackerson et al. (1977) stated that since very high diffusive resistances were obtained only on leaves that were visibly wilted, measurement of leaf diffusive resistance may not be a reliable estimate of plant water stress and related physiological activity. Measurement of stomatal activity may not be a good criterion for assessing plant water status of cotton. The measurement of one or more physiological processes may prove a better index of plant water status as well as providing sensitive selection criteria for breeding more drought tolerant varieties.

Cutler and Rains (1977) found that control plants began to close stomata on leaves at the ninth node at water potentials of about -18 bars, whereas plants from treatments subjected to stress during development maintained open stomata at the same nodal position to water potentials as low as -22 to -24 bars. They also observed that the diffusive resistance of older leaves at node 3 was slightly greater throughout the range of water status studied, and in these leaves stomatal closure occurred at slightly higher values of water potential than in leaves at node 9. Raschke (1975) argued that there should be no expectation of close relationship between various physiological processes, since stomatal opening is related most intimately to turgor potential differential between guard cells and adjacent epidermal cells, not to any measure of bulk tissue water status.

Light intensity and leaf water potential are two of the most important factors controlling stomatal resistance of whole plants and individual leaves (Jordan et al., 1975). Turner (1974), Turner and Incoll (1971), and Turner and Begg (1973) reported in their studies with maize (*Zea mays* L.), sorghum (*Sorghum bicolor* Moench), and tobacco (*Nicotiana tabacum*) that the higher values for the diffusive resistance of leaves near the bottom of the plant canopy were due to lower irradiation and senescence. There was no increase in leaf resistance until the leaves were visibly senescent and yellow. In contrast with the above reports, studies by Holmgren et al. (1965) showed that stomatal resistance of cotton leaves grown under controlled conditions (adequate soil moisture) increased with age. Davis (1974) observed in a study that increases in leaf resistance of beans (*Phaseolus spp.* L.) occurred at a nearly constant "developmental age" (80% of time from leaf maturity to death) regardless of leaf position on the plant.

In Mississippi, several weeks of induced drought reduced rates of leaf extension, height increase, and vegetative node production as much as 50% at mean daily water potential values of -11 bars (McMichael and Heskesh, 1978). Stomatal conductance was reduced 50% at -27 bars (McMichael and Heskesh, 1978). The authors found that flowering was apparently unaffected by the treatments. However, boll periods (days from white flower to open harvestable boll) were shortened by several days by the dry treatments. Boll size (total surface area) was not significantly reduced, but a significant yield reduction in the two drier treatments indicated that another yield component was significantly affected (McMichael and Heskesh, 1978). Davenport et al. (1978) studied the effects of water stress on cotton. They found that water stress inhibited transport of IAA, but not ABA, GA_3 or Kinetin. Acetyl COA carboxylase appeared to be unaffected by the level of water-stress applied, whereas synthesis or activity of the fatty acid synthase was stimulated. After a period of rehydration, they observed that previously stressed cotton leaves produced more wax than was being produced prior to being stressed.

Moisture stress decreases leaf area, photophosphorylation, polyribosome content, and protein synthesis and causes closure of stomata (Boyer, 1973). Moisture stress decreases synthesis and activity of ribulose 1,5 diphosphate carboxylase (Jones, 1973) and increases photorespiration (Lawlor and Fock, 1975). These effects decrease net photosynthesis and, thereby create a nutrient shortage. They also found that moisture stress also causes hormonal imbalance. A water logged condition from over irrigation, low infiltration rate or flooding can be as detrimental to yield as excessive moisture deficits.

Tanner (1963) concluded from his studies in Wisconsin with alfalfa (Medicago sativa L.) that a 10% decrease in transpiration in early September caused a temperature increase of 1°C. Consequently, a measure of the difference in temperatures between plants and the environment might yield a difference in transpiration. Hsiao (1973) found that water stress leads to stomatal closure which in turn causes increases in leaf temperature as a result of reduced transpiration. Plant water status can be evaluated by the difference in canopy temperature between stressed and nonstressed plants. Tanner (1963) reported that non-irrigated plants had higher temperatures than irrigated plants. The high temperature in non-irrigated plants was probably due to stomatal closure caused by water stress. Under differential irrigation conditions, Gardner et al. (1981) found that the daily standard deviation of midday canopy temperatures in fully irrigated plots of corn (Zea mays L.) was about ±3°C, whereas it was as large as ±4.2°C in non-irrigated plots. It was suggested that irrigation is needed when a standard deviation is above ±3°C. Ehrler (1973) used thermocouples embedded in cotton leaves to determine leaf temperatures. He found that the leaf-air temperature differences decreased after irrigation, reached a minimum some days later and then increased as the soil-water became limiting. Observing that there was a linear relationship between the leaf-air temperature difference and the vapor pressure deficit of air, Ehrler (1973) concluded that these differences could be successfully used to schedule irrigation. Idso et al. (1977) and Jackson et al. (1977) used the canopy temperatures minus the air temperature as an index of crop water status. They called the difference the "stress-degree day" and related this parameter to yield and water requirements.

Sabbe and Cathey (1969) observed that in plants stressed for water, more of the photosynthate is translocated to the roots. The roots, being stressed the least, would probably be requiring the most photosynthate for growth. Bolls closest to photosynthetically active leaves serve as strong sinks for photosynthate exported from such leaves (Ashley, 1972). However, young bolls are shed despite their closeness to active leaves and older bolls get priority for available photosynthate.

Jordan and Ritchie (1971) found that stomatal resistance in cotton, estimated from transpiration measurements, was unaffected by water potentials down to -27 bars, although it increased to infinity at a leaf water potential of -16 bars in potted plants. Jordan (1970) commented that water potentials must decrease to at least -18 bars during part of the day for growth to be affected. The diameters of cotton bolls increased consistently for 16 days, even when leaves were severely wilted (Anderson and Kerr, 1943). Meyer et al. (1960, P. 159-160) suggested that growth in such bolls, as well as in other meristematic regions, was not suppressed by water stress, except when stress was very severe. Clearly, photosynthesis, leaf expansion and meristematic activity differ in sensitivity to changes in water stress.

Cotton fiber length is determined primarily by the genetic make-up of the cultivar. However, fiber length may be shorter than normal if the plant is subjected to stress during the fiber elongation period. Marani and Amirav (1971), and Amir and Bielorai (1969) did not find any effects of prolonged periods of soil moisture stress on lint quality. Water stress lowered yield by reducing boll size late in the season.

Water stress not only has a marked effect on production of squares and boll setting, it also effects the time to reach maturity (Marani and Amirav, 1971).. Drought hastens maturity and excessive soil moisture often delays it. When maturity is reached, boll setting and square production cease. Both can resume when mature bolls start to open, leading to a second fruiting.

Adaptation of Plants to Water Stress

The capacity of plants to adjust in order to prevent water stress injury has not been well investigated even though there have been extensive research done on the sensitivity of plants to water stress. The concept of "adaptation" (or "hardening") to water deficits is a relatively old one (Maximov, 1929), however little attention has been paid to the phenomenon and its manifestations. Plants subjected to various degrees of water stress are known to be "hardened" and thus capable of surviving subsequent drought with less injury than plants not previously stressed (Levitt, 1972). Hearn (1972) reported that there was a consistent though small, reduction in node number with decreasing water status. Cutler and Rains (1977) stated that the ability of plants to recover is a function of stress intensity and/or duration of stress. They also found that leaf growth was affected by the conditioning treatments more than was mainstem growth. Levitt (1972) determined that leaf area is essential in influencing potential productivity and interacts with root absorption, through its influence on transpiration, in determining water balance.

Parker (1968) suggested that a reduction in transpiring leaf area and/or an increase in root absorbing surface play a central role in drought adaptation. Cutler and Rains (1977) observed that leaf weight and stem weight, as a fraction of total plant weight, decreased with decreasing irrigation frequency while the root weight percentage increased. Browner and de Wit (1968) reported a dramatic increase with moderate stress in root/shoot and root/leaf ratios, thus illustrating a strong influence of irrigation frequency on net dry weight partitioning.

The purpose of this work was to evaluate the effects of different water levels on the transpiration, diffusive resistance, leaf temperature, leaf area ratio, net assimilation rate, relative growth rate, crop growth rate, plant height, dry weight partitioning and yield of cotton grown under drip irrigation. The physiological and morphological development of cotton were analyzed under eight irrigation treatments over two growing seasons. These analyses help to understand cotton development under drip irrigation.

CHAPTER 3

MATERIALS AND METHODS

Field Experiments of Summer 1983

Location and Materials

The experiment was conducted in a field of drip irrigated cotton (Gossypium hirsutum L. 'Stoneville 506'). The field was located on a farm owned by Mr. John Kai, approximately 17.6 km north of Tucson, Arizona.

A below ground drip irrigation tape was laid 5 cm along one side of each row of cotton plants and buried to about 5 to 8 cm below the soil surface. Irrigation water was filtered, the pressure regulated to 0.07 MPa and then delivered through a 2.0 mm polyethylene Chapin^R Twin-wall drip tape. An Irri-Trol^R timer controlled the different rates of water applied to the soil.

On 30 March 1983, a four-row planter was used to dry-plant cotton on a Vinton-Anthony sandy loam soil. The row spacing was 1.02 m. The field was first irrigated on 30 April.

The 1.5 ha experimental site was subdivided into three equal sized plots. Each plot was assigned one of the three irrigation treatments. The three water levels were 103, 93, and 87% of 63.6 ha-cm which was the estimated consumptive use of cotton in Marana, Arizona during 1983 (Matthais et al., 1983). The three treatments, 103, 93 and 87%, represented 65.5, 59.1 and 55.3 ha-cm of irrigation water, respectively. They were referred to as the wet, medium, and dry treatments, respectively. Because of the problems related to the installation and operation of the drip system, the water treatments were not started until 9 July 1983. Each of the three plots were divided into eight subplots. Each subplot consisted of eight rows of plants and was 30.3 m in length.

Pink bollworm (Pectinophore gossyiella Saunders), bollworm (Heliothis zea Boddie), and lygus (Lygus SSP.) were controlled with Vydate (methyl 2 - (dimethylamino) -NCC (methylamino) carbonyl (oxy) - 2 - oxoethanidothioale). The experimental area was treated with glyphosate (isopropylamine salt of N. (phosphono-methyl) glycine) for weed control. Additional hand weeding was done as needed throughout the growing season.

A sheltered Science Associate, Inc. hygrothermograph was used to record ambient temperature in the field. Rainfall data were obtained from a rain gauge placed in the experimental site.

Sampling Techniques

Dry weight and leaf area determination: Determinations of leaf area and dry matter accumulation were made from plant samples taken on seven dates: 21 June, 27 June, 5 July, 14 July, 21 July, 29 July and 11 August.

One plant was chosen randomly from an outside row in each subplot at each sampling date. A total of eight plants per treatment were used for dry weight and leaf area measurements. These plants were cut at the ground level, placed in large plastic bags and brought back to the laboratory for evaluations. In the laboratory, each plant was separated into bolls and squares, stems, leaves and petioles. The samples were oven-dried at 80°C for 24 hours and dry weights determined.

Nine representative leaves, three from the top, three from the middle and three from the base of each plant, were detached from the plant. Leaf area of the nine leaves was measured with a Li-Cor^R Model 3100 area meter. The leaves were then oven-dried at 80°C for 24 hours and the leaf area (m^2) to leaf weight (g) ratio ($A\ WL^{-1}$) determined.

To estimate the total leaf area (m^2) of the plant, the total dry weight (g) of the leaves from the whole plant samples was multiplied by specific leaf area ($A\ WL^{-1}$).

Growth Parameters Determination

The following growth parameters were calculated from the dry weights and leaf area values:

Leaf Area Index (LAI): Calculated by dividing the total leaf area (m^2) of the plant by the ground area (m^2) covered (Kvet et al., 1971).

$LAI = A\ GA^{-1}$

Mean Leaf Area Ratio ($\overline{LAR}$): Calculated as the mean ratio of the assimilatory material (m^2) per unit of plant material present (kg) (Radford, 1967).

$\overline{LAR} = (A_2 - A_1)(W_2 - W_1)^{-1}(LnW_2 - LnW_1)(LnA_2 - LnA_1)^{-1}$ m^{2}kg^{-1}

A_1 = Leaf area (m^2) at previous sampling period

A_2 = Leaf area (m^2) at current sampling period

W_1 = Total plant dry weight (g) at previous sampling period

W_2 = Total plant dry weight (g) at current sampling period.

Mean Net Assimilation Rate ($\overline{NAR}$): Calculated as mean increase of plant material (g) per unit of assimilatory material (dm^2) per unit of time (day) (Radford, 1967).

$\overline{NAR} = (W_2 - W^1)(A^2 - A^1)_{-1}(LnA_2 - LnA_1)(T_2 - T_1)^{-1}$ g dm^{-2} day^{-1}

T_1 = Previous sampling day

T_2 = Current sampling day

Mean Relative Growth Rate ($\overline{RGR}$): Calculated as the mean increase of plant material (g) per unit material present (100g) per unit of time (day) (Radford, 1967).

$\overline{RGR} = (LnW_2 - LnW_1)(T_2 - T_1)^{-1}$ g 100g^{-1} day^{-1}

Mean Crop Growth Rate ($\overline{CGR}$): Calculated as the mean increase of plant material per unit of time (Kvet et al., 1971).

$\overline{CGR} = (W_2 - W_1)(T_2 - T_1)^{-1}$ g m^{-2} day^{-1}

Plant Height and Number of Nodes Measurements

A total of 24 randomly chosen plants were tagged at the cotyledonary nodes. There were 8 tagged plants in each irrigation treatment. Height measurements and counts of mainstem nodes were made on these plants on the following five dates: 5 July, 12 July, 21 July, 29 July, and 15 September.

Photosynthetic Measurement

Apparent photosynthesis was measured using the methods of Clegg and Sullivan (1975), Clegg et al. (1978) and Cain (1984). All apparent photosynthesis measurements were made on relatively clear days and approximately the same period in the day (between 1000 MST and 1300 MST).

Transpiration, Diffusive Resistance, Leaf and Ambient Temperature Measurement

A Li-Cor^R LI 1600 steady state porometer was used in the field to measure transpiration rate (g H_2O $m^{-2}s^{-1}$), diffusive resistance (s m^{-1}), leaf temperature (°C) and cuvette temperature (°C). Cuvette temperature corresponds to the ambient temperature at the time of measurement. The Li-Cor LI 1600 is made up of two parts: the readout-control console and the sensor head. A sample is inserted onto the cuvette aperature and held in place by a plexiglas clamp. The aperature of the porometer was 2.0 cm^2. The relative humidity of the cuvette, in contact with the sample, is held constant. A period of approximately 30 seconds was necessary for a reading from the porometer which was placed on the leaf sample (most recently matured leaf). Dessicant was as dry as possible before the instrument is taken in the field. The small hose fittings had to be continuously checked, otherwise damaged ones cause considerable errors in reading. The porometer measurements were made at the same time as the photosynthetic measurements, thus obtaining all the physiological variables under similar environmental conditions.

At each sampling period, three plants per plot were measured with the porometer for a total of 24 plants per treatment and 72 plants for the entire experimental field. Data were collected from the porometer on the following seven dates: 22 June, 1 July, 6 July, 13 July, 28 July, 11 August and 1 September, 1983.

Soil Moisture

Soil moisture level was monitored throughout the growing season with a Campbell Pacific Nuclear Corporation Model 503 neutron probe. Twenty-four metal access tubes (7.6 cm diameter) were installed at approximately 1.22 m deep in the field. To calibrate the access tubes, soil samples were collected at four 30.5 cm intervals to a depth of 1.22 m, placed in cans and their wet weights (g) were determined. These soil samples were oven-dried and weighed. From the two weights, percent moisture was calculated as follows: (wet weight - dry weight) (dry weight)$^{-1}$. Just after the soil samples were collected, neutron probe readings were taken at the four depths. The readings were then converted into count ratios by dividing actual probe reading by the average of the standard counts. A linear regression model was constructed to relate count ratio with percent soil moisture. Count ratio and percent soil moisture were graphed to obtain a standard curve.

During the growing season, neutron probe readings at the four depths were recorded and count ratios determined by dividing the actual readings by the average of 10 standard counts. Using count ratio as independent variables, the dependent variables were read from the standard curve; the dependent variables represented soil moisture percentages at four depths.

Field Experiments of Summer 1984

Location and Materials

This work was conducted in a field of drip irrigated cotton (*Gossypium hirsutum* L. 'Deltapine 90'). The experiment was laid out as a randomized complete block with four replications in a field located in Stanfield, Arizona on a farm owned by Mr. Dennis Nowlin. The experimental site was 4.05 hectares in size.

On 30 March, 1984, a John Deere 7100 was used to plant cotton at a planting rate of four seeds per 30.48 cm of row on a Trix clay loam soil. Because of stand failure, the field was replanted on 28 April. A drip tube placed on the surface in the center of every seedbed was used to irrigate the cotton field. The plots were 96.5 cm in width and 146.3 meters in length. There were eight rows per experimental plot. The drip lines, 157.5 cm apart, were laid on the wide beds between two plant rows. The quantity and frequency of irrigation water applied were controlled by a Matarol^{R} controller. From 3 July to 10 August, 1984, 192.64 kg of nitrogen per ha were applied to the field by fertigation.

Cotton seeds were treated with Vita-Vax and an in furrow treatment at planting of PCNB-gran (pentachloronitrobenzene) and Captan (N-[(trichloromethyl-thio)]-4-Cyclo). Caparol and Treflan were incorporated into the soil prior to planting for weed controls.

Caparol was also sprayed after emergence to eradicate weeds. Additional hand hoeing was done as needed throughout the growing season.

Eight irrigation treatments were used to study the effects of various water levels on the physiological and morphological development of cotton. The eight treatments received either small daily amounts of water (daily treatment) or large weekly amounts of water (weekly treatments) for a total of 92.4, 77.0, 61.6, 46.2 ha-cm corresponding respectively to 120%, 100%, 80% and 60% of estimated consumptive use (79.5 ha-cm). Each irrigation treatment consisted of eight rows of plants and four drip lines. The irrigation treatments were initiated on 8 July 1984. An estimated total of 226.1 mm of precipitation fell during the growing season.

Soil Moisture

To monitor soil moisture, thirty-two 1.37 meter metal access tubes were placed at a depth of approximately 1.22 m in the field. Each access tube was installed between two rows of plants near the drip line in every treatment. The calibration of the access tubes was done as described earlier. A Troxler^R neutron probe was used to take readings at four depths (30.5 cm intervals).

Sampling Techniques

Dry weight and leaf area determination: The sampling method was as described in the 1983 field experiment in Marana, Arizona. Plant samples for determination of dry weight and leaf area were collected on 12 dates: 2 July, 10 July, 17 July, 24 July, 1 August, 7 August, 16 August, 21 August, 30 August, 6 September, 13 September, and 19 September, 1984.

One meter of plants was randomly chosen from the two outside rows in each treatment at each sampling date. Plant samples were not taken from the four middle rows which were used for yield estimates. The two outside rows of plants were not sampled because of possible border effect. Due to time and equipment constraints, plant samples were not collected from the 80% daily and weekly treatments.

The sampling technique and the measure of leaf area were as described earlier in the 1983 field experiment in Marana, Arizona.

Transpiration, Diffusive Resistance, Leaf and Ambient Temperature Measurement

Transpiration rate (g H_2O $m^{-2}s^{-1}$), diffusive resistance (s m^{-1}), leaf temperature (C) and cuvette temperature (C) were measured with a Li-Cor^R LI 1600 steady state porometer. At each sampling period, three plants per treatment were measured with the porometer for a total of 24 plants per replication and 96 plants for the entire experimental field. Data were collected from the porometer on the following seven dates: 19 July, 24 July, 1 August, 7 August, 21 August, 6 September, and 13 September, 1984.

Transpiration rates, diffusive resistance and temperature differential of individual treatments across a wide range of environmental conditions were analyzed with the regression analysis technique developed by Finlay and Wilkinson (1963). Each individual regression line compares the response of the individual irrigation treatment with the mean response of all treatments being compared.

Growth Parameters Determination

Leaf area index, mean leaf area ratio (m^2 kg^{-1}), mean net assimilation rate (g dm^{-2} day^{-1}), mean relative growth rate (g $100g^{-1}$ day^{-1}), mean crop growth rate (g m^{-2} day^{-1}) were calculated as previously described.

Plant Height and Number of Nodes Measurement

Thirty-two randomly chosen plants were evaluated for height and number of nodes. Orange tags were attached at the base of the stems of the plants, thus making possible easy observation on the same plants. Height measurements and counts of number of mainstem nodes were made on the same plants on 11 sampling dates: 3 July, 10 July, 17 July, 24 July, 1 August, 7 August, 21 August, 30 August, 6 September, 13 September, and 19 September.

Fruiting Characteristics and Yield

To determine the fruiting characteristics during the flowering period, flowers in 2.13 meter long subplots were tagged as they opened. There was one subplot in each of the 32 plots. Mature bolls were hand harvested along with the dated tags at the end of the growing season. On 2 November, the four middle rows of each treatment plot were machine harvested to obtain a second yield estimate.

CHAPTER 4

RESULTS AND DISCUSSION

Physiological and morphological characteristics of the cotton plant were measured to determine the effects of different drip irrigation treatments on the development of cotton. The results were obtained from field experiments conducted during the 1983 and 1984 growing seasons in Marana and Stanfield, Az., respectively.

The regression analysis technique developed by Finlay and Wilkinson (1963) provides a meaningful way of analyzing the physiological characteristics (transpiration, diffusive resistance and temperature differential) of individual treatments across a wide range of environmental conditions. In this analysis, each of the individual regression lines compares the response of the individual irrigation treatment with the mean response of all the treatments being compared. A wide range of environmental conditions is then created by combining the physiological responses of cotton from all the treatments being evaluated. The two important factors in the regression analysis are the regression coefficient (b) and the mean treatment response. By definition the average stability for a group of responses is b=1.0. The deviation of the regression coefficient from 1.0 determines the degree of stability of the treatment plants across the range of environmental conditions. If two or more irrigation treatments have the same mean physiological response, the one with the lowest regression coefficient would be considered the most stable across a wide range of environmental conditions.

Irrigation Effects on Cotton Physiology

Transpiration

The seasonal transpiration rates showed a declining trend among the 103, 93, and 87% of 63.6 ha-cm which was the estimated consumptive water use of cotton in Marana in 1983 (Table 1). The transpiration rate in the 103% treatment was greater than the rate in the 93% treatment. The transpiration rate in the 87% treatment was intermediate to the rates in the 93 and 103% treatments. This could be due in part to the small differences between the amounts of water applied and the excessive precipitation (49.0 cm).

After 13 July 1983 when treatments were initiated, the 103% treatment plants had consistently higher transpiration rates than the 93% treatment plants. However, the relationship between the 87% and the other two treatments was inconsistent. The 87% treatment plants tended to have transpiration rates similar to the 103% treatment plants.

There was no significant difference in the seasonal mean transpiration rates of cotton grown under the eight irrigation treatments in 1984 (Table 2). Overall mean transpiration rates ranged from 0.2370 to 0.2560 g H_2O m^{-2} s^{-1}. In general, the mean transpiration rate of daily treatments (0.2491 g H_2O $m^{-2}s^{-1}$) were slightly higher than the means of weekly treatments

TABLE 1. Transpiration rates over the growing season of cotton grown under three drip irrigation treatments. Marana, AZ. 1983.

Treatment[1]	Transpiration Rates ($g\ H_2O\ m^{-2}s^{-1}$)							
	22 June	1 July	6 July	13 July	28 July	11 Aug.	1 Sept.	Mean
103	0.1545	0.2090	0.2318	0.3238	0.3101	0.2600	0.2840	0.2513
93	0.1559	0.1796	0.1904	0.3379	0.2806	0.2400	0.2537	0.2392
87	0.1753	0.1900	0.2148	0.3245	0.3007	0.2600	0.2577	0.2449
MEAN	0.1625	0.1900	0.2123	0.3287	0.2971	0.2500	0.2651	0.2431

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[1] Percent of estimated consumptive use (28.60 ha-cm) of cotton in Marana.

TABLE 2. Transpiration rates over the growing season of cotton grown under eight drip irrigation treatments. Stanfield, AZ. 1984.

Treatment[1]	Transpiration Rates ($g\ H_2O\ m^{-2}s^{-1}$)							
	19 July	24 July	1 Aug.	7 Aug.	21 Aug.	6 Sept.	13 Sept.	
120 D	0.1745 ABC[2]	0.2601 A	0.3262	0.4069 B	0.2287 AB	0.1986 C	0.1972 B	0.2560
100 D	0.1705 ABC	0.2985 ABC	0.3355	0.3725 AB	0.2324 B	0.1673 CB	0.1920 B	0.2540
80 D	0.1908 BC	0.3043 ABC	0.3380	0.3673 AB	0.2219 AB	0.1312 B	0.1772 B	0.2472
60 D	0.1815 ABC	0.3338 C	0.3450	0.3573 AB	0.2182 AB	0.0952 A	0.1530 A	0.2406
120 W	0.1653 AB	0.2999 ABC	0.3293	0.3481 AB	0.2035 AB	0.2029 C	0.1975 B	0.2510
100 W	0.1614 A	0.3194 BC	0.3337	0.3254 A	0.1973 A	0.1518 B	0.1834 B	0.2389
80 W	0.1939 C	0.2789 AB	0.3275	0.3546 AB	0.2253 AB	0.1546 B	0.1851 B	0.2457
60 W	0.1689 ABC	0.3048 ABC	0.3330	0.3345 AB	0.2081 AB	0.1336 B	0.1761 B	0.2370
Mean	0.1758	0.3000	0.3335	0.3583	0.2169	0.1544	0.1827	0.2459

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1. Percent of estimated consumptive use (32.2 ha-cm) of cotton in Stanfield, applied on a daily (D) or a weekly (W) basis.

2. Values followed by the same letter within a date are not significantly different at the 0.05 level according to the Student-Newman Keuls Multiple Range Test.

(0.2428 g H_2O $m^{-2}s^{-1}$). It should be noted that, due to the problems (longer time required to apply weekly treatments than to apply daily ones) in applying weekly treatments, the responses of various physiological and morphological attributes of cotton under those treatments were less consistent than under daily treatments. As expected, mean transpiration rates from wetter (120%) treatments (0.2560 g H_2O $m^{-2}s^{-1}$) were slightly greater than the means from drier (60%) treatments (0.2406 g H_2O $m^{-2}s^{-1}$). These differences in mean transpiration rates were very small and could be partially explained by the fact that due to high rainfall (22.6 cm) and the late initiation of treatments (8 July 1984) little real water stress existed throughout the growing season.

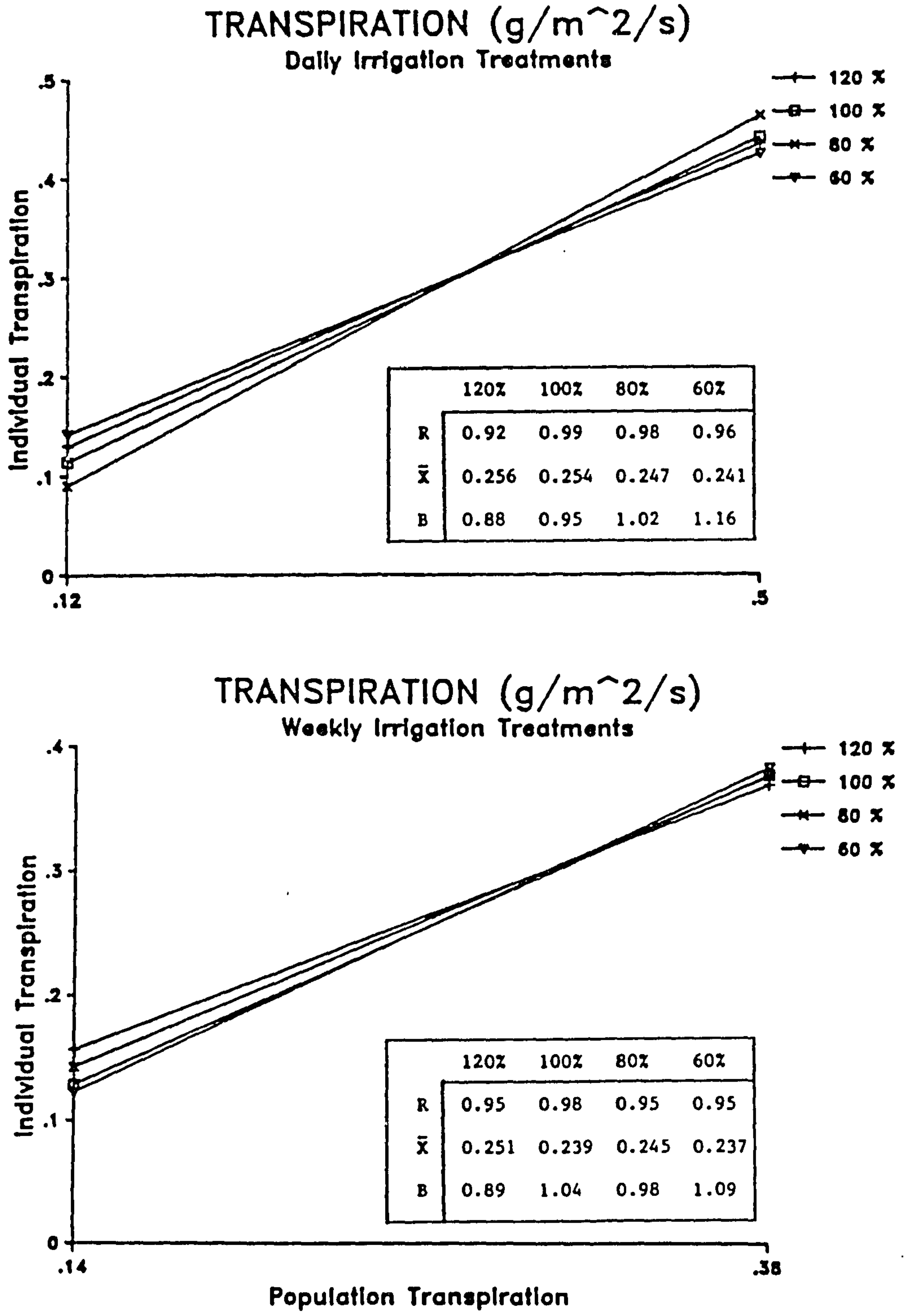
Transpiration rates were significantly different within each sampling date except on 1 Aug. 1984. Mean transpirations were greater than 0.3000 g H_2O $m^{-2}s^{-1}$ when measurements were made between 24 July and 7 Aug. 1984. These values were considerably greater than those measured earlier (19 July) or later (6, 13 September) in the season. The high mean transpiration rates were probably due to high temperatures, soil moisture due to precipitation and more active growing plants during that part of the season. These results are contrary to the results reported by Bielorai and Hopmans (1975), who stated that transpiration rates of cotton decreased with decreasing soil moisture. They measured transpiration rates in the range of 0.33 to 0.36 g $m^{-2}s^{-1}$ in the wet treatment, 0.18 to 0.23 g $m^{-2}s^{-1}$ in the medium and 0.10 g $m^{-2}s^{-1}$ in the dry treatment. Furthermore, the results of Pallas et al. (1967) indicated that transpiration was positively correlated with soil water potential.

The four daily treatments had similar mean transpiration rates but the 120% treatment (120% of 79.5 ha-cm which is the estimated consumptive use of cotton in Stanfield) tended to be the most stable across all environments because of its lowest regression coefficient using the Finlay and Wilkinson (1963) technique (Fig. 1). The plants in the 60% treatment were the most unstable across all environments as indicated with a large regression coefficient (b=1.16) followed by those in the 80% treatment and in the 100% treatment.

The mean transpiration responses in the four weekly treatments were not statistically different (Table 2). However, the plant responses in the 120% treatment appeared to be the most stable across all environmental conditions because of their low regression coefficient, b=0.89 (Fig. 1). The plants in the 120% treatment transpired the most when conditions were unfavorable and the least under favorable conditions. They had a greater seasonal transpiration rate than the three other treatments. The high regression coefficient (b=1.09) in the 60% irrigation treatment suggests that the plant responses were more unstable across the environmental conditions. The trends for the weekly and daily treatments were very similar except for the 100 and 80% treatments.

Diffusive Resistance

The seasonal diffusive resistance means of cotton grown in the 93% treatment were greater than those in the 103% irrigation



	120%	100%	80%	60%
R	0.92	0.99	0.98	0.96
$\bar{X}$	0.256	0.254	0.247	0.241
B	0.88	0.95	1.02	1.16

	120%	100%	80%	60%
R	0.95	0.98	0.95	0.95
$\bar{X}$	0.251	0.239	0.245	0.237
B	0.89	1.04	0.98	1.09

Fig. 1. Finlay and Wilkinson regressions with correlation coefficient (R), mean ($\bar{X}$) and slope (B) for transpiration of cotton grown under four daily and four weekly drip irrigation treatments. Stanfield, AZ. 1984.

treatment in 1983 (Table 3). Before treatments were initiated on 13 July 1983, relatively high diffusive resistances (94.0 to 167.9 s m^{-1}) were measured in all three treatments. After the initiation of the treatments, the diffusive resistances in the 103, 93, and 87% treatments decreased and ranged from 42.6 to 51.1 s m^{-1}. There were no appreciable differences between the diffusive resistances in the three treatments within three of the four sampling dates after 13 July (Table 3). This might be due to a masking of treatment differences by excessively high rainfall.

The trend of the seasonal diffusive resistances in the three treatments was similar to that of the transpiration rates. The results showed that the mean responses for diffusive resistance and for transpiration rates in the 93% treatment tended to be different from the mean responses in the 103% treatment (Tables 1, 3). However, the responses for the same physiological characteristics in the 87% treatment tended to be similar to those in the 103 and 93% treatments.

Significant differences were detected between the seasonal diffusive resistance means in the eight treatments in 1984 (Table 4). The cotton plants grown in the lowest water levels (60% of consumptive use) had the highest diffusive resistance, 101 s m^{-1} in the daily treatment and 84 s m^{-1} in the weekly treatment. Diffusive resistances of cotton were low under 120% treatment, averaging 70 and 72 s m^{-1} in the daily and weekly treatments, respectively. Cutler and Rains (1976) and Ackerson and Krieg (1977) have shown that stomatal resistances in field grown cotton are little affected by plant water potentials

TABLE 3. Diffusive resistance over the growing season of cotton grown under three drip irrigation treatments. Marana, AZ. 1983.

Treatment[1]	Diffusive Resistance $(s\ m^{-1})$							
	22 June	1 July	6 July	13 July	28 July	11 Aug.	1 Sept.	Mean
103	102.8	139.5	101.5	47.6	47.3	44.6	42.6	76.5
93	94.0	156.1	167.9	51.0	48.2	47.2	49.1	91.8
87	88.4	149.1	136.9	48.7	47.0	45.6	48.2	82.3
MEAN	96.4	151.7	135.4	49.1	47.5	45.8	46.6	83.5

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[1] Percent of estimated consumptive use (28.6 ha-cm) of cotton in Marana.

TABLE 4. Diffusive resistance over the growing season of cotton grown under eight drip irrigation treatments. Stanfield, AZ. 1984.

Treatment[1]	Diffusive Resistance ($s\ m^{-1}$)							
	19 July	24 July	1 Aug.	7 Aug.	21 Aug.	6 Sept.	13 Sept.	Mean
120 D	67	93 B[2]	56	51	48	101 A	71 A	69 A
100 D	69	78 AB	55	57	51	146 AB	74 A	76 A
80 D	61	75 AB	51	57	52	203 B	85 A	83 AB
60 D	65	65 A	53	57	57	307 C	106 B	101 B
120 W	69	77 AB	56	69	57	108 A	69 A	72 A
100 W	70	66 A	55	70	56	158 AB	71 A	78 A
80 W	64	82 AB	54	62	47	162 AB	79 A	79 A
60 W	68	75 AB	54	69	54	186 AB	80 A	84 AB
MEAN	67	76	54	61	53	171	80	80

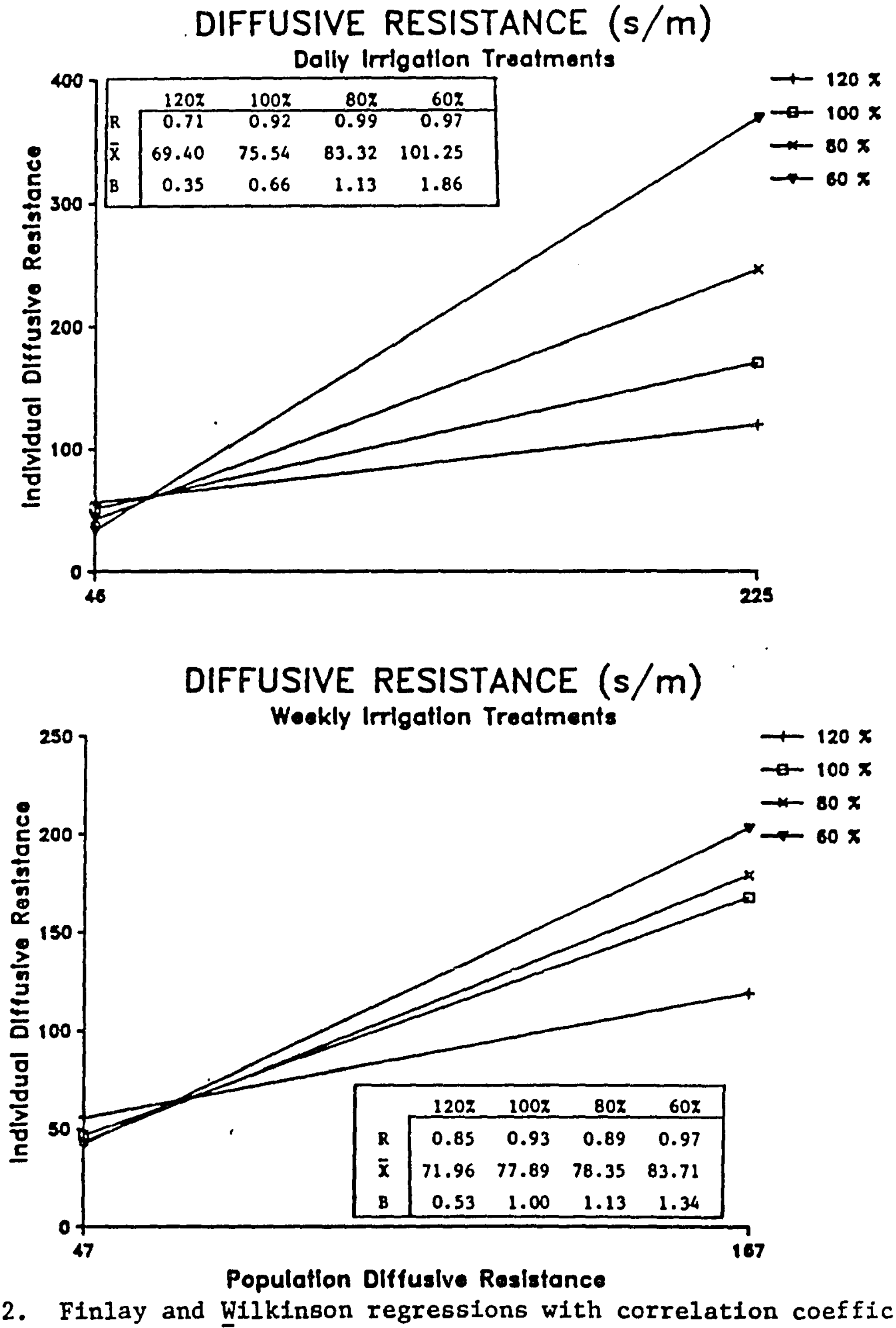
1. Percent of estimated consumptive use (32.2 ha-cm) of cotton in Stanfield, applied on a daily (D) or a weekly (W) basis.

2. Values followed by the same letter within a date are not significantly different at the 0.05 level according to the Student-Newman Keuls Multiple Range Test.

greater than -26 to -30 bars. The seasonal diffusive resistances reported here are considerably lower than those measured by Cutler and Rains (1976). They reported leaf resistances values of 400 to 700 s m^{-1} at leaf water potentials of -29 bar for field grown cotton plants. The degree of water stress and the method of irrigation system could have caused the differences in the ranges of diffusive resistances. Likewise, Bielorai and Hopmans (1975) measured leaf diffusive resistances which were greater than those determined in this experiment under low soil moisture level. They found a range for leaf diffusive resistance of 200 to 400 s m^{-1}.

For most of the growing season, diffusive resistances in the different irrigation treatments were not statistically different within the sampling dates (Table 4). When they were different, the values from the low water level (60% treatment) tended to be higher than those from the high water level (120% treatment). These results agree with the findings of Bielorai and Hopmans (1975) which indicated that leaf diffusive resistance increased with soil moisture stress. The high diffusive resistances measured late in the growing season could be explained by the study of Jordan et al. (1975). In that study they reported that stomatal response of cotton to leaf water potential depended mainly on leaf age.

The plants in the 120% daily treatment had the lowest diffusive resistance. They were also the most stable across the environmental conditions as indicated by their lowest regression coefficient, b=0.35 (Fig. 2). The 60% treatment plants had the highest



	120%	100%	80%	60%
R	0.71	0.92	0.99	0.97
$\bar{X}$	69.40	75.54	83.32	101.25
B	0.35	0.66	1.13	1.86

	120%	100%	80%	60%
R	0.85	0.93	0.89	0.97
$\bar{X}$	71.96	77.89	78.35	83.71
B	0.53	1.00	1.13	1.34

Fig. 2. Finlay and Wilkinson regressions with correlation coefficient (R), mean ($\bar{X}$) and slope (B) for diffusive resistance of cotton grown under four daily and four weekly drip irrigation treatments. Stanfield, AZ. 1984.

diffusive resistances. They were the most unstable across the environmental conditions (b=1.86). The low correlation coefficient of the 120% treatments indicates erratic responses across all conditions.

In the weekly treatments, the cotton plants in the 120% plots showed superior responses in terms of diffusive resistances than those from the other three weekly treatments. This superiority was characterized by the low diffusive resistance of 71.96 s m^{-1} (Table 4). The low regression coefficient (b=0.53) indicates the stability of the diffusive resistances of plants across the environmental conditions (Fig. 2). The 60% treatment plants had the highest diffusive resistance and the most unstable responses across the environment as shown by their high regression coefficient (b=1.34). The 100 and 80% treatments were intermediate in responses and stability across the environmental conditions (Fig. 2).

Leaf Temperature and Temperature Differentials

The cotton leaf temperatures over the 1983 growing season were slightly higher in the 103% treatment than in the 87 and 93% treatments (Table 5). This observation conflicts with the findings of Bielorai and Hopmans (1975), which showed that leaf temperatures decreased with high soil water potential. It is known that transpiration has a cooling effect on plants. Transpiration rates are expected to increase with greater water availability, thus reducing leaf temperatures. The inconsistency in the trends of leaf temperatures throughout the sampling dates is probably due to the small differences in soil moisture.

TABLE 5. Leaf temperature over the growing season of cotton grown under three drip irrigation treatments. Marana, AZ. 1983.

Treatment[1]	Cotton Leaf Temperature (C)							
	22 June	1 July	6 July	13 July	28 July	11 Aug.	1 Sept.	Mean
103	27.19	35.07	34.11	29.54	30.82	29.97	31.94	31.15
93	26.89	34.29	36.13	30.68	29.35	29.04	31.29	31.09
87	27.49	35.03	35.08	29.63	29.95	29.84	31.34	31.10
Mean	27.20	34.79	35.10	29.95	30.04	29.62	31.53	31.11

1. Percent of estimated consumptive use (28.60 ha-cm) of cotton in Marana.

In 1984, however, there were no statistical differences between the seasonal cotton leaf temperatures in the eight treatments (Table 6). Leaf temperatures were significantly different within the sampling dates, except in 19 July and 21 August. No apparent trend could be associated with the differences in leaf temperatures of cotton grown under the eight water levels.

The overall responses for the temperature differential (air-leaf temperature) in 1983 (Table 7) were not consistent with those reported by Bielorai and Hopmans (1975). At a high soil water potential (0.2 bars), the authors measured temperature differential of 0.5 c as compared to the 3.44 to 3.31 c reported here. With a decrease in soil water potential (-16 bars), the authors reported temperature differential values of 2.5 c which are lower than the 3.61 c measured in this study under the 87% treatment. Bielorai and Hopmans (1975) have also stated that, in general after irrigation in the dry treatment, the leaf to ambient temperature difference dropped at first rapidly and then more gradually, reached after two days the level characteristic of a rehydrated plant. Again, this inconsistency is probably due to the small soil moisture differences between treatments.

The temperature differentials were significantly different in 1984 (Table 8). In the daily treatments there appeared to be a trend of high to low temperature differentials from the 120 to the 60% irrigation treatment. This trend was expected since the 120% treatment was conducive to increased transpiration rate which, in turn, had a cooling effect on the cotton leaves. Leaf temperatures and

TABLE 6. Leaf temperature over the growing season of cotton grown under eight drip irrigation treatments. Stanfield, AZ. 1984.

Treatment[1]	Cotton Leaf Temperature (c)							
	19 July	24 July	1 Aug.	7 Aug.	21 Aug.	6 Sept.	13 Sept.	Mean
120 D	31.26	35.07 AB[2]	34.43 AB	35.26 C	32.61	32.96 A	31.33 BC	33.27
100 D	30.86	35.38 B	34.75 B	34.90 BC	32.48	33.33 AB	31.12 ABC	33.26
80 D	31.26	35.09 AB	34.18 A	34.01 A	32.48	34.13 BC	31.38 BC	33.22
60 D	30.93	35.12 AB	34.56 AB	34.23 AB	32.61	34.65 C	31.68 C	33.40
120 W	30.75	35.22 AB	34.53 AB	35.42 C	32.73	32.93 A	31.30 BC	33.27
100 W	30.85	34.76 A	34.53 AB	34.79 ABC	32.18	33.13 A	30.41 A	32.95
80 W	31.40	35.10 AB	34.35 AB	34.45 AB	32.23	33.74 AB	31.41 BC	33.24
60 W	30.92	35.10 AB	34.42 AB	34.38 AB	31.94	34.08 BC	30.64 AB	33.07
MEAN	31.03	35.10	34.47	34.68	32.41	33.62	31.16	33.21

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1. Percent of estimated consumptive use (32.2 ha-cm) of Cotton in Stanfield applied on a daily (D) or a weekly (W) basis.

2. Values followed by the same letter within a date are not significantly different at the 0.05 level according to the Student-Newman Keuls Multiple Range Test.

TABLE 7. Temperature differential[1] over the growing season of cotton grown under three drip irrigation treatments. Marana, AZ. 1983.

Treatment[2]	Temperature Differential (C)							
	22 July	1 July	6 July	13 July	28 July	11 Aug.	1 Sept.	Mean
103	4.39	1.57	4.10	5.25	3.40	2.10	2.79	3.42
93	4.55	2.38	3.52	4.99	3.28	1.85	3.01	3.39
87	4.75	1.82	3.57	5.62	3.80	2.08	2.63	3.54
Mean	4.57	1.93	3.73	5.29	3.49	2.01	2.81	3.45

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[1] Temperature differential = Ambient temperature - Leaf temperature.

[2] Percent of estimated consumptive use (28.60 ha-cm) of cotton in Marana.

TABLE 8. Temperature differential[1] over the growing season of cotton grown under eight drip irrigation treatments. Stanfield, AZ. 1984.

Treatment[2]	Temperature Differential (C)							
	19 July	24 July	1 Aug.	7 Aug.	21 Aug.	6 Sept.	13 Sept.	Mean
120 D	0.48	0.32	0.68	0.78 AB[3]	1.29	1.46 C	0.78 AB	0.83 B
100 D	0.59	0.26	0.77	0.85 AB	1.20	0.87 BC	1.02 AB	0.79 AB
80 D	0.54	0.36	0.96	0.91 AB	0.92	0.54 AB	0.60 AB	0.69 AB
60 D	0.48	0.38	0.78	0.81 AB	1.04	-0.08 A	0.40 A	0.57 A
120 W	0.58	0.45	0.83	0.55 A	0.91	1.56 C	0.93 AB	0.83 B
100 W	0.58	0.69	0.71	0.71 AB	0.83	0.94 BC	1.28 B	0.82 B
80 W	0.53	0.52	0.82	0.72 AB	1.03	0.91 BC	0.64 AB	0.74 AB
60 W	0.60	0.39	0.78	0.95 B	0.99	0.33 AB	1.23 B	0.75 AB
MEAN	0.55	0.42	0.79	0.78	1.03	0.81	0.86	0.75

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1. Temperature differential = ambient temperature - leaf temperature.

2. Percent of estimated consumptive use (32.2 ha-cm) of cotton in Stanfield applied on a daily (D) or a weekly (W) basis.

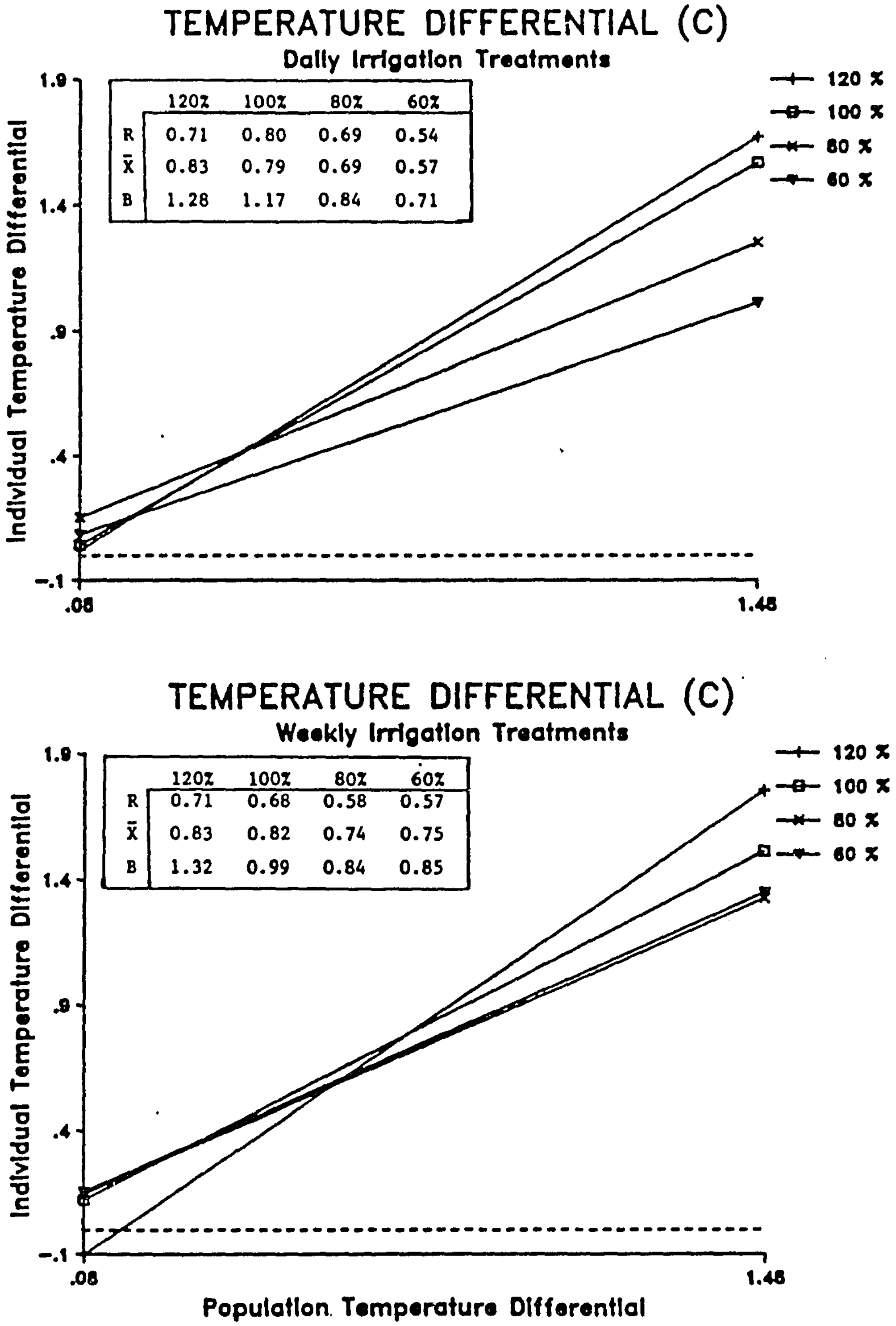
3. Means followed by the same letter within a date are not significantly different at the .05 level According to the Student-Newman Keuls Multiple Range Test.

temperature differentials from the daily irrigation treatments were negatively correlated. On the other hand, the weekly treatments did not show any consistent trends in temperature differentials.

Significant differences were found between the temperature differentials in the eight treatments within three of the seven sampling dates (Table 8). Temperature differentials were the lowest in the 60% daily treatment. The results obtained throughout the seven sampling dates are not in agreement with the findings of Tanner (1963) who reported that stressed plants had higher temperatures than nonstressed plants. The values reported here ranged from -0.08 to 1.46xc. These results were lower and their range wider than those reported by Bielorai and Hopmans (1975). They found a range for temperature differentials of 0.5 to 2.5xc.

The regression analysis of the temperature differentials from the daily treatments shows that the 120% treatments were most unstable across the environmental conditions as indicated by the high b value of 1.28 (Fig. 3). Temperature differentials measured in the 60% treatment were the most stable across the environment (b=0.71). However, having a seasonal mean of 0.57 c, the 60% treatment did not reflect a favorable response as compared to 0.83 c in the 120% treatment. The low correlation coefficient of 0.54 in the 60% treatment indicates erratic responses across all environments.

The temperature differentials in the weekly treatments were more erratic across the environmental conditions than those in the daily treatments as suggested by the relatively low correlation



Daily Irrigation Treatments

	120%	100%	80%	60%
R	0.71	0.80	0.69	0.54
$\bar{X}$	0.83	0.79	0.69	0.57
B	1.28	1.17	0.84	0.71

Weekly Irrigation Treatments

	120%	100%	80%	60%
R	0.71	0.68	0.58	0.57
$\bar{X}$	0.83	0.82	0.74	0.75
B	1.32	0.99	0.84	0.85

Fig. 3. Finlay and Wilkinson regressions with correlation coefficient (R), mean ($\bar{X}$) and slope (B) for temperature differential of cotton grown under four daily and four weekly drip irrigation treatments. Stanfield, AZ. 1984.

coefficients (Fig. 3). The 120% treatments responses were more unstable (b=1.32) across the environmental conditions than the other three weekly treatments which had homogeneous regression coefficients. These homogeneous regression coefficients indicate similar responses across all environments.

Interrelationships Among the Physiological Parameters

Correlation coefficients between the different physiological measurements were computed for each irrigation treatment in 1984 (Table 9 to 11). These correlations were analyzed to determine whether water levels had any effect on the significance of association between leaf temperature, transpiration, diffusive resistance, and temperature differentials. An overall study of the correlations between these measurements across all the eight irrigation treatments was also done and presented in Table 11.

In each of the eight irrigation levels, there was a consistent highly significant correlation between transpiration and leaf temperature (Tables 9 to 10). As leaf temperature went up, transpiration rates also increased.

The positive correlation between air temperature and transpiration observed over all the irrigation treatments was expected. These correlations showed that the irrigation treatments did not affect the degree of relationships between leaf temperature, air temperature and transpiration. These results are consistent with the lack of significance in differences between transpiration and leaf temperature from the eight treatments (Tables 9 to 11). The correlation between

TABLE 9. Correlation coefficients (N=84) between leaf temperature, air temperatures transpiration rates, diffusive resistance and temperature differential (Ambient - leaf temperature) of cotton grown under 120, 100, 80, and 60% of estimated consumptive use (32.2 ha-cm) applied on a daily basis. Stanfield, AZ. 1984.

		Leaf Temperature (C)				Transpiration Rates ($g\ H_2O\ m^{-2} s^{-1}$)				Diffusive Resistance ($s\ m^{-1}$)				Temperature Differential (C)			
		120	100	80	60	120	100	80	60	120	100	80	60	120	100	80	60
Air temperature (C)	120	0.947***				0.737***				-0.057				0.049			
	100		0.958***				0.750***				-0.071				0.016		
	80			0.963***				0.589**				0.037				0.046	
	60				0.962***				0.629***				0.005				0.054
Leaf temperature (C)	120					0.718***				0.018				-0.275*			
	100						0.714***				0.026				-0.271*		
	80							0.502***				0.145				-0.225*	
	60								0.496***				0.204				-0.220
Transpiration rates ($g\ H_2O\ m^{-2} s^{-1}$)	120									-0.522***				-0.026			
	100										-0.558***				0.030		
	80											-0.621***				0.267*	
	60												-0.639				0.434***
Diffusive resistance ($S\ m^{-1}$)	120													-0.227*			
	100														-0.340*		
	80															-0.404***	
	60																-0.729***

*, **, *** Values are significantly correlated at the 0.05, 0.01 and 0.001 levels of probability, respectively.

TABLE 10. Correlation coefficients (n=84) between leaf temperature, air temperature, transpiration rates, diffusive resistance and temperature differential (ambient-leaf temperatures) of cotton grown under 120, 100, 80, and 60% of consumptive use (32.2 ha-cm) applied on a weekly basis. Stanfield, AZ. 1984.

		Leaf Temperature (C)				Transpiration Rates (g H_2O $m^{-2}s^{-1}$)				Diffusive Resistance (s m^{-1})				Temperature Differential (C)			
		120	100	80	60	120	100	80	60	120	100	80	60	120	100	80	60
Air temperature (C)	120	0.950***				0.742***				0.024				-0.005			
	100		0.958***				0.751***				-0.023				-0.021		
	80			0.962***				0.606***				0.085				-0.006	
	60				0.971***				0.672***				0.020				-0.224*
Leaf temperature (C)	120					0.714***				0.075				-0.317**			
	100						0.723***				0.037				-0.306**		
	80							0.547***				0.167				-0.278*	
	60								0.573***				0.134				-0.449***
Transpiration rates (g H_2O $m^{-2}s^{-1}$)	120									-0.461***				-0.032			
	100										-0.526***				-0.028		
	80											-0.590***				0.130	
	60												-0.612***				0.176
Diffusive resistance (S m^{-1})	120													-0.166			
	100														-0.205		
	80															-0.313	
	60																-0.474***

*, **, *** Values are significantly correlated at the 0.05, 0.01 and 0.001 levels of probability, respectively.

TABLE 11. Correlation coefficients (N=672) between leaf temperature, air temperature, transpiration rates, diffusive resistance and temperature differential[1] of cotton grown under all eight drip irrigation treatments[2] combined. Stanfield, AZ. 1984.

	Leaf Temperature (C)	Transpiration Rates ($g\ H_2O\ m^{-2}s^{-1}$)	Diffusive Resistance ($s\ m^{-1}$)	Temperature Differential (C)
Air temperature (C)	0.958***	0.680***	0.001	-0.010
Leaf temperature (C)		0.615***	0.112	-0.296**
Transpiration rates ($g\ H_2O\ m^{-2}s^{-1}$)			-0.553***	0.122
Diffusive resistance ($s\ m^{-1}$)				-0.387***

1. Temperature differential = Air temperature - Leaf temperature.

2. 120, 100, 80, 60% of consumptive use (32.2 ha-cm) of cotton in Stanfield applied on a daily and a weekly basis.

*,** Values are significantly correlated at the 0.05, 0.01 and 0.001 levels of probability, respectively.

diffusive resistance and transpiration was independent of the irrigation treatments probably because irrigation treatments were not significantly different and because of excessive rainfall. Significant negative correlations existed between leaf temperature and temperature differentials in all treatments except in the 60% daily treatment (Table 9).

The 80 and 60% daily irrigation treatments had significant correlations between transpiration and temperature differentials (Table 9). The negative correlation between transpiration rates and temperature differentials in the 120% treatments was unexpected. Higher transpiration rates should have lowered leaf temperatures which in turn, should have led to an increase in temperature differentials.

Apparent Photosynthesis

The mean apparent photosynthetic mean rates (APS) reported by Cain (1984) of the three treatments did not tend to be different during the 1983 season, except on 28 July and 1 September (Table 12). In each case where there were differences, the 93 and 87% treatment plants had higher APS than the 103% treatment plants. The 93% treatment plants had a seasonal APS of 0.85 mg CO_2 $m^{-2}s^{-1}$ followed by the 87 and 103% treatment plants averaging 0.78 and 0.73 mg CO_2 $m^{-2}s^{-1}$, respectively. There were no differences between the APS in the three treatments during the first four sampling dates, probably because the treatments have not started until 9 July 1983. A considerable amount of rainfall (4.8 cm) was recorded within a three day period before 11 Aug. 1983. This might have neutralized the treatment effects on the APS;

TABLE 12. Apparent photosynthetic rates based on leaf area of cotton grown under three drip irrigation treatments. Marana, AZ. 1983.

Treatment[1]	Apparent Photosynthetic Rates ($mg\ CO_2\ m^{-2}s^{-1}$)							
	22 June	1 July	6 July	13 July	28 July	11 Aug.	1 Sept.	Mean
103	0.71	0.67	0.89	0.77	0.67	0.65	0.77	0.73
93	0.71	0.86	0.90	0.83	0.87	0.77	0.99	0.85
87	0.59	0.73	0.77	0.77	0.85	0.77	0.97	0.78
MEAN	0.67	0.75	0.85	0.79	0.80	0.73	0.91	0.79

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1. Percent of estimated consumptive use (28.6 ha-cm) of cotton in Marana.

consequently there were no differences in the APS under the 103, 93 and 87% treatments on 11 August.

These results which indicated that the seasonal APS means of the 87% treatment and 103% treatment plants were not different and that the 93% treatment plants had a higher APS then the 103% treatment ones are not in agreement with the findings of Bielorai and Hopmans (1975). The authors reported that photosynthesis and transpiration of cotton were greatly reduced by induced water stress. Under the conditions described by the authors, the 103% treatment plants would be expected to have the highest APS whereas the dry treatment plants would have the lowest APS.

Dry Matter Production and Partitioning

Patterson et al. (1978) stated that the total amount of dry matter produced and accumulated by a plant is a function of its photosynthetic and respiratory activity. How these assimilates are distributed to various parts of the plant is of importance.

Percent Dry Matter Partitioned into Leaves, Stems and Fruit

Throughout the seven sampling dates in 1983, no differences were detected in the proportion of total dry weight which was partitioned into the leaves, stems and fruit (squares & bolls) of cotton grown under the three irrigation treatments (Fig. 4). The cotton leaves in the three irrigation treatments made up 64 to 66% of the total plant dry weight, 82 days after planting. They were followed by stems which ranged from 33 to 35% and fruit, 0.60 to 1.1% of total dry

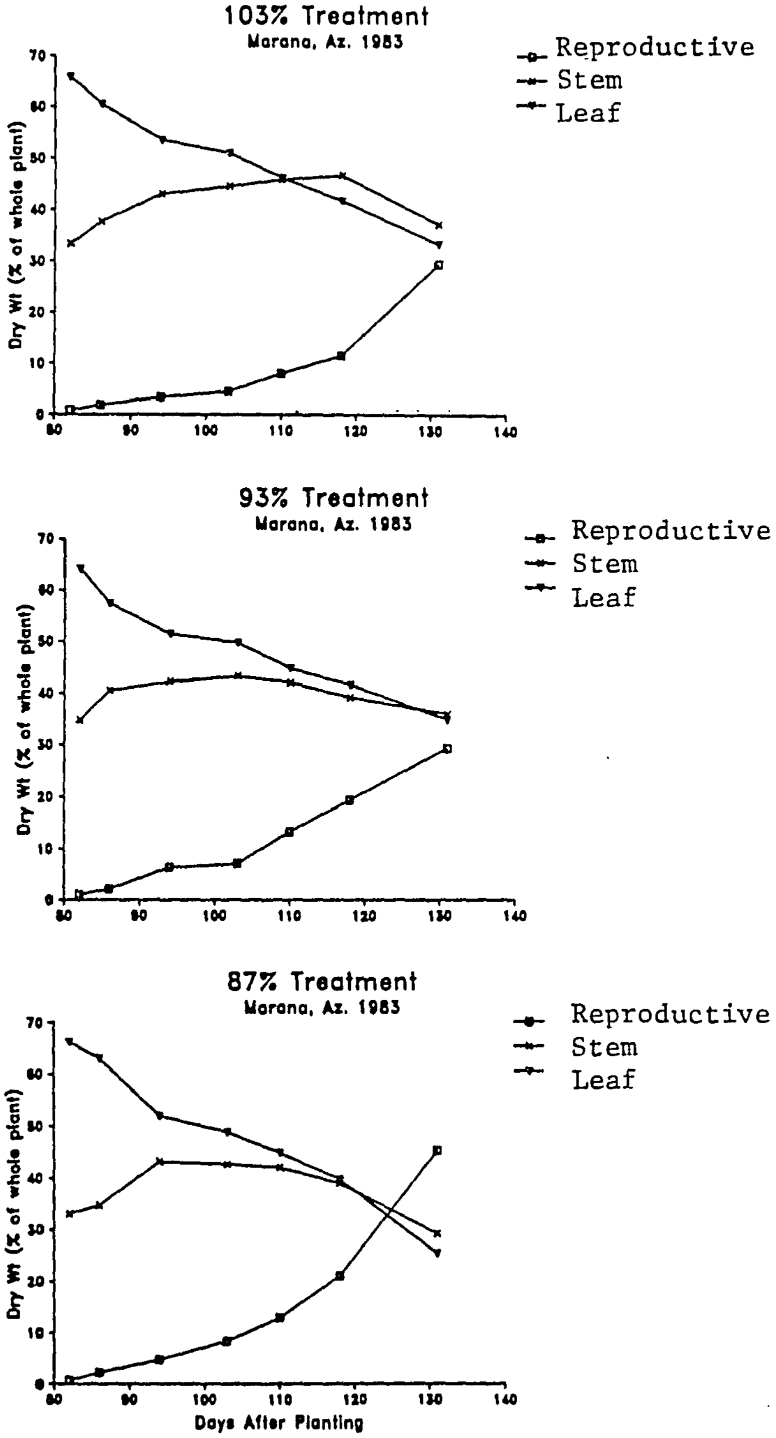


Fig. 4. Percent dry weight partitioned into leaf, stem and reproductive tissue of cotton grown under three drip irrigation treatments during the first 131 days after planting in 1983.

weight of plants. These results suggest that early in the season, the plant was accumulating large amount of dry matter into its vegetative parts and only a small amount into the fruiting parts which were just being produced by the plant. During the remainder of the growing season, the proportion of dry weight distributed to the fruit continued to increase at the expense of the proportion dispersed into vegetative forms. The squares and bolls become stronger sinks for assimilates than the leaves and stems.

One hundred and thirty days after planting, the partitioning of dry weight was nearly even between the leaves, stems and fruits, except in the 87% treatment. The percent of total dry matter partitioned into the stems was 35 to 37% under 103 and 93% treatments. The leaves were the next largest accounting for 33 to 34% under 103 and 93% treatments. The fruit followed with 29%. However, in the 87% treatment the distribution of dry matter into various parts of the plant was different than in the other two treatments. The squares and bolls were the largest parts with 59% and leaves with 25%. At the latter part of the season the plants in the 87% treatment were more efficient in partitioning assimilates into fruiting forms. This is a desirable characteristic because a greater proportion of dry matter went into the fruit which are the harvestable products. This was probably due to the decreased vegetative growth caused by water deficit which was not severe enough to have an adverse affect on photosynthesis negatively. Therefore, most of the photosynthates were directed to the bolls. Another possible explanation is that probably the plants in the 103 and 93% treatments shed some of their squares and bolls, due to excessive soil moisture.

In 1984, there were no significant differences in the dry matter partitioning into leaves, stems, and fruit of the cotton plants grown under the six irrigation treatments (Figs. 5, 6, and 7). The cotton leaves under all irrigation treatments represented 56 to 57% of total plant dry weight 93 days after planting. Stems followed with 36 to 38% and fruits with 5 to 6% of total dry weight. Approximately 130 days after planting the proportion of total dry weight partitioned into the various plant parts shifted in favor of fruit.

Bolls and squares were the largest components accounting for 54 to 59% of total dry weight under all irrigations, while stems and leaves represented 22 to 27% and 11 to 20% of total dry weight, respectively, 172 days after planting. The results from 1984 season suggest that there was no irrigation effect on the dry matter partitioning into leaves, stems, and fruit. It should be noted that 144 days after planting, there appears to be some sampling errors in the 120 and 100% weekly treatments as shown by the abnormal data points in Figs. 5, 6, 9, and 10.

Average Dry Weight of Leaves, Stems and Fruit

Although no differences were detected among the percent dry matter partitioned into the leaves, stems and fruit under the three treatments, the average dry weights of each plant part were different among the three irrigation treatments in 1983 (Fig. 8). The actual dry weights of each component were not different among the three

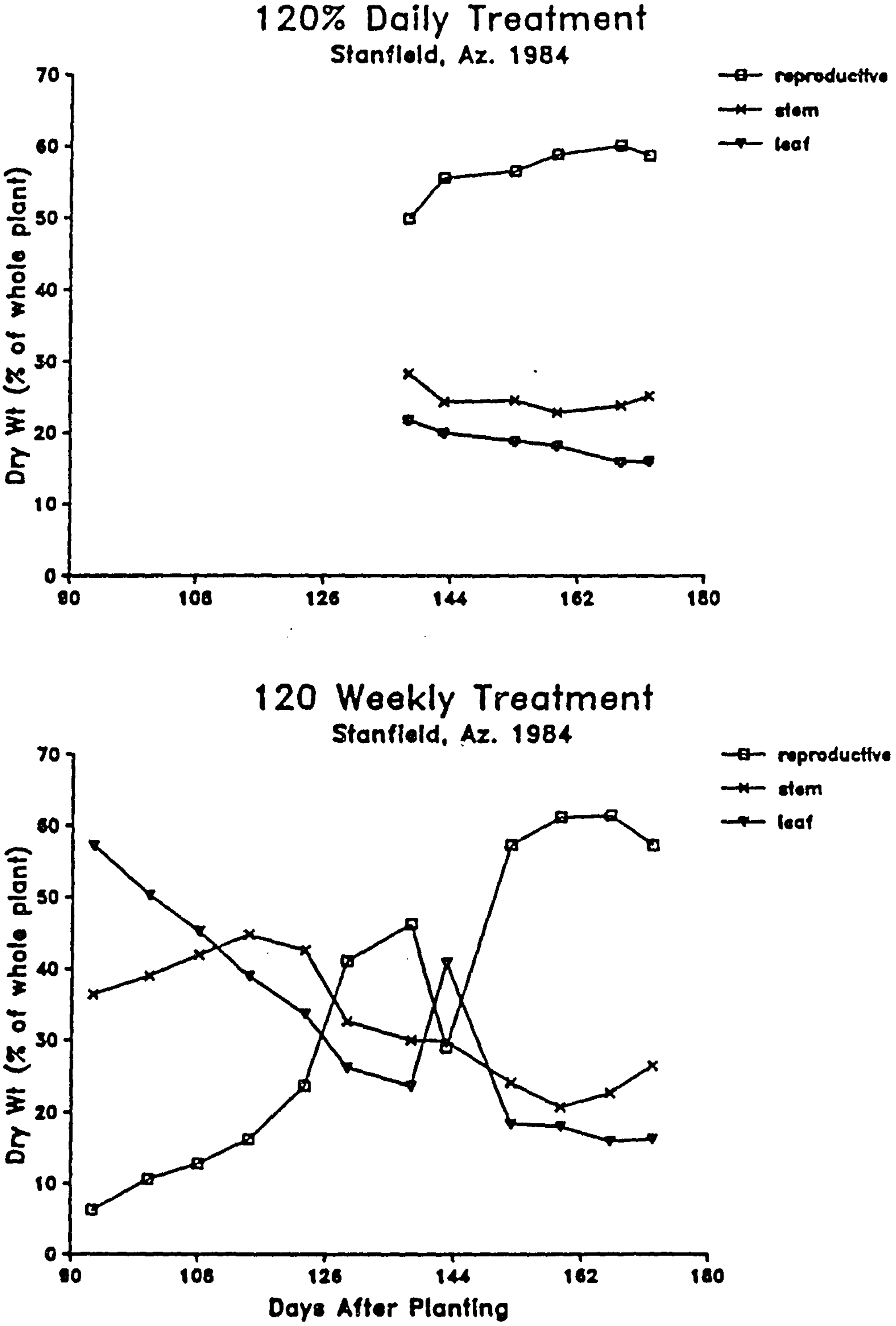
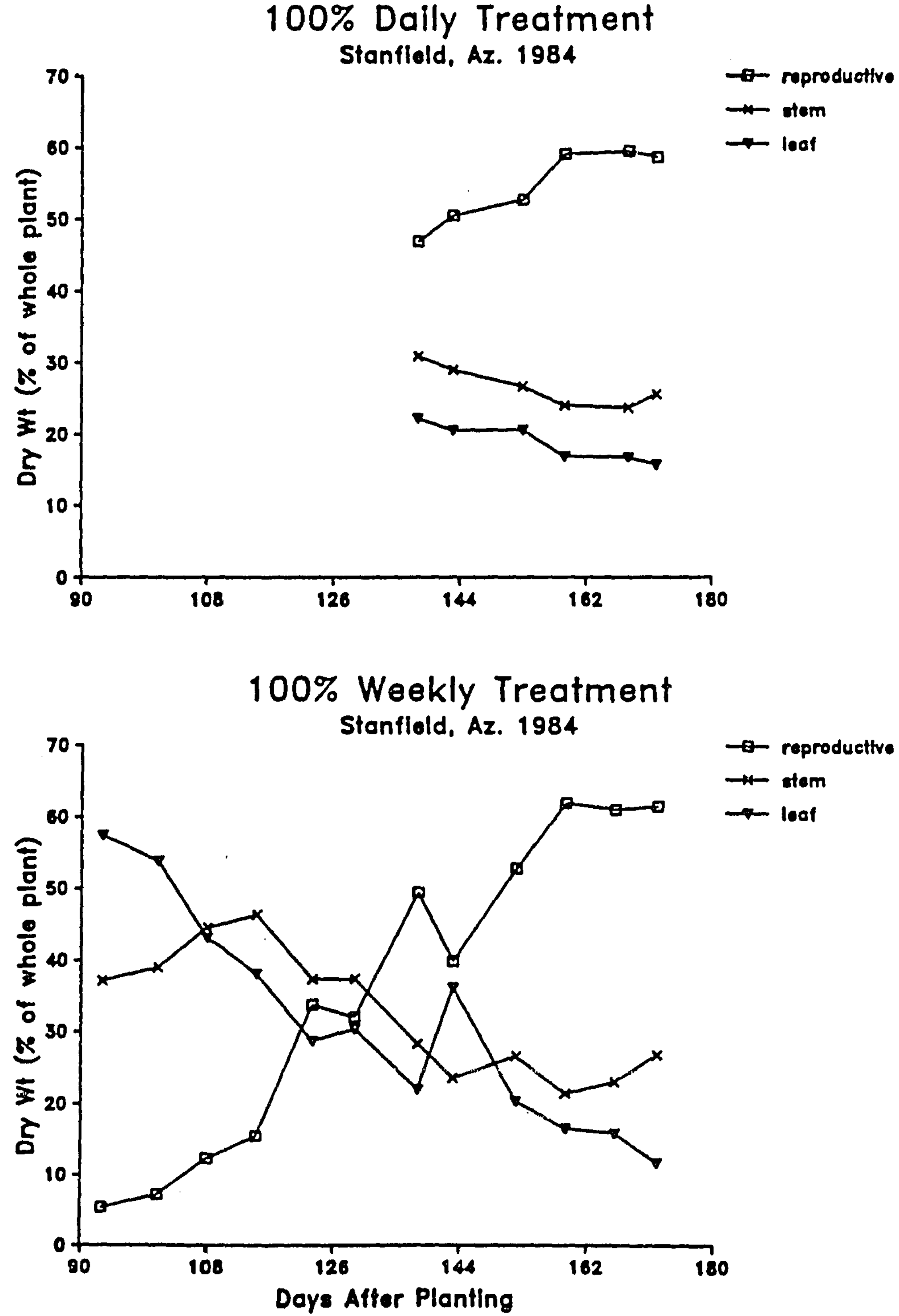


Fig. 5. Percent dry weight partitioned into leaf, stem and reproductive tissue of cotton grown under 120% daily and weekly drip irrigation treatments during the first 172 days after planting in 1984.



100% Daily Treatment

Stanfield, Az. 1984

100% Weekly Treatment

Stanfield, Az. 1984

Fig. 6. Percent dry weight partitioned into leaf, stem and reproductive tissue of cotton grown under 100% daily and weekly drip irrigation treatments during the first 172 days after planting in 1984.

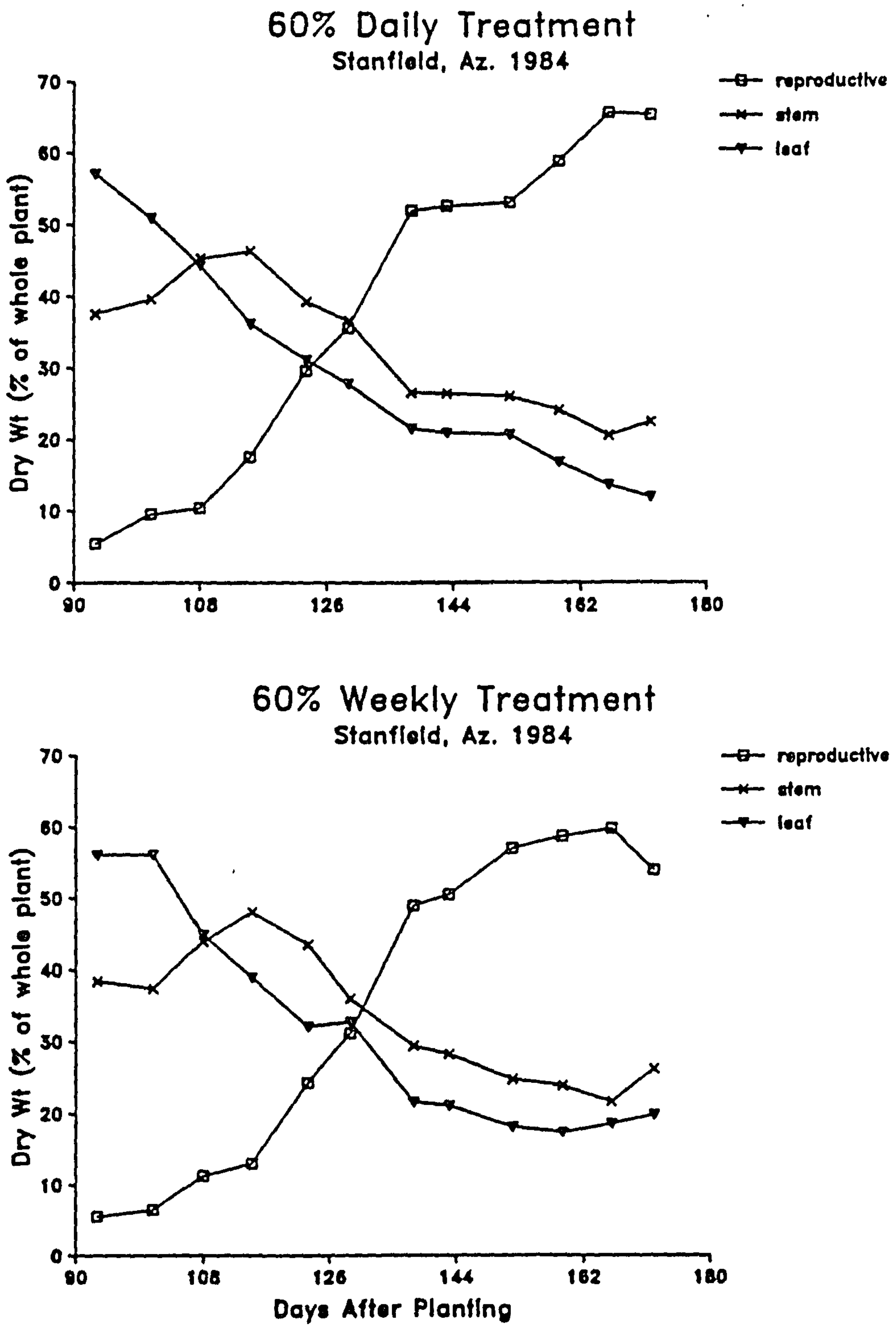


Fig. 7. Percent dry weight partitioned into leaf, stem and reproductive tissue of cotton grown under 60% daily and weekly drip irrigation treatments during the first 172 days after planting in 1984.

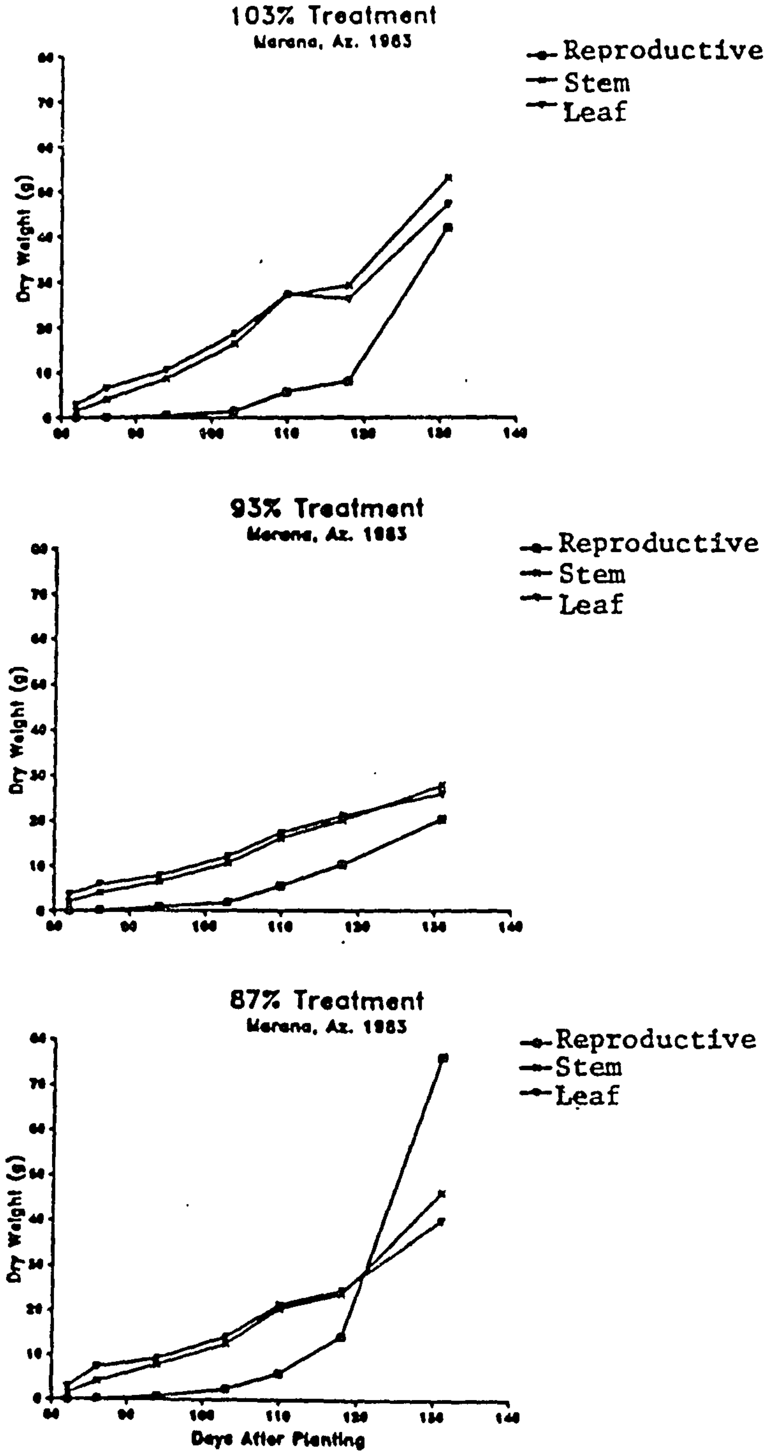


Fig. 8. Dry weight (g) partitioned into leaf, stem and reproductive tissue of cotton grown under three drip irrigation treatments during the first 131 days after planting in 1983.

treatments 82 days after planting in 1983. These values, however, were different later in the season, 131 days after planting. It should be pointed out that the lack of differences early in the sampling period was probably due to the delay in the initiation of irrigation treatments. The middle of the growing season and the flowering period were critical periods in terms of the effects of water-deficit or excess on the development of the plant; therefore, treatment effects reflected on the dry weight differences under the three water levels.

The cotton leaves averaged 40 to 47 g per plant in the 103 and 87% treatments and only 26 g per plant in the 93% treatment. The actual dry weights of the stems were 53 and 46 g in the 103 and 87% treatment, respectively but only 28 g in the 93% treatment. It is unclear why the dry weights of leaves and stems were greater in the 93% treatment than in the 103 and 87% treatments.

A different trend of dry matter accumulation in the fruit was observed among the three treatments in 1983. The 87% treatment plants had the highest fruit dry weight, averaging 76 g per plant as compared to 42 g in the 103% treatment and 20 g per plant in the 93% treatment. There is no consistency in these results. The high fruit dry weight obtained in the 87% treatment was a desirable occurrence because the bolls were the harvestable sinks. There were, however, no differences in the seasonal average dry weights of fruit under the 103, 93 and 87% treatments.

The results from the 1984 dry matter distribution did not show any significant differences between the actual dry weights of the leaves, stems and fruits under the six irrigation treatments (Figs. 9, 10, 11). The average dry weights of cotton leaves under all treatments ranged from 176 to 223 g per meter of row of plants. During the same period, the stems and the bolls averaged 224 to 299 g and 386 to 486 g per meter of row of plants, respectively. Bolls and squares had consistently higher dry weights than leaves and stems beyond 138 days after planting. The actual dry weights were 645 to 1019 g for bolls and squares, 299 to 435 g for stems, and 137 to 278 g for leaves in all six treatments, 172 days after planting. These results indicated that the dry weight partitioning favored the bolls and squares regardless of the irrigation treatments.

Irrigation Effects on Cotton Morphology

Plant Height and Number of Nodes

Plant height measurements may help to explain some of the differences in yields. Differences were observed between plant heights of cotton grown under the three irrigation treatments for all five measurement dates in 1983; however, the number of mainstem nodes were not different (Table 13). The cotton plants from the 103% treatment were consistently taller than those from the other two treatments, except during the first two sampling dates (5 July and 12 July 1983) when the 103 and 87% treatment plants were not different in height. There is no clear explanation for the 87% treatment plants to be taller than the 93% treatment plants since low soil moisture usually

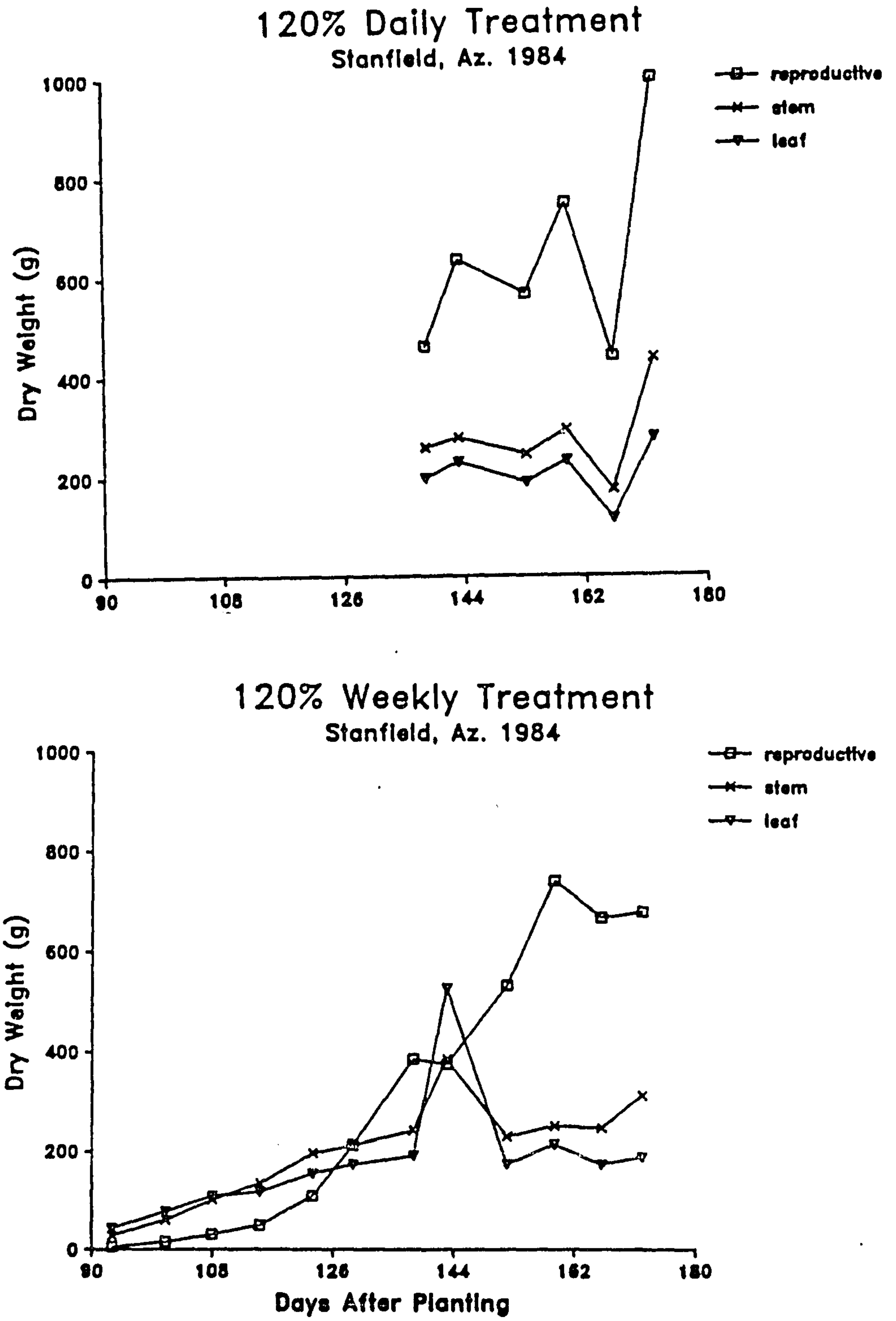
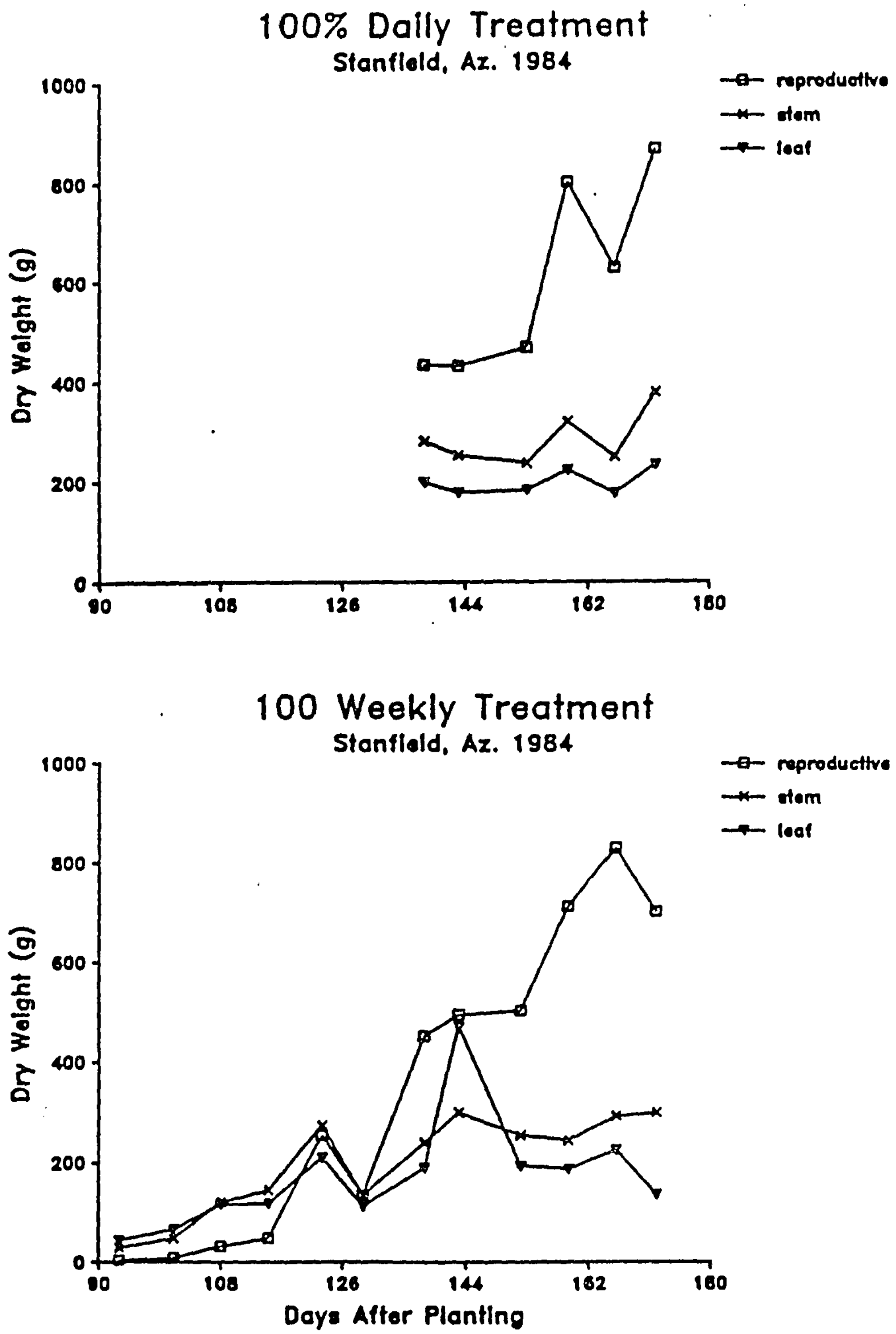


Fig. 9. Dry weight (g) partitioned into leaf, stem and reproductive tissue of cotton grown under 120% daily and weekly drip irrigation treatments during the first 172 days after planting in 1984.



100% Daily Treatment
Stanfield, Az. 1984

100 Weekly Treatment
Stanfield, Az. 1984

Fig. 10. Dry weight (g) partitioned into leaf, stem and reproductive tissue of cotton grown under 100% daily and weekly drip irrigation treatments during the first 172 days after planting in 1984.

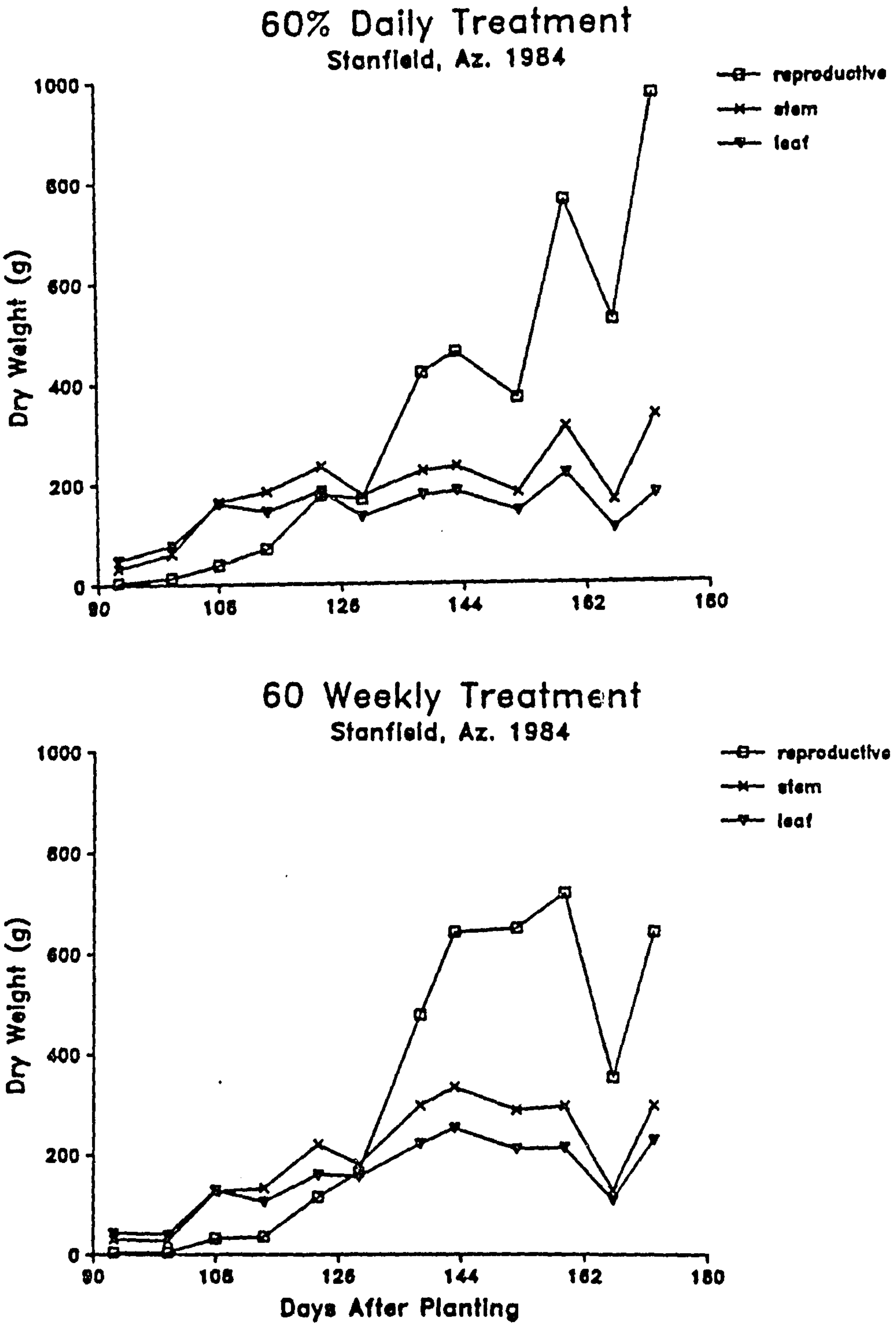


Fig. 11. Dry weight (g) partitioned into leaf, stem and reproductive tissue of cotton grown under 60% daily and weekly drip irrigation treatments during the first 172 days after planting in 1984.

TABLE 13. Average height and number of nodes per plant at five sampling dates. Marana, AZ. 1983.

Treatment[1]	Sampling Dates									
	5 July		12 July		21 July		29 July		15 Sept.	
	Height (cm)	Nodes	Height (cm)	Nodes	Height (cm)	Nodes	Height (cm)	Nodes	Height (cm)	Nodes
103	39.2	12	55.2	14	74.2	17	90.3	19	109.3	19
93	31.8	11	40.8	12	51.3	15	58.6	17	68.1	19
87	40.7	12	52.0	14	64.4	16	72.1	18	78.8	19
Means	37.2	12	49.3	13	63.3	16	72.7	18	85.4	19

[1] Percent of estimated consumptive use (28.6 ha-cm) of cotton in Marana.

causes reduction in plant height. The three treatments plants had an average of 16 mainstem nodes.

The results from the 1984 data do not reveal any significant differences between the plant heights and the number of mainstem nodes of plants grown under the eight irrigation treatments (Table 14). No apparent trend could be associated with the plant heights in the different treatments. These results, in conjunction with those of dry matter partitioning (Figs. 5, 6, 7) are in partial agreement with the findings of Saxena (1963). He reported that dry matter accumulation, yield of seed cotton and height in the '216F' cotton cultivar are positively correlated. This present study was consistent in showing no significant differences between both the dry matter partitioning and the plant heights in all eight treatments.

Leaf Area Index (LAI)

Cotton plants from the six irrigation treatments showed no significant differences between leaf area indexes (LAI) throughout the 12 sampling dates in 1984 (Table 15). No apparent trend could be observed in the LAI values. In general, leaf area indexes were small, early during the sampling date (2 July) averaging 0.71 to 0.79 for all treatments. Variation in LAI during the remaining sampling dates were small. In general, the leaf area indexes reported in this study were within the range of LAI measured by Ashley et al. (1965) in their examination of the seasonal growth of cotton plants. They reported LAI values ranging from 2.0 to 5.0.

TABLE 14. Average height and number of nodes per plant at eleven sampling dates. Stanfield, AZ. 1984.

Treatment[2]	Sampling Dates									
	3 July		10 July		17 July		24 July		1 Aug.	
	Height (cm)	Nodes (no.)	Height (cm)	Nodes (no.)	Height (cm)	Nodes (no.)	Height (cm)	Nodes (no.)	Height (cm)	Nodes (no.)
120 D	39.38	--[1]	54.00	17	69.00	21	72.75	20	87.05	22
100 D	41.13	--	46.25	16	76.50	21	74.65	20	100.90	23
80 D	36.88	--	48.55	16	69.90	21	80.95	21	104.80	23
60 D	39.88	--	51.10	17	74.15	20	77.45	22	103.35	22
120 W	36.88	--	47.20	16	66.95	20	65.65	19	85.30	24
100 W	38.50	--	50.05	19	69.45	20	79.15	23	95.25	23
80 W	38.88	--	46.15	16	78.35	21	70.15	21	106.35	24
60 W	38.88	--	48.80	17	82.65	22	76.25	22	119.70	26
Mean	38.80		49.01	17	73.37	21	74.63	21	100.34	23

1. -- Counts were not made on this date.

2. Percent of estimated consumptive use (32.2 ha-cm) of cotton in Stanfield, applied on a daily (D) or a weekly (W) basis.

TABLE 14. -- Continued.

Treatment[1]	Sampling Dates											
	7 Aug.		21 Aug.		30 Aug.		6 Sept.		13 Sept.		19 Sept.	
	Height	Nodes	Height	Nodes	Height	Nodes	Height	Nodes	Height	Nodes	Height	Nodes
120 D	82.20	21	87.90	25	83.05	23	93.40	26	84.45	24	105.15	29
100 D	87.70	22	104.85	26	88.10	24	106.05	27	90.20	26	110.35	29
80 D	100.70	23	115.25	28	106.45	27	115.30	28	107.00	27	116.35	28
60 A	94.30	26	106.20	24	93.75	25	106.50	25	94.00	25	106.45	26
120 W	78.10	23	86.80	24	83.65	25	86.30	24	89.75	27	90.10	25
100 W	100.40	26	100.15	26	101.60	29	100.15	26	102.65	29	102.50	28
80 W	83.95	23	115.45	27	83.40	23	116.00	29	83.40	24	118.30	30
60 W	95.60	26	131.70	29	103.10	29	134.45	31	103.40	30	134.55	31
Mean	90.37	24	106.04	26	92.89	25	107.27	27	94.36	26	110.47	28

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[1] Percent of estimated consumptive use (32.2 ha-cm) of cotton in Stanfield, applied on a daily (D) or a weekly (W) basis.

TABLE 15. Leaf area index of cotton plants grown under six drip irrigation treatments at twelve sampling dates. Stanfield, AZ. 1984.

Treatment[2]	Leaf Area Index											
	2 July	10 July	17 July	24 July	1 Aug.	7 Aug.	16 Aug.	21 Aug.	30 Aug.	6 Sept.	13 Sept.	19 Sept
120 D	--[1]	--	--	--	--	--	3.82	4.81	3.37	4.51	2.41	4.91
100 D	--	--	--	--	--	--	3.99	3.42	3.57	4.39	3.49	4.11
60 D	0.79	1.38	3.35	3.14	3.96	2.84	3.34	3.55	2.65	4.27	1.85	2.07
120 W	0.73	1.32	2.00	2.35	3.65	3.53	3.81	--	3.08	3.87	3.33	3.43
100 W	0.75	1.24	2.28	2.47	4.67	2.24	3.73	--	3.56	3.40	4.35	2.26
60 W	0.71	0.67	2.50	2.30	3.33	3.31	4.27	5.03	4.04	4.09	2.09	3.97

1. -- Plant samples were not taken.

2. Percent of estimated consumptive use (32.2 ha-cm) of cotton in Stanfield applied on a daily (D) or a weekly (W) basis.

Milthorpe (1956) stated that differences in rates of leaf area development were associated with differences in rates of dry matter production among cottons. The results of this study were consistent with the findings on dry matter production and partitioning into leaves, stems and fruits. The lack of significant differences between leaf area indexes could be associated with the non-significant differences between dry weights from the six irrigation treatments.

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

Differences were detected between the $\overline{\text{LAR}}$ of cotton plants grown under the three irrigation treatments in 1983 (Table 16). The 103% treatment plants tended consistently to have the highest $\overline{\text{LAR}}$. The 87% treatment plants had a trend of higher $\overline{\text{LAR}}$ than the 93% treatment plants at early sampling periods. From 14 July to 8 Sept. 1983, the 93% treatment plants had greater $\overline{\text{LAR}}$ than the 87% treatment ones. This variation of differences between $\overline{\text{LAR}}$ at the early and late part of the sampling periods could be due to the date of treatment irrigation (9 July).

The $\overline{\text{LAR}}$ from six irrigation treatments in 1984 were not statistically different, except during the fourth sampling period (16 to 30 Aug. 1984, Table 17). As the season progressed, $\overline{\text{LAR}}$ tended to decrease, from approximately 8.5 to 3.0 m^2Kg^{-1}. A similar trend was observed in the 1983 results (Table 16).

The decreasing trend in LAR observed under all treatments could be attributed to the variation in dry weight partitioning between the leaves and the rest of the plant, as plants aged. As the season

TABLE 16. Mean leaf area ratio of cotton grown under three drip irrigation treatments at seven sampling periods. Marana, AZ. 1983.

Treatment[1]	Mean Leaf Area Ratio (m^2 Kg^{-1})							
	21-27 June	27 June - 5 July	5-14 July	14-21 July	21-29 July	29 July - 11 Aug.	11 Aug. - 8 Sept.	
103	8.1	7.1	7.3	7.0	6.7	6.6	4.7	6.8
93	7.6	6.5	6.4	6.3	6.0	5.8	4.0	6.1
87	8.3	7.1	6.6	6.2	5.6	4.3	3.2	5.9
Mean	8.0	6.9	6.8	6.5	6.1	5.6	4.0	

1. Percent of estimated consumptive use (28.6 ha-cm) of cotton in Marana.

TABLE 17. Mean leaf area ratio of cotton plants grown under six drip irrigation treatments at five sampling periods. Stanfield, AZ. 1984.

Treatment[3]	Mean Leaf Area Ratio $(m^2\ Kg^{-1})$					
	2-17 July	17 July - 1 Aug.	1-16 Aug.	16-30 Aug.	30 Aug. - 13 Sept.	Means
120 D	--[1]	--	4.5	3.8 A[2]	3.1	3.8
100 D	--	--	5.1	3.8 A	3.2	4.0
60 D	8.5	7.1	4.8	3.7 A	2.7	3.7
120 W	8.2	7.0	5.4	5.1 B	3.0	4.5
100 W	8.8	6.8	4.9	4.5 AB	2.8	4.1
60 W	8.5	7.1	4.9	3.7 A	3.3	4.0

[1] -- Plant samples were not taken.

[2] Means followed by the same letter within a sampling period are not significantly different at the 0.05 level according to the Student-Newman Keuls Multiple Range Test.

[3] Percent of estimated comsumptive use (32.2 ha-cm) of cotton in Stanfield applied on a daily (D) or a weekly (W) basis.

progressed, non-leaf tissues grew more rapidly than leaf tissues. This was in agreement with the results of Blackman and Wilson (1951), and Wallace and Manger (1965) who reported that $\overline{\text{LAR}}$ changed greatly as the season progressed. As expected, the higher $\overline{\text{LAR}}$ found in the non-stressed plants was indicative of higher vegetative growth compared to the stressed plants.

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

Mean net assimilation rate is the rate of dry weight (g) increase per unit of assimilatory material (dm^2) per unit of time (day). The 103, 93 and 87% treatment plants in 1983 did not reveal any difference between $\overline{\text{NAR}}$, except during the last two sampling periods (29 July to 11 August and 11 August to 8 September, Table 18). No apparent trend could be observed in $\overline{\text{NAR}}$ from all three treatments throughout the seven sampling periods. No significant differences between $\overline{\text{NAR}}$ of cotton plants were observed under the six irrigation treatments in 1984 (Table 19).

During both 1983 and 1984 seasons, $\overline{\text{NAR}}$ of cotton plants grown under different water levels appeared to be high at the first part of the sampling periods (Tables 18, 19). $\overline{\text{NAR}}$ tended to decrease as cotton plants grew older. This tendency was reflected in the low values of $\overline{\text{NAR}}$ obtained during the later sampling periods.

$\overline{\text{NAR}}$ decreased as LAI increased. Low $\overline{\text{NAR}}$ at high LAI might be due to the decreasing quantity of light flux density to lower leaves because of mutual shading, a condition which existed under high LAI. These results were somewhat in agreement with the studies of Watson

TABLE 18. Mean net assimilation rate of cotton plants grown under three drip irrigation treatments at seven sampling periods. Marana, AZ. 1983.

Treatment[1]	Mean Net Assimilation Rate ($g\ dm^{-2}\ day^{-1}$)							
	21-27 June	27 June - 5 July	5-14 July	14-21 July	21-29 July	29 July - 11 Aug.	11 Aug. - 8 Sept.	Mean
103	0.15	0.11	0.10	0.09	0.02	0.09	0.04	0.09
93	0.11	0.09	0.09	0.08	0.07	0.04	0.12	0.09
87	0.17	0.08	0.09	0.11	0.07	0.17	0.01	0.10
Mean	0.14	0.09	0.09	0.10	0.05	0.10	0.06	

1. Percent of estimated consumptive use (28.6 ha-cm) of cotton in Marana.

TABLE 19. Mean net assimilation rate of cotton plants grown under six drip irrigation treatments at five sampling periods. Stanfield, AZ. 1984.

Treatment[2]	Mean Net Assimilation Rate ($g\ dm^{-2}\ day^{-1}$)					
	2-17 July	17 July - 1 Aug.	1-16 Aug.	16-30 Aug.	30 Aug. - 13 Sept.	Means
120 D	--[1]	--	0.04	0.04	0.04	0.04
100 D	--	--	0.05	0.03	0.03	0.04
60 D	0.09	0.03	0.05	0.05	0.03	0.04
120 W	0.09	0.07	0.05	0.06	0.02	0.04
100 W	0.07	0.05	0.06	0.02	0.02	0.03
60 W	0.06	0.05	0.08	0.02	0.06	0.05

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1. -- Plant samples were not taken.

2. Percent of estimated consumptive use (32.2 ha-cm) of cotton in Stanfield applied on a daily (D) or a weekly (W) basis.

(1952) who found that, with an increase in LAI, $\overline{\text{NAR}}$ would probably decrease because of mutual shading of lower leaves. Furthermore, these results are supported by the findings of Buttery (1970) who reported that $\overline{\text{NAR}}$ for maize and soybeans was less at LAI equal to 4 than at LAI equal to 1.

Mean Relative Growth Rates ($\overline{\text{RGR}}$)

Mean relative growth rate is the mean increase of plant material (g) per 100 g of plant material per unit of time (day). $\overline{\text{RGR}}$ of cotton plants did not differ greatly between the three treatments during the first five sampling periods in 1983 (Table 20). The 103 and 87% treatment plants showed a trend of higher $\overline{\text{RGR}}$ than the 93% treatment plants.

No significant differences were noted between the $\overline{\text{RGR}}$ of cotton grown under the six irrigation treatments at four sampling periods in 1984 (Table 21). It did not appear that there was a pattern in $\overline{\text{RGR}}$ values under the six treatments. But at the fourth sampling period (16 to 30 Aug. 1984), $\overline{\text{RGR}}$ of nonstressed plants were greater than those of stressed plants. The weekly treatment plants had higher $\overline{\text{RGR}}$ than the daily treatment plants.

During both years $\overline{\text{RGR}}$ of cotton plants were higher at early sampling periods and decreased as season progressed. The $\overline{\text{RGR}}$ of 103% treatment plants were 12.55 g 100 g^{-1} day^{-1} at the first sampling period (21 June to 27 July 1983) as compared to 1.66 g 100 g^{-1} day^{-1} at the last sampling period (11 Aug. to 8 Sept. 1983), Table 20. Similar trends were obtained in the 87 and 93% treatments where the $\overline{\text{RGR}}$ ranged

TABLE 20. Mean relative growth rate of cotton plants grown under three drip irrigation treatments at seven sampling periods. Marana, AZ. 1983.

Treatment[1]	Mean Relative Growth Rate (g 100 g^{-1} day^{-1})							
	21-27 June	27 June - 5 July	5-14 July	14-21 July	21-29 July	29 July - 11 Aug.	11 Aug. - 8 Sept.	Mean
103	12.55	8.05	7.20	6.30	1.36	5.73	1.66	6.12
93	8.46	5.23	5.75	5.50	3.82	2.53	4.28	5.08
87	13.78	5.36	5.77	6.89	3.49	7.04	0.45	6.11
Mean	11.60	6.21	6.24	6.23	2.89	5.10	2.13	

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[1] Percent of estimated consumptive use (28.6 ha-cm) of cotton in Marana.

TABLE 21. Mean relative growth rate of cotton plants grown under six drip irrigation treatments at five sampling periods. Stanfield, AZ. 1984.

Treatment[3]	Mean Relative Growth Rate ($g\ 100\ g^{-1}\ day^{-1}$)					
	2-17 July	17 July - 1 Aug.	1-16 Aug.	16-30 Aug.	30 Aug. - 13 Sept.	Means
120 D	--[1]	--	1.85	1.89 A[2]	0.60	1.45
100 D	--	--	3.08	0.50 A	0.85	1.48
60 D	7.55	2.06	2.59	0.12 A	0.90	1.20
120 W	7.25	4.40	2.74	4.08 B	0.40	2.41
100 W	6.60	3.49	2.92	1.17 A	0.84	1.64
60 W	5.10	3.60	4.09	0.70 A	2.12	2.30

[1] -- Plant samples were not taken.

[2] Means followed by the same letter within a sampling period are not significantly different at the 0.05 level according to the Student-Newman Keuls Multiple Range Test.

[3] Percent of estimated consumptive use (32.2 ha-cm) of cotton in Stanfield attlied on a daily (D) or a weekly (W) basis.

from 8.46 and 13.78 g 100 g^{-1} day^{-1} at the first sampling period as compared to 4.28 and 0.45 g 100 g^{-1} day^{-1} at the last sampling period in the 93 and 87% treatment plants, respectively.

In 1984, $\overline{RGR}$ ranged from 5.10 to 7.55 g 100 g^{-1} day^{-1} at the first sampling period and dropped to a range of 0.40 to 2.12 g 100 g^{-1} day^{-1} at the last sampling period. These results were in agreement with the findings of Buttery (1970) who reported reduction in $\overline{RGR}$ as plants aged. As it was discussed with $\overline{NAR}$, $\overline{RGR}$ were higher at low LAI and then declined as LAI increased.

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

Mean crop growth rate is the mean increase of plant material per unit of time (g m^{-2} day). No differences were detected between the $\overline{CGR}$ of plants grown under the 103, 93 and 87% treatments at the first five sampling periods in 1983 (Table 22). The 93% treatment plants had lower $\overline{CGR}$ than the 103 and 87% treatment at the last two sampling periods.

These $\overline{CGR}$ values in 1984 did not display any statistical differences at the first three sampling periods (Table 23). A consistent trend was not evident at the last two sampling periods even though there were significant differences between the $\overline{CGR}$ of cotton plants grown under the six water levels. There seemed, however, to be an increasing trend in $\overline{CGR}$ from the first to the third sampling period under all irrigation treatments.

During both seasons, 1983 and 1984, the differences in $\overline{CGR}$ were inconsistent at all sampling dates. Mean crop growth rates were found

TABLE 22. Mean crop growth rate of cotton plants grown under three drip irrigation treatments at seven sampling periods. Marana, AZ. 1983.

Treatment[1]	Mean Crop Growth Rate ($g\ m^{-2}\ day^{-1}$)							
	21-27 June	27 June - 5 July	5-14 July	14-21 July	21-29 July	29 July - 11 Aug.	11 Aug. - 8 Sept.	Mean
103	0.93	1.12	2.11	2.95	0.49	5.63	3.13	2.34
93	0.63	0.64	1.15	1.80	1.79	1.63	5.75	1.91
87	1.05	0.77	1.39	2.33	2.16	7.16	0.84	2.24
Mean	0.87	0.84	1.55	2.36	1.48	4.81	3.24	

[1] Percent of estimated consumptive use (28.6 ha-cm) of cotton in Marana.

TABLE 23. Mean crop growth rate of cotton plants grown under six drip irrigation treatments at five sampling periods. Stanfield, AZ. 1984.

Treatment[3]	Mean Crop Growth Rate (g m^{-2} day^{-1})					
	2-17 July	17 July - 1 Aug.	1-16 Aug.	16-30 Aug.	30 Aug. - 13 Sept.	Means
120 D	--[1]	--	16.38	18.29 A[2]	6.85 A	13.84
100 D	--	--	21.26	1.18 C	9.71 A	10.72
60 D	13.35	9.36	18.24	1.11 C	9.61 A	9.65
120 W	9.47	17.8	21.15	35.06 B	3.84 A	20.01
100 W	9.62	16.04	19.99	7.28 C	12.28 AB	13.18
60 W	8.28	13.27	31.16	5.27 C	19.60 B	18.57

1. -- Plant samples were not taken.

2. Means followed by the same letter within a sampling period are not significantly different at the 0.05 level according to the Student-Newman Keuls Multiple Range Test.

3. Percent of estimated consumptive use (32.2 ha-cm) of cotton in Stanfield applied on a daily (D) or a weekly (W) basis.

to be as low as 0.63 and as high as 35.06 g m^{-2} day^{-1}. These results are not in agreement with the findings of Fowler (1976) who reported a decrease of $\overline{\text{CGR}}$ and LAI late in the growing season, and with those of Wolf and Carson (1973) associating maximum $\overline{\text{CGR}}$ with high LAI.

Correlations Between the Growth Parameters

Correlation coefficients between $\overline{\text{LAR}}$, $\overline{\text{NAR}}$, $\overline{\text{RGR}}$ and $\overline{\text{CGR}}$ were determined for each irrigation treatment in 1984 (Tables 24, 25). The correlation coefficients were evaluated to determine whether water level had any effect on the association between the four growth parameters.

There was a positive significant correlation between $\overline{\text{LAR}}$, $\overline{\text{NAR}}$, $\overline{\text{RGR}}$ and $\overline{\text{CGR}}$ regardless of the irrigation treatment (Tables 24 to 25). This positive correlation is supported by the results previously presented in Tables 19, 21 which showed that $\overline{\text{NAR}}$ and $\overline{\text{RGR}}$ decreased consistently as the season progressed. A significant positive correlation existed between $\overline{\text{LAR}}$ and $\overline{\text{RGR}}$ under the 60% daily treatment and under all three weekly treatments. It was unclear why the correlation between $\overline{\text{LAR}}$ and $\overline{\text{RGR}}$ was significant under all irrigation treatments, except under the 120 and 100% treatments. A probable explanation is that under water stress conditions and under less frequent, weekly applications, $\overline{\text{RGR}}$ became influenced by changes in $\overline{\text{LAR}}$. In contrast, the interaction between $\overline{\text{NAR}}$ and $\overline{\text{RGR}}$ remained unchanged under all soil moisture conditions. These results join the list of the conflicting results from many studies on the relative importance of LAR and NAR in determining plant growth. These results were not consistent

TABLE 24. Correlation coefficients (N=12) between leaf area ratio ($\overline{\text{LAR}}$), mean net assimilation rate ($\overline{\text{NAR}}$), mean relative growth rate ($\overline{\text{RGR}}$), mean crop growth rate ($\overline{\text{CGR}}$) of cotton plants grown under 120, 100 and 60% of consumptive use (32.2 ha-cm) applied on a daily basis. Stanfield, AZ. 1984.

	$\overline{\text{NAR}}$ (g dm^{-2} day^{-1})			$\overline{\text{RGR}}$ (g 100 g^{-1} day^{-1})			$\overline{\text{CGR}}$ (g m^{-2} day^{-1}		
	120	100	60	120	100	60	120	100	60
$\overline{\text{LAR}}$ (m^2 Kg^{-1})									
120	0.323			0.444			0.299		
100		0.131			0.270			0.149	
60			0.462*			0.738***			0.172
NAR (g dm^{-2}day^{-1})									
120				0.984***			0.986***		
100					0.963***			0.990***	
60						0.900***			0.863***
$\overline{\text{RGR}}$ (g 100g^{-1}day^{-1})									
120							0.966***		
100								0.982***	
60									0.594***

*, **, *** Values are significantly correlated at the 0.05, 0.01 and 0.001 levels of probability, respectively.

TABLE 25. Correlation coefficients (N=12) between leaf area ratio ($\overline{\text{LAR}}$), mean net assimilation rate ($\overline{\text{NAR}}$), mean relative growth rate ($\overline{\text{RGR}}$), mean crop growth rate ($\overline{\text{CGR}}$) of cotton plants grown under 120, 100 and 60% of consumptive use (32.2 ha-cm) applied on a weekly basis. Stanfield, AZ. 1984.

	$\overline{\text{NAR}}$ (g dm^{-2} day^{-1})			$\overline{\text{RGR}}$ (g 100 g^{-1} day^{-1})			$\overline{\text{CGR}}$ (g m^{-2} day^{-1})		
	120	100	60	120	100	60	120	100	60
$\overline{\text{LAR}}$ (m^2 Kg^{-1})									
120	0.439*			0.562**			0.146		
100		0.368			0.649***			0.071	
60			0.346			0.498**			0.194
$\overline{\text{NAR}}$ (g dm^{-2} day^{-1})									
120				0.968***			0.850***		
100					0.886***			0.847***	
60						0.920***			0.905***
$\overline{\text{RGR}}$ (g 100 g^{-1} day^{-1})									
120							0.751***		
100								0.578***	
60									0.716***

*, **, *** Values are significantly correlated at the 0.05, 0.01 and 0.001 levels of probability, respectively.

with the findings of Watson (1952) who found that differences in leaf area production were more important than differences in NAR in determining growth. They did not agree either with the results of Potter and Jones (1977) who reported that differences in RGR were not well correlated with differences in NAR.

Fruiting Characteristics and Yield

The total number of flowers did not differ greatly among the three irrigation treatments in 1983 (Table 26). The 103% treatment plants produced slightly more flowers than both 93 and 87% treatment plants. However, the hand harvested seed cotton yields of the 103% treatment were the lowest at 5322 Kg ha^{-1} of seed cotton, respectively. A similar trend was obtained from the total of the first and second machine harvests of all three treatments. The 87% treatment plants yielded the most seed cotton (4544 Kg ha^{-1}) as compared to 4400 and 4245 Kg ha^{-1} seed cotton in the 93 and 103% treatments, respectively. The 103% treatment plants had the highest total number of flowers but the lowest seed cotton yields, probably because of a greater square and boll shedding or boll rot caused by excessive soil moisture. Using a gin turnout of 27.5%, the lint yields in the machine harvested plots were found to be 1250.0, 1210.0, and 1167.4 Kg ha^{-1} from the 87, 93, and 103% treatments, respectively. The hand harvested yields were 1612.6, 1610.1, 1463.6 Kg ha^{-1} from the 87, 93, and 103% irrigation treatments, respectively.

No significant differences were detected between the total number of flowers produced in the eight irrigation treatments in 1984

TABLE 26. Total number of flowers and seed cotton yields in the hand harvested plots and seed cotton yields, turnout and lint yields in the machine harvested plots. Marana, AZ. 1983.

Irrigation Treatment[2]	HAND HARVEST		MACHINE HARVEST		
	Flowers per ha (x 1000)	Seed Cotton	Seed Cotton[1]	Turnout	Lint
	—no.—	—Kg ha^{-1}—		—%—	—Kg ha^{-1}—
103	2823.3	5322	4245	27.5	1167.4
93	2790.7	5855	4400	27.5	1210.0
87	2504.1	5864	4544	27.5	1250.0

1. Total seed cotton yield (first and second machine harvest).

2. Percent of estimated consumptive use (23.6 ha-cm) of cotton in Marana.

(Table 27). In contrast to the results in 1983, there was no apparent trend in the number of flowers from the 120 to the 60% treatments in 1984. Although there were no significant differences between the seed cotton yields from the hand harvested plots, a consistent downward trend was evident in seed cotton yields from the 120 to the 60% daily irrigation treatments (Table 27). The weekly treatment harvests were inconsistent and were not correlated to the amount of irrigation water (Table 27).

Significant differences were observed between the seed cotton yield from the machine harvested plots (Table 27). The lowest seed cotton yield, 3547 Kg ha^{-1} was obtained from the 60% daily treatment plots. It should be noted that the 60% daily treatment plants had the lowest transpiration, the highest diffusive resistance and the lowest temperature differentials on 6 and 13 September in 1984 (Tables 2, 4 and 8). These physiological responses could probably explain the lowest seed cotton yield obtained in the 60% plots. Seed cotton yields decreased from 4174 to 3547 Kg ha^{-1} as the daily irrigation treatment dropped from 120 to 60% of estimated consumptive use (32.2 ha-cm). The seed cotton yields from the weekly treatments did not, however, display any consistent trend among the four water levels. The seed cotton yields from the 60% weekly treatment were not statistically different from the yields in the three wetter weekly treatments. Perhaps the less frequent, weekly irrigations caused a larger cross section of the soil profile to be moistened and favored more extensive root development. Consequently the cotton plants were able to make

TABLE 27. Total number of flowers and seed cotton yields in the hand harvested plots and seed cotton yields, turnout and lint yields in the machine harvested plots. Stanfield, AZ. 1984.

Irrigation Treatment[2]	HAND HARVEST		MACHINE HARVEST		
	Flowers per ha (x 1000)	Seed Cotton	Seed Cotton[1]	Turnout	Lint
	no.	Kg ha^{-1}		%	Kg ha^{-1}
120 D	2810	4841	4174 A[2]	35.2	1469.3 A
100 D	2923	4636	4128 A	34.4	1420.0 A
80 D	2993	4496	4022 A	34.5	1387.6 A
60 D	2869	4417	3547 B	33.5	1188.3 B
120 W	2691	4666	4038 A	34.4	1389.1 A
100 W	2933	5069	4190 A	34.2	1433.0 A
80 W	2763	4560	4022 A	34.3	1379.6 A
60 W	2854	4318	4174 A	34.0	1419.2 A

1. First pick seed cotton yield.

2. Percent of estimated consumptive use (32.2 ha-cm) of cotton in Marana applied on a daily (D) or a weekly (W) basis.

efficient and better use of rain water stored in the "dry furrows". It should be noted again that, in 1983, there was no water stress and this might have caused the inconsistent results.

CHAPTER 5

SUMMARY AND CONCLUSIONS

The physiological and morphological development of cotton grown under drip irrigation were evaluated over a two year period. In 1983, an underground and in 1984 an above ground drip irrigation system were studied in Marana, and Stanfield, Az., respectively. Cotton was grown in Marana, Az. in 1983 under three water levels (29.3, 26.7 and 24.8 ha-cm) representing 103, 93 and 87 of estimated consumptive use (28.6 ha-cm) of cotton in Marana, respectively.

In 1984, irrigation treatments 37.49, 31.21, 24.93, and 18.74 ha-cm representing 120, 100, 80, and 60% of the estimated consumptive use (32.2 ha-cm) of cotton in Stanfield, Az., respectively, were used to study cotton grown under an above ground drip irrigation system. These amounts of water were applied as small daily doses and larger weekly doses for a total of eight irrigation treatments. There were four replications in a randomized complete block design.

In 1983 the 103% treatment plants had greater transpiration, lower diffusive resistance and lower APS than the 93% treatment plants. The physiological responses in the 87% treatment were inconsistent with the trends observed in the 103 and 93% treatments. The 87% treatment plants did not differ in transpiration rates, diffusive resistances and APS from the other two treatments. No differences were observed between the seasonal leaf temperatures and temperature differentials of cotton plants grown under the three water levels in 1983.

While there were no differences in the proportion of total dry weight which was partitioned into the leaves, stems and fruit (squares and bolls), the dry weights of each plant part were different between the cotton plants grown under the three irrigation treatments in 1983. The 103 and 87% treatment plants had higher leaf and stem dry weights than the 93% treatment plants over the first 131 days after planting. The plants in the 87% treatment had the highest fruit dry weight at 131 days after planting.

Cotton plants in the 103% treatment were consistently taller than those in the 87 and 93% treatments in 1983. No differences were observed in mean net assimilation rate ($\overline{\text{NAR}}$), mean relative growth rate ($\overline{\text{RGR}}$) and mean crop growth rate ($\overline{\text{CGR}}$) of cotton plants grown under the three irrigation treatments. There were differences in the $\overline{\text{LAR}}$ with the 103% treatment plants having the highest $\overline{\text{LAR}}$ followed by the 87% and then the 93% treatment plants.

Although no differences were found among the total number of flowers produced in the three irrigation treatments, the 93 and 87% treatment plants produced more seed cotton than the 103% treatment plants in 1983. There was more boll rot in the 103 than the 93 and 87% treatments.

In 1984 there were no significant differences in the seasonal transpiration rates and leaf temperatures from the eight irrigation treatments. However, in the daily treatments, there appeared to be a consistent trend of slightly higher transpiration rates in the wetter plots as compared to the drier plots. Significant differences were detected between the seasonal diffusive resistances of the eight irrigation treatment plants and between the temperature differentials. As expected, diffusive resistances of plants were the highest in the low water levels. Cotton plants grown under higher soil moisture conditions showed superior diffusive resistance responses than those grown under water stress conditions. Temperature differentials were higher in the daily, wetter treatments than in the daily, drier treatments.

As in 1983, no significant differences were observed in the proportion of total dry matter partitioned into leaves, stems, and fruits of the cotton plants grown under the six irrigation treatments in 1984. However, unlike the results from 1983, the actual dry weights of each plant part failed to show any significant differences among the six water levels in 1984.

There were no statistical differences between plant heights from the eight irrigation treatments in 1984. Likewise, $\overline{\text{LAR}}$, $\overline{\text{NAR}}$, $\overline{\text{RGR}}$, and $\overline{\text{CGR}}$ did not reveal any significant differences between the six irrigation treatments evaluated in 1984.

The total number of flowers produced in the eight treatments was not statistically different in 1984. However, there was a consistent trend of lower seed cotton yields in the low soil moisture conditions (60 and 80% of estimated consumptive use). Machine harvested seed cotton yields in the 60% daily treatment were significantly the lowest.

During both years, 1983 and 1984, it appeared that the physiological and morphological responses of cotton plants were inconsistent across the different water levels. The results obtained from using the Finlay and Wilkinson (1963) regression analysis confirmed the erratic physiological responses in the eight irrigation treatments across all environmental conditions in 1984. The data collected from the weekly treatments were more inconsistent than those from the daily treatments.

This study showed that only the 60% daily treatment produced significantly less seed cotton yield in 1984. Due to the problems associated with the late dates of treatment initiation, high rainfall masking treatment differences the morphological and physiological responses of cotton were erratic during 1983 and 1984. Further studies should be done to determine the optimum irrigation rate and frequency for drip irrigated cotton.

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