

Preconditioning Cotton to Improve Water Use Efficiency  
and Conserve Irrigation Water

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## ABSTRACT

Water is often the major limiting factor to crop production in New Mexico. With the growing competition among industrial, urban and agricultural water users for the state's limited water resources, conservation and water use efficiency are of priority interest. Preconditioning or hardening crop plants to water deficits has been proposed as a means of utilizing deficit irrigation for conserving irrigation water while minimizing yield reductions, thus improving water use efficiency. This approach, however, has not been explored as a water conservation tool. Greenhouse studies were conducted to determine the feasibility of preconditioning a crop to water deficits for the purpose of reducing subsequent water use with minimal impact on yield. Cotton (Gossypium hirsutum L.) was utilized as the experimental plant material.

Results suggest that cotton plants subjected to low levels of soil water potential (-1.50 MPa) during the preflowering stage used significantly less water than plants optimally irrigated [-0.17 MPa soil water potential at irrigation (SWPI)]. No significant differences in water use were observed, however, between -0.17 MPa SWPI and a moderate level of irrigation (-0.45 MPa SWPI) applied during the flowering stage. Furthermore, water-use efficiency was not significantly influenced by SWPI levels applied during either stage or by their interaction. The cotton crop, therefore, did not seem to lose its sensitivity to water stress during the flowering stage and the low (-1.50 MPa) SWPI level applied before flowering did not produce a preconditioning effect resulting in a reduction of water use during the flowering stage. Yet, the threshold leaf water potential for zero turgor and stomatal closure was lowered significantly when the plants were subjected to a stress level of

-3.00 MPa leaf water potential during the preflowering stage. This lowered threshold may contribute to the earliness of crop maturity by allowing photosynthesis and assimilate transport to proceed at lower leaf water potentials and thus reduce the boll maturation period which may reduce water use by shortening the effective growing season. The results indicate that the -1.50 MPa SWPI level applied before flowering promoted the earliness of crop maturity without any significant reductions in yield. Furthermore, the results suggest that savings in irrigation water can be achieved.

Key words: water conservation, drought tolerance, irrigation management, moisture deficit, water use efficiency, drought preconditioning, deficit irrigation, cotton

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## INTRODUCTION

In the semiarid and arid regions of the United States, water is often the major limiting factor to agricultural production. In these areas, efficient utilization of the water resources is crucial. With the growing competition among industrial, urban, and agricultural water users for limited water resources, conservation and water use efficiency are of priority interest.

The concept of drought hardening or preconditioning of plants to water deficits is relatively old (Maximov 1929). The term "hardening" has been defined as an exposure to a sublethal stress that results in resistance to an otherwise lethal stress (Levitt 1972). In recent usage, the term "preconditioning" has been broadened to encompass those morphological and physiological changes resulting from an exposure to stress that lessen the impact of subsequent stress. Such conditioning responses most commonly imply an increase in tolerance to the stress. However, an increase in avoidance of the stress may also occur. By definition, tolerance enables a plant to survive the stress until such time that the stress is removed and the plant can recommence its normal metabolism, growth, and development. Avoidance, on the other hand, implies that the plant continues to function more or less normally by making adjustments that enable the plant to maintain tissue water levels as if the stress were not present. Maximov's (1929) classification of xerophytes points to two distinct types of drought avoiders--the water savers and the water spenders. The water savers avoid drought by water conservation; whereas, the water spenders avoid drought by absorbing water rapidly enough to keep up with their rapid water loss through more extensive root systems, larger proportion of conducting to nonconducting tissue and a higher water absorption potential. Levitt (1972) defines one type of drought tolerance as dehydration avoidance that deviates somewhat from the definition of tolerance given above as this



adaptation allows tolerance to low water potential without cessation of growth. With this type of tolerance, plant cells continue to grow when exposed to drought stress because the cells accumulate sufficient solute to produce a lower osmotic potential than that of their environment. Thus, cell turgor is maintained in spite of drought stress and cell division and enlargement can continue.

For crops totally dependent upon irrigation, the importance of water spender drought avoidance or drought tolerance that does not permit continued growth is of questionable value for deficit irrigation management. A water-saving, avoidance or dehydration avoidance type of conditioning response, on the other hand, may enable the crop to continue growth and development under deficit moisture conditions. It is assumed that a crop that has been hardened and has developed some degree of dehydration avoidance or drought avoidance of the water-saving type would use less water. The extent that a water deficit would lower yields would depend on the nature of the avoidance mechanisms as well as the degree of stress imposed. As water use efficiency is related to yield, the level at which a "hardened" plant could maintain normal growth would significantly influence crop water use efficiency.

Cotton (Gossypium hirsutum L.) is a major crop of New Mexico where it is grown primarily as an irrigated crop. Cotton belongs to the genus, Gossypium, and species of this genus grow naturally in relatively arid areas in the tropical and subtropical regions of the Middle East, Africa, the Americas, Australia, and certain islands in the Pacific (Lewis and Richmond 1968). In man's domestication and use of cotton as an agricultural crop, these cultivated species have been distributed into some of the more humid and temperate areas of the world. But, it is well known that cotton can endure long periods of drought, resuming growth when favorable conditions return. This drought

tolerance is thought to be related, in part, to several inherent characteristics of the genus such as an extensive root system, the ability to abscise leaves and fruit under water stress, and a flexible fruiting period (Eaton 1955, King 1922, Tharp 1960). There is evidence that cotton can also develop drought resistance mechanisms as a result of tissue water deficits (Brown et al. 1976, Cutler and Rains 1977, Cutler et al. 1977a, Cutler et al. 1977b, Thomas et al. 1976). These drought conditioning responses of cotton to previous water stress apparently have not been evaluated in terms of effects on water use, fruiting, and final yield. Therefore, it was the purpose of this research to test the hypothesis that cotton (G. hirsutum L.) can be preconditioned to water deficits resulting in conservation of irrigation water and improved water use efficiency. The specific objective was to study the nature of the preconditioning response in cotton under greenhouse conditions by evaluating the effects of preconditioning water stress on plant morphology, yield components, plant water use, and the physiological responses related to leaf water potential components and stomatal activity.

## MATERIALS AND METHODS

Two experiments were conducted under greenhouse conditions at New Mexico State University (NMSU) at Las Cruces. The plants were grown in large polyethylene containers having length x width x depth of 122 x 61 x 61 cm, filled with sand:clay loam (1:2 by volume) growth medium. Approximately 8 cm of gravel was placed in the bottom of each container prior to filling with growth medium. Urea and superphosphate fertilizers at the rate of 134 kg N and 224 kg P<sub>2</sub>O<sub>5</sub> per hectare, respectively, were mixed with the growth medium before planting.

About 100 to 150 acid delinted, good quality seeds of 'Acala 1517-77' cotton (Gossypium hirsutum L.) were planted in each container in two rows 43 cm apart. Seedlings were hand thinned to 24 per container (12 per row) after the appearance of the first true leaf. Temik-10 G [2-methyl-2(methylthio)proppionaldehyde-O-(methylcarbanyl)oxime] at the rate of 10 kg ha<sup>-1</sup> was banded along the rows and mixed into the soil for insect control.

The water holding capacity of the growth medium as determined by the pressure membrane and pressure plate method in the Soil and Water Testing Laboratory, Department of Crop and Soil Sciences, NMSU, was 15.2% on a mass basis. The mass water content retained at pressure potentials of 0.03, 0.50, and 1.50 MPa was 15.2, 11.0, and 10%, respectively. Other physiochemical properties of the sand:clay loam mixture used as a growth medium are given in table 1.

Soil moisture content was determined by the neutron-scattering technique using a depth moisture gauge (Model 3226, Troxler International, Inc., Triangle Park, NC). One aluminum access tube was placed at the center of each container before filling the container with the growth medium. The depth moisture gauge was calibrated by taking the count ratio readings and the

Table 1. Some physiochemical properties of the sand:clay loam mixture used as the growth medium.

Property	Quantity
Organic matter	1.8 g kg <sup>-1</sup>
Calcium carbonate	6.4%
Electrical conductivity (Sat. Extract)	0.363 S m <sup>-1</sup>
NO <sub>3</sub> <sup>-</sup> -N	66.5 mg kg <sup>-1</sup>
NaHCO <sub>3</sub> -P	8.1 mg kg <sup>-1</sup>
NH <sub>4</sub> OAC-K	287.4 mg kg <sup>-1</sup>
<u>Exchangeable Cations</u> (Sat. Extract)	
Na	117 mmol(Na <sup>+</sup> ) kg <sup>-1</sup>
Ca	218 mmol(1/2Ca <sup>2+</sup> ) kg <sup>-1</sup>
Mg	49 mmol(1/2Mg <sup>2+</sup> ) kg <sup>-1</sup>
Sodium Adsorption Ratio	1.2

gravimetric samples at different moisture contents. The effective radius of the probe of the Model 3226 depth moisture gauge ranges from 27.6 to 27.7 cm at moisture contents of 15.2 and 10.0%, respectively (Instruction Manual, 3220 Series Depth Moisture Gauges; Troxler Laboratories, Research Triangle Park, NC). Moisture determinations were made by lowering the probe of the depth moisture gauge so that the depth of the neutron source was 30 cm below the soil surface in the access tube, thereby confining the sphere of influence of the source to a 56 cm diameter in the approximate center of the soil medium within the tank.

#### Experiment 1

This study was conducted to evaluate the effects of preconditioning water stress on plant morphology, yield components, plant water use, and the physiological responses related to LWP components and stomatal activity. The plants were grown in large polyethylene containers as described above during the period of January through May 1983. A 2.5 cm thick layer of white quartz chips about 1 cm in diameter was placed over the soil surface to minimize surface evaporation. Monthly averages of relative humidity and minimum, maximum, and mean temperatures observed during the study period are given in table 2.

Four treatments were selected by dividing the irrigation season into two developmental stages, preflowering and flowering, which encompassed the period from planting to first flower and from first flower to the end of the irrigation season, respectively. The soil moisture regimes were established on the basis of soil water potential. Four irrigation treatments consisted of the factorial combinations of two levels (-0.17 and -1.50 MPa) of the soil water potential at irrigation (SWPI) before flowering (preflowering) with two levels (-0.17 and -0.45 MPa) of SWPI during the flowering stage. Treatment details

Table 2. Temperature and relative humidity values recorded in the greenhouse during the study period, Experiment 1.

Month	Air temperature			Relative humidity
	Mean	Maximum	Minimum	
	-----°C-----			%
January	25.0	31.4	18.6	25.3
February	25.0	31.8	18.2	23.3
March	26.4	33.8	19.7	28.5
April	23.5	30.5	16.4	30.6

are given in table 3. These treatments were selected to provide a preconditioning water stress (-1.50 MPa) during preflowering and a moderate water stress (-0.45 MPa) during flowering to test the persistence of the preflowering conditioning. A control (-0.17 MPa) was included in each stage for comparison purposes. The treatments were replicated five times in a randomized complete block design as shown in figure 1. As the soil moisture content during the preflowering stage approached the target SWPI level of -0.17 MPa, plants in treatments 0.17/0.17 and 0.17/0.45 were watered back to field capacity (-0.03 MPa) and the process continued. On the other hand, as the soil moisture was depleted to -1.50 MPa SWPI, plants in treatments 1.50/0.17 and 1.50/0.45 were not watered back to field capacity. Moisture content was maintained between -0.17 and -1.50 MPa up to 55 days after emergence (DAE), and between -0.45 and -1.50 MPa SWPI thereafter, until the initiation of flowering (70 DAE) when the plants were watered back to field capacity. At this stage, four plants from each container were harvested, and stem height, number of leaves, leaf area, dry weight of stems and leaves, and specific leaf weight were determined. Stem height was measured from the cotyledonary node to the tip of the growing point of the central axis. The plants were then separated into leaves and stems, and the leaves were counted. Leaf area was determined with a leaf area meter (Model LI-3000 Leaf Area Meter with a LI-3050A Transparent Belt Conveyor Accessory, LI-COR Inc., Lincoln, NE), and expressed on a per plant basis. The dry weights of the stems and leaves were estimated after drying in a forced draft oven at 70°C. These weights were also expressed on a per plant basis. The specific leaf weight was calculated as the ratio of the leaf dry weight to its leaf area.

The remaining 20 plants in each container were irrigated as indicated for the flowering stage in table 3. On 26 April 1983, when the plants were 97

Table 3. Details of the irrigation treatments in Experiment 1.

Treatment	SWPI <sup>+</sup>		Water applied		
	Preflowering	Flowering	Preflowering	Flowering	Total
	-----MPa-----		-----L/container-----		
0.17/0.17	0.17	0.17	122.2	143.2	265.4
0.17/0.45	0.17	0.45	123.0	129.2	252.2
1.5/0.17	1.50	0.17	78.8	117.2	196.0
1.5/0.45	1.50	0.45	85.2	109.6	194.8

<sup>+</sup> SWPI = Soil water potential at irrigation



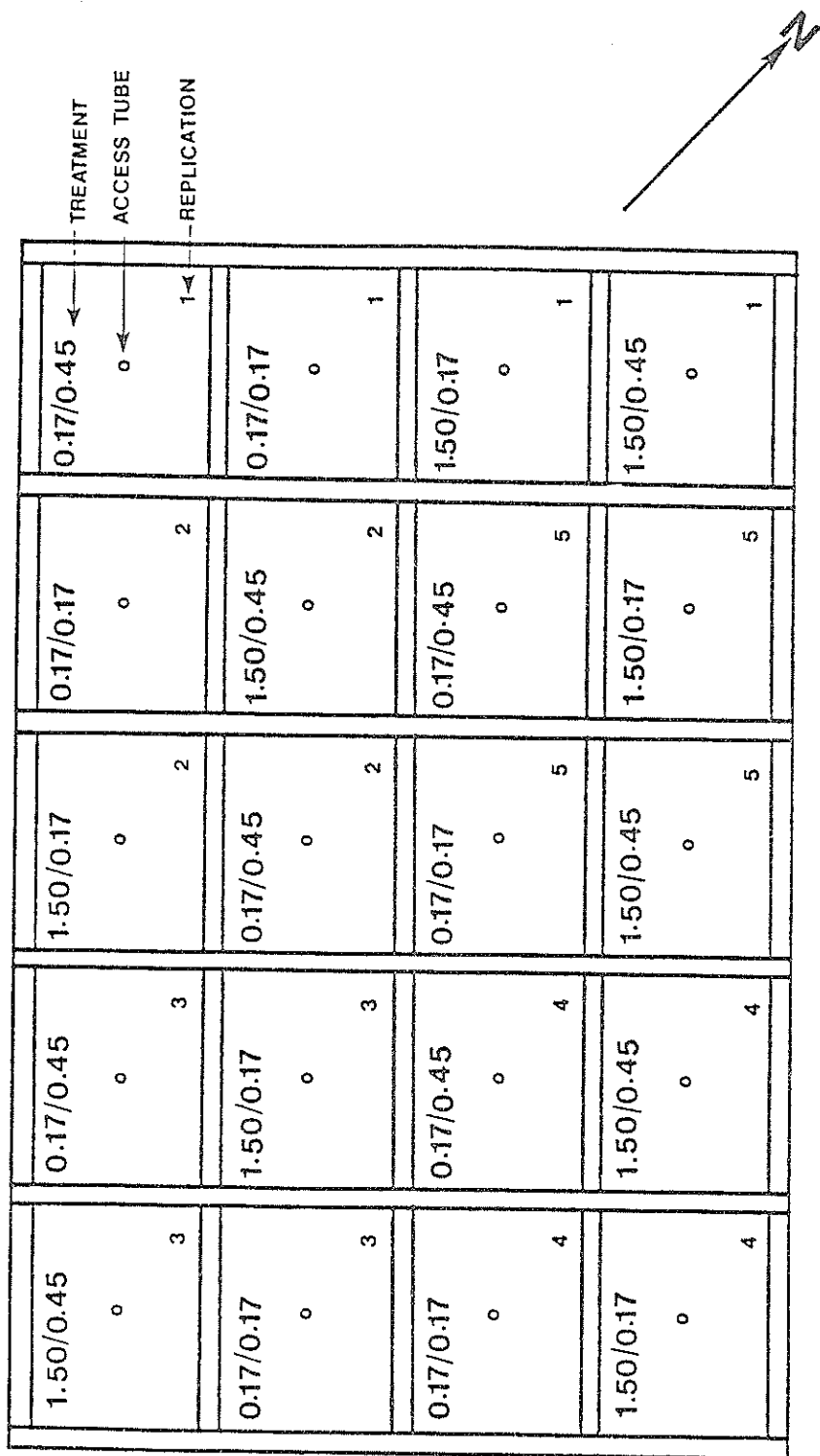


Figure 1. Layout plan showing the distribution of treatments in Experiment 1.

days old, a final irrigation was applied and plants were subjected to a final drying cycle lasting seven days, i.e., up to May 2. During this period, daily measurements of leaf water potential, leaf osmotic potential, and porometric data were taken on three plants in each container.

Diffusion resistance of both the abaxial and adaxial leaf surfaces was measured with a steady-state porometer (Model LI-1600, LI-COR Inc., Lincoln, NE) as described by Beardsell et al. (1972). All the measurements were taken between 1300 and 1600 hours (MDT) on the second or third fully expanded leaf from the top of the main stem. Total leaf resistance was calculated by assuming that both leaf surfaces acted as parallel resistors. The reciprocal of the resistance (stomatal conductance) was used for evaluating the degree of stomatal closure. The value of stomatal conductance  $\leq 0.05 \text{ cm s}^{-1}$  was taken as an indication of stomatal closure. After the determination of diffusion resistance, the leaf was cut at the base of the petiole and leaf water potential measured with a pressure chamber (Scholander et al. 1965). This technique has proved satisfactory for measurement of leaf water potential in cotton and some other crops (Jordan 1970, Sojka et al. 1979, Turk and Hall 1980b). Pressurization rate was 1.2 to 1.8 MPa/min. Leaf osmotic potential of the same leaf was then determined with a vapor pressure osmometer (Model 5130C, Wescor Inc., Logan, Utah). After the measurement of leaf water potential in the pressure chamber, the leaf lamina was placed in a disposable plastic hypodermic syringe, frozen in dry ice, and stored in a freezer at  $-20^{\circ}\text{C}$ . The osmotic potential was measured at  $25^{\circ}\text{C}$  on the sap expressed from the leaf material with the syringe plunger. An 8 L aliquot of the expressed sap was absorbed on a filter paper disc and placed in the sample chamber of the osmometer to obtain the osmolality reading, which was later converted to osmotic potential. Leaf turgor potential was calculated by subtracting leaf

osmotic potential from the leaf water potential. The occurrence of the preconditioning response was evaluated on the basis of the leaf water potential at which the stomates closed or zero turgor was reached.

On the last day of the drying cycle (104 DAE), 10 plants from each container were harvested for the determination of stem height, leaf area, stem and leaf dry weight, and specific leaf weight as described previously. The bolls from all 20 plants in each container were harvested and grouped into four boll-size categories: diameter less than 1 cm, 1 to 2 cm, 2 to 3 cm, and larger than 3 cm. The bolls in each size category were counted, and then dried in a forced draft oven at 70°C. Both the number and the dry weight of the bolls in each category were expressed on a per plant basis. The earliness of crop maturity was determined by taking the ratios of the number of bolls per plant in each size category to the total number of bolls per plant as well as the weight of bolls per plant in each category to the total weight of bolls per plant, respectively. These ratios will hereafter be referred to as the percent number of bolls and percent weight of bolls, respectively.

Water-use efficiency was estimated as the ratio of the weight of bolls from 20 plants to the total water applied, and was expressed as g/L.

## Experiment 2

This study was conducted from January 1984 to March 1984, to determine the level of leaf water potential necessary to produce a preconditioning response in cotton. The plants were grown in large polyethylene containers as described in experiment 1. Three treatments consisted of different levels of leaf water potentials (-1.50 MPa, -2.25 MPa, and -3.00 MPa) measured between 1300 and 1600 hours (MDT). Hereafter, treatment -1.50 MPa will be considered the control treatment, while treatments -2.25 MPa and -3.00 MPa will be known as the preconditioning treatments. These treatments were replicated five

times in a randomized complete block design, but one replication was discarded because of the large variation in solar radiation. The layout plan is shown in figure 2. The treatments were initiated when the plants were 35 days old and roots had completely occupied the containers. As the leaf water potential reached the target levels of -1.50, -2.25, or -3.00 MPa, plants in that particular treatment were watered back to field capacity, and then were subjected to a severe drying cycle in which leaf water potential was allowed to reach -3.50 to -4.00 MPa. For example, as the leaf water potential of the plants in treatment -1.50 MPa reached this level (-1.50 MPa), they were watered back to field capacity and the final drying cycle began. The final drying cycle lasted 3 days in treatment -3.00 MPa to 13 days in treatment -1.50 MPa. The differences in the length of the drying cycle resulted from the differences in leaf water potential at field capacity before the initiation of the drying cycle. The leaf water potential in treatments -1.50 MPa and -2.25 MPa increased to about -1.00 MPa following irrigation, but in treatment -3.00 MPa LWP did not rise above -2.00 MPa. Thus, the plants in treatments -1.50 MPa and -2.25 MPa required a longer period of time to reach -4.00 MPa than treatment -3.00 MPa. The final drying cycle ended when the leaf water potential in that particular treatment reached -3.50 and -4.00 MPa. During this final drying cycle, measurements of leaf water potential, leaf osmotic potential, and porometry were taken daily from three plants in each container, as described in experiment 1.

#### Statistical Analyses

All the data on the morphological and physiological measurements in Experiment 1 were subjected to the analysis of variance procedure (Steel and Torrie 1980), and the means were separated by using the least significant difference (LSD) test with a 0.05 or less probability level. The data on

TREATMENT		REPLICATION	
3.00	2.25	1.50	3.00
2.25	1.50	3.00	2.25
1.50	3.00	2.25	1.50
3.00	2.25	1.50	3.00
2.25	1.50	3.00	2.25
1.50	3.00	2.25	1.50
3.00	2.25	1.50	3.00
2.25	1.50	3.00	2.25
1.50	3.00	2.25	1.50

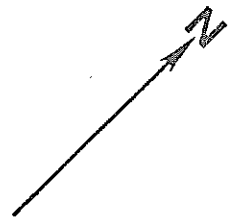


Figure 2. Layout plan showing the distribution of treatments in Experiment 2.

stomatal conductance and leaf water potential components were also analyzed by the stepwise multiple regression procedure using dummy variables (Draper and Smith 1981). The stomatal conductance (SC), leaf osmotic potential (LOP), and leaf turgor potential (LTP) were regressed on the leaf water potential (LWP) using the model:

$$SC, LOP, LTP = \beta_0 + \beta_1(LWP) + \beta_2(D_1) + \beta_3(D_1LWP) + \beta_4(D_2) + \beta_5(D_2LWP) + \beta_6(D_3) + \beta_7(D_3LWP) + E_i$$

where  $\beta_0$  is the intercept,  $\beta_1$  through  $\beta_7$  are the partial regression coefficients, and  $D_1$ ,  $D_2$ ,  $D_3$  are the dummy variables corresponding to treatments 0.17/0.45, 1.50/0.17, and 1.50/0.45, respectively. The dummy variables take on the values of 1 for their corresponding treatments, and 0 for any other treatment, and the model for the reference category (treatment 0.17/0.17) thus, reduces to:

$$SC, LOP, LTP = \beta_0 + \beta_1(LWP) + E_i$$

The daily changes in leaf water potential and leaf turgor potential during the final drying cycle in experiment 1 under different treatments were compared and dummy variables were used to separate the differences in intercepts and slopes of the regression lines. The model used was:

$$LWP, LTP = \beta_0 + \beta_1(\text{day}) + \beta_2(D_1) + \beta_3(D_1\text{day}) + \beta_4(D_2) + \beta_5(D_2\text{day}) + \beta_6(D_3) + \beta_7(D_3\text{day}) + E_i$$

The variable day in this model represents the day of the drying cycle, and  $\beta_0$  through  $\beta_7$  and  $D_1$  through  $D_3$  are the same as defined above. The model is reduced to:

$$\text{LWP, LTP} = \beta_0 + \beta_1(\text{day})$$

for treatment 0.17/0.17.

The physiological measurements of SC, LWP, LOP, and LTP from Experiment 2 were also subjected to similar regression procedures except that the dummy variables were defined differently. The regression model used was:

$$\begin{aligned} \text{SC, LOP, LTP} = & \beta_0 + \beta_1(\text{LWP}) + \beta_2(D_1) + \beta_3(D_1\text{LWP}) + \beta_4(D_2) \\ & + \beta_5(D_2\text{LWP}) + E_i \end{aligned}$$

where  $\beta_0$  is the intercept,  $\beta_1$  through  $\beta_5$  are the partial regression coefficients, and  $D_1, D_2$  are the dummy variables. The dummy variables  $D_1$  and  $D_2$  assume the value of 1 corresponding to the treatments -2.25 MPa and -3.00 MPa, but 0 for other treatments. The regression model for the treatment 1.50 MPa was, therefore,

$$\text{SC, LOP, LTP} = \beta_0 + \beta_1(\text{LWP}) + E_i$$

The differences in the intercepts and slopes of the regression lines in all the above cases were separated at 0.05 or less probability level by the least significant difference method.

## RESULTS AND DISCUSSION

### Experiment 1

Morphological Measurements. The effect of preflower SWPI levels of  $-0.17$  and  $-1.50$  MPa on some morphological characteristics evaluated at 70 days after emergence is shown in table 4. It is clear that  $-1.50$  MPa SWPI level caused significant reductions in the stem height, number of leaves, leaf area, and the dry weight of stems and leaves, but increased the specific leaf weight, as compared to the  $-0.17$  MPa SWPI level. The plants in the low ( $-1.50$  MPa) SWPI level were 38 percent shorter in height than the plants in the high ( $-0.17$  MPa) SWPI level, and the results agree well with those of Cutler and Rains (1977) and Valera (1984). The reduction in plant height under the low SWPI level could be attributed to the reductions in the number of nodes as well as the length of the internodes (Hearn 1980, Valera 1984) and reflects the effect of water stress on cell enlargement (Hsiao 1973). The results of a greenhouse study by Cutler and Rains (1977) indicate that plant height of weekly irrigated plants was reduced by 42 percent as compared with those of the daily irrigated plants, and mainstem elongation stopped at leaf water potentials below  $-1.4$  MPa.

Leaf area is an important determinant of crop productivity and also regulates plant water balance through its effect on transpiration (Levitt 1980). Significant differences in leaf area were observed between  $-0.17$  and  $-1.50$  MPa SWPI levels applied during the preflowering stage (table 4). Low ( $-1.50$  MPa) SWPI level caused a 45 percent reduction in leaf area as compared with the high ( $-0.17$  MPa) SWPI level. These results support the findings of Kies (1982), who found that leaf area of upland cotton at 156 days after emergence in a dry treatment of  $-1.50$  MPa soil water potential was 33 percent less than in a wet treatment of  $-0.05$  MPa soil water potential.



Table 4. The effect of soil water potential at irrigation (SWPI) before flowering (preflowering) on stem height, number of leaves, leaf area, dry weight of stems and leaves, and specific leaf weight at 70 days after emergence, Experiment 1.

SWPI <sup>†</sup> Level	Stem height	Leaves	Leaf area	Dry weight		Specific leaf weight
				Stems	Leaves	
-MPa	m	no/pl	m <sup>2</sup> /pl	-----g/pl-----		kg m <sup>-2</sup>
0.17	0.55a <sup>‡</sup>	25.2a	0.175a	5.76a	7.25a	0.042a
1.50	0.34b	17.7b	0.095b	3.56b	4.68b	0.051b
Mean	0.45	21.5	0.135	4.66	5.96	0.046
c.v.(%)	14.88	12.81	20.29	27.75	17.41	16.49

<sup>†</sup>SWPI = Soil water potential at irrigation

<sup>‡</sup>Means followed by the same letter in the same column are not significantly different at the 5% probability level according to the least significant difference (LSD) test.

Dry weight of stems and leaves was reduced by 38.2 and 36.6 percent, respectively, in the -1.50 MPa SWPI level as compared to that in the -0.17 MPa SWPI level (table 4). Similar results were also reported by Marani and Levi (1973) and Bielorai and Hopmans (1975), who found significant reductions in dry matter production of both field-grown and chamber-grown cotton under a dry treatment as compared with that under a wet treatment.

The specific leaf weight was increased significantly ( $P < 0.001$ ) by the water stress treatment (-1.50 MPa SWPI) over that of the control (-0.17 MPa SWPI). These results are consistent with the effect of water stress on specific leaf weight (Kies 1982) and reflect the differences in leaf thickness of well-watered and water-stressed plants (Van Volkenburgh and Davies 1977). It is suggested that cell size is reduced and cell wall thickness increased in plants subjected to water stress conditions (Cutler et al. 1977a) and both these changes contribute to the increases in specific leaf weight. The increases in specific leaf weight can confer increased drought resistance but may not always increase yield. Turk and Hall (1980b) found that the specific leaf weight of cowpeas increased with the increasing levels of drought but was negatively correlated with yield.

Table 5 shows the effect of SWPI levels applied before flowering (-0.17 and -1.50 MPa) and during flowering (-0.17 and -0.45 MPa) on morphological characteristics evaluated at 104 days after emergence. It is clear that low (-1.50 MPa) SWPI level applied before flowering caused significant reductions in stem height, leaf area and dry weight of leaves and stems, but increased the specific leaf weight. These responses are similar to those observed at 70 days after emergence. No significant differences in any of these morphological characteristics were observed, however, between -0.17 MPa and -0.45 MPa SWPI levels applied during the flowering stage.

Table 5. The effect of irrigation regimes applied before flowering (pre-flowering) and during flowering on stem height, leaf area, dry weight of stems and leaves, and specific leaf weight at 104 days after emergence, Experiment 1.

SWPI† level	Stem height	Leaf area	Dry weight		Specific leaf weight
			Stems	Leaves	
-MPa	m	m <sup>2</sup> /pl	-----g/pl-----		kg m <sup>-2</sup>
<u>Preflowering</u>					
0.17	0.58a‡	0.170a	11.49a	9.35a	0.055b
1.50	0.43b	0.108b	5.90b	6.57b	0.061a
<u>Flowering</u>					
0.17	0.51	0.141	9.02	7.99	0.0058
0.45	0.50	0.138	8.38	7.92	0.0058
Mean	0.50	0.139	8.70	7.96	0.0058
c.v. (%)	17.17	19.84	27.46	17.95	8.80

†SWPI = Soil water potential at irrigation

‡Means followed by the same letter in the same column within the same crop developmental stage are not significantly different at the 5% probability level according to the least significant difference (LSD) test. Means without letters indicate no significant difference.

The interaction between the preflowering and flowering SWPI levels was not significant.

The total number of bolls per plant was significantly reduced by pre-flower SWPI level of -1.50 MPa as compared with -0.17 MPa SWPI (table 6). Different SWPI levels during the flowering stage did not have any significant effect on the number of bolls per plant, and the preflowering x flowering interaction was not significant. The number of bolls in the size categories of 1 to 2 cm and of 2 to 3 cm were significantly less on plants under pre-flower SWPI of -1.5 MPa as compared with those under -0.17 MPa SWPI. The number of bolls of size 1 to 2 cm and of 2 to 3 cm decreased from 0.64 and 2.86 per plant in the -0.17 MPa SWPI to 0.35 and 1.72 per plant in the -1.50 MPa SWPI, respectively (Table 6). The number of bolls smaller than 1 cm or larger than 3 cm were not significantly different among preflower SWPI levels. The irrigation regimes during the flowering stage did not have any significant effect on bolls per plant in any of these categories. The preflowering x flowering interaction was also non-significant. The total weight of bolls per plant was not influenced by irrigation regimes during either stage, but the weight of bolls of size 1 to 2 cm and of 2 to 3 cm was significantly reduced by preflower SWPI of -1.50 MPa (table 7). The weight of bolls in these categories decreased from 0.39 and 6.65 g/plant under -0.17 MPa SWPI to 0.17 and 4.74 g/plant in the -1.50 MPa SWPI level, respectively (table 7).

The number of bolls per plant in boll size categories of <1 cm, 1 to 2 cm, 2 to 3 cm, and >3 cm, taken as the percentage of the total number of bolls per plant was used to evaluate the earliness of crop maturity and is referred to as the percent number of bolls. It is clear from the data in table 8 that SWPI levels (-0.17 MPa and -0.45 MPa) applied during the

Table 6. Number of bolls per plant as influenced by irrigation regimes applied before flowering (preflowering) and during flowering at 104 days after emergence, Experiment 1.

SWPI <sup>†</sup> level	Bolls				Total
	< 1 cm	1-2 cm	2-3 cm	> 3 cm	
-MPa	no/plant				
	<u>Preflowering</u>				
0.17	0.54	0.64a <sup>‡</sup>	2.86a	1.39	5.43a
1.50	0.56	0.35b	1.72b	1.40	4.03b
	<u>Flowering</u>				
0.17	0.53	0.54	2.37	1.30	4.74
0.45	0.57	0.45	2.21	1.49	4.72
Mean	0.55	0.49	2.29	1.40	4.73
c.v. (%)	62.46	52.26	24.52	37.21	18.58

<sup>†</sup>SWPI = Soil water potential at irrigation

<sup>‡</sup>Means followed by the same letter in the same column within the same crop developmental stage are not significantly different at the 5% probability level according to the least significant difference (LSD) test. Means without letters indicate no significant difference.

Table 7. Weight of the bolls per plant as influenced by irrigation regimes applied before flowering (preflowering) and during flowering at 104 days after emergence, Experiment 1.

SWPI <sup>†</sup> level	Weight of bolls				Total
	<1 cm	1-2 cm	2-3 cm	>3 cm	
-MPa	-----g/plant-----				
	<u>Preflowering</u>				
0.17	0.17	0.39a <sup>‡</sup>	6.65a	6.22	13.41
1.50	0.16	0.17b	4.74b	6.80	11.88
	<u>Flowering</u>				
0.17	0.15	0.31	5.85	5.76	12.06
0.45	0.18	0.25	5.54	7.25	13.23
Mean	0.17	0.28	5.70	6.51	12.65
c.v.(%)	71.85	51.51	25.16	30.23	25.00

<sup>†</sup>SWPI = Soil water potential at irrigation

<sup>‡</sup>Means followed by the same letter in the same column within the same crop developmental stage are not significantly different at the 5% probability level according to the least significant difference (LSD) test. Means without letters indicate no significant difference.

Table 8. The percent number of bolls in each size category as influenced by irrigation regimes applied before flowering (preflowering) and during flowering at 104 days after emergence, Experiment 1.

SWPI <sup>†</sup> level	Percent number of bolls			
	<1 cm	1-2 cm	2-3 cm	>3 cm
-MPa	-----%			
	<u>Preflowering</u>			
0.17	10.57	12.11	51.73a <sup>‡</sup>	25.59
1.50	14.74	8.31	42.46b	34.49
	<u>Flowering</u>			
0.17	11.64	11.09	49.73	27.54
0.45	13.67	9.33	44.47	32.53
Mean	12.65	10.21	47.10	30.03
c.v. (%)	83.13	51.63	15.09	32.32

<sup>†</sup>SWPI = Soil water potential at irrigation

<sup>‡</sup>Means followed by the same letter in the same column within the same crop developmental stage are not significantly different at the 5% probability level according to the least significant difference (LSD) test. Means without letters indicate no significant difference.

flowering stage did not have any significant effect on the percent number of bolls in any of these categories, while preflower SWPI levels influenced the percent number of bolls in the boll size category of 2 to 3 cm, which was reduced from 51.73 percent in the -0.17 MPa SWPI to 42.46 percent in the -1.50 MPa SWPI.

The weight of bolls per plant in each boll size category taken as a percentage of the total weight of bolls per plant was also used to evaluate the earliness of crop maturity and is known as the percent weight of bolls (table 9). Low SWPI (-1.50 MPa and -0.45 MPa) applied before flowering and during flowering, respectively, decreased the percent weight of bolls in size category of 2 to 3 cm, but increased that of bolls larger than 3 cm. Such an increase in percent weight of larger bolls on plants subjected to a low soil moisture regime is an indication of the earliness of crop maturity and these results agree well with the data of Spooner et al. (1958) and Valera (1984). Spooner et al. (1958) found that cotton plants receiving no irrigation reached the peak of blooming two weeks earlier than those receiving regular irrigations, and thus a greater percentage of the bolls from the non-irrigated plants matured early. This finding is further supported by the data of Valera (1984), who used the percentage of developing, full-size, and open bolls to evaluate earliness and found that the percentage of full-size bolls was higher and those of open bolls lower in a -0.17 MPa SWPI than in a -1.50 MPa SWPI level. He thus concluded that low moisture supply before flowering hastens the earliness of maturity.

Table 10 shows the weight of bolls per plant, total water applied and the water-use efficiency as influenced by SWPI levels applied during the preflowering and flowering stages. Though no significant differences in water-use efficiency were observed between SWPI levels, low (-1.50 MPa and -0.45 MPa) SWPI levels produced numerically higher water-use efficiency than the -0.17



Table 9. Percent weight of bolls in each size category as influenced by irrigation regimes applied before flowering (preflowering) and during flowering at 104 days after emergence, Experiment 1.

SWPI <sup>†</sup> level	Percent weight of bolls			
	<1 cm	1-2 cm	2-3 cm	>3 cm
-MPa	-----%			
	<u>Preflowering</u>			
0.17	1.77	3.76	50.55a <sup>‡</sup>	43.92b
1.50	2.70	1.88	41.89b	53.53a
	<u>Flowering</u>			
0.17	1.96	3.38	50.06a	44.60b
0.45	2.51	2.27	42.39b	52.83a
Mean	2.23	2.82	46.22	48.72
c.v. (%)	149.00	84.49	9.20	15.51

<sup>†</sup>SWPI = Soil water potential at irrigation

<sup>‡</sup>Means followed by the same letter in the same column within the same crop developmental stage are not significantly different at the 5% probability level according to the least significant difference (LSD) test. Means without letters indicate no significant difference.



MPa SWPI level. Furthermore, low (-1.50 MPa) SWPI level applied before flowering used significantly less water than -0.17 MPa SWPI level in producing a numerically equal yield. Stewart et al. (1975) proposed three criteria for evaluating the drought conditioning response. These criteria are that: (1) yield is lower but water-use efficiency is higher in treatment with prior stress, (2) yield is the same but water-use efficiency is higher, and (3) yield is higher with the same or higher water-use efficiency. The data from the present study agree well with their second criterion, which seems to be of utmost importance in areas of limited water supply. This optimization approach, or preconditioning criterion, is suggested to be useful in arid regions and attempts to increase water-use efficiency by lowering the water use while maintaining the yield or with relatively less reduction in yield per unit of water used.

Physiological Measurements. The daily mean values of leaf water potential, leaf osmotic potential, leaf turgor potential, stomatal conductance, and transpiration rate under different irrigation treatments are shown in table 11. These measurements were taken during the final drying cycle (April 26 to May 2), and the data for each day were analyzed separately using the analysis of variance procedure (Steel and Torrie 1980). The leaf water potential values on April 26, 27 in treatments 0.17/0.17 and 0.17/0.45 were significantly lower than in treatments 1.50/0.17 and 1.50/0.45, respectively. However, the differences in leaf water potential between treatments 0.17/0.17 and 0.17/0.45, as well as between 1.50/0.17 and 1.50/0.45, were not statistically significant. The differences in leaf water potential among treatments were statistically significant on all days, with the lowest leaf water potential observed in treatment 0.17/0.17 and the highest in treatment 1.50/0.45 each day. The leaf water potential on the last day of the drying cycle (May 2) in treatment 1.50/0.45 was 0.67 MPa higher than in treatment 0.17/0.17.

Table 11. Leaf water potential (LWP), leaf osmotic potential (LOP), leaf turgor potential (LTP), stomatal conductance (SC), and transpiration rate (TR) of each day during the final drying cycle as influenced by various irrigation treatments, Experiment 1.

Treatment-SWPI† Preflower/Flower	LWP	LOP	LTP	SC	TR
	-MPa		MPa	cm s <sup>-1</sup>	g cm <sup>-1</sup> s <sup>-1</sup>
<u>26 April</u>					
0.17/0.17	1.97b‡	2.25c	0.29b	0.43b	7.62b
0.17/0.45	1.85b	2.29c	0.43a	1.34a	19.75a
1.50/0.17	1.54a	1.86a	0.32ab	1.21a	17.66
1.50/0.45	1.65a	2.05b	0.41ab	1.23a	18.27a
Mean	1.75	2.11	0.36	1.05	15.83
c.v.(%)	9.71	9.19	50.30	38.35	34.05
<u>27 April</u>					
0.17/0.17	2.24b	2.26b	0.02	0.07b	2.29b
0.17/0.45	2.13b	2.25b	0.12	0.89a	16.16a
1.50/0.17	1.92a	2.00a	0.08	0.90a	16.99a
1.50/0.45	1.83a	2.01a	0.18	1.05a	18.60a
Mean	2.03	2.13	0.10	0.73	13.52
c.v.(%)	7.49	7.50	169.00	29.14	29.54
<u>28 April</u>					
0.17/0.17	2.41c	2.29b	-0.12	0.06c	1.64c
0.17/0.45	2.41c	2.30b	-0.11	0.26b	6.05b
1.50/0.17	2.08b	1.96a	-0.12	0.23b	5.64b
1.50/0.45	1.96a	1.93a	-0.03	0.45a	9.56a
Mean	2.22	2.12	-0.10	0.25	5.72
c.v.(%)	7.02	6.64	140.04	53.00	51.62
<u>29 April</u>					
0.17/0.17	2.77d	2.53b	-0.24	0.04d	0.91c
0.17/0.45	2.61c	2.31a	-0.30	0.21b	5.12a
1.50/0.17	2.43b	2.21a	-0.22	0.14c	3.15b
1.50/0.45	2.16a	2.19a	0.03	0.29a	4.67b
Mean	2.49	2.31	-0.20	0.17	3.46
c.v.(%)	7.46	11.62	140.25	56.77	56.44
<u>2 May</u>					
0.17/0.17	3.83c	3.35c	-0.48	0.02	0.53
0.17/0.45	3.51b	3.14b	-0.37	0.02	0.62
1.50/0.17	3.58b	3.10b	-0.48	0.02	0.51
1.50/0.45	3.16a	2.71a	-0.45	0.02	0.61
Mean	3.63	3.08	-0.55	0.02	0.57
c.v.(%)	5.18	5.36	37.47	27.06	25.74

†SWPI = Soil water potential at irrigation

‡Means followed by the same letter in the same column within the same date are not significantly different at the 5% probability level according to the least significant difference (LSD) test. Means without letters indicate no significant difference.

Parallel changes occurred in the leaf osmotic potential and the differences between treatments were highly significant. Each day the lowest leaf osmotic potential occurred in treatment 0.17/0.17, whereas the highest was observed in treatment 1.50/0.45 except on 26 April when treatment 1.50/0.17 had the highest LOP. These parallel changes in leaf water potential and leaf osmotic potential narrowed the differences in leaf turgor potential, which were significant on the first (April 26) and the fourth (April 29) day of the final drying cycle.

Similarly, the stomatal conductance and transpiration rate of plants in treatments 0.17/0.17 were always lower than those of the plants in all other treatments, i.e., 0.17/0.45, 1.50/0.17, and 1.50/0.45, and the differences were significant at the 5 percent probability level. The stomates in treatment 0.17/0.17 on the second day of the drying cycle were almost completely closed at values of leaf water potential of about -2.24 MPa. Even though the leaf turgor potential on the third day (April 28) was negative in all the treatments, the stomates were open in treatments 0.45/0.17, 1.50/0.17 and 1.50/0.45. On the last day of the drying cycle (May 2), stomates were closed in all the treatments as the leaf and soil water potentials decreased below -3.0 MPa and -1.5 MPa, respectively. The plants were severely wilted.

The differences among treatments in the rate of decline of leaf water potential and leaf turgor potential examined by the stepwise regression procedure are shown in figures 3 and 4, respectively. The dummy variables, as defined in the "Materials and Methods" section, were used to detect the differences in the intercepts and slopes of the regression lines. It is clear from figure 3 that leaf water potential in treatments 0.17/0.45 and 1.50/0.45 decreased at significantly slower rates than in treatment 0.17/0.17 and treatment 1.50/0.17. Differences in the slopes of regression lines of these treatments were statistically significant ( $P < 0.001$ ).

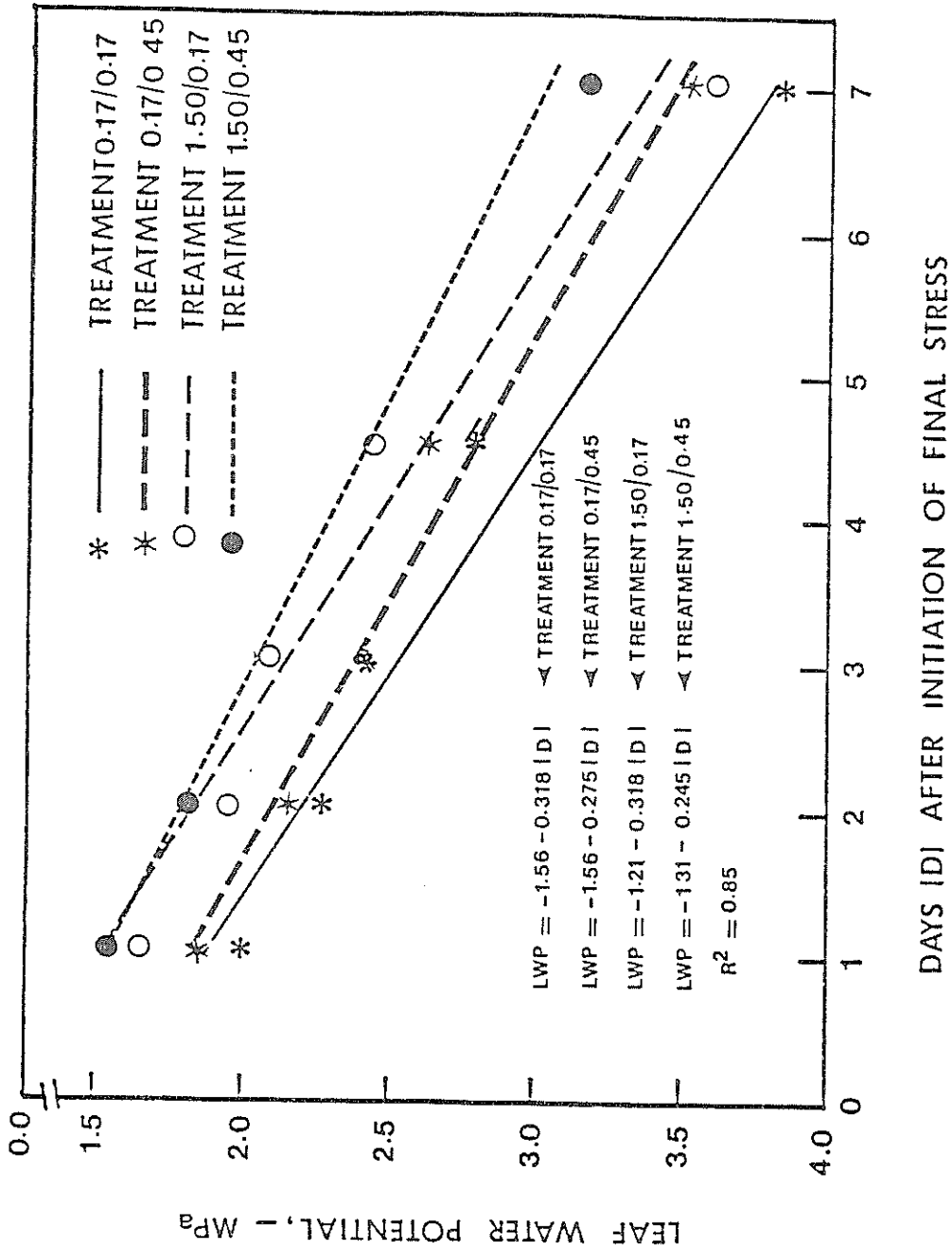


Figure 3. Regressional relationship showing the daily rate of decline in leaf water potential during the final drying cycle as influenced by different irrigation treatments, Experiment 1.

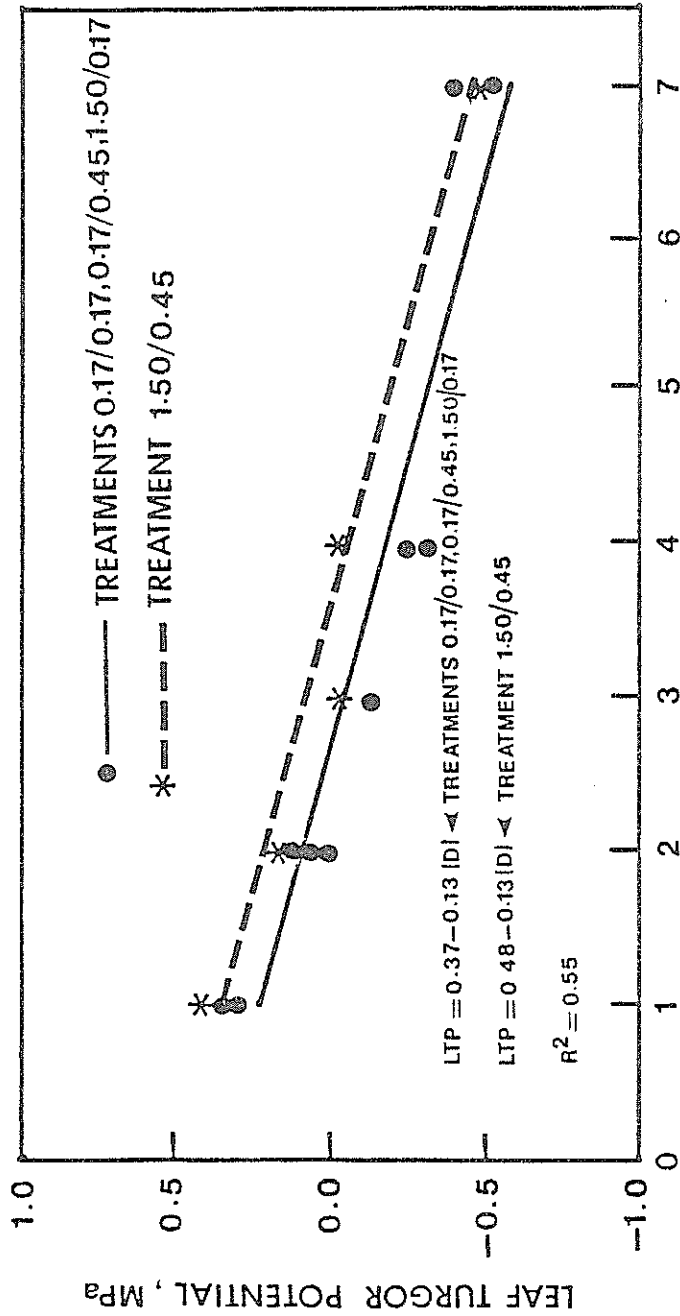


Figure 4. Regressional relationship showing the daily rate of decline in leaf turgor potential during the final drying cycle as influenced by different irrigation treatments, Experiment 1.

Leaf turgor potential decreased at the same rate in all the treatments, but was always higher in treatment 1.50/0.45 than in all other treatments as indicated by the significant differences in intercepts.

The regression relationships of stomatal conductance, leaf osmotic potential, and leaf turgor potential with leaf water potential were examined by stepwise regression to evaluate the preconditioning response. Figure 5 shows that leaf osmotic potential decreased at the same rate per unit change in leaf water potential in all the treatments. The leaf osmotic potential in treatments 0.17/0.17 and 0.17/0.45 was always lower than in treatment 1.50/0.17 and 1.50/0.45, as indicated by the differences in intercepts. Similarly, the leaf osmotic potential in treatment 1.50/0.17 was lower than in treatment 1.50/0.45. The model explained 74 percent of the variation in leaf osmotic potential. Contrary to the expected results, the leaf turgor potential in treatment 1.50/0.45 was always lower than in treatment 0.17/0.17 at the same leaf water potential (figure 6).

In general, treatment 0.17/0.17 had the lowest leaf water potential while the highest occurred in treatment 1.50/0.45, and the differences were statistically significant on all days. A similar trend was observed for stomatal conductance and transpiration rate per unit area. The differences in leaf water potential can arise from the differences in leaf area, root resistance, or the resistance between the xylem vessels and the mesophyll cells. Although significant differences were observed in leaf area, the amount of water transpired was similar because of the differences in transpiration rates per unit area. The decline in leaf water potentials during periods of peak transpiration have been attributed to the increase in root or plant resistance to water flow (Ackerson and Krieg 1977, Barrs 1970, Camacho-B et al. 1974, Kaufmann 1976). This implies that the resistance to water flow in treatment 0.17/0.17



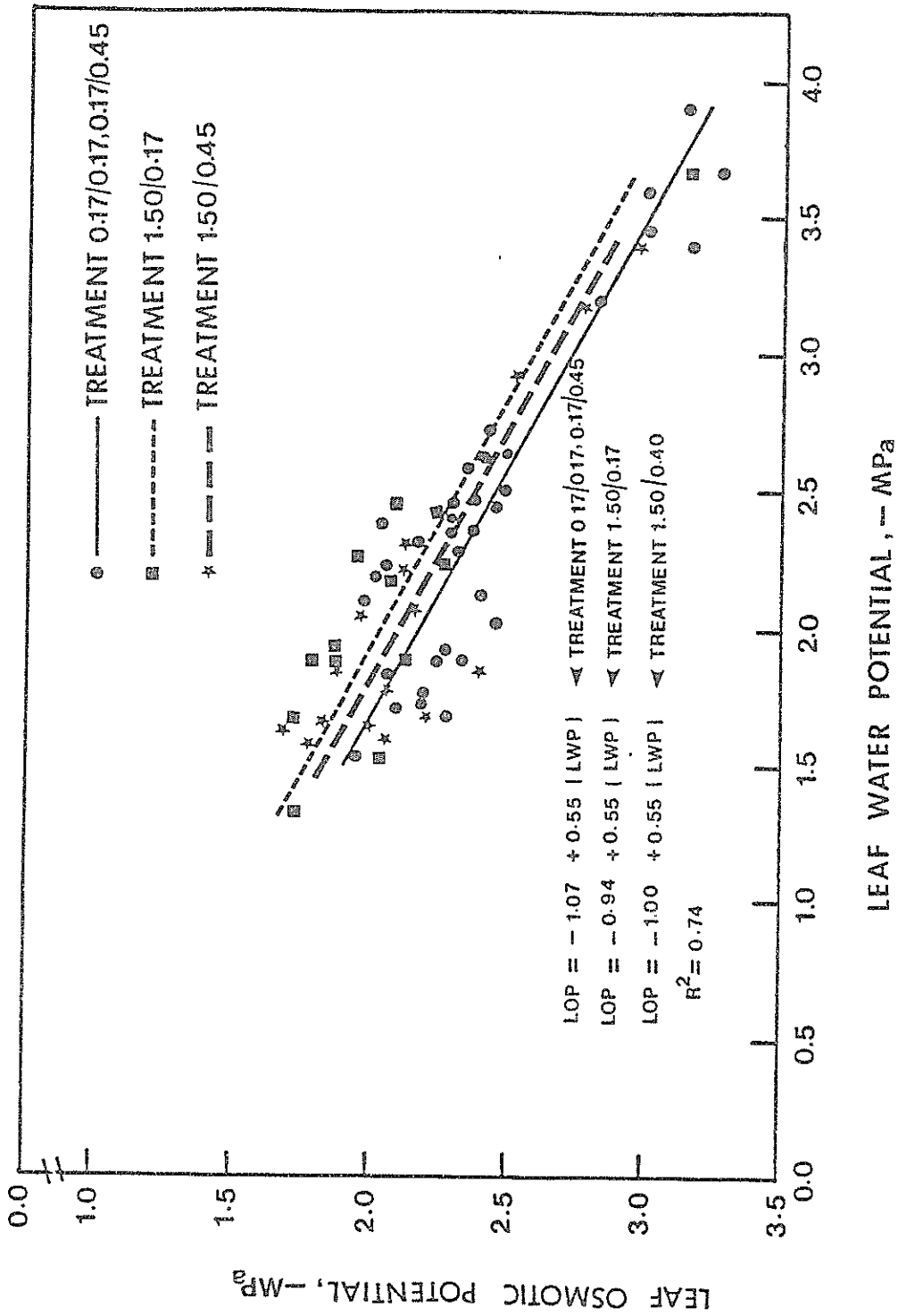


Figure 5. Effect of different irrigation treatments on the relationship of leaf osmotic potential and leaf water potential observed during the period of the final drying cycle, Experiment 1.

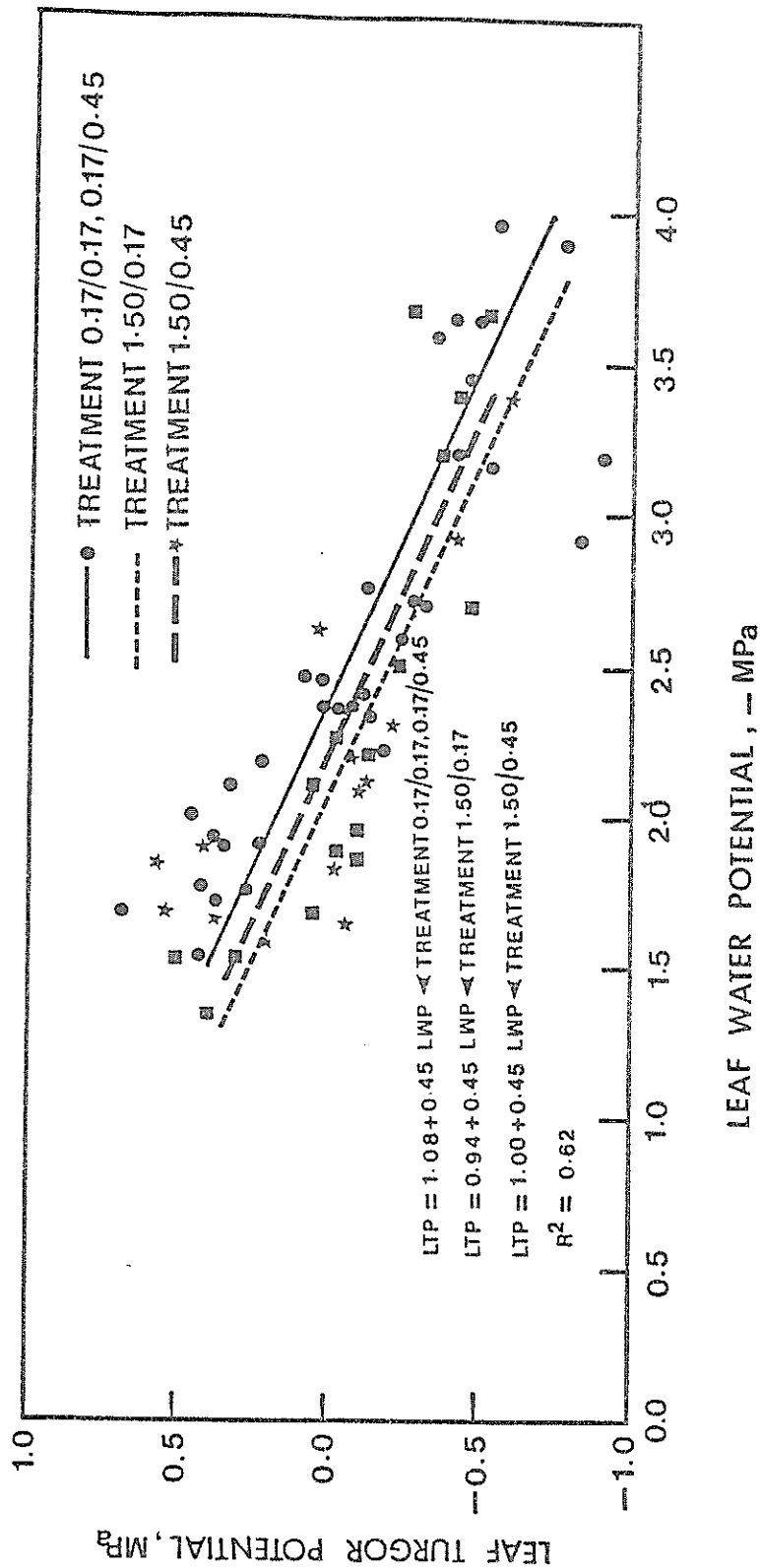


Figure 6. Effect of different irrigation treatments on the relationship between leaf turgor potential and leaf water potential observed during the period of final drying cycle, Experiment 1.

was higher than in treatment 1.50/0.45, which enabled the plants in treatment 1.50/0.45 to transport more water and maintain a favorable leaf water status. Cotton has been reported to be more efficient in transporting water than sorghum under limiting soil water conditions (Ackerson and Krieg 1977). They suggested that an efficient transport system may confer drought tolerance to species when stomatal control of water loss is nonexistent. Whether these differences exist among differentially irrigated plants is not quite clear. However, Camacho-B (1973) reported increases in root resistance of citrus (Citrus sinensis L.) plants subjected to repetitive drying cycles. Lastly, the differences in leaf water potentials could also arise because of the differences in the resistance between the xylem vessels and the mesophyll cells of the leaf (Tomar and O'Toole 1982). It should be emphasized that these measurements of transpiration represent only the time of measurement, and may differ at other times of the day. Treatment 0.17/0.17 could transpire more water at some other time of the day, as is suggested by the data on soil moisture content. Accordingly, the slower decline in leaf turgor potential in treatment 1.50/0.45 could possibly be attributed to the higher water potential in that treatment (figures 3 and 4).

The data in figure 6 indicate that at the same leaf water potential, the plants in treatment 1.50/0.17 and 1.50/0.45 had lower turgor potential than in treatments 0.17/0.17 and 0.17/0.45, respectively. The plausible explanation for this discrepancy could be either the lack of osmotic adjustment or the greater export of assimilates from plants in treatments 1.50/0.17 and 1.50/0.45, respectively. Sionit and Kramer (1977) did not find any evidence of osmotic adjustment in soybean at the pod-filling stages, although some osmotic adjustment was observed during the vegetative stage. It may be emphasized that osmotic adjustment occurs only if the solutes (assimilates) are retained in

the leaves, which probably did not occur in cotton at the boll-maturation stage. It was observed that leaves of the prestressed cotton plants exported their assimilates at a greater rate and to a more complete depletion than those of the control plants (Karami et al. 1980, Ackerson 1981). Moreover, assimilate transport is also promoted by a strong sink. Therefore, it seems logical that the young leaves of the plants in treatments 1.50/0.17 and 1.50/0.45, though photosynthesizing at a higher rate than those in treatments 0.17/0.17 and 0.17/0.45, were also exporting assimilates to the bolls at a faster rate than in other treatments (0.17/0.17 and 0.17/0.45). The lower level of osmotically active solutes in leaf mesophyll cells would result in higher osmotic potentials and thus reduce the visible evidence of osmotic adjustment, which probably occurred in this study. The lack of osmotic adjustment should not, however, be construed as an absence of preconditioning response, as the evidence for preconditioning response is available from the earliness of maturity, conservation of water, and numerically higher water-use efficiency of plants subjected to -1.50 MPa SWPI level during the preflowering stage. Moreover, significant osmotic adjustment was observed in Experiment 2, when the measurements were taken during the preflowering stage.

#### Experiment 2

This study was conducted to clarify the level of leaf water potential required to produce a preconditioning response in greenhouse-grown cotton during the preflowering stage. Figure 7 shows the regressional relationship between leaf water potential and leaf osmotic potential for different treatments. It is clear that with decreasing leaf water potential, the leaf osmotic potential in treatment -3.00 MPa decreased at a significantly lower rate than in treatments -1.50 MPa and -2.25 MPa, respectively. The slopes of

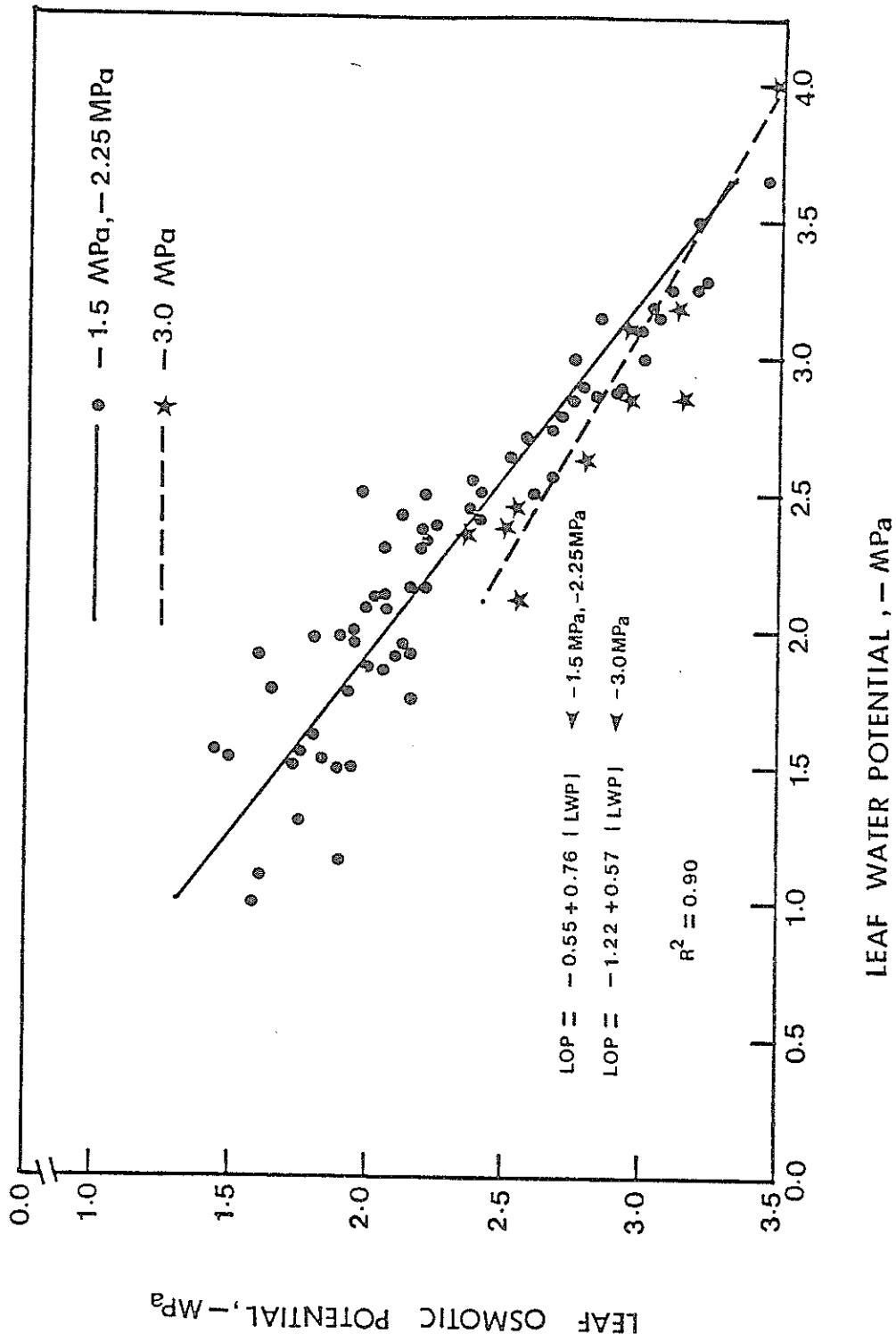


Figure 7. Relationship between leaf osmotic potential and leaf water potential as influenced by irrigation treatments, Experiment 2.

the regression lines were significantly different ( $P < 0.01$ ). As the differences in intercepts were also significant ( $P < 0.001$ ), the leaf osmotic potential in treatment  $-3.00$  MPa was always lower than in treatments  $-1.50$  MPa and  $-2.25$  MPa. The lower leaf osmotic potential in treatment  $-3.00$  MPa further altered the relationship between leaf water potential and leaf turgor potential (figure 8). Though the leaf turgor potential in treatment  $-3.00$  MPa declined at a faster rate, it was still higher in treatment  $-3.00$  MPa than in the other treatments at the same leaf water potential down to  $-3.5$  MPa, primarily because of the significant differences in intercepts ( $P < 0.01$ ). The plants in treatment  $-3.00$  MPa reached zero turgor at leaf water potential of  $-2.8$  MPa, while in treatments  $-1.50$  MPa and  $-2.25$  MPa plants reached zero turgor at  $-2.3$  MPa leaf water potential. Thus, downward adjustment of  $0.50$  MPa in leaf water potential at zero turgor (osmotic adjustment) was observed in treatment of  $-3.00$  MPa (figure 8). A similar downward adjustment in leaf water potential at zero turgor of preconditioned plants has also been reported in cotton and several other crops (Brown et al. 1976, Jones and Turner 1978, Ackerson and Hebert 1981, Shackal and Hall 1983). Though we did not estimate the osmoles of solutes, the lowered leaf osmotic potential, and thus the leaf water potential at zero turgor, is attributed to the accumulation of solutes either by concentration or by synthesis (Cutler et al. 1977a, Ackerson and Hebert 1981). Osmotic adjustment in the form of solute accumulation may occur in plants in which the turgor threshold for cessation of growth is higher than that required for the inhibition of photosynthesis, i.e., solutes accumulate provided they are retained in the leaf. Ackerson (1981) found that the sugars (glucose, sucrose), as well as starch, accumulated in cotton plants conditioned to water stress and the overall growth was inhibited. He suggested that water stress reduced the sink capacity and solutes accumulated as a

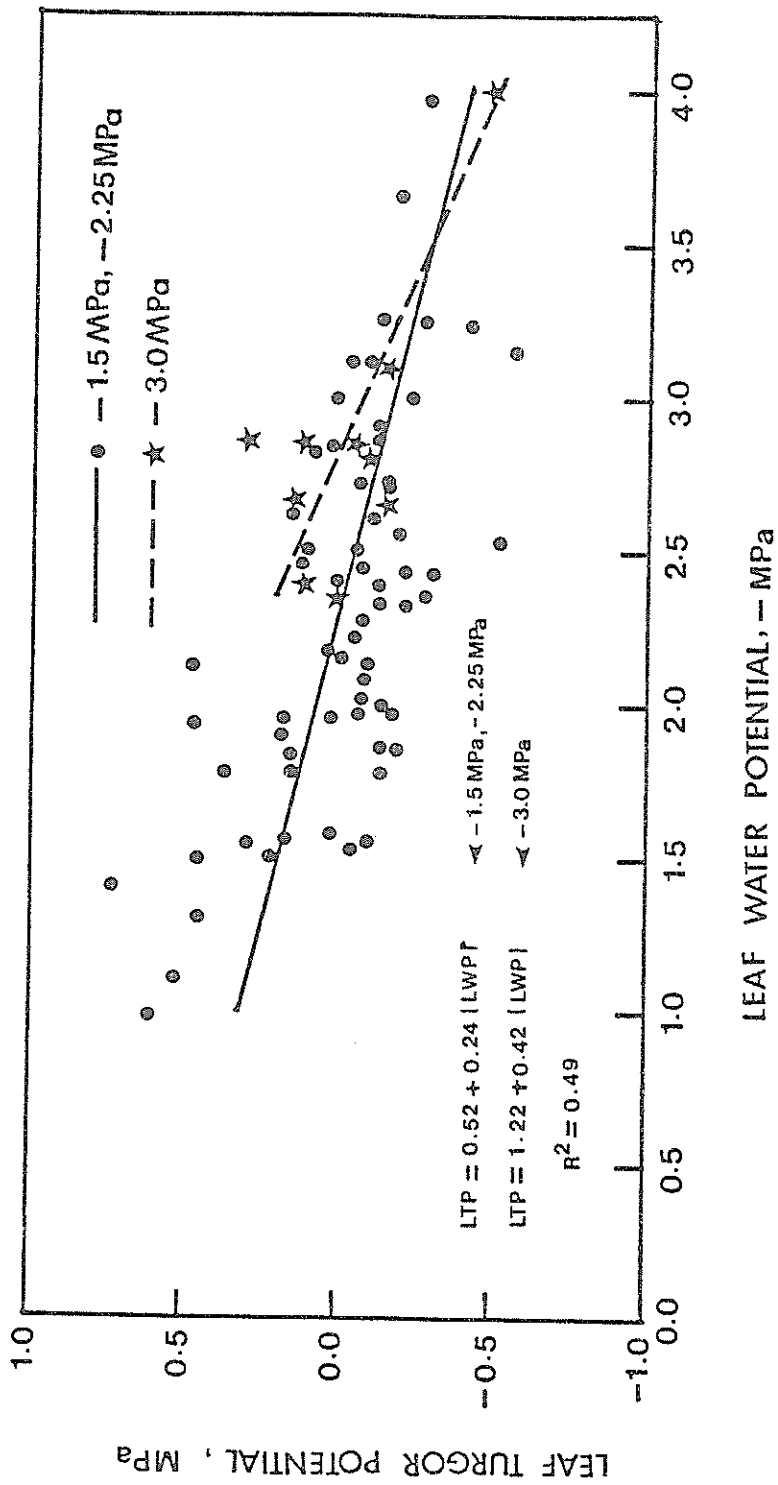


Figure 8. Relationship between leaf turgor potential and leaf water potential as influenced by irrigation treatments, Experiment 2.

consequence. Visual observations indicated that the plants in treatment -3.00 MPa stopped growing and did not put on any new leaves during the final drying cycle. The leaves were smaller in size and the supporting evidence may be obtained from the higher specific leaf weight of preconditioned plants (-1.50 MPa SWPI) in experiment 1. These data support the hypothesis that the non-osmotic cell volume is increased under stress (Cutler et al. 1977a, Ackerson and Hebert 1981). Both solute accumulation and higher non-osmotic volume can lower osmotic potential, and thus the leaf water potential at zero turgor (Cutler et al. 1977a, Shakel and Hall 1983). Turgor maintenance through osmotic adjustment allows the preconditioned plants to maintain open stomates to lower leaf water potentials than the plants not stressed before (Brown et al. 1976, Thomas et al. 1976, Cutler and Rains 1977, Ackerson and Hebert 1981), and our results agree with those findings. Stomates of plants in treatment -3.00 MPa closed at a leaf water potential 0.9 MPa lower than those in treatments of -1.50 MPa and -2.25 MPa. The regression equations given below for different treatments indicate that the slopes were the same.

$$SC = 0.401 + 0.0115(LWP) \text{ ----- } -1.50, -2.25 \text{ MPa treatment}$$

$$SC = 0.500 + 0.0115(LWP) \text{ ----- } -3.00 \text{ MPa treatment}$$

The low  $R^2$  of 0.47 indicates that the stomatal regulation is not entirely dependent upon leaf water potential but also varies with environmental variables (Jordan and Ritchie 1971, Ackerson et al. 1977). The osmotic adjustment occurring in response to preconditioning water stress has, therefore, some obvious advantages by regulating the stomatal opening. As water stress develops, if the stomates of preconditioned plants remain open over a longer period of time than those in the non-conditioned treatment, then the plants in the preconditioning treatment may be able to remain photosynthetically active



for a longer period of time, and thus increase productivity. Ludlow and Ng (1976) have shown evidence that plants of a tropical grass (Panicum maximum Jacq.) that had been conditioned to osmotically adjust maintained photosynthetic rates at lower leaf water potentials. Recently, Jones and Rawson (1979) and Ackerson and Hebert (1981) made similar observations in sorghum and cotton, respectively. The latter authors found that prestressed plants maintained photosynthesis to a much lower leaf water potential than did the control plants, which they attributed to the high stomatal conductance in prestressed plants. Similarly, Karami et al. (1980) found that the superokra leaf genotype, which was able to adjust osmotically, could maintain photosynthesis to lower leaf water potentials. The benefit of preconditioning in increasing the water-use efficiency through conservation of irrigation water will depend upon the ability of the prestressed plants to reduce the boll maturation period. If the leaves of preconditioned plants export their assimilates to the developing bolls at a faster rate than those of the non-conditioned plants, this would help the bolls mature earlier than those of the non-conditioned plants. The shortened boll-maturation period would hasten maturity, shorten the irrigation season, and thus improve the water-use efficiency. As mentioned previously, Karami et al. (1980) found that the superokra leaf genotype, which was able to adjust osmotically, exported its current assimilates at a greater rate than the normal leaf genotype. Furthermore, the superokra leaf type had a more complete depletion of the previous day's assimilates. Similarly, Ackerson (1981) observed that adapted leaves exported sucrose, whereas the nonadapted leaves of the same age accumulated sucrose at the same leaf water potential. The evidence suggests that the preconditioning treatments could reduce water use by shortening the crop growing season, but the question of assimilate transport and its relation to boll maturation period needs further study.

## CONCLUSIONS

The results suggest that cotton plants subjected to low (-1.50 MPa) SWPI level during the preflowering stage used significantly less water than those under -0.17 MPa SWPI level. This reduction in water use resulted primarily from the smaller leaf area of the plants at the low SWPI level. No significant differences in water use were observed, however, between -0.17 and -0.45 MPa SWPI levels applied during the flowering stage. Furthermore, the water-use efficiency was not significantly influenced by SWPI levels applied during either stage or by their interaction. The cotton crop, therefore, did not seem to lose its sensitivity to water stress during the flowering stage and the low (-1.50 MPa) SWPI level applied before flowering did not produce a preconditioning effect resulting in a reduction of water use during the flowering stage. Yet, the threshold leaf water potential for zero turgor and stomatal closure was lowered significantly when the plants were subjected to a stress level of -3.00 MPa leaf water potential during the preflowering stage. This may contribute to the earliness of crop maturity by allowing photosynthesis and assimilate transport to proceed at lower leaf water potentials and thus reduce the boll maturation period. The results from experiment 1 indicated that -1.50 MPa SWPI level applied before flowering promoted the earliness of crop maturity without any significant reductions in yield. Furthermore, the results suggested that savings in irrigation water can be achieved.

Finally, it should be pointed out that the study was conducted under greenhouse conditions. The results need further verification in the field to test the validity of the hypothesis that cotton can be preconditioned to water stress resulting in conservation of irrigation water and improved water-use efficiency.

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