Timing of Environmental Stress Affects Growth, Water Relations and Salt Tolerance of Pinto Bean

G. J. Hoffman, J. A. Jobes, Z. Hanscom, E. V. Maas
MEMBER
ASAE

ABSTRACT

THE influence of a cool, humid vs. a hot, dry environment on the growth, water relations, and salt tolerance of pinto bean (*Phaseolus vulgaris* L.) was determined at several salinity concentrations of the root medium. The effects of changing from the cool, humid to the hot, dry environment for 2 wk during the vegetative and the flowering growth stages were also investigated.

Growth and pod yield of bean plants exposed to the hot, dry environment during the vegetative stage were comparable with those of plants continuously exposed to the cool, humid environment. Exposure to the hot, dry environment during flowering, however, reduced yields significantly, but not to levels for plants exposed continuously to the hot, dry environment. This interaction with environment was the same for all salinity levels. Bean grown in the cool, humid environment tolerated higher salt levels than those predicted from published tolerance data.

Transpiration rates changed rapidly in response to environmental changes. Differences in transpiration decreased as salinity increased.

Linear relationships were found between the osmotic potential of the root medium and leaf water potential and its components. Stomatal conductance was also found to be linearly related to leaf water potential and its components. Stomatal conductance was higher in the cool, humid than in the hot, dry environment for any value of the root medium osmotic potential.

INTRODUCTION

Plants function as biological integrators of the many elements of their environment. For the aerial environment, these elements include light, temperature, carbon dioxide, humidity, and wind. The influence of each of these elements on growth and water relations of plants has been studied extensively. However, the influence of the aerial environment on crop salt tolerance has received limited attention, although high atmospheric humidity has been shown to be beneficial for salt-sensitive crops (Hoffman and Rawlins, 1971; Hoffman and Jobes, 1978). Temperature-salinity interactions have been studied less, but yields of many crops are decreased more by salinity in warm than in cool climates (Magistad et al., 1943; Ahi and Powers, 1938; Hoffman and Rawlins, 1970).

The influence of periodic changes in the aerial environment on yield, water status, and ultimately, salt tolerance is relatively unknown. Many experiments have shown that short stress periods, such as a water shortage, suppress plant growth, but few have dealt with the influence of short-term aerial environmental changes. Pasternak and Wilson (1969) reported that grain sorghum yield was reduced by a "heat wave" during flowering. Grain number and yield, regardless of atmospheric humidity, were reduced by high temperatures (42 °C during the day and 32 °C at night) that damaged flowers on inflorescences that were wholly or largely enclosed in the leaf sheath. Fully emerged heads had only slight reductions in grain numbers from the "heat wave" as compared with control plants grown in a cool environment (27 °C during the day and 22 °C at night). Likewise, increasing the diurnal temperature regime at full bloom from 17 °C during the day and 7 °C at night to 27 °C and 17 °C, respectively, reduced pea yields, regardless of humidity (Nonnecke et al., 1971). The yields were intermediate between those for continuously cool or warm temperature regimes but the results were not consistent among cultivars. Changes in relative humidity during a given growth stage have also been shown to influence yield. For example, the flowering rate of peanut plants was increased by transfer from a low (50 percent) to a high (97 percent) relative humidity as compared with the opposite transfer (Lee et al., 1972).

This study was conducted to determine the effects of short-term aerial environmental stresses during two different growth stages on growth, yield, water use, leaf water potential, and stomatal conductance. We chose pinto bean as the test plant because it is salt-sensitive, and its water relations under different environmental conditions have been studied (Hoffman and Rawlins, 1970). Furthermore, we expected bean to be quite sensitive to short-term environmental stresses. We conjectured that if our test results were not significant for bean, they probably would not be significant for many other crops.

EXPERIMENTAL PROCEDURE

Pinto bean (*Phaseolus vulgaris* L.) was grown in gravel cultures in the four sunlit climate chambers, described by Hoffman and Rawlins (1970), from March 19 to May 21, 1976, and then repeated from June 1 to August 12. The initial test was terminated because of an air conditioning equipment failure. All of the growth, yield, and transpiration data were for the second test

Article was submitted for publication in July 1977; reviewed and approved for publication by the Soil and Water Division of ASAE in October 1977. Presented as ASAE Paper No. 76-5529.

This is a cooperative investigation of the U.S. Salinity Laboratory, USDA-SEA, Riverside, CA, and the Plant Science Dept., University of California, Riverside.

The authors are: G. J. HOFFMAN, Supervisory Agricultural Engineer, and J. A. JOBES, Agricultural Research Technician, U.S. Salinity Lab., Riverside, CA; Z. HANSCOM, Research Assistant, University of California, Riverside; E. V. MAAS, Plant Physiologist, U.S. Salinity Lab., Riverside, CA.

Keywords: bean yield, stomatal conductance, leaf water potential, transpiration.

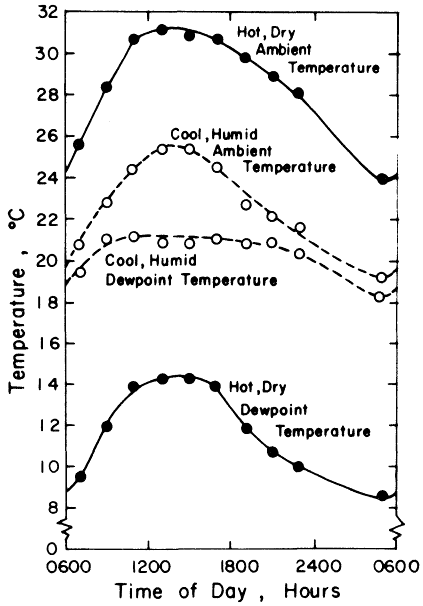

FIG. 1 Diurnal change in ambient and dewpoint temperatures for the hot, dry and cool, humid environments.

only; gas exchange measurements were from the first test, whereas leaf water potential measurements were combined from both tests. Two distinctly different environments were studied—one hot and dry and the other cool and humid. The diurnal patterns of ambient and dewpoint temperature for the two environments are shown in Fig. 1. Under this diurnal pattern, relative humidities remained near 35 percent throughout the day in the hot, dry environment and varied between 80 and 90 percent in the cool, humid environment.

The continuously cool, humid environment (denoted as cool/cool) was maintained in one chamber throughout the experiment as a control treatment. In contrast, a continuously hot, dry environment (denoted as hot/hot) was continuously maintained in a second chamber. The remaining two chambers were cool and humid, except for 2 wk during different plant growth stages when the hot, dry environment was imposed. One of these chambers (denoted as hot/cool) was hot and dry for 2 wk during the vegetative growth stage (18 to 32 days old); the other (denoted as cool/hot) was hot and dry for 2 wk during flowering and early pod-filling (32 to 46 days old).

Four salinity treatments, replicated four times, were established in a Latin square pattern in each chamber. The osmotic potentials of the salinity treatment solutions ($^S\Psi_O$), including the -0.04 MPa* (megaPascal) osmotic potential of the modified half-strength Hoagland nutrient solution (Maas et al., 1973) were -0.04, -0.20, -0.30, and -0.40 MPa. Salination was started 10 days after planting by adding NaCl and $CaCl_2$ (2:1 molar ratio) in four equal daily increments to the nutrient solution.

Seeds were germinated between moist papers in an incubation chamber for 3 days. Ten seedlings were then transplanted into each 18-L gravel culture and thinned to five per container after 3 wk.

The plants constituting the four replications of the salinity treatment within each chamber were irrigated by pumping solution from a 220 L drum into the gravel cultures for 30 min every hour. The solution filled each container within 6 to 8 min, after which the excess returned to the drum through an overflow drain. Following each irrigation, the solution drained from the bottom of each gravel culture to the storage drum. Tensiometers placed at the center of the gravel culture read zero throughout the irrigation cycle.

The average transpiration rate of the plants in each treatment was determined every 1 to 5 days from the quantity of demineralized water added to restore the solution level in each drum. The maximum solution level in each culture was about 10 mm below the gravel surface. Evaporation was less than 100 mL/day/culture (five plants/culture) in the hot, dry environment with the plants removed. The solutions were completely renewed every 3 wk; pH ranged from 6 to 7.

Leaf total water potential ($^L\Psi_t$) was measured on detached leaf disks with thermocouple psychrometers. From three to five mature, sunlit leaves were sampled between 1000 and 1100 h on 4 consecutive days each week for 3 wk, beginning when the plants were 21 days old. A total of about 30 samples were taken for each treatment during each test, although not all of the samples gave reliable measurements. Leaf osmotic potential ($^L\Psi_O$) was measured on the same sample in the same psychrometer after dipping the leaf disk in liquid nitrogen to rupture the cell membranes. Psychrometer equilibrium times were 2 h for $L\psi_t$ and 3 h for $L\psi_O$. Leaf pressure potential ($L\psi_p$) was calculated as the difference between $L\psi_t$ and $L\psi_O$.

Gas exchange characteristics of pinto bean leaves were estimated from measurements with a dual-isotope diffusion porometer (Johnson et al., 1978). The water vapor portion of the porometer is based on the assumption that diffusion of tritiated water (THO) vapor into a leaf follows the same physical pathway as water vapor leaving, thereby encountering the same flow resistance. The carbon-14 labeled carbon dioxide ($^{14}CO_2$) portion of the porometer is a modification of the instrument designed by Shimshi (1969). The measurements were taken by passing an air stream of $^{14}CO_2$ through THO for humidification and then through a small chamber clamped to a leaf for 30 s. The concentration of THO vapor was maintained at a constant known level by bubbling air through tritiated water of known specific activity [9.25 x 10^7 disintegrations per second (dps)/ml of stock solution] and known temperature. Ambient CO_2 concentrations (300 μL/liter) were used. The exposed leaf area (57 mm^2) was removed immediately and dropped into cold 80 percent methanol. Isotope concentrations in the leaf samples were determined by liquid scintillation counting to a standard 1 percent level of counting efficiency.

The gas exchange equation, $r = \Delta/F$, where Δ represents the isotope diffusion gradient in dps/mm^3, and F, the rate of isotope uptake in $dps/mm^2 \cdot s$, was used to calculate diffusion resistance, r, which was converted to conductance (mm/s), the reciprocal of resistance. Transpirational fluxes were calculated by multiplying the water vapor gradient by THO conductance. Only stomatal conductance to water vapor will be presented here. A subsequent paper will present CO_2 conductance and CO_2 uptake data and their relationships to water vapor conductance as functions of the environmental and salinity treatments.

*1 MPa = 10 bar ≅ 10 atm.

TABLE 1. INFLUENCE OF ENVIRONMENT AND SALINITY ON THE GROWTH AND YIELD OF PINTO BEAN.

Environmental treatment	Mean dry weight of plant parts				Ratio of stems to shoot	Ratio of pods to total plant
	Shoots	Roots	Pods	Total plant		
	g/plant				g/g	g/g
	$S\psi_o$ = - 0.04 MPa					
cool/cool	32.0c*	10.8b	55.6a	98.4a	0.77	0.57
hot/cool	33.4c	14.9b	60.7a	109.0a	0.80	0.56
cool/hot	60.5b	13.8b	35.0b	109.3a	0.60	0.32
hot/hot	83.1a	19.5a	14.2c	116.8a	0.58	0.12
	$S\psi_o$ = - 0.20 MPa					
cool/cool	20.5c	5.2ab	34.3a	60.0a	0.55	0.57
hot/cool	24.3bc	2.9c	32.0a	59.2a	0.44	0.54
cool/hot	38.5ab	3.8bc	11.3b	53.6a	0.42	0.21
hot/hot	42.2a	5.6a	0.9b	48.7a	0.41	0.02
	$S\psi_o$ = - 0.30 MPa					
cool/cool	8.8ab	1.7a	6.6a	17.1ab	0.45	0.39
hot/cool	13.6a	1.8a	10.6a	26.0a	0.40	0.41
cool/hot	11.9ab	1.5a	2.3b	15.7b	0.37	0.15
hot/hot	6.8b	0.8b	0.0b	7.6b	0.31	0.00
	$S\psi_o$ = - 0.40 MPa					
cool/cool	3.0b	0.7a	0.4a	4.1ab	0.33	0.10
hot/cool	4.9a	0.6a	0.0b	5.5a	0.22	0.00
cool/hot	3.0b	0.7a	0.2ab	3.9ab	0.37	0.05
hot/hot	2.9b	0.4a	0.0b	3.3b	0.28	0.00

*Values followed by the same letter in each column within each salinity treatment are not significantly different at the 5 percent level (Duncan's Multiple Range Test).

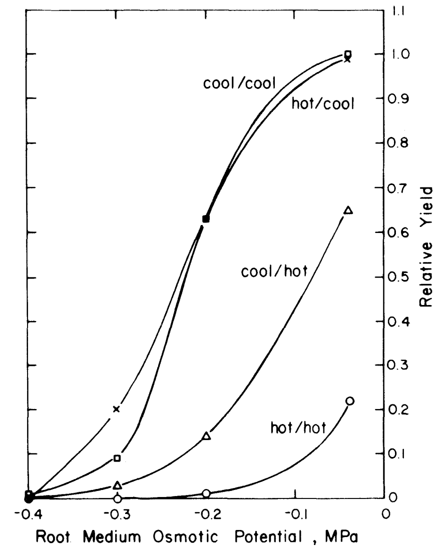

FIG. 2 Interactive effect of environment and salinity on the yield of pinto bean relative to yield for cool/cool nonsaline treatment.

Except for a few mature pods removed during the eighth week, harvest was begun with the most saline treatment when the plants were 9 wk old and completed for the nonsaline treatment at the end of the tenth week. The plants were divided into pods, shoots, and roots, and dried at 70 °C. Senescent leaves that had dropped off before harvest were not collected. After obtaining dry shoot weights, all the leaves were removed, and the stems were weighed to determine the stem:shoot ratio to detect differences in leaf senescence among treatments. The roots were removed from the gravel by washing and floating them onto a 1.5-mm mesh screen.

RESULTS AND DISCUSSION

Growth

The effects of salinity and environment on growth and yield components of pinto bean are summarized in Table 1. The dry weights are means of the 20 plants constituting each salinity treatment. The hot/hot environment had a lower stem-to-shoot ratio than the cool/cool environment at all salinity levels, indicating that the hot environment did not accelerate leaf drop.

Regardless of the aerial environment, increasing salinity consistently reduced the growth of all plant parts. More importantly, increasing salinity reduced pod yields more than vegetative growth. Yields from the hot, dry environment agreed with published salt tolerance data (Maas and Hoffman, 1977). The values of $S\psi_o$, at which yields were reduced 50 percent below that for the nonsaline treatment, were -0.13, -0.12, and -0.21 MPa for the published tolerance data, the hot, dry environment, and the cool, humid environment, respectively. Yields for the cool, humid environment were reduced only 25 percent at a $S\psi_o$ of -0.13 MPa. This agreed with the findings of an earlier study (Hoffman and Rawlins, 1970) and emphasized the importance of climatic effects on crop salt tolerance.

Without salinity, total plant dry weight was not significantly different among environmental treatments. But cool, humid conditions promoted pod production, whereas the hot, dry environment stimulated vegetative growth (Table 1). For either the cool/cool or hot/cool environments, pod yields constituted more than half of the total biomass produced. For the cool/hot environment, the pod yield was less than a third of the total biomass; and for the hot/hot environment less than an eighth. The 2-wk period of hot, dry environment during flowering and early pod-filling apparently forced metabolic production into shoot growth rather than pod production. For the hot/hot treatment, metabolic production went into both shoot and root growth at the expense of pod yield.

Although salinity at -0.20 MPa decreased growth of all plant parts, the environmental effects on mean dry weight of plant parts were similar to those of the nonsaline treatment. Pod production again was significantly greater for the cool/cool and hot/cool environments than for either the cool/hot or hot/hot environments.

Even at the highest salinity levels, where growth was markedly decreased, the environmental influence remained significant. At -0.30 MPa osmotic potential, the hot/cool treatment increased total plant growth and pod production as compared with the cool/hot and hot/hot treatments. At -0.40 MPa, the plants in the hot/hot environment died midway through the experiment.

The interaction between environment and salinity on bean production is emphasized in Fig. 2 by comparing pod yields relative to the yield for the cool/cool nonsaline treatment. The hot, dry environment during flowering (cool/hot treatment) greatly reduced yields, whereas the same environment during the vegetative stage (hot/cool treatment) did not.

These results suggest that if sprinkling, misting, or other environmental controls are used to increase humidity and/or reduce temperature (Carolus et al., 1965; Howell et al., 1971; Sanders and Nylund, 1972), they would be more beneficial at flowering than at the vegetative growth stage. Likewise, a cool, humid environment during flowering could significantly increase the plant's salt tolerance.

TABLE 2. INFLUENCE OF ENVIRONMENT AND SALINITY ON TOTAL WATER USE, TRANSPIRATION DURING SELECTED GROWTH STAGES, INSTANTANEOUS TRANSPIRATION RATE, AND TRANSPIRATION RATIO OF PINTO BEAN

Environmental treatment	Transpiration: Total water use	Daily rate: Vegetative	Daily rate: Flowering	Instantaneous: Vegetative	Instantaneous: Flowering	Transpiration ratio
	L/plant	mL/plant·day		$\mu L/m^2 \cdot s$		L H_2O/g pods
			$S\psi_o = -0.04$ MPa			
cool/cool	49.0	300	925	49	42	0.9
hot/cool	62.4	750	925	133	48	1.0
cool/hot	58.6	200	1350	——	102	1.7
hot/hot	96.1	750	1750	91	121	6.8
			$S\psi_o = -0.20$ MPa			
cool/cool	28.5	225	625	50	42	0.8
hot/cool	25.2	300	350	106	57	0.8
cool/hot	21.8	100	475	——	96	1.9
hot/hot	40.2	450	725	83	136	44.7
			$S\psi_o = -0.30$ MPa			
cool/cool	7.8	100	150	52	44	1.2
hot/cool	11.5	225	175	62	28	1.1
cool/hot	8.3	75	250	——	14	3.6
hot/hot	10.0	300	200	71	47	∞
			$S\psi_o = -0.40$ MPa			
cool/cool	3.2	50	25	42	4	8.0
hot/cool	3.8	150	25	28	——	∞
cool/hot	2.8	50	75	——	——	14.0
hot/hot	2.2	150	——	8	——	∞

Water Use

The influence of environment and salinity on the average daily rate of transpiration of pinto bean, computed on a weekly basis, is illustrated in Fig. 3. The period when each treatment is exposed to the hot, dry environment is cross-hatched for easy reference. Table 2 gives the total volume of water transpired throughout the growing season, the average daily rate of transpiration for the 2-wk periods when the hot, dry environment was imposed in the hot/cool and cool/hot treatments, the instantaneous rates of transpirational flux measured with the dual-isotope porometer, and the transpiration ratio (ratio of water transpired to mature pod yield).

As expected, because of the decrease in growth, transpiration decreased as $S\psi_o$ decreased. Transpiration for the nonsaline, constant-environment treatments (cool/cool and hot/hot) increased steadily with plant growth but decreased the last week before harvest (Fig. 3). At higher salinity levels, the seasonal peak in transpiration was lower and occurred earlier in the season.

The daily and instantaneous transpiration values in Table 2 indicate the bean plants responded rapidly to changes in the environment. The daily transpiration rate of each plant in the nonsaline treatment increased 425 ml or more when the environment was changed from cool and humid to hot and dry. The instantaneous transpiration rate in the hot environment, measured near midday, was double that in the cool environment. Conversely, when the environment was returned to cool and humid after being hot and dry for 2 wk, transpiration rates returned to levels consistent with those where the environment was not changed (Fig. 3). Similar, although smaller, responses were found for the saline treatments.

For the nonsaline treatments, plants in the hot/hot environment transpired almost twice as much during the season as plants in the cool/cool environment (Table 2). Differences in total transpiration decreased at higher salinities, and at a level of -0.40 MPa, transpiration was greater in the cool/cool environment than in the hot/hot environment. This was caused by reduced plant growth and eventual death of those in the hot environment.

The transpiration ratio is a measure of water-use efficiency. At all $S\psi_o$ levels, the transpiration ratio

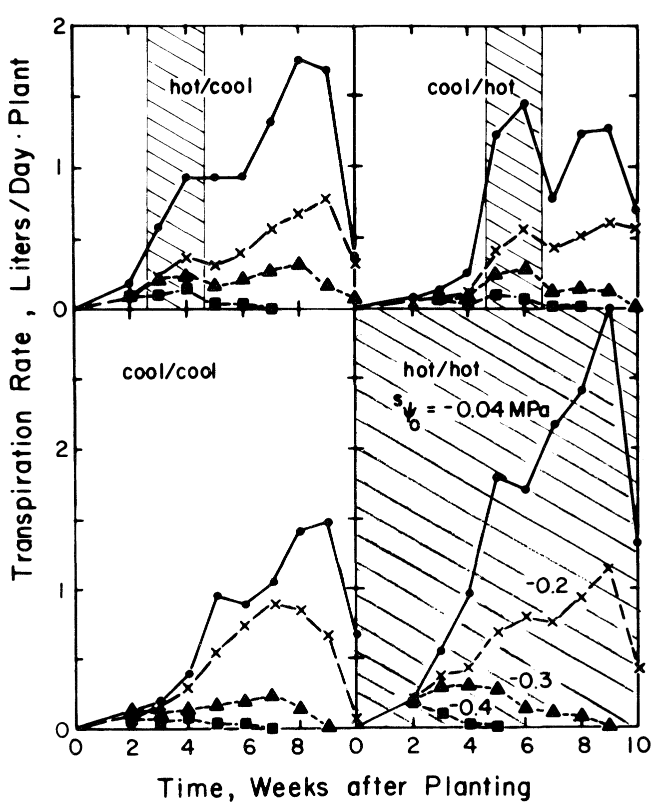

FIG. 3 Transpiration rate of pinto bean as a function of time for the four salinity treatments in each of the four environmental treatments.

TABLE 3. EFFECT OF ENVIRONMENT AND ROOT MEDIUM OSMOTIC POTENTIAL ($S\psi_o$), ON TOTAL WATER POTENTIAL ($L\psi_t$), AND PRESSURE POTENTIAL ($L\psi_p$) FOR PINTO BEAN LEAVES

$S\psi_o$	Environment	$L\psi_t$	n*	S_x†	$L\psi_o$	n	S_x	$L\psi_p$
MPa		MPa			MPa			MPa
-0.04	cool, humid	-0.42a‡	38	0.08	-1.02a	39	0.14	+0.60
	hot, dry	-0.66b	46	0.09	-1.10ab	41	0.12	+0.44
-0.20	cool, humid	-0.73b	46	0.12	-1.23bc	52	0.16	+0.50
	hot, dry	-0.79bc	43	0.12	-1.25bc	49	0.17	+0.46
-0.30	cool, humid	-0.90c	48	0.14	-1.32cd	47	0.11	+0.42
	hot, dry	-1.06d	38	0.19	-1.53de	41	0.20	+0.47
-0.40	cool, humid	-1.09d	45	0.19	-1.43ef	53	0.15	+0.34
	hot, dry	-1.18d	28	0.16	-1.65f	26	0.17	+0.47

*n is the total number of samples.
†S_x is the standard deviation.
‡Values followed by the same letter in a column are not significantly different at the 5 percent level (Duncan's Multiple Range Test).

was lower in the cool/cool environment than in the continuously hot environment. The effects of the short stress periods on water-use efficiency are closely related to the effects on yield. The 2-wk hot period during the vegetative stage (hot/cool treatment) did not lower the water-use efficiency significantly from that of the continuously cool treatment; however, the same period during flowering reduced the water-use efficiency to a value between that of the continuously cool and continuously hot environments.

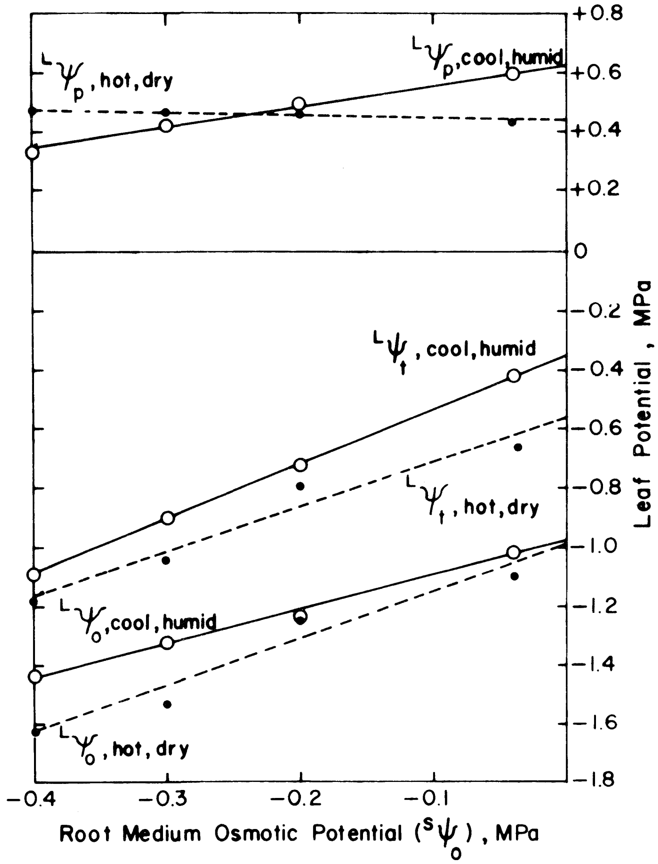

FIG. 4 Influence of salinity and the environment on leaf total water ($L\psi_t$), osmotic ($L\psi_o$), and pressure ($L\psi_p$) potentials in 3- to 6-wk-old pinto bean.

Leaf Water Potential

The influence of aerial environment and salinity on $L\psi_t$, $L\psi_o$, and $L\psi_p$ is summarized in Table 3. The standard deviation (S_x) was typically 15 percent of the $L\psi_t$ measurement, slightly less for $L\psi_o$ measurements. As expected, both $L\psi_t$ and $L\psi_o$ decreased significantly as $S\psi_o$ decreased. In fact, leaf water potential and its components were linearly related to $S\psi_o$ (Fig. 4). Similar linear relationships for bean have been reported previously (Hoffman et al., 1973). The maximum difference in $S\psi_o$ among saline treatments of -0.36 MPa resulted in $L\psi_t$ adjustments of -0.67 and -0.52 MPa for the cool and hot environments, respectively. Correspondingly, $L\psi_o$ decreased 0.41 and 0.55 MPa. These data indicate that both $L\psi_t$ and $L\psi_o$ over-adjusted to $S\psi_o$.

Although both $L\psi_t$ and $L\psi_o$ were higher in the cool, humid environment than in the hot, dry environment, because of the lower vapor pressure deficit, only the difference in $L\psi_t$ between environments for the non-saline treatment was statistically significant (Table 3). The difference in $L\psi_o$ tended to increase with increasing salinity. This resulted in $L\psi_p$ decreasing linearly as $S\psi_o$ decreased in the cool, humid environment, whereas $L\psi_p$ was independent of $S\psi_o$ in the hot, dry environment. Published results for bean indicate that $L\psi_p$ is normally maintained under salination (Gale et al., 1967; Hoffman and Phene, 1971; Jensen, 1975).

Stomatal Response

Table 4 shows the effect of salinity and the aerial environment on leaf stomatal conductance to water vapor. The conductance values are the means of the measurements taken during the vegetative and flowering growth stages of 3- to 6-wk old pinto bean. Stomatal conductance was significantly greater in the cool, humid environment than in the hot, dry environment in the nonsaline treatment. Although the difference in stomatal conductance between environmental treatments remained about 3 mm/s, the differences were not statistically significant in the more saline treatments. As the osmotic potential of the root medium decreased from -0.04 to -0.40 MPa, stomatal conductance decreased linearly about 6 mm/s, regardless of environment. This linear relationship between $S\psi_o$ and stomatal conductance is illustrated in Fig. 5.

TABLE 4. INFLUENCE OF ENVIRONMENT AND SALINITY ON LEAF STOMATAL CONDUCTANCE TO WATER VAPOR FOR 3- TO 6-WEEK OLD PINTO BEAN

Root medium osmotic potential	Environment	Stomatal conductance	n*	S_x†
MPa		mm/s		
-0.04	cool, humid	11.0a‡	24	5.5
	hot, dry	7.1bc	25	2.4
-0.20	cool, humid	9.2ab	23	4.2
	hot, dry	5.6cd	30	1.9
-0.30	cool, humid	5.3cd	20	3.1
	hot, dry	2.6de	23	1.3
-0.40	cool, humid	3.7de	10	2.2
	hot, dry	0.8e	11	0.6

*n is the total number of samples.
†S_x is the standard deviation.
‡Values followed by the same letter are not significantly different at the 5 percent level (Duncan's Multiple Range Test).

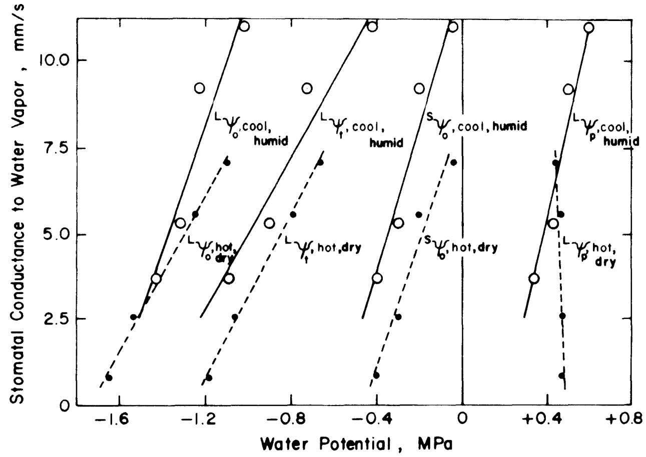

FIG. 5 Leaf stomatal conductance to water vapor as a function of leaf total water ($^L\psi_t$), osmotic ($^L\psi_o$), and pressure ($^L\psi_p$) potentials and the osmotic potential of the root medium ($^S\psi_o$) for 3- to 6-wk-old pinto bean for the cool, humid and the hot, dry environments.

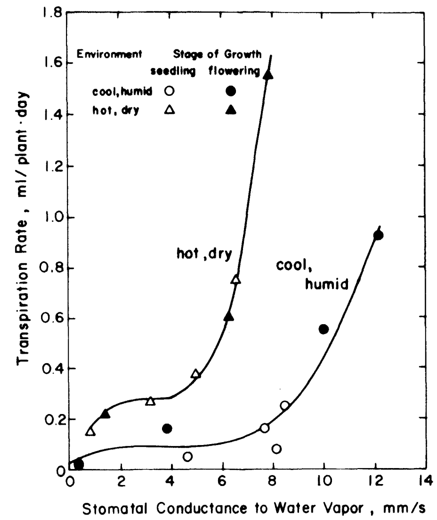

FIG. 6 Influence of environment on the relationship between transpiration and leaf stomatal conductance for pinto bean.

The relationships between stomatal conductance and $^L\psi_t$, $^L\psi_o$, and $^L\psi_p$ for both environments are also shown in Fig. 5. These relationships are all linear except $^L\psi_p$ in the hot environment was independent of stomatal conductance as salinity increased. In the range where the stomata are influencing transpiration, neither fully open or closed, linear relationships between stomatal conductance and $^L\psi_t$ have been reported for bean (Kanemasu and Tanner, 1969), wheat (Frank et al., 1973), and cotton (Thomas et al., 1976). Kanemasu and Tanner (1969) also found that $^L\psi_p$ decreased linearly as stomatal conductance decreased.

Daily transpiration rate as a function of leaf stomatal conductance of water vapor is given in Fig. 6. Stomatal conductance was calculated from measurements with the dual-isotope porometer and daily transpiration was taken from Table 2. We found two distinct relationships, one for measurements taken in the cool, humid environment, and the other for the hot, dry environment. Differences among the salinity treatments established the relationships between conductance and transpiration, which held for both the vegetative and flowering growth stages. For small values of stomatal conductance, transpiration in the hot environment was about double that in the cool environment. Above a conductance of 6 mm/s, transpiration increased very rapidly as conductance increased. The rate of transpiration tripled when conductance increased from 6 to 8 mm/s or 6 to 9 mm/s in the hot, dry or cool, humid environments, respectively. Undoubtedly, a large portion of this increase can be attributed to larger plants in the less saline treatments.

SUMMARY AND CONCLUSIONS

The influence of two distinctly different environments, one cool and humid and the other hot and dry, on the growth, water relations, and salt tolerance of pinto bean was determined at several salinity concentrations in the root medium. The effects of a 2-wk hot, dry period during two different plant growth stages were also investigated.

Exposing bean plants to the hot, dry environment during the vegetative growth stage did not decrease growth or yield as compared with plants continuously exposed to the cool, humid environment. Exposure during flowering and early pod-filling, however, reduced yields significantly, but not to levels for plants exposed continuously to the hot, dry environment. This interaction with environment held for all salinity levels. Bean grown in the cool, humid environment tolerated higher salt levels than those predicted from published tolerance data.

Transpiration rates changed rapidly in response to environment changes. Transpiration in the hot environment was about double that in the cool environment under nonsaline conditions. Linear relationships were found between $^S\psi_o$ and $^L\psi_t$, $^L\psi_o$, and $^L\psi_p$, which agreed with published results. Stomatal conductance to water vapor was also linearly related to $^S\psi_o$, $^L\psi_t$, $^L\psi_o$, and $^L\psi_p$. For each salinity treatment, conductance was higher in the cool, humid than in the hot, dry environment.

The leaf water potential and transpiration data supported the growth-response results. They indicated that a hot, dry period during the vegetative stage had no adverse affect on bean yield, whereas the same hot, dry period during flowering was detrimental to yield. The higher leaf water potential values in the cool, humid environment also verified that yield decline due to salinity was aggravated by a hot, dry environment.

References

1 Ahi, S. M., and W. L. Powers. 1938. Salt tolerance of plants at various temperatures. Plant Physiol. 13:767-789.

2 Carolus, R. L., A. E. Erickson, E. H. Kidder, and R. Z. Wheaton. 1965. The interaction of climate and soil moisture on water use, growth and development of the tomato. Quarterly Bull. Reprint, vol. 47, no. 4, Michigan State Univ., East Lansing.

3 Frank, A. B., J. F. Power, and W. O. Willis. 1973. Effect of temperature and plant water stress on photosynthesis, diffusion resistance, and leaf water potential in spring wheat. Agron. J. 56:777-780.

4 Gale, J., H. C. Kohl, and R. M. Hagan. 1967. Changes in the water balance and photosynthesis of onion, bean, and cotton plants under saline conditions. Physiol. Plant. 20:408-420.

5 Hoffman, G. J., and J. A. Jobes. 1978. Growth and water relations of cereal crops as influenced by salinity and relative humidity. Agron. J. (In press).

6 Hoffman, G. J., E. V. Maas, and S. L. Rawlins. 1973. Salinity-ozone interactive effects on yield and water relations of pinto bean. J. Environ. Qual. 2:148-152.

(Continued on page 722)

Timing of Environmental Stress

(Continued from page 718)

7 Hoffman, G. J., and C. J. Phene. 1971. Effect of constant salinity levels on water-use efficiency of bean and cotton. TRANSACTIONS of the ASAE 14(6):1103-1106.

8 Hoffman, G. J., and S. L. Rawlins. 1970. Design and performance of sunlit climate chambers. TRANSACTIONS of the ASAE 13(5):656-660.

9 Hoffman, G. J., and S. L. Rawlins. 1971. Growth and water potential of root crops as influenced by salinity and relative humidity. Agron. J. 63:877-880.

10 Howell, T. A., E. A. Hiler, and C. H. M. van Bavel. 1971. Crop response to mist irrigation. TRANSACTIONS of the ASAE 14(5):906-910.

11 Jensen, C. R. 1975. Effect of salinity in the root medium. 1. Yield, photosynthesis, and water relationships at moderate evaporative demands and various light intensities. Acta Agric. Scand. 25:3-10.

12 Johnson, H. B., I. P. Ting, and P. G. Rowlands. 1978. Measuring water use efficiency in photosynthesis using $^{14}CO_2$ and THO. (in preparation).

13 Kanemasu, E. T., and C. B. Tanner. 1969. Stomatal diffusion resistance of snap beans. I. Influence of leaf-water potential. Plant Physiol. 44:1547-1552.

14 Lee, T. A., D. L. Ketring, and R. D. Powell. 1972. Flowering and growth response of peanut plants (*Arachis hypogaea* L. var. Starr) at two levels of relative humidity. Plant Physiol. 49:190-193.

15 Maas, E. V., and G. J. Hoffman. 1977. Crop salt tolerance—Current assessment. J. Irrig. and Drainage Div., Proc. Amer. Soc. Civil Eng. 103:(IR27):115-134.

16 Maas, E. V., G. J. Hoffman, S. L. Rawlins, and G. Ogata. 1973. Salinity-ozone interaction on pinto bean. Integrated response to ozone concentration and duration. J. Environ. Qual. 2:400-404.

17 Magistad, O. C., A. D. Ayers, C. H. Wadleigh, and H. G. Gauch. 1943. Effect of salt concentration, kind of salt, and climate on plant growth in sand cultures. Plant Physiol. 18:151-166.

18 Nonnecke, I. L., N. O. Adedipe, and D. P. Ormrod. 1971. Temperature and humidity effects on the growth and yield of pea cultivars. Can. J. Plant Sci. 51:479-484.

19 Pasternak, D., and G. L. Wilson. 1969. Effects of heat waves on grain sorghum at the stage of head emergence. Aust. J. Exp. Agric. and Animal Husbandry 9:636-638.

20 Sanders, D. C., and R. E. Nylund. 1972. The influence of mist irrigation on the potato. I. Micro-environment and leaf water relations. Amer. Potato J. 49:123-137.

21 Shimshi, D. 1969. A rapid field method for measuring photosynthesis with labeled carbon dioxide. J. Exp. Bot. 20:391-401.

22 Thomas, J. C., K. W. Brown, and W. R. Jordan. 1976. Stomatal response to leaf water potential as affected by preconditioning water stress in the field. Agron. J. 68:706-708.