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Effect of a Rapid Water Stress and a Slow Water Stress on the Growth of 'Redhaven' Peach Trees[1]

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Abstract

A rapid water stress (RWS) and recovery treatment and two levels of a slow water stress (SWS) treatment (rewatering at 50 and 25% of control water use) were applied to one-year-old peach trees (*Prunus persica*, L., Batsch, cv. 'Redhaven'/'Halford') under greenhouse conditions. Growth, growth rates, leaf water potential components, and stomatal conductance were observed. Occurrence of statistical differences between treatments was used to determine sensitivity to stress. Total leaf water potential was 0.18MPa less than control for the stress trees after one week of RWS. Leaf emergence was more sensitive than leaf or shoot growth; however, leaf growth rates recovered first after rewatering. Leaf emergence, leaf length, and shoot length were reduced by 80, 77, and 65% respectively. Available soil water declined to 40 and 20% of the control for the 50 and 25% SWS treatments. Leaf emergence, leaf growth, shoot extension, and trunk diameter were reduced by 58, 82, 56, 76, and 64% for the 50% treatment, and 50, 75, 36, 57, and 39% for the 25% treatment, respectively. Significant reductions in stomatal conductance followed with the reductions in growth within 2-7 days for the SWS experiment.

Additional index words: trickle irrigation, irrigation scheduling, water relations, water potential, stomatal conductance.

Introduction

Irrigation of peach orchards in temperate areas has become economically feasible with drip irrigation. Scheduling drip irrigation according to Class A pan evaporation (E pan) or soil water status are relatively easy methods (6); however, these methods do not account for growth, physiological status or water needs of the tree. A plant parameter may be used to schedule irrigation, however, it must reliably represent tree growth and water status of the tree and it must be easy to obtain.

Plant water potential (ψw) is a reliable indicator of the stressed status of a plant (9, 12). As an indicator of stress ψw of fruit trees was most reliable before dawn; whereas, the midafternoon ψw tended to reflect the hot, dry environment more than the stressed status of the tree (14, 20). Leaf position, leaf age, time of day and season, and environmental factors were shown to influence leaf ψw (10, 14, 17). Measurement of stomatal activity has been widely used in water stress responses of fruit trees (3, 8, 5). Although stomatal movement is regulated by the turgidity of the guard cells, environmental stimuli, e.g., light, CO_2 concentrations, vapor pressure deficit (humidity) and temperature influence stomatal action (12, 15).

The goal of this study was to characterize the growth and water relations responses of 'Redhaven' peach trees under a rapid water stress (RWS) and a slow water stress (SWS). Understanding the sensitivity of the growth responses to water stress could aid in developing trickle irrigation schedules.

Materials and Methods

General. One-year-old peach trees (*Prunus persica*, L., cv. 'Redhaven'/'Halford') were potted in 19 liter containers in a soil:sphagnum moss:

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sand (2:1:1, V:V:V) mixture, placed in a greenhouse, and pruned to two branches in September 1981 for the rapid water stress (RWS) experiment and in April 1982 for the slow water stress (SWS) experiment. High irradiation density lamps, cooling fans and steam radiator heat were used to maintain a 15 h photoperiod, a night temperature 17 ± 2°C and a day temperature 30 ± 5°C. A water soluble fertilizer (20-20-20) was applied at 250 ppm nitrogen with alternate waterings. Miticides and fungicides were applied sparingly as needed.

The number of leaves (no.) were counted from the base of the shoot, including every leaf longer than 2 mm. Leaf length (mm) was measured from the petiole base to the leaf tip. Shoot length (cm) was measured from the base of the shoot to the tip of the newest emerging leaf or to the tip of the terminal bud. Trunk diameter was measured with a digital micrometer (Mitutoyo, Japan, Model 193-101, range 0-25 ± 0.05 mm) at marked locations on the trunk 10-20 cm above the graft union.

Cumulative increases in number of leaves, shoot length, and trunk diameter were calculated based on the measurement made on day 1 of each experiment.

Equation 1: $C = M_n - M_1$

Where: C = cumulative increase (mm, cm, or no.)

M_n = measurement on day n (mm, cm, or no.)

M_1 = measurement on day 1 (mm, cm, or no.)

Rates of leaf emergence, shoot extension and trunk diameter change were calculated for two- to four-day intervals.

Equation 2: $R = \frac{Mc - Mp}{n}$

Where: R = growth rate (mm, cm, or no. · day^{-1})

Mc = current measurement (mm, cm, or no.)

Mp = previous measurement (mm, cm, or no.)

n = number of days between measurements (day)

Stomatal conductance (gs) was determined with a steady-state porometer (Li-Cor, Inc., Lincoln, NB, Model 1600) on the abaxial side of a recently expanded leaf. The same leaf was used for leaf water potential (ψl) measurements with a pressure bomb (PMS, Corvallis, OR) (Scholander et al., 1965). Then the leaf was sealed in a "Ziploc" bag and within two hours frozen to -20°C. The leaf osmotic potential (ψs) was determined by dewpoint hygrometry (Wescor, Inc., Logan, UT, microvoltmeter = Model HT-T 33 and chamber = Model C-52) using one thawed 5 mm disc from each leaf and a 15 min. equilibration time in chamber. Turgor pressure, ψp, was determined from the following equation:

Equation 3: $\psi S + \psi p = \psi l$

If ψs and ψl are known, then

$$\psi p = \psi w - \psi s.$$

The experiment designs were randomized complete blocks with four replications; blocks determined by trunk diameter. Each date was analyzed separately. Significant differences were determined by a least significant difference (LSD) statistic at the 0.05 level (18).

Rapid Water Stress Experiment (RWS). A rapid water stress situation was created by withholding water until the leaves wilted, and the soil water tension approached 60 kPa. The number of leaves, leaf length and shoot length were recorded beginning at 0800 h at three to four day intervals during the prestress period, day 1-5 (October 15-19, 1981), during the stress period, day 6-16 (October 20-30, 1981), and during the recovery period, day

17-33 (October 31-November 16, 1981). For the leaf length measurements, leaves emerging on day 1, 12 and 22 were named collectively, Leaf Group (LG) A, B and C, respectively. Leaf water potential was determined at 1300 h at three-to-four day intervals during the stress period.

Slow Water Stress Experiment (SWS). A simulation of gradual soil water depletion was created by replacing 100, 50 or 25% of the water used by fully watered trees per watering period. During the prestress period, every tree received 2 liters of water every two to three days for two weeks. The volumed drained after 24 h was subtracted from 2 l to determine the amount of water used between waterings. Average water use per tree per watering period was 400 ± 50 ml. Fifty of 25% of the volume used (i.e., 200 or 100 ml) was applied every two to three days for the stress treatments; the control treatment continued to receive 2 l. After 16 days the volume of water applied to all trees was adjusted according to the increased water use by the control treatment. The number of leaves, leaf length, shoot length and trunk diameter were recorded beginning at 0800 h at two to three day intervals from day 1 (May 20, 1982), two days prior to initiating the stress treatments, and were continued until day 29 (June 19, 1982), when the stress was relieved. For the leaf length measurements, leaves emerging two weeks before day 1, on day 1 and on day 12 were named collectively Leaf Group (LG) A′, B′ and C′, respectively. Stomatal conductance and transpiration were measured at 1000 and 1400 h three times during the stress period and one day after rewatering.

Table 1. Effect of rapid water stress (RWS), rewatering, and time (days) on the rates of leaf emergence, leaf expansion, and shoot extension.

	Time after initiation of experiment (Days)^z							
Treatment	5	8	12	15	19	22	26	30
			Leaf Emergenge (No. day^{1-})^y					
Control	0.58^y	0.53	0.63a	0.37	0.70a	0.63	0.63	0.80
Stress	0.50	0.53	0.25b	0.20	0.10b	0.63	0.65	0.60
			Leaf Group A (cm day^{-1})^y					
Control	0.50	0.65	1.05	1.67a	1.03	0.43	0.13	0.28
Stress	0.53	0.60	0.85	0.43b	0.58	0.63	0.25	0.25
			Leaf Group B (cm day^{-1})^y					
Control				0.47a	0.75	1.20	0.95	1.05
Stress				0.03b	0.28	0.80	0.93	0.93
			Leaf Group C (cm day^{-1})^y					
Control							0.65	0.85
Stress							0.40	0.98
			Shoot Extension (cm day^{-1})^y					
Control	0.95	1.27	1.33	1.33a	1.33a	1.57a	1.33a	1.58
Stress	1.18	1.10	0.80	0.30b	0.48b	0.57b	0.73b	1.13

^{z}Water was withheld between day 6 and 16.
^{y}Mean separation within time of LSD, 5% level.

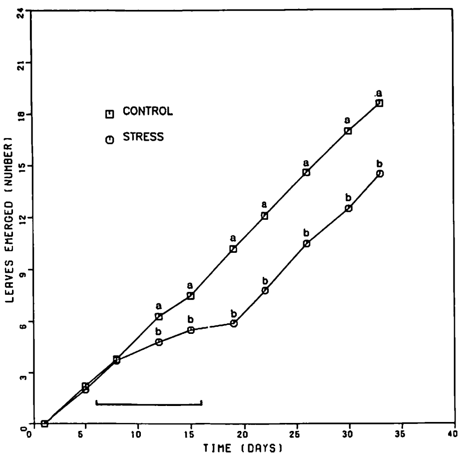

Figure 1. Effect of rapid water stress, rewatering, and time (days) on leaf emergence of 'Redhaven' peach. Mean separation within time by LSD, 5% level. ________ indicates period of time where water was withheld.

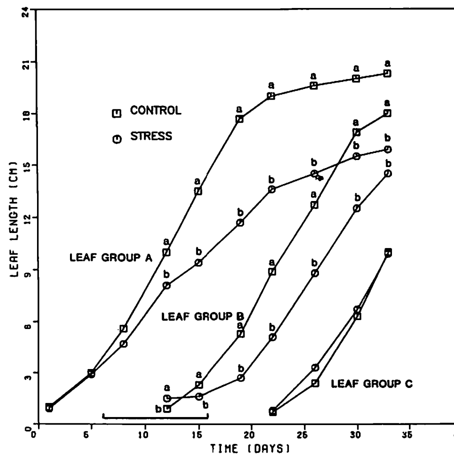

Figure 2. Effect of rapid water stress (RWS), rewatering, and time (days) on the length of 'Redhaven' peach leaves. Mean separation by LSD, 5% level. ________ indicates period of time when water was withheld.

Results

Rapid Water Stress Experiment. Increases in the number of leaves, shoot length, and leaf length of emerging (LG-B) or rapidly expanding (LG-A) were reduced by the RWS treatment (Fig. 1, 2 and 3). After rewatering, leaf growth rate recovered faster than leaf emergence or shoot growth rate; however, the recovery of leaf emergence rate was more complete (Table 1). About two weeks elapsed after rewatering before the shoot growth rate for stressed and control trees were similar (Table 1). The length and growth rate of leaves emerging after rewatering (LG-C) were not affected by the stress (Fig. 2 and Table 1).

On the third day of the stress period, ψ_s of the stressed trees differed significantly from the control trees, but ψ_p and ψ_l did not (Table 2). After one week of the stress treatment, ψ_p and ψ_l for each treatment differed significantly; however, s did not.

Slow Water Stress Experiment. The 50 and 25% watering treatments resulted in a progressive decrease in available soil water (Fig. 4). By day 24, the available soil water had decreased to approximately 40 and 20% of the control for the 50 and 25% treatments, respectively.

Growth was significantly reduced for all stress treatments except shoot growth for the 50% treatment (Table

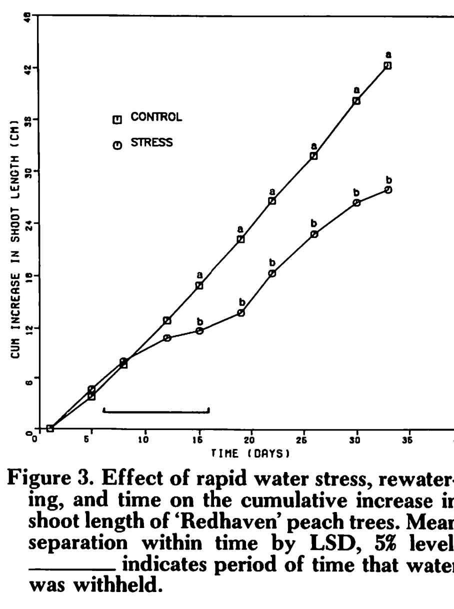

Figure 3. Effect of rapid water stress, rewatering, and time on the cumulative increase in shoot length of 'Redhaven' peach trees. Mean separation within time by LSD, 5% level. ________ indicates period of time that water was withheld.

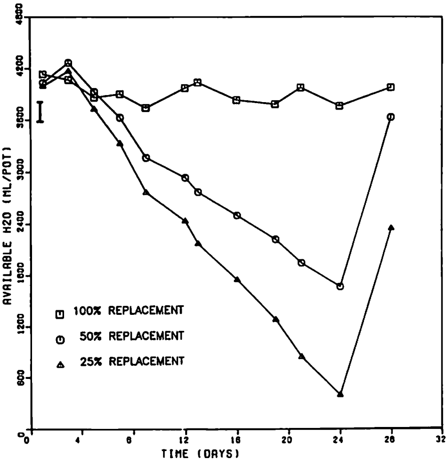

Figure 4. Calculated available water (ml/pot) for the 100, 50, and 25% treatments.

3). The effects were observed 12-16 days after the treatments were initiated (Fig. 5, 6, 7 and 8). The stress was sufficient to arrest leaf emergence by days 17 and 21 for the 25 and 50% treatments, respectively, and shoot growth by day 19 for the 25% treatment (Fig. 5 and 7). The phase of rapid leaf expansion was more affected by the stress than the emerging phase.

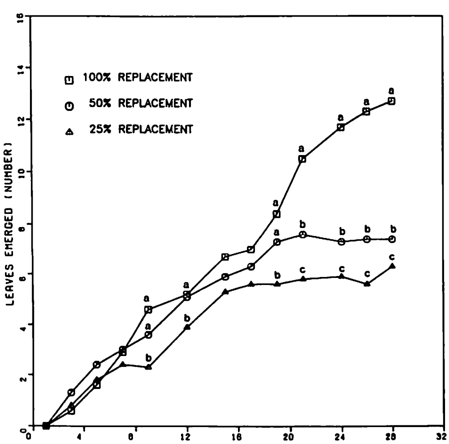

Figure 5. Effect of three levels of replacement of water used (100, 50, and 25%) and time (days) on leaf emergence of 'Redhaven' peach leaves. Mean separation by LSD, 5% level.

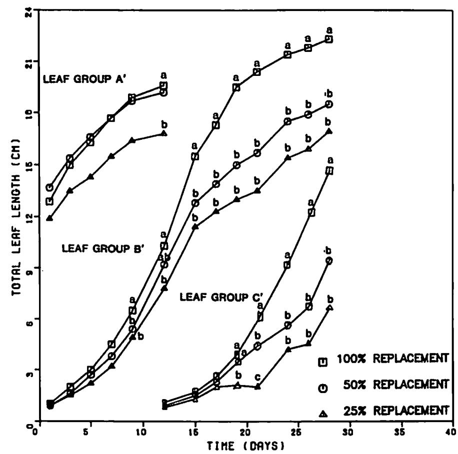

Figure 6. Effect of three levels of replacement of water used (100, 50, and 25%) and time (days) on length of 'Redhaven' peach leaves. Mean separation by LSD, 5% level.

Differences in stomatal conductance were observed after the growth of the stressed trees was affected by reduced water supply (Table 4-6). On day 17, stomatal conductance at 1000 h was significantly less for the 25% treatment. At 1400 h stomatal conductance for both stress treatments were significantly different. One day after rewatering, there were no differences in stomatal conductance.

Table 2. Effect of rapid water stress (RWS) and time (days) on the osmotic potential (s), tugor potential (p), and total leaf potential (l), of 'Redhaven' peach leaves.

Time[z] (days)	Water withheld (days)	Treatment	s[y] (MPa)	p[y] (MPa)	l[y] (MPa)
6	0	Control	-2.98	1.58	-1.40
		Stress	-2.87	1.06	-1.71
9	3	Control	-2.38a	1.08	-1.42
		Stress	-2.80b	0.98	-1.82
13	7	Control	-2.60	1.42a	-1.28a
		Stress	-2.82	0.98b	-1.81b

[z]Number of days after initiation of experiment. Water was withheld between day 6 and 16.
[y]Mean separation within time by LSD, 5% level.

Table 3. Effect of three levels of replacement of water used (100, 50, and 25%) and time (days) on the rates of leaf emergence, leaf expansion, shoot extension, and trunk diameter change of 'Redhaven' peach trees.

	Time After Initiation of Experiment (Days)[z]											
Treatment	3	5	7	9	12	15	17	19	21	24	26	28
Leaf Emergence (No. day^{-1})												
100%	0.30a[y]	0.65	0.50	0.00b	0.73a	0.60	0.25	0.75a	0.90a	0.50a	0.25a	0.30a
50%	0.65b	0.55	0.30	0.45a	0.43b	0.27	0.30	0.40ab	0.20b	0.00b	0.05b	0.00b
25%	0.40a	0.50	0.30	0.00b	0.53a	0.47	0.20	0.00b	0.05b	0.10b	0.00b	0.20a
Leaf Group A' (cm day^{-1})												
100%	0.80	0.65	0.55	0.60	0.30a							
50%	0.90	0.65	0.60	0.55	0.13b							
25%	0.80	0.40	0.55	0.50	0.17ab							
Leaf Group B' (cm day^{-1})												
100%	0.25b	0.55a	0.80a	1.05a	1.27	1.77a	0.90a	0.60a	0.55a	0.30b	0.20	0.25
50%	0.35a	0.55a	0.55b	0.75b	1.27	1.20b	0.55b	0.55ab	0.35ab	0.60a	0.30	0.30
25%	0.30ab	0.35b	0.50b	0.75b	0.97	1.20b	0.45b	0.35b	0.25b	0.73a	0.35	0.50
Leaf Group C' (cm day^{-1})												
100%						0.20	0.45	0.60a	1.00a	1.07a	1.20a	1.25
50%						0.20	0.25	0.40ab	0.40b	0.67ab	0.60b	0.85
25%						0.17	0.30	0.20b	0.20b	0.43b	0.30b	0.80
Shoot Extension (cm day^{-1})												
100%		1.00	1.55a	1.45	1.17	1.87a		1.75a	1.37a		1.20a	0.75a
50%		1.35	1.35a	1.30	1.47	0.97b		0.68b	0.57b		0.63b	0.25b
25%		1.35	0.90b	1.35	1.23	1.17b		0.38c	0.23c		0.15b	0.15b
Trunk Diameter Change (mm day^{-1} x 10)												
100%	0.45a	0.40	0.05	0.40	0.53a	0.43	0.65a	0.85a	1.05a	1.27a	1.67a	1.20ab
50%	0.05b	0.45	0.00	0.35	0.23ab	0.53	0.35b	0.60a	0.15b	1.30a	0.00b	1.90a
25%	0.30b	0.10	0.05	0.35	0.30b	0.47	0.10c	0.15b	0.03a	0.60b	0.40b	0.40b

Discussion

Timely and economical irrigation is dependent, in part, on determining when the plant is under stress and needs water. In this study, when a parameter changed significantly, the plant was said to be under stress, and the sooner the change occurred, the more sensitive to stress a parameter was. Leaf growth rate and leaf emergence rate were more sensitive to water stress than trunk diameter growth rate, which was more sensitive than shoot growth rate (Table 1 and 4). Newly emerging leaves (LG B and LG-C') were more sensitive to water

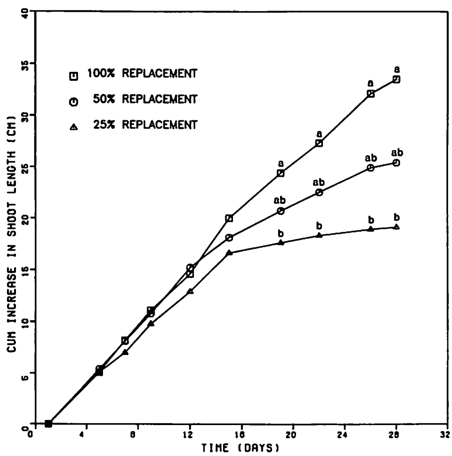

Figure 7. Effect of three levels of replacement of water used (100, 50. and 25%) and time (days) on the cumulative increase in shoot length of 'Redhaven' peach trees. Mean separation within time by LSD, 5% level.

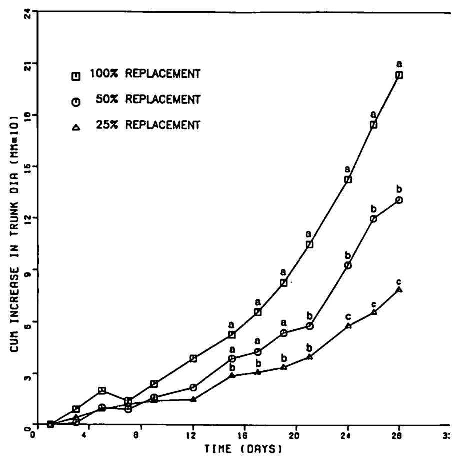

Figure 8. Effect of three levels of replacement of water used (100, 50, and 25%) and time (days) on the cumulative increase in trunk diameter of 'Redhaven' peach trees. Mean separation within time by LSD, 5% level.

stress than leaves which were rapidly expanding at the same time (LG A and LG B') (Table 1 and 4).

Indications of recovery from stress and the results of cumulative effects of stress are equally important as predicting onset of stress. Leaf growth rate parameters recovered sooner and more completely from the stress than shoot growth rate. For the RWS stress treatment and the SWS 25% treatment, the cumulative no. of leaves was reduced to 82 and 83% of control, whereas shoot length was reduced to 68 and 76% of control. Therefore, no. of leaves may be a more reliable and consistent indicator of stress and recovery.

Water relations parameters, stomatal conductance and water potential appeared to be less sensitive to water stress than the most sensitive growth parameters (Table 1-4). Olien and Lakso (1988) found similar results with field-grown, drought-stressed grape vines. Therefore, water relations parameters may be less reliable as early indicators of stress. In addition, it has been shown that stomatal conductance and water potential are immediately influenced by radiation, temperature and ambient humidity regardless of soil water availability (15).

The use of plant growth parameters as indicators of stress has disadvan-

Table 4. Effect of three levels of replacement of water used (100, 50, and 25%) and time (days, h) on the stomatal conductance of 'Redhaven' peach leaves.

Time (days)[z]	Stress period (days)	Treatment	Stomatal conductance ($cm\ s^{-1}$)[y] Time (h) 1000	1500
1	-2	100%	1.60	1.75
		50	1.70	1.76
		25	1.76	1.77
12	9	100%	1.94	2.06
		50	1.97	1.88
		25	1.89	1.94
17	14	100%	1.63a	1.93a
		50	1.60ab	1.57b
		25	1.30b	1.16b
28	25	100%	2.13	1.72
		50	2.15	1.83
		25	2.09	1.75

[z]Treatments were begun on day 3; stress relieved on day 29.
[y]Mean separation within time (day) and time (h) by LSD; 5% level.

tages and restrictions. The data can be time-consuming to collect. Frequent manipulation of the vegetation can inflict damage and affect growth (1); however, Haun and Coston (11) have developed a method and scale for visually rating leaf emergence which minimized the physical damage. Measurements of linear and diameter growth must be made at similar times during the day because the diurnal shrinking and swelling of plant tissues can lead to erroneous assessment of real growth (2, 11). Even the timing of watering relative to the timing of growth measurement can affect measurement and detection of true treatment effects (Unpublished results, Olien and Flore). In the SWS experiment the rates of leaf emergence and trunk diameter growth were affected by watering, even when only small amounts of water were added (compare Fig. 4 with Fig. 5 and 8).

These experiments suggest that for potted plant studies, RWS type experiments may be less reliable than SWS type experiments for predicting the best indicators of stress under field conditions. Wilting and soil water depletion occurred in seven to ten days after the last watering in experiments with potted trees (5, 19, 20). Soil water depletion can require four weeks in an orchard (4, 8, 20). The RWS required 10 days and the SWS 24 days to achieve wilting and soil water depletion.

Literature Cited

1. Causton, D. R. and J. C. Hill. 1981. The biometry of plant growth. Edward Arnold Publ. Ltd., London.
2. Chalmers, D. J. and I. B. Wilson. 1978. Productivity of peach trees: Tree growth and water stress in relation to fruit growth and assimilate demand. Ann. Bot. 42:285-94.
3. Chalmers, D. J., K. A. Olson, and T. R. Jones. 1983. Water relations of peach trees and orchards, pp. 197-232. In: Water deficits and plant growth, Vol. 8. Academic Press, Inc., New York.
4. Cullinan, F. P. and J. J. Weinberger. 1932. Studies on the influence of soil moisture on growth of fruit and stomatal behavior of 'Elberta' peaches. J. Amer. Soc. Hort. Sci. 29:28-33.
5. Davies, F. S. and A. N. Lakso. 1979. Water stress responses of apple trees. I. Effects of light and soil preconditioning treatments on tree physiology. J. Amer. Soc. Hort. Sci. 104:392-95.
6. Elfving, D. C. 1982. Crop responses to trickle irrigation. Hort. Rev. 4:1-48.
7. Haun, J. R. and D. C. Coston. 1983. Relationship of daily growth and development of peach leaves and fruit to environmental factors. J. Amer. Soc. Hort. Sci. 108:666-71.
8. Hendrickson, A. H. 1926. Certain water relations of the genus *Prunus*. Hilgardia 1:479-524.
9. Hsiao, T. C. 1973. Plant responses to water stress. Ann. Rev. Plant Physiol. 24:519-70.
10. Klepper, B. 1968. Diurnal pattern of water potential in woody plants. Plant Physiol. 43:1931-34.
11. Kozloswki, T. T. 1968. Diurnal changes in diameters of fruits and tree stems of 'Montmorency' cherry. J. Hort. Sci. 43:1-15.
12. Kramer, P. J. 1969. Plant and soil water relationships: A modern synthesis, pp. 365-68. McGraw-Hill Book Company, New York.
13. Olien, W. C. and A. N. Lakso. 1988. Physiological responses of mature grape vines to drought. Amer. Soc. Hort. Science (Abstr.).
14. Proebsting, E. L. and J. E. Middleton. 1980. The behavior of peach and pear trees under extreme drought stress. J. Amer. Soc. Hort. Sci. 105:380-85.
15. Raschke, K. 1975. Stomatal action. Annual review of Plant Physiology 49:229-34.
16. Scholander, P. F., H. F. Hammel, E. D. Bradstreet, and E. A. Hemmingsen. 1965. Sap pressure in vascular plants. Science 148:339-46.
17. Stanley, C. D., B. K. Harbaugh, and J. F. Price. 1983. Environmental factors influencing leaf water potential of chrysanthemum. J. Amer. Soc. Hort. Sci. 108:237-40.
18. Steele, R. G. D. and J. H. Torrie. 1980. Principals and procedures of statistics. A biometrical approach. McGraw-Hill Book Company, Inc., New York.
19. Tan, C. S. and B., R,. Buttery. 1982. Response of stomatal conductance, transpiration, photosynthesis, and leaf water potential in peach seedlings to different watering regimes. HortScience 17:222-23.
20. Xiloyannis, C., K. Uriu, and G. C. Martin. 1980. Seasonal and diurnal variations in abscissic acid, water potential and diffusive resistance in leaves from irrigated and non-irrigated peach trees. J. Amer. Soc. Hort. Sci. 105:412-15.