California Avocado Association 1939 Yearbook 24: 96-102

Root Temperature Effects on the Growth of Walnut and Avocado Seedlings

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Brief access to the temperature tanks of the Division of Plant Pathology permitted a study of the effects of root temperature on the growth of seedling trees. The water tanks used for the temperature control of roots are of large size and are equipped to maintain a given temperature for long periods. The heating and cooling systems in the water in the tanks were so regulated as to secure the following temperatures: Tank 1, 10°C; Tank 2, 17°C; Tank 3, 24°C; Tank 4, 31°C; and Tank 5, 38°C. The temperature records of the tanks were taken three times each day. Table 1 shows the accuracy with which the temperatures of the water in the tanks was controlled.

TABLE 1

Average tank temperatures, June 1-October 10, 1938

	Tank									
	1		2		3		4		5	
Readings	9.8°C		16.9°C		24.1°C		31.0°C		37.7°C	
Range (Min.-Max.)	9.4-10.4		16.3-17.9		23.0-24.6		30.6-32.4		36.8-38.0	
Frequency of min. and max. temperatures	9	1	2	1	1	11	2	1	1	2

The temperature of the water in the tanks is the temperature at which it is assumed the roots were exposed. The tops of the plants were grown at the air temperature of the lightly white-washed glasshouse.

The containers for the plant cultures were made of galvanized iron heavily coated with asphalt (Gilacoat) paint. The containers were 8 inches in diameter at the top, 6.5 inches in diameter at the base and 12 inches deep. Concrete lids about an inch thick and heavily coated with asphalt paint served as covers for the culture containers. The lids possessed a hole in the center through which the trunks protruded and there were several small holes for the entry of a glass aeration tube and for the addition of distilled water which was used at all times. The containers without lids weighed approximately 4.5 pounds.

The temperature tank covers had holes into which the culture containers could be inserted down into the water of the tanks. The containers each had a crimped collar near the top so as to hold them from slipping too deeply into the tanks.

TABLE 2
Mean air temperature of glasshouse (1938)

Week Ending	°F	Week Ending	°F
May 23	74	Aug. 1	79
May 31	72	Aug. 8	78
June 6	73	Aug. 15	75
June 13	65	Aug. 22	71
June 20	69	Aug. 29	78
June 27	73	Sept. 6	77
July 5	68	Sept. 12	71
July 11	72	Sept. 19	79
July 18	77	Sept. 26	75
July 25	78	Oct. 3	73
		Oct. 10	66

The average air temperature for the glasshouse was 77.1°P. The mean air temperatures of the glasshouse during the experimental period are given in table 2.

WALNUT SEEDLINGS

The effect of root temperature was first studied with two English walnut seedlings in each container filled with culture solution. The seeds were germinated in sand and were used in the solution cultures when the roots were about 3 inches long. The composition of the culture solution expressed as parts per million (p.p.m.) was as follows:

Na	K	Ca	Mg	Fe	Mn	B	NO_3	Cl	SO_4	PO_4	Total
7	185	318	54	1	0.25	0.5	1211	10	216	105	2107.75

The culture solutions used in the containers in each temperature tank were: a, control nutrient solution of the composition given; b, the nutrient solution containing in addition to a, 35.48 p.p.m. chlorine and 22.997 p.p.m. sodium; c, the nutrient solution containing in addition to a, 70.92 p.p.m. chlorine and 45.994 p.p.m. sodium; and d, the nutrient solution containing in addition to a, 106.38 p.p.m. chlorine and 68.991 p.p.m. sodium. The amount of solution used in each culture was 7.5 liters. A small additional amount of distilled water was used to bring the level of the solution to the desired place. Additional boron was occasionally added to each culture. Distilled water was added each day to replace the water lost through transpiration.

The walnut solution cultures were aerated continuously and were grown from May 17 to August 2, 1938. One factor that required close attention was to prevent the trunk from dropping down into the culture solution after the seed had become detached. It requires only a short exposure of the trunk to the solution to completely destroy the cambium layers. The solution levels were kept slightly below the lids and the seeds were supported on the lids. When the seeds became detached, wedge-shaped corks were used to hold the trunks in place.

Analyses were made of the chlorine in the cultures at the start and at the end of the experiment (table 3). While the data in table 3 are not complete, they suggest that the plants in the control culture (a) of tank 3 were the largest 'and absorbed the most

chlorine of all the control cultures at the various temperatures. All plants were soon injured at the root temperature of 38 °C and no success was had at that temperature regardless of the number of times the plantings were made.

TABLE 3

Chlorine concentration (p.p.m.) in the actual culture solution

Culture	May 17, 1938			August 2, 1938			
	Tanks 1 & 2	Tanks 3 & 4	Tank 5	Tank 1	Tank 2	Tank 3	Tank 4
a	9.3	9.4	9.9	6.6	5.4	2.1	7.6
b	41.0	40.7	39.2	36.9	38.7	.....	41.0
c	76.9	69.5	73.4	.....	73.6	68.8	71.8
d	107.6	109.4	109.6	98.9	94.7	95.4	104.5

TABLE 4

WEIGHTS OF 2 ENGLISH WALNUT SEEDLINGS GROWN IN AERATED CULTURE SOLUTIONS AT VARIOUS CONSTANT ROOT TEMPERATURES

	Leaves									Trunks and roots							
	Fresh wt. (gms.)					Dry wt. (gms.)				Fresh wt. (gms.)				Dry wt. (gms.)			
Added to culture sol.	10° C	17° C	24° C	31° C	38° C	10° C	17° C	24° C	31° C	10° C	17° C	24° C	31° C	10° C	17° C	24° C	31° C
Nothing (control) (Contains 10 p.p.m. Cl and 7 p.p.m. Na)	13.5	85.5	92.5	18.0	Plants and replants died	3	13.5	15.9	3	77.0	132.5	169.5	72.0	21.7	24.9	29.7	18.0
35.5 p.p.m. Cl and 23 p.p.m. Na	13.5	33.0	...*	15.0		2.7	6.8	....	3.4	71.5	98.5	....	35.0	18.7	19.5	....	7.0
71 p.p.m. Cl and 46 p.p.m. Na	13.5	24.5	37.5	22.0		2.7	3.9	7.1	4.0	75.0	89.5	79.5	48.0	20.5	18.6	18.0	14.0
106.5 p.p.m. Cl and 69 p.p.m. Na	10.0	31.5	54.0	23.0		2.0	6.5	8.6	3.7	60.5	99.0	100.5	55.0	16.9	21.8	18.6	11.7

* Plants once vigorous but were badly injured by sliding down into the culture solution.

Table four gives the weights of the walnut seedlings at the end of the experiment. At 10°C the growth was so sparse that the sodium chloride was not given much of an opportunity to show its effect. At 17°C and 24°C the sodium chloride markedly reduced the amount of growth as compared with the controls. A temperature of 24°C appeared to give the best growth among the control cultures. Growth was better at 17°C than at 31°C in the control cultures.

TABLE 5
Chlorine (as per cent of dry matter) in walnut plants at the end of the experiment

	Leaves				Trunk and roots			
Culture	10°C	17°C	24°C	31°C	10°C	17°C	24°C	31°C
a	0.40	0.20	0.20	0.27	0.08	0.04	0.10	0.06
b	0.48	4.28	.....	0.21	0.09	0.09	.....	0.11
c	0.58	0.39	0.27	0.27	0.12	0.12	0.08	0.09
d	0.65	0.39	0.33	0.23	0.11	0.11	.....	0.09

The concentrations of chlorine in the dried leaves were lower (table 5) in the plants grown at root temperatures that permitted growth to take place, the percentages for the leaves of plants grown at 10°C being greatest.

The roots in the control cultures were of a healthy white color. With increasing amounts of sodium chloride in the culture solution the roots usually were dark and beaded and with hooked and enlarged root tips.

TABLE 6
Transpiration of two English walnut seedlings at various root temperatures

	5:00 P.M. July 26 to 1:00 P.M. July 30, 1938				1:00 P.M. July 30 to 10:15 A.M. Aug. 2, 1938			
Culture	10°C	17°C	24°C	31°C	10°C	17°C	24°C	31°C
	c.c.	c.c.	c.c.	c.c.	c.c.	c.c.	c.c.	c.c.
a	200	1140	1300	675	295	920	1000	775
b	225	330	875	300	325	265	250*	105
c	460	300	265	350	285	280	280	175
d	175	400	320	340	150	415	645	300

*Plants slid down into the culture solution.

Table 6, culture a, indicates that the greatest amount of water loss occurred at 17° and 24°C which agrees with the sizes of the plants given in table 4. The decreased amount of water lost by cultures b, c, and d at temperatures above 10°C as compared with cultures a at the same temperatures is related to the amount of growth made (table 4) which in turn is related to the amount of sodium chloride present in the culture solution.

When the experiment with the walnut plants was concluded, the leaves were removed and the trunks were cut off about 10 cm. above the lids. A Tycos thermometer 5.5 inches long and with graduations extending -10 to +110°C was used to roughly determine the temperature within the trunks. The cut-off trunks were cut downward into many segments. The narrow thermometer bulb was placed inside the splinted trunk and the splints were firmly bound about the bulb by means of cord or tape. The trunks were too small to obtain very accurate results but they afforded an opportunity that was not overlooked. Table 7 shows the lower temperatures within the trunks (notwithstanding the heat developed in the wounding of the trunks) than in the surrounding air.

TABLE 7

Temperature (°C) within the trunks of young walnut seedlings grown in solution cultures at various root temperatures

Temperature of tank	Culture	Distance above lid	Temperature within the trunk	Temperature of outside air next to trunk
°C		cm.	°C	°C
10	a	5-6	33.5	35.0
	b	10-11	33.5	35.0
	c	8-9	33.5	36.0
17	a	14	32.0	35.0
	a	14	30.5	35.0
	a	14	30.0	35.0
	b	10	31.5	37.5
24	a	18-19	31.0	37.5
	c	14	32.5	36.5
31	a	10	34.0	37.0
	a	10	33.7	37.0
38*	b	9	35.0	38.5
	b	9	35.0	38.5
	c	7-8	35.0	38.0
	c	7-8	34.7	38.0

*Replants.

There is some indication therefore that the temperatures inside the trunks and possibly in the leaves are affected by the temperatures near the roots.

AVOCADO SEEDLINGS

Puebla seedling avocado plants were grown in soil in porous clay pots until the roots were about an inch or more in length. Two seedling plants were then transplanted into each soil culture. The containers used for the cultures were the same as those used for the walnuts except that soil was used instead of culture solution and that no lids were necessary. Each container was given approximately 25 pounds of screened and well mixed pasture soil (Hanford series) obtained from near the Citrus Experiment Station. A suitable moisture content of the soil was maintained by knowing the permanent wilting point and the field capacity of the soil and by periodically weighing the soil cultures and adding distilled water.

The experiment was begun on August 4, 1938 and was terminated on October 6, 1938. The tank temperatures were 10°C, 17°C, 24°C, 31°C, and 38°C, respectively, as shown in table 1. Pour cultures were placed in each of the five tanks. At the start of the experiment two of the cultures in each tank were each given a solution of calcium nitrate (the equivalent of 3.0757 grams Ca $(NO_3)_2$ $4H_2O$) while each of the other two cultures in each tank received a solution of ammonium sulfate (the equivalent of 1.7221 grams $(NH_4)2SO_4$. Each culture therefore received 0.3650 grams of nitrogen.

At the end of the experiment the total elongation of the trunks of the 4 seedlings grown at a given soil temperature and soil fertilization was noted (table 8) due allowance being made for the length of the trunks at the start of the experiment. A soil temperature of 38°C was not conducive to the greatest elongation of the trunk, 24°C - 31°C giving the maximum growth.

TABLE 8

Total elongation (cm.) of four trunks of Puebla avocado seedlings grown in soil at various constant soil temperatures

	10°C	17°C	24°C	31°C	38°C
Soil fertilized with calcium nitrate	5.5	36.0	70.5	64.5	37.5
Soil fertilized with ammonium sulfate	6.5	37.0	53.5	100.0	27.5

TABLE 9

WEIGHTS OF FOUR PUEBLA AVOCADO SEEDLINGS GROWN IN SOIL AT VARIOUS CONSTANT SOIL TEMPERATURES

	Soil fertilized with calcium nitrate										Soil fertilized with ammonium sulfate									
	Fresh wt. (gms.)					Dry wt. (gms.)					Fresh wt. (gms.)					Dry wt. (gms.)				
	10° C	17° C	24° C	31° C	38° C	10° C	17° C	24° C	31° C	38° C	10° C	17° C	24° C	31° C	38° C	10° C	17° C	24° C	31° C	38° C
Old leaves	29.0	33.0	35.5	35.0	35.0	7.4	8.9	8.5	8.5	9.2	24.0	27.0	33.0	42.0	23.0	5.7	5.8	7.4	10.0	5.1
New leaves	3.5	20.0	37.0	52.0	30.0	0.7	3.2	7.0	11.5	7.0	5.5	19.0	36.0	53.0	25.0	1.1	3.0	7.3	11.8	5.5
Trunks	24.5	34.0	45.0	61.0	17.0	7.0	8.1	9.7	14.6	9.2	26.5	27.0	47.0	64.0	25.0	6.5	5.5	9.8	14.2	8.9
Roots	25.5	40.0	48.0	34.0	21.0	3.7	4.7	6.0	7.1	4.7	25.5	49.0	62.0	31.0	13.0	3.0	6.0	7.3	6.0	3.2
Seed	105.0	109.0	125.5	169.0	122.0	22.0	21.4	21.0	32.0	22.7	158.5	118.5	137.0	129.0	115.0	45.4	20.3	19.5	18.6	23.7

As shown in table 9 the greatest fresh and dry weights of the trunks occurred at 31°C, likewise the greatest combined dry weights of new and mature leaves occurred at 31°C. The fresh weight of the roots was greatest at 24°C in each case. It is unfortunate that the tanks could not be obtained for a longer growth period.

While the dismantling of the cultures was in progress at the conclusion of the experiment, it was considered advisable to secure soil samples of some of the remaining soil cultures. Table 10 shows the marked difference in the pH of the calcium nitrate and ammonium sulfate-treated soils. The pH of the soil before the experiment began was 7.01. Calcium nitrate increased the pH while ammonium sulfate decreased it. It is of interest that the pH in the ammonium sulfate-treated soil became more acid as the temperature at which the soil was maintained increased. Several interpretations of this are possible, some of which are: 1. nitrification to nitric acid was probably hastened by the higher temperatures and 2. the greater growth at the higher temperatures may have brought about greater absorption of the ammonium than of the sulfate ions, increasing the acidity by differential absorption. It should be stated here that in the future the pH values of soil samples will be determined not on such an artificial soil-

water-ratio basis as 1-5, but will be determined rather at the moisture content actually occurring in the soil.

TABLE 10
pH of soil* from avocado cultures grown at various constant soil temperatures

Culture No.	Soil fertilized with calcium nitrate			Soil fertilized with ammonium sulphate		
	10°C	17°C	24°C	10°C	17°C	24°C
1	7.49	7.49	7.27	5.80	5.61	5.53
2	7.48	7.43	7.49	5.92	5.67	5.49

*Soil samples were drawn at the conclusion of the experiment from two cultures at each soil temperature. pH was determined on 1-5 soil-water ratio suspensions of oven-dried samples (105° C).

The data taken as a whole indicate that although the tops of the avocado seedlings were grown at the same air temperature, differences in root temperature greatly affected the growth of the tops.