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SOME EFFECTS OF SODIUM SALTS ONTHE GROWTH OF THE TOMATO[1]

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(with six figures)

Introduction

In a previous study (6) the influence of high osmotic concentrations of sodium salts and nutrient solutions upon the vegetative development of the tomato was reported, hut no data were obtained on the fruiting responses. To investigate this problem, to obtain further information on the relative toxicity of the Cl- and $SO_4^{=}$ ions, and the effect of osmotic concentration, experiments were set up to determine the response of tomato plants to sodium chloride and sodium sulphate when supplied together in different proportions and at several levels of total concentration.

Experimental procedure and methods

Marglobe tomatoes were grown under greenhouse conditions in automatically irrigated sand cultures of the type designed by EATON (2). Two series of five treatments each were set up with three replications. The treatments were: Base nutrient solution (control) ; and base nutrient ; 40, 80, 120, and

TABLE I

CONSTITUTION OF CULTURE SOLUTIONS

SERIES AND CULTURE	TREATMENT	OSMOTIC CONC.	SALTS					
			$Ca(NO_3)_2$	KNO_3	$MgSO_4$	KH_2PO_4	NaCl	Na_2SO_4
	m.e. Na/l.	atm.	m.e./l.	m.e./l.	m.e./l.	m.e./l.	m.e./l.	m.e./l.
A & B-1	Control	1.6	14.4	14.4	14.4	1.8	....	....
A-2	40	2.9	"	"	"	"	10	30
A-3	80	4.1	"	"	"	"	20	60
A-4	120	5.3	"	"	"	"	30	90
A-5	160	6.4	"	"	"	"	40	120
B-2	40	3.2	"	"	"	"	30	10
B-3	80	4.6	"	"	"	"	60	20
B-4	120	6.1	"	"	"	"	90	30
B-5	160	7.7	"	"	"	"	120	40

Micro-nutrients: B, 1 p.p.m.; Zn, 0.1 p.p.m.; Mo, 0.1 p.p.m.; Mn, 0.4 p.p.m.; Cu, 0.01 p.p.m.; Fe, 5 p.p.m., supplied as iron citrate.

Analysis of Riverside tap water, m.e./l.

Ca	Mg	Na	K	Cl	SO_4	HCO_3
1.40	0.23	1.51	0.05	0.45	0.75	2.50

[1] Contribution from the U.S. Regional Salinity Laboratory, Bureau of Plant Industry, Soils, and Agricultural Engineering, Riverside, California in cooperation with the eleven western states and the Territory of Hawaii.

160 milliequivalents per liter of sodium salts. To segregate the supplementary effects of the anions, 25 per cent. of the sodium was supplied as Cl- and 75 per cent. as $SO_4^=$ in series A; and 75 per cent. as Cl- and 25 per cent. as $SO_4^=$ in series B. The constituents of the base nutrient solution, the amounts of sodium salts added, the osmotic concentration of the culture solutions, and the analysis of the tap water at Riverside, California, are shown in table I.

FIG. 1. Growth response to treatment with sodium salts. A. Series A (high sulphate treatments) ; B. Series B (high chloride treatments). The osmotic concentration for each sodium treatment is shown in figure 6. Photographed five weeks before the final harvest.

All cultures mere started with the base nutrient solution; and, after the seedlings were well established, sodium salts were added by 20-m.e. increments at two-day intervals to bring the respective treatments to full concentration. Seven changes of the solutions were made during the course of the experiment to maintain the osmotic concentration within a 0.5 atm. range and to keep the nutrient ions above deficiency levels. The H-ion concentration was adjusted daily to a pH of 7.0 with HNO_3. The volume of the culture solutions was maintained by the addition of tap water daily, or twice daily when transpiration was high.

PLANTING, THINNING, AND HARVEST DATES

The seeds were planted July 8, 1940, and six plants per culture were maintained until August 6, when four were harvested. On August 28, one of the plants was harvested, and the remaining one was carried to the final harvest on November 8. To conserve space and permit a better analysis of flowering and fruit development, the vines were pruned to single stems (fig. 1).

TABLE II

FRESH AND DRY WEIGHTS. PERCENTAGE OF DRY MATTER, AND OSMOTIC CONCENTRATION OF EXPRESSED JUICE OF VINES

SERIES AND CULTURE	TREATMENT	HEIGHT	HARVEST, 8-28-40		FINAL HARVEST, 11-8-40			
			FRESH WT.*	OSMOTIC CONC. JUICE	FRESH WT.*	DRY WT.	DRY MATTER	OSMOTIC CONC JUICE
	m.e. Na/l.	*cm.*	*gm.*	*atm.*	*gm.*	*gm.*	%	*atm.*
A &B-1	Control	65	494	10.7	2155	353	16.4	11.6
A-2	40	67	343	11.2	1910	327	16.9	12.4
A-3	80	60	244	11.9	1664	285	17.1	13.6
A-4	120	51	151	12.7	1180	204	17.3	15.0
A-5	160	46	104	13.7	797	142	17.8	15.0
B-2	40	64	310	12.6	1832	324	17.7	13.7
B-3	80	57	206	12.9	1662	261	15.7	14.9
B-4	120	45	117	13.3	1091	181	16.6	16.4
B-5	160	35	74	15.3	443	75	17.0	15.9

* All weights are averages of tops per plant.

METHODS OF ANALYSIS OF JUICE

In order to determine to what extent the ions were accumulating, and to get some indication of the effect of the salt treatments on carbohydrate synthesis, analyses of the juice of the tops and of the fruit were made for the principal ions, reducing sugar, and organic nitrogen. Samples of vegetative material and fruit were rapidly frozen with dry ice and placed in cold storage until analyses could be made. The material was then thawed, the juice expressed with a Carver press under 2000 pounds pressure per square inch, and the freezing point depression of the juice determined. The juice was centrifuged for 15 minutes at 1800 r.p.m., hydrogen-ion concentrations determined, and chemical analyses made by A.O.A.C. methods except for K^+ which was assayed by the HIBBARD and STOUT procedure (7). Analyses were run for reducing sugars. Non-reducing sugars were not found in significant quantities. The sap was cleared by the method described by HASSID

(5), and the sugar determinations were made by a modified HARDING and DOWNS procedure as outlined by VAN DER PLANK (12).

Results

VEGETATIVE RESPONSES AND GROWTH DATA

Growth data were obtained at the intermediate and final harvests. The higher the concentration of the culture solution, the greater was the reduc-

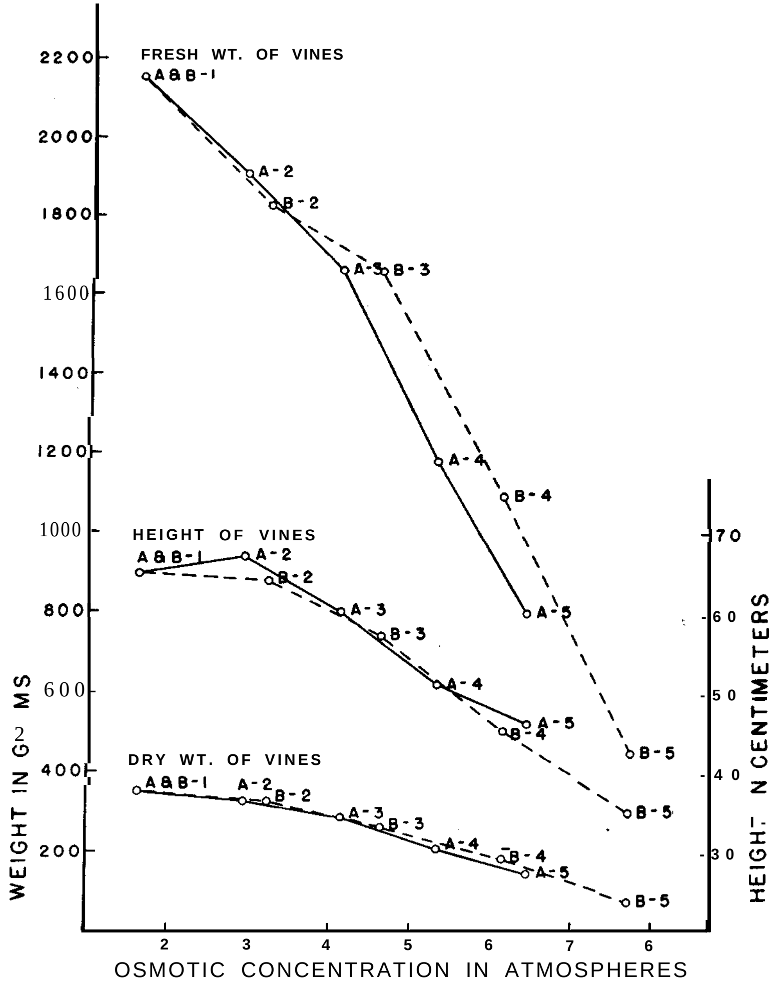

FIG. 2. Height, and fresh and dry weight of vines, plotted against osmotic concentration of the substrate. The letters A and B refer to salt treatments as shown in table I. Series A, high sulphate treatments; and series B, high chloride treatments.

tion in the height of stems and fresh and dry weight of vines (table II). At equivalent concentration of sodium, plants in the high chloride series showed greater growth inhibition than those in the high sulphate series (figs. 1

and 4). This might suggest that the toxic effect of the Cl- ion exceeds that of the $SO_4^=$ ion, but it should be recognized that the activity of the Cl- ion is much higher than that of the $SO_4^=$ ion in the respective solutions. Osmotic concentration is possibly the dominant factor in this difference in growth response since, at corresponding levels of sodium treatment, the osmotic concentration of the culture solution is greater in the chloride series, the

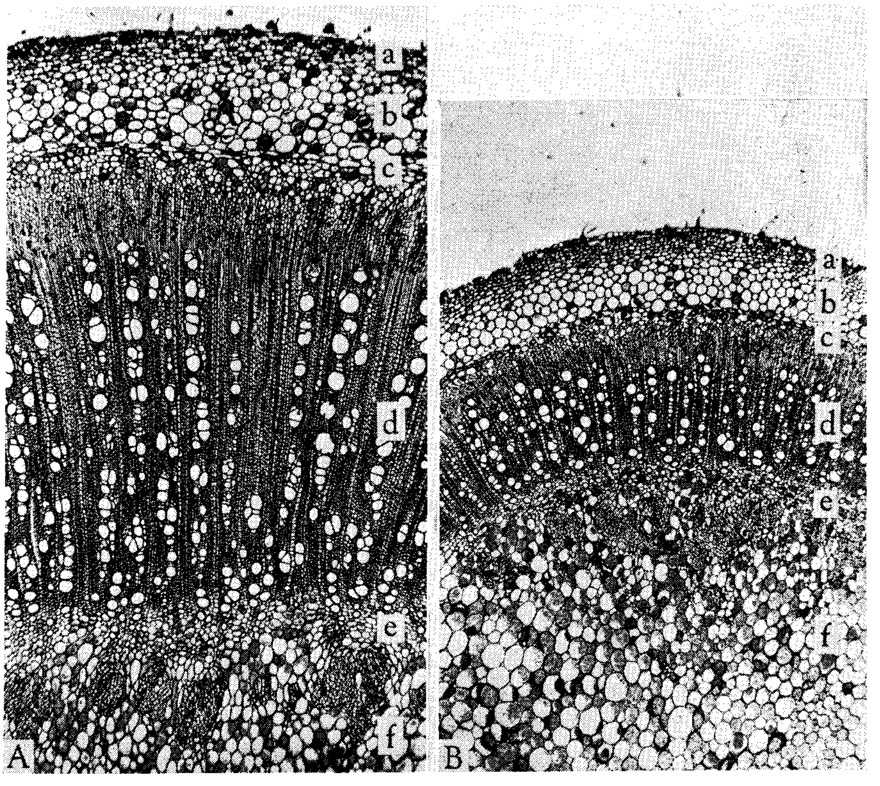

FIG. 3. Histological responses to high concentrations of sodium salts. Comparable sectors of transections of the middle internode of the tomato vine. A. Control culture (A-l) 1.6 atm. osmotic concentration; B. High salt treatment (A-5) 160 m.e. Na/l., 6.4 atm. osmotic concentration. The high salt stem has smaller, thicker-walled collenchyma (a), pericyclic fibers (c), and secondary xylem elements (d). The parenchymatous cells of the cortex (b) and pith (f) are smaller in the high salt stem, and those of the pith contain more starch. (The larger cells of the pith in the control stem are not shown in the figure.) The smaller size of the zone of secondary vascular tissues in B, from pericycle (e) to primary xylem (e), is the result of a slower rate of cambial activity at high osmotic concentrations, and the maturation of cells of smaller size. A and B at same magnification.

differences ranging from 0.3 atm. with 40 m.e. of added salt to 1.3 atm. at the 160 m.e. level (table I). When height of stems and fresh and dry weight of vines are plotted against the osmotic concentration of the culture solutions, the differential effect of the Cl- and $SO_4^=$ ions is very small (fig. 2). In fact, at isosmotic concentrations, there is little difference in the growth inhibition as expressed in terms of height of stems and dry weight of vines, and the chloride plants (series B) had greater fresh weights of vines than did the sulphate plants (series A) at the higher levels. This is probably due to the tendency of plants to be more succulent when grown in high chloride than in high sulphate solutions.

ANATOMICAL RESPONSES

The anatomical and histological responses observed were similar to those noted in an earlier study with high concentrations obtained by additions of sodium salts to a base nutrient solution and by multiplying the constituents

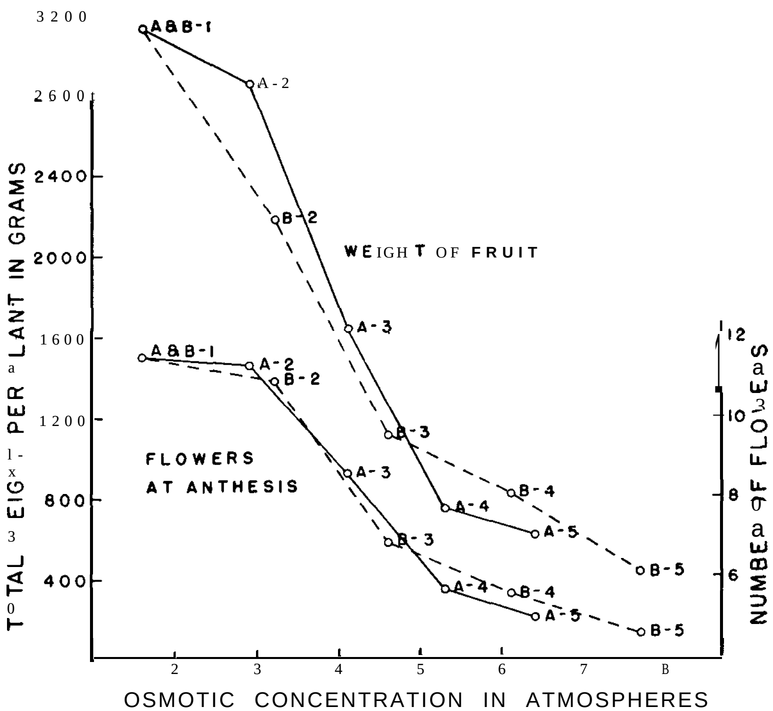

FIG. 4. Number of flowers at anthesis, daily average for 30 days, and total weight of fruit per plant plotted against osmotic concentration of the substate. The letters A and B refer to salt treatments as shown in table I. Series A, high sulphate treatments; and series B, high chloride treatments.

of the base nutrient (6). The smaller stems of vines grown at the high sodium levels as compared with the control vines were the result of decreased cambial activity, consequent reduction in the amount of secondary vascular tissue differentiated, and the smaller size of the mature cells. This was especially noticeable in the secondary xylem vessels and cells of the mechanical tissues of the high salt plants which were much smaller and had proportionately thicker walls. There was also a marked reduction in the amount of cortical and medullary parenchyma and in the size of the cells of those

TABLE III

FLOWERING AND FRUITING RESPONSES

Series and culture	Treatment	Flowers at anthesis*	Fruit set†	Fruit harvested: No. per plant	Fruit harvested: Total wt. fruit per plant	Wt. per fruit	Blossom-end-rot
	m.e. Na/l.				gm.	gm.	%
A & G-1	Control	11.5	188.5	56.5	3124	55.2	16.8
A-2	40	11.3	207	57.0	2856	50.1	33.3
A-3	80	8.6	136	55.7	1638	29.4	39.5
A-4	120	5.7	72	33.7	743	22.1	18.8
A-5	160	5.0	73	30.0	615	20.5	36.7
B-2	40	10.9	197	55.7	2183	39.2	29.9
R-3	80.	6.9	111	39.3	1115	28.4	44.1
B-4	120	5.6	72	34.0	816	24.0	41.2
B-5	160	4.6	28	16.0	427	26.7	18.8

* Daily average, 30 days.
† Average per replication.

tissues. At the high salt concentrations, the accumulation of starch in the medullary and ray parenchyma was greater than in the control plants (fig. 3).

FLOWERING AND FRUITING RESPONSES

Evident flower buds were observed first in the control and low salt cultures and last on plants under high salt treatments. With one exception,

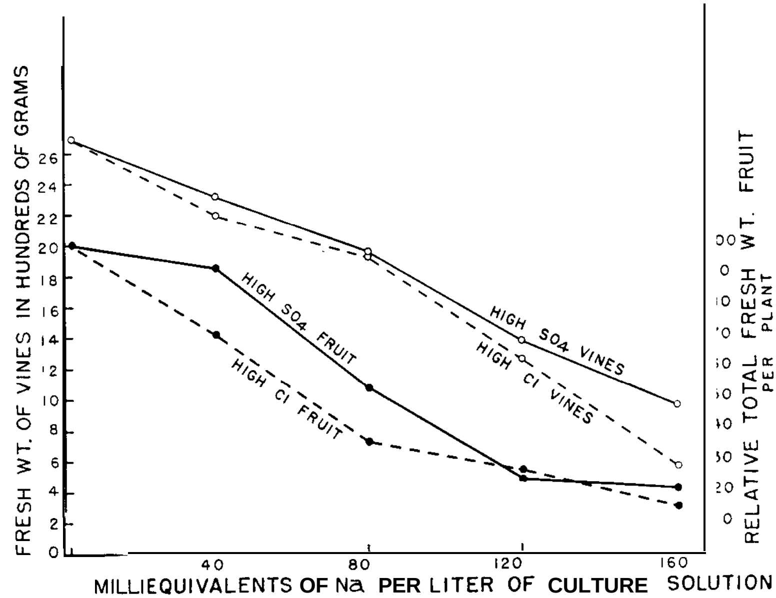

Fig. 5. The fresh weight of the vines and the relative total fresh weight of the fruit per plant for series A (high sulphate treatments) and series B (high chloride treatments).

this sequence also obtained for anthesis, the lag ranging from 3 to 6 days. From August 20 to September 24, floral counts were made to determine daily averages of flowers at anthesis per plant under each treatment. In both series, there was a marked decrease in the number of flowers formed with increasing concentrations of salt, but there was no significant difference in the effect of the Cl- and SO,' ions (fig. 4). The total weight of fruit per plant and weight per fruit were reduced by the salt treatments. The reduction in total weight of fruit was not great at the 40 m.e. level in series A, but there was a sharp drop at higher salt concentrations (table III). The crop at the 120 m.e. level was about 25 per cent. of that of the control, and less than 15 per cent. at the 160 m.e. salt level in the B series (high chloride) (fig. 5).

On the basis of osmotic concentration, the high sulphate plants (series A) produced a greater total weight of fruit per plant than those of the high chloride series (B) at the lower osmotic values, but the reverse was true at the upper levels of salt concentration (fig. 4). Like the vegetative responses, the production of fruit indicates that the osmotic concentration of the substrate is more significant, than the specific effect of the Cl- and $SO_4^=$ ions.

The incidence of blossom-end rot was high in all treatments. ROBBINS (11) found that approximately 80 per cent. of fruits on plants grown with solutions adjusted to 1.7 and 3.1 atm. osmotic concentration developed blossom-end rot and suggested that it was associated with wide fluctuations in the rates of evaporation, and occurred when the rate of transpiration was high. We observed that it was possible to reduce the amount of blossom-end rot by bringing the solutions up to volume frequently, thereby reducing the variations in water stress.

ANALYSIS OF JUICE OF VINES

The osmotic concentration of the juice of the vines increased as the vines matured. In every case, the juice of vines harvested in November was more concentrated than that for equivalent plants harvested in late August. At the final harvest, the osmotic concentration of the juice was greater at high concentrations of the culture solution, except at the highest levels where there was little change or a slight reduction as compared with the next lower level of salt treatment. Equivalent concentrations of sodium resulted in a higher osmotic concentration in the sap in the chloride than in the sulphate series, following the relationship of the culture solutions in this respect (fig. 6).

Calcium, magnesium, and potassium were supplied to all cultures in equal amounts, sodium being progressively increased from 1.6 m.e./l. (average content in Riverside tap water) to 160 m.e./l. In general, the total cations present in the juice tended to be uniform regardless of treatment. With one exception (B-5)) there was an increase in sodium at each succeeding higher sodium treatment and this was accompanied by a decrease in the

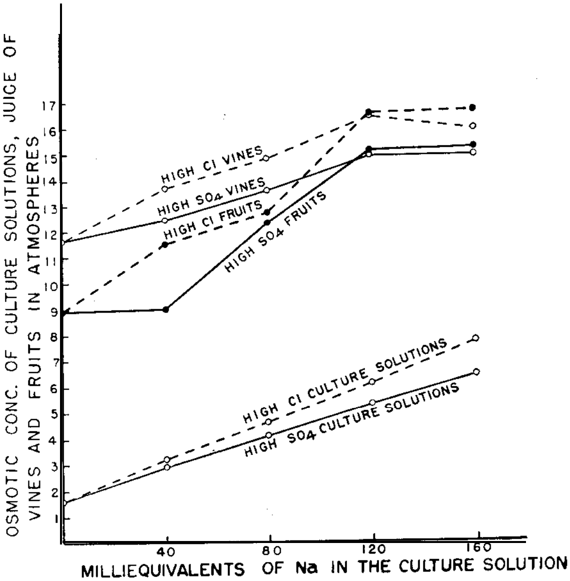

FIG. 6. The osmotic concentrations for the culture solutions, juice of vines, and juice of fruit at the different levels of sodium treatment. The high sulphate curves refer to series A, high chloride curves to series B.

concentration of other cations in the jniee. In the A series (high sulphate) with increasing increments of sodium salts, the reduction in the amounts of Ca, Mg, and K was progressive. In the B series (high chloride), the relationship was not so clear owing to anomalous results from the B-3 cultures. With one exception (B-5)) chloride and sulphate increased in the vines with increasing concentration in the cnltnre solutions, the proportion of the two sodium salts in them being reflected in the greater SO, accumulation in the vines of the A series and the increased Cl concentration in those of the series B (table IV).

TABLE IV

ANALYSIS OF JUICE OF TOPS

SERIES AND CULTURE	TREATMENT	Ca	Mg	Na	K	SO_4	Cl	N*	REDUCING SUGAR
	m.e. Na/l.	m.e./l.	m.e./l.	m.e./l.	m.e./l.	m.e./l.	m.e./l.	m.e./l.	%
A & B-1	Control	81	156	10	163	113	13	92	1.42
A-2	40	97	140	55	135	136	41	a3	1.24
A-3	80	69	139	110	115	164	65	96	1.20
A-4	120	51	130	135	117	171	92	117	1.17
A-5	160	48	111	151	112	174	92	130	1.21
R-2	40	85	158	75	120	118	102	104	1.47
B-3	80	50	115	121	101	108	162	95	1.00
B-4	120	70	127	150	110	122	184	112	1.17
B-5	160	70	128	114	112	120	168	111	1.11

* Organic and ammoniacal N.

TABLE V

Analysis of juice of ripe fruit. Osmotic concentration, accumulation of ions, N, and percentage N, reducing sugar and acid

Series and culture	Treatment	Osmotic conc.	Ca	Mg	Na	K	SO_4	Cl	N*	Nitrogen	Reducing sugar	Acid†
	m.e. Na/l.	*atm.*	*m.e./l.*	*m.e./l.*	*m.e./l.*	*m.e./l.*	*m.e./l.*	*m.e./l.*	*m.e./l.*	%	%	%
A & B–1	Control	8.9	1.4	8.2	6.9	69.2	4.5	3.5	99	0.14	3.35	0.52
A–2	40	9.0	1.4	7.7	5.5	64.6	5.6	6.9	81	0.11	3.88	0.53
A–3	80	12.3	2.0	9.3	6.6	77.5	7.6	10.5	106	0.15	5.38	0.61
A–4	120	15.1	1.4	10.1	8.7	108.2	9.7	14.2	158	0.22	6.19	0.82
A–5	160	15.2	4.5	17.5	11.5	115.8	11.1	18.2	179	0.25	5.78	0.88
B–2	40	11.5	1.3	9.1	6.5	80.3	5.2	13.4	110	0.15	4.06	0.62
B–3	80	12.7	2.4	11.3	7.1	92.4	5.7	18.4	125	0.17	4.70	0.63
B–4	120	16.5	7.1	14.4	12.4	119.4	9.5	23.7	206	0.29	5.73	0.84
B–5	160	16.6	7.0	17.1	12.7	121.2	8.5	31.5	209	0.29	5.33	0.86

* Organic and ammoniacal N.
† Calculated as citric acid.

Organic nitrogen increased in plants grown under high sodium treatments, but there was little or no increase at intermediate levels. Reducing sugars were lower in the salt treatments than in the controls except in the B-2 culture, but the differences between treatments were slight (table IV).

ANALYSIS OF JUICE OF RIPE FRUIT

In ripe fruits, the osmotic concentration of the expressed juice increased with increasing concentration of the sodium salts in the nutrient solution; and, like the vines, the osmotic concentrations were higher in the B series at corresponding levels of treatment. As CHANDLER (1) and ROBBINS (11) have pointed out, in most cases the osmotic concentration of the juice of vegetative parts tends to exceed that of the fruit. At control, low, and intermediate levels of sodium concentration where the osmotic concentration of the substrate ranged from 1.6 to 4.6 atm. we found that the osmotic concentration of the vegetative sap exceeded that of the fruit by one to three atm. At the higher levels of salt treatment, however, in which the osmotic concentrations of the culture solutions were from 5.3 to 7.7 atm., the osmotic concentration of the fruit juice equaled or exceeded that of the vegetative sap (fig. 6).

These relationships suggest that hydrostatic stresses may be operating to limit hydration which, as MACDOUGAL (10) has pointed out, is fundamental to growth. It seems probable that the growth of fruit at the highest salt levels was inhibited not so much by lack of food reserves as by inadequate hydration. As indicated in table V, the organic nitrogen in the juice of the fruit increased progressively up to the highest level of salt treatment; and the percentage of reducing sugar was highest under the 120 m.e. Na/l. treatment and only slightly less than that peak under the highest salt concentrations.

As compared with the vegetative tissues, the accumulation of Ca, Mg, Na, SO_4, and Cl in the fruit was low, and differences as the result of treatment were small (table V). Potassium and nitrogen occurred in larger amounts, the former approximating the accumulation in the vegetative saps at the high salt levels. With one exception, nitrogen values of the fruit juices were progressively higher with increasing concentration. The accumulation of sodium in the juice of the fruit increased with increasing increments of sodium in the substrate except for a slight decrease in the A-2 culture. The accumulations of SO_4 and Cl reflected the treatments, more of the former occurring in the A series, and of the latter in the B ; but the amounts present were small as compared with the vegetative juice and with the concentration of these ions in the substrates in which the plants were grown (table V).

Discussion

Analyses of the fruit juices indicated that on a percentage basis, there was a slight increase in nitrogen, reducing sugars and mineral constituents with increasing concentrations of salts. Flavor and quality may be adversely affected by the presence of Cl, SO.,, and Na ions and by the higher acid values that were found under high salt treatments, but the amounts of these ions accumulated as compared with their concentration in the vegetative sap were small. It should be added that no determinations were made for vitamin content of the fruit, such as those of HAMNER, LYON and HAMNER (4) for ascorbic acid, so that we have no information as to how high salt treatment may affect that aspect of the nutritional picture.

The principal deleterious effects of high salt concentration under the conditions of this study appear to be marked reduction in the number of fruits set and the weight and size of the fruits that reach maturity. Studies with several varieties of tomatoes yielding results in line with those given here have been reported by other investigators. ROBBINS (11) experimenting with the same variety used in our work, found that fruits produced on plants grown in nutrient solutions of 3.1 atm. osmotic concentration were much smaller than those grown at lower concentrations. LYON (8) using added Na_2SO_4 at 80 and 120 m.e./l. levels, found significant reductions in the mean weight of tomatoes of the Johannisfeuer variety and a reduction of 40 per cent. in the fresh weight of fruit, produced at the higher salt level. EATON (3) growing the Stone variety at two concentrations of chloride and sulphate salts (50 and 150 m.e./l.) obtained 19 per cent. and 96 per cent. reductions in the relative dry weights of fruits at the low and high chloride levels respectively, and a 28 per cent. and 73 per cent. reduction with the corresponding sulphate treatments.

There also appears to be an increase in the incidence of blossom-end rot when the osmotic concentration of the substrate is high, although this condition is somewhat alleviated when fluctuations in water stress are reduced by keeping the concentration of the solution constant by frequent additions of water. Although our experience, like that of ROBBINS (11), indicates that irregularities in hydrostatic stress and the restriction of rate of absorption of water are probably the most important factors in the development of blossom-end rot, there is some evidence that the lack of accumulation, or the accumulation in excess, of certain ions may be contributing causes of this disorder.

On the basis of work reported here and additional unpublished data, it appears that the accumulation of potassium may be significant in blossom-end rot and that calcium map have an ameliorating effect. LYON, BEESON and BARRENTINE (9) using the Bonny Best variety and working with nutrient solutions of relatively low concentration found that "fruits produced in treatments where rot was most severe were low in calcium content and high in potassium and magnesium content." Our data are not directly comparable to those of the workers just mentioned since we were concerned with very high concentrations of total ions and of K, Mg, and Ca, and they were working at much lower levels. EATON (3) using Stone tomatoes in sand culture has obtained data that suggest that "calcium and magnesium accumulations singly or combined were important contributing factors" to the incidence of blossom-end rot.

Summary

1. Marglobe tomatoes were grown in sand cultures using a nutrient solution with NaCl and Na_2SO_4 as the added salts. Two series were set up with five treatments each: control, 40, 80, 120, and 160 m.e. Na/l. To segregate supplementary effects of the anions, series A had the sodium supplied as 25 per cent. Cl- and 75 per cent. SO,‘, series B as 75 per cent. Cl- and 25 per cent. $SO_4^{=}$. The plants were grown to maturity to obtain data on flowering and fruit production.

2. The osmotic concentration of the substrate appears to be a primary factor in growth inhibition, although secondary effects of the Cl- and $SO_4^{=}$ are noted.

3. The principal effects of high concentration of the substrate were:

   a. Reduction in height and diameter of stems and fresh and dry weight of vines.

   b. Reduction in cambial activity, maturation of cells of smaller size, and relatively thicker walls in xylem elements and mechanical cells.

   c. Inhibited floral development and reduced set of fruit.

   d. Reduction in total yield of fruit and in size and weight per fruit.

   e. Increase in osmotic concentration of the vegetative and fruit juices.

4. The accumulation of Ca, K, Mg, and N in the juice of the ripe fruit was greater at high osmotic concentrations of the substrate although those elements were supplied in equal amounts for all treatments.

5. The accumulation of Cl, SO,, and Na in the vegetative and fruit juices increased with increasing increments of salt in the substrate.

6. Flavor did not appear to be impaired by salt treatments.

7. The incidence of blossom-end rot appeared to be related to wide fluctuations in water stress. It is suggested that high accumulation of potassium may be a contributing factor.

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