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W. L. BLIZZARD, *Director* LOUIS E. HAWKINS, *Vice Director*

Greenhouse Studies of the Toxicities of Oklahoma Salt Contaminated Waters

By

ROBERT F. WALL
Department of Agricultural Chemistry Research

and

FRANK B. CROSS
Department of Horticulture

Stillwater, Oklahoma

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SUMMARY

Greenhouse crops were grown under conditions which varied only in the kind of water applied. The waters used contained different kinds of salts and alkalies, alone and in various combinations. After the effects of the different kinds of waters had been observed, various treatments to render the waters safe for greenhouse use were tested.

The results showed that each type of plant is an individual problem. For instance, tomatoes were killed by water containing 2,000 parts per million of sodium chloride, while chrysanthemums could withstand up to 50 percent more of this salt, or 3,000 parts per million. On the other hand, sodium bicarbonate was more damaging to chrysanthemums than to tomatoes.

For neutralizing alkaline waters, sulfuric acid was found most effective; but other acids were used satisfactorily.

No satisfactory means has yet been found for correcting salt waters. However, the greenhouse methods listed under "Recommendations" will be found helpful.

Further studies aimed at determining more precise recommendations for specific plants are now under way.

RECOMMENDATIONS

When difficulty is experienced with a water source, the first step is to secure a chemical analysis of the water.

Before locating a new greenhouse, the water source or possible water sources should be analyzed.

Experiment station chemists and horticulturists will gladly assist in interpreting the results of chemical analyses and in suggesting means of overcoming difficulties.

In some cases, it may be necessary to resort to stored rain water.

Salt Waters

Waters containing 200 p. p. m. (parts per million) or less of salts, and little or no alkalies, are excellent for greenhouse use.

At 500 p. p. m., difficulty will be encountered only with the more susceptible plants or under unfavorable conditions of temperature, light, and humidity.

Waters of 1,000 p. p. m. can generally be used satisfactorily. However, the kinds of salts present, and their relative quantities, must be considered. Particularly susceptible plants (See Table VII, page 35) may cause considerable trouble; and all plants will suffer more quickly from unfavorable soil, light, and temperature conditions.

Waters containing 2,000 p. p. m. are not at all desirable, but can and are being used. More care in the selection of plant varieties is necessary, and the effect of adverse conditions is more marked, especially in hot summer months.

No practical method is known for reducing the toxicity of salt water by use of chemicals. When a new source of water cannot be obtained, the handicap can in part be overcome by extra care in providing other growing conditions which are as nearly perfect as possible. In addition, the following special practices will be helpful:

1. Water more heavily, and not so often.
2. Keep the soil as moist as possible without retarding plant growth.
3. Use a heavy type of soil containing considerable organic matter.
4. Keep the temperature lower and the humidity higher than would be done with normal waters.
5. Select varieties which are most tolerant to the type of water being used.

Alkaline Waters

Waters containing 200 p. p. m. (parts per million), or less, of bicarbonates will seldom cause difficulties, and then only with susceptible plants.

Waters containing more than 500 p. p. m. probably should be neutralized for general use.

Sulfuric acid is recommended for neutralization, although other acids may be used.

Cost of neutralization can be reduced by neutralizing only the water which is used on plants that are sensitive to alkaline waters.

Greenhouse Studies of the Toxicities of Oklahoma Salt Contaminated Waters

By ROBERT F. WALL and FRANK B. CROSS*

INTRODUCTION

Many plants are injured by waters containing excessive amounts of salt or alkali. Such waters are common in Oklahoma, both from natural and contaminated sources, and they present a problem to greenhouse operators. The results of the use of such waters in irrigation have been carefully determined for many field crops; but the information is not applicable to the greenhouse, where we have continuous and intensive production, frequent watering, rapid evaporation, shallow beds, and salt accumulation. For this reason, the Oklahoma Agricultural Experiment Station started in 1935 to determine under actual greenhouse conditions:

(1) The concentration of a salt that would prove to be toxic.

(2) The relative toxicity of different salts and the effect of mixtures.

(3) If methods could be devised to avoid or counteract the toxicity.

With such information, growers could use a chemical analysis of the water in locating a greenhouse and its source of water supply; and, in case no high-grade supply is available, methods of using these waters to the best purpose would be known. The problem is complicated; certain plants are more sensitive to salt injury than others, and no two naturally occurring soils are the same. Certain basic facts can be used, however, in predicting results after a consideration of the soils and the types of plants.

The salts most often encountered in Oklahoma are the chlorides, sulfates, and bicarbonates of sodium, calcium, and magnesium, with occasionally a more alkaline carbonate.

Certain results of this work have been published in previous reports from this station (9, 14, 15, 24).

REVIEW OF LITERATURE

Any information dealing with toxicity of salt waters to plants must be gathered chiefly from irrigation experiments. A survey of this field is found in the review by Ahi and Powers (1), and the references in that article will not be cited in this report.

An article by Hilgard (16) defines many terms which were adopted for use in this report. He regards as "white alkali" those salts which leave a white encrustation upon evaporation (i. e., sodium chloride, sodium sulfate, sodium nitrate, magnesium sulfate, magnesium chloride, calcium chloride, etc.) and as "black alkali" those salts which leave a black encrustation (chiefly sodium carbonate and bicarbonate). "Black alkali" is generally considerably more toxic than an equivalent quantity of "white alkali." Hilgard more specifically reports the limits of plant tolerance for sodium carbonate, sodium chloride, and sodium sulfate.

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* Respectively, Research Assistant, Department of Agricultural Chemistry Research, and Head, Department of Horticulture. Assistance in the research was given by E. L. Hartman, now on military leave of absence, and V. G. Heller, Head, Department of Agricultural Chemistry Research. Professor Heller also assisted in preparing final draft of the manuscript after Mr. Wall was called into national defense industry.

Krone and Weinard (18) watered various common flowers with solutions of sodium chloride in concentrations of 100, 200, 500, 1000, and 2000 p. p. m., and found that growth was progressively reduced at 200 p. p. m. and over. These findings were confirmed in general by Zimmerman and Berg (26).

Harris and Pittman (12) grew a variety of crops in loam soil in tumblers and found that satisfactory yields of ordinary crops could not be obtained when salts were added to the soils in higher concentrations than 4000 p. p. m. of chlorides, 8000 p. p. m. of carbonates, and 1200 p. p. m. of sulfates. With some crops, marked reduction in yield was observed with concentrations much lower than these.

Harris and Butt (11) concluded that the use of irrigation water containing as a maximum 500 p. p. m. of sodium carbonate, or 1000 p. p. m. of sodium chloride, or 4000 p. p. m. of sodium sulfate, was harmful before three years. A mixture of these salts was less harmful than the most toxic individual salt, although more than 4000 p. p. m. of any salt mixture proved to be dangerous.

Lipman et al. (19) used solution cultures to study the sodium chloride tolerance of barley, peas, and beans, and found these plants to be, in general, highly resistant. Low concentrations (500 to 1000 p. p. m.) depressed growth somewhat, but higher concentrations (4000 p. p. m.) produced a stimulation, even at concentrations as high as 10,000 p. p. m.

It is commonly recognized that mixtures of salts are often less injurious than the individual salts in like concentration. Kearney and Harter (17) observed that calcium sulfate diminishes the toxicity of magnesium and sodium salts, and Harris and his associates (11, 13) recorded similar observations and explain further (13), in connection with studies on the alleviation of black alkali soils, that "this phenomenon may be due in part at least to the specific stimulation of plant growth by these substances rather than any antagonistic action on the sodium carbonate." They found barnyard manure to be effective on soils containing 2000 p. p. m. or less of sodium carbonate, and further state that calcium sulfate, in combination with manure and sulfur, was the most effective corrective used, particularly on the black alkali soils.

Harris (10) reports that only about half as much alkali is required to prohibit the growth of plants in sand as in loam.

Both Means (20) and Scofield (22) suggest the desirability of using liberal quantities of water where it is necessary to use water containing considerable quantities of dissolved salts, with Scofield explaining that sufficient water should be used to leach the root zone and thus carry away the accumulated salts left by evaporated water. In essence, the greater the salt content of the irrigation water the greater the quantities that should be used in irrigation.

Lipman (19) believes the effects of sodium chloride upon plants to be conditioned by the climatic factors of temperature, light, and humidity.

Greaves and Lund (7) assign an important role in salt toxicity to osmotic pressure effects, but attach a considerable significance to the physiological action of the salts and their ions upon the protoplasm in altering its chemical and physiological properties and inhibiting to a greater or lesser degree its normal functioning.

While the fundamental methods of salt absorption are very probably the same for all plants, the effect of environmental factors during the long evolutionary process has left differences in the toxicity of the various salts to the various plants. It is generally accepted that salt accumulation by plants parallels respiratory and transpirational processes, although the mechanism of the whole is obscure. This view is presented in the review by Steward (23), and later work has affirmed that a high transpiration rate increases mineral absorption (6), and that a high or low humidity decreases or increases salt absorption in parallel with the effect in decreasing transpiration (5, 21).

GENERAL EXPERIMENTAL PROCEDURE

Soil culture studies were conducted with a mixture of loam and compost. Sand culture studies used fine quartz sand and a nutrient solution consisting of 12 ml. of 0.5 mol. calcium nitrate, 1 ml. of 4% solution of ferric citrate dissolved with the aid of ammonia, and 1 ml. of an A-Z solution suggested by Haas (8). The sand in each pot was leached at weekly intervals to prevent excessive accumulation of salts. At the termination of the experiments, Kodachrome photographs of the plants were taken as the best record of the appearance and condition. During the experiment, records were kept of the amount of solutions used, the general appearance of the plants and the onset of toxicity symptoms, and the length of plant life. At the termination of the experiment, the plants were clipped at ground level and the green weight taken. The dry weight was taken and the dry plants and a representative sample of soil were analyzed. Sodium was determined by the method of Barber and Kolthoff (3), potassium by the method of Wilcox (25), chloride by the method of Caldwell and Mayer (4), and calcium, magnesium, manganese, phosphorus, and nitrogen by the methods of the A. O. A. C. (2).

EXPERIMENTS WITH TOMATOES

Tomatoes (Marglobe) were used in five groups of experiments because they are readily propagated, intermediate in sensitivity and growth requirements, and satisfactory for use as a standard comparison plant

Two groups were grown in soil to determine the toxicity of the various salts and salt mixtures in the medium; two groups were grown by sand culture to outline the toxicity of the various salts and ions; and one group was grown in sand to establish the treatments most effective in alleviating bicarbonate toxicity. Five plants grown in six-inch porous clay pots were used as comparative units of study.

Toxicity of Single Salts (in Soil)

The first groups of experiments on the toxicity of single salt solutions in concentrations to 7000 p. p. m. to tomatoes in soil cultures are reported graphically in Figures 1-6. These are arranged in a series of decreasing toxicities; i. e., $NaHCO_3$, NaCl, $MgCl_2$, Na_2SO_4,$MgSO_4$. In all these graphs the ash increased with increasing salt concentration. The percentage in the plant of the ions added in the experimental salt water increases considably lesser degree. The same holds true in the soil. Thus, the sodium ion is highly mobile, the plant cell membranes are readily permeable to this ion, and it tends to increase the permeability of the cell membranes; therefore the percentage of Na in plants watered with Na salts increased rather sharply. Ca and Mg, conversely, are less mobile and are absorbed to a considerably lesser degree than is Na.

Positive ions affect the absorption of negative ions, and negative ions have a corresponding effect on the absorption of positive ions. Chloride ions, which are mobile and readily absorbed, permit the ready absorption of positive ions, such as Na, or enhance the absorption of a slowly absorbed positive ion, such as Mg. Conversely, SO_4 ions, which are slowly absorbed, retard the absorption of readily absorbed positive ions, such as Na.

FIG. 1.—$NaHCO_3$ TOXICITY
TOMATOES - SOIL

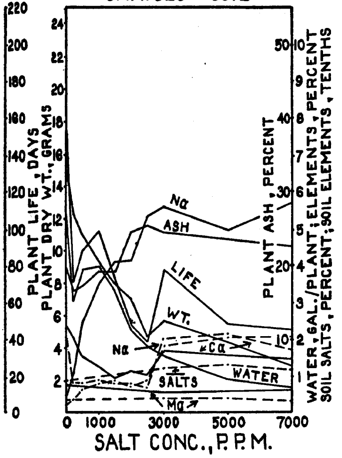


FIG. 2.—NaCl TOXICITY
TOMATOES - SOIL

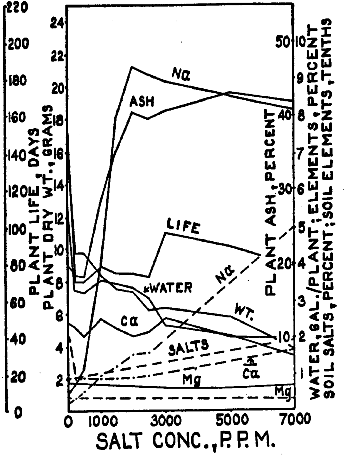


FIG. 3.—$MgCl_2$ TOXICITY
TOMATOES - SOIL

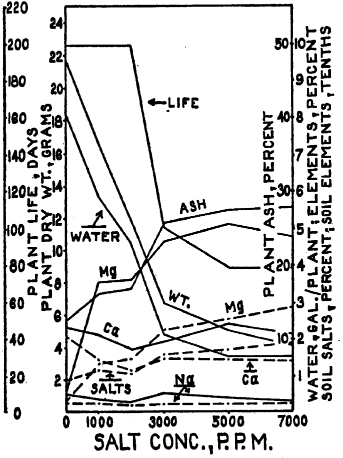
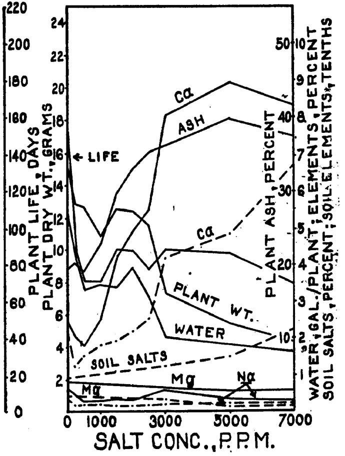


FIG. 4.—$CaCl_2$ TOXICITY
TOMATOES - SOIL



An inspection of Figures 2 and 5 confirms the reduction of absorption (and, therefore, toxicity) of Na ion by So_4 ion as compared with the effect of chloride ion. Similarly, Figure 3 demonstrates greater absorption of Mg from the chloride than from the sulfate, and a correspondingly greater toxicity. Thes graphs illustrate a greater toxicity of Na_2SO_4 over $MgSo_4$, and of NaCl over $CaCl_2$ and $MgCl_2$.

It should not be inferred from this discussion that the toxicity of a salt is a function only of the absorption of its component ions. The salts, or ions, demonstrate characteristic toxicity effects on the various plants, varying in type and intensity with the different plants. In this experiment, certain general effects were evident:

FIG. 5.—Na_2SO_4 TOXICITY
TOMATOES - SOIL

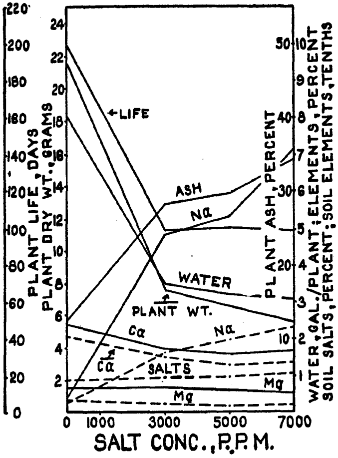
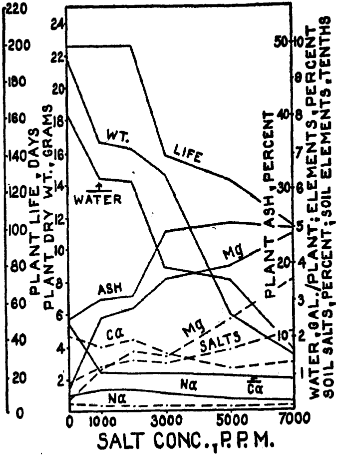


FIG. 6.—$MgSO_4$ TOXICITY
TOMATOES - SOIL



1. Plants receiving high concentrations of salts soon stopped growing, leaves turned yellow and fell, and plants died relatively early in the experiment.

2. Plants watered with sulfate salts maintained a dark green color until injury was very pronounced.

3. The leaves of plants watered with chloride salts exhibited a typical yellowish green chlorosis and a high turgidity. These leaves finally lost their turgidity, rolled, and died.

4. Plants which were treated with salt solutions did not wilt so readily as did the controls.

5. Salt injury was first apparent on the lower leaves and branches, and moved progressively up the plant with increasing time and concentration.

6. Each of the salts had its own characteristic degree and type of toxicity.

A leveling off of the curves for plant dry weight and ash, such as that shown in Figure 1 for $NaHCO_3$, was noticed with each of the exceedingly toxic salts. This effect is most probably explained by considering that after a certain concentration of salt has been reached, growth and salt absorption are very nearly at a standstill.

$NaHCO_3$. (Figure 1). The plants quickly became extremely chlorotic. An early turgidity was soon followed by a wilted condition. and, as is shown on the graph, many of the plants died before the termination of the experiment. An examination of the root systems disclosed a browning and die-back of the root fibers at 100 p. p. m. of $NaHCO_3$, and appearances of toxic action at even lower concentrations. In essence, both plant production and quality were reduced very sharply.

NaCl. (Figure 2). The plants watered with NaCl all exhibited severe chlorosis the leaves were yellowed, and lower leaves quickly died. The general appearance was very bad, and the growth was quite stunted; i. e., there was a marked reduction in quality as well as decreased production. was evident. These toxic effects were sharply graded until a condition

$MgCL_2$. (Figure 3). The yellow-green chlorosis characteristic of the chloride ion was apparent at low concentrations and early in the experiment, and a particularly turgid, cupped, and distorted type of leaf growth was evident. These toxic effects were sharply graded until a condition of extremely stunted growth was reached, with the lower leaves dead and the upper leaves yellow and wilting. Plants remained in this state, using very little more water.

$CaCl_2$. (Figure 4). The considerably curtailed production at rather low concentration of $CaCl_2$ was accompanied by reduction in quality.

Na_2SO_4. (Figure 5). In the early stages of the experiment, and with low concentrations of Na_2SO_4, the effect of the sulfate ion in intensifying the green color was evident; later a lightening of the color and yellowing characteristic of the sodium ion considerably obscured this.

$MgSO_4$. (Figure 6). The plants watered with $MgSO_4$ were of a darker green than the control or the Na_2SO_4 plants; individually both Mg and SO_4 accentuate the greenness.

Some general observations may be recorded from a comparison of Figures 1 to 6. In all cases the plant dry weight dropped in proportion to a corresponding increase in the percentage of ash and of the ion added in the salt investigated. The degree of these variations paralleled the degree of toxicity of the respective salts. The percentages of the other ions in the plants were generally depressed slightly. Water consumption of the plants paralleled the length of plant life and dry weight quite closely.

In the soil the total salts increased steadily, and the added ions increased considerably. The percentage of other ions present was generally slightly depressed.

In evaluating the relative toxicities of the various salts, the concentration of a salt that would reduce the dry weight of the plant to one-half the value for the control plant was arbitrarily selected as a comparison point of toxic concentration. It is, of course, not invariable, and is merely used in conjunction with the general appearance of the plants as an aid in estimating the relative toxicities of the salts. Actually, a curtailment of growth occurs long before this arbitrarily selected value of weight reduction is reached. The relative order of decreasing toxicity and the corresponding toxic concentrations and percentages of total salts in the soil at those concentrations are as follows:

Salts in order of decreasing toxicity	Concentration producing a .5 reduction in plant dry weight	Percentage of total salts in soil at toxicity concentration
$NaHCO_3$	1750	
$NaCl$	2000	
$MgCl_2$	2300	1.18
$CaCl_2$	3000	1.26
Na_2SO_4	3500	.94

In this experiment, both general appearance of the plant and the arbitrary toxic concentration indicated the same order of toxicity.

Toxicity of Salt Mixtures (in Soil)

The foregoing experiments demonstrated certain trends in toxicity for single salt solutions. A salt-contaminated water, however, rarely if ever can be classed as a single-salt water. Rather, salt waters vary from those containing a single predominating salt to those containing a heterogeneous mixture of several salts. A group of experiments was therefore set up to investigate the toxicity of salt mixtures as compared with single salt solu-

TABLE I.—Analyses of Tomato Plants and of Soils.

SALT AND CONC. in Thousand P. P. M.	Experiment Duration (Days)	Water Consumption (gal./plant)	PLANT						SOIL			
			Dry Wt. (grams/plant)	% Dev. from dry wt., Princ. salt, 3 Conc.	Ash (percent)	Ca (percent)	Mg (percent)	Na (percent)	Ca (percent)	Mg (percent)	Na (percent)	Calcualted Sum, $CaCl_2$, $MgSO_4$ and NaCl
Control	280	11.9	20.94		16.89	2.60	.78	23	2.15	.064	.041	1.01
3 $NaHCO_3$	54	1.7	2.52		22.76	1.39	.51	3.67	.200	.059	.204	1.36
+1 $NaHCO_3$	58	2.1	2.36	— 6.4	24.02	1.45	.54	4.06	.219	.064	.266	1.58
Na_2SO_4	67	2.3	2.91	+ 15.5	28.64	1.39	.68	6.53	.197	.053	.276	1.51
NaCl	80	2.4	3.22	+ 27.8	24.97	1.52	.76	7.46	.195	.059	.369	1.77
$CaSO_4$	131	3.7	5.46	+116.6	34.13	1.82	.58	3.87	.279	.147	.206	2.02
$CaCl_2$	184	4.2	5.75	+128.8	36.64	1.75	.65	7.57	.285	.045	.383	1.98
$MgSO_4$	136	5.0	6.19	+145.6	25.82	1.09	.99	5.46	.197	.127	.240	1.79
$MgCl_2$	160	3.5	6.45	+156.0	31.90	1.55	1.44	6.80	.189	.143	.310	2.02
3 Na_2SO_4	252	5.0	5.30		32.23	1.57	.67	4.73	.208	.055	.428	1.93
+1 Na_2SO_4	269	6.0	6.87	+ 15.7	30.32	1.23	.70	4.47	.173	.061	.462	1.95
$MgCl_2$	249	5.1	7.28	+ 37.4	40.60	1.74	2.42	5.16	.145	.158	.355	2.08
$MgSo_4$	265	7.5	8.35	+ 57.6	26.68	1.12	1.54	3.32	.131	.157	.360	2.05
$NaHCO_3$	264	6.4	8.73	+ 67.7	30.19	1.54	.66	6.72	.161	.046	.412	1.72
$CaSO_4$	280	7.3	8.81	+ 66.3	25.63	2.64	.73	2.64	.504	.049	.367	2.57
NaCl	257	6.1	9.42	+ 77.8	45.94	1.92	.87	8.59	.140	.049	.473	1.85
$CaCl_2$	224	5.1	10.62	+100.0	34.73	2.75	.61	5.69	.400	.056	.358	2.29
3 $MgCl_2$	178	3.8	7.66		24.54	1.73	4.84	.26	.172	.356	.042	2.34
+1 $MgSO_4$	138	2.6	5.60	— 26.9	25.69	1.97	4.94	.19	.128	.352	.035	2.18
NaCl	136	2.7	6.66	— 13.0	29.74	2.04	4.05	1.81	.164	.327	.187	2.54
$NaHCO_3$	200	4.0	7.06	— 7.8	25.97	1.74	4.22	1.29	.148	.318	.141	2.35
Na_2SO_4	167	3.3	7.66	+ 0.0	32.90	2.03	4.46	2.42	.126	.285	.140	2.11
$CaCl_2$	162	3.3	7.72	+ .8	30.56	4.14	4.29	.36	.337	.357	.051	2.83
$MgCl_2$	183	3.5	8.22	+ 7.3	25.00	1.72	4.90	.27	.202	.386	.031	2.54
$CaSo_4$	170	3.0	10.23	+ 33.6	28.91	3.11	4.30	.28	.206	.247	.033	1.87

TABLE I.—(Continued).

SALT AND CONC. in Thousand p. p. m.	Experiment Duration (Days)	Water Consumption (gal./plant)	PLANT						SOIL			
			Dry Wt. (grams/plant)	% Dev. from dry wt., Princ. salt, 3 Conc.	Ash (percent)	Ca (percent)	Mg (percent)	Na (percent)	Ca (percent)	Mg (percent)	Na (percent)	Calculated Sum, $CaCl_2$, $MgSO_4$ and $NaCl$
3 $NaCl$	197	4.8	8.12		36.20	2.17	.55	5.39	.164	.060	.448	1.88
+1 $NaHCO_3$	102	2.6	3.56	— 56.2	43.62	2.14	.81	10.39	.227	.057	.471	2.25
Na_2SO_4	139	3.3	4.23	— 47.9	43.21	2.27	.76	10.15	.175	.050	.414	1.78
$NaCl$	129	3.2	4.70	— 42.1	46.97	2.30	.84	10.87	.178	.052	.535	2.10
$MgCl_2$	143	3.6	4.82	— 40.7	41.08	2.39	2.04	6.46	.151	.120	.313	1.81
$CaCl_2$	170	3.7	5.29	— 34.9	44.95	3.92	.66	5.86	.301	.046	.417	2.12
$MgSo_4$	193	3.5	5.90	— 27.4	43.53	2.26	1.90	7.48	.151	.113	.480	2.20
$CaSO_4$	208	5.1	7.44	— 8.4	41.81	3.58	.62	7.52	.276	.032	.413	1.96
3 $CaCl_2$	262	6.0	9.28		32.34	7.30	.55	.20	.636	.049	.033	2.08
+1 $CaCl_2$	172	3.6	6.03	— 35.0	38.66	8.64	.67	.29	.647	.041	.029	2.14
$NaCl$	177	5.1	6.40	— 31.0	37.33	7.62	.63	1.76	.586	.052	.195	2.37
$MgCl_2$	213	5.3	7.37	— 20.6	34.54	6.34	1.59	.16	.581	.104	.027	2.19
$MgSo_4$	199	3.8	8.22	— 11.4	33.39	6.27	1.56	.24	.570	.152	.017	2.35
$NaHCO_3$	237	6.2	9.58	+ 3.4	38.80	7.42	.64	1.33	.679	.046	.145	2.48
Na_2SO_4	225	4.9	9.85	+ 6.1	40.83	7.01	.55	1.48	.515	.071	.115	2.07
$CaSO_4$	235	5.3	10.79	+ 16.3	41.53	9.24	.59	.31	.751	.027	.021	2.26
3 $MgSo_4$	280	6.5	12.06		17.35	.67	2.67	.18	.175	.317	.022	2.10
+1 $MgCl_2$	241	5.2	10.47	— 13.2	24.41	1.31	4.71	.18	.140	.587	.036	3.38
$NaHCO_3$	280	7.3	10.60	— 12.1	22.18	.72	3.63	1.41	.167	.353	.133	2.55
$MgSO_4$	280	5.9	11.00	— 9.2	20.02	.62	3.04	.11	.167	.302	.028	2.02
Na_2SO_4	280	5.3	11.40	— 5.7	31.02	.71	3.60	2.22	.181	.402	.191	2.97
$NaCl$	215	3.9	13.28	+ 10.1	27.97	1.18	3.87	1.65	.164	.311	.168	2.41
$CaSO_4$	280	6.0	14.33	+ 18.8	22.05	1.05	3.52	.15	.466	.295	.022	2.80
$CaCl_2$	276	6.3	15.17	+ 25.8	27.85	2.32	4.54	.26	.509	.323	.629	3.06

TABLE I.—(Continued).

1NaCl, 1$CaCl_2$ 1$MgCl_2$	259	6.2	7.66	42.41	4.83	2.32	2.30	.328	.192	.222	2.42
1NaCl, 1$CaCl_2$ 1$CaSo_4$	200	3.7	9.47	34.80	5.76	.42	2.69	.370	.038	.140	1.54
1NaCl, 1$CaCl_2$ 1$NaHCO_3$	229	4.9	12.18	32.06	3.55	.54	3.58	.312	.042	.284	1.78
1NaCl, 1$CaCl_2$ 1Na_2SO_4	227	4.3	13.73	36.02	3.63	.62	5.06	.323	.055	.263	1.83
1NaCl, 1$CaCl_2$ 1$MgSO_4$	235	3.3	14.79	36.72	3.65	1.92	3.22	.312	.151	.177	2.06
1$MgCl_2$, 1Na_2SO_4, 1$NaHCO_3$	210	4.4	9.43	34.33	1.77	2.24	2.91	.170	.183	.273	2.06
1$MgCl_2$, 1Na_2SO_4, 1NaCl	181	3.9	9.45	33.99	1.93	2.03	4.60	.137	.145	.308	1.90
1$MgCl_2$, 1Na_2SO_4, 1$MgSO_4$	242	5.3	10.57	29.10	1.59	3.56	2.14	.137	.242	.159	2.00
1$MgCl_2$, 1Na_2SO_4, 1$CaSO_4$	221	4.4	10.92	30.53	2.68	2.40	2.57	.318	.190	.152	2.21
1Na_2SO_4, 1$MgSO_4$ 1$NaHCO_3$	272	6.6	10.33	29.77	1.24	1.80	4.02	.173	.177	.292	2.10
1Na_2SO_4, 1$MgSO_4$ 1NaCl	241	5.3	11.22	29.56	1.56	2.21	3.89	.145	.164	.277	1.91
1Na_2SO_4, 1$MgSO_4$ 1$CaSO_4$	272	6.9	12.00	25.83	1.43	2.07	1.84	.487	.153	.150	2.49
1Na_2SO_4, 1$MgSO_4$ 1$CaCl_2$	239	5.2	14.59	34.72	2.45	2.35	2.71	.340	.166	.152	2.15
1$CaCl_2$, 1$MgCl_2$, 1Na_2SO_4	238	4.4	10.57	33.54	3.70	1.83	1.90	.293	.127	.115	1.72
1$CaCl_2$, 1$MgCl_2$, 1$MgSo_4$	234	4.7	11.27	36.39	4.07	3.35	.36	.304	.251	.026	2.15
1$CaCl_2$, 1$MgCl_2$, 1$CaSO_4$	214	4.0	11.57	34.61	5.80	2.03	.43	.386	.148	.031	1.88
1$CaCl_2$, 1$MgCl_2$, 1$NaHCO_3$	228	5.3	13.43	30.36	3.62	2.36	1.85	.312	.200	.170	2.28
1000 $CaSO_4$	280	10.2	23.51	17.92	2.92	.75	.65	.572	.050	.027	1.90
1760 $CaSO_4$ (sat.)	280	10.0	23.36	24.49	3.52	.86	.44	1.050	.074	.026	3.32

tions. The experimental procedure was the same as described for the preceding experiments with single salt solutions. The salt mixtures used and the analytical results obtained are presented in Table I, arranged in order of decreasing toxicity. The salts were added in 1000 p. p. m. to 3000 p. p. m. of the major salt, to make a total concentration of 4000 p. p. m. It may be noted that in many cases the addition of 1000 p. p. m. of a salt produced a considerable alleviation of toxicity, and that the trinary salt mixtures were in general less toxic than equivalent concentrations of single salts. It is also evident that, of the salts used, the NaCl toxicity was the least responsive to any decrease of toxicity. Of the added salts, $CaSO_4$ seemed to be the most beneficial in lowering toxicity. As general statements, it seems that the positive ions, Ca, Mg, and Na, and the negative ions, sulfate and chloride, relieved toxicity in that general order of decreasing effect. These statements should be considered as indicating a trend rather than a rule.

The wide variation in toxicities with the addition of other salts indicates that factors other than osmotic concentration are of importance in salt toxicity; at the same time the high toxicities evident with all salt combinations give proof that osmosis and other factors that are direct functions of concentration are of fundamental importance.

All these results are affected to a greater or lesser extent by the complicated nature of the soil; and, therefore, its varied absorption of added salts. To overcome this difficulty, sand cultures and nutrient solutions were used as set forth in the methods. The results confirm in a more positive manner most of the conclusions drawn from the soil tests. These results have been reported (14, 24) and will be omitted here. Those interested are referred to the original article.

Neutralization of Alkalinity

In the previous experiments, the extreme toxicity of $NaHCO_3$ was correlated with the high pH resulting from this salt. Alkaline waters having large proportions of bicarbonate are quite prevalent in many western and southern states and constitute a major problem of agricultural production. Although some procedures and apparatus have been developed for the neutralization of alkaline waters, there are still many difficulties to be solved. In order to estimate the relative value of several neutralizing agents, an experiment using sand culture tests was set up to outline the toxicity of $NaHCO_3$ to tomatoes and the efficiency of the various neutralizing treatments. The concentration of alkali and neutralizing agent used is set forth in Table II.

In all cases the sodium bicarbonate or the sodium bicarbonate plus the calculated quantity of neutralizing agent was added to the nutrient solution and the mixture stored for use. The pH of all solutions was adjusted to a pH value of 5.6 to 6.0, with the exception of sulfur and superphosphate treatments.

All solutions were vigorously stirred before application to the plants and used in the quantities required to satisfy the water requirements of the plants. The plants receiving the higher concentrations of unneutralized or neutralized alkali used less water.

The high toxicity characteristic of sodium bicarbonate was evidenced by dead lower leaves, progressive chlorotic discolorations, and stunted growth of the plants. There was an apparent sharp rise in injury to the plants treated with 1500 and 2000 parts per million of sodium bicarbonate.

The series neutralized with phosphoric acid, the acid commonly recommended for neutralizing alkaline water, demonstrated an apparent de-

TABLE II.—Experimental Treatment of Tomato Plants and Parts per Million of $NaHCO_3$ Added to Nutrient Solution

Treatment	Parts per Million of $NaHCO_3$					
$NaHCO_3$ unneutralized	500	1000	1500	2000	2500	3000
$NaHCO_3$ $+H_2SO_4$ to neutrality	500	1000	1500	2000	2500	3000
$NaHCO_3$ $+HNO_3$ to neutrality	500	1000	1500	2000	2500	3000
$NaCHO_3$ $+H_3PO_4$ to neutrality	500	1000	1500	2000	2500	3000
$NaHCO_3$ +Superphosphate, 5 g./gallon	500	1000	1500	2000	2500	3000
$NaHCO_3$ +Sulphur, 5 g./gallon		1000		2000		3000

Plus five control groups.

crease in the injury and an improved appearance and color of the plants; however, a high degree of injury was still apparent by the sharply stunted growth of plants treated with 1500 and 2000 parts per million concentrations of the neutralized alkali.

The series of plants in which nitric acid was the neutralizing agent showed a lessened toxicity and improved plant appearance both in size and color.

Neutralization with sulphuric acid gave by far the best results of the treatments tried. The plants at the highest concentration (3000 parts per million of sodium bicarbonate) which were neutralized with this acid appeared equal to the control plants in color, and nearly equal in size.

Two experiments were tried in which substances other than acids were used as the neutralizing media. One, superphosphate, was added on the theory that there would be some neutralization from the residual acidity. There was very slight, if any, improvement in the size and appearance of the plants in this series as compared to the plants treated with unneutralized sodium bicarbonate.

Sulphur was added in one experiment, as it was thought that its slow oxidation to sulphuric acid in the presence of air might provide a gradual neutralization of the sodium bicarbonate. Careful observations indicated that the plants treated with higher concentrations of sodium bicarbonate and neutralized with sulphur had longer internodes, less dense foliage and smaller stalks, and attained greater height than the controls.

The dry weights of all series were determined and are shown graphically in Figure 7. The broken line represents the unneutralized sodium bicarbonate series; solid lines represent equal concentrations of sodium bicarbonate neutralized as noted.

The growth of the plants in the series neutralized with sulphuric acid demonstrated that this was the most effective treatment. The growth of plants treated with the maximum concentration of alkali and neutralized with sulphuric acid was not reduced sufficiently to render production unprofitable.

The nitric acid treatment was less beneficial, but still proved valuable in the alleviation of alkaline injury. The sulphur treatment was of value in reducing the extreme toxicity of the higher concentrations, and the phosphoric acid and superphosphate treatments were of no signifcant value.

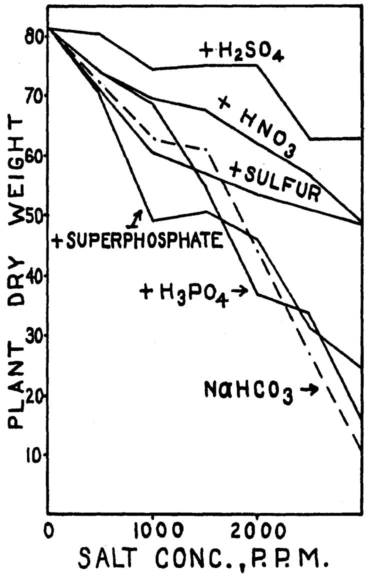


Fig. 7

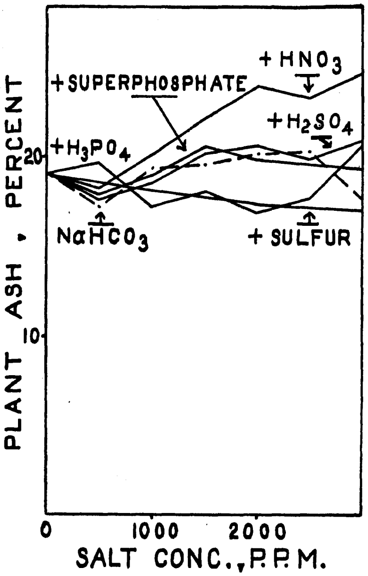


Fig. 8

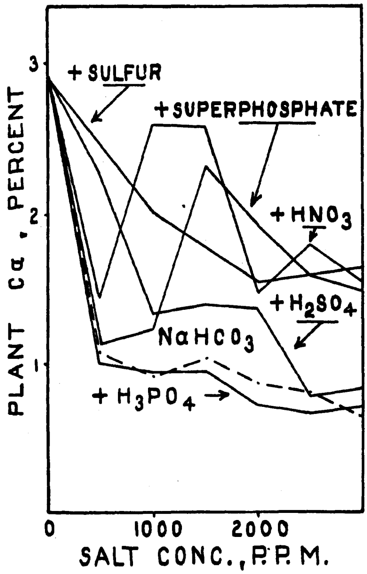


Fig. 9

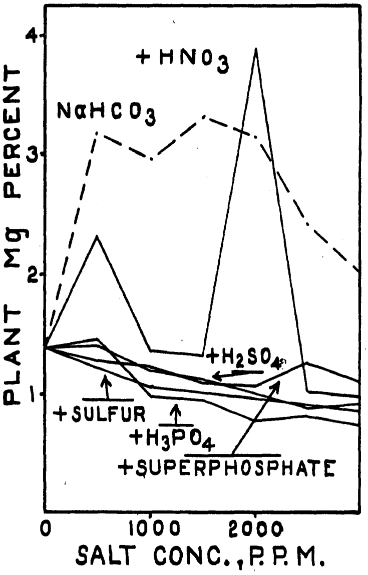


Fig. 10

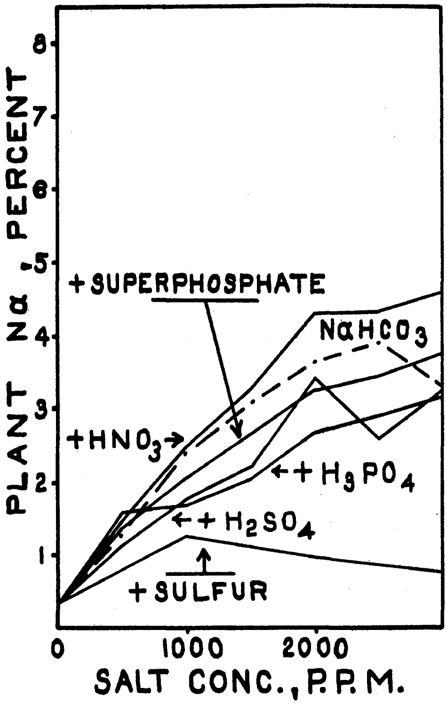


Fig. 11

FIG. 12. NaH_2PO_4 TOXICITY
TOMATOES – SAND

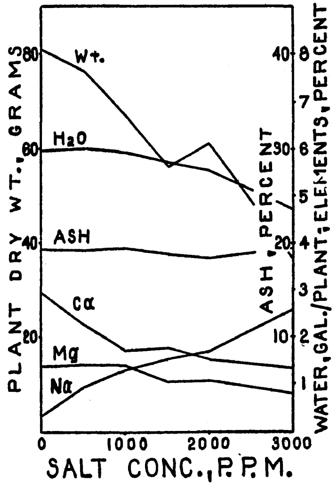
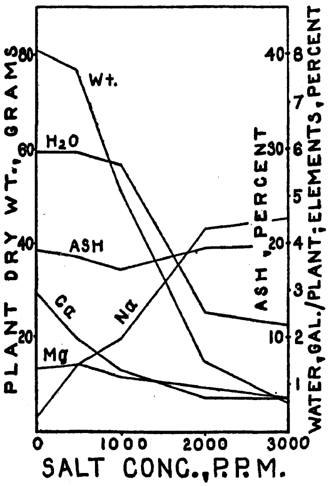


FIG. 13. Na_2HPO_4 TOXICITY
TOMATOES – SAND



Ash, calcium, magnesium, and sodium were determined in an effort to find if there was any correlation between analytical data and plant growth, and to ascertain the effect of the various treatments upon the assimilation of the various ions.

The ash contents of the plants of each series are shown in Figure 8. Although the neutralization of the sodium bicarbonate with sulphuric acid was the most effective in alleviation of injury to the plants, and superphosphate the least effective, these two series of plants had essentially the same ash content as the plants treated with the unneutralized sodium bicarbonate. The highest content of ash was in the plants treated with sodium bicarbonate and neutralized with nitric acid. The plants assimilated less minerals when sulphur and phosphoric acid were used for the neutralization.

The calcium content of each series of plants is shown in Figure 9. The nitric acid treatment gave the highest absorption of calcium. Sulphuric acid gave a slight increase, and phosphorus acid made no appreciable difference. The plants treated with superphosphate gave an appreciable increase in plant calcium. Sulphur treatment gave a greater increase in plant calcium than would be predicted from the sulphuric acid curve.

The curves in Figure 10 show how the plants assimilated magnesium under the various treatments. The unneutralized sodium bicarbonate curve demonstrates abnormally high absorption, and the nitric acid curve an erratically high magnesium content. All other treatments lowered the magnesium content of the plants as indicated by the general trend of the curves.

The sodium content of each series of plants is demonstrated by the curves in Figure 11. The sulphur treatment exhibited the greatest depression of sodium content in the plants. The sodium content was highest in the plants where nitric acid was used as the neutralizing agent, being slightly higher than the unneutralized sodium bicarbonate series. Plants treated with the other neutralizing agents contained slightly less sodium than the unneutralized alkali series.

Two groups were run in which the toxicities of NaH_2PO_4 and Na_2HPO_4 were compared. The results are presented in Figures 12 and 13 respectively, which show that the more alkaline Na_2HPO_4 was more toxic as evidenced by an appreciably lesser plant dry weight.

It must be remembered that these plants were grown in sand and that their reactions would not necessarily be identical with plants grown in soil. This is indicated by the rather ineffective influence of sulphur as a neutralizing agent in the sand media, whereas sulphur is usually quite effective in reclamation of alkali land. Addition of sulphur to the sodium bicarbonate treatments did not alleviate alkali injury as measured by plant growth in sand; however, the decrease in the sodium content of the plant material with the increasing sodium bicarbonate additions indicates that sulphur may function in this manner as an important alleviating agent in alkali soils.

Using as criteria plant growth measured by the dry weight of the plants and observed appearance, the following results were obtained:

In the unneutralized sodium bicarbonate series the plant injuries were accentuated as the concentrations were increased. Plants treated with solutions containing 1500 to 2000 p. p m. of unneutralized alkali were reduced in dry weight to one-half that of the control plants.

The plants treated with solutions containing the highest concentration of sodium bicarbonate (3000 p. p. m.) were but slightly injured in growth and appearance when neutralized with sulphuric acid. Under these conditions this treatment proved to be most effective from an economic standpoint.

When nitric acid was used as the neutralizing agent, there was some alleviation of the alkaline injury. Nitric acid, however, was not as effective as the sulphuric acid in the reduction of injury to the plants.

The sulphur treatment was of value in reducing the extreme toxicity of the higher concentration. Superphosphate and phosphoric acid exhibited little or no activity in alleviation of sodium bicarbonate injury to the tomato plants.

Effects of Salt Mixtures on Accumulations of Salts in the Plants

A further study with tomato plants in sand culture attempted to define the effect of those same waters upon the accumulation in the plant of several of the inorganic elements essential to both plant and animal nutrition, and to interpret these effects both as they are involved in the mechanism of salt toxicity and as they are related to animal nutrition. This study has been reported elsewhere (24). In general, it emphasized the effect of factors affecting transpiration and respiration in modifying salt injury to tomatoes, since it was conducted from October, 1940, to February, 1941, whereas preceding studies had been conducted during summer months when temperature, light, and humidity conditions were much different. The results also showed that irrigation with salt contaminated waters may cause the production of food materials having reduced contents of calcium, phosphorus, and manganese. In all cases the nitrogen content was reduced. Although the reduction was not always marked, it indicates a general reduced nutritive value, which in turn suggests that the crops so grown would probably be of inferior feeding value.

Summary of Tomato Experiments

1. The coordinated effects of temperature, light, humidity, transpiration and respiration as they influence salt absorption must be considered in adequately defining salt toxicity. Salt absorption and therefore salt injury, parallels the transpirational and respirational processes of the plants.

2. Salt toxicity is apparently due to the high ionic concentration, reduction in availability and/or absorption of other ions, and the effect of the induced pH. The pH toxicity exceeds the other toxic factors with $NaHCO_3$; with other salts the pH effect is subordinate.

3. The greater the number of potential ions for equal weight concentrations of the salts used the greater the comparative toxicity of the respective salts to tomato plants.

4. The order of decreasing toxicity of salts to tomatoes was $NaHCO_3$, NaCl, $MgCl_2$, $CaCl_2$, Na_2SO_4, $MgSO_4$.

5. Sulphuric acid was the best for neutralizing $NaHCO_3$ waters.

EXPERIMENTS WITH OTHER GREENHOUSE PLANTS

The experiments with tomatoes outlined certain salt effects upon this particular plant; however, the literature and information from growers indicated that each plant is an individual problem. Accordingly, salt toxicity experiments were conducted for several other greenhouse plants.

Geraniums

Geranium plants were propagated from cuttings and later transferred to the six-inch pots used in conducting the experiment. The soil used and general procedure were the same as for tomatoes. The results obtained are presented graphically in Figures 14 to 19.

Certain general observations can be made on these experiments:

1. Injury was first evidenced by yellowing and dying of the lower leaves, progressing upwards as the degree of injury increased.

2. The water consumption of all plants treated with salt solutions was decreased.

FIG. 14.—NaCl

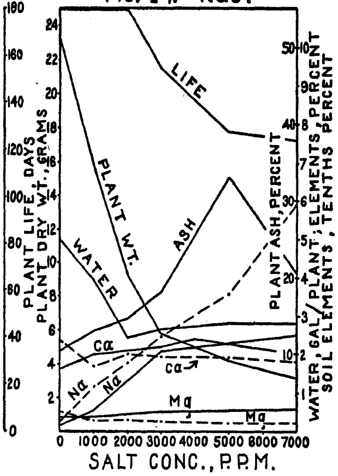


FIG. 15. NaHCO3

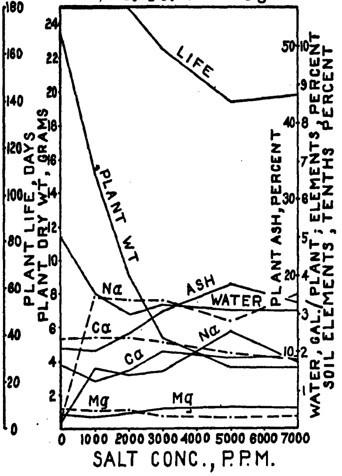


Fig. 16.—MgCl2

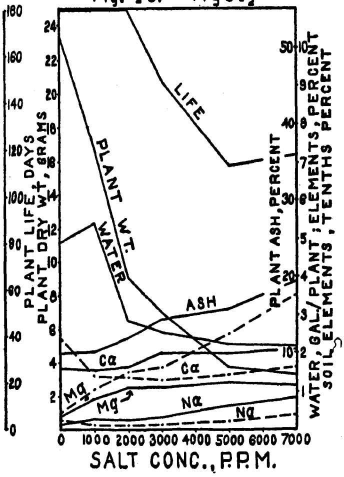


FIG. 17.—MgSO4

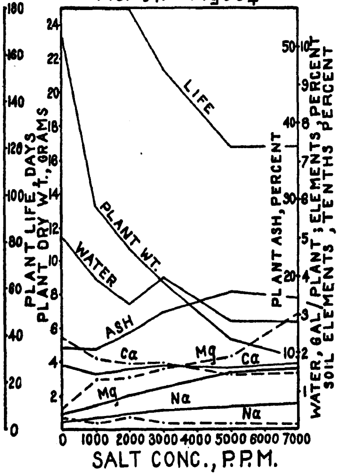


FIG. 18.—$CaCl_2$

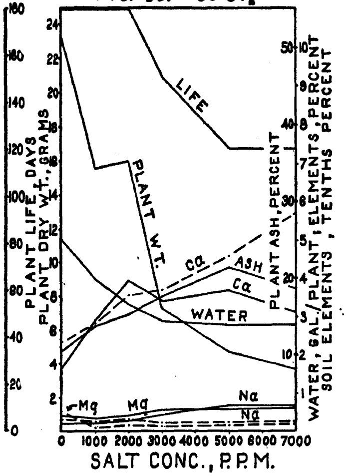
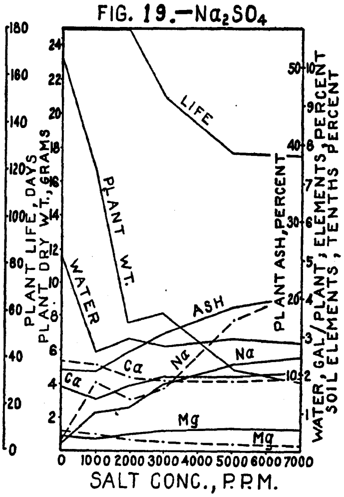


FIG. 19.—Na_2SO_4



3. The reduction in dry weight, water consumption, and length of plant life were roughly parallel.

4. Toxicities tended to be evidenced by sharp gradients of plants dry weight, etc., with the first increments of increasing salt concentration, followed by a general leveling off of the curves at the higher concentrations and toxicities. This same effect was discussed in connection with the tomato experiments.

The order of decreasing toxicity to geranium plants of the salts used in these experiments as determined by the reduction in dry weight and the general appearance of the plants, was NaCl, $NaHCO_3$, $MgCl_2$, $MgSO_4$, Na_2SO_4.

Certain general salt effects were present in these experiments. Chloride salts, as with tomatoes, were more toxic than sulfates, and produced the typical yellow-green chlorosis. Sodium also tended to stimulate chlorotic effects. The sulphate, magnesium, and calcium ions produced less discoloration of the foliage, and in some instances and concentrations even darkened the leaves.

The individual effects of the various salts, briefly described, were:

NaCl (Figure 14) was highly toxic. The chlorotic effects were severe and evidenced quite early and at low concentrations. Production was markedly reduced and of a very low quality.

$NaHCO_3$ (Figure 15) was very similar to NaCl in the degree of toxicity, but less chlorosis was produced and the appearance of the plants was better.

$MgCl_2$ (Figure 16) toxicity caused a slightly less severe reduction in dry weight. The salt chlorosis was quite marked.

$MgSO_4$ (Figure 17) caused a more gradual reduction in weight. Chlorosis was not evidenced in the low concentrations, nor in the high concentrations until the plants were near death. The dark green color characteristically produced by $MgSO_4$ improved the appearance of the plants and considerably lessened the apparent toxicity.

$CaCl_2$ (Figure 18) produced less reduction of plant dry weight and a less chlorotic plant, particularly at low concentrations, than did $MgCl_2$. Ash, plant Ca, and soil Ca all showed considerable increase.

Na_2SO_4 (Figure 19) was still less sharply toxic. The appearance, although chlorotic, was not severely so at the lower concentrations, and the chlorosis of the high concentrations was evidenced less rapidly.

In this series of experiments, much the same ion effects as were noted with the tomato experiments were evident. Chloride and sodium ions are highly mobile and permeable to plant cell membranes, and tend to build up high concentrations of minerals in the plant. Sulfate, magnesium, and calcium are less mobile, do not pass through plant cell membranes readily, and have less tendency toward building up high mineral concentrations in the plant. The comparison of the curves for NaCl and Na_2SO_4 illustrates the marked effect of the sulfate ion in retarding and of the chloride ion in accelerating absorption. An examination of the NaCl, $MgCl_2$, and $CaCl_2$ curves demonstrates the relative effect of the Na, Mg, and Ca ions (Figures 12 to 17).

The order of toxicity indicated by a one-half reduction in plant dry weight, as determined from the smoothest cures, is as follows:

Salts in order of decreasing toxicity	Salt concentration reducing plant dry weight by .5
NaCl	1550
$NaHCO_3$	1550
$MgCl_2$	1600
$MgSO_4$	1800
$CaCl_2$	2000
Na_2SO_4	2100

The order and degree of salt toxicity are both different from the values reported for tomato plants in soil, i. e., $NaHCO_3$ is less toxic and $MgSO_4$ more toxic relative to the other salts, and the concentrations producing a one-half reduction in plant dry weight are considerably less.

Calendulas

In a continuation of the work on the varietal differences in salt toxicity, a series of Golden Ball and Lemon Queen varieties of calendulas was grown in sand culture. Five-inch plants were transplanted into quartz sand in six-inch clay pots and watered with the nutrient solution previously described, plus the experimental salts added to the concentrations indicated. The results are presented graphically in Figures 20 to 25.

The order of decreasing toxicity in these experiments was $MgSO_4$, $NaHCO_3$, NaCl, Na_2SO_4, $MgCl_2$, $CaCl_2$.

$MgSO_4$ (Figure 20) the most toxic to calendulas of the salts used, produced the characteristic dark green coloration of foliage, but stunted growth very markedly and killed plants at a relatively low concentration. Flowering was inhibited, the plants were small, and the leaf growth distorted. Leaf scorch developed along the edges and in spots. At higher concentrations of $MgSo_4$, the leaf burn developed until the plants were completely killed early in the experiment.

$NaHCO_3$ (Figure 21) while very toxic, as evidenced by stunted growth and reduced dry weight of plants, did not inhibit flowering nor cause leaf burn so severely as did $MgSO_4$. The sharp increase in plant Na, the slight increase in ash, and the reduction in Ca and Mg is demonstrated in the figures.

FIG. 20. $MgSO_4$ TOXICITY CALENDULAS – SAND

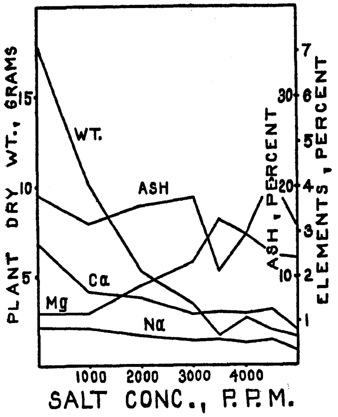


FIG. 21.–$NaHCO_3$ TOXICITY CALENDULAS – SAND

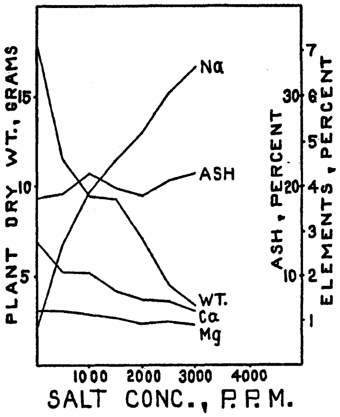


FIG. 22.–NaCl TOXICITY CALENDULAS – SAND

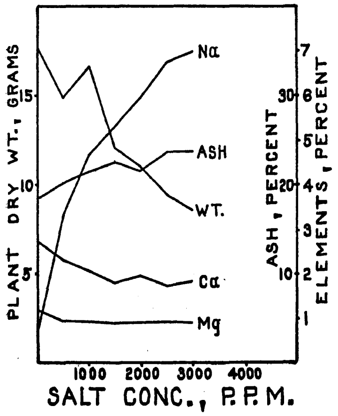
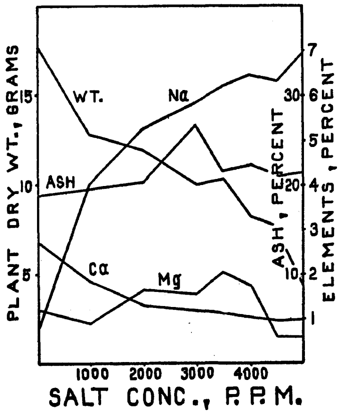


FIG. 23. Na_2SO_4 TOXICITY CALENDULAS – SAND



NaCl (Figure 22) produced a less sharp reduction in plant growth than did either $MgSO_4$ or $NaHCO_3$. as evidenced by plant dry weight. The greater permeability of the Na and Cl ion is shown by the very great increase in plant Na, a larger increase in ash, and graded reduction in Ca and Mg.

Na_2SO_4 (Figure 23) produced a less severe reduction in plant growth than did the salts thus far considered. Na_2SO_4 produced somewhat distorted type of leaf growth and induced leaf burn to some extent, but neither symptom was severe.

$MgCl_2$ (Figure 24) toxicity was not severe. The plants were somewhat chlorotic, and leaf burn was evident in the higher concentrations, but the gradation in appearance was not sharp.

FIG. 24. $MgCl_2$ TOXICITY CALENDULAS - SAND

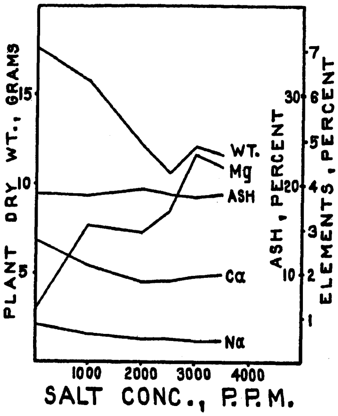
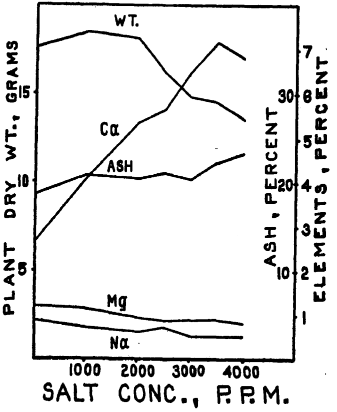


FIG. 25. $CaCl_2$ TOXICITY CALENDULAS - SAND



$CaCl_2$ (Figure 25) was the least toxic to calendulas of the salts studied. In appearance, the plants receiving the lower concentrations of $CaCl_2$ were equal to the controls. The higher concentrations exhibited the usual leaf burn and stunted growth, but in less severity and later than with the other salts.

The previously reviewed effects of the various ions upon the permeability of the plant cell membranes and the absorption of ions by the plants were also followed by the calendulas. The variances in absorption due to the various ions may be observed by examining the graphs of the analytical results.

The order of toxicity and the weight reduction value are tabulated below:

Salts in order of decreasing toxicity	Concentration of salt causing .5 reduction dry weight
$MgSO_4$	1500
$NaHCO_3$	2000
NaCl	3000
Na_2SO_4	4000
$MgCl_2$	4500 (exterpolated)
$CaCl_2$	Not approached

The order of toxicity is different from that obtained for either tomatoes or geraniums. The differences in the toxicities characteristic of the individual salts are particularly marked, and vary considerably more than the differences between these salts with the other plants studied.

Chrysanthemums

Toxicities of the various salts to chrysanthemums were determined by growing them in sand cultures. The techniques previously described were followed. The growth and analytical results are presented graphically in Figures 26 to 31.

The order of decreasing toxicity in this experiment was $NaHCO_3$, NaCl. Na_2SO_4, $CaCl_2$ $MgCl_2$, $MgSo_4$.

FIG. 26. $NaHCO_3$ TOXICITY CHRYSANTHEMUMS-SAND

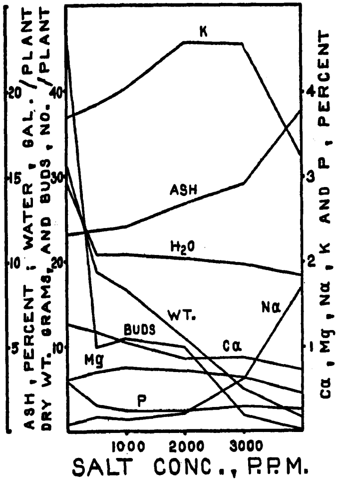


FIG. 27.—NaCl TOXICITY CHRYSANTHEMUMS-SAND

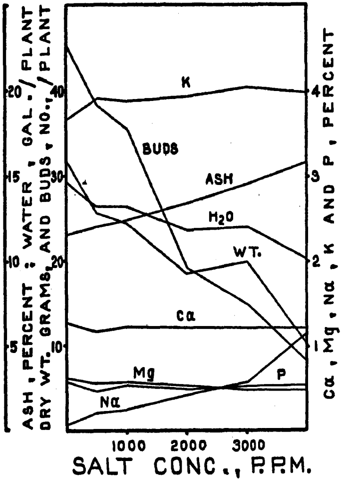


FIG. 28. Na_2SO_4 TOXICITY CHRYSANTHEMUMS-SAND

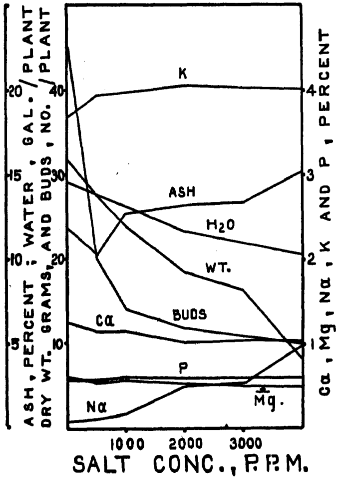
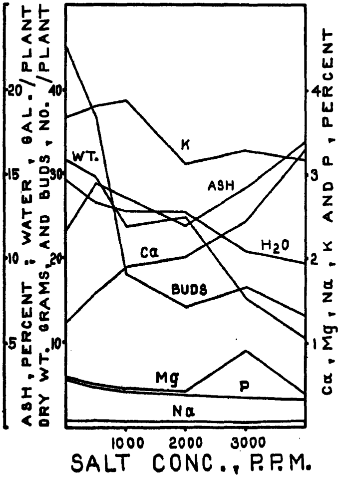


FIG. 29. $CaCl_2$ TOXICITY CHRYSANTHEMUMS-SAND



$NaHCO_3$ (Figure 26) demonstrated an extreme toxicity. Plant dry weight droped sharply and quite regularly to a very low value. The number of buds, included as a measure of production, dropped very sharply and to only a small fraction of the control value. The plants exhibited yellow chlorosis at as low a concentration as 1000 p. p. m., were extremely stunted and chorotic at 2000 p. p. m., and completely dead at 3000 p. p. m.

NaCl (Figure 27) was quite toxic to chrysanthemums. The plant dry weight decreased to a low value with increasing concentrations of NaCl. Plant ash increased very regularly but not sharply. The number of buds

FIG. 30.–$MgCl_2$ TOXICITY CHRYSANTHEMUMS-SAND

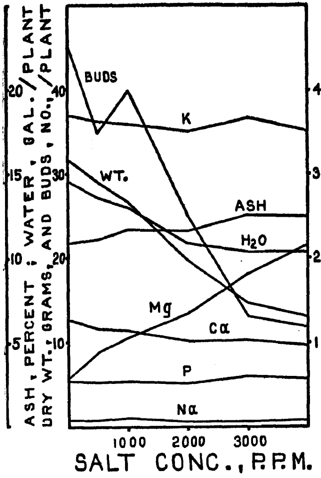
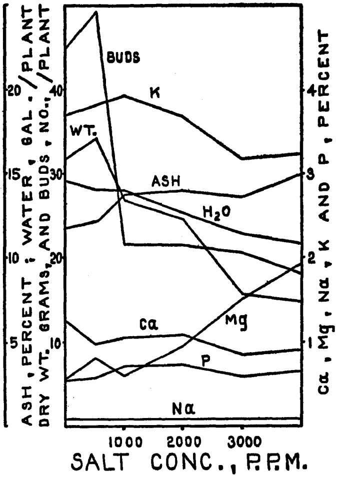


FIG. 31. $MgSO_4$ TOXICITY CHRYSANTHEMUMS-SAND



decreased quite sharply with increments of added NaCl, but the decrease was both less and more regular than for $NaHCO_3$. The appearance of the plants was marred by a chlorosis, first appreciable at about 1500 p. p. m., and becoming severe at 3000 p. p. m.

Na_2SO_4 (Figure 28) demonstrated a considerable toxicity. Plant dry weight dropped more regularly and to a lesser degree than did the corresponding curve for $NaHCO_3$. While growth was decreased to about the same degree as with NaCl, the appearance of the plants was much better. Chlorosis was not evident until a concentration of about 2000 p. p. m. was reached, and was not at all severe at 4000 p. p. m.

$CaCl_2$ (Figure 29) did not cause as great a decrease in plant dry weight as did the other salts discussed. The number of buds decreased quite sharply to a low value that remained essentially constant with $CaCl_2$, while the plant growth was stunted in proportion to the concentration, the general appearance of the plants was quite good. Even at the high concentration of 4000 p. p. m., with very little growth, there was no chlorosis or dying of leaves.

$MgCl_2$ (Figure 30) exhibited less toxicity than the previous salts discussed. Plant dry weight decreased quite regularly to a low value, but the gradient of the curve was less than for the other salts. The number of buds decreased, but not so sharply as with the four more toxic salts. Growth was not stunted as severely, particularly at the higher concentrations, as with $CaCl_2$, but there was appreciable chlorosis at 3000 and 4000 p. p. m.

$MgSO_4$ (Figure 31) demonstrated the least reduction in plant dry weight of the salts. The number of buds formed increased slightly, and then fell abruptly to an essentially level value. Growth was stunted, but not nearly as sharply as with other plants, and the color was an excellent dark green at all concentrations.

In the appearance, SO_4, Ca, and Mg ions seemed to inhibit or reduce chlorosis, and even to deepen the green color of the foliage. This was again particularly noticeable with $MgSO_4$.

The toxicity as determined by the previously described dry weight is as follows:

Salts in order of decreasing toxicity	Concentration p. p. m. of salts causing a .5 reduction in dry weight
$NaHCO_3$	1200
$NaCl$	3000
Na_2SO_4	3000
$CaCl_2$	3100
$MgCl_2$	3200
$MgSO_4$	3800

It is evident that there is no significant variation in the stunting of growth between $NaCl$, Na_2SO_4, $CaCl_2$, and $MgCl_2$. $NaHCO_3$ is definitely highly toxic and $MgSO_4$ much less toxic than the other salts. From $NaCl$ to $MgCl_2$ the salts are ranked on the basis of their effect upon the general appearance of the plants.

Carnations

Carnations are a major greenhouse crop, and have growth characteristics different from most other crops. In the carnation experiments, a flower production record was kept as a criterion of the toxicity of the individual salts. The average diameter and length, as well as number of blooms, were recorded to afford some indication of quality as well as quantity. The usual growth and analytical data were also recorded. All information is presented in Table III.

From an examination of the data for flower production, certain facts stand out. Water containing 1000 p. p. m. of $CaSO_4$ produced somewhat more flowers than did the control, and the flowers were of equal quality. With saturated $CaSO_4$ there was a very slight reduction in both number and quality of flowers. $NaHCO_3$ solutions produced comparatively slight toxicity in 1000 p. p. m., exhibiting no appreciable reduction in either number or quality of flowers; and at 3000 p. p. m. of $NaHCO_3$ the toxicity was much less than the toxicity of 1000 p. p. m. of $MgCl_2$, $CaCl_2$ or $NaCl$. Carnations prefer an alkaline growth medium (pH), and the acid hydrolizing salts are also the most toxic. The order of decreasing toxicity of the salts used is $MgCl_2$, $CaCl_2$. $NaCl$, $MgSO_4$, $NaHCO_3$, $CaSO_4$, based upon the data presented in Table III and the general appearance of plants and flowers.

A subsequent experiment was outlined with carnations to determine if the toxic effects of some of the salts used could be in part alleviated by supplementary treatment. In this experiment the same general order of toxicity as that of the previous experiment was obtained. $MgCl_2$ had been indicated to be the most toxic of the single salts, and was therefore used as the basis of the considerable variety of treatments intended to alleviate toxicity. The general outline of the experimental procedure is listed in Table IV, page 29.

No satisfactory alleviation of toxicity was demonstrated by any treatment. The only benefit that was at all appreciable was secured by manuring the soil. It was concluded, on the basis of both carnation experiments that carnations are rather insensitive to salts in general, but that they prefer a definitely alkaline growth medium, and that relatively heavy liming might be beneficial. Optimum fertilization was indicated as being the only alleviatory treatment of value.

TABLE III.—Analyses of Carnation Plants and Soil, and Flower Production of Carnations.

Salt Treatment		Plant Dry Wt. (g./plt)	Water consumption (g./plt)	FLOWER PRODUCTION			PLANT ANALYSIS (Percent of dry plant)				SOIL ANALYSIS (Percent of dry soil)			
				Ave. no. per plant	Ave. Diam. (inches)	Ave. Stem length (inches)	Ash	Ca	Mg	Na	Ca	Mg	Na	Sol. solids
Control		20.4	4.83	8.50	2.50	19.5	12.16	1.69	.60	.31	.21	.062	.028	.23
1000 p. p. m.	$MgCl_2$	22.9	3.42	4.42	1.95	13.4	13.50	2.23	1.25	.20	.23	.128	.031	.81
2000 p. p. m.	$MgCl_2$	20.2	3.00	2.50	1.90	13.0	14.61	2.01	1.68	.20	.22	.227	.029	1.07
3000 p. p. m.	$MgCl_2$	15.1	2.66	1.83	1.95	10.8	14.62	2.06	1.79	.23	.21	.268	.024	1.38
1000 p. p. m.	$CaCl_2$	23.2	3.75	5.41	2.33	15.7	14.77	2.57	.64	.24	.28	.056	.025	1.01
2000 p. p. m.	$CaCl_2$	20.8	3.33	5.50	2.05	12.6	16.03	3.41	.71	.25	.36	.056	.031	1.16
3000 p. p. m.	$CaCl_2$	17.8	2.66	2.25	1.76	10.0	17.06	4.10	.79	.27	.40	.045	.028	1.18
1000 p. p. m.	NaCl	18.7	3.25	5.66	2.20	16.8	14.57	2.08	.73	1.03	.23	.072	.151	1.02
1000 p. p. m.	NaCl	15.1	3.25	4.75	1.98	10.8	16.68	2.23	.75	1.68	.23	.052	.219	1.41
3000 p. p. m.	NaCl	14.5	3.00	4.58	1.85	10.5	15.99	2.03	.75	1.73	.21	.060	.226	1.45
1000 p. p. m.	$MgSO_4$	26.2	4.66	7.75	2.32	16.6	14.60	1.47	1.04	.18	.22	.190	.028	.90
2000 p. p. m.	$MgSo_4$	26.6	4.91	6.33	2.56	16.8	14.97	1.24	1.16	.15	.21	.222	.023	1.35
3000 p. p. m.	$MgSo_4$	29.4	4.42	7.83	2.20	15.0	12.86	1.18	2.53	.20	.19	.259	.022	1.80
1000 p. p. m.	Na_2SO_4	18.8	4.00	7.83	2.43	19.7	13.39	1.52	.64	.84	.20	.079	.114	.82
2000 p. p. m.	Na_2SO_4	19.5	3.92	8.41	2.26	19.1	13.17	1.43	.55	1.23	.23	.059	.223	1.59
3000 p. p. m.	Na_2SO_4	17.1	4.00	7.25	2.21	15.9	14.41	1.56	.57	1.69	.22	.061	.326	2.23
1000 p. p. m.	$NaHCO_3$	21.2	4.50	8.50	2.48	18.5	13.17	1.67	.55	.91	.19	.053	.089	.40
2000 p. p. m.	$NaHCO_3$	18.0	3.92	8.08	2.36	18.7	12.61	1.45	.52	1.43	.20	.051	.169	1.01
3000 p. p. m.	$NaHCO_3$	16.0	3.92	7.75	2.23	16.8	13.60	1.56	.53	1.77	.20	.049	.215	1.02
1000 p. p. m.	$CaSO_4$	22.9	4.66	9.58	2.50	19.3	13.28	1.82	.55	.25	.28	.055	.028	.79
1750 p. p. m.	$CaSO_4$ (sat.)	22.3	4.91	8.17	2.48	18.5	13.25	1.94	.53	.24	.37	.043	.026	1.12

Primulas

Considerable trouble is frequently encountered in growing primulas, and especially with salt waters. Soil cultures therefore were run to outline the effects of the various salts on this plant. The salts previously used were employed, including series in which $NaHCO_3$ was neutralized with H_2SO_4, HNO_3, H_3PO_4, and sulfur. Plant dry weight, water consumption, and the appearance of the plants are presented in Table V, page 30.

It is evident from examination of the table that with few exceptions, the dry weight of the plants was not affected severely. The principal symptom of salt toxicity was the appearance of leaf burn, which seemed characteristic of primulas. Accordingly, notes on the appearance of the plants have been incorporated in the table. The salts are arranged in order of decreasing toxicity, with the general appearance of the plants as the principal criterion of rating.

TABLE IV.—Effects of Alleviatory Treatments on Toxicity of Salts to Carnations.

TREATMENT		
Toxic salt and conc. (p. p. m.)	Alleviatory treatment per 8 gal. solution	GENERAL EFFECTS
$MgCl_2$, 2000		¶ The toxicity of $MgCl_2$ was quite evident. There was no appreciable improvement in those carnations to which the alleviatory treatments were applied. Fertilization produced a slight improvement, but comparison with the appearance of a fertilized control plot showed that the improvement probably could not be attributed to an alleviation of salt toxicity.
$MgCl_2$, 2000	$NaHCO_3$ 15 g.; $CaSO_4$ 30 g.	
$MgCl_2$, 2000	$CaCO_3$ 5 g.; $CaSO_4$ 30 g.	
$MgCl_2$, 2000	$CaCO_3$ 5 g.; soil fertilized	
$MgCl_2$, 2000	Sulfur 5 g.	
$MgCl_2$, 2000	$CaSO_4$ 30 g.	
$MgCl_2$, 2000	Urea 5 g.	
$CaCl_2$, 2000		¶ The toxicity of $CaCl_2$ was quite evident. Fertilization had the same efffect as with $MgCl_2$.
$CaCl_2$, 2000	$CaCO_3$ 5 g.; soil fertilized	
$CaCl_2$, 2000		
NaCl, 2000		¶ The toxicity of NaCl was quite evident. Fertilization had the same effect as with $MgCl_2$.
NaCl, 2000	$CaCO_3$ 5 g.; soil fertilized	
NaCl, 2000		
Na_2SO_4, 3000		¶ The toxicity of Na_2SO_4 was quite evident. Fertilization had the same effect as with $MgCl_2$.
Na_2SO_4, 3000	$CaCO_3$ 5 g.; soil fertilized	
Na_2SO_4, 3000		
$MgSO_4$, 3000		¶ The toxicity of $MgSO_4$ was quite evident. Fertilization had the same effect as with $MgCl_2$.
$MgSO_4$, 3000	$CaCO_3$ 5 g.; soil fertilized	
$MgSO_4$, 3000		
$MgCl_2$, 5000	$CaSO_4$ 50 g.;	¶ Toxicity moderately severe. Alleviation very slightly effective.
$MgCl_2$, 5000	$CaCO_3$ 15 g.	
NaCl, 5000	$CaSO_4$ 50 g.;	¶ Toxicity moderately severe. Alleviation very slightly evident.
NaCl, 5000	$CaCO_3$ 15 g.	
$NaHCO_3$, 5000		¶ Toxicity moderately severe. Alleviation very slightly evident.
$NaHCO_3$, 5000	$MgSO_4 . 4H_2O$; 5 g.	

TABLE V.—Effects of Salt Water on Primulas.

SALT TREATMENT				
Salt	Salt conc. (p.p.m.)	Water per plant (Liters)	Plant dry wt. (grams)	PLANT APPEARANCE
Control		4.6	5.8	
$NaCl$	100	4.4	5.8	Slight chlorosis evident.
$NaCl$	200	3.4	4.6	Further chlorosis; leaf burn evident.
$NaCl$	500	3.8	5.0	Leaf burn severe.
$NaCl$	1000	2.6	4.0	Leaf burn very severe and appeared early. Plant died.
$NaCl$	2000	2.2	1.4	Leaf burn extremely severe; plant killed early.
$CaCl_2$	200	4.2	5.4	Slightly poorer than controls.
$CaCl_2$	500	4.0	4.2	Definitely stunted. Leaf burn evident.
$CaCl_2$	1000	3.0	4.8	Leaves severely burned, appearance bad.
$CaCl_2$	2000	2.8	3.6	Leaves severely burned, growth stunted, appearance bad.
$NaHCO_3$ + Sulfur	500	4.2	4.6	¶ Appearance and growth were essentially equal to the controls. At 1000 and 2000 p. p. m. growth was slightly stunted and leaf burn was evident. Appearance at all concentrations was poorer than straight $NaHCO_3$, and at high concentrations particularly so.
$NaHCO_3$ + Sulfur	1000	4.4	4.2	
$NaHCO_3$ + Sulfur	2000	3.8	3.8	
$NaHCO_3$ + H_3PO_4	500	4.2	4.6	¶ Appearance and growth essentially equal to controls. At 1000 p. p. m. growth was slightly stunted and leaf burn was evident. At 2000 p. p. m. growth was considerably stunted and leaf burn was severe.
$NaHCO_3$ + H_3PO_4	1000	3.4	4.8	
$NaHCO_3$ + H_3PO_4	2000	2.8	2.8	
$MgSO_4$	200	4.2	5.8	Excellent appearance. Darker color than controls.
$MgSO_4$	500	3.8	5.4	Darker color, but slight leaf burn and distorted growth.
$MgSO_4$	1000	4.0	5.0	Leaf burn and distorted growth further progressed.
$MgSO_4$	2000	3.8	6.6	Leaf burn more evident, not severe.
$NaHCO_3$ + H_2SO_4	500	3.8	5.2	¶ Growth about equal to the controls at all but 2000 conc., where growth was somewhat stunted. Color good at all conc., but some tendency for leaf burn at 1000 and 2000 p. p. m.
$NaHCO_3$ + H_2SO_4	1000	4.2	5.6	
$NaHCO_3$ + H_2SO_4	2000	3.2	5.0	

TABLE V.—Concluded.

SALT TREATMENT		Water per plant (Liters)	Plant dry wt. (grams)	PLANT APPEARANCE
Salt	Salt conc. (p. p. m.)			
$NaHCO_3$ + HNO_3	200	4.4	7.8	¶ Growth accelerated by NO_3 to 500 p. p. m. then decreased, and stunted at 2000 p. p. m. Color darker than controls and appearance excellent to 1000 p. p. m., where leaf burn first appeared. At 2000 p. p. m. leaf burn was severe.
$NaHCO_3$ + HNO_3	500	4.4	8.4	
$NaHCO_3$ + HNO_3	1000	4.2	7.8	
$NaHCO_3$ + HNO_3	2000	3.0	4.6	
$MgCl_2$	200	4.8	5.4	Slightly lighter color and poorer general appearance than control.
$MgCl_2$	500	3.4	4.4	Some chlorosis and leaf burn evident.
$MgCl_2$	1000	3.6	5.4	Some chlorosis and leaf burn evident.
$MgCl_2$	2000	3.4	5.0	Some chlorosis and leaf burn evident.
$CaSO_4$	500	3.8	5.8	¶ Growth not appreciably stunted at any concentration. Appearance good. Color excellent. Maturing of plants somewhat slowed.
$CaSO_4$	1000	4.2	5.2	
$CaSO_4$	1750*	4.0	5.6	
$NaHCO_3$	200	4.8	6.2	¶ Color and appearance were better than controls at all concentrations. Slight tendency toward leaf burn at 2000 p. p. m. but not severe. Growth improved to 500 p. p. m.; 1000 and 2000 p. p. m. were at least equal to controls.
$NaHCO_3$	500	4.4	6.2	
$NaHCO_3$	1000	3.6	5.2	
$NaHCO_3$	2000	4.0	5.4	
Control		4.6	5.8	

* Saturated.

The order of toxicity thus determined was NaCl, $CaCl_2$, $MgSO_4$, $NaHCO_3$ + H_3PO_4, $NaHCO_3$ + sulfur, $MgCl_2$ $NaHCO_3$ + HNO_3, $CaSO_4$, $NaHCO_3$. Those plants treated with $NaHCO_3$ which was neutralized with HNO_3 were larger and better appearing than the controls. Those receiving 2000 p. p. m. had severe leaf burn. $CaSO_4$ plants were of very excellent color and clean healthy appearance, of about the same size as the controls. No leaf burn was evident. Plants receiving $NaHCO_3$ solutions were larger than the controls, had an excellent dark green color, and a particularly healthy appearance. Both $CaSO_4$ and $NaHCO_3$ could be considered to have helped rather than harmed the plants in this experiment. These results are different from those obtained in other plants. Apparently primulas are sensitive to acid and very tolerant toward alkali. Chloride and sodium ions are indicated as being of great toxicity.

Poinsettias

Poinsettias have a particular susceptibility to adverse growth conditions in that they tend to drop leaves from the stem, and the formation of the bracts is affected. The experimental setting was the same as that followed for primulas. St. Louis, Paul Eck, and Oak Leaf variety poinsettias were used.

The same type of record was taken as with primulas, and the results of the experiment are presented in Table VI.

TABLE VI.—Toxicity of Alkaline Waters to Poinsettias.

SALT TREATMENT		(p.p.m.) Water per plant (Liters)	Plant dry wt. (grams)	PLANT APPEARANCE
Salt	Salt Conc.			
Control		11.3	28	
$NaHCO_3$	200	10.6	28	¶ Toxicity graded quite sharply from 200 p. p. m. At 200 p. p. m. the plants were about as well leafed as the controls and had comparable bracts. At 2000 p. p. m., the plants were practically leafless and the bracts were about ½ the diameter of the controls. Chlorosis was evident.
$NaHCO_3$	500	7.8	21	
$NaHCO_3$	1000	7.0	13	
$NaHCO_3$	2000	6.0	7	
$NaHCO_3$ + H_2SO_4	500	9.2	23	¶ The toxicity was slightly less sharply graded than the unneutralized $NaHCO_3$, but very comparable. There were a few more leaves and the color was slightly better.
$NaHCO_3$ + H_2SO_4	1000	7.6	23	
$NaHCO_3$ + H_2SO_4	2000	5.8	12	
$NaHCO_3$ + H_3PO_4	500	9.6	19	¶ Appearance and results very similar to unneutralized $NaHCO_3$.
$NaHCO_3$ + H_3PO_4	1000	7.4	19	
$NaHCO_3$ + H_3PO_4	2000	5.4	6	
$NaHCO_3$ + HNO_3	500	9.4	24	¶ Practically the same results as described for H_2SO_4. NO_2 had deepened the green color somewhat.
$NaHCO_3$ + HNO_3	1000	7.6	13	
$NaHCO_3$ + HNO_3	2000	7.2	11	
$NaHCO_3$ + Sulfur	200	9.2	24	¶ About the same as the unneutralized $NaHCO_3$ plants, but fewer leaves were dropped.
$NaHCO_3$ + Sulfur	500	8.8	19	
$NaHCO_3$ + Sulfur	1000	7.8	14	
$NaHCO_3$ + Sulfur	2000	7.0	10	

TABLE VI.—Concluded.

SALT TREATMENT				
Salt	Salt conc. (p. p. m.)	Water per plant (Liters)	Plant dry wt. (grams)	PLANT APPEARANCE
$MgCl_2$	200	10.8	25	¶ Plants became regularly more slender, more chlorotic, and dropped more leaves with increasing concentration, 2000 p. p. m. practically bare. Bracts slightly smaller at 200 p. p. m. and about ½ diameter of controls at 2000 p. p. m.
$MgCl_2$	500	9.6	26	
$MgCl_2$	1000	9.0	17	
$MgCl_2$	2000	7.6	15	
NaCl	200	10.4	26	¶ Plants became regularly more slender. dropped more leaves, and the size of the bracts graded to ½ the diameter of the controls with increasing concentration to 2000 p. p. m. 2000 p. p. m. had approximately ⅓ the number of leaves of controls. Chlorosis was evident but not severe.
NaCl	500	10.6	24	
NaCl	1000	8.4	19	
NaCl	2000	7.0	9	
$CaCl_2$	200	11.0	28	¶ Plants were all shorter than the controls. Regular gradation in chlorosis, which, however, was never severe. 200 p. p. m. had about the same and 2000 p. p. m. had about ½ the number of leaves of controls. Bracts slightly affected at high concentration.
$CaCl_2$	500	11.4	26	
$CaCl_2$	1000	9.4	23	
$CaCl_2$	2000	8.8	18	
$MgSO_4$	200	11.2	25	¶ Plants became regularly more slender, more chlorotic, and dropped more leaves with increasing concentration. Color was good at all concentrations. Bracts at 2000 p. p. m. about ¾ the diameter of controls. Others proportional.
$MgSO_4$	500	10.2	26	
$MgSO_4$	1000	10.2	24	
$MgSO_4$	2000	7.8	17	
$CaSO_4$	200	11.0	28	¶ Plants all shorter than controls but better leafed. Excellent color at all concentrations. ⅓ more leaves than controls at 200 p. p. m., decreasing to about the same at 2000 p. p. m. Bracts at 1000 and 2000 p. p. m. about ⅔ diameter of controls; others the same.
$CaSO_4$	500	10.4	32	
$CaSO_4$	1000	9.8	29	
$CaSO_4$	1750*	10.0	28	

* Saturated.

The order of toxicity, with general appearance as the principal criterion, was $NaHCO_3$, $NaHCO_3 + H_2SO_4$, $NaHCO_3 + H_3PO_4$, $NaHCO_3 + HNO_3$, $NaHCO_3$ + sulphur, $MgCl_2$, NaCl, $CaCl_2$, $MgSO_4$, $CaSO_4$. There was very little difference between any of the $NaHCO_3$ series, either neutralized or unneutralized, and all these series were quite definitely poorer in appearance than those watered with the other salts used. From $MgCl_2$ to $CaCo_4$ there was a regular gradation of toxicity which was, however, not great.

It appears evident from these experiments that sodium ion is quite toxic to poinsettias, and that these plants are also sensitive to alkali. Chloride ion seems next in toxicity.

GENERAL RESULTS AND CONCLUSIONS

An examination of the preceding tables, figures, and data point to certain outstanding facts. Waters containing excessive amounts of dissolved salts and alkalis are always toxic to all varieties of plants. The removal of these salts from the water or the counteracting of their toxicity beyond limited ranges is difficult or impossible. In the case of alkalis considerable improvement can be made by proper neutralization of the alkalinity. Beyond these generalities each plant, each soil, and each salt solution requires a special consideration, as it appears that plants' tolerance to salts and alkalinity vary widely and even this tolerance is very much influenced by temperature, light, humidity, transpiration, and respiration.

Among all these experiments, there were certain differences and common factors that aid in a better understanding of the symptoms of salt toxicity and in formulating general statements and applications of the results obtained.

There were many irregularities in the results, explained probably by the fact that a plant's absorbing mechanism is dependent upon so many factors. Relatively minor changes in the effective concentration of an ion added to the effects of the added salt upon the ionization, solubility, or complex formation of other salts present, may produce a considerable distortion of the mechanism for salt absorption and a consequent marked effect upon the plant. Trends have been established, however, that are regular, reproducible, and significant; and it is upon these trends the following conclusions are based.

The relative order of toxicity of the various salts to the plants used in the experiments seemed to be definitely characteristic of each plant. The orders of toxicity are tabulated for comparison in Table VII. The respective toxic concentrations of the salts, as determined by reduction in dry weight, are listed for those experiments in which this appeared to be a reliable index of toxicity. In the carnation experiment the cutting of flowers made the dry weights valueless, and the relative toxicities of the salts are best estimated from the flower records presented in Table III. With both primulas and poinsettias the dry weights were erratic, and appearance was a more significant index of toxicity.

RECOMMENDATIONS

Knowing that many Oklahoma waters are salty or alkaline, and that such waters may be injurious to plants, a chemical analysis should be procured and considered before choosing a site for a greenhouse. If the water is not found to be free of objectionable materials, and if no other source is available, then a study of the possibility of correcting these troubles must be considered from a chemical and an economic standpoint. In some cases, only stored rain water can be resorted to.

TABLE VII.—Order of Toxicity of Salt Waters to Greenhouse Plants.

Plant	Salts in order of decreasing toxicity (left to right); and toxic concentration (p. p. m.)						
Tomatoes	$NaHCO_3$ 1750	$NaCl$ 2000	$MgCl_2$ 2300	$CaCl_2$ 3000	Na_2SO_4 3500		
Geraniums	$NaCl$ 1550	$NaHCO_3$ 1550	$MgCl_2$ 1600	$MgSO_4$ 1800	$CaCl_2$ 2000	Na_2SO_4 2100	
Calendulas	$MgSO_4$ 1500	$NaHCO_3$ 2000	$NaCl$ 3000	Na_2SO_4 4000	$MgCl_2$ 4500	$CaCl_2$ Not reached	
Chrysanthemums	$NaHCO_3$ 1200	$NaCl$ 3000	Na_2SO_4 3000	$CaCl_2$ 3100	$MgCl_2$ 3200	$MgSO_4$ 3800	
Carnations	$MgCl_2$	$CaCl_2$	$NaCl$	$MgSO_4$	Na_2SO_4	$NaHCO_3$	$CaSO_4$
Primulas	$NaCl$	$CaCl_2$	$MgSO_4$	$MgCl_2$	$CaSO_4$	$NaHCO_3$	
Poinsettias	$NaHCO_3$	$MgCa_2$	$NaCl$	$CaCl_2$	$MgSO_4$	$CaSO_4$	

A determination of the total solids in the water will indicate if the concentration falls within the safety limit of a particular type of plant, and the determination of pH and a qualitative test of the proportion of the various salts and the ions present will permit a rather accurate estimation of the relative toxicity of this water and the possibilities of correcting the undesirable factor. Whether a water is very good or very bad can then be definitely stated. With waters of the rather broad intermediate group, the variations in toxicities that have been illustrated for various plants, and the effects of environmental factors on these plants, make accurate recommendations very difficult.

Nearly neutral waters having a total solids content of 200 p. p. m. are excellent sources for greenhouses With waters of 500 p. p. m. total solids, difficulty will be encountered only with the more susceptible plants and under relatively unfavorable conditions. Waters of 1000 p. p. m. can generally be used satisfactorily, although the type and distribution of salts present will have a modifying effect, and particularly susceptible plants may cause considerable trouble. The sensitivity of plants to adverse environmental conditions will also be increased. Many waters containing 2000 p. p. m. of total solids are in use. More care in the selection of plant varieties is necessary and the effect of adverse conditions is more marked; effects are particularly troublesome during the hot summer months. 2000 p. p. m. is not at all desirable, but it can be used.

Waters containing 200 p. p. m. bicarbonates or less will seldom cause difficulties, and then only with plants susceptible to a high pH. The toxicity of this type of water then increases sharply with increasing concentration. 500 p. p. m. is probaly as high a concentration as could be tolerated for general use without neutralization. Carnations and primulas grew very well at 1000 p. p. m. of $NaHCO_3$, while chrysanthemums and tomatoes were very definitely affected by 500 p. p. m.; this illustrates the variance in toxicity that may be obtained. Various acids may be used to neutralize such waters, but in these tests sulfuric acid proved to be the most effective.

In view of the demonstrated variance in the sensitivity of plants to alkaline waters, it may be preferable to neutralize only the water that is used on plants that are sensitive to a high pH. Plants exhibiting a preference for a high pH may even grow better with moderately alkaline waters; for example, carnations and primulas appeared better than the controls at 500 p. p. m. of $NaHCO_3$. The expense and trouble of neutralizing a considerable quantity of water could thus be avoided.

No satisfactory means has been found to appreciably reduce the toxicity of high salt waters. Distillation is far too costly. Permutite type water softeners merely replace Ca and Mg with Na, and water thus treated is converted in the direction of a single salt water having Na as the predominating positive ion; single salt waters have been demonstrated to be more toxic than mixed salt waters of equal concentration, and Na ion is generally more toxic than Ca and/or Mg. A greenhouse man would, therefore, pay the cost of softening to obtain a water supply worse than he originally had.

A man may thus be faced with the problem of successful production using waters containing appreciable quantities of salt and/or black alkali. This entails careful application of several principles:

1. Water heavily at less frequent intervals than would be done with a supply of pure water. This tends to prevent salt accumulation and to leach accumulated salts from the soil. It should be appreciated that nutrient minerals may also be leached, and fertilization thus be made necessary.

2. Keep the soil as moist as is consistent with good plant growth, and prevent concentration of salts in the soil solution by evaporation.

3. If possible, select a "heavy" type of soil containing considerable organic matter. Such soils are more effective than light soils in buffering salt toxicity.

4. High transpiration accentuates salt toxicity. Therefore better net results may possibly be obtained by keeping the temperature lower and the humidity higher than would be done with normal waters, as transpiration would thus be reduced.

5. Extra care in establishing growing conditions as nearly perfect as possible is desirable. The effect of any errors in fertilization, pH, etc., are accentuated by salt waters.

6. Select plant varieties that are the most tolerant to the pH and salts of the water available.

7. With waters whose toxicity is predominately due to a high pH, neutralize to the correct pH for the plants it is used on.

8. This attention to detail also results in finer production when normal waters are available.

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