TOXICITY OF SALINE AND ALKALINE WATERS TO CERTAIN GREENHOUSE PLANTS.

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TO CERTAIN GREENHOUSE PLANTS

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Bachelor of Science

Kansas State College

Manhattan, Kansas

1938

Submitted to the Department of Chemistry

Oklahoma Agricultural and Mechanical College

In Partial Fulfillment of the Requirements

For the degree of

MASTER OF SCIENCE

1940

APPROVED:

Director of Research

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ACKNOWLEDGEMENT

The author wishes to express his appreciation to Dr. V. G. Heller for his assistance and supervision, and to Mr. F. L. Hartman of the Horticulture Department, for his cooperation and assistance in the greenhouse work.

INTRODUCTION

Due to the high salt concentration and varied nature of the saline and alkaline waters of Oklahoma, considerable importance is attached to the study of the injurious effects of these waters on typical greenhouse plants. An abundant supply of water of low salt concentration is one of the major factors in successful greenhouse production. Waters of this type are very limited in Oklahoma, because of the fact that deposits of gypsum, magnesium sulfate, salt, and sodium bicarbonate which underlie large areas of this state contaminate the wells, springs and streams. Much work has been done to determine the toxic concentrations of saline and alkaline waters in field irrigation, but these results cannot be safely applied to greenhouse problems where frequent watering, rapid evaporation and continous production result in a rapid increase in the salt concentration of the soil. The purpose of this experiment was to determine the concentrations at which various alkaline and saline waters are toxic to typical greenhouse plants and to determine whether any of the salts employed have a beneficial antagonistic action when mixtures of the salts are used in the treatments.

REVIEW OF LITERATURE

Many phases of salt toxicity are discussed in a detailed review of the literature by Ahi and Powers (1). A few facts pertinent to this experiment will be given here.

Hilgard (16) distinguishes between two types of alkali: (a) "white alkali", which includes one or more of such salts as sodium chloride, sodium sulfate, sodium nitrate, magnesium sulfate, magnesium chloride or calcium chloride; and (b) "black alkali", which usually consists mainly of sodium carbonate. "Black alkali" is more destructive, generally, than "white alkali".

Toxic Limits for Salinity

The limits of plant tolerance for sodium carbonate, sodium chloride, and sodium sulfate, as reported by Hilgard (16) are 0.1 to 0.25, 0.3 to 0.5, and 0.5 to 1.0 per cent, respectively. The results of Hibbard (15) show that much smaller amounts of various salts may be very injurious in some instances, while in other cases, larger amounts will produce little effect. Harris (8) states that more than o.5 per cent soluble salts where chlorides, nitrates, or carbonates predominate, and 1.0 per cent of salts predominantly sulfates, were unsuited for crop production without reclamation. Bancroft (2) found that the following salt concentrations killed bean plants:

Magnesium chloride.....2640 p.p.m.
Sodium carbonate.......2710 p.p.m.
Sodium chloride........3600 p.p.m.
Sodium nitrate.........3700 p.p.m.
Sodium sulfate.........6510 p.p.m.
Sodium bicarbonate....12300 p.p.m.

His results indicate that magnesium chloride is the most toxic and sodium bicarbonate is the least toxic of the salts studied.

Brezaeale (4) also places magnesium chloride as the most toxic of the salts occurring in alkali soil. He also states that the limit of tolerance of a plant to an alkali depends on the composition of the soil solution at the wilting point of the plant and not upon the percentage of salts in the dry soil. On the other hand, Kearney (19) believes that salines can be classified only on the basis of percentages of salt referred to the dry weight of the soil. He classifies salinity into seven grades depending on the percentage of salts. For white alkali, he placed the critical concentration at 1.0 per cent for most staple field crops and 0.3 per cent for most crops.

Hilgard (16) stated that the presence of salts in quantities as low as 200 to 300 p.p.m. is harmful to legumes. He places the limit for growth at about 1650 p.p.m. of total salts; at about 300 p.p.m. of sodium carbonate; and at about 1390 p.p.m. of sodium sulfate. Headly, Curtis and Scofield (13) found that sodium carbonate added to the soil and allowed to remain several weeks is only partly recovered with the water extract of the soil. The limit of tolerance of crops to salt which killed half of the young wheat seedlings was 0.04 per cent for sulfates.

Harris and Pittman (11) have pointed out the discrepancy between the amount of added alkali salts and the amount which may be recovered in the water extract after such additions.

Krone and Weinard (20) grew various common flowers, which were treated with solutions of sodium chloride containing 100, 200, 500, 1000 and 2000 p.p.m.. It was found that the 200 p.p.m. and stronger solutions reduced the growth of the plants, the reduction being greater as the concentrations increased. The findings of Berg and Zimmerman (28) agree in a general way with those of Krone and Weinard.

Harris and Pittman (10) grew a variety of crops in loam soil in tumblers and found that when salts were added to the soil in higher concentrations than 4000 p.p.m. of chlorides, 8000 p.p.m. of carbonates, and 12,000 p.p.m. of sulfates satisfactory yields of ordinary crops could not be obtained. With some crops, marked reduction in yield was brought about by much lower concentrations than these.

Harris and Butt (9) concluded that the use of irrigation water containing 500 p.p.m. of sodium carbonate, or more than 1000 p.p.m. of sodium chloride or over 4000 p.p.m. of sodium sulfate was harmful after two or three years or less. A mixture of these salts was less harmful than the most toxic individual salt, although more than 4000 p.p.m. of salt mixtures proved to be dangerous.

Lipman and associates (21) who used solution cultures to grow barley, peas and beans, found that these plants were highly resistant to sodium chloride. They state that low concentrations (500 to 1000 p.p.m.) may depress growth, while higher concentrations (4000 p.p.m.) may stimulate it. Plants made some growth at concentrations as high as 10,000 p.p.m. of sodium chloride.

From a practical standpoint a good criterion of the tolerance of a plant for alkali, according to Neidig and Magnuson (25), is the capacity of that plant to grow to maturity and produce good yields rather than its response during the germination period only.

Factors Influencing Plant Tolerance

It is a commonly recognized fact that mixtures of salts are often less injurious than the individual salts. Kearney and Harter (18) observed the fact that calcium sulfate diminishes the toxicity of magnesium and sodium salts. Harris and his associates (9), (12) recorded similar observations. They (12) state however, that 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 (i.e. other salts used to reduce the toxicity of sodium carbonate) rather than any antagonistic action on the sodium carbonate." They found barnyard manure to be an effective amendment on soils containing 2000 p.p.m. or less of sodium carbonate and further state that calcium sulfate in combination with manure and sulphur was the most effective corrective used, particularly on the more toxic black alkali soils.

Harris (7) reported that only about half as much alkali is required to prohibit the growth of plants in sand as in loam. Harris and Pittman (11) concluded that loam soil may be successfully farmed at a higher alkali content than others, and recommended that alkaline soils be kept as moist as was compatible with good plant growth.

Both Means (24) and Scofield (27) suggest the desirability of using liberal quantities of water where it was necessary to apply water containing considerable quantities of soluble salts. Scofield found that sufficient water should be used to leach the root zone and thus carry away the salts left by the evaporated water. In other words, the greater the salt content of the irrigation water, the larger the quantities of the water that should be used in irrigation.

Lipman (21) believes that the effects of sodium chloride upon plants may be conditioned by the climatic conditions of temperature, light and humidity. Ahi and Powers (1) showed that temperature plays an important role in salt injury.

Breazeale (4) contends that toxicity is the function of both molecules and ions. He is of the opinion that the tolerance of a plant to the ion or molecule depends on the number of times the plant has come in contact with alkali in that form during their long period of adaptation. Harris (7) states that the anion, not the cation determines the toxicity of alkali in the soil and that injury is not so marked in soils as in solution cultures.

Although osmotic pressure has been assigned an important role in salt toxicity by Greaves and Lund (6), they conclude that toxicity is not entirely due to osmotic pressure, but that it is partly due to a physiological action of the substances upon the protoplasm, changing its chemical and physiological properties so that it cannot function.

PROCEDURES

Plants

The tomato plants used in this experiment were of the Marglobe variety. The plants were sprouted from seeds in flats, and later transferred to four-inch pots. When the plants were from four to six inches high they were transplanted into soil filled six-inch porous clay pots and the experimental watering initiated. The soil used in these experiments was composed of loam and compost which were mixed in a quantity sufficient to last the duration of the experiment.

Plants of uniform size were divided into groups, each of which was watered with a different salt solution. The salts used were sodium, magnesium and calcium chloride, sodium, magnesium and calcium sulfate and sodium bicarbonate. Rain water was used to make the solutions, the concentrations of which were varied by the addition of 250 to 7000 p.p.m. of the different salts. Control groups were watered with rain water. The plants were watered frequently to keep them moist, but never with quantities large enough to cause leaching of the soil. Pot saucers were used to guard against loss of water.

In the first experiment, the toxic concentration of each of six single salt solutions was determined by watering plants with solutions whose concentrations varied from 250 to 7000 p.p.m.. The salts used were sodium, magnesium and calcium chloride, sodium and magnesium sulfate, and sodium bicarbonate. Later experiments were carried out using solutions composed of double, tertiary and quaternary mixtures of these six salts and of calcium sulfate to determine whether any of the salts decreased toxicity or induced beneficial antagonism.

Geranium plants of General Grant variety were propagated from cuttings in two-inch pots and later transferred to six inch pots, in which they were treated with the saline solutions. The division of the plants into groups, the soil used, the method of preparing the solutions and their applications were similar to the methods used in the tomato studies, with the exception that salts mixtures were not used.

Records were made of the amounts of solutions used, the general appearance of the plants, the length of life, and the dry weights of the plants. Chemical analyses were made of the plants and soils.

Sampling

The plants were clipped off at the ground level when dead or at the termination of the experiment. After partial drying in a dehydrator, the samples were placed in a drying oven at 105° C. for twenty four hours, at the end of which time they were weighed. Each sample was ground through a 1 m.m. screen in a Wiley mill, redried

ground through a 1 m.m. screen in a Wiley mill, redried

and stored for analysis.

The soils were removed from the pots, crushed, screened and mixed, then powdered in a Braun mill, dried and stored.

Method of Analysis

Plant samples were weighed in platinum dishes and ashed in a muffle furnace at 500° C. for twenty-four hours, then cooled and weighed. The residue was treated with 10 ml. of hydrochloric acid, heated to boiling and evaporated to dryness on a steam bath, then redissolved with 10 ml. (1-1) hydrochloric acid and heated to boiling. It was then filtered and washed with hot water. The residue and filter paper were placed in a weighed crucible and ignited in the muffle to determine silica by weight. The filtrate was analyzed as follows: sodium was determined by a method devised by Barber and Kolthoff (3), calcium by the McCrudden method (23), and magnesium by the Loomis and Shull procedure (22). Soil samples were prepared for analysis as described by Schollenberger and Dreibelbis (26). The resultant filtrate was analyzed for sodium, calcium, and magnesium as previously described.

TABULATION AND DISCUSSION OF RESULTS

TOMATOES

The plants in these experiments were uniform and in excellent condition at the beginning of the experiment. Growth of the plants was rapid at first and the salt injuries appeared slowly. All plants treated with high concentrations of salts, but expecially those which received sodium bicarbonate, exhibited salt injuries first. These injuries manifested themselves in various ways, the most predominant characteristic was the yellowing and dying of the lower leaves. As the injury became more pronounced, the upper leaves and branches were affected. The continued addition of the salt solutions caused these conditions to move progressively to the plants treated with the lower concentrations.

Some general observations of both plant and soil conditions are listed as follows:

1. The plants receiving high concentrations of salts soon stopped growing, the leaves turned yellow and began to fall, their growth was stunted and they died earlier than those receiving lower concentrations.

2. A dark green color was maintained by plants receiving sodium and magnesium sulfate until injury was very pronounced.

3. Leaves of plants treated with chloride salts turned yellowish green, became very turgid, later rolled and then died.

4. In all cases where injury was noted the amount of water utilized by the plants was reduced.

5. Plants which were treated with solutions of salts or salt mixtures did not wilt as readily as the controls.

6. The soil receiving sodium bicarbonate developed a thick, black top crust, while that treated with sodium and magnesium sulfate turned white.

7. The observed order of decreasing toxicity was as follows: $NaHCO_3$, NaCl, $CaCl_2$, $MgCl_2$, Na_2SO_4 and control.

It may be observed by referring to the tables that these plants were not all grown in the same season. There is, however, a surprising agreement in view of the variations of temperature, humidity, light intensity and other factors.

The reduction of dry weight of the plant is the best criterion of salt injury in that it is indicative of plant growth and reactions and can be accurately measured. In this work the amount of salt expressed in parts per million which would reduce the dry weight of the experimental plants to half the dry weight of the control plant, was established as the toxic concentration. This toxic concentration is not an invariable value and should be used only in a general manner to evaluate the toxicity of saline and alkaline waters.

Treatment with Single Salt Solutions

A discussion of the effects of each of the various salts will be given in order of their decreasing toxicity, which is shown in Table I.

TABLE I. TOXIC LIMITS OF TOMATO PLANTS

Salt	Salt conc. of solution - p.p.m.
$NaHCO_3$	1750
NaCl	2000
$MgCl_2$	2300
$CaCl_2$	3000
Na_2SO_4	3500
$MgSO_4$	4000

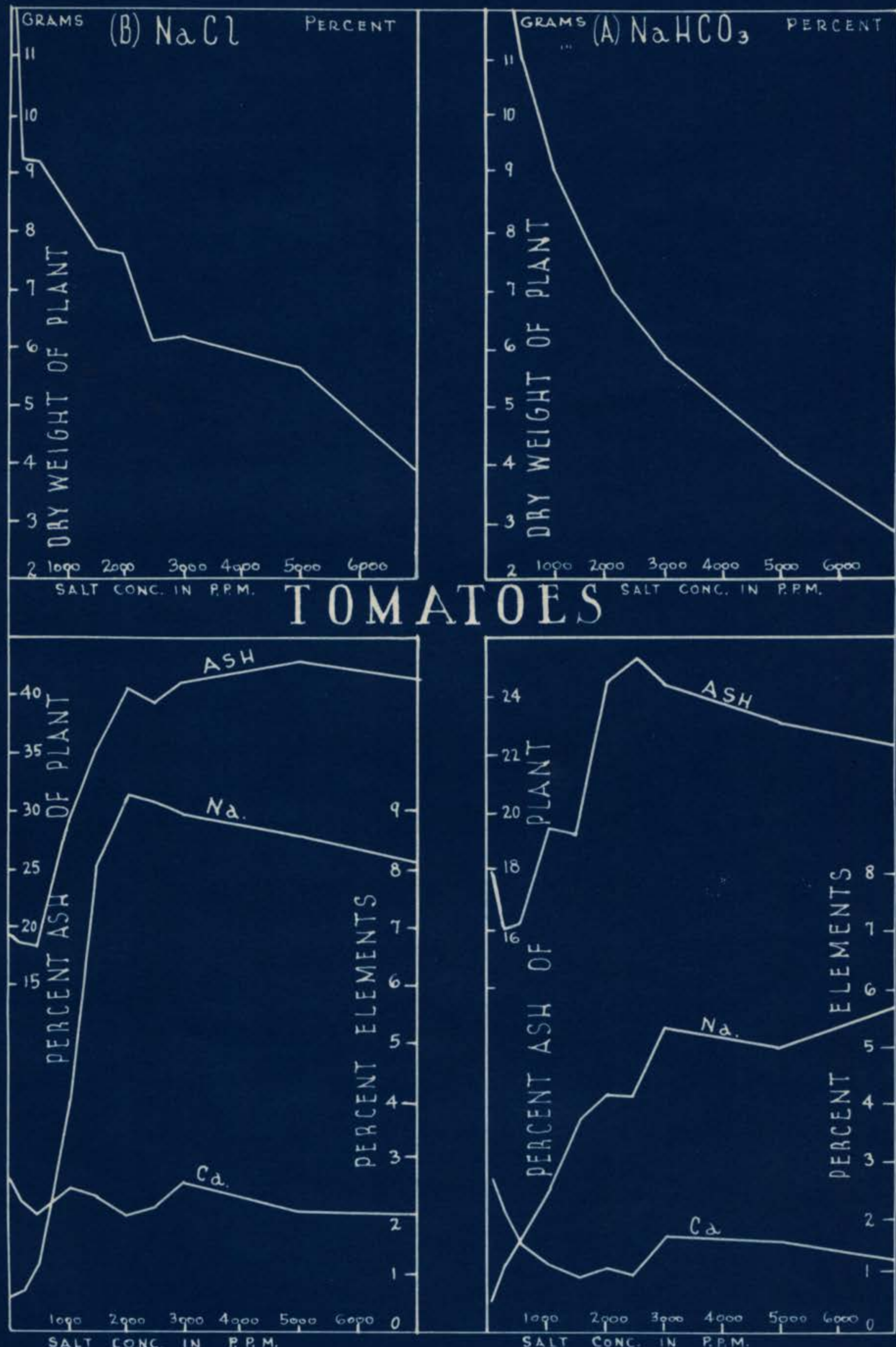
$NaHCO_3$ The results of the experimental treatment of the tomato plants watered with sodium bicarbonate solutions are given in Table II. It will be observed that the application of high concentrations of the alkali salt caused the plants to die quickly and that the water consumption of the plants was inversely proportional to increased concentrations of the salt solutions applied. The dry weight of the plant was sharply decreased by the addition of low (250-500 p.p.m.) concentrations of the alkali salt, as is shown by Figure 1 (A). At a concentration of 1750 p.p.m., the toxic point, the dry weight of the plant was reduced to half that of the control. The addition of small amounts of sodium bicarbonate produced a decrease in the ash content of the plants but above 1000 p.p.m. the ash content increased sharply and then decreased.

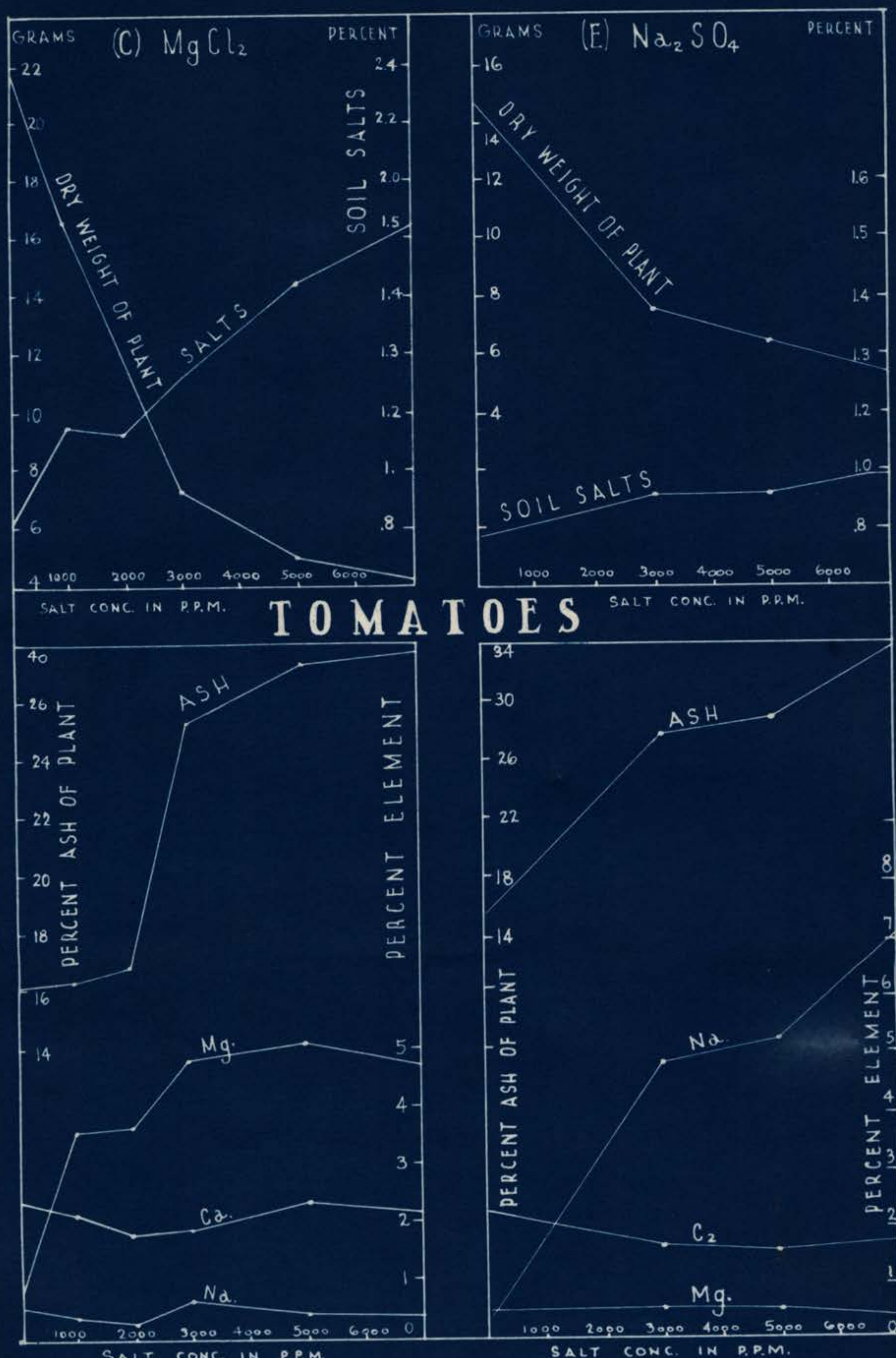
The decrease in the ash content of the plants which were watered with high concentrations of salt may be explained by the increased pH values in the soil. This condition would tend to produce insoluble mineral compounds which were not readily available to the plant. The sodium content increased rapidly and continously as the concentration of the salt solutions was increased until the salt application reached a concentration of 3000 p.p.m., but from 3000 to 7000 p.p.m. the sodium content of the plant tended to decline from its maximum value. The calcium content of the plant was decreased from one-third to one-half that of the control in nearly all cases. This decrease in calcium my be attributed to the increased

FIGURE I. Graphs showing the Dry Weight of Tomato Plants, their percentage of Ash and Constituents of Ash, and the Soil Salts.*

(dry basis)

* The sum of the percentages of calcium chloride, magnesium sulfate, and sodium chloride calculated from the amounts calcium, magnesium and sodium found in the soil.


TOMATOES
(B) NaCl
(A) $NaHCO_3$
GRAMS
PERCENT
DRY WEIGHT OF PLANT
11
10
9
8
7
6
5
4
3
2
1000 2000 3000 4000 5000 6000
SALT CONC. IN P.P.M.
PERCENT ASH OF PLANT
PERCENT ELEMENTS
ASH
Na.
Ca.
40
35
30
25
20
15
24
22
20
18
16
9
8
7
6
5
4
3
2
1
0



(C) $MgCl_2$
GRAMS
PERCENT
DRY WEIGHT OF PLANT
SOIL SALTS
SALTS
SALT CONC. IN P.P.M.
(E) Na_2SO_4
GRAMS
PERCENT
DRY WEIGHT OF PLANT
SOIL SALTS
SALT CONC. IN P.P.M.
TOMATOES
PERCENT ASH OF PLANT
PERCENT ELEMENT
ASH
Mg.
Ca.
Na.
SALT CONC. IN P.P.M.
ASH
Na.
Ca
Mg.
PERCENT ASH OF PLANT
PERCENT ELEMENT
SALT CONC. IN P.P.M.

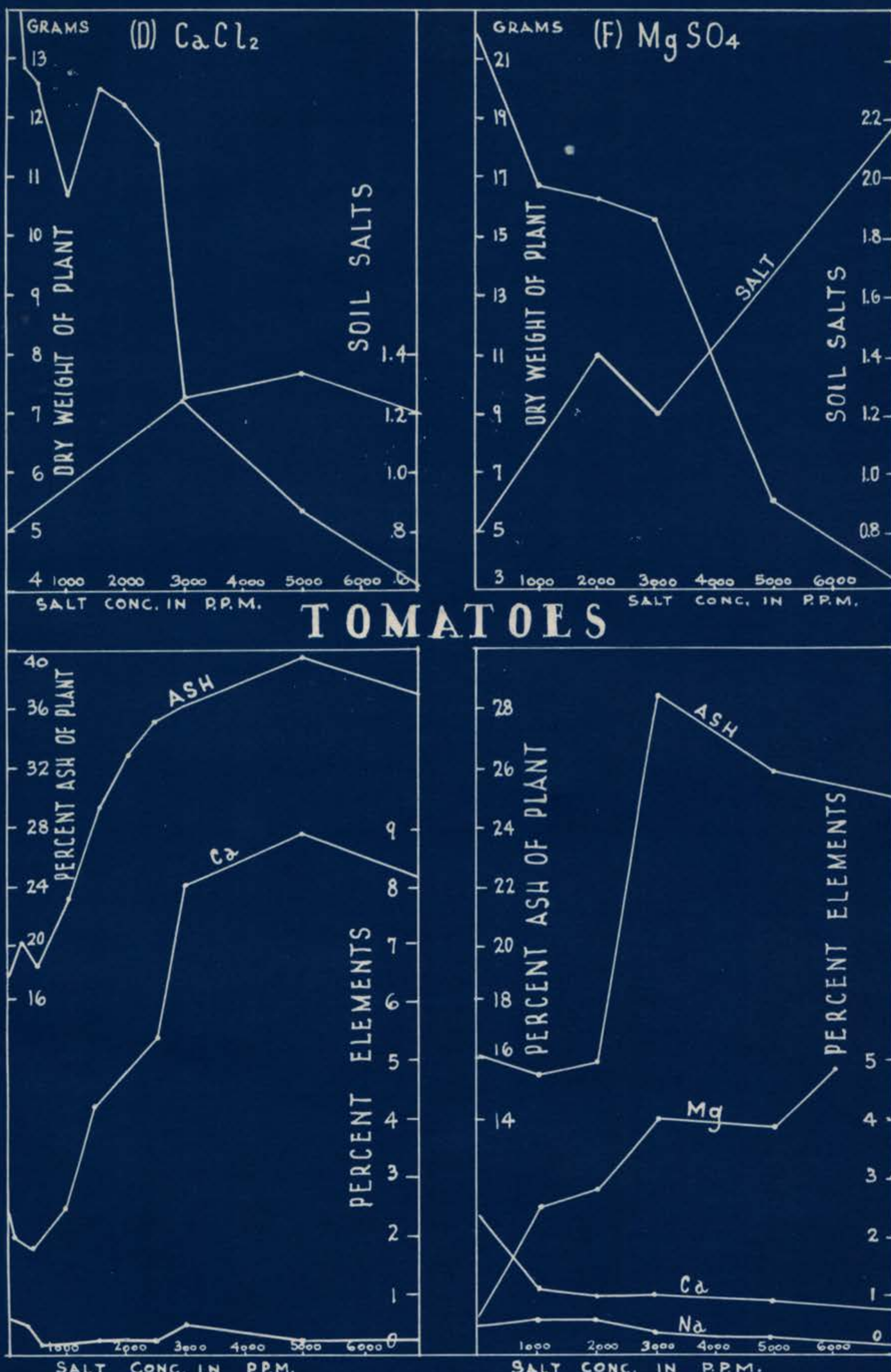

GRAMS
(D) $CaCl_2$
DRY WEIGHT OF PLANT
SOIL SALTS
SALT CONC. IN P.P.M.
GRAMS
(F) $MgSO_4$
DRY WEIGHT OF PLANT
SALT
SOIL SALTS
SALT CONC. IN P.P.M.
TOMATOES
PERCENT ASH OF PLANT
ASH
Ca
PERCENT ELEMENTS
SALT CONC. IN P.P.M.
PERCENT ASH OF PLANT
ASH
PERCENT ELEMENTS
Mg
Ca
Na
SALT CONC. IN P.P.M.

TABLE II. ANALYSIS OF TOMATO PLANTS WATERED WITH SINGLE SALT SOLUTIONS (dry basis)

Salt	Concentration P.P.M.	Experimental Period (days)	Water Consumption per plant (gallons)	Weight per plant (gms.)	% Ash	% Ca	% Na	% Mg
Control		151*	5.4	14.90 a	19.75	2.38	.515	.736
Control		198*	8.0	21.63 b	12.50	2.35	.429	.625
$NaHCO_3$	250	71*	3.1	12.25 a	16.00	2.10	1.15	
$NaHCO_3$	500	88*	3.9	10.96 a	16.36	1.58	2.49	
$NaHCO_3$	1000	99⊥	4.0	9.23 a	19.55	1.23	3.62	
$NaHCO_3$	1500	73⊥	3.4	8.09 a	19.14	0.95	4.08	
$NaHCO_3$	2000	47⊥	2.3	7.17 a	24.50	1.16	4.11	
$NaHCO_3$	2500	38⊥	1.9	4.46 a	25.34	1.02	5.30	
$NaHCO_3$	3000	78⊥	1.6	5.82 c	24.51	1.69	5.69	.56
$NaHCO_3$	5000	48⊥	.9	4.19 c	23.24	1.60	4.98	.61
$NaHCO_3$	7000	44⊥	.7	2.93 c	22.47	1.43	5.66	.65
NaCl	250	71*	3.3	9.25 a	17.89	2.26	.736	
NaCl	500	71*	3.2	9.23 a	17.24	2.02	1.22	
NaCl	1000	79⊥	3.6	8.42 a	28.38	2.50	3.95	
NaCl	1500	75⊥	3.5	7.72 a	35.47	2.29	7.96	
NaCl	2000	75⊥	3.4	7.61 a	40.67	2.03	9.30	
NaCl	2500	73⊥	3.1	6.12 a	39.15	2.16	9.13	
NaCl	3000	93⊥	2.3	6.18 c	40.81	2.57	8.92	.68
NaCl	5000	89⊥	2.1	5.67 c	42.99	2.07	8.52	.65
NaCl	7000	78⊥	1.5	3.86 c	41.65	2.00	8.14	.71
$MgCl_2$	1000	198⊥	5.8	16.60 b	16.20	2.13	.359	3.55
$MgCl_2$	2000	198⊥	4.6	12.00 b	16.91	1.72	.231	3.61
$MgCl_2$	3000	105⊥	2.2	6.14 b	25.35	2.06	.362	4.51
$MgCl_2$	3000	95⊥	1.9	7.28 c	25.37	1.79	.653	4.81
$MgCl_2$	5000	78⊥	1.5	5.02 c	27.21	2.38	.413	5.13
$MgCl_2$	7000	78⊥	1.5	4.14 c	27.66	2.13	.340	4.71

TABLE II (Continued)

Salt	Concentration p.p.m.	Experimental Period (days)	Water Consumption per plant (gallons)	Weight per plant (gms.)	% Ash	% Ca	% Na	% Mg
$CaCl_2$	250	88*	4.3	12.83 a	20.35	2.01	.347	
$CaCl_2$	500	71*	3.3	12.60 a	18.70	1.82	.196	
$CaCl_2$	1000	71*	3.6	10.65 a	23.52	2.55	.202	
$CaCl_2$	1500	88*	3.4	12.47 a	29.30	4.24	.321	
$CaCl_2$	2000	87⊥	3.9	12.23 a	33.05	4.89	.316	
$CaCl_2$	2500	77⊥	3.1	11.58 a	35.76	5.44	.339	
$CaCl_2$	3000	88⊥	2.0	7.31 c	36.25	8.02	.544	.57
$CaCl_2$	5000	86⊥	1.8	5.38 c	39.40	8.93	.305	.48
$CaCl_2$	7000	68⊥	1.6	4.13 c	37.22	8.22	.276	.54
Na_2SO_4	3000	98⊥	3.4	7.79 c	28.21	1.73	4.87	.65
Na_2SO_4	5000	101⊥	3.2	6.56 c	29.47	1.60	5.29	.60
Na_2SO_4	7000	99⊥	3.1	5.66 c	34.02	1.70	7.09	.53
$MgSO_4$	1000	198⊥	6.3	16.70 b	15.53	1.11	.650	2.53
$MgSO_4$	2000	198⊥	6.2	16.23 b	15.97	1.02	.631	2.82
$MgSO_4$	3000	141⊥	4.0	13.93 b	19.87	1.11	.271	3.25
$MgSO_4$	3000	139⊥	3.8	15.47 c	28.34	1.01	.417	3.97
$MgSO_4$	5000	126⊥	3.6	5.99 c	25.82	.95	.318	3.88
$MgSO_4$	7000	101⊥	1.7	3.45 c	24.96	.81	.229	4.73

* plants alive
⊥ plants dead
a plants grown in summer 1936
b plants grown in winter 1937
c plants grown in summer 1937

TABLE III. ANALYSIS OF SOILS WATERED WITH SINGLE SALT SOLUTIONS (Tomato)

Salt	Concentration p.p.m.	% Ca	% Na	% Mg	Sum of calculated salts - $CaCl_2$, $MgSO_4$ NaCl
Control		.205	.026	.046	.85
Control		.205	.024	.032	.78
$NaHCO_3$	250	.077	.036		
$NaHCO_3$	500	.073	.064		
$NaHCO_3$	1000	.082	.078		
$NaHCO_3$	1500	.076	.085		
$NaHCO_3$	2000	.068	.062		
$NaHCO_3$	2500	.056	.082		
$NaHCO_3$	3000	.208	.181	.043	1.25
$NaHCO_3$	5000	.217	.216	.041	1.35
$NaHCO_3$	7000	.185	.211	.031	1.20
NaCl	250	.086	.034		
NaCl	500	.092	.055		
NaCl	1000	.085	.099		
NaCl	1500	.087	.126		
NaCl	2000	.089	.158		
NaCl	2500	.097	.160		
NaCl	3000				
NaCl	5000				
NaCl	7000	.178	.50	.030	1.91
$MgCl_2$	1000	.141	.025	.142	1.15
$MgCl_2$	2000	.118	.019	.149	1.12
$MgCl_2$	3000	.168	.015	.253	1.76
$MgCl_2$	3000	.123	.027	.188	1.34
$MgCl_2$	5000	.145	.022	.241	1.65
$MgCl_2$	7000	.141	.025	.282	1.84

TABLE III. (Continued)

Salt	Concentration p.p.m.	% Ca	% Na	% Mg	Sum of calculated salts $Cacl_2$, $MgSO_4$, NaCl
$CaCl_2$	250	.117	.011		
$CaCl_2$	500	.149	.013		
$CaCl_2$	1000	.176	.015		
$CaCl_2$	1500	.189	.013		
$CaCl_2$	2000	.219	.013		
$CaCl_2$	2500	.248	.015		
$CaCl_2$	3000	.426	.018	.025	1.33
$CaCl_2$	5000	.476	.024	.019	1.47
$CaCl_2$	7000	.670	.025	.022	2.15
Na_2SO_4	3000	.154	.162	.023	.95
Na_2SO_4	5000	.131	.197	.017	.94
Na_2SO_4	7000	.139	.229	.020	1.06
$MgSO_4$	1000	.179	.019	.115	1.12
$MgSO_4$	2000	.190	.016	.167	1.39
$MgSO_4$	3000	.156	.015	.159	1.25
$MgSO_4$	3000	.160	.021	.137	1.17
$MgSO_4$	5000	.120	.019	.261	1.67
$MgSO_4$	7000	.139	.018	.353	2.17

pH values of the soil which favored the formation of insoluble caclium carbonate.

NaCl Table II and Figure 1 (B) show that high concentrations of sodium chloride did not cause a sharp reduction in the length of life of the plant, although increased concentrations of the salt decreased the water consumption of the plant.

The dry weight of the plant decreased very sharply in that 250 p.p.m. of the salt produced a reduction of over one-third that of the control. The toxic concentration of sodium chloride was found to be 2000 p.p.m..

The ash content of the plants treated witn sodium chloride increased very rapidly and in plants watered with high concentrations of salt solutions reached the exceedingly high value of twice that of the control plants The sodium content increased rapidly, the sharpest slope of the curve occurred between concentrations of 1000 to 2000 p.p.m. of the salt. The largest increment in the sodium content of the plants occurred at approximately the toxic concentration of the salt. The calcium content of the plants remained rather constant but was less than that of the controls. This does not agree with the work of Carolus (5) who found that the sodium ion was beneficial in the absorption of calcium by the bean plant.

$MgCl_2$ Plants watered with magnesium chloride solutions died earlier than the controls and consumed decreasing amounts of water as the concentration of the salt was increased.

Figure 1 (C) shows that the dry weight decreased rapidly with the application of magnesium chloride solutions up to a concentration of 5000 p.p.m.. The toxic comentration of this salt was 2300 p.p.m.. The ash content increased with the application of higher concentrations of magnesium chloride, the largest increment occurring between 2000 and 3000 p.p.m. of the salt. The magnesium content of the plant increased to six times that of the control with the application of a magnesium chloride solution containing 1000 p.p.m. of the salt, and reached even larger values with application of solutions which contained higher concentrations of the salt. The calcium and sodium content of the plants did not undergo marked changes as the salt concentration was increased.

<u>$CaCl_2$</u> Table II shows that treatment with calcium chloride solutions produced no uniform reduction in the length of life of the plant although it caused a rather gradual reduction in the water consumption. The growth curve represented by the dry weight of the plants in Figure 1 (D) shows irregularities but in all cases the weight of the control exceeded that of plants treated with the salt solutions.

A concentration of 3000 p.p.m. of calcium chloride solution proved to be toxic to the plant. The percentage of ash of these plants increased rapidly and maintained high values when treated with increased concentrations of the salt. The trend of the curve of the calcium percentages was similar to that of the ash content of the plant.

Plants treated with the three highest concentrations of calcium chloride had a calcium content three times that of the control plants. The sodium content was slightly depressed by the addition of calcium chloride.

Na_2SO_4 The sodium sulfate experiment revealed no marked changes in the length of life of the plant or in the water consumption of the plant as is illustrated by the data presented in Table II; Figure 1 (E) shows a gradual declination in the dry weight of the plant. The toxic concentration of sodium sulfate was 3500 p.p.m.. The ash content of the plants showed a gradual increase as the salt concentrations were increased.

It is interesting to note that plants treated with either the sodium ion, the chloride ion or both, had the highest percentages of ash, with the exception of magnesium chloride.

The sodium content of the plants increased rapidly with the increased concentrations of sodium sulfate and at 7000 p.p.m. of the salt reached a value fourteen times the sodium content of the controls. The calcium content of the plants was depressed by the addition of the salt. An explanation of this may be that the solubility of calcium sulfate is rather limited and the excess sulfate ion present in the solution favored the production of insoluble calcium sulfate which reduced the availability of the calcium to the plant. The magnesium content remained constant even with the application of the highest concentration of salts.

<u>$MgSO_4$</u> The application of increased concentrations of magnesium sulfate to the tomato plants produced a more gradual reduction in the growth of the plants than did the application of any of the other salts. This is shown by the plotted values of the dry weights in Figure 1 (F). The toxic concentration of magnesium sulfate was approximately 4000 p.p.m.. The ash content of the plants increased rapidly with the increased salt concentration of the solution applied, however above 3000 p.p.m. of the salt there was a slight decrease in the ash content. The magnesium content of the plants increased gradually and at its maximum value contained eight times the amount present in the control plants. The calcium content was depressed by the addition of increased amounts of magnesium sulfate. This can be explained by the relative insolubility of the calcium sulfate and by the fact that calcium and magnesium have similar properties and are closely related in the periodic table of elements. It is therefore possible that the plant may unselectively absorb the magnesium in preference to the calcium which is relatively unavailable. This latter explanation may be supported by the work of Hurd-Karrer (17) on unselective absorption.

The sodium content of the plants was slightly decreased by the application of magnesium sulfate.

Table III presents the percentage of calcium, sodium, and magnesium as found (by analysis) in the soil and the sum of the calculated percentages of calcium chloride, sodium chloride and magnesium sulfate. Figure 1 (C), (D), (E) and (F) shows the sums of these salts plotted against the increased salt concentrations of the different solutions. From these curves the toxic concentration of the sums of the soil salts can be evaluated from the established toxic concentrations of the salt solutions. The point of intersection of the ordinate of the toxic concentration of salt solutions and the soil salts curves gives the toxic percentages of soil salt.

A comparison of the toxic salt solution concentrations and the toxic percentages of soil salts is as follows:

Salt	Toxic salt solution concentration in p.p.m.	Toxic percentages of soil salts
$MgCl_2$	2300	1.18
$CaCl_2$	3000	1.26
Na_2SO_4	3500	.94
$MgSO_4$	4000	1.42

The rating of toxicity by the percentages of soil salts is in good agreement with the toxic rating of salt solution concentration, with the exception of sodium sulfate.

Using the methods of soil analysis previously described, and the same arbitrary standards for calculation of the soil salts this procedure may prove to be of value in determining whether or not a soil will permit successful greenhouse production.

Treatment With Salt Mixture Solutions (Tomatoes)

The data presented in Table IV are the experimental results obtained with tomatoes grown in soil and watered with various salt mixture solutions. The salt mixtures and their concentrations are arranged in the table in order of their increasing toxicity as measured by the dry weight of the plant. Table V presents the data giving the realts of the analysis of the soils in which these tomato plants were grown.

The following facts were observed from the results of this experiment.

(1) Magnesium sulfate was the least toxic of the salts used. High concentrations of magnesium sulfate in the salt mixtures caused less reduction in the dry weight of the plant than did equal amounts of other salt mixtures.

(2) Salt mixtures composed predominantly of one salt (3000 p.p.m.) were generally more toxic than those of equal concentrations that were composed of equal amounts of two or more salts.

(3) Sodium chloride toxicity was not appreciably reduced by the addition of other salts. Sodium chloride did not cause the plants to die quickly but it produced marked stunting of plant growth.

(4) Plants treated with salt mixtures which contained as one of its components 3000 p.p.m. of sodium bicarbonate had a short life period. Calcium sulfate produced a marked reduction in sodium bicarbonate toxicity when these two salts were used in a binary mixture.

TABLE IV. ANALYSIS OF TOMATO PLANTS WATERED WITH SALT MIXTURE SOLUTIONS

Experimental Period - March 26 to July 28, 1938

Salt and Conc. in Thousand p.p.m.	Duration of Expr. in da.	H_2O added per plant (gal.)	Dry Wt. Per plant	% Ash	% Ca	% Na	% Mg
Control	124*	6.5	15.89	24.48	2.86	.52	.787
3 $MgSO_4$ 1 $CaCl_2$	112	3.8	13.89	23.81	1.83	.53	4.23
1.5 $MgSO_4$ 1.5 Na_2SO_4	124*	3.8	13.45	33.92	1.36	3.68	2.02
3 $MgSO_4$ 1 Na_2SO_4	114	2.5	13.14	28.13	1.05	2.28	3.33
1.5 $MgSO_4$ 1.5 Na_2SO_4 1 $CaSO_4$	124*	4.0	11.75	29.74	1.78	3.74	2.38
1 NaCl 1 $CaCl_2$ 1 $MgCl_2$	113	3.3	11.34	40.24	5.68	5.09	1.25
1 NaCl 2 $CaCl_2$ 1 $CaSO_4$	108	3.3	10.30	43.92	8.54	3.62	.655
2 NaCl 1 $MgCl_2$ 1 $CaSO_4$	113	3.3	10.25	39.12	3.55	6.75	1.92
2 $CaCl_2$ 1 $MgCl_2$	112	3.5	9.99	38.07	7.93	.69	2.15
3 $MgSO_4$ 1 $CaSO_4$	100	2.7	9.86	29.27	1.30	.56	4.55
2 $CaCl_2$ 1 NaCl	110	3.5	9.52	44.94	8.25	.48	.734
2 $MgCl_2$ 1 NaCl 1 $CaSO_4$	113	2.7	9.32	36.55	3.55	3.82	3.62
3 $CaCl_2$ 1 Na_2SO_4	109	1.7	9.28	42.42	8.57	3.62	.907
1.5 NaCl 1.5 $CaCl_2$	107	1.8	8.98	40.66	6.36	5.09	.936
2 $MgCl_2$ 1 $CaCl_2$	117	3.7	8.75	32.84	5.13	.97	3.72
2 NaCl 1 $CaCl_2$ 1 $CaSO_4$	103	2.6	8.55	45.51	6.14	7.92	.712
2 $MgCl_2$ 1 $CaCl_2$ 1 $CaSO_4$	100	2.5	8.44	35.04	5.74	.52	2.96
2 $CaCl_2$ 1 $MgCl_2$ 1 $CaSO_4$	94	2.3	8.30	40.33	8.37	.46	2.03
3 Na_2SO_4 1 $CaCl_2$	117	3.5	8.28	39.51	2.49	9.58	.338
3 $NaHCO_3$ 1 $CaSO_4$	80	2.0	8.26	26.64	1.61	6.85	.635
3 Na_2SO_4 1 $CaSO_4$	115	2.7	8.03	39.48	1.64	9.18	.528
2 NaCl 1 $CaCl_2$	113	3.3	7.92	41.96	5.18	7.36	.664
1.5 $CaCl_2$ 1.5 $MgCl_2$ 1 $CaSO_4$	106	1.3	7.75	35.23	6.29	.59	2.08
2 NaCl 1 $MgCl_2$	112	3.3	7.55	36.78	2.31	7.21	2.26
1 NaCl 1 $CaCl_2$ 1 $MgCl_2$ 1 $CaSO_4$	113	3.2	7.37	38.26	5.75	3.70	1.70
1.5 $CaCl_2$ 1.5 $MgCl_2$	92	2.3	7.22	35.66	6.12	1.08	2.18

TABLE IV. (Continued)

Salt and Conc. in thousand p.p.m.	Duration of Expr. in da.	H_2O added per plant (gal.)	Dry Wt. Per Plant	% Ash	% Ca	% Na	% Mg
2 $MgCl_2$ 1 NaCl	106	2.7	6.97	32.32	2.36	3.06	3.49
3 NaHCO 1 $CaCl_2$	97	1.4	6.70	27.72	1.66	6.38	.645
3 $MgCl_2$ 1 Na_2SO_4	97	2.3	6.41	30.80	2.30	2.45	3.96
1.5 NaCl 1.5 $CaCl_2$ 1 $CaSO_4$	83	2.3	6.30	39.63	6.56	4.44	1.26
3 $MgCl_2$ 1 $CaSO_4$	77	1.7	6.17	31.21	3.97	1.04	4.36
3 $MgCl_2$ 1 $CaCl_2$	103	2.5	6.05	31.24	4.25	.59	4.02
3 NaCl 1 Na_2SO_4	104	2.7	5.99	41.57	2.27	10.09	.725
1.5 NaCl 1.5 $MgCl_2$	87	2.7	5.91	34.06	2.54	4.68	3.49
3 $CaCl_2$ 1 $CaSO_4$	67	1.5	5.62	40.44	9.67	.85	.884
1.5 NaCl 1.5 $MgCl_2$ 1 $CaSO_4$	75	1.9	5.40	46.72	2.68	11.28	.852
3 $NaHCO_3$ 1 Na_2SO_4	39	1.2	5.07	29.17	1.98	8.66	1.02
3 NaCl 1 $CaCl_2$	68	1.7	3.66	43.28	4.31	8.23	.859

* Only plants alive.

TABLE V. ANALYSIS OF SOILS WATERED WITH SALT MIXTURE SOLUTIONS (Tomato)

Salt and Concen. in thousand p.p.m.	% Ca	% Na	% Mg	Sum of calculated salts $CaCl_2$, $MgSO_4$, NaCl
Control	.234	.044	.052	.98
3 $MgSO_4$ 1 $CaCl_2$	.503	.026	.208	2.47
1.5 $MgSO_4$ 1.5 Na_2SO_4	.225	.225	.166	2.01
3 $MgSO_4$ 1 Na_2SO_4	.211	.127	.045	1.12
1.5 $MgSO_4$ 1.5 Na_2SO_4 1 $CaSO_4$	.458	.162	.099	2.16
1 NaCl 1 $CaCl_2$ 1 $MgCl_2$	.267	.119	.088	1.47
1 NaCl 2 $CaCl_2$ 1 $CaSO_4$	.507	.142	.042	1.96
2 NaCl 1 $MgCl_2$ 1 $CaSO_4$	.254	.159	.096	1.58
2 $CaCl_2$ 1 $MgCl_2$	.337	.030	.094	1.46
3 $MgSO_4$ 1 $CaSO_4$	.446	.040	.389	3.26
2 $CaCl_2$ 1 NaCl	.383	.126	.045	1.60
2 $MgCl_2$ 1 NaCl 1 $CaSO_4$	.203	.109	.140	1.53
3 $CaCl_2$ 1 Na_2SO_4	.501	.134	.173	2.57
1.5 NaCl 1.5 $CaCl_2$	.326	.168	.050	1.58
2 $MgCl_2$ 1 $CaCl_2$	.219	.062	.138	1.43
2 NaCl 1 $CaCl_2$ 1 $CaSO_4$	.370	.201	.014	1.60
2 $MgCl_2$ 1 $CaCl_2$ 1 $CaSO_4$	.394	.034	.188	2.10
2 $CaCl_2$ 1 $MgCl_2$ 1 $CaSO_4$	.496	.032	.104	1.96
3 Na_2SO_4 1 $CaCl_2$	.381	.520	.033	2.53
3 $NaHCO_3$ 1 $CaSO_4$	.233	.238	.053	1.40
3 Na_2SO_4 1 $CaSO_4$	.410	.516	.070	2.79
2 NaCl 1 $CaCl_2$	.304	.216	.064	1.71
1.5 $CaCl_2$ 1.5 $MgCl_2$ 1 $CaSO_4$	.443	.032	.209	2.34
2 NaCl 1 $MgCl_2$	.157	.162	.112	1.39
1 NaCl 1 $CaCl_2$ 1 $MgCl_2$ 1 $CaSO_4$	.128	.378		1.61
1.5 $CaCl_2$ 1.5 $MgCl_2$	.354	.036	.131	1.71
2 $MgCl_2$ 1 NaCl	.167	.122	.155	1.54
3 $NaHCO_3$ 1 $CaCl_2$	.320	.445	.045	2.23
3 $MgCl_2$ 1 Na_2SO_4	.199	.090	.199	1.77

TABLE V. (Continued)

Salt and Concen. in thousand p.p.m.	% Ca	% Na	% Mg	Sum of calculated salts $CaCl_2$, $MgSO_4$, NaCl
1.5 NaCl 1.5 $CaCl_2$ 1 $CaSO_4$	.486	.171	.148	2.50
3 $MgCl_2$ 1 $CaSO_4$	.252	.035	.279	2.16
3 $MgCl_2$ 1 $CaCl_2$	.255	.034	.231	1.93
3 NaCl 1 Na_2SO_4	.203	.355	.038	1.65
1.5 NaCl 1.5 $MgCl_2$	.177	.151	.156	1.64
3 $CaCl_2$ 1 $CaSO_4$	.533	.035	.055	1.82
1.5 NaCl 1.5 $MgCl_2$ 1 $CaSO_4$	.293	.154	.145	1.91
3 NaCl 1.$CaSO_4$	.277	.031	.046	1.07
3 $NaHCO_3$ 1 Na_2SO_4	.209	.233	.030	1.32
3 NaCl 1 $CaCl_2$	.291	.279	.108	2.05

(5) The increased total percentage of soil salts which was necessary to cause death of the plants indicates a beneficial ion antagonism or buffering of the salts. This is in accord with the commonly recognized fact that salt mixtures are not as toxic as single salt solutions.

In Table VI are presented the results of the second experiment with tomato plants treated with various salt mixtures. This experiment was carried out to determine whether one of the seven salts used would reduce the toxicity of any of the remaining six salts when added to a single salt solution. Such a reduction might be effected by the buffering action of the salts or by beneficial antagonism.

The following procedure was used to determine which salt possessed the greatest buffer capacity as measured by the reduction of the toxicity of another salt. In this experiment each series consisted of three plants each and was treated with a different salt solution. Six series of plants were treated with solutions which contained 3000 p.p.m. of calcium, magnesium and sodium chlorides, sodium bicarbonate and magnesium and sodium sulfates.[1] Six series of plants were treated with solutions which contained 4000 p.p.m. of each of these six salts. The solutions used to determine the reduction of toxicity of sodium bicarbonate

1 Calcium sulfate could not be used as its maximum solubility is 1723 p.p.m..

TABLE VI. ANALYSIS OF TOMATO PLANTS WATERED WITH SALT MIXTURE SOLUTIONS
Experimental Period - August 19, 1938 to May 26, 1939

Salt and Conc. in thousand p.p.m.	Duration of Expr. (days)	H_2O added per plant (gals.)	Dry Wt. per plant	% Ash	% Ca	% Na	% Mg
Control	280*	11.9	20.94	16.89	2.60	.232	.783
3 $NaHCO_3$	54	1.7	2.52	22.76	1.39	3.67	.511
4 $NaHCO_3$	58	2.1	2.36	24.02	1.45	4.06	.542
3 $NaHCO_3$ 1 NaCl	80	2.4	3.22	34.97	1.52	7.46	.764
3 $NaHCO_3$ 1 Na_2SO_4	67	2.3	2.91	28.64	1.39	6.53	.681
3 $NaHCO_3$ 1 $CaCl_2$	184	4.2	5.75	36.64	1.75	7.57	.646
3 $NaHCO_3$ 1 $MgSO_4$	136	5.0	6.19	25.82	1.09	5.46	.987
3 $NaHCO_3$ 1 $MgCl_2$	160	3.5	6.45	31.80	1.55	6.80	1.44
3 $NaHCO_3$ 1 $CaSO_4$	131	3.7	5.46	34.13	1.82	3.87	.581
3 NaCl	197	4.8	8.12	36.20	2.17	5.39	..550
4 NaCl	129	3.2	4.70	46.97	2.30	10.87	.838
3 NaCl 1 $NaHCO_3$	102	2.6	3.56	43.62	2.14	10.39	.808
3 NaCl 1 Na_2SO_4	139	3.3	4.23	45.21	2.27	10.15	.764
3 NaCl 1 $CaCl_2$	170	3.7	5.29	44.95	3.92	5.86	.655
3 NaCl 1 $MgSO_4$	193	3.5	5.90	43.53	2.26	7.48	1.90
3 NaCl 1 $MgCl_2$	143	3.6	4.82	41.08	2.39	6.46	2.04
3 NaCl 1 $CaSO_4$	208	5.1	7.44	41.81	3.58	7.52	.616
3 Na_2SO_4	252	5.0	5.30	32.23	1.57	4.73	.668
4 Na_2SO_4	269	6.0	6.87	30.32	1.23	4.47	.703
3 Na_2SO_4 1 $NaHCO_3$	264	6.4	8.73	30.19	1.54	6.72	.655
3 Na_2SO_4 1 NaCl	257	6.1	9.42	45.94	1.92	8.59	.856
3 Na_2SO_4 1 $CaCl_2$	224	5.1	10.62	34.73	2.75	5.69	.607
3 Na_2SO_4 1 $MgSO_4$	265	7.5	8.35	26.68	1.12	3.32	1.54
3 Na_2SO_4 1 $MgCl_2$	249	5.1	7.28	40.60	1.74	5.16	2.42
3 Na_2SO_4 1 $CaSO_4$	280*	7.3	8.81	25.63	2.64	2.64	.731
3 $CaCl_2$	262	16.0	9.28	32.34	7.30	.198	.550

TABLE VI. ANALYSIS OF TOMATO PLANTS WATERED WITH SALT MIXTURE SOLUTIONS

Salt and Conc. in thousand p.p.m.	Duration of Expr. (days)	H_2O added per plant (gals.)	Dry Wt. Per Plant	% Ash	% Ca	% Na	% Mg
4 $CaCl_2$	172	3.6	6.03	38.66	8.64	.291	.673
3 $CaCl_2$ 1 $NaHCO_3$	237	6.2	9.58	35.80	7.49	1.33	.642
3 $CaCl_2$ 1 NaCl	177	5.1	6.40	37.33	7.62	1.76	.633
3 $CaCl_2$ 1 Na_2SO_4	225	4.9	9.85	40.83	7.01	1.48	.546
3 $CaCl_2$ 1 $MgSO_4$	199	3.8	8.22	33.39	6.27	.236	1.56
3 $CaCl_2$ 1 $MgCl_2$	213	5.3	7.37	34.54	6.34	.163	1.59
3 $CaCl_2$ 1 $CaSO_4$	235	5.3	10.79	41.53	9.24	.313	.590
1.5 NaCl 1.5 $MgSO_4$	245	6.3	8.82	31.95	2.17	2.55	2.89
1.4 NaCl 1.6 $CaSO_4$	236	5.1	9.62	32.69	4.40	3.21	.751
1.8 Na_2SO_4 1.2 $MgCl_2$	201	4.4	8.14	32.24	1.58	3.82	2.54
1.7 Na_2SO_4 1.3 $CaCl_2$	223	5.3	10.76	32.37	4.58	3.90	.764
1.5 $CaCl_2$ 1.5 $MgSO_4$	239	5.3	10.37	29.26	3.88	.274	2.87
1.2 $MgCl_2$ 1.8 $CaSO_4$	280*	5.8	9.16	27.96	3.93	.192	3.29
3 $MgSO_4$	280*	6.5	12.06	17.85	.67	.178	2.67
4 $MgSO_4$	280*	5.9	11.00	20.02	.92	.110	3.04
3 $MgSO_4$ 1 $NaHCO_3$	280*	7.3	10.60	22.18	.72	1.41	3.63
3 $MgSO_4$ 1 NaCl	215	3.9	13.28	27.97	1.18	1.65	3.87
3 $MgSO_4$ 1 Na_2SO_4	280*	5.3	11.40	31.08	.71	2.22	3.60
3 $MgSO_4$ 1 $CaCl_2$	276	6.3	15.17	27.85	2.32	.255	4.54
3 $MgSO_4$ 1 $MgCl_2$	241	5.2	10.47	24.41	1.31	.176	4.71
3 $MgSO_4$ 1 $CaSO_4$	280*	6.0	14.33	22.05	1.05	.150	3.52
3 $MgCl_2$	178	3.8	7.66	24.54	1.73	.261	4.84
4 $MgCl_2$	183	3.5	8.22	25.00	1.72	.270	4.99
3 $MgCl_2$ 1 $NaHCO_3$	200	4.0	7.06	25.97	1.74	1.29	4.22

* Only plants alive.

TABLE VI. (Continued)

Salt and conc. in thousand p.p.m.	Duration of Expr. in days	H_2O added per plant (gals.)	Dry Wt. per plant	% Ash	% Ca	% Na	% Mg.
3 $MgCl_2$ 1 NaCl	138	2.7	6.66	29.74	2.04	1.81	4.05
3 $MgCl_2$ 1 Na_2SO_4	167	3.3	7.66	32.90	2.03	2.42	4.46
3 $MgCl_2$ 1 $CaCl_2$	162	3.3	7.72	30.56	4.14	.356	4.29
3 $MgCl_2$ 1 $MgSO_4$	138	2.6	5.60	25.69	1.97	.185	4.94
3 $MgCl_2$ 1 $CaSO_4$	170	3.0	10.23	28.91	3.11	.277	4.30
1 NaCl 1 $CaCl_2$ 1 $MgCl_2$	259	6.2	7.66	42.41	4.83	2.30	2.39
1 NaCl 1 $CaCl_2$ 1 $NaSO_4$	227	4.3	13.73	36.02	3.63	5.06	.620
1 NaCl 1 $CaCl_2$ 1 $MgSO_4$	235	3.3	14.79	36.72	3.65	3.22	1.92
1 NaCl 1 $CaCl_2$ 1 $CaSO_4$	200	3.7	9.47	34.80	5.76	2.69	.419
1 NaCl 1 CaCl 1 $NaHCO_3$	229	4.9	12.18	32.06	3.55	3.58	.537
1 $CaCl_2$ 1 $MgCl_2$ 1 Na_2SO_4	238	4.4	10.57	33.54	3.70	1.90	1.83
1 $CaCl_2$ 1 $MgCl_2$ 1 $MgSO_4$	234	4.7	11.27	36.39	4.07	.362	3.35
1 $CaCl_2$ 1 $MgCl_2$ 1 $NaHCO_3$	228	5.3	13.43	30.36	3.62	1.85	2.36
1 CaCl 1 $MgCl_2$ 1 $CaSO_4$	214	4.0	11.57	34.61	5.80	.427	2.03
1 $MgCl_2$ 1 Na_2SO_4 1 NaCl	181	3.9	9.45	33.99	1.93	4.60	2.03
1 $MgCl_2$ 1 Na_2SO_4 1 $MgSO_4$	242	5.3	10.57	29.10	1.59	2.14	3.55
1 $MgCl_2$ 1 Na_2SO_4 1 $NaHCO_3$	210	4.4	9.43	34.35	1.77	4.91	2.24
1 $MgCl_2$ 1 Na_2SO_4 1 $CaSO_4$	221	4.4	10.92	30.53	2.68	2.57	2.40
1 Na_2SO_4 1 $MgSO_4$ 1 NaCl	241	5.3	11.28	29.56	1.56	3.89	2.21
1 Na_2SO_4 1 $MgSO_4$ 1 $CaCl_2$	239	5.2	14.59	34.78	2.45	2.71	2.35
1 Na_2SO4 1 $MgSO_4$ 1 $NaHCO_3$	272	6.6	10.32	29.77	1.24	4.02	1.80
1 Na_2SO4 1 $MgSO_4$ 1 $CaSO_4$	272	6.9	12.00	25.83	1.43	1.84	2.07
3 $NaHCO_3$ + H_3PO_4 until neutral	110	3.3	4.26	27.04	1.04	4.24	.642
1 $NaHCO_3$ 1 NaCl 1 $CaCl_2$	252	7.0	15.33	35.20	3.82	5.31	.598
1 $CaSO_4$	280*	10.2	23.51	17.92	2.92	.646	.751
Sat. $CaSO_4$	280*	10.0	23.36	24.49	3.52	.441	.860

* Only plants alive

contained the following salt mixtures.

3000	p.p.m.	$NaHCO_3$	1000	p.p.m.	$NaCl$
"	"	"	"	"	Na_2SO_4
"	"	"	"	"	$CaCl_2$
"	"	"	"	"	$CaSO_4$
"	"	"	"	"	$MgSO_4$
"	"	"	"	"	$MgCl_2$

The reduction of toxicity of each of the five salts, sodium chloride, sodium sulfate, calcium chloride, magnesium sulfate, and magnesium chloride were made in a similar manner as shown by Table VII.

TABLE VII. The Effects of the buffering action of the seven salts, and their ability to reduce the toxicity of single salt solutions as measured by the dry weight of the plant.

Predominating Salt	Buffer Salt	Weight per plant(grams)
3000 p.p.m. $NaHCO_3$		2.52
4000 p.p.m. NaHCO		2.36
3000 p.p.m. $NaHCO_3$	1000 p.p.m. $MgCl_2$	6.45
" " "	1000 p.p.m. $MgSO_4$	6.19
" " "	" " $CaCl_2$	5.75
" " "	" " $CaSO_4$	5.46
" " "	" " Na_2Cl	3.22
" " "	" " Na_2SO_4	2.91
3000 p.p.m. NaCl		8.12
4000 p.p.m. NaCl		4.70
3000 p.p.m. NaCl	1000 p.p.m. $CaSO_4$	7.44
" " "	" " $MgSO_4$	5.90
" " "	" " $CaCl_2$	5.29
" " "	" " $MgCl_2$	4.82
" " "	" " Na_2SO_4	4.23
" " "	" " $NaHCO_3$	3.56
3000 p.p.m. Na_2SO_4		5.30
4000 p.p.m. Na_2SO_4		6.87
3000 p.p.m. Na_2SO_4	1000 p.p.m. $CaCl_2$	10.62
" " "	" " Nacl	9.42
" " "	" " $CaSO_4$	8.81
" " "	1000 p.p.m. $NaHCO_3$	8.73
" " "	" " $MgSO_4$	8.35
" " "	" " $MgCl_2$	7.28
3000 p.p.m. $CaCl_2$		7.30
4000 " $CaCl_2$		6.03
3000 p.p.m. $CaCl_2$	1000 p.p.m. $CaSO_4$	10.79
" " "	" " Na_2SO_4	9.85
" " "	" " $NaHCO_3$	9.58
" " "	" " $MgSO_4$	8.22
" " "	" " $MgCl_2$	7.47
" " "	" " NaCl	6.40
3000 p.p.m. $MgSO_4$		12.06
4000 p.p.m. $MgSO_4$		11.00
3000 p.p.m. $MgSO_4$	1000 p.p.m. $CaCl_2$	15.17
" " "	" " $CaSO_4$	14.33
" " "	" " NaCl	13.28
" " "	" " Na_2SO_4	11.40
" " "	" " $NaHCO_3$	10.60
" " "	" " $MgCl_2$	10.47
3000 p.p.m. $MgCl_2$		7.66
4000 p.p.m. $MgCl_2$		8.22
3000 p.p.m. $MgCl_2$	1000 p.p.m. $CaSO_4$	10.23

TABLE VII (Continued)

Predominating Salt	Buffer Salt	Weight per plant in grams
3000 p.p.m. $MgCl_2$	1000 p.p.m. $CaCl_2$	7.72
" " "	" " Na_2SO_4	7.66
" " "	" " $NaHCO_3$	7.06
" " "	" " NaCl	6.66
" " "	" " $MgSO_4$	5.60

A comparison of the weights of the plants treated with binary salt mixture solutions with those treated with single salt solutions is given in Table VII. From this data the following conclusions may be drawn:

(1) The toxicity of single salt solutions was reduced in most cases by the addition of a buffer salt. This bears out the commonly recognized fact that mixtures of salts are often less injurious than individual salts.

(2) The toxicity of the salts is not and additive property. This would indicate that salt toxicity does not depend entirely upon osmotic pressure changes in the soil solutions.

(3) Sodium and magnesium chlorides do not respond in an appreciable manner to buffering by addition of other salts.

(4) The toxicity of sodium bicarbonate is reduced when it is mixed with other salts, especially when salts of magnesium and calcium are added.

(5) In general, the chloride salts show the greatest loss in toxicity when they are mixed with buffer salts containing the sulfate ion. The converse is also true.

(6) The plants treated with solutions that contained the magnesium salts show greatest response to the buffering of the calcium salts.

(7) The addition of calcium sulfate as a buffer salt in most instances caused the greatest reduction in toxicity of the single salt solutions.

Table VIII presents the results of the soil analysis of the second experimental series of tomato plants treated with salt mixture solutions.

TABLE VIII. ANALYSIS OF SOILS WATERED WITH SALT MIXTURE SOLUTIONS (Tomato)

Salt and Concen. in thousand p.p.m.	% Ca	% Na	% Mg	Sum of calculated salts $CaCl_2$, $MgSO_4$, NaCl
Control	.215	.041	.064	1.01
3 $NaHCO_3$	.200	.204	.059	1.36
4 $NaHCO_3$	.219	.266	.064	1.58
3 $NaHCO_3$ 1 NaCl	.195	.369	.059	1.77
3 $NaHCO_3$ 1 Na_2SO_4	.197	.276	.053	1.51
3 NaHCO 1 $CaCl_2$	.285	.383	.045	1.98
3 $NaHCO_3$ 1 $MgSO_4$	.197	.240	.127	1.79
3 $NaHCO_3$ 1 $MgCl_2$	.186	.310	.143	2.02
3 $NaHCO_3$ 1 $CaSO_4$	.279	.206	.147	2.02
3 NaCl	.164	.448	.060	1.88
4 NaCl	.178	.535	.052	2.10
3 NaCl 1 $NaHCO_3$	.227	.471	.057	2.25
3 NaCl 1 Na_2SO_4	.175	.414	.050	1.78
3 NaCl 1 $CaCl_2$	.301	.417	.046	2.12
3 NaCl 1 $MgSO_4$	.151	.480	.113	2.20
3 NaCl 1 $MgCl_2$	.151	.313	.120	1.81
3 NaCl 1 $CaSO_4$	.276	.413	.032	1.96
3 Na_2SO_4	.208	.428	.055	1.93
4 Na_2SO_4	.173	.462	.061	1.95
3 Na_2SO_4 1 $NaHCO_3$	.161	.412	.046	1.72
3 Na_2SO_4 1 NaCl	.140	.473	.049	1.83
3 Na_2SO_4 1 $CaCl_2$	.400	.358	.056	2.29
3 Na_2SO_4 1 $MgSO_4$	.131	.360	.157	2.05
3 Na_2SO_4 1 $MgCl_2$	.145	.355	.158	2.08
3 Na_2SO_4 1 $CaSO_4$	.504	.367	.049	2.57
3 $CaCl_2$	.636	.033	.049	2.08
4 $CaCl_2$	.674	.029	.041	2.14
3 $CaCl_2$ 1 $NaHCO_3$	.679	.145	.046	2.48

TABLE VIII (Continued)

Salt and Concen. in thousand p.p.m.	%Ca	% Na	% Mg	Sum of calculated salts $CaCl_2$, $MgSO_4$, NaCl
3 $CaCl_2$ 1 NaCl	.586	.195	.052	2.37
3 $CaCl_2$ 1 Na_2SO_4	.515	.115	.071	2.07
3 $CaCl_2$ 1 $MgSO_4$	.570	.017	.152	2.35
3 $CaCl_2$ 1 $MgCl_2$	.581	.027	.104	2.19
3 $CaCl_2$ 1 $CaSO_4$	.751	.021	.027	2.26
1.5 NaCl 1.5 $MgSO_4$	.159	.140	.200	1.78
1.4 NaCl 1.6 $CaSO_4$	.430	.242	.044	2.01
1.8 Na_2SO_4 1.2 $MgCl_2$	.175	.236	.190	2.01
1.7 Na_2SO_4 1.3 $CaCl_2$	.416	.205	.050	1.92
1.5 $CaCl_2$ 1.5 $MgSO_4$	.496	.025	.195	2.39
1.2 $MgCl_2$ 1.8 $CaSO_4$	.449	.018	.214	2.35
3 $MgSO_4$	.175	.022	.317	2.10
4 $MgSO_4$	.167	.028	.302	2.02
3 $MgSO_4$ 1 $NaHCO_3$	.167	.133	.353	2.55
3 $MgSO_4$ 1 NaCl	.164	.168	.311	2.41
3 $MgSO_4$ 1 Na_2SO_4	.181	.191	.402	2.97
3 $MgSO_4$ 1 $CaCl_2$	.509	.029	.323	3.06
3 $MgSO_4$ 1 $MgCl_2$	.140	.036	.587	3.38
3 $MgSO_4$ 1 $CaSO_4$	.466	.022	.295	2.80
3 $MgCl_2$	.172	.042	.356	2.34
4 $MgCl_2$	.202	.031	.386	2.54
3 $MgCl_2$ 1 $NaHCO_3$	.148	.141	.318	2.35
3 $MgCl_2$ 1 NaCl	.164	.187	.327	2.54
3 $MgCl_2$ 1 Na_2SO_4	.126	.140	.285	2.11
3 $MgCl_2$ 1 $CaCl_2$	.337	.051	.357	2.83
3 $MgCl_2$ 1 $MgSO_4$	.128	.035	.352	2.18
3 $MgCl_2$ 1 $CaSO_4$	.206	.033	.247	1.87
1 NaCl 1 $CaCl_2$ 1 $MgCl_2$	.328	.222	.192	2.42
1 NaCl 1 $CaCl_2$ 1 Na_2SO_4	.323	.263	.055	1.83
1 NaCl 1 $CaCl_2$ 1 $MgSO_4$	.312	.177	.151	2.06
1 NaCl 1 $CaCl_2$ 1 $CaSO_4$	.370	.140	.038	1.54
1 NaCl 1 $CaCl_2$ 1 $NaHCO_3$	.312	.284	.042	1.78

TABLE VIII. (Continued)

Salt and Concen. in thousand p.p.m.	% Ca	% Na	% Mg	Sum of calculated salts $CaCl_2$, $MgSO_4$, NaCl
1 $CaCl_2$ 1 $MgCl_2$ 1 Na_2SO_4	.293	.115	.127	1.72
1 $CaCl_2$ 1 $MgCl_2$ 1 $MgSO_4$	.304	.026	.251	2.15
1 $CaCl_2$ 1 $MgCl_2$ 1 $NaHCO_3$	.312	.170	.200	2.28
1 $CaCl_2$ 1 $MgCl_2$ 1 $CaSO_4$	.386	.031	.148	1.88
1 $MgCl_2$ 1 Na_2SO_4 1 NaCl	.137	.308	.145	1.90
1 $MgCl_2$ 1 Na_2SO_4 1 $MgSO_4$	.137	.159	.242	2.00
1 $MgCl_2$ 1 Na_2SO_4 1 $NaHCO_3$	.170	.273	.183	2.06
1 $MgCl_2$ 1 Na_2SO_4 1 $CaSO_4$	.318	.152	.190	2.21
1 Na_2SO_4 1 NaCl 1 $MgSO_4$	.145	.277	.164	1.91
1 Na_2SO_4 1 $MgSO_4$ 1 $CaCl_2$	.340	.152	.166	2.15
1 Na_2SO_4 1 $MgSO_4$ 1 $NaHCO_3$	.173	.292	.177	2.10
1 Na_2SO_4 1 $MgSO_4$ 1 $CaSO_4$	.487	.150	.153	2.49
3 $NaHCO_3$+H_3PO_4 until neutral	.173	.205	.071	1.35
1 $NaHCO_3$ 1 NaCl 1 $CaCl_2$	.274	.359	.045	1.89
1 $CaSO_4$	.572	.027	.050	1.90
Sat. $CaSO_4$	1.05	.026	.074	3.32

GERANIUMS

Treatment With Single Salt Solutions

The most noticeable characteristics of geranium plants treated with single salt solutions are given in the following statements.

(1) Plants treated with magnesium sulfate had very dark green leaves.

(2) Injury was first noticed in the yellowing and dying of the lower leaves. Later this injury progressed to the upper branches.

(3) The water consumption of the plants was reduced when the plants were treated with any of the salt solutions.

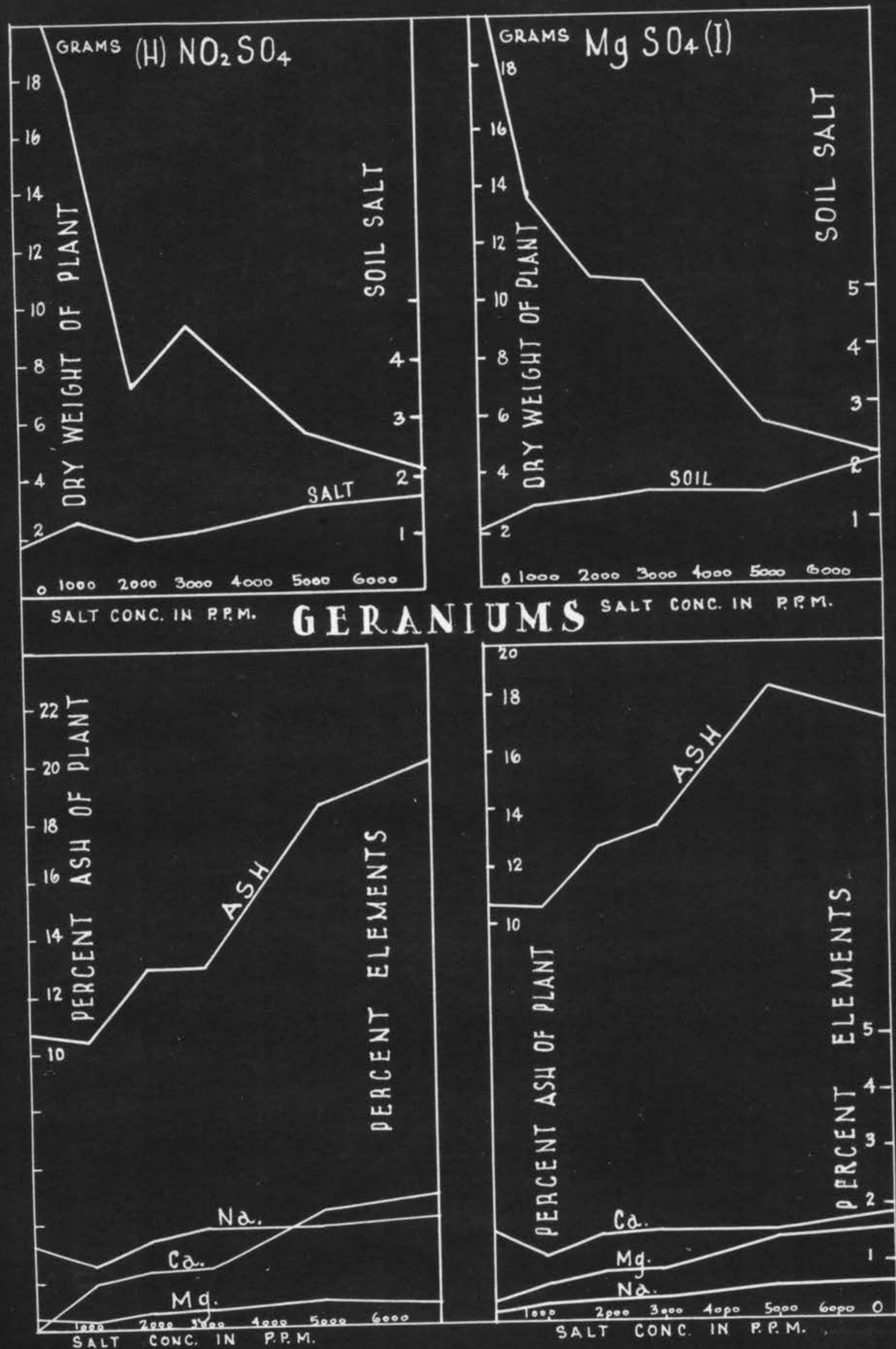
(4) The observed order of the decreasing toxicity was as follows: $MgCl_2$, $CaCl_2$, $MgSO_4$, NaCl, Na_2SO_4 and $NaHCO_3$.

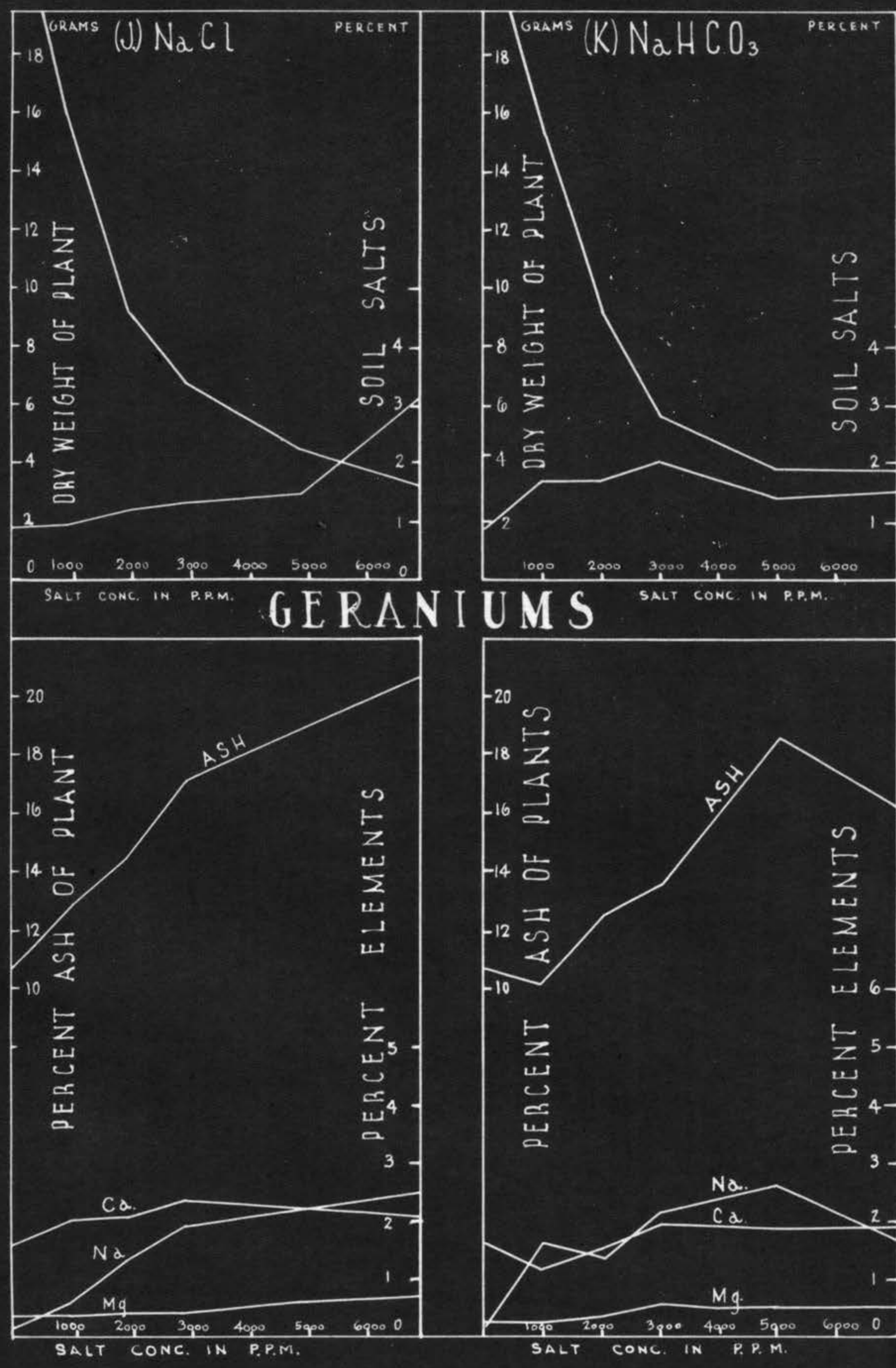
Table IX shows that, in general, the length of life of the plant and its water consumption were decreased proportional to the increased salt concentration of the solution applied.

The effects of the individual salts on geranium plants will be briefly discussed in the order of the decreasing toxicity. The toxicity of the salt solutions to the geraniums was measured in the same manner as for the tomato plants; the concentration of salt which reduced the dry weight of the plant under treatment to half the weight of the control plant was considered the toxic concentration.

Figure 2. Graphs showing the Dry Weight of Geranium Plants, their percentage of ash and constituents of Ash, and the soil salts. * (dry basis.)

* The sum of the percentages of calcium chloride, magnesium sulfate, and sodium chloride calculated from the amounts of Calcium magnesium and sodium found in the soil.


GRAMS (H) NO2 SO4
DRY WEIGHT OF PLANT
SOIL SALT
SALT
SALT CONC. IN P.P.M.
GRAMS Mg SO4 (I)
DRY WEIGHT OF PLANT
SOIL SALT
SOIL
SALT CONC. IN P.P.M.
GERANIUMS
PERCENT ASH OF PLANT
ASH
PERCENT ELEMENTS
Na.
Ca.
Mg.
SALT CONC. IN P.P.M.
ASH
PERCENT ASH OF PLANT
PERCENT ELEMENTS
Ca.
Mg.
Na.
SALT CONC. IN P.P.M.



GERANIUMS
(J) NaCl
(K) NaHCO3
GRAMS
PERCENT
DRY WEIGHT OF PLANT
SOIL SALTS
SALT CONC. IN P.P.M.
PERCENT ASH OF PLANT
PERCENT ASH OF PLANTS
PERCENT ELEMENTS
ASH
Ca.
Na.
Mg

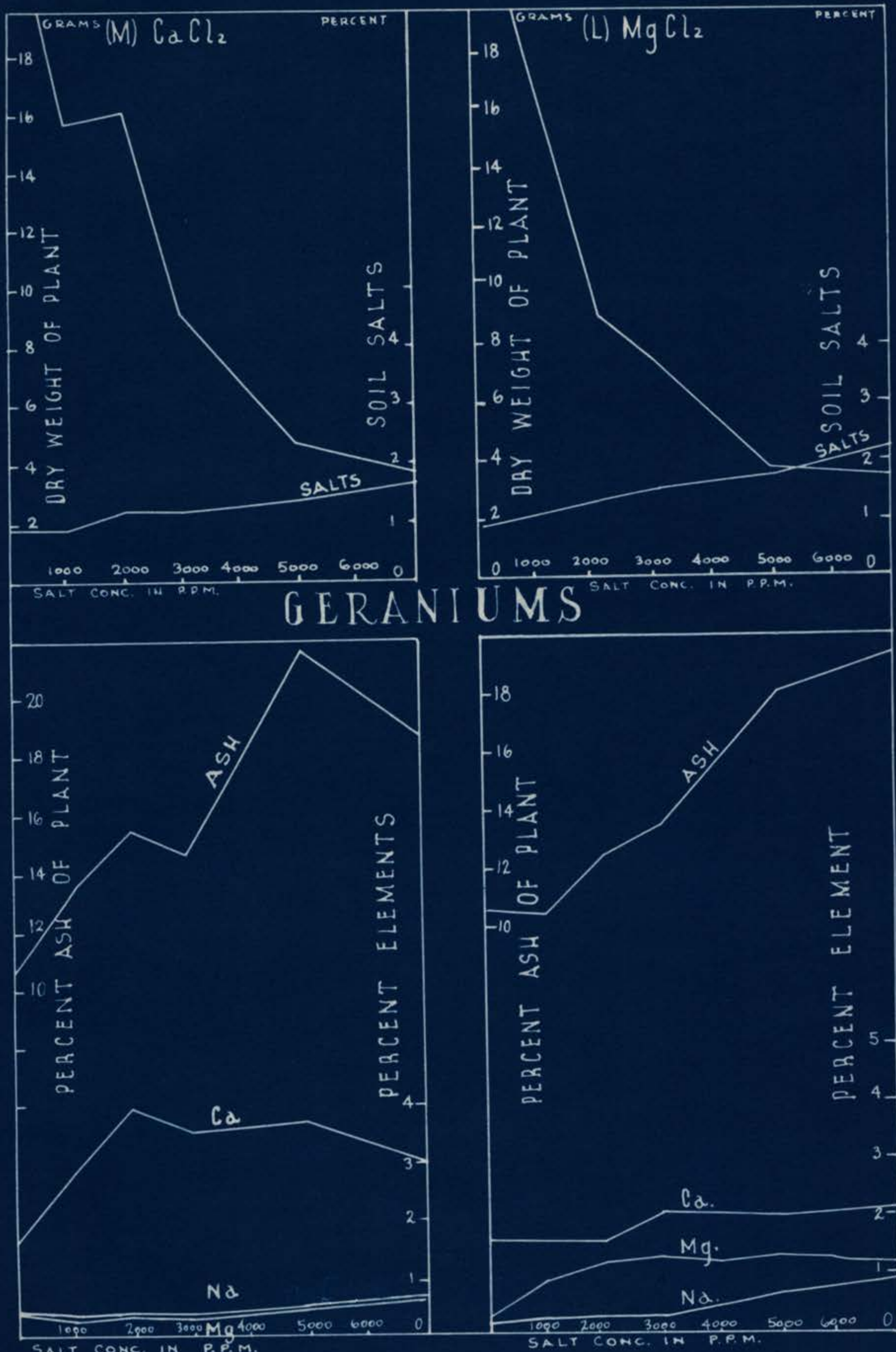

(M) CaCl₂
GRAMS
PERCENT
DRY WEIGHT OF PLANT
SOIL SALTS
SALTS
SALT CONC. IN P.P.M.
(L) MgCl₂
GRAMS
PERCENT
DRY WEIGHT OF PLANT
SOIL SALTS
SALTS
SALT CONC. IN P.P.M.
GERANIUMS
PERCENT ASH OF PLANT
PERCENT ELEMENTS
ASH
Ca
Na
Mg
SALT CONC. IN P.P.M.
PERCENT ASH OF PLANT
PERCENT ELEMENT
ASH
Ca.
Mg.
Na.
SALT CONC. IN P.P.M.

TABLE IX. ANALYSIS OF GERANIUM PLANTS WATERED WITH SINGLE SALT SOLUTIONS

Salt	P.P.M.	Experimental Period (days)	Water Consumption (gallons)	Weight per plant (gms)	% Ash	% Ca	% Na	% Mg
Control		181[1]	5.00	23.48 a	10.76	1.63	.214	.365
Na_2SO_4	1000	181[1]	2.60	17.16 a	10.44	1.36	1.00	.292
Na_2SO_4	2000	181[1]	2.95	7.38 a	12.90	1.73	1.17	.414
Na_2SO_4	3000	181[1]	2.60	9.27 a	12.99	1.88	1.18	.455
Na_2SO_4	3000	131*	2.90	7.32 c	17.86	1.87	2.35	.543
Na_2SO_4	5000	130*	2.90	5.42 c	18.52	1.90	2.18	.617
Na_2SO_4	7000	128*	2.80	4.11 c	20.04	1.96	2.41	.584
$MgSO_4$	1000	181[1]	3.90	13.33 a	10.57	1.34	.301	.706
$MgSO_4$	2000	181[1]	3.25	10.63 a	12.79	1.54	.404	.902
$MgSO_4$	3000	181[1]	5.15	10.30 a	13.71	1.64	.396	.923
$MgSO_4$	3000	128*	2.90	7.65 c	17.14	1.73	.701	1.302
$MgSO_4$	5000	121*	2.80	5.37 c	18.09	1.59	.590	1.500
$MgSO_4$	7000	123*	2.80	4.39 c	17.13	1.74	.686	1.560
$NaHCO_3$	1000	181[1]	3.45	15.32 a	10.19	1.24	1.59	.326
$NaHCO_3$	2000	181[1]	3.00	9.10 a	12.58	1.56	1.45	.373
$NaHCO_3$	3000	181[1]	3.20	5.75 a	13.70	1.97	1.07	.475
$NaHCO_3$	3000	146*	3.20	5.26 a	18.13	2.07	2.13	.569
$NaHCO_3$	5000	140*	3.10	3.78 c	18.66	1.89	2.62	.576
$NaHCO_3$	7000	143*	3.10	3.78 c	16.45	1.91	1.79	.553
NaCl	1000	181[1]	3.95	15.93 a	12.89	1.99	.58	.370
NaCl	2000	181[1]	2.40	9.23 a	14.55	2.08	1.30	.430
NaCl	3000	181[1]	2.55	6.66 a	17.21	2.33	1.90	.430
NaCl	3000	128*	2.90	5.08 c	19.45	2.09	2.64	.610
NaCl	5000	127*	2.80	4.14 c	33.04	2.42		.570
NaCl	7000	124*	2.80	3.17 c	20.45	2.02	2.49	.620

TABLE IX. (Continued)

Salt	P.P.M.	Experimental Period (days)	Water Consumtion (gals)	Weight Per Plant (gms)	% Ash	% Ca	% Na	% Mg
$MgCl_2$	1000	181⊥	5.50	16.82 a	10.49	1.59	.284	.896
$MgCl_2$	2000	181⊥	2.90	9.07 a	12.42	1.66	.278	1.19
$MgCl_2$	3000	181⊥	2.73	7.55 a	13.44	2.06	.260	1.04
$MgCl_2$	3000	119*	2.50	6.29 a	17.44	1.99	.592	1.37
$MgCl_2$	5000	115*	2.30	3.87 c	18.00	2.03	.721	1.29
$MgCl_2$	7000	120*	2.25	3.67 c	19.35	2.13	.886	1.23
$CaCl_2$	1000	181⊥	4.00	15.70 a	13.72	2.92	.185	.312
$CaCl_2$	2000	181⊥	3.30	16.05 a	15.58	3.94	.228	.400
$CaCl_2$	3000	181⊥	3.05	9.30 a	14.74	3.63	.223	.394
$CaCl_2$	3000	126*	2.80	5.79 c	20.45	3.41	.603	.687
$CaCl_2$	5000	121*	2.80	4.89 c	21.61	3.78	.747	.620
$CaCl_2$	7000	121*	2.80	3.89 c	18.77	3.13	.703	.659

⊥ Plant alive
* Plant dead
a grown in winter of 1938
c grown in summer of 1937

<u>$MgSO_4$</u> The decrease in the weight of the geranium plants treated with increased concentrations of magnesium sulfate is given in Figure 2 (1). The toxic concentration of this salt was 1500 p.p.m..

The plants treated with magnesium sulfate showed an increased ash content as the concentration of the applied solution increased. The magnesium content of the plants treated with maximum quantities of the salt was four times greater than of the controls. The calcium content of these geranium plants remained rather constant after an initial fluctuation, and contained approximately the same percentage of calcium as the control plants. This did not agree with the theoretical expectations.

<u>$NaHCO_3$</u> Figure 2 (K) indicates that increased concentrations of sodium bicarbonate sharply reduced the growth of geranium plants. The toxic concentration was 1500 p.p.m. There was an increase in ash content of the plant as the concentrations of the solutions were increased to 5000 p.p.m. but above this concentration the ash content decreased.

The sodium content of the experimental plants which received high concentrations of the salt was increased to twelve times that of the control plants. There was an increase in the calcium content of the plants but the magnesium content remained constant as increased concentrations of the salt solution were applied.

<u>NaCl</u> Plants treated with sodium chloride, Figure 2 (J) showed a very sharp decrease in their dry weights as the result of addition of increased concentrations of the

salt. The ash content of the plants was increased to twice that of the controls. There was a marked increase in the sodium content and a slight increase in the calcium content of the plants as the result of applications of salt solutions of increased concentrations. Sodium chloride was toxic at a concentration of 1550 p.p.m..

$MgCl_2$ Figure 2 (M) indicates that 1600 p.p.m. of magnesium chloride was toxic to the plants. There was a sharp decrease in the growth of the plant as measured by dry weight when they were treated with solutions of increased concentrations. As a result of the addition of high concentration of the salt, the ash and magnesium content of the plant were increased in appreciable amounts while the sodium and calcium of these experimental plants were increased slightly.

Na_2SO_4 The extreme depression of the growth of plants treated with 2000 p.p.m. of sodium sulfate seems to be in error. If this one point is disregarded the toxic concentration of sodium sulfate can be evaluated at 2000 p.p.m.. Figure 2 (H) shows that ash and sodium content of the plants were increased two and twelve times, respectively, over that of the control plants. The calcium and magnesium content of the plants remained rather constant over the entire range of salt concentration.

$CaCl_2$ The plotted values of the dry weights of the plants treated with calcium chloride showed irregularities but the general trend indicated that the toxic concentration of the salt was 2500 p.p.m.. In this experiment the ash and the calcium content were increased as the salt concentration was

TABLE X. ANALYSIS OF SOILS WATERED WITH SINGLE SALT SOLUTIONS (Geranium)

Salt	p.p.m.	% Ca	% Na	% Mg	Sum calculated as total salts - NaCl, $CaCl_2$, $MgSO_4$
Control		.230	.026	.047	.92
Na_2SO_4	1000	.220	.180	.040	1.26
Na_2SO_4	2000	.192	.117	.027	0.96
Na_2SO_4	3000	.196	.162	.031	1.10
Na_2SO_4	3000	.183	.190	.020	1.09
Na_2SO_4	5000	.183	.340	.018	1.46
Na_2SO_4	7000	.193	.404	.014	1.62
$MgSO_4$	1000	.192	.023	.133	1.25
$MgSO_4$	2000	.173	.038	.159	1.37
$MgSO_4$	3000	.159	.022	.196	1.47
$MgSO_4$	3000	.195	.023	.127	1.23
$MgSO_4$	5000	.151	.020	.193	1.44
$MgSO_4$	7000	.151	.018	.302	2.01
$NaHCO_3$	1000	.237	.348	.040	1.74
$NaHCO_3$	2000	.239	.341	.041	1.73
$NaHCO_3$	3000	.244	.415	.046	1.95
$NaHCO_3$	3000	.205	.240	.017	1.26
$NaHCO_3$	5000	.198	.283	.019	1.36
$NaHCO_3$	7000	.183	.354	.027	1.54
NaCl	1000	.176	.119	.030	.94
NaCl	2000	.202	.179	.031	1.16
NaCl	3000	.193	.244	.031	1.30
NaCl	3000	.195	.265	.024	1.33
NaCl	5000	.188	.360	.023	1.55
NaCl	7000	.178	.589	.023	3.11

TABLE X. (Continued)

Salt	p.p.m.	% Ash	% Ca	% Mg	Sum Calculated as total salts NaCl, $CaCl_2$, $MgSO_4$
$MgCl_2$	1000	.163	.019	.117	1.08
$MgCl_2$	2000	.151	.028	.161	1.29
$MgCl_2$	3000	.140	.022	.194	1.51
$MgCl_2$	3000	.136	.019	.149	1.17
$MgCl_2$	5000	.153	.029	.266	1.80
$MgCl_2$	7000	.163	.042	.339	2.23
$CaCl_2$	1000	.288	.019	.014	.91
$CaCl_2$	2000	.356	.026	.023	1.17
$CaCl_2$	3000	.367	.022	.014	1.13
$CaCl_2$	3000	.378	.021	.019	1.20
$CaCl_2$	5000	.464	.022	.017	1.42
$CaCl_2$	7000	.568	.029	.020	1.73

increased. The magnesium and sodium content of the plants did not under go marked changes.

Table X shows the results of the analysis of the soils in which the geraniums watered with single salt solutions were grown.

The following list of salts show their toxic concentration and the calculated sum of soil salts or the toxic soil salt concentration.

Salt	Concentration in p.p.m.	Toxic soil salt concentration %
$MgSO_4$	1500	1.45
$NaHCO_3$	1500	
NaCl	1550	1.10
$MgCl_2$	1600	1.20
Na_2SO_4	2000	1.07
$CaCl_2$	2500	1.20

SUMMARY

A study was made to determine the concentrations at which seven commonly occurring saline and alkaline salt solutions are toxic to various greenhouse plants and to determine whether antagonism of ions and buffering by the salts produces a reduction of toxicity of salt mixtures. In this work the toxic concentration of a salt was defined as that concentration of salt expressed in parts per million which reduced the dry wieght of the experimental plants to half the weight of the controls.

The salts employed and their toxic concentrations as

established under experimental conditions may be arranged in order of their decreasing toxicity to tomato plants as follows:

Salt	Toxic concentration
$NaHCO_3$	1750 p.p.m.
NaCl	2000 "
$MgCL_2$	2300 "
$CaCl_2$	3000 "
Na_2SO_4	3500 "
$MgSO_4$	4000 "

The toxic soil salt concentrations calculated from their plotted values give in general the same order of toxicity for the salts as determined by the concentrations of single salt solutions toxic to tomato plants. These curves of the calculated soil salts may prove to be of value in determining whether or not a soil will permit successful greenhouse production.

The data presented for the salt mixture experiments substantiates the commonly recognized fact that salt mixtures are less toxic than individual salts. The addition of calcium sulfate to salt mixtures proved to be more effective than any other salt used in reducing toxicity of the salt mixtures.

The salts employed and their toxic concentrations as determined under experimental conditions may be arranged in order of their decreasing toxicity to geranium plants as follows:

Salt	Toxic Concentration
$MgSO_4$	1500 p.p.m.
$NaHCO_3$	1500 "
NaCl	1550 "
$MgCl_2$	1600 "
Na_2SO_4	2000 "
$CaCl_2$	2500 "

The order of toxicity of the salts are entirely different for the geranium and tomato plants. This would indicate that to determine the limit of tolerance of a specific plant individual experiments would be necessary. However, general conclusions are to be drawn from this experiment which should aid in determining whether the salt content of water or soil will permit successful greenhouse production.

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Typed by Betty Lewis.