GROWTH AND COMPOSITION OF LEAVES AND ROOTS IN RELATION TO THE SUPPLY OF CERTAIN ANIONS TO MONTMORENCY CHERRY TREES

By

EDWIN VILIS PARUPS

AN ABSTRACT

Submitted to the School of Graduate Studies of Michigan
State University of Agriculture and Applied Science
in partial fulfillment of the requirements
for the degree of

DOCTOR OF PHILOSOPHY

Department of Horticulture

1955

Approved ____________________

EDWIN VILIS PARUPS ABSTRACT

The influence of anion supply on growth and the chemical composition of leaves and fibrous roots of Montmorency cherry trees was studied by means of nutrient culture methods. The amounts of cations (potassium, calcium and magnesium) and minor elements were kept constant. Anions (sulphate, chloride, phosphorus, nitrogen, and carbonate) were varied. Eighteen different nutrient solutions were obtained. Seventy-two one-year-old Montmorency cherry trees were selected, pruned uniformly, weighed, and planted in clay pots in the greenhouse. Coarse sand was used as growing media. Trees were arranged in four replicates and randomized. Trees were harvested and the linear growth was measured and dry weight of leaves, shoots, roots, and trunk was obtained. Leaves and fibrous roots were analyzed for twelve elements--nitrogen, phosphorus, chlorine, sulfur, potassium, calcium, magnesium, iron, manganese, copper, boron, and zinc.

Increased supply of anions had a significant effect upon growth. When the supply of these anions was increased to a high level apparent toxicity appeared as indicated by reduction of growth and the appearance of chloride toxicity symptoms. These symptoms were: marginal and tip burning of leaves. Omission of sulfate under certain conditions resulted in visible sulfur deficiency symptoms. The leaves with these symptoms exhibited the typical yellowing of midrib and veins.

In general, the absorption of various anions was proportional to their supply; however, some interactions were present. Chlorine content was reduced by nitrogen and phosphorus. Sulfur and chlorine did not affect the absorption of each other. The presence of high concentrations of sulfate and chloride increased the absorption of nitrogen from solutions containing large amounts of nitrogen. Nitrogen absorption was favored by the presence of large quantities of chloride and phosphorus in combination. The presence of large quantities of chloride and nitrogen in combination appeared to increase phosphorus absorption.

Potassium levels in leaves and roots were generally higher when sulfate was present. Large quantities of chloride reduced potassium absorption. Potassium absorption was favored by carbonate, but was depressed by high nitrogen. Calcium and magnesium absorption was depressed by sulfate. Increasing supplies of nitrogen and phosphorus reduced the sulfate effect upon calcium absorption. High nitrogen in presence of chloride depressed calcium uptake. The supply of anions appeared to reduce the influence of potassium and calcium upon the absorption of magnesium. Iron content in leaves was depressed by phosphorus, but carbonate and sulfate increased its content in roots. Larger supplies of sulfate, chloride, and nitrogen appeared to increase the copper content of the roots. Zinc absorption by leaves was decreased by larger supplies of sulfate, while chloride depressed zinc content in the roots. Manganese absorption was increased with high levels of chloride and was further aided by nitrogen additions. Higher levels of phosphorus depressed manganese content of the roots, but increased it in the leaves.

Root growth was relatively promoted, or shoot growth retarded, by high sulfate or chloride, high phosphorus, or by combinations of sulfate and chloride in approximately equal concentrations.

Some suggestions were advanced in regard to the prevention of chloride toxicity of plants. The balance and supply of anions and their importance in plant nutrition were emphasized.

GROWTH AND COMPOSITION OF LEAVES AND ROOTS IN RELATION TO THE SUPPLY OF CERTAIN ANIONS TO MONTMORENCY CHERRY TREES

By

EDWIN VILIS PARUPS

A THESIS

Submitted to the School of Graduate Studies of Michigan
State University of Agriculture and Applied Science
in partial fulfillment of the requirements
for the degree of

DOCTOR OF PHILOSOPHY

Department of Horticulture

1955

ACKNOWLEDGMENTS

The author wishes to express his sincere appreciation to Dr. A. L. Kenworthy, who spent much time and assisted in planning the experiment, and in the preparation of the manuscript; to Drs. H. B. Tukey, C. R. Megee, G. P. Steinbauer, and K. Lawton for their guidance and editing of the manuscript, and to Dr. E. J. Benne and his staff for carrying out the chemical analyses.

The author is grateful to the Agricultural Institute of Canada for its financial assistance during the course of this study.

Special acknowledgment is made to Mr. George Wilson, and to the author's wife, Margaret, for their constant encouragement and assistance.

TABLE OF CONTENTS

INTRODUCTION

Anions, such as nitrogen, phosphorus, sulfur, and chlorine are important elements in plant nutrition. They are also important as carriers of cations; i. e., potassium, calcium, magnesium, manganese, and iron.

Numerous studies have shown that these and other elements interact in complex ways with each other in influencing the growth of plants.

Optimal growth of plants may occur only where the nutrients are taken up in certain relative proportions. The excess or inadequacy of one element may lead to an insufficiency or over-abundance of another element with consequent detrimental effects to the plants. Cation relationships and antagonisms have been studied extensively, however little is known about the anion influence upon the absorption of anions and cations as related to growth.

The purpose of this study was to ascertain the role and interaction of nitrogen, phosphorus, sulfur, and chlorine upon each other and other nutrient-elements. It was hoped to establish the anion-anion and anion-cation relationships and their influence by recording the growth measurements, leaf, and root analysis of one-year-old sour cherry (*Prunus cerasus* L.) trees grown in sand cultures. The Montmorency variety was chosen because of its economic importance to this region.

LITERATURE REVIEW

The essentiality of anions, such as nitrogen, phosphorus, and sulfur as plant nutrients is generally known and accepted. Chlorine, on the other hand, has been considered to be non-essential. With some species, applications of chlorides have resulted in retardation of plant growth, while with other species a definite beneficial effect was noticed. Lipman (32) found that chloride, if not actually essential, definitely benefited the growth of buckwheat and peas. Only recently Broyer *et al.* (5) showed that chloride is an essential element for higher plants. They contended that the chlorine requirement was not small in comparison to other micronutrients and may be higher than iron, boron, manganese, zinc, copper, and molybdenum. They also stated that bromine appeared to compliment chlorine when supplied at about ten times the required chlorine levels. This statement conveyed the idea that there may be a substitution of ions whereby one ion may replace another physiologically related ion; i.e., chlorine was replaced by bromine.

Bear's work (2) with cation constancy in alfalfa established the principal of cation or anion constancy. According to his report, if one ion is being absorbed to a lesser extent, some other ion or ions must be absorbed to a greater extent to keep the sum of ions constant.

Overstreet and Dean (44) summarized their findings as follows: '"The ion absorption process is an exchange process. Predominantly cations are absorbed in exchange for H-ions of the plant and are released to the culture medium. Anions are absorbed in exchange for OH^- or HCO_3^- which are released to the culture medium. The evidence indicates that no ion passes in or out of a healthy plant except by exchange for another ion. Ion accumulation is to a large extent selective. Due to the exchange character of the process, anions can enter the plant independently of cations, and vice versa. Also, ions are not absorbed at the same rates. In general, the cations K+, NH_4+, Rb+, and Cs+ are rapidly accumulated, while Ca++, Mg++, and Ba++ are much more slowly taken up. The anions NO_3-, Br-, and Cl- are usually rapidly absorbed. The anions SO_4-- and H_2PO_4- are moving rather slowly; the anion HCO_3- is apparently not absorbed at all."

Overstreet and Dean also stated that the different elements showed rather widely different longitudinal absorption patterns in the root tips. Regions in the tissue which absorb H_2PO_4- very rapidly do not necessarily absorb I- rapidly.

This idea was further elucidated by Epstein (16). He stated that the absorption of ions, cations as well as anions, entails the combination of the ion with metabolically generated binding compounds or carriers.

These carrier-ion complexes are labile and break down again, releasing the ion to the interior of the cell. The carriers possess several distinct binding sites which differ in their affinities for various ions, according to the chemical characteristics of the ions. He found that chlorine interfered with bromine uptake. Bromine uptake was again hindered by iodine. Halides were competitive with respect to one another--they were bound by the same binding sites. In contrast, it was found that nitrate did not interfere with bromine--nitrate does not compete for the halide binding sites.

Lundegårdh (33) stated that although the uptake of anions takes place on the basis of a particular mechanism (anion respiration), there is a general ionic equilibrium between anions and cations. A unilateral uptake of anions can proceed for a short period, but eventually an acidification of the protoplasm will take place, and this, in turn, on the basis of increased electronegative charge, will bring about an increased attraction of cations. In addition to the action of the general anion + cation balance, the anions also influence the movement of cations because of growth promoting effect. They may also determine to a certain extent the colloidal state and the membrane permeability of the protoplasm. Thus, the uptake of anions creates the absorption potential for cation uptake. This explains, in part, the importance of correct balance of anions and cations.

There has not been much work conducted to determine the influence of one anion upon another. At the same time a certain amount of disagreements are evident. Several authors have arrived at different conclusions, perhaps because of using different species or experimental techniques.

Hamner (25) pointed out that the relationship between phosphorus and nitrogen in soybean is important in overcoming the toxicity of phosphorus. He stated that one part of nitrate will overcome the toxic effects of two parts of phosphorus. In older plants this ratio may be different. He concluded that phosphorus is toxic in very small amounts if nitrogen is lacking, but it is not toxic even in fairly high concentrations if larger amounts of nitrogen is present.

Also, Mullison's (39) experiments with barley seedlings showed the apparent toxicity of phosphorus in absence of nitrate, or when a high phosphate-low nitrate ratio existed.

Breazeale (4) found that phosphate absorption of wheat seedlings was slightly increased by nitrate. Eaton (13) grew sunflower plants in plus and minus phosphorus media. He found that total nitrogen was higher in the plus phosphorus plants. The same conditions were found with black mustard (15).

McCalla (36) on the other hand, working with wheat, found that when nitrogen was limiting, the effect was chiefly felt in increased phosphorus absorption. In one case the increased phosphorus absorption resulting from limiting nitrogen supply was fully equivalent to the decreased nitrogen uptake.

Nitrate accumulation under phosphorus deficiency was found also by Richards and Templeman (47), and Eaton (14). Colby (8) in an experiment with French prune trees, also investigated nitrogen and phosphorus relationships. He found that nitrogen starvation resulted in low ash content, except in the wood, and very low nitrogen throughout. The young wood was normal in phosphorus. Main roots were extremely low in nitrogen and low in phosphorus. Phosphorus starvation resulted in leaf tissue high in ash and nitrogen, and low in phosphorus. All the other parts were low in nitrogen.

This picture of nitrogen-phosphorus relationships is further complicated by Mulder's (39) citation of Alberda's work. Alberda found, working with Zea Mays that the uptake of phosphorus was running parallel to the growth of the whole plant. Absorption of phosphorus was found to be independent of the concentration of other anions (nitrate, sulfate, chloride) in the solution.

According to Leonard and others (31), who worked on sweet potatoes, the sulfate ions seem to depress the absorption of nitrate ions to a greater extent than the phosphate ions.

Ergle (18) working with cotton, Nightingale and others (42) with tomato, and Eaton (11, 12) with soybeans and sunflower, found nitrate or nitrogen accumulation in sulfur deficient plants. Sulfur deficiency in cotton caused an accumulation of nitrate and soluble organic nitrogen in the leaves. In contrast, nitrogen deficiency reduced the accumulation of sulfate and organic sulfur in the leaves.

Also Gauch and Wadleigh (19) reported, from their work with beans, the tendency for nitrogen to decrease in plant tissues with increasing amounts of calcium chloride, sodium chloride, and sodium sulfate in the media. The sodium chloride series gave consistently higher nitrogen values. The concentration of sulfate in the roots was very closely paralleled by a similar increase of sulfate in the leaves. Also, in another report they (20) found that the increasing amounts of chloride resulted in decreased absorption of phosphate and nitrogen.

Colby (8) indicated that sulfur deficiency of French prune trees resulted in leaf tissue low in nitrogen and ash, and also low in sulfur content.

In the recent work with avocados by Haas and Brusca (24) an observation was made that chloride content of plants was considerably lower where nitrogen and sulfate or phosphate were applied.

The importance of anion influence upon cations may be very well illustrated by Kenworthy's (29) recent work. He found that grapes and peaches absorbed more potassium from soils supplied with potassium sulfate than from soils supplied with potassium chloride.

Vinet's (51) opinion was that the sulfate ion, when applied with the potassium ion, proved to be better than the chloride ion. In his opinion, the chloride ion hindered the action of the potassium, while the sulfate ion favored this action by increasing potassium uptake by grapes.

Gilbert and others (21) arrived at a different conclusion: Leaves of tung trees accumulated more potassium when the plants were supplied with monovalent anions than when the potassium was supplied from polyvalent salts. The anions in question were chloride, nitrate, sulfate, tartrate and pectate

Carolus (6) observed that nitrate, phosphate, chloride, and sulfate had no detrimental influence on calcium intake and utilization by the bean plant. The nitrate and phosphate anions had a slight detrimental effect on potassium absorption, and probably a slight detrimental effect on magnesium utilization.

Colby's (8) investigations, mentioned earlier in respect to sulphur and nitrogen relationships, revealed also that French prune trees had very high calcium and magnesium and normal potassium in the wood correlated with nitrogen deficiency. Also, young roots were low in calcium and magnesium and high in potassium. Main roots were extremely low in nitrogen, low in magnesium and high in calcium. Phosphorus deficiency resulted in leaf tissue high in magnesium and iron, but low in calcium. The roots were low in magnesium. Sulfur deficiency decreased potassium and increased magnesium and calcium absorption.

Sulfur deficiency in cotton, according to Ergle and Eaton (17) resulted in accumulation of calcium and magnesium; iron and potassium were changed little.

Also, Naguib and Overstreet (41) indicated that the chloride ion may depress growth. Different sodium salts depressed the elongation of the radish seedlings in the following order: $NaHCO_3$, NaCl, Na_2SO_4, NaH_2PO_4 and $NaNO_3$. Stimulation was observed in the lower concentration range of $NaNO_3$. They pointed out that the extremely toxic effect of $NaHCO_3$ is in agreement with previous work. The same effect was noted also with $CaCl_2$ and $Ca(NO_3)_2$. $CaCl_2$ resulted in maximum depression of the elongation.

Hayward and Long (26) found that high concentration (2836 ppm Cl, 7684 ppm SO_4) of either chloride or sulfate salts resulted in a marked reduction in the diameter of peach stems. The reduction of linear growth was also the same with either high chloride or sulfate levels. There was somewhat less depression at the intermediate chloride level. The leaves of high chloride treatment were showing marked chlorosis, tip, and marginal burning, and there was considerable abscission.

Magistad and others (34) found that chloride and sulfate salts, when compared on the basis of equal osmotic concentration, depressed growth to an equal extent with a number of crops. With other crops, chloride ions were slightly more toxic than sulfate ions at equal osmotic concentration. Total salt concentration was a greater factor in determining the amount of growth reduction than effects caused by specific ions.

Corn and tomato plants, according to Eaton (9) developed more roots in dilute than in concentrated solutions when grown with their roots divided between two or more solutions of unequal concentrations. The foregoing was found irrespective of whether the differences in concentration were affected by the addition of chloride, sulfate, or additional nutrient salts to the base nutrient. Little difference in water uptake or in root growth resulted in solutions of similar osmotic pressure when one part of root was high in chloride, and the other in complete nutrient media, indicating that osmotic pressures rather than specific ion effects were primarily involved.

Naguib and Overstreet (41) disagreed with the above conclusions. They contended that the depressing effect of salt on the elongation of the radish seedling was due to the inhibitory effect of the different elements and not to the increased osmotic pressure of the culture medium and the resulting restriction in availability of water to the plant. They found that there is a much greater divergence in the inhibition effect with cations than with anions, and agree with Mullison (39) in this respect.

Chlorine has been reported to have a favorable influence upon the water balance of the plant, according to Haas (24). At the same time, large amounts of chlorides have been found to decrease the total sum of carbohydrates in potato leaves, according to Baslavskaja (1) and thus may have been associated with a lowered content of chlorophyll per unit leaf area and weakened photosynthetic activity.

MATERIALS AND METHODS

To obtain combinations of nutrient solutions with different amounts of anions, the standard solution of Hoagland (27) was taken as a basis. The amounts of cations (potassium, calcium, and magnesium) and minor elements were kept constant. Anions were varied without altering the cation content by using different amounts of various chemicals containing the anions involved (Appendix Table 1). Eighteen different solutions (Table 1) were obtained by dissolving the chemicals in distilled water, using only C.P. grade chemicals. Solu-bridge (conductivity) readings were taken on each solution with Solu-bridge (model DR-15). pH was measured with Beckman pH meter, model G.

Seventy-two one-year-old sour cherry trees (*Prunus cerasus* L. var. Montmorency) budded on *Prunus Mahaleb* rootstocks were chosen. The trees were pruned uniformly and divided in four size groups according to the weight after pruning. Trees with approximately the same weight were put in the same replicate, thus making four replicates for each treatment. The average green and dry weights of four representative trees were obtained, and the per cent of dry matter calculated was used later to calculate dry weight at planting time.

Table 1

Treatment Numbers, Chloride, Sulfate, Phosphorus, Nitrogen, and Carbonate Content (Ppm), pH, and Solu-bridge (Conductivity) Readings of Nutrient Solutions.

Treatment No.	Anions (Ppm) Cl	SO_4	P	N	CO_3	pH	Conductivity Mhos x 10^{-5}
1 (check)	0	190	31	210	0	5.8	170
2	177	432	31	210	0	5.2	234
3	247	0	31	210	0	5.5	190
4	350	192	31	210	150	7.8	250
5	350	380	31	210	0	5.6	300
6	350	432	31	210	0	5.4	400
7	527	192	31	210	0	5.2	390
8	671	0	31	210	0	5.1	380
9	0	672	31	210	0	5.3	320
10	0	0	31	196	0	5.6	225
11	140	0	338	210	0	5.5	185
12	327	0	419	210	0	5.8	240
13	0	480	31	210	0	6.2	210
14	0	480	150	210	0	6.1	210
15	490	0	31	210	180	7.7	240
16	671	0	31	630	0	5.6	400
17	0	672	31	630	0	7.2	440
18	0	432	31	210	150	6.6	225

Note: Cation concentrations (ppm) were: potassium - 234, calcium - 200, magnesium - 48. Minor element concentrations (ppm) were: iron - 1.0, manganese - 0.5, copper - 0.2, boron - 0.5, and zinc - 0.5.
N - supplied as NO_3^- and NH_4^+; P - as $PO_4^{\equiv}$ (Appendix Table 1).

The trees were planted in 12-inch pots in the greenhouse on January 13, 14 and 15. The pots were previously painted inside with an asphalt paint in order to avoid any possible root contact with the surface of the clay pots. Coarse sand was used as the growing media.

The pots and trees were numbered and arranged in randomized blocks on two greenhouse benches. Each plant received one quart of solution every second day. Later, when growth was vigorous, and the day temperature was higher, each plant was given one quart of solution daily.

The trees were harvested on May 21, 23 and 24. Linear growth, dry weight of leaves, shoots, roots, and trunk was obtained, and the total increase in dry weight was calculated. Fibrous roots were separated from the root system and prepared for analysis.

Leaves and fibrous roots from each tree were analyzed chemically in the laboratories of Agricultural Chemistry Department. Nitrogen was determined by the Kjeldahl method, potassium by flame photometer, and chlorine according to a modified method by Samson (47). Phosphorus, calcium, magnesium, manganese, iron, zinc, and boron were determined spectrographically. Sulfur was determined gravimetrically for trees in certain treatments according to A. O. A. C. (42) methods.

RESULTS

General Responses

Linear growth, weight of leaves, weight of shoots, weight of fibrous roots, and increase in dry weight as influenced by the various treatments are presented in Table 2. Statistical analysis showed that there were significant differences between treatments for all measurements of growth.

Increase in dry weight varied from 17.76 grams to 125.30 grams per tree. The length of shoot growth varied from 57.3 cm. to 319.8 cm. per tree. Similar variations were found for dry weight of leaves, shoots, and fibrous roots.

Results of the chemical analysis of leaves are presented in Table 3. All elements, except boron and copper, showed statistically significant differences, depending on the anion treatments.

Leaf analysis for nitrogen and potassium resulted in values considerably above those found under field conditions. Although there were no variations in the concentration of potassium, calcium, magnesium, and other cations, leaf analyses for these elements showed large variations between treatments. The greatest variation in leaf composition was found for chlorine.

Table 2

Treatment Numbers and Growth Measurements*

Treatment No.	Total Growth (Gms)	Linear Growth (Cms)	Leaves (Gms)	Shoots (Gms)	Fibrous Roots (Gms)
1 (check)	125.30	250.2	33.19	25.68	16.90
2	70.60	217.8	24.27	15.55	17.95
3	93.85	206.0	26.07	19.69	16.75
4	32.50	69.6	11.21	4.56	10.87
5	44.47	125.7	16.53	9.27	11.27
6	40.42	143.3	16.40	8.14	14.02
7	40.75	127.1	16.90	8.52	10.62
8	25.70	61.0	10.13	4.0	8.70
9	36.67	57.3	11.59	4.98	10.80
10	90.32	180.8	22.80	20.16	15.40
11	53.80	160.1	18.16	10.08	14.32
12	39.65	168.6	14.72	8.23	14.12
13	104.99	213.0	35.38	25.24	15.92
14	90.21	319.8	31.29	22.59	20.82
15	49.98	171.1	17.61	10.04	12.50
16	24.08	74.6	13.46	5.08	7.65
17	17.76	78.3	10.67	4.62	5.10
18	118.84	277.5	33.71	23.46	18.40
L.S.D. 5%	23.52	69.78	4.004	4.870	5.30
1%	31.36	93.04	5.339	6.504	7.07

*The composition of nutrient solutions is given in Table 1.

Table 3

Treatment Numbers and Composition of Cherry Leaves*

Treatment No.		Elements (Per Cent in Dry Matter)										
	N	P	Cl	S	K	Ca	Mg	Fe	Mn	Zn	B	Cu
1 (check)	3.23	0.15	0.0015	0.222	4.40	2.02	0.60	0.013	0.0051	0.0031	0.0045	0.0023
2	3.68	0.34	0.436		3.13	1.48	0.65	0.040	0.0213	0.0014	0.0122	0.0018
3	3.33	0.18	0.737	0.175	3.78	2.27	0.74	0.023	0.0148	0.0028	0.0075	0.0023
4	3.80	0.44	1.105		2.37	1.95	0.75	0.035	0.0183	0.0027	0.0106	0.0024
5	3.63	0.38	1.240	0.446	2.39	1.43	0.73	0.016	0.0164	0.0022	0.0098	0.0010
6	3.67	0.44	1.154		2.00	2.69	0.94	0.021	0.0321	0.0016	0.0145	0.0022
7	3.42	0.40	1.647		2.12	2.99	1.05	0.026	0.0357	0.0024	0.0136	0.0014
8	3.83	0.53	1.236	0.209	2.08	3.42	0.91	0.025	0.0203	0.0035	0.0095	0.0016
9	3.35	0.21	1.130	0.751	3.53	0.77	0.42	0.010	0.0072	0.0008	0.0041	0.0008
10	3.23	0.15	0.0007	0.130	4.51	3.00	0.80	0.019	0.0060	0.0042	0.0024	0.0023
11	4.26	1.21	0.103		3.30	1.14	0.60	0.010	0.0138	0.0008	0.0137	0.0015
12	3.82	1.87	0.404		2.78	0.98	0.53	0.006	0.0159	0.0018	0.0064	0.0005
13	3.52	0.26	0.0007	0.328	4.10	1.21	0.41	0.018	0.0150	0.0012	0.0136	0.0017
14	3.62	0.60	0.0008	0.426	4.10	1.94	0.53	0.019	0.0256	0.0016	0.0151	0.0027
15	3.70	0.35	1.042		2.46	2.88	0.76	0.031	0.0211	0.0044	0.0084	0.0019
16	5.16	0.73	0.653		2.08	2.56	0.78	0.022	0.0231	0.0028	0.0075	0.0046
17	4.23	0.39	0.0013	0.443	3.05	1.21	0.46	0.018	0.0091	0.0011	0.0080	0.0011
18	3.43	0.14	0.0010		5.80	1.15	0.30	0.011	0.0047	0.0006	0.0090	0.0026
L.S.D 5%	0.49	0.36	0.55	0.82	1.44	0.45	0.30	0.017	0.0117	0.0020	--	--
1%	0.65	0.48	0.74	0.112	1.93	--	0.42	--	0.0156	--	--	--

*The composition of nutrient solutions is given in Table 1.

The chemical composition of fibrous roots is shown in Table 4. Sulfur values were not determined. All elements showed statistically significant differences.

Root composition was affected less than leaf composition by the variation in the supply of anions. The nitrogen, potassium, manganese, zinc, and copper content of the roots were comparable to leaf contents. However, phosphorus, chlorine, and iron were considerably higher in roots than in leaves, but less variable in the roots.

Table 4

Treatment Numbers and Composition of Fibrous Roots*

Treatment No.	Elements (Per Cent in Dry Matter)										
	N	P	Cl	K	Ca	Mg	Fe	Mn	Zn	B	Cu
1 (check)	2.67	0.78	0.060	1.91	1.18	0.28	0.239	0.0263	0.0030	0.0078	0.0018
2	3.14	0.79	0.573	1.83	0.47	0.21	0.211	0.0141	0.0014	0.0066	0.0029
3	2.79	0.58	0.528	1.60	0.92	0.31	0.274	0.0590	0.0023	0.0057	0.0027
4	2.94	0.69	0.800	1.89	0.59	0.21	0.295	0.0227	0.0018	0.0050	0.0030
5	2.97	0.79	0.817	1.78	0.51	0.19	0.206	0.0088	0.0013	0.0063	0.0026
6	3.37	0.64	0.676	1.50	0.52	0.20	0.243	0.0103	0.0015	0.0057	0.0037
7	3.39	0.73	0.828	1.51	0.48	0.20	0.188	0.0078	0.0016	0.0062	0.0032
8	3.21	0.75	0.825	1.32	0.49	0.18	0.199	0.0136	0.0014	0.0059	0.0035
9	2.84	0.64	0.801	1.62	0.51	0.18	0.272	0.0088	0.0014	0.0053	0.0032
10	2.94	0.92	0.043	1.55	1.34	0.29	0.180	0.0420	0.0031	0.0066	0.0025
11	3.09	2.17	0.224	1.52	0.51	0.18	0.274	0.0291	0.0015	0.0093	0.0033
12	3.36	1.90	0.289	1.21	0.55	0.19	0.218	0.0144	0.0033	0.0095	0.0031
13	2.97	0.81	0.056	1.45	0.83	0.22	0.296	0.0599	0.0037	0.0083	0.0037
14	3.20	1.19	0.030	1.18	0.67	0.21	0.295	0.0230	0.0024	0.0090	0.0036
15	3.23	0.64	0.816	1.63	0.68	0.21	0.272	0.0200	0.0019	0.0057	0.0030
16	3.55	0.77	0.156	0.75	0.54	0.17	0.344	0.0121	0.0013	0.0065	0.0044
17	4.01	0.78	0.038	1.10	0.58	0.17	0.324	0.0130	0.0017	0.0064	0.0038
18	2.88	0.86	0.053	2.17	1.04	0.24	0.416	0.0540	0.0023	0.0094	0.0031
L.S.D. 5%	0.33	0.24	0.141	0.31	0.19	0.028	0.109	0.0119	0.00115	0.0019	0.00051
1%	0.45	0.32	0.187	0.41	0.26	0.037	--	0.0159	0.00154	0.0026	0.00068

*The composition of nutrient solutions is given in Table 1.

Influence of Sulfate Concentration

Growth

A certain amount of sulfate appeared to be necessary for maximum increase in dry weight (Table 5). When no sulfate was used all measurements of growth was significantly lower than that obtained from a solution containing 190 ppm of sulfate. A foliage symptom developed and leaves abscissed when no sulfate was used (Figure 1). Increasing the level of sulfate up to 480 ppm decreased growth; however, the decrease was not significant. A pronounced reduction of growth occurred when the sulfate concentration of the nutrient solution was increased to 672 ppm (Figure 2).

Leaf Composition

Table 6 shows the influence of increasing the sulfate content of nutrient solutions upon the chemical composition of the leaves. Nitrogen and phosphorus levels did not change appreciably, although there was a tendency to have higher levels of these elements with increasing amounts of sulfate. Since no chloride was applied, only traces of this element were present, except for treatment 9. The leaves from this treatment were found to contain an unusual amount of chlorine (1.13 per cent)

Table 5

Influence of Sulfate Concentrations in Nutrient Solutions upon the Growth of Montmorency Cherry Trees.

Treatment No.	Anions Varied (Ppm)	Increase in Dry Weight (Gms)	Leaves (Gms)	Shoots (Gms)	Fibrous Roots (Gms)	Linear Growth (Cms)
10	SO_4-0	90.32	22.80	20.16	15.40	180.8
1	SO_4-190	125.30	33.19	25.68	16.90	250.2
13	SO_4-480	104.99	35.38	25.24	15.92	213.0
9	20_4-672	36 67	11.59	4.98	10.80	57.3
	L.S.D 5%	23.52	4 004	4 870	5.30	69.78
	1%	31.36	5.339	6.504	7.07	93.04

Table 6

Relationship of Sulfate Concentration in Nutrient Solution to Chemical Composition of Montmorency Cherry Leaves.

Elements (Per Cent)	Treatment Numbers and Anions Varied (Ppm)				L.S.D.	
	10	1	13	9		
	SO_4-0	SO_4-190	SO_4-480	SO_4-672	5%	1%
Nitrogen	3.23	3.23	3.52	3.35	0.49	0.65
Phosphorus	0.15	0.15	0.26	0.21	0.36	0.48
Chlorine	0.0007	0.0015	0.0070	--	0.55	0.74
Sulphur	0.130	0.222	0.328	0.751	0.090	0.124
Potassium	4.51	4.40	4.10	3.53	1.44	1.93
Calcium	3.00	2.02	1.21	0.77	0.45	--
Magnesium	0.80	0.60	0.41	0.42	0.31	0.42
Iron	0.019	0.013	0.018	0.010	0.017	--
Manganese	0.0060	0.0051	0.0150	0.0072	0.0117	0.0156
Zinc	0.0042	0.0031	0.0012	0.0008	0.0020	--

Figure 1. Sulfur deficiency on Montmorency cherry trees.
(Sulfur content of leaves 0.13 per cent)


A
10

Figure 2. Growth in relation to sulfate content of the nutrient solutions. (On left, 190 ppm sulfate; on right, 672 ppm sulfate).


A
1


B
9

Since the phenomenon could not be explained, the data were omitted. The sulfur content of the leaves was proportional to the sulfate level of the nutrient solution. Sulfate levels of 480 and 672 ppm resulted in a significant increase in the sulfur content of the leaves. Potassium levels tended to decrease with increasing levels of sulfate. Calcium content of the leaves declined significantly with increasing sulfate in the nutrient solutions. Also, the magnesium content of the leaves was reduced significantly with the higher levels of sulfate. Iron and manganese values showed no relationship to sulfate ion concentration and no significant differences were found. The zinc analyses were significantly lower for solutions containing larger amounts of sulfate.

Root Composition

Table 7 shows that increasing the amount of sulfate in the solutions did not affect the nitrogen content of roots. The phosphorus content of roots from trees receiving the high level of sulfate contained significantly less phosphorus than where no sulfates were used. Chlorine was present in uniform amounts, although higher than found in the leaves. Leaf potassium was highest with 190 ppm of sulfate, and was significantly higher than for the other concentrations of sulfate. Calcium and magnesium content of the roots declined significantly with increasing concen-

Table 7

The Chemical Composition of Fibrous Roots from Montmorency Cherry Trees in Relation to Sulfate Concentration in the Nutrient Solutions.

Elements (Per Cent in Dry Matter)	Treatment Numbers and Anions Varied (Ppm)				L. S. D.	
	10	1	13	9		
	SO_4-0	SO_4-190	SO_4-480	SO_4-672	5%	1%
Nitrogen	2.94	2.67	2.97	2 84	0.33	0.45
Phosphorus	0.92	0.78	0.81	0.64	0.24	0.32
Chlorine	0.043	0 060	0.056	--	0.141	0 187
Potassium	1.55	1.91	1.45	1 62	0 31	0.41
Calcium	1.34	1.18	0.83	0.51	0.19	0 26
Magnesium	0.29	0.28	0.22	0.18	0.028	0.037
Iron	0.180	0.239	0.296	0.272	0.109	--
Manganese	0.0420	0.0263	0.0599	0.0088	0.0119	0.0159
Copper	0.0025	0.0018	0.0037	0.0032	0.00051	0.00068
Boron	0.0066	0.0078	0.0083	0.0053	0.0019	0.0026
Zinc	0.0031	0.0030	0.0037	0.0014	0.00115	0 00154

trations of sulfate. The treatment using 480 ppm of sulfate resulted in significantly higher manganese values than found for the other sulfate concentrations. The manganese content of the roots was significantly reduced with the use of 672 ppm of sulfate in the solution. The boron content of the roots was increased with medium concentrations of sulfate, but higher concentrations of sulfate resulted in a level of boron comparable to that found when the sulution contained no sulfates. High sulfate (672 ppm) caused a significant decrease in the zinc content of the roots. The copper content of the roots was significantly increased with higher concentrations of sulfate. Also, the copper content was higher for the solution containing 480 ppm of sulfate than for the solutions containing 672 ppm of sulfate.

Influence of Chloride Concentration

Growth

A moderately high level of chloride (247 ppm) did not have any influence upon growth (Table 8). Increasing the chloride content of the nutrient solution to a concentration of 671 ppm significantly reduced all measurements of growth (Figure 3) with some chloride injury occurring when the solution contained 671 ppm of chloride.

Leaf Composition

Leaf nitrogen, phosphorus, and chlorine levels increased significantly with increasing amount of chloride in nutrient solutions, as shown in Table 9. There was a non-significant increase in the sulfur content of the leaves with increased chlorine contents. Potassium levels decreased as the chlorine concentration increased, and the difference between the two extremes (671 and 0.0 ppm of chloride) was highly significant. Calcium level sharply decreased when the chloride level was increased from 0.0 to 247 ppm, but increased again with higher concentrations of chloride. These changes were significant. Magnesium, although not significantly influenced, followed the same trend as shown for calcium. Iron and zinc content of the leaves showed no significant

Table 8

Influence of Chloride Concentrations in Nutrient Solutions upon the Growth of Montmorency Cherry Trees.

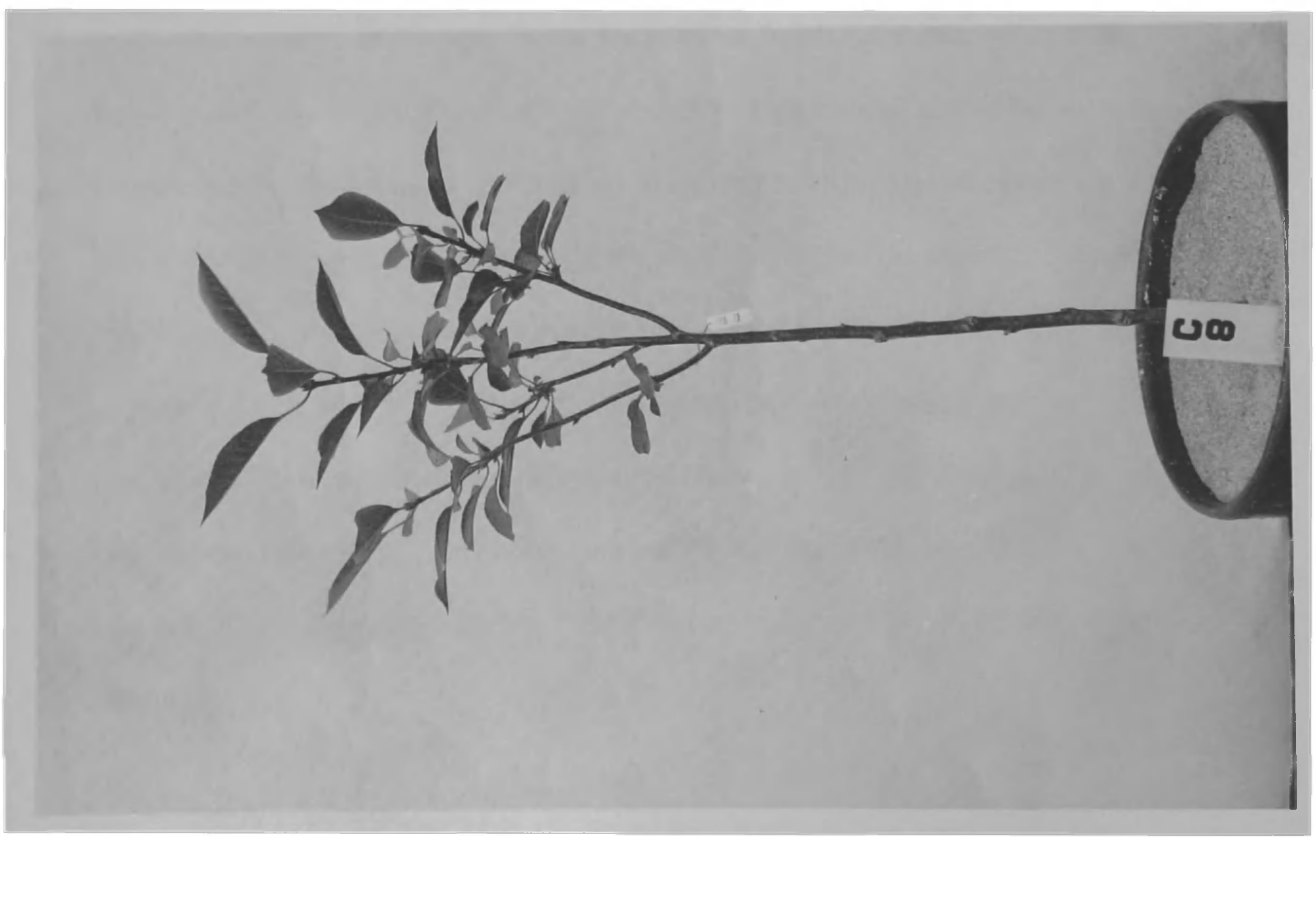
Treatment No	Anions Varied (Ppm)	Increase in Dry Weight (Gms)	Leaves (Gms)	Shoots (Gms)	Fibrous Roots (Gms)	Linear Growth (Cms)
10	Cl-0	90. 32	22. 80	20. 16	15. 40	180. 8
3	Cl-247	93. 85	26. 07	19. 69	16. 75	206. 0
8	Cl-671	25. 70	10. 13	4. 0	8. 70	61. 0
	L. S. D. 5%	23. 52	4. 004	4. 870	5. 30	69. 78
	1%	31. 36	5. 339	6 504	7. 07	93. 04

Table 9

Relationship of Chloride Concentration in Nutrient Solutions to Chemical Composition of Montmorency Cherry Leaves.

Elements (Per Cent in Dry Matter)	Treatment Numbers and Anions Varied (Ppm)			L. S. D.	
	10	3	8		
	Cl-0	Cl-247	Cl-671	5%	1%
Nitrogen	3.23	3.33	3.83	0.49	0.65
Phosphorus	0.15	0.18	0.53	0.36	0.48
Chlorine	0.0007	0.737	1.236	0.55	0.74
Potassium	4.51	3.78	2.08	1.44	1.93
Calcium	3.00	2.27	3.42	0.45	--
Magnesium	0.80	0.74	0.91	0.30	0.42
Iron	0.019	0.023	0.025	0.017	--
Manganese	0.0060	0.0148	0.0203	0.0117	0.0156
Zinc	0.0042	0.0028	0.0035	0.0020	--

Figure 3. Chloride injury to Montmonency cherry trees. Left, growth resulting from 671 ppm chloride; Right, visible symptoms of chloride injury. Chloride content of leaves 1.236 per cent.


C8

differences resulting from the various concentrations of chloride. Higher concentrations of chloride significantly increase manganese in the leaves.

Root Composition

Nitrogen in the roots (Table 10) had the highest values with the higher chloride treatments. There was a significant increase in the nitrogen percentage when the chloride was increased from 247 to 671 ppm. Phosphorus was highest where there was no chloride. With a moderately high chloride level (247 ppm), the phosphorus content decreased significantly. Further increases of chloride produced slight, non-significant increases in phosphorus quantities, but the phosphorus content was lower than that found when the solution contained no chlorides. Potassium and magnesium in the roots appeared to be reduced with the highest level of chloride in the solution. Increasing amounts of chloride in the solution significantly reduced the calcium content of the roots. Manganese content decreased significantly with the higher (672 ppm) chloride level in the solution. Copper content of the roots increased, and zinc content of the roots decreased with increasing amounts of chloride in the solutions. Boron level was not affected.

Table 10

The Chemical Composition of Fibrous Roots from Montmorency Cherry Trees in Relation to Chloride Concentration in the Nutrient Solutions.

Elements (Per Cent in Dry Matter)	Treatment Numbers and Anions Varied (Ppm)			L. S. D.	
	10	3	8		
	Cl-0	Cl-247	Cl-671	5%	1%
Nitrogen	2.94	2.79	3.21	0.33	0.45
Phosphorus	0.92	0.58	0.75	0.24	0.32
Chlorine	0.043	0.528	0.825	0.141	0.187
Potassium	1.55	1.60	1.32	0.31	0.41
Calcium	1.34	0.92	0.49	0.19	0.26
Magnesium	0.29	0.31	0.18	0.028	0.037
Iron	0.180	0.274	0.199	0.109	--
Manganese	0.0420	0.0590	0.0136	0.0119	0.0159
Copper	0.0025	0.0027	0.0035	0.00051	0.00068
Boron	0.0066	0.0067	0.0059	0.0019	0.0026
Zinc	0.0031	0.0023	0.0014	0.00115	0.00154

Influence of Sulfate-Chloride Combinations

Growth

Table 11 shows that chloride and sulfate content of nutrient solutions may be varied to a considerable extent without too much influence upon growth. As shown in Table 5, an increase in sulfate concentration from 190 to 480 ppm decreased growth. The addition of 177 ppm of chloride to a solution containing 432 ppm of sulfate (as compared to 480) resulted in significantly less increase in dry weight, but comparable terminal growth. When sulfate was kept at 432 ppm, but chloride increased from 177 to 350 ppm, there was again a significant reduction of growth. Further moderate variations of chloride and sulfate in treatments 4, 5, 6 and 7 resulted in growth comparable to that obtained from 350 ppm of chloride.

Leaf Composition

Leaf composition, in relation to various combinations of sulfates with chlorides, is presented in Table 12. When sulfates were maintained at a low level, and chlorides increased, there was an increase in nitrogen, phosphorus, chlorine, calcium, magnesium, iron and manganese, but a decrease in potassium. An increase in chlorine, calcium,

Table 11

Influence of Sulfate-Chloride Combinations in Nutrient Solutions upon the Growth of Montmorency Cherry Trees.

Treatment No.	Anions Varied (Ppm)		Increase in Dry Weight (Gms)	Leaves (Gms)	Shoots (Gms)	Fibrous Roots (Gms)	Linear Growth (Cms)
	SO_4	Cl					
1	190	0	125.30	33.19	25.68	16.90	250.2
7	192	527	40.75	16.90	8.52	10.62	127.1
2	432	177	70.60	24.27	15.55	17.95	217.8
6	432	350	40.42	16.40	8.14	14.02	143.3
4	192	350	32.50	11.21	4.56	10.87	69.6
5	380	350	44.47	16.53	9.27	11.27	125.7
6	432	350	40.42	16.40	8.14	14.02	143.3
	L.S.D.	5%	23.52	4.00	4.870	5.30	69.78
		1%	31.36	5.33	6.504	7.07	93.04

Table 12

Relationship of Sulfate-Chloride Combinations in Nutrient Solutions to Chemical Composition of Montmorency Cherry Leaves.

Elements (Per Cent)	Treatment Numbers and Anions Varied (Ppm)							L. S. D.	
	1	7	2	6	4	5	6		
	Cl 0	527	177	350	350	350	350		
	SO_4 190	192	432	432	192	380	432	5%	1%
Nitrogen	3.23	3.42	3.68	3.67	3.80	3.63	3.67	0.49	0.65
Phosphorus	0.15	0.40	0.34	0.44	0.44	0.38	0.44	0.36	0.48
Chlorine	0.0015	1.647	0.436	1.154	1.105	1.240	1.154	0.55	0.74
Potassium	4.40	2.12	3.13	2.00	2.37	2.39	2.20	1.44	1.93
Calcium	2.02	2.99	1.48	2.69	1.95	1.43	2.69	0.45	--
Magnesium	0.60	1.05	0.65	0.94	0.75	0.73	0.94	0.30	0.42
Iron	0.012	0.026	0.040	0.021	0.035	0.016	0.021	0.017	--
Manganese	0.0051	0.0357	0.0213	0.0321	0.0183	0.0164	0.0321	0.0117	0.0156
Zinc	0.0031	0.0024	0.0014	0.0016	0.0027	0.0022	0.0016	0.0020	--

magnesium and manganese, but a decrease in potassium and iron occurred when sulfates were at a moderate level, and chlorides were increased. Maintaining a moderate level of chlorides, and increasing the concentrations of sulfates in the solution resulted in only minor changes in leaf composition, except for an increase in manganese.

Root Composition

The effects of various combinations of sulfates with chlorides in the solutions upon root composition (Table 13) were in some respects similar to the effects of anions when varied separately. An increase in the concentration of chlorides with a low level of sulfates resulted in an increase in nitrogen, chlorine and copper, while potassium, calcium, magnesium, manganese and zinc decreased. With a moderate level of sulfates, an increase in chloride concentration resulted in a decrease in potassium, an increase in copper, and no significant changes for the other elements. When the concentration of chlorides was maintained at a moderate level, and sulfates increased, there was a decrease in potassium and manganese, but no significant effect upon the other elements.

Table 13

The Chemical Composition of Fibrous Roots from Montmorency Cherry Trees in Relation to Sulfate-Chloride Combinations in the Nutrient Solutions.

Elements (Per Cent)	Treatment Numbers and Anions Varied (Ppm)							L. S. D.	
	1	7	2	6	4	5	6		
	Cl 0	527	177	350	350	350	350		
	SO_4 190	192	432	432	192	380	432	5%	1%
Nitrogen	2.67	3.39	3.14	3.37	2.94	2.97	3.37	0.33	0.45
Phosphorus	0.78	0.73	0.79	0.64	0.69	0.79	0.64	0.24	0.32
Chlorine	0.060	0.823	0.573	0.676	0.800	0.817	0.676	0.141	0.187
Potassium	1.91	1.51	1.83	1.50	1.89	1.78	1.50	0.31	0.41
Calcium	1.18	0.48	0.47	0.52	0.59	0.51	0.52	0.19	0.26
Magnesium	0.28	0.20	0.21	0.20	0.21	0.19	0.20	0.028	0.037
Iron	0.239	0.188	0.211	0.243	0.295	0.206	0.243	0.109	--
Manganese	0.0263	0.0078	0.0141	0.0103	0.0227	0.0088	0.0103	0.0119	0.0159
Copper	0.0018	0.0032	0.0029	0.0037	0.0030	0.0026	0.0037	0.00051	0.00068
Boron	0.0078	0.0062	0.0066	0.0057	0.0050	0.0063	0.0057	0.0019	0.0026
Zinc	0.0030	0.0016	0.0014	0.0015	0.0018	0.0013	0.0015	0.00115	0.00154

Influence of Sulfate-Nitrogen and Chloride-Nitrogen Combinations

Growth

High nitrogen (630 ppm) content in nutrient solutions did not relieve the detrimental effect of high chloride (671 ppm), or high sulfate (672 ppm) concentrations. Table 14 shows that when nitrogen was increased from 210 to 630 ppm the growth was not changed significantly. High sulfate and high nitrogen decreased the growth more than high chloride and high nitrogen. When nitrogen was increased in the presence of high chlorides there was a slight increase in length of shoots, weight of leaves, and weight of shoots, but a decrease in weight of fibrous roots and total increase in dry weight. Increasing the nitrogen level in the presence of high sulfates resulted in a slight increase in length of shoots, and a decrease in all other growth measurements with fibrous roots being reduced significantly, Figs. 4 and 5.

Leaf Composition

High nitrogen content in solution, together with high sulfate, given in Table 15, significantly increased the nitrogen and calcium levels in leaves. The same trend was apparent with phosphorus, magnesium, iron, manganese, and zinc. However, the potassium level was decreased slightly.

Table 14

Influence of Sulfate-Nitrogen, and Chloride-Nitrogen Combinations in Nutrient Solutions upon the Growth of Montmorency Cherry Trees

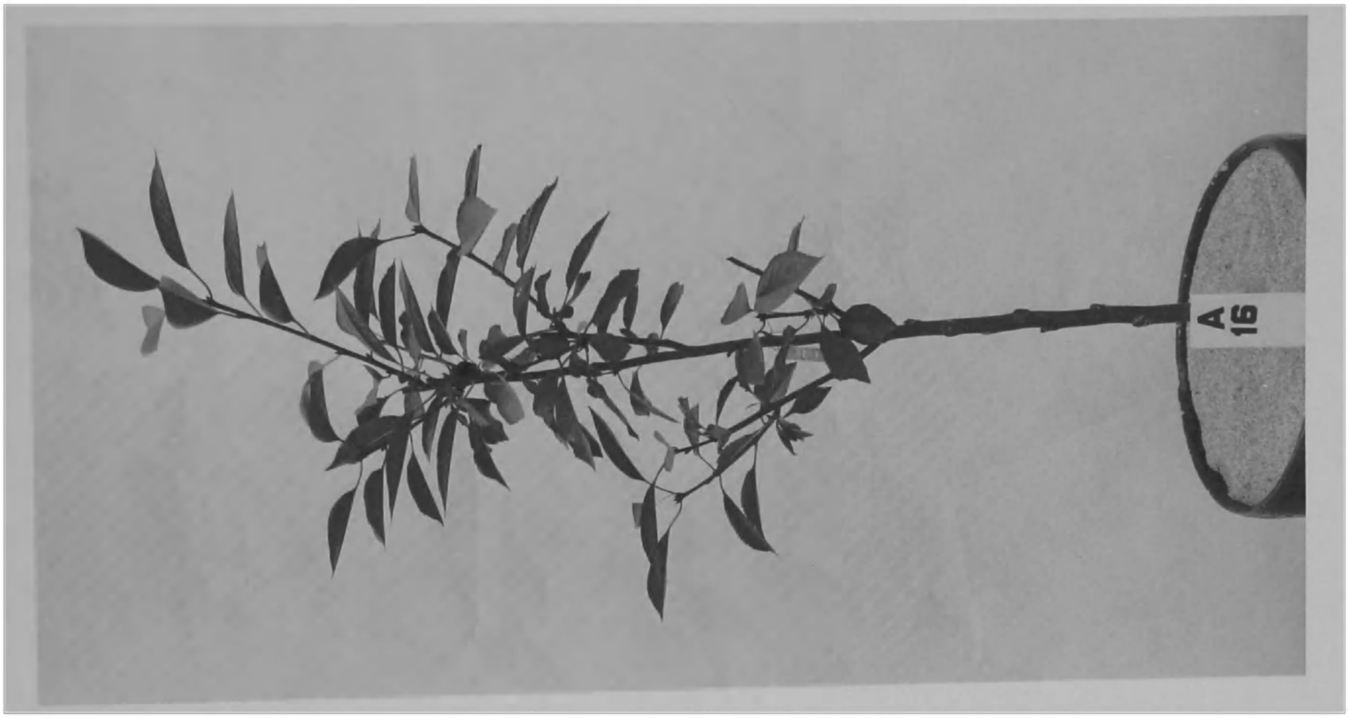
Treatment No.	Anions Varied (Ppm)		Increase in Dry Weight (Gms)	Leaves (Gms)	Shoots (Gms)	Fibrous Roots (Gms)	Linear Growth (Cms)
	SO_4	N					
17	672	630	17.76	10.67	4.62	5.10	78.30
9	672	210	36.67	11.59	4.98	10.80	36.67
	Cl	N					
16	671	630	24.08	13.46	5.08	7.65	74.60
8	671	210	25.70	10.13	4.00	8.70	61.00
	L.S.D.	5%	23.52	4.00	4.87	5.30	69.78
		1%	31.36	5.33	6.50	7.07	93.04

Table 15

Relationship of Sulfate-Nitrogen and Chloride-Nitrogen Combinations in Nutrient Solutions to Chemical Composition of Montmorency Cherry Leaves.

Elements (Per Cent)	Treatment Numbers and Anions Varied (Ppm)				L. S. D.	
	17	9	16	8		
	N 630	210	630	210		
	SO_4 672	672	0	0		
	Cl 0	0	671	671	5%	1%
Nitrogen	4.23	3.35	5.16	3.83	0.49	0.65
Phosphorus	0.39	0.21	0.73	0.53	0.36	0.48
Chlorine	0.0013	--	0.653	1.236	0.55	0.74
Potassium	3.05	3.53	2.08	2.08	1.44	1.93
Calcium	1.21	0.77	2.56	3.42	0.45	--
Magnesium	0.46	0.42	0.87	0.91	0.30	0.42
Iron	0.018	0.010	0.022	0.025	0.017	--
Manganese	0.0091	0.0072	0.0231	0.0203	0.0117	0.0156
Zinc	0.0011	0.0008	0.0028	0.0035	0.0020	-

Figure 4. Terminal growth in relation to increasing nitrogen content of nutrient solutions in the presence of high chloride supply (671 ppm). Left, 210 ppm nitrogen; Right, 630 ppm nitrogen.


A 16

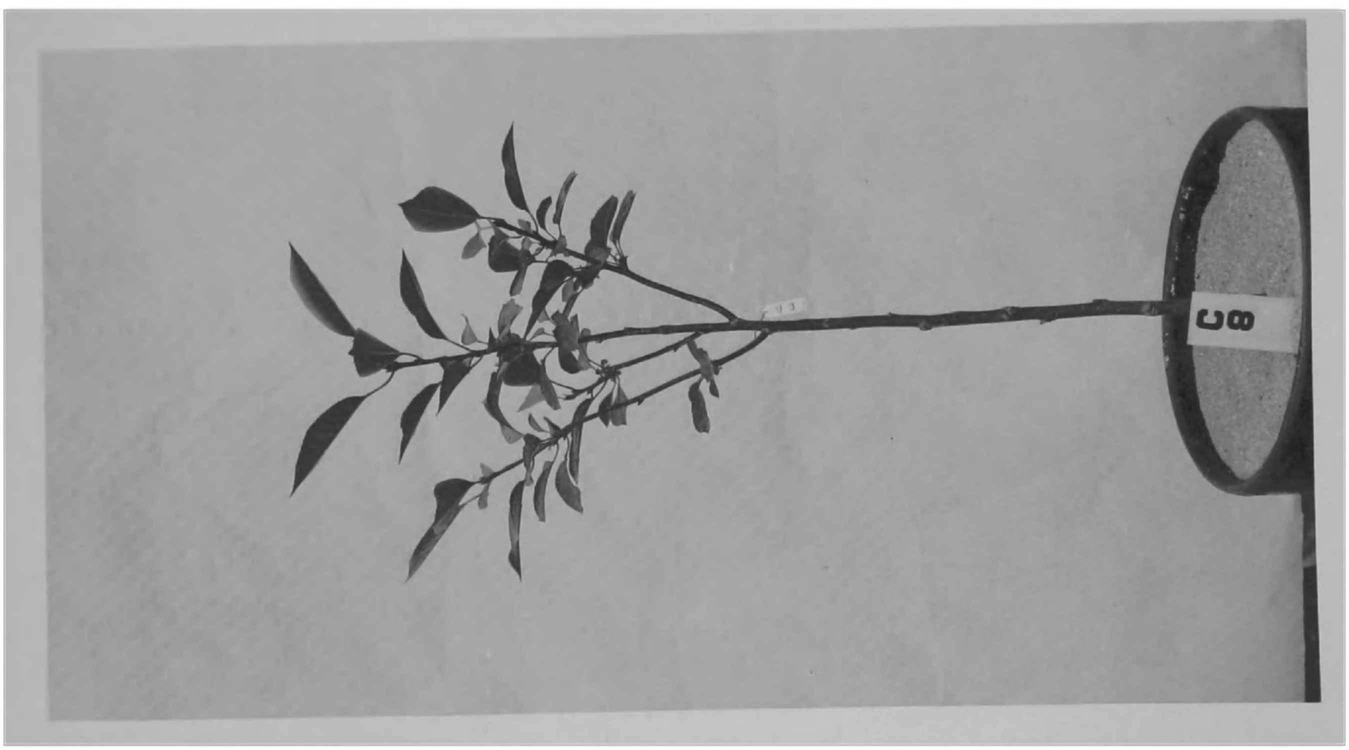

C 8

Figure 5. Terminal growth in relation to increasing nitrogen content of nutrient solutions in the presence of high sulfate supply (672 ppm). Left, 210 ppm nitrogen; Right, 630 ppm nitrogen.


B
9


A
17

When the same concentration of nitrogen was combined with high chloride, nitrogen showed a significant increase, while chlorine and calcium decreased significantly. Phosphorus, manganese, and zinc were increased slightly, but potassium and magnesium values remained almost constant.

Root Composition

When the nitrogen concentration was increased in the presence of high concentrations of either chlorides or sulfates (Table 16) there was a significant increase in root nitrogen and iron, and a decrease in root potassium. The combination of high nitrogen with high chlorides significantly decreased the chlorine content of the roots. The increase in nitrogen content with either high chlorides or high sulfates resulted in a slight increase in phosphorus, calcium and copper content of the roots. Magnesium levels was not influenced by these treatments, but also were lower than in treatment 1. Manganese level was significantly higher in treatments which had little or no sulfate or chloride. It was difficult to detect any pattern in the uptake of boron and zinc.

Table 16

The Chemical Composition of Fibrous Roots from Montmorency Cherry Trees in Relation to Sulfate-Nitrogen and Chloride-Nitrogen Combinations in the Nutrient Solutions.

Elements (Per Cent)	Treatment Numbers and Anions Varied (Ppm)				L. S. D.	
	17	9	16	8		
	N 630	210	630	210		
	SO_4 672	672	0	0		
	Cl 0	0	671	671	5%	1%
Nitrogen	4.01	2.84	3.55	3.21	0.33	0.45
Phosphorus	0.78	0.64	0.77	0.75	0.24	0.32
Chlorine	0.038	--	0.156	0.825	0.141	0.187
Potassium	1.10	1.62	0.75	1.32	0.31	0.41
Calcium	0.58	0.51	0.54	0.49	0.19	0.26
Magnesium	0.17	0.18	0.17	0.18	0.028	0.037
Iron	0.324	0.272	0.344	0.199	0.109	--
Manganese	0.0130	0.0088	0.0088	0.0121	0.0119	0.0159
Copper	0.0038	0.0032	0.0032	0.0044	0.00051	0.00068
Boron	0.0064	0.0053	0.0053	0.0065	0.0019	0.0026
Zinc	0.0017	0.0014	0.0013	0.0014	0.00115	0.00154

Influence of Sulfate-Phosphorus and Chloride-Phosphorus Combinations

Growth

With 480 ppm of sulfate in solution (Table 17) growth (as measured by weight) was noticeably decreased by increases of phosphorus content from 31 to 150 ppm. However, the increase in phosphorus significantly increased linear growth. This was evident also with combinations of chloride and phosphorus. A decrease of chloride from 247 to 140 ppm coupled with an increase in the phosphorus concentration from 31 to 338 ppm significantly decreased all measurements of growth. Further increases in the concentration of chloride and phosphorus resulted in a noticeable, but non-significant additional decrease.

Leaf Composition

Calcium, phosphorus, and manganese contents of leaves (Table 18) increased significantly when the phosphorus level was raised from 31 to 150 ppm, while the sulfate concentration was kept at 480 ppm. The other elements increased slightly when the phosphorus concentration was increased.

There was a significant increase in nitrogen, and a significant decrease in calcium content of the leaves with increasing amounts

Table 17

Influence of Sulfate-Phosphorus, and Chloride-Phosphorus Combinations in Nutrient Solutions upon the Growth of Montmorency Cherry Trees.

Treatment No.	Anions Varied (Ppm)			Increase in Dry Weight (Gms)	Leaves (Gms)	Shoots (Gms)	Fibrous Roots (Gms)	Linear Growth (Cms)
	SO_4	Cl	P					
13	480	0	31	104.99	35.38	25.24	15.92	213.0
14	480	0	150	90.21	31.29	22.59	20.82	319.8
3	0	247	31	93.85	26.07	19.69	16.75	206.0
11	0	140	338	53.80	18.16	10.08	14.32	160.1
12	0	327	419	39.65	14.72	8.23	14.12	168.6
		L.S.D.	5%	23.52	4.004	4.870	5.30	69.78
			1%	31.36	5.339	6.504	7.07	93.04

Table 18

Relationship of Sulfate-Phosphorus and Chloride-Phosphorus Combinations in Nutrient Solutions to Chemical Composition of Montmorency Cherry Leaves.

Elements (Per Cent)	Treatment Numbers and Anions Varied (Ppm)					L.S.D.	
	13	14	3	11	12		
	SO_4 - 480	480	0	0	0		
	Cl - 0	0	247	140	327		
	P - 31	150	31	338	419	5%	1%
Nitrogen	3.52	3.62	3.33	4.26	3.82	0.49	0.65
Phosphorus	0.26	0.60	0.18	1.21	1.87	0.36	0.48
Chlorine	0.0007	0.0008	0.73	0.10	0.40	0.55	0.74
Potassium	4.10	4.10	3.78	3.30	2.78	1.44	1.93
Calcium	1.21	1.94	2.27	1.14	0.98	0.45	--
Magnesium	0.41	0.53	0.74	0.60	0.53	0.30	0.42
Iron	0.018	0.019	0.023	0.010	0.006	0.017	--
Manganese	0.0150	0.0256	0.0148	0.0138	0.0159	0.0117	0.0156
Zinc	0.0012	0.0016	0.0028	0.0018	0.0018	0.0020	--

of phosphorus in the solutions containing chlorides. Under the same conditions, potassium, magnesium and iron declined slightly, but manganese and zinc levels remained almost constant. Chloride uptake was hindered by high phosphorus.

Root Composition

Table 19 shows that an increase of phosphorus from 31 to 150 ppm with 480 ppm of sulfate in the solution caused a significant rise in phosphorus content of the roots, but only an inconsiderable increase in root nitrogen levels. At the same time, the zinc and manganese levels were reduced significantly. Chlorine, potassium, calcium and manganese contents also were reduced. Magnesium, iron, copper and boron levels did not change.

With medium high levels of chloride (140 to 327 ppm) an increase of phosphorus in the solutions brought about very significant increases of nitrogen, phosphorus and boron percentages. Chlorine, calcium, magnesium, and manganese levels decreased very significantly; iron decreased slightly; but copper and zinc did not change to any great extent. An increase in the chloride concentration appeared to hinder the absorption of phosphorus from solutions having a high phosphorus concentration.

Table 19

The Chemical Composition of Fibrous Roots from Montmorency Cherry Trees in Relation to Sulfate-Phosphorus and Chloride-Phosphorus Combinations in the Nutrient Solutions.

Elements (Per Cent)	Treatment Numbers and Anions Varied (Ppm)					L. S. D.	
	13	14	3	11	12		
	SO_4 - 480	480	0	0	0		
	Cl - 0	0	247	140	327		
	P - 31	150	31	338	419	5%	1%
Nitrogen	2.97	3.20	2.79	3.09	3.36	0.33	0.45
Phosphorus	0.81	1.19	0.58	2.17	1.90	0.24	0.32
Chlorine	0.056	0.030	0.528	0.224	0.289	0.141	0.187
Potassium	1.45	1.18	1.60	1.52	1.21	0.31	0.41
Calcium	0.83	0.67	0.92	0.51	0.55	0.19	0.26
Magnesium	0.22	0.21	0.31	0.18	0.19	0.028	0.037
Iron	0.296	0.295	0.274	0.274	0.218	0.109	--
Manganese	0.0599	0.0230	0.0590	0.0291	0.0144	0.0119	0.0159
Copper	0.0037	0.0036	0.0027	0.0033	0.0031	0.00051	0.00068
Boron	0.0083	0.0090	0.0067	0.0093	0.0095	0.0019	0.0026
Zinc	0.0037	0.0024	0.0023	0.0015	0.0033	0.00115	0.00154

Influence of Sulfate-Carbonate and Chloride-Carbonate Combinations

Growth

Substitution of sulfate by carbonate in the presence of chloride did not change the growth appreciably (Table 20). However, there was a trend showing that sulfate in moderate amounts (192 ppm) was less beneficial than 180 ppm of carbonate. Carbonate added to nutrient solutions containing moderately high (432 to 480 ppm) of sulfate produced a slight, non-significant increase in growth as measured by increase in dry weight, length of growth, and weight of fibrous roots.

Leaf Composition

Substitution of sulfate by carbonate at medium high concentrations of chloride (Table 21) did not change the leaf composition noticeably, except for a significant decrease in manganese. The addition of carbonate to a moderately high level (432 to 480 ppm) of sulfate caused a significant increase in potassium uptake.

Root Composition

Sulfate replacement by carbonate at a moderately high chloride concentration in solution did not change the composition of roots

Table 20

Influence of Sulfate-Carbonate and Chloride-Carbonate Combinations in Nutrient Solutions upon the Growth of Montmorency Cherry Trees.

Treatment No.	Anions Varied (Ppm)			Increase in Dry Weight (Gms)	Leaves (Gms)	Shoots (Gms)	Fibrous Roots (Gms)	Linear Growth (Cms)
	Cl	SO_4	CO_3					
7	527	192	0	40.75	16.90	8.52	10.62	127.1
15	490	0	180	49.98	17.61	10.04	12.50	171.1
13	0	480	0	104.99	35.38	25.24	15.92	213.0
18	0	432	150	118.84	33.71	23.46	18.40	277.5
		L. S. D.	5%	23.52	4.004	4.87	5.32	69.78
			1%	31.36	5.339	6.50	7.07	93.04

Table 21

Relationship of Sulfate-Carbonate and Chloride-Carbonate Combinations in Nutrient Solutions to Chemical Composition of Montmorency Cherry Leaves.

Elements (Per Cent)	Treatment Numbers and Anions Varied (Ppm)				L.S.D.	
	7	15	13	18		
	Cl - 527	490	0	0		
	SO_4 - 192	0	480	432		
	CO_3 - 0	180	0	152	5%	1%
Nitrogen	3.42	3.70	3.52	3.43	0.49	0.65
Phosphorus	0.40	0.35	0.26	0.14	0.36	0.48
Chlorine	1.64	1.23	0.0007	0.0010	0.55	0.74
Potassium	2.12	2.46	4.10	5.80	1.44	1.93
Calcium	2.99	2.88	1.21	1.15	0.45	--
Magnesium	1.05	0.91	0.41	0.30	0.30	0.42
Iron	0.026	0.025	0.018	0.011	0.017	--
Manganese	0.0357	0.0203	0.0150	0.0047	0.0117	0.0156
Zinc	0.0024	0.0035	0.0012	0.0006	0.0020	--

Table 22

The Chemical Composition of Fibrous Roots from Montmorency Cherry Trees in Relation to Sulfate-Carbonate and Chloride-Carbonate Combinations in the Nutrient Solutions.

Elements (Per Cent)	Treatment Numbers and Anions Varied (Ppm)				L. S. D.	
	7	15	13	18		
	Cl - 527	490	0	0		
	SO_4 - 192	0	480	432		
	CO_3 - 0	180	0	150	5%	1%
Nitrogen	3.39	3.23	2.97	2.88	0.33	0.45
Phosphorus	0.73	0.64	0.81	0.86	0.24	0.32
Chlorine	0.828	0.816	0.056	0.053	0.141	0.187
Potassium	1.51	1.63	1.45	2.17	0.31	0.41
Calcium	0.48	0.68	0.83	1.04	0.19	0.26
Magnesium	0.20	0.21	0.22	0.24	0.028	0.037
Iron	0.188	0.272	0.296	0.416	0.109	--
Manganese	0.0078	0.0200	0.0599	0.0540	0.0119	0.0159
Copper	0.0032	0.0030	0.0037	0.0031	0.00051	0.00068
Boron	0.0062	0.0057	0.0083	0.0094	0.0019	0.0026
Zinc	0.0016	0.0019	0.0037	0.0023	0.00115	0.00154

except for a significant increase in calcium and manganese (Table 22). Carbonate additions to solutions containing moderately high sulfate did not change the nitrogen, phosphorus, chlorine, magnesium, manganese, copper, and boron contents of the roots. Potassium, calcium, and iron showed significant increase when 150 ppm of carbonate was added to the solution containing moderately high concentrations of sulfates.

DISCUSSION

Increasing the supply of certain anions (chloride, sulfate, phosphorus, nitrogen and carbonate) had a significant effect upon growth as measured by increase in dry weight of the tree, length of terminal growth, and weight of leaves, shoots and fibrous roots. When the supply of these anions (particularly chloride and sulfate) was increased to a high level, apparent toxicity developed as indicated by a depression of growth. However, the only visible symptoms that developed were for chlorine excess and sulfur deficiency.

The symptoms for chlorine excess were not present in all treatments receiving the highest concentrations of chloride.

Trees of treatment 8, with 671 ppm of chloride in the nutrient solution showed leaf burn typical to chloride injury. The leaves showed tip and marginal burning, and there was some abscission. This description agrees with the one given by Hayward and Long (26).

The cherry leaves from treatment 8 showed a comparatively low potassium (2.08 per cent) and a rather high (3.42 per cent) calcium value as compared with 1.91 per cent potassium, and 1.18 per cent of calcium in treatment 1, the check treatment, which also showed the highest increase in dry weight. Boresh (3) found that chloride fertilizers frequently cause currant leaves to show blighting at the edges resembling a symptom of potassium deficiency. He theorized further that the potassium content may be present for normal requirements, but not sufficient to combine with all the chlorine in the leaves. According to him the excess chlorine is combined with calcium, and an antagonism between potassium and calcium produces the symptoms of potassium deficiency.

However, a later work by Sideris and Young (49) gives a more plausible theory about chloride toxicity and potassium deficiency in plants. They conclude that the terminal leaf necrosis of pineapple plants is affected by changes in the metabolic conditions of the tissues resulting from high chloride concentrations in association with potassium deficiency. Pineapple plants amply supplied with potassium, even in the presence of relatively great chloride concentrations, failed to develop leaf necrosis. The chemical differences in leaf tissue composition between plants with ample, and with deficient potassium, are mainly in the concentrations of polysaccharide--starch and sugars. It is possible that starch and sugars produced with ample potassium increase the tolerance of the cells to high chloride concentrations

From this discussion and the data of chemical analysis of cherry leaves and roots an approach may be charted how to overcome chloride toxicity, or the apparent potassium deficiency. Potassium chloride would have to be avoided because of its double action in preventing the uptake of potassium and increasing the levels of chlorine in plant tissues. Instead of potassium chloride, sulfate or carbonate of potash may be preferred. In addition, a higher level of nitrogen and phosphorus appeared to reduce chlorine absorption. Marshall and Upchurch (36) stated that a monovalent cation, such as sodium or potassium, is more extensively taken up from a solution of the bicarbonate than from chloride or sulfate. Potassium uptake may be influenced by several factors as given by Pierre and Bower (45).

Also the symptoms for sulfur deficiency were not present in all treatments receiving no sulfate. Plants of the treatment 10 exhibited yellowing of leaves. Since this treatment did not include any sulfate, there were indications that this may be the appearance of sulfur deficiency. The midribs of the leaves began to show yellowing, which spread further along the midrib and veins. Many of the leaves dropped earlier, as compared with the trees from other treatments

Symptoms similar to these were observed by Chapman and Brown (7) on citrus. They also found a tendency for the midrib to be a little more yellow than the mesophyll tissues. When the leaves aged, the midribs on many were more yellow than the rest of the leaf They noticed premature dropping of the sulfur deficient leaves. Very similar phenomena were observed by McMurtrey (38) on sulfur-deficient tobacco plants, and by Ergle (18) on sulfur-deficient cotton plants.

The leaves from treatment 10 contained 0.13 per cent sulfur and was the lowest of all treatments. This amount would appear to be somewhat low if Thomas and others (50) work is consulted. They found that the organic sulfur content of leaves was usually between 0.2 and 0.4 per cent, the lower range indicating sulfur deficiency. The methods used in this study did not permit the evaluation of organic sulfur, therefore, the figures are not strictly comparable. However, the sulfur content of the leaves from treatment 10 would indicate sulfur deficiency.

Moreover, Kretschmer and others (30) indicated that variation in $S0_4$ content of substrate had little effect of $S0_4$ content in plants. This gives further evidence that the limit between high and low sulfur content is rather narrow. A somewhat wider range in sulfur content was found for the cherry leaves produced in this study, and the $S0_4$ content of the substrate had a marked effect upon the sulfur content of the leaves. Marsh (35) found only from 0.22 to 0.48 per cent of sulfur in apple leaves.

It is interesting to note that treatments 3 and 8 did not have any sulfate applied, and did not show visible deficiencies. The chemical analysis showed slightly higher per cent of sulfur in these treatments than in treatment 10; however, the differences were not significant. It may be suggested that higher amounts of chloride in the solution may have caused a greater uptake and utilization of the available sulfur or may have masked the visible symptoms of sulfur deficiency. At the same time, there is evidence of a considerable increase in phosphorus which increased from 0.15 per cent in treatment 10 to 0.53 per cent in treatment 8. As the chloride content was increased in solutions not containing sulfates, the absorption of other nutrients also varied.

In general, the absorption of various anions, measured as leaf and fibrous root composition, was proportional to the supply. Certain interactive effects were detected. The chlorine and sulfur content of leaves and roots was reduced when the supply of nitrogen and phosphorus was increased. The supply of sulfate, however, did not have any influence upon the absorption of chlorine. Sulfate absorption was not affected by the presence of chloride. The presence of high concentrations of $SO_4^=$ and Cl^- appeared to increase the absorption of nitrogen from solutions containing large amounts of nitrogen. However, nitrogen absorption was favored by the presence of large quantities of chloride and phosphorus in combination. The presence of large quantities of chloride and nitrogen in combination appeared to increase phosphorus absorption.

High phosphorus applications in treatments 11, and 12 caused a sharp increase in leaf nitrogen and phosphorus, and a decrease in calcium. The same phenomenon is exhibited by the root analysis; the nitrogen values are high, although not extremely high if compared with other treatments; phosphorus values are extremely high; calcium is among the lowest of all treatments. The trees of these treatments showed the symptoms of nitrogen deficiency--leaf color was yellowish and shoots were spindly. The high values of nitrogen and phosphorus from both leaf and root analysis indicated that the growth phenomena exhibited may have been caused by phosphorus toxicity. The high nitrogen content did not overcome the toxic effect of phosphorus, although the symptoms resembled nitrogen shortage. These indications, regarding phosphorus and nitrogen, are very well in line with those of Hamner (25) and Mullison (40).

Top (weight of leaves and shoots) and fibrous root ratios showed that either root growth was promoted, or shoot growth was retarded by high sulfate, high chloride, high phosphorus, or in the treatments where sulfate and chloride were of the same concentration. The top-root ratio of these treatments varied from 1.44 to 1.75. Top growth was greater than root growth in treatments that showed the best growth.

The ratio for these treatments was from 3.80 to 3.11. High nitrogen, together with either high chloride or high sulfate, promoted top growth and resulted in top-root ratios of 2.42 and 2.99, as compared to 1.62 for high chloride and 1.53 for high sulfate. Low sulfate (treatment 1) or low chloride (treatment 3) had top-root ratios of 3.43 and 2.73.

Although the cation content of the solutions was not varied, certain significant effects upon cation absorption were found to be associated with an increased supply of the various anions. Potassium levels in leaves and roots were generally higher where sulfate was present than where chloride was present. While increased supply of sulfate did not have a significant effect upon potassium absorption, the presence of large quantities of chloride significantly reduced potassium absorption. Potassium absorption, also, was favored by the presence of carbonates, while the presence of excess nitrogen depressed potassium absorption.

Calcium absorption was not influenced significantly by the presence of increasing amounts of chloride, but was depressed significantly with large quantities of sulfate. Increasing the supply of nitrogen and phosphorus in the presence of high levels of chloride appeared to depress calcium absorption, but the increased supply of nitrogen and phosphorus appeared to reduce the depressing effects of sulfate upon calcium absorption. The presence of carbonate in the solution also improved the absorption of calcium.

The absorption of magnesium was depressed with increased amounts of sulfate, but higher concentrations of chloride did not appear to have any significant effect. The supply of the anion also appeared to reduce the influence of greater absorption of potassium and calcium upon the absorption of magnesium.

Iron content of the leaves was depressed with an increased supply of phosphorus, while solutions containing carbonates and sulfates in large quantities increased the iron content of the roots. Larger supply of sulfate, chloride and nitrogen appeared to increase the copper content of the roots. Zinc absorption, however, was decreased with larger supplies of sulfate. A larger supply of chlorides depressed the zinc content of the roots.

Manganese absorption was increased with high levels of chloride. The addition of larger amounts of nitrogen in the presence of high levels of chloride resulted in a further increase in manganese absorption. Higher levels of phosphorus appeared to depress the manganese content of the roots, but increased the manganese content of the leaves. Similar effects upon manganese absorption were found as sulfate and carbonate replaced chloride in the solution.

In this experiment with cherries, the accumulation of heavy metals in the roots was evident, which was in accord with the findings of Reuther and Smith (46). Iron, manganese and copper accumulated in roots to a greater extent than in leaves. This effect was more pronounced with iron and copper than with manganese. Zinc accumulation in roots was not always greater than in the leaves. High sulfate, high sulfate and high nitrogen, or high phosphorus, tended to increase zinc absorption by leaves.

A comparison of root analysis with leaf analysis showed that phosphorus content was higher in roots than in leaves. Nitrogen ratios approached unity. Potassium, calcium, and magnesium was absorbed more by leaves than by the roots. Chlorine was absorbed more by leaves than roots whenever there was chlorine supplied in the nutrient solutions. When chloride was not applied, the traces of this element were retained by the roots. Calcium and magnesium absorption, which was higher in leaves than in roots, was favored by high chloride with or without high nitrogen, and high chloride with a moderate amount of sulfate (treatments 7, 8, and 16). Medium high sulfate level in nutrient solutions favored the uptake of calcium and magnesium by roots. In general, the chemical composition of roots was not as variable as the composition of leaves.

Goodall and Gregory (22) reported from 2.06 to 2.13 per cent of potassium, 0.0104 per cent of boron, and 0.0053 to 0.0071 per cent of manganese in cherry leaves. Kenworthy (28) found under field conditions, the following average amounts of elements in cherry leaves: nitrogen, 2.83; phosphorus, 0.267; potassium, 1.54; calcium, 1.91; magnesium, 0.740; manganese, 0.0114; iron, 0.0280; copper, 0.0055; and boron, 0.0067 per cent dry weight. These values compare rather favorably with leaf analysis values of this experiment if treatment I may be taken as a check. Phosphorus, magnesium, iron, manganese and copper were below, while potassium and nitrogen were above the values reported by Kenworthy (28).

It may not be assumed that all these relationships mentioned earlier will be infallible under all conditions.

Since the effects of chlorides and sulfates upon the absorption of potassium, calcium and magnesium were more pronounced at high concentrations, their influence may have escaped field observations because above normal applications of fertilizer would be required. To obtain the level of chloride or sulfates that resulted in a depression of growth and altered cation absorption application of approximately 1,000 pounds per acre of potassium chloride or potassium sulfate would be required. In addition, the presence of carbonates and the buffering capacity of soils would prevent chlorides and sulfates from having as marked effects as observed with the use of nutrient solution. Since many orchard soils in eastern United States are acid in reaction, the use of lime, mulch, and good cover cropping practices may tend to reduce the toxic effects of chlorides or sulfates as indicated by the influence of carbonates upon potassium absorption.

The results of this study suggest that applications of potassium chloride may accentuate potassium deficiency under conditions of low soil potassium coupled with conditions conducive to the fixation of potash in the soil. Calcium and magnesium deficiency may be induced by the presence of excess sulfates. Thus, a balance of the anions appears to be as essential as a balance of cations. In addition, the supply of anions would need to be studied in order to be sure of a satisfactory approach of correcting an unbalanced condition of cations.

SUMMARY

The influence of anion supply upon growth and the chemical composition of leaves and fibrous roots of Montmorency cherry trees was studied by means of nutrient culture methods The amounts of cations (potassium, calcium, and magnesium) and minor elements were kept constant. Anions (sulfate, chloride, phosphorus, nitrogen, and carbonate) were varied without altering the cation content by using different amounts of various chemicals containing the anions involved. Eighteen different solutions were obtained. Seventy-two one-year-old Montmorency cherry trees were selected, pruned uniformly, weighed, and planted in clay pots in the greenhouse. Coarse sand was used as growing media. Trees were arranged in four replicates and randomized. At the beginning of the experiment, the nutrient solutions were applied every second day. During the latter part of the test, the solutions were applied daily. Trees were harvested and the linear growth was measured and dry weight of leaves, shoots, roots, and trunk was obtained. Leaves and fibrous roots were analyzed for twelve elements--nitrogen, phosphorus, chlorine, sulfur, potassium, calcium, magnesium, iron, manganese, copper, boron and zinc.

Increasing the supply of anions had a significant effect upon growth as measured by increase in dry weight of the tree, length of terminal growth, and weight of leaves, shoots, and fibrous roots. When the supply of these anions was increased to a high level apparent toxicity appeared as indicated by reduction of growth and the appearance of chloride toxicity symptoms. Omission of sulfate under certain conditions resulted in visible sulfur deficiency symptoms.

In general, the absorption of various anions was proportional to their supply; however, some interactions were present. Chlorine content was reduced by nitrogen and phosphorus. Sulfur and chlorine did not affect the absorption of each other. The presence of high concentrations of $SO_4^{=}$ and Cl^- appeared to increase the absorption of nitrogen from solutions containing large amounts of nitrogen. Nitrogen absorption was favored by the presence of large quantities of chloride and phosphorus in combination. The presence of large quantities of chloride and nitrogen in combination appeared to increase phosphorus absorption.

Potassium levels in leaves and roots were generally higher when sulfate was present than when chloride was present. Large quantities of chloride reduced potassium absorption. Potassium absorption was favored by carbonate, but was depressed by high nitrogen. Calcium and magnesium absorption was depressed by sulfate. Increasing supplies of nitrogen and phosphorus reduced the sulfate effect upon calcium absorption. High nitrogen in presence of chloride depressed calcium uptake. The supply of anion appeared to reduce the influence of potassium and calcium upon the absorption of magnesium. Iron content in leaves was depressed by phosphorus. Carbonate and sulfate in large quantities increased iron in roots.

Larger supplies of sulfate, chloride, and nitrogen appeared to increase the copper content of the roots. Zinc absorption by leaves was decreased by larger supplies of sulfate, while chloride depressed zinc content in the roots. Manganese absorption was increased with high levels of chloride, and was further aided by nitrogen additions. Higher levels of phosphorus depressed manganese content of the roots, but increased it in the leaves.

The ratios of top (weight of leaves and shoots) to fibrous root were affected by the anion supply. Root growth was relatively promoted, or shoot growth retarded, by high sulfate or chloride, high phosphorus, or by combinations of sulfate and chloride in approximately equal concentrations.

The visible symptoms of chloride toxicity and sulfur deficiency were described. Some suggestions were advanced in regard to the prevention of chloride toxicity of plants. The balance and supply of anions and their importance in plant nutrition were emphasized.

LITERATURE CITED

1. Baslavskaja, S. S. Influence of chloride ion on the content of carbohydrates in potato leaves. Plant Phys. 11: 863-871 1936.

2. Bear, F. E., and Prince, A. L. Cation-equivalent constancy in alfalfa. Jour. Amer. Soc. Agr. 37: 217-222. 1945.

3. Boresh, K. Further investigations on the leaf edge disease of currant caused by chlorides. Zeitschrift f. Bodenkunde u Pflanzenernahrung. 14: 230-247. 1939.

4. Breazeale, J. F. The effect of one element of plant food upon the absorption by plants of another element. Univ. Ariz. Agr. Exp. Sta. Tech. Bul. 19. 1928.

5. Broyer, T. C., Carlton, A. B., Johnson, C. M., and Stout, P. R. Chlorine--a micro nutrient for higher plants. Plant Phys. 29: 526-532. 1954.

6. Carolus, R. L. Effect of certain ions, used singly and in combination on the growth, and potassium, calcium, and magnesium absorption of the bean plant. Plant Phys. 13: 349-363. 1938.

7. Chapman, H. D., and Brown, S. M. The effects of sulfur deficiency on citrus. Hilgardia 14: 185-196. 1941.

8. Colby, H. L. Effects of starvation on distribution of mineral nutrients in French prune trees grown in culture solutions. Plant Phys. 8: 357-393. 1933.

9. Eaton, F. M. Water uptake and root growth as influenced by inequalities in the concentration of substrate. Plant Phys. 16: 545-564. 1941.

10. ____________. Toxicity and accumulation of chloride and sulfate salts in plants. Jour. Agr. Res. 64: 357-399. 1942.

11. Eaton, S. V. Influence of sulfur deficiency on the metabolism of the soybean. Bot. Gaz. 97: 68-100. 1935.

12. Eaton, S. V. Influence of sulfur deficiency on metabolism of the sunflower. Bot. Gaz. 102: 536-535. 1941.

13. ___________. Effects of phosphorus deficiency on growth and metabolism of sunflower. Bot. Gaz. 110: 449-464. 1949.

14. ___________. Effects of phosphorus deficiency on growth and metabolism of soybean. Bot. Gaz. 111: 426-436. 1950.

15. ___________. Effects of phosphorus deficiency on growth and metabolism of black mustard. Bot. Gaz. 113: 301-309. 1952.

16. Epstein, E. Ion absorption by plant roots. Proc. 4th Ann. Oak Ridge Summer Symposium. 1952.

17. Ergle, D. R., and Eaton, F. M. Sulfur nutrition of cotton. Plant Phys. 26: 639-654. 1951.

18. ___________. Effect of low nitrogen and sulfur supply on their accumulation in the cotton plant. Bot. Gaz. 114: 417-426. 1951.

19. Gauch, H. G., and Wadleigh, C. H. The influence of saline substrates upon the absorption of nutrients by bean plants. Proc. Amer. Soc. Hort. Sci. 41: 365-369. 1942.

20. ___________________________. Effect of high concentration of sodium, calcium, chloride, and sulfate on ionic absorption by bean plants. Soil Sci. 59: 139-153. 1945.

21. Gilbert, S. G., Drosdoff, M., and Sell, H. M. Differential absorption by tung seedlings of potassium from sources of its salts. Soil Sci. 78: 219-224. 1954.

22. Goodall, D. W., and Gregory, F. G. Chemical composition of plants as an index of their nutritional status. Tech. Communication No. 17 Imperial Bur. Hort. and Plantation Crops. 1947.

23. Haas, A. R. C. Influence of chlorine on plants. Soil Sci. 60: 53-61. 1945.

24. Haas, A. R. C., and Brusca, J. N. Chloride toxicity in avocados. Cal. Agric. 9, No. 2: 12. 1955.

25. Hamner, C. L. Growth responses of Biloxi soybeans to variation in relative concentrations of phosphates and nitrates in the nutrient solutions. Bot. Gaz 101: 637-649. 1940.

26. Hayward, H. E., and Long, E. M. Vegetative responses of the Elberta peach on Lovell and Shalil rootstocks to high chloride and sulfate solutions. Proc. Amer. Soc. Hort. Sci 41: 149-155. 1942.

27. Hoagland, D. R., and Arnon, D. I. The water culture method for growing plants without soil. Univ. Calif Cir. 347, Berkeley. 1950.

28. Kenworthy, A. L. Nutrient-element composition of leaves from fruit trees. Proc. Amer. Soc. Hort. Sci. 55: 41-46. 1950.

29. ________________ Unpublished data. 1955.

30. Kretschmer, A. E., Toth, S. J., and Bear, F. E. Effect of chloride versus sulfate ions on nutrient-ion absorption by plants. Soil Sci. 76: 193-199. 1953.

31. Leonard, O. A., Anderson, W. S., and Gieger, M. Effect of nutrient level on the growth and chemical composition of sweetpotatoes in sand cultures. Proc. Amer. Soc. Hort. Sci. 53: 387-392. 1949.

32. Lipman, C. B. Importance of silicon, aluminum, and chlorine for higher plants. Soil Sci. 45: 189-198. 1938

33. Lundegardh, H. Leaf Analysis. Hilger and Watts, London, England. 1951.

34. Magistad, O. C., Ayers, A. D., Wadleigh, C. H., and Gauch, H. G. Effect of salt concentration, kind of salt, and climate on plant growth in sand cultures. Plant Phys. 18: 151-166. 1943.

35. Marsh, R. S. Seasonal variation of sulfur content in certain tissues of the apple tree. Bot. Gaz. 75: 400-413. 1923.

36. Marshall, C. E., and Upchurch, W. J. Chemical factors in cation exchange between root surfaces and nutrient media. Soil Sci. Soc Amer. Proc. 17: 222-227 1953.

37. McCalla, A. G., and Woodford, E. K. Effects of a limiting element on the absorption of individual elements and on the anion-cation balance in the wheat. Plant Phys. 13: 695-712. 1938

38. McMurtrey, J. E. Jr. Symptoms on field grown tobacco characteristics of the deficient supply of each of several essential elements. U. S. D. A. Tech. Bul. 612: 1-30. 1938.

39. Mulder, E. G. Annual Review of Plant Physiology 1: 1-24. 1950.

40. Mullison, W. R. The effect on barley seedlings of some inter-relations of cations and anions in a three-salt nutrient solution. Plant Phys. 16: 813-820. 1941.

41. Naguib, H. M., and Overstreet, R. Elongation of seedlings as a biological test of alkali soils: 1. Effect of ions on elongation. Soil Sci. 73: 315-326. 1952.

42. Nightingale, G. T., Schermerhorn, L. G., and Robbins, W. R Effect of sulfur deficiency on metabolism in tomato. Plant Phys. 7: 565-595. 1932.

43. Official and Tentative Methods of Analysis. 7th Ed., Assoc. Official Agr. Chemists, Washington, D. C

44. Overstreet, R., and Dean, L. A Mineral nutrition of plants. E. Truog, Editor, University of Wisconsin Press. p. 89 1951.

45. Pierre, W. H., and Bower, C. A. Potassium absorption by plants as affected by cationic relationships Soil Sci 55: 23-37. 1943.

46. Reuther, W., and Smith, P. I "Leaf analysis as a guide to the nutritional status of orchard trees". Analyse des plantes et problems des fumures minerales. I R H O - 11, Square Petrargue, Paris 1954.

47. Richards, F. J., and Templeman, W. G. Physiological studies in plant nutrition. Nitrogen metabolism in relation to nutrient deficiencies and age in leaves of barley. Ann. Bot. 50: 367-402. 1936.

48. Samson, S. A new method for the quantitative determination of chloride in plant materials. Nature 172: 1042. 1953

49. Sideris, C. P., and Young, H. Y. Effect of chlorides on the metabolism of pineapple plants. Amer. Jour. Bot. 41: 847-854. 1954.

50 Thomas, M. D., Hendricks, R. H., and Hill, G. R. Sulfur content of vegetation. Soil Sci. 70: 9-18. 1950.

51. Vinet, E. Contribution a l'etude du role physiologigue du potassium chez la vigne. Anne Agron. Paris 12(2): 224-239. 1942 (Abstract Biol. Abst. 20(1): 1688. 1946).

APPENDIX

Table 1

Milliliters of 0.5 M Stock Solutions Used to Make One Liter of Nutrient Solutions Employed in the Study of Anion Balance.*

Treatment No.	KNO_3	KCl	K_2SO_4	KH_2PO_4	K_2CO_3	$Ca(NO_3)_2$	$CaCl_2$	$Mg(NO_3)_2$	$MgSO_4$	$MgCl_2$	NH_4NO_3	$(NH_4)_2SO_4$	$NH_4H_2PO_4$	$(NH_4)_2CO_3$	Minor
1	10			2		10			4						2
2		10		2		10			4			5			2
3		12				10		3		1			2		2
4				2	5		10		4		15				2
5	10			2			10		4			5			2
6			5	2			10		4		15				2
7		10		2			10		4		15				2
8		10		2			10			4	15				2
9			10	2		10			4			5			2
10	10			2		10		4							2
11				12		10				4			10		2
12				12		7.5	2.5			4			15		2
13			6			10			4		4		2		2
14			6			10			4				10		2
15					6		10			4	13		2		2
16		10		2			10			4	45				2
17			10			10			4		30	5			2
18			10	2		10			4					5	2

*Minor elements, as given by Hoagland (27).