A STUDY OF THE INFLUENCE OF EXCESS CONCENTRATIONS OF CERTAIN SALTS ON THE GROWTH AND DEVELOPMENT OF GLASSHOUSE TOMATO PLANTS, WITH SPECIAL REFERENCE TO THE SPECIFIC ION EFFECTS OF THESE SALTS

A thesis presented in part fulfilment of the requirements
for the Degree of Master of Horticultural Science
in
Massey University of Manawatu,
New Zealand.

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1964

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INTRODUCTION

The yield and quality of fruit obtained from a glasshouse tomato crop is determined by the genetic make-up of the variety and the environment in which the crop is grown. The closer the environment to the optimum for the variety concerned, the closer the genetic limits will be approached. The environment can be divided into two parts - the above ground environment and the below ground environment. The below ground environment affects yields and quality through three primary factors:

(a) Moisture availability.

(b) Nutrient availability.

(c) Physical condition of the soil.

High levels of soluble salts in the soil can so influence these three factors that plant growth and development can be greatly depressed. With glasshouse tomatoes, depressions due to changes in the physical condition of the soil have not been reported, and are, in fact, not likely to occur.

Under glasshouse conditions, the development of high concentrations of soluble salts results from the excess use of fertilizers and not from natural processes. Over a period of years, high fertilizer rates, unless combined with adequate management techniques, will build up the salinity to a critical level. This build up results from the carry over of unused fertilizers at the end of the season, due to excessive applications of fertilizers to the soil, and also from the use of fertilizers containing one ion which is not absorbed by the plants to any extent.

Salinity is thus a problem on older glasshouse soils, and in the last ten years the more widespread use of winter flooding and trickle irrigation has resulted in a reduction in incidence of this problem. Flooding will remove unwanted residues from the rooting zone, while trickle irrigation systems use liquid feeds containing chemicals where both ions are absorbed by the crop. Thus these techniques help to prevent the accumulation of a high concentration of soluble salts.

Salinity also occurs as a transient problem in some seasons when, during dull weather, growers apply fertilizers to "hold their plants back". On the advent of better weather, the plants are slow in making growth due to moderate salinity levels which are removed only by the application of excess water. This in turn may induce other problems.

Hayward and Wadleigh (1949) and Bernstein and Hayward (1957), in their reviews on the subject of soil salinity and plant growth, have concluded that the reductions in plant performance are due to two mechanisms - osmotic effects, and specific ion effects.

A number of workers have investigated the effects of high concentrations of soluble salts in the growing medium, on the growth and development of tomato plants. In most cases they have not attempted to distinguish between osmotic and specific ion effects, and have regarded the reduction in plant performance as mainly due to reduced water availability. Thus there is limited information in the literature on the specific effects of excess soluble salts on the growth and development of the tomato.

The present study was undertaken to determine the influence of excess concentrations of certain salts on the growth and the

development of the tomato plant, with particular reference to the specific ion effects of these salts rather than to their osmotic pressure effects. The responses of the treated plants in relation to the horticulturally important characters of the crop were of particular interest.

CHAPTER 1

REVIEW OF LITERATURE

1.1. Osmotic Effects of Excess Soluble Salts

Smith and Warren (1957) found that the marketable yield of fruit decreased with increasing levels of salinity. Clay and Hudson (1960) obtained depressions in vegetative growth and yield of fruit as the salinity of the soil was increased to different levels by additions of a 3 : 1 ratio of K_2SO_4 and $MgSO_4$. The reduction in plant performance, with increasing osmotic pressure of the soil solution, is regarded by many workers as the result of an increase in the "total soil moisture stress". This term was defined by Wadleigh and Ayers (1945) as the sum of the soil moisture tension and the osmotic pressure of the soil solution when both are expressed in atmospheres.

Slatyer (1961) found that with young tomato plants subjected for 24 hours to osmotic pressures of 5 and 10 atmospheres, produced by the addition of NaCl and KNO_3 salts to a base nutrient solution, the leaves experienced a diffusion pressure deficit (hereafter referred to as D.P.D.) equal to that of the osmotic pressure of the imposed substrate. These diffusion pressure deficits were of the same value as those produced by soil moisture tensions of 5 and 10 atmospheres, but of a different nature.

Slatyer (loc cit.) reported that, after an initial period of adjustment, turgor pressure and tissue volume remained unaltered, and the osmotic pressure increased by an amount equal to that of the imposed substrate, thus differing from a soil moisture induced

stress where turgor pressure and tissue volume decrease, and osmotic pressure increases only slightly. The osmotic pressure increases due to the salt treatments were due to salt uptake, whereas osmotic pressure increases where soil moisture tensions are concerned are due to decreases in cell volume. In both cases the cells suffer a D.P.D. and are not fully turgid. Mannitol and sucrose were also used; mannitol produced a D.P.D. intermediate between that caused by NaCl and KNO_3 and soil moisture stress. This was due to some mannitol uptake by the plants, while the effect of sucrose was similar to NaCl and KNO_3.

Bernstein (1961) suggested that, since turgor pressure is not reduced in the case of a saline induced D.P.D., an alternative explanation for reduced growth on saline soils was required. He based this assumption on the work of Ordin (1960), who found that, with Avena coleoptiles, it was turgor pressure, not D.P.D., that controlled cell elongation and cell wall elaboration. This, however, was not demonstrated with other plant species, or with older plants of the same species, and this still remains to be investigated (Ordin, loc cit.). Bernstein (1961, 1963) has suggested alternative osmotic mechanisms which might bring about the reduced growth observed on saline soils.

Despite the foregoing conclusions by Bernstein, there is still much evidence supporting the traditional theory of osmotic inhibition due to an induced D.P.D., which restricts plant growth and development. Slatyer (1961) has established the existence of such a D.P.D. in the leaves of the tomato plant, and in so doing has emphasised the manner in which it differs from that of a similar D.P.D. induced by soil moisture tension.

Bernstein and Pearson (1954) showed that tomatoes decrease their top/root ratio under conditions of salinity, which is a phenomenon comparable with that normally observed with plants growing in a dry soil. As such, it is interpreted as an attempt by the plant to find more water to support the growth and development above the ground (Hudson, 1960). Clay and Hudson (1960) found with tomatoes grown on a saline soil kept close to field capacity, that most water was absorbed from the least saline area of the root zone. At Cornell, Farkas and Pratt (1961) showed that tomatoes grown on a non-saline soil absorbed most water from the wettest part of the root zone. Here again salinity and soil moisture tension evoke similar responses in the tomato plant. Salter (1957) reported that tomatoes grown under glass in a soil kept close to field capacity gave the most satisfactory yield. Smith and Warren (1957) reported similar advantages of a soil low in soluble salts.

Magistad et al. (1943) grew tomatoes and several other crops and found that when grown under similar salinity treatments in sand culture in differing climates, the most marked reduction in plant performance occurred in areas where transpiration was the highest. Bernstein and Hayward (1958) suggested that this indicated a water stress in the plant as being the limiting factor.

The above evidence, although much of it is of an observational nature, strongly implicates a water stress or diffusion pressure deficit in the plant as the mechanism of osmotic inhibition of plant growth and development.

1.2. Specific Ion Effects of Excess Soluble Salts

Bernstein and Hayward (1958) classified specific ion effects as either toxic or nutritional. An ion of high concentration in the soil solution has a toxic effect if the reduction in plant performance is due to excessive accumulation of this ion in the plant tissues, and/or has a nutritional effect if its high concentration in the soil solution results in reduced absorption of some essential element.

Specific ion effects have often all been described as toxicities. The above authors point out that it is often hard to distinguish between the two. With cations, they state that nutritional effects are perhaps the more common, while with anions, toxic effects are by far the more important. This is possibly due to the specific absorption sites for these anions (Epstein, 1956).

1.2.1. Sodium

The tomato plant appears to absorb sodium readily. In nutrient culture, Kidson (1963b) found, by using large quantities of sodium sulphate to raise the osmotic pressure, that the plants absorbed a considerable amount without apparently affecting the vigour of fruiting or vegetative growth, provided that the calcium and magnesium uptake were not reduced to deficiency levels. Sodium also appeared to limit potassium uptake, an effect shown mainly in the leaves. This worker suggested that luxury absorption of potassium may occur in the tomato plant or that sodium may be able to substitute for potassium in the leaves. Kidson (1963a) reported that, with isosmotic concentrations of sodium sulphate and potassium sulphate, the sodium treatment was more effective in reducing magnesium intake and less effective in reducing calcium intake.

Geraldson (1957) investigated factors affecting the calcium nutrition of tomato plants, and found that, on an equivalent basis, excess sodium decreased calcium uptake less than did excess potassium, magnesium or ammonium. In the field the tomato may be adversely affected by sodium, primarily due to its effect on soil structure (Thorne, 1945).

Joham (1955) found that cotton plants deprived of their calcium supply apparently lost their ability to absorb water, and that the plants wilted badly. Sodium prevented wilting and growth appeared to be normal. Geraldson (1957) suggested that this may have been due to the ability of sodium to substitute for calcium to some extent.

1.2.2. Potassium

Beeson et al. (1944), when investigating the effects of variations in concentration of the macro-nutrients of culture solutions on the ionic absorption of tomato plants, was able to correlate potassium content positively with potassium concentration in the solution, and calcium content negatively with potassium concentration in the solution. Clay and Hudson (1960) applied 3 : 1 mixtures of excess potassium and magnesium sulphates and obtained calcium deficiency symptoms. They suggested that the cations, potassium and magnesium, depressed calcium uptake. Evidence of the relative effects of sodium and potassium on calcium (Kidson, 1963a; Geraldson, 1957) and magnesium (Kidson, 1963a) uptake have been mentioned.

Heimann and Ratner (1961) found that with sunflower, maize and tomato, the uptake of sodium was strongly reduced by the presence of potassium, whereas the uptake of potassium was not markedly influenced by the presence of sodium. These workers suggested that

in saline soils where sodium is a predominant cation, the presence of potassium would be important as a means of reducing toxic accumulations of sodium in plant tissues. Such a function is in addition to the established nutritional role of potassium. The influence of sodium on the potassium uptake suggested by these workers does not appear to be of the same magnitude as that reported by Kidson (1963b).

1.2.3. Magnesium

Hayward and Wadleigh (1949) stated that the deleterious effect of magnesium on plant performance may be due to excessive absorption of magnesium accompanied by greatly reduced absorption of calcium and potassium. Beeson et al. (1944) and Geraldson (1957) also obtained reduced calcium absorption. The latter author found this was more so than with excess sodium. Gauch and Wadleigh (1944) reported that magnesium salts retarded the growth of red kidney beans more than isosmotic solutions of other salts. The concentration of magnesium in the leaves was found by Beeson et al. (loc cit.) to be positively correlated with magnesium concentration in the solution.

1.2.4. Chloride

Where excess chloride has reduced plant growth and development, it has been due to toxic effects (Bernstein and Hayward, 1958). Meyer, Warren and Langston (1957) grew young tomato plants in nutrient solutions of approximately one atmosphere, where the chloride and sulphate ions were compared at two levels of concentration. They found that, on an equivalent basis, the chloride treatments absorbed less phosphate than the sulphate treatments, and that there was no significant difference between

the levels used for either anion. The chloride also increased the succulence of the young tomato plants as indicated by a lower dry matter percentage.

In another experiment, with only one level of chloride and sulphate and a chloride-sulphate mixture, the plants in the chloride treatment absorbed less nitrogen on a dry weight basis. They also found that the chloride-sulphate mixture produced the highest dry weight of plant top, and the sulphate treatment the least. They suggested that, at any particular level of osmotic pressure, a mixture of anions is more favourable to plant growth than a single anion.

Hayward and Long (1941) found that, with tomato plants grown in isosmotic concentrations of NaCl and Na_2SO_4, the plants of the sulphate treatment had the lowest dry weight, and that plants grown in NaCl solutions were the more succulent. Control solutions of similar osmotic concentration produced better growth than either of the salt solutions, a result supported by other workers. (Meyer et al. 1957; Heimann, 1958; Heimann and Ratner, 1961.)

Eaton (1942) found that 100 milliequivalents per litre of sulphate reduced the dry weight of vines and fresh weight of fruit of tomato plants more than 50 milliequivalents per litre of chloride. He reported that most of the plant species tested were, however, more tolerant of sulphates than of chlorides, a conclusion also reached by Magistad et al. (1943).

1.2.5. Nitrate

Smith and Warren (1957) grew lettuce and tomato plants under saline conditions to determine which fertilizer salts were the most injurious to plant growth under conditions of high salinity. They

reported that, on an equal molar basis, KCl decreased plant growth more than did KNO_3, while $CaCl_2$ decreased plant growth more than did $Ca(NO_3)_2$. Thus chlorides would appear to be the more depressive on the growth of these two species than are nitrates.

Lyon, Beeson and Barrentine (1942), and Wittwer and Teubner (1957) have reported the beneficial effect of nitrate due to increased fruitfulness of the tomato plant. In these studies the nitrate concentrations were not excessive.

1.2.6. Sulphate

Comparisons of the specific effects of chloride and sulphate have already been discussed. The specific effect of the sulphate may be due to excessive accumulation of this ion (Hayward and Long, 1943), or to reduced activity of the calcium ion in the root zone (Hayward and Wadleigh, 1949).

Hayward and Long (1941) found that starch accumulated in parenchymatous tissues as the salt concentration increased. This effect was most marked in their sulphate treatments.

1.3. Blossom-end Rot of Tomatoes

Blossom-end rot of tomato fruit is described in Bulletin No. 370 of the N.Z. Department of Agriculture on "Growing Tomatoes in Glasshouses" (1960), as follows:-

> "In its early stages the trouble appears as a small spot at or near the blossom end of the tomato and at this stage the affected area has the appearance of a bruise, being water soaked and dark green. As the size of the affected area increases the tissues become firm, leathery and brown to black. At times the whole of the blossom end of the fruit becomes flattened and black."

A number of factors were reported by workers in the first half of this century as causing blossom-end rot. Unsatisfactory water

relationships were associated most commonly with the disorder (Brooks, 1914; Chamberlain, 1933; Robbins, 1937).

More recently, however, calcium nutrition and factors affecting the availability of calcium to the tomato plant have been related with this condition. Robbins (1937) showed that it was associated with high osmotic pressures of nutrient solutions, and concluded that this was the result of decreased water availability. He did not examine the effect of variable osmotic pressures of the nutrient solution on the mineral content of the plant. Raleigh and Chucka (1944) established a critical calcium value of .20% (dry weight basis) in the tomato fruit, above which symptoms rarely occur. These authors concluded that nutrient element imbalance was more important as a cause of blossom-end rot than was the osmotic pressure of the nutrient solution. Lyon, Beeson and Barrentine (1942), using sand culture, found that, with treatment solutions of different macronutrient proportions, the incidence of the rot increased as the amount of calcium in the treatment solution decreased. The calcium content of the infected fruit was low.

Evans and Troxler (1953) were able to reduce the incidence of blossom-end rot by using high calcium fertilizer applications, calcium chloride sprays and calcium gluconate injections into the tomato fruit. Geraldson (1957) obtained complete control by using regular .04 molar calcium chloride sprays. He also found that a low ratio of p.p.m. calcium to p.p.m. total salts in the soil solution, the Ca/S.S.S. ratio, was associated with rot symptoms. A Ca/S.S.S. ratio of above 15-20 was suggested as desirable on most soils, if blossom-end rot was to be controlled. Such a ratio was favoured by

applications of soluble calcium-bearing fertilizers and was decreased by additions of fertilizers containing magnesium, ammonium, potassium and sodium. He considered that in his experience sodium had not been associated with blossom-end rot to the same extent as the other cations.

Clay and Hudson (1960) grew tomatoes under glass in plots which had first been watered with solutions containing varying amounts of a 3 : 1 mixture of potassium and magnesium sulphates. They found that the incidence of blossom-end rot was highest on the most saline plots, and that the use of gypsum as a base fertilizer reduced the prevalence of the disorder.

Spurr (1959) investigated the anatomical aspects of blossom-end rot of field grown tomatoes. The distal end of healthy and infected fruit was found to have a lower calcium content than the basal end, and it was this distal portion of the fruit where the symptoms occurred. Infected fruits were retarded in length growth, and necrotic cells developed in the epidermis and in the underlying cells of the pericarp. These cells contained light yellow to brown proteinaceous inclusions, and the tissues of these areas were often gutted with starch.

The accumulation of starch is not an absolute criterion of calcium deficiency, but it has been associated with calcium deficient castor bean plants (Venning, 1954) and calcium deficient tomato plants (Nightingale et al. 1931). This accumulation of starch may account for the higher dry matter percentage in calcium deficient tomato plants than in control plants (McIlrath, 1950; Kalra, 1956).

Severely infected plants may show symptoms other than those typical of fruit symptoms. These include restricted shoot growth,

death of growing points, the development of yellow, brown and purple tints in the distal leaflets of younger growths, and the distal flower trusses may die (Wallace, 1953). These symptoms are typical of calcium deficiency effects in other plant species (Hewitt, 1963).

Calcium is not readily redistributed in plant tissues. Thus, young leaves may show deficiency symptoms on plants where older leaves have large calcium reserves (Nanson and McElroy, 1963). McIlrath (1950) and Geraldson et al. (1954) found that the tomato fruit contained much less calcium than other portions of the plant. McIlrath reported that, on a dry weight basis, the percentage calcium was 2.77, 4.15, 1.76, and 0.40 for the roots, leaves, stems and fruits of normal tomato plants. Spurr (1959) suggested that the striking difference in calcium content between the leaves and fruit of the tomato may account for the fact that the fruit may show calcium deficiency symptoms and the leaves may not.

From the foregoing, it is apparent that there is much evidence in the literature which strongly implicates lack of calcium as the fundamental cause of blossom-end rot.

1.4. Inter-relationship between Vegetative Growth and Fruit Development in the Tomato Plant

McCollum (1934) suggested that fruits secrete a growth inhibiting substance which retards vegetative growth.

Salter (1958) investigated the effects of different water-regimes on the vegetative growth and fruit development of tomato plants at a number of regulated fruit loads. Reductions in fruit load, by the exclusion of fruit setting sprays or the removal of flower trusses, produced increases in vegetative growth of the aerial parts of plants.

Vegetative growth was checked to varying degrees by certain treatments, but the growth rate of fruits during their grand period of growth was not significantly different. Salter suggested that this was the result of the ability of the fruit to monopolize the food resources of the plant under sub-optimal conditions. The total yield and average weight of fruits, however, were still influenced by the water-regime.

Cooper (1961) found that in the U.K. during November, December and January, fruit and leaf development were both retarded. Fruit development was retarded more than leaf development, and thus the leaf area/fruit volume ratio rose rapidly. He pointed out that this finding does not support the proposal that fruit can monopolize food resources under sub-optimal conditions. Cooper found that once fruiting began, there was a rapid decrease in the leaf area/fruit volume ratio until a minimal value was attained, which, apart from the November - January period, was maintained throughout the remainder of the life of the plant. He therefore suggested a regulatory mechanism that maintains a balance between the two, rather than the existence of competition between vegetative growth and fruit development.

CHAPTER 2

MATERIALS AND METHODS

2.1. The Experiments

Two experiments were carried out. The first experiment investigated the importance of specific ion effects of certain excess soluble salts on the growth and development of the tomato plant, while the second experiment studied the importance of calcium deficiency as a specific ion effect of these excess soluble salts. Throughout the two experiments, which were conducted under glass, the variety of tomato grown was Potentate (N.Z. Government Approved Seed) and the growing medium used was vermiculite. The water and nutrients necessary for growth were supplied by applications of a nutrient solution. From planting out onwards, the plants were grown in tins $8\frac{1}{2}$" high, the volume of which was approximately 290 cubic inches.

Salt enriched treatment solutions were prepared by adding the required amount of salt to the nutrient solution, while control plants received nutrient solution only.

The nutrient solution, used in both experiments, was that developed by Hewitt (1952) at the Long Ashton Research Station for the nutrient culture of fruit trees. It has been found to be satisfactory for a wide range of crops, tomatoes included. The composition of this solution is given in Table 2.1.

TABLE 2.1.

Composition of Nutrient Solution

Salt	Weight in grams/100 litres nutrient solution
Major nutrients:	
KNO_3	20.2
$Ca(NO_3)_2.4H_2O$	94.4
$NaH_2PO_4.2H_2O$	20.8
$MgSO_4.7H_2O$	36.9
Minor nutrients:	
Ferric citrate	2.45
$MnSO_4.4H_2O$	0.223
$CuSO_4.5H_2O$	0.024
$ZnSO_4.7H_2O$	0.029
H_3BO_3	0.186
$(NH_4)_6Mo_7O_{24}.4H_2O$	0.0035

The design of the two experiments, the preparation of the nutrient solution, the composition and preparation of the salt enriched treatment solutions, and the technique used in growing the plants, are described in the subsequent sections.

2.2. Experimental Design

The first experiment was carried out in the 1961 and the second in the 1962 growing seasons. Experiment I was designed to establish the existence and make comparisons between specific ion effects of the salts used to enrich the nutrient solution. To facilitate comparisons between monovalent and divalent ions, and

to provide information on osmotic pressure effects, these salts were applied at three levels of osmotic pressure.

Experiment II was designed to study reduced calcium availability as a factor contributing to specific ion effects of the salt enriched treatments of Experiment I. Two series of salt enriched treatments at one level of osmotic pressure were used. One series was sprayed with .04 M $CaCl_2$ and the other was unsprayed. These sprays were applied in an attempt to control calcium deficiency symptoms; the technique used was similar to that reported by Geraldson (1957).

2.2.1. Experiment I

The salts used for enrichment of the nutrient solution were: NaCl, KCl, KNO_3, K_2SO_4 and $MgSO_4$. NaCl and $MgSO_4$ were of commercial grade; the remainder laboratory grade. Of these salts, only NaCl is of no commercial significance in tomato growing. Owing to the small amount of these salts present in the nutrient solution, and the inert nature of the vermiculite, it was assumed that the major contribution to the concentration of a particular salt, in any one salt enriched treatment, was due to the amount of salt added to the nutrient solution.

It was decided that an osmotic pressure of $4\frac{1}{2}$ atmospheres was the highest level of salt concentration that could be applied without bringing about severe reductions in plant performance. This level was in keeping with those suggested by Bernstein and Pearson (1954) and McNaught and Houston (1956). In addition, levels of 2 and 3 atmospheres were selected. The treatments used in Experiment I are listed in Table 2.2. One plant per treatment was grown in each of the six blocks (2.4.3.).

TABLE 2.2.

Treatments - Experiment I

Level of osmotic pressure	Treatments
$\frac{1}{2}$ atmosphere	Control (nutrient solution only)
2 atmospheres)Sum of O.P.)of nutrient	NaCl, KCl, KNO_3, K_2SO_4 and $MgSO_4$.
3 atmospheres)solution)and added	" " " " "
$4\frac{1}{2}$ atmospheres)salt.	" " " " "

The seed for this experiment was sown on the 12th October, 1961, the seedlings pricked out on 25th October, the plants planted into tins on 18th November, and the treatments first applied on 27th November. The first truss was harvested on 28th December; the final harvest and killing dates for the various levels are reported in the results.

2.2.2. Experiment II

The salt enriched treatments used were those of the 2 atmosphere level of Experiment I. One new salt enriched treatment, referred to hereafter as 'control 2 atmospheres', was added. In this treatment, the major nutrients of the nutrient solution were concentrated to raise the osmotic pressure from $\frac{1}{2}$ atmosphere to 2 atmospheres.

The treatments used in Experiment II are listed in Table 2.3. One plant per treatment was grown in each of the six blocks.

TABLE 2.3.

Treatments - Experiment II

Level of osmotic pressure	Treatments	
	Unsprayed series	Calcium sprayed series
$\frac{1}{2}$ atmosphere	Control	
2 atmospheres	Control 2 atmospheres	
2 atmospheres	NaCl, KCl, KNO_3, K_2SO_4 and $MgSO_4$.	NaCl, KCl, KNO_3, K_2SO_4 and $MgSO_4$.

The seed for this experiment was sown on 14th July, 1962, the seedlings pricked out on the 28th July, the plants planted into tins on 1st September, and the treatment solutions first applied on the 8th September. The $CaCl_2$ sprays were first used on 20th September, and then twice weekly till the end of the experiment.

Harvesting of the fruit commenced on 2nd November, the final harvest being on 3rd December, 1962, one day before the plants were killed.

2.3. Composition and Preparation of the Solutions used in Experiments I and II

Details of the composition and preparation of the various solutions used in the experiments are described below. Throughout this report, individual solutions are referred to by the terms used in this section.

2.3.1. Concentrated nutrient solution

A 44 gallon drum painted with bituminous paint was used to store the concentrated nutrient solution. The addition of 200 ml. of tap water to 800 ml. of this solution prepared 1 litre of nutrient solution.

The concentrated nutrient solution was prepared from nutrient stock solutions containing the salts listed in Table 2.1. The composition of these stock solutions is given in Appendix 1.

2.3.2. Treatment solutions

Experiment I: The control plants were fed the nutrient solution, of $\frac{1}{2}$ atmosphere osmotic pressure. The salt enriched treatment solutions were obtained by adding enough salt to raise the osmotic pressure of this nutrient solution to the required level.

The weight of salt, expressed as p.p.m., required to achieve the desired osmotic pressure for a particular salt enriched treatment, was obtained from graphs prepared from data on the freezing point depressions of aqueous solutions of salts reported in International Critical Tables, Vol. 4 (1929). The details of these calculations are given in Appendix 2.

Stock solutions based on these specifications were prepared and stored in 2 litre jars. The composition of these stock solutions were such (Appendix 3) that, to prepare one litre of the required salt enriched treatment, 200 ml. of the appropriate stock solution was added to 800 ml. of the concentrated nutrient solution.

Experiment II: The control and salt enriched treatment solutions were prepared as in Experiment I. The control 2 atmosphere treatment solution was prepared by adding the required amounts of the major nutrients from the nutrient stock solutions to the concentrated nutrient solution, and water (Appendix 4).

Hereinafter the salt enriched treatments are referred to as the NaCl treatment, KCl treatment, etc. and the control $\frac{1}{2}$ atmosphere treatment as the control treatment.

2.4. Technique Used in Growing the Tomato Plants

2.4.1. Propagation and rooting medium

The seed was sown in vermiculite (No. 3 grade) to ensure adequate aeration and moisture availability to the roots. The initial high pH of this medium fell rapidly under leaching.

The seedlings were raised in the propagating house, and were pricked out into 3" plastic pots at the time of cotyledon expansion. For both experiments, one and a half times the number of seedlings required were pricked out to allow for the selection of an even line of plants. The seedlings were watered with the nutrient solution as required, and the final selection of plants was made at the time of planting into tins.

2.4.2. Planting out

At this stage the root volume of the plastic pots was fully occupied, and the first truss was just visible. Six drainage holes were punched in the bottom of the tins, which were then painted with a bituminous paint to prevent any possible chemical reaction between the treatment solutions and the tin. Small stones were placed at the bottom of the tins for drainage and, in Experiment I, No. 3 grade, and in Experiment II, No. 4 grade vermiculite was used as the growing medium.

On planting out, the plants were well watered with tap water to lower the pH of the vermiculite from 9.5 to 6.5, and then given one pint of the nutrient solution per plant and transferred to the glasshouse.

2.4.3. Glasshouse

The glasshouse used for the experiments was a 20 x 20 ft. even

span house, with a height of 6 ft. to the top plate. The house was orientated north-south. The ventilation system consisted of six side ventilators (three per side), plus two roof ventilators on the western side, and three on the eastern side. The floor of the house was covered with sawdust, and, in the second experiment, black polythene sheeting was laid under the tins to prevent roots entering the sawdust.

The house was divided into six equal sized blocks. The rows in these blocks ran east-west, three rows per block in Experiment I and two rows per block in Experiment II. A row was designated within each block to each of the three levels of osmotic pressure in Experiment I, and to both the calcium sprayed and unsprayed series of Experiment II. The rows were selected for the various levels or series by the use of random numbers, as also were the positions of the treatments within these rows.

2.4.4. Watering

Throughout the experiments the plants were watered daily. Enough solution was applied to allow a small loss to drainage. It was considered that this leaching would prevent the accumulation of salt residues and would also provide adequate moisture for plant growth.

Occasional heavy leachings were given to ensure adequate removal of any salt residues. The plants were fed on the nutrient solution for a short time in the glasshouse prior to the application of the treatments. In both experiments the treatment solutions were prepared for each watering in gallon tins; there was one tin per treatment.

2.4.5. Training of plants, fruit set, disease and pest control

The plants were trained on single stems and were delateralised and tied up as required. Bamboo stakes were used to support the plants. These stakes were supported by wires stretched along the line of the rows, from top plate to top plate.

Satisfactory fruit set was obtained by natural means, while good disease and pest control was achieved by using aerosol sprays. Support stakes, seed boxes and the interior of the glasshouse were all treated with a 2% formalin solution prior to use. No tobacco-mosaic virus symptoms were observed in either experiment.

2.4.6. Temperature control

A Cassela Thermograph was used throughout the experiments to record temperature variations. Day temperatures rose to high levels on a number of occasions. Conventional methods of shading, ventilation and damping down were used to lower temperatures. A small 1 kw. electric fan heater was used in the early part of Experiment II to keep night temperatures at a satisfactory level.

2.5. Measurements Made on Tomato Plants

2.5.1. Measurements made on fruit

In Experiment I, all the fruit in the first truss, for all treatments, was harvested on the same date. This was done as a number of treatments of levels 3 and $4\frac{1}{2}$ were showing severe calcium deficiency, and it was considered that some of these plants should be killed immediately, in case the deficiency brought about the death of those plants severely affected. The harvesting of the first truss, before the plants were killed, allowed comparisons to be made on the fresh weight of fruit and the numbers of fruit for all treatments.

The harvesting of the remainder of the fruit in Experiment I, and that of Experiment II, was carried out as the fruit first coloured, except for the final harvests, which included all the fruit of diameter greater than $\frac{1}{2}$".

At each harvest the fresh weight, and the number of healthy fruit and the number of fruit showing blossom-end rot symptoms, were recorded. It was therefore possible to compare the percentage of infected fruit that occurred under the various salt treatments. This was only done for level 2 of Experiment I, as in all other cases most of the fruit showed blossom-end rot symptoms, even though with some salt treatments the infection of the fruit was slight.

An analysis of covariance was used to test for the presence of a treatment effect on the percentage of blossom-end rot infected fruit, independent of the effect of those treatments on the total number of fruit harvested.

The mean weight of fruit harvested for the different treatments, in both experiments was calculated from the data collected on total number and total fresh weight of fruit harvested.

The total soluble solids content of the expressed sap of a sample of fruit taken from the calcium sprayed series of Experiment II at the final harvest, was measured with a refractometer. The refractive indices were expressed as percentage soluble solids by use of conversion tables. Winsor (1957, 1958) has shown there is a close relationship between such readings and the dry matter percentage of the fruit sap.

2.5.2. Measurements made on plant top

The number of leaves up to the third truss, and the number of

flowers in the first, second and third trusses were recorded for every plant in Experiment II.

In both experiments, plants were killed immediately after the final harvest of fruit. The plant tops were then oven dried at 150°F. for 48 to 60 hours, and the weight of dry matter recorded. The length of the drying time depended on the size of the plants. Due to the limited amount of oven space, the killing of plants in certain instances in Experiment I had to be spread over several days.

In Experiment II the fresh weight of plant top was measured immediately after killing the plants just prior to oven-drying.

2.6. Methods of Comparing Salt Effects and Specific Ion Effects, and of Determining the Presence of Osmotic Effects of the Salt Treatments

2.6.1. Comparison of salt effects

The effects of the salt treatments on certain aspects of plant growth and development were compared within each of the three levels of osmotic pressure. This not only supplied information on salt effects at equal levels of osmotic concentration, but also allowed certain comparisons to be made between like-charged ions (2.6.2.). Similar salt treatments of the calcium sprayed and unsprayed series of Experiment II were also compared, to determine the importance of interference by these treatments in the calcium nutrition of the tomato plant.

2.6.2. Comparison of specific ion effects

Like-charged ions were compared to determine which had the greater depressing effect on the particular aspect of plant growth and development under consideration.

It is well known that the effects of excess concentrations of

salts, and thus of ions, are in most instances of a depressing nature. In the present investigation, where a beneficial effect has accompanied an increase in salt concentration, then the arguments developed in this section are still valid.

The ionic composition of the salt treatments used in the experiments allowed the following comparisons to be made:

(a) Sodium versus potassium: NaCl and KCl treatments were compared at equal levels of osmotic pressure. Thus the mean activity of the ions of each electrolyte was the same. On the reasonable assumption that the common chlorine ion had a similar activity in both solutions, the activities of the sodium and potassium ions would have been of comparable magnitudes. Hence differences in plant response can be attributed to the specific effects of the cation components.

(b) Chloride versus nitrate: KCl and KNO_3 treatments were compared at equal levels of osmotic pressure. Thus the mean activity of the ions of each electrolyte was the same. On the reasonable assumption that the common potassium ion had a similar activity in both solutions, the activities of the chloride and nitrate ions would have been of comparable magnitudes. Hence differences in plant response can be attributed to the specific effects of the anion components.

(c) Sulphate versus chloride: K_2SO_4 and KCl treatments were compared at adjacent levels of osmotic pressure, the latter treatment at the higher level. In these circumstances, the activity of the chloride ion was unquestionably greater than the activity of the sulphate ion.

If the K_2SO_4 treatment depressed plant performance more than the

KCl treatment, then it was considered reasonable to assume that such a result could only occur if the sulphate ion was more depressive than the chloride ion, and could not be accounted for by a possible greater activity of the potassium ion in the K_2SO_4 treatment. The K_2SO_4 treatment was also at the lower osmotic pressure.

If, however, the KCl treatment was the more depressive on plant performance, then no comparison could be made, as it would not be possible to distinguish between the osmotic and ionic effects of this salt treatment.

2.6.3. Determination of the presence of an osmotic effect of the salt treatments

Comparisons between the same salt treatment, at the three levels of osmotic pressure of Experiment I, were made in order to establish whether or not increasing concentrations of a particular salt brought about depressions in plant performance. The only comparison possible in Experiment II was between the control and control 2 atmosphere treatments.

CHAPTER 3

RESULTS

3.1. Fresh Weight of Fruit

3.1.1. Fresh weight of fruit on first truss and total fresh weight of fruit harvested in Experiment I

The fresh weight of fruit on the first truss was recorded for all treatments. For level 2 (all blocks) and for levels 3 and $4\frac{1}{2}$ of blocks II, IV and VI, the total fresh weight of fruit up till the time of killing the plants was recorded. No further measurements of fruit weight were made on the other treatments, as these plants were killed soon after harvesting the first truss.

The results of analyses of variance carried out on the above data are presented in summarised form in Tables 3.1. and 3.3. (Appendix 5)

TABLE 3.1.

Fresh weight of fruit on first truss for all blocks, harvesting completed 28.12.61.

Treatment (Yield in grams)						
Level of O.P. (Atmos.)	NaCl	KCl	KNO_3	K_2SO_4	$MgSO_4$	$C_{\frac{1}{2}}$+
2	68	65	49	47	38	(130)*
3	60	41	47	22	21	
$4\frac{1}{2}$	47	34	27	10	13	

+ $C_{\frac{1}{2}}$ refers to the control $\frac{1}{2}$ atmosphere treatment.

* Bracketed figure not included in analysis due to magnitude of mean yield.

Significant differences: 14.6 (p = .05) and 19.4 (p = .01)

From Table 3.1., using the .05 level of significance, it is possible to make the following deductions with respect to the comparative effects of (i) whole salts, and (ii) individual ions, where systems of equal osmotic pressure are compared (Table 3.2.).

The notation A > B is used to indicate that molecular or ion species A reduces the fresh weight of fruit to a value below that obtained using species B.*

TABLE 3.2.

Comparisons of whole salts and individual ions that are possible from data presented in Table 3.1.

	Osmotic level	Order of reduction in fresh weight of fruit.
Whole salts	2	$MgSO_4$, K_2SO_4, KNO_3 > KCl, NaCl > $C_{\frac{1}{2}}$
	3	$MgSO_4$, K_2SO_4 > KCl, KNO_3, NaCl > $C_{\frac{1}{2}}$ KCl > NaCl
	$4\frac{1}{2}$	K_2SO_4, $MgSO_4$ > KCl, NaCl > $C_{\frac{1}{2}}$ K_2SO_4 > KNO_3 > NaCl > $C_{\frac{1}{2}}$
Individual ions	2	NO_3^- > Cl^-
	3	K^+ > Na^+

* This notation is employed throughout this chapter in making comparisons of molecular or ion species effects, irrespective of the basis on which plant performance is compared.

TABLE 3.3.

Total fresh weight of fruit harvested

Blocks	Treatment (Yield in grams)							Date of final harvest
	Level of O.P.	NaCl	KCl	KNO_3	K_2SO_4	$MgSO_4$	Control	
	(Atmos.)							
I - VI	2	776	683	614	144	310	(2717)	2.3.62
II,IV,VI	3	332	208	214	58	127	(872)	24.1.62
II,IV,VI	$4\frac{1}{2}$	305	183	124	12	40		24.1.62

Significant differences: Level 2 - 86.8 ($p = .05$) and 118.4 ($p = .01$)

Levels 3 & $4\frac{1}{2}$ - 68.8 ($p = .05$) and 94.2 ($p = .01$)

TABLE 3.4.

Comparisons of whole salts and individual ions that are possible from data presented in Table 3.3.

	Osmotic level	Order of reduction in fresh weight of fruit
Whole salts	2	$K_2SO_4 > MgSO_4 > KNO_3$, $KCl > NaCl > C_{\frac{1}{2}}$
	3	$K_2SO_4 > MgSO_4 > KCl$, $KNO_3 > NaCl > C_{\frac{1}{2}}$
	$4\frac{1}{2}$	K_2SO_4, $MgSO_4 > KNO_3$, $KCl > NaCl > C_{\frac{1}{2}}$
Individual ions	2	$K^+ > Na^+$
	3	$K^+ > Na^+$
	$4\frac{1}{2}$	$K^+ > Na^+$
	*$3/4\frac{1}{2}$	$SO_4^{--} > Cl^-$

* Level 3 K_2SO_4 compared with level $4\frac{1}{2}$ KCl (2.6.2.c.).

(a) Osmotic pressure effects: In Tables 3.1. and 3.3., although differences between adjacent levels of osmotic pressure are not always significant (p = .05), the trend of means for every salt treatment is to decrease as the osmotic pressure increases. In Table 3.1., differences between levels 2 and $4\frac{1}{2}$ are all significant (p = .01). As the harvesting of level 2 of Table 3.3. was completed later than for levels 3 and $4\frac{1}{2}$, its means cannot be compared with those of the other levels.

3.1.2. Total fresh weight of fruit harvested in Experiment II

The fresh weight of fruit for all treatments was recorded up till the final harvest on 3.12.62. The results of analyses of variance carried out on this data are presented in summarised form in Table 3.5. (Appendix 6)

TABLE 3.5.

Total fresh weight of fruit harvested

Treatment (Yield in grams)							
Series	NaCl	KCl	KNO_3	K_2SO_4	$MgSO_4$	$C_{\frac{1}{2}}$	C_2*
Unsprayed	948	648	446	204	205	2045	1318
Sprayed	1035	987	913	881	563		

* C_2 refers to the control 2 atmosphere treatment.

Significant differences: 160.8 (p = .05) and 214.2 (p = .01)

Figure 1. Comparison of plants of the calcium sprayed and unsprayed $MgSO_4$ treatments in Experiment II. The calcium sprayed plant on the left has the larger sized fruit (3.3.2.a.) and thus a greater total weight of fruit (3.1.2.a.) than the unsprayed plant on the right. The unsprayed plant also shows symptoms typical of calcium deficiency - blossom-end rot of the fruit and die back of the terminal shoot.

TABLE 3.6.

Comparisons of whole salts and individual ions that are possible from data presented in Table 3.5.

	Series	Order of reduction in fresh weight of fruit.
Whole Salts	Unsprayed	K_2SO_4, $MgSO_4$ > KNO_3 > KCl > NaCl > C_2 > $C_{\frac{1}{2}}$
	Sprayed	$MgSO_4$ > K_2SO_4, KNO_3, KCl, NaCl > C_2 > $C_{\frac{1}{2}}$
Individual ions	Sprayed	$K^+ > Na^+$
		$NO_3^- > Cl^-$

(a) Calcium spray effects: In Table 3.5., there is no significant difference between the NaCl treatments, but for all other comparisons calcium sprays significantly increased ($p = .01$) the fresh weight of fruit.

(b) Osmotic pressure effects: Table 3.5. shows that the fresh weight of fruit of the control treatment was significantly greater ($p = .01$) than that of the control 2 atmosphere treatment.

3.2. Total Number of Fruit Harvested

3.2.1. Total number of fruit harvested in Experiment I

Of the data collected, only that for level 2 (all blocks) and levels 3 and $4\frac{1}{2}$ of blocks II, IV and VI were considered important. The data for all other treatments referred only to the first truss, which was not affected in respect of fruit number. The number of fruit set in the first truss depended mainly on the number of flowers initiated during propagation, and not on the salt treatments.

The results of analyses of variance carried out on the relevant data are presented in summarised form in Table 3.7. (Appendix 7)

TABLE 3.7.

Total number of fruit harvested

Treatment (Number of fruit)						
Level of O.P. (Atmos.)	NaCl	KCl	KNO_3	K_2SO_4	$MgSO_4$	$C\frac{1}{2}$
2	49	61	60	35	60	52
3	31	40	38	15	21	33
$4\frac{1}{2}$	34	32	28	6	13	

Significant differences: Level 2 - 14.1 (.05) and 19.1 (.01)

Levels 3 & $4\frac{1}{2}$ - 8.7 (.05) and 11.9 (.01)

TABLE 3.8.

Comparisons of whole salts and individual ions that are possible from data presented in Table 3.7.

	Osmotic level	Order of reduction in numbers of fruit.
Whole salts	2	$K_2SO_4 > C\frac{1}{2}$, $MgSO_4$, KNO_3, KCl
	3	K_2SO_4, $MgSO_4 >$ NaCl, $C\frac{1}{2}$, KNO_3, KCl
		NaCl > KCl
	$4\frac{1}{2}$	K_2SO_4, $MgSO_4 > KNO_3$, KCl, $C\frac{1}{2}$, NaCl
Individual ions	3	$Na^+ > K^+$
	*3/$4\frac{1}{2}$	$SO_4^{--} > Cl^-$

* Level 3 K_2SO_4 compared with level $4\frac{1}{2}$ KCl.

(a) Osmotic pressure effects: In Table 3.7., differences between levels 3 and $4\frac{1}{2}$ are not always significant (p = .05), but in most cases the trend of means is to decrease as the osmotic pressure increases.

3.2.2. Total number of fruit harvested in Experiment II

The results of the analysis of variance carried out on the relevant data are presented in summarised form in Table 3.9. (Appendix 8)

TABLE 3.9.

Total number of fruit harvested

Treatment (Number of fruit)							
Series	NaCl	KCl	KNO_3	K_2SO_4	$MgSO_4$	$C_{\frac{1}{2}}$	C_2
Unsprayed	36	42	46	31	33	40	43
Sprayed	34	32	37	30	24		

Significant differences: 6.3 (p = .05) and 8.3 (p = .01)

TABLE 3.10.

Comparisons of whole salts that are possible from data presented in Table 3.9.

	Series	Order of reduction in number of fruit.
(a) Whole salts	Unsprayed	K_2SO_4, $MgSO_4$ > $C_{\frac{1}{2}}$, KCl, C_2, KNO_3
		NaCl > C_2, KNO_3
	Sprayed	$MgSO_4$, K_2SO_4 > KNO_3, $C_{\frac{1}{2}}$, C_2
		$MgSO_4$ > KCl, NaCl
		KCl > $C_{\frac{1}{2}}$, C_2
		NaCl > C_2

(a) Calcium spray effects: Table 3.9. shows that calcium sprays reduced (p = .01) the total number of fruit harvested in the KCl, KNO_3 and $MgSO_4$ treatments. Although differences are not significant with the other salt treatments, spraying produced a reduction in fruit numbers.

(b) Osmotic pressure effects: In Table 3.9., there is no significant difference between the total number of fruit harvested for the control and control 2 atmosphere treatments.

3.3. Mean Weight of Fruit Harvested

3.3.1. Mean weight of fruit harvested in Experiment I

The mean weight of fruit was calculated for level 2 (all blocks) and for levels 3 and $4\frac{1}{2}$ of blocks II, IV and VI.

The results of analyses of variance carried out on the above data are presented in summarised form in Table 3.11. (Appendix 9)

TABLE 3.11.

Mean weight of fruit

Treatment (Mean weight of fruit in grams)						
Level of O.P. (Atmos.)	NaCl	KCl	KNO_3	K_2SO_4	$MgSO_4$	$C_{\frac{1}{2}}$
2	16.0	11.3	10.3	4.1	5.4	(57.4)
3	10.7	5.2	5.7	3.9	6.0	(28.5)
$4\frac{1}{2}$	9.0	6.1	4.5	2.2	2.8	

Significant differences: Level 2 - 1.90 (p = .05) and 2.59 (p = .01)

Levels 3 & $4\frac{1}{2}$ - 2.66 (p = .05) and 3.64 (p = .01)

TABLE 3.12.

Comparisons of whole salts and individual ions that are possible from data presented in Table 3.11.

	Osmotic level	Order of reduction in mean weight of fruit.
Whole salts	2	K_2SO_4, $MgSO_4$ > KNO_3, KCl > NaCl > $C_{\frac{1}{2}}$
	3	K_2SO_4, KCl, KNO_3, $MgSO_4$ > NaCl > $C_{\frac{1}{2}}$
	$4\frac{1}{2}$	K_2SO_4, $MgSO_4$, KNO_3, KCl > NaCl > $C_{\frac{1}{2}}$
		K_2SO_4, $MgSO_4$ > KCl
Individual ions	2	K^+ > Na^+
	3	K^+ > Na^+
	$4\frac{1}{2}$	K^+ > Na^+

(a) Osmotic pressure effects: In Table 3.11., only levels 3 and $4\frac{1}{2}$ can be compared, as level 2 was killed at a later date. A significant decrease ($p = .05$) in mean weight of fruit occurred for the $MgSO_4$ treatments as the osmotic pressure increased. Non-significant trends, in the same direction, are apparent for most of the other treatments.

3.3.2. Mean weight of fruit harvested in Experiment II

The results of the analysis of variance carried out on the relevant data are presented in summarised form in Table 3.13. (Appendix 10)

TABLE 3.13.

Mean weight of fruit

Treatment (Mean weight of fruit in grams)							
Series	NaCl	KCl	KNO_3	K_2SO_4	$MgSO_4$	$C_{\frac{1}{2}}$	C_2
Unsprayed	26.7	15.7	10.0	5.9	6.3	52.4	31.5
Sprayed	31.0	31.1	24.7	30.1	24.0		

Significant differences: 5.0 ($p = .05$) and 6.7 ($p = .01$)

Figure 2. Comparison of plants of the control 2 atmosphere and control treatments in Experiment II. The control plant on the right has the larger sized fruit (3.3.2.b.) and thus a greater total weight of fruit (3.1.2.b.) than the control 2 atmosphere plant on the left. Neither plant shows any symptoms of calcium deficiency (3.8.2.).

TABLE 3.14.

Comparisons of whole salts and individual ions that are possible from data presented in Table 3.13.

	Series	Order of reduction in mean weight of fruit
Whole salts	Unsprayed	K_2SO_4, $MgSO_4$, KNO_3 > KCl > NaCl, C_2 > $C_{\frac{1}{2}}$
	Sprayed	$MgSO_4$, KNO_3 > K_2SO_4, NaCl, KCl, C_2 > $C_{\frac{1}{2}}$
Individual ions	Unsprayed	$K^+ > Na^+$
		$NO_3^- > Cl^-$
	Sprayed	$NO_3^- > Cl^-$

(a) Calcium spray effects: In Table 3.13., there is no significant difference between the NaCl treatments, but for all other comparisons, calcium sprays significantly increased ($p = .01$) the mean weight of fruit.

(b) Osmotic pressure effects: Table 3.13. shows that the mean weight of fruit of the control treatment was significantly greater ($p = .01$) than that of the control 2 atmosphere treatment.

3.4. Dry Weight of Plant Top

3.4.1. Dry weight of plant top in Experiment I

Dry weight measurements were made on all the plant top excluding the fruit. Plants of blocks I, III and V of levels 3 and $4\frac{1}{2}$ were killed on the 9th and 5th of January respectively, but those of blocks II, IV and VI of levels 3 and $4\frac{1}{2}$ were killed on the 24th January, and all plants of level 2 were killed on the 2nd March, 1962.

The results of analyses of variance carried out on the above data are presented in summarised form in Table 3.15. (Appendix 11)

TABLE 3.15.

Dry weight of plant top

Blocks	Treatment (Yield in grams)						
	Level of O.P.	NaCl	KCl	KNO_3	K_2SO_4	$MgSO_4$	$C_{\frac{1}{2}}$
	(Atmos.)						
I - VI	2	94	123	130	135	121	160
I,III,V	3	55	56	58	57	44	
II,IV,VI	3	74	85	86	66	67	98
I,III,V	$4\frac{1}{2}$	40	46	44	41	27	
II,IV,VI	$4\frac{1}{2}$	62	70	62	49	43	

Significant differences: Level 2 - 12.4 ($p = .05$) and 16.8 ($p = .01$)
Level 3 (blocks I,III,V) - 4.5 ($p = .05$) and 6.5 ($p = .01$)
Level $4\frac{1}{2}$ (" I,III,V) - 5.4 ($p = .05$) and 7.8 ($p = .01$)
Levels 3 & $4\frac{1}{2}$ (" II,IV,VI) - 12.7 ($p = .05$) and 17.3 ($p = .01$)

TABLE 3.16.

Comparisons of whole salts and individual ions that are possible from data presented in Table 3.15.

	Osmotic level	Blocks	Order of reduction in dry weight of plant top.
Whole salts	2	I - VI	$NaCl > MgSO_4$, KCl, KNO_3, $K_2SO_4 > C_{\frac{1}{2}}$
			$MgSO_4 > K_2SO_4$
	3	I,III,V	$MgSO_4 > NaCl$, KCl, K_2SO_4, KNO_3
	3	II,IV,VI	K_2SO_4, $MgSO_4$, $NaCl > C_{\frac{1}{2}}$
			K_2SO_4, $MgSO_4 > KCl$, KNO_3
			$KCl > C_{\frac{1}{2}}$
	$4\frac{1}{2}$	I,III,V	$MgSO_4 > NaCl$, K_2SO_4, KNO_3, KCl
			$NaCl > KCl$
	$4\frac{1}{2}$	II,IV,VI	$MgSO_4$, $K_2SO_4 > NaCl$, KNO_3, $KCl > C_{\frac{1}{2}}$
Individual ions	2	I - VI	$Na^+ > K^+$
	$4\frac{1}{2}$	I,III,V	$Na^+ > K^+$

(a) Osmotic pressure effects: In Table 3.15., the only comparisons that are valid are those between levels 3 and $4\frac{1}{2}$ of blocks II, IV and VI.

With the exception of the NaCl treatments, increases in the osmotic pressure of the salt treatments produced significant reductions ($p = .05$) in the dry weight of the plant top. A reduction in the dry weight of plant top also occurred with the NaCl treatment, but the difference is not quite significant ($p = .05$).

3.4.2. Dry weight of plant top in Experiment II

All the plants were killed on 4.12.62. The results of the analysis of variance carried out on the relevant data are presented in summarised form in Table 3.17. (Appendix 12)

TABLE 3.17.

Dry weight of plant top

Treatment (Weight in grams)							
Series	NaCl	KCl	KNO_3	K_2SO_4	$MgSO_4$	$C_{\frac{1}{2}}$	C_2
Unsprayed	80	107	136	108	69	101	122
Sprayed	80	75	98	66	45		

Significant differences: 11.7 ($p = .05$) and 15.5 ($p = .01$)

TABLE 3.18.

Comparisons of whole salts and individual ions that are possible from data presented in Table 3.17.

	Series	Order of reduction in dry weight plant top.
Whole salts	Unsprayed	$MgSO_4$, NaCl > $C_{\frac{1}{2}}$, KCl, K_2SO_4 > C_2 > KNO_3
	Sprayed	$MgSO_4$ > K_2SO_4, KCl, NaCl > KNO_3, $C_{\frac{1}{2}}$ > C_2
		K_2SO_4 > NaCl
Individual ions	Unsprayed	Na^+ > K^+
		Cl^- > NO_3^-
	Sprayed	Cl^- > NO_3^-

(a) Calcium spray effects: Table 3.17. shows that apart from the NaCl treatments where no significant difference is apparent, the calcium spray significantly reduced ($p = .01$) the dry weight of plant top.

(b) Osmotic pressure effects: Table 3.17. shows that the dry weight of plant top of the control treatment was significantly less ($p = .01$) than that of the control 2 atmosphere treatment.

3.5. Fresh Weight of Plant Top in Experiment II

All the plants were killed on 4.12.62. The results of the analysis of variance carried out on the relevant data are presented in summarised form in Table 3.19. (Appendix 13)

TABLE 3.19.

Fresh weight of plant top

	Treatment (Weight in grams)						
Series	NaCl	KCl	KNO_3	K_2SO_4	$MgSO_4$	$C_{\frac{1}{2}}$	C_2
Unsprayed	541	687	950	647	419	749	863
Sprayed	553	557	759	446	286		

Significant differences: 79.2 ($p = .05$) and 105.4 ($p = .01$)

TABLE 3.20.

Comparisons of whole salts and individual ions that are possible from data presented in Table 3.19.

	Series	Order of reduction in fresh weight of plant top.
Whole salts	Unsprayed	$MgSO_4 > NaCl > K_2SO_4$, KCl, $C_{\frac{1}{2}} > C_2 > KNO_3$
		$K_2SO_4 > C_{\frac{1}{2}}$
	Sprayed	$MgSO_4 > K_2SO_4 > NaCl$, $KCl > C_{\frac{1}{2}}$, $KNO_3 > C_2$
Individual ions	Unsprayed	$Na^+ > K^+$
		$Cl^- > NO_3^-$
	Sprayed	$Cl^- > NO_3^-$

(a) Calcium spray effects: Table 3.19. shows that, apart from the NaCl treatments where no significant difference is apparent, the calcium spray significantly reduced ($p = .01$) the fresh weight of plant top.

(b) Osmotic pressure effects: Table 3.19. shows that the fresh weight of plant top for the control treatment was significantly less ($p = .01$) than that of the control 2 atmosphere treatment.

3.6. Percentage Dry Matter of Plant Material in Experiment II

3.6.1. Percentage dry matter of plant top

The percentage dry matter was calculated as follows:

$$\frac{\text{dry weight}}{\text{fresh weight}} \times \frac{100}{1}$$

The results of the analysis of variance carried out on the relevant data are presented in summarised form in Table 3.21. (Appendix 14)

TABLE 3.21.

Percentage dry matter of plant top

Treatment							
Series	NaCl	KCl	KNO_3	K_2SO_4	$MgSO_4$	$C_{\frac{1}{2}}$	C_2
Unsprayed	14.7	15.6	14.3	16.8	16.7	13.6	14.2
Sprayed	14.5	13.5	12.9	14.8	15.5		

Significant differences: .88 ($p = .05$) and 1.17 ($p = .01$)

TABLE 3.22.

Comparisons of whole salts and individual ions that are possible from data presented in Table 3.21.

	Series	Order of increase in percentage dry matter of plant top. (Highest % on left.)
Whole salts	Unsprayed	K_2SO_4, $MgSO_4$ > KCl > NaCl, KNO_3, C_2, $C_{\frac{1}{2}}$
		NaCl > $C_{\frac{1}{2}}$
	Sprayed	$MgSO_4$, K_2SO_4, NaCl > $C_{\frac{1}{2}}$, KCl, KNO_3
		$MgSO_4$ > NaCl, C_2
		C_2 > KNO_3
Individual ions	Unsprayed	$K^+ > Na^+$
		$Cl^- > NO_3^-$
	Sprayed	$Na^+ > K^+$

(a) Calcium spray effects: Table 3.21. shows that, apart from the NaCl treatments where no significant difference is apparent, the calcium spray significantly reduced ($p = .01$) the percentage dry matter of plant top.

(b) Osmotic pressure effects: In Table 3.21. there is no significant difference between the percentage dry matter of plant top for the control and control 2 atmosphere treatments.

3.6.2. Percentage soluble solids of expressed sap of tomato fruit

A small sample of fruit, at all stages of maturity, was collected from the five salt treatments of the calcium sprayed series, and the control and control 2 atmosphere treatments at the final harvest.

The data collected was not suitable for statistical analysis. Table 3.23. presents the average values of the percentage soluble solids of the expressed sap of the fruit collected from each treatment. (Appendix 15)

TABLE 3.23.

Percentage soluble solids of expressed sap of tomato fruit

Treatment	Percentage soluble solids	Treatment	Percentage soluble solids
NaCl	6.9	$MgSO_4$	7.3
KCl	7.1	C_2	7.1
KNO_3	7.8	$C_{\frac{1}{2}}$	4.7
K_2SO_4	6.9		

(a) Osmotic pressure effects: The data in Table 3.23. suggests that the rise in osmotic pressure from $\frac{1}{2}$ atmosphere of the control treatment to 2 atmospheres of the control 2 atmosphere and the salt treatments, was accompanied by a rise in the percentage soluble solids content of the fruit sap.

3.7. Flower Number in the First Three Trusses and Leaf Number up to the Third Truss in Experiment II

3.7.1. Flower number

There were no significant treatment effects on flower number for the first and second trusses. (Appendix 16) The results of the analysis of variance carried out on the data for the third truss are presented in summarised form in Table 3.24. (Appendix 16)

TABLE 3.24.

Number of flowers in third truss

Treatment							
Series	NaCl	KCl	KNO_3	K_2SO_4	$MgSO_4$	$C_{\frac{1}{2}}$	C_2
Unsprayed	8.3	11.3	18.3	9.5	10.2	10.8	14.0
Sprayed	11.7	11.2	19.8	10.7	10.0		

Significant differences: 6.20 ($p = .05$) and 8.26 ($p = .01$)

TABLE 3.25.

Comparisons of whole salts and individual ions that are possible from data presented in Table 3.24.

	Series	Order of increase in number of flowers in third truss. (Highest on left.)
Whole salts	Unsprayed	KNO_3 > KCl, $C_{\frac{1}{2}}$, $MgSO_4$, K_2SO_4, NaCl
	Sprayed	KNO_3 > NaCl, KCl, $C_{\frac{1}{2}}$, K_2SO_4, $MgSO_4$
Individual ions	Unsprayed	NO_3^- > Cl^-
	Sprayed	NO_3^- > Cl^-

(a) Table 3.24. shows that there were no significant responses to calcium spraying or to increases in osmotic pressure.

3.7.2. Leaf number

The data on number of leaves up to the third truss is given in Appendix 17. The variation in data is such that statistical analysis was not warranted, due to the obvious lack of treatment effects.

3.8. Calcium Deficiency

3.8.1. The percentage calcium/total soluble salts ratio of the treatment solutions in both experiments

The percentage Ca/SSS ratio of Geraldson (1957) was calculated (Appendix 18) for the various treatment solutions. The results of these calculations are presented in Table 3.26.

TABLE 3.26.

Percentage Ca/SSS ratio of the treatment solutions

Treatment							
Level	NaCl	KCl	KNO_3	K_2SO_4	$MgSO_4$	$C_{\frac{1}{2}}$	C_2
$\frac{1}{2}$						13.1	
2	4.8	4.1	3.2	2.7	2.0		13.3
3	3.4	2.8	2.1	1.7	1.2		
$4\frac{1}{2}$	2.3	1.9	1.4	1.1	0.8		

3.8.2. The percentage of blossom-end rot infected fruit for the salt treatments of level 2, Experiment I

The results of the analysis of covariance carried out on the relevant data are presented in summarised form in Table 3.27. (Appendix 19)

TABLE 3.27.

Percentage of blossom-end rot infected fruit

Treatment	NaCl	KCl	KNO_3	K_2SO_4	$MgSO_4$
NaCl	37.0	n.s.	n.s.	**	**
KCl		40.8	n.s.	**	**
KNO_3			43.8	**	**
K_2SO_4				72.0	*
$MgSO_4$					62.6

** p = .01

* p = .05

TABLE 3.28.

Comparisons of whole salts that are possible from data presented in Table 3.27.

	Order of increase in percentage blossom-end rot. (Highest % on left.)
Whole salts	K_2SO_4 > $MgSO_4$ > KNO_3, KCl, NaCl

Symptoms of blossom-end rot did not occur on the fruit of plants grown in the control, control 2 atmosphere, or calcium sprayed salt treatment solutions.

CHAPTER 4

DISCUSSION

4.1. Introduction

As the experimental plants were grown in nutrient solutions, care must be taken in extrapolating conclusions drawn from the experiments, to tomato crops grown in soil under similar salt treatments. Cation effects in particular are generally more striking in sand or similar media-culture than in soil culture, due, undoubtedly, to the buffering action of the soil. Exchangeable calcium in the soil here plays an important part in reducing the specific effects of Na^+, K^+ or Mg^{++} (Bernstein and Hayward, 1958). This point should be kept clearly in mind, as calcium deficiency played a major part in reducing plant performance in the experiments reported here. Apart from this important difference, the tomatoes, grown in the two experiments, experienced environmental conditions and management techniques similar to those pertaining to a commercial cool house crop growing over the same period of the year.

4.2. Osmotic Effects of Excess Soluble Salts

4.2.1. The effects of increases in salt concentration on the growth and development of the tomato plant

The results of the experiments showed that, as the osmotic pressure of the treatment solutions increased, the fresh weight of fruit decreased [3.1.1.(a), 3.1.2.(b)]. Smith and Warren (1957) and Clay and Hudson (1960) obtained similar responses with tomatoes grown in soil at varying levels of salinity. The latter authors also calculated the mean weight of fruit, and found that this decreased as

salinity increased.

In the present investigation, despite the fact that differences in treatment means were not always significant, there were definite trends indicating that both the number of fruit and the mean weight of fruit decreased as the osmotic concentration of the treatment solutions increased [3.2.1.(a), 3.3.1.(a), 3.3.2.(b)]. This suggested that the decrease in yield of fruit was due partly to a decrease in the size of the fruit, and partly to a decrease in the number of fruit.

The control 2 atmosphere treatment of Experiment II was included to represent a treatment of similar osmotic pressure to the salt treatments, but to be of a balanced nutritional composition. Thus specific ion effects of this treatment were negligible. This experiment suggested that the difference in yield of fruit between the control and control 2 atmosphere treatments was due mainly to a reduction in the mean weight of fruit (Tables 3.5., 3.9., 3.13.). Such a result indicated that increases in osmotic pressure reduced the yield of fruit by decreasing the mean weight of fruit, rather than by reducing the total number of fruit. Therefore, the reduction in fruit numbers that occurred with the increasing osmotic pressure of the salt treatments must have been due to an intensification of the specific ion effects of these treatments.

Clay and Hudson (loc cit.) found that vegetative growth was reduced by increases in soil salinity. The results of the present investigation were not entirely in agreement with the findings of these workers. In Experiment I, increases in the concentration of salt treatments, with the exception of the NaCl treatment, caused significant reductions in dry weight of plant top [3.4.1.(a)].

The NaCl treatment showed the same trend, but it was not quite significant.

This reduction in dry weight of plant top by increased osmotic pressure of the treatment solutions was, however, not apparent with the control and control 2 atmosphere treatments of Experiment II. In this case, the dry weight of plant top increased as the osmotic pressure was raised from $\frac{1}{2}$ to 2 atmospheres (Table 3.17.). This apparent contradiction might be explained by the fact that the control plants were grown under extremely favourable conditions, and the crop yield was considerably greater than that obtained by the control 2 atmosphere plants. This crop yield would be at the expense of materials otherwise available for vegetative growth. The balance between vegetative growth and reproductive development will be discussed later (4.5.).

The comments made above on the increased dry weight, produced by an increase in the osmotic pressure of the nutrient solution, would apply equally well to the results obtained for fresh weight of plant top for the control and control 2 atmosphere treatments of Experiment II (Table 3.19.).

Although the difference between the dry matter percentage of plant top for these two treatments (Table 3.21.). was not significant, the data suggests that a rise in osmotic pressure increased the dry matter percentage. A similar trend was noted for total soluble solids of the tomato fruit [3.6.2.(a)]. Similar responses have been reported by Hayward and Long (1941) and Kidson (1963b) for plant top and fruit respectively. The increased osmotic pressure was produced by these workers by increasing the concentration of the major nutrients. Thus the decreased succulence was due to

osmotic, and not specific ion effects.

It is apparent that an increase in the osmotic pressure of the treatment solutions reduced the growth and development of the tomato. As yield and size of fruit are all horticulturally important aspects of a crop, these reductions are undesirable. The increase in total soluble solids of the tomato fruit would be very desirable in some cases (production tomato paste), but it is doubtful if this increase would compensate for the loss in yield.

4.2.2. Mechanism involved in the reduction of tomato growth and development by increases in salt concentration of the growing medium

In both experiments, the control plants had the greatest transpiration rate, as they required the most solution at each watering. The daily water requirement of these plants was twice that of the salt treatments of level 2 (2 pints versus 1 pint), four and seven weeks respectively, after the treatments were first applied in Experiments I and II. As the environmental conditions around each plant were substantially the same, and the difference in amount of foliage between the control treatment and salt treatments of level 2 was not great, the salt treatments must have resulted in reduced availability of water.

A response of an identical nature has been reported by Stanhill (1958) with glasshouse tomatoes. He found that, in the same glasshouse, the water loss from tomatoes grown on saline plots was less than that from plants grown on non-saline plots where the plant cover was similar. Thus the imposition of saline conditions would appear to reduce transpiration rates of plants, a response also noted by some workers when soil moisture tension was increased (Abd el Rahman and Bierhuizen, 1960; Thorne and Hendrickson, 1955; Makkink and

van Heemst, 1956).

Although no root measurements were made, the handling of the plants in their tins indicated that the plants at the higher levels of osmotic pressure had larger root systems. Salter (1954) made similar observations on tomato root systems grown under different soil moisture regimes. The drier regimes produced a deeper and more extensive root system.

Salter (1954, 1957, 1958) reported that the total yield and mean weight of fruit and the dry weight of plant top all decreased as the soil moisture tension increased. Abd el Rahman and Bierhuizen (1960) have shown that the dry matter percentage of plant top increased as the soil moisture tension increased, as also did Wight et al. (1962) with the total soluble solids content of fruit. The responses of tomato plants to soil moisture stress, reported by these workers, were all obtained in the present investigation in response to increases in osmotic pressure of the growing medium.

The above evidence, although only of a qualitative nature, implicates reduced water uptake as a major factor in producing the plant responses reported here. An intensification of the specific ion effects of the salt treatments (4.3.) would also be involved. The mechanism responsible for the reduced water uptake is presumably an osmotic one (1.1.).

4.3. Specific Ion Effects of Excess Soluble Salts

4.3.1. Sodium

The results of Experiment II showed that, on spraying with .04M $CaCl_2$, differences in total fresh weight of fruit, number of fruit (unsprayed comparison almost significant), mean weight of fruit,

dry weight of plant top and fresh weight of plant top, between the NaCl and KCl treatments, were no longer significant (Tables 3.6., 3.9., 3.14., 3.18., 3.20.). It was concluded, therefore, that differences between these two treatments were due largely to differences in calcium nutrition.

The responses of the KCl treatment to the calcium sprays were very marked, but those of the NaCl treatment were slight. This indicated that the potassium ion reduced the uptake of calcium by the tomato plant, more than did the sodium ion; a result reported by a number of workers (Geraldson, 1957; Kidson, 1963a).

It has been suggested by Geraldson (loc cit.) that sodium may be able to substitute to some extent for calcium. The data presented by Kidson (loc cit.), and discussed below, would support this statement.

The potassium sulphate treatment of Kidson showed calcium deficiency symptoms in the form of blossom-end rot of fruit. The calcium content of these fruit on a dry matter basis was .09%, and that of the sodium sulphate treatment .13%, both lower than the .20% suggested by Raleigh and Chucka (1944), as the critical level below which calcium deficiency symptoms were likely to occur. The fact that blossom-end rot symptoms were negligible on the sodium treatment, even though the calcium content was low, could be presented as evidence of a sodium substitution.

Wallace (1953) and Spurr (1959) have reported that the tomato fruit is more susceptible to calcium deficiency than vegetative parts of the plant. It is suggested that differences in the effects of the KCl and NaCl treatments were mainly due to the potassium ion affecting the calcium nutrition of the tomato fruit. The reduced amount of calcium available to the fruit decreased the fruit size and thus the

total weight of fruit, so that a greater proportion of the nutritive materials were available for the vegetative organs. This would explain why the KCl treatment had the lower total yield and mean weight of fruit, and higher dry weight and fresh weight of plant top.

The lower fruit number of the NaCl treatment, it is considered, was a consequence of the larger fruit load retarding the development of late formed fruit, and not an effect on flower formation. This was further supported by the data collected on flower numbers in the first three trusses of Experiment II, where there was no evidence of these two salt treatments influencing flower numbers (3.7.1.).

Hayward and Long (1941) reported that NaCl treatment solutions produced a lower dry weight of plant top than control solutions of similar osmotic pressure. This response was also obtained in the present investigation (Tables 3.16., 3.18.), and after spraying with $CaCl_2$, significant differences still showed in growth and development between the NaCl treatment and the control 2 atmosphere treatment (Table 3.18.). The possibility of some beneficial nutritional effects of this "balanced" treatment of two atmospheres concentration cannot be overlooked, but if such effects existed, they were presumed to be slight. Differences must have therefore been due to specific effects of the sodium and/or chloride ions, other than those due to calcium deficiency.

The toxic effect of the sodium ion should not have been great, as Kidson (1963b) has shown that tomato plants absorb large quantities of this element without detrimental effects. Thus, most of the differences after spraying could be attributed to specific effect(s) of the chloride ion.

4.3.2. Potassium

The comparative effect of the potassium and sodium ions on the calcium nutrition, and thus the growth and development of the tomato plant, has been discussed (4.3.1.).

The use of the $CaCl_2$ spray increased the total fresh weight of fruit and mean weight of fruit in the K_2SO_4 treatment to a greater extent than it did in the $MgSO_4$ treatment (Tables 3.5., 3.13.). This suggests that K_2SO_4 reduces calcium uptake more than does isosmotic concentrations of $MgSO_4$. The data on percentage blossom-end rot infected fruit (Table 3.28.) adds further support to this suggestion, as the K_2SO_4 treatment produced a higher percentage of diseased fruit than did the $MgSO_4$ treatment.

The greater effect of the K_2SO_4 treatment in reducing calcium uptake would be due to the higher activity of the potassium ion compared to that of the magnesium ion. The potassium ion could feasibly have a greater specific effect on calcium uptake than the magnesium ion, but it was not possible to determine this, due to the impossibility of calculating the actual activities of these ions.

The results of Experiment I showed that the K_2SO_4 treatment reduced the total fresh weight of fruit and number of fruit more than did the $MgSO_4$ treatment (Tables 3.4., 3.7.). Similar, but non-significant, trends were also recorded for the mean weight of fruit in both experiments (Tables 3.11., 3.13.). It is concluded that these differences between isosmotic concentrations of K_2SO_4 and $MgSO_4$ were due to differences in the effect of these treatments on calcium uptake by the tomato plant.

4.3.3. Magnesium

The comparative effect of the $MgSO_4$ and K_2SO_4 treatments on calcium uptake by the tomato plant has been discussed (4.3.2.).

In Experiment II, the $CaCl_2$ sprayed $MgSO_4$ treatment produced a yield of fruit, and a dry weight and fresh weight of plant top, that was lower than any of the other treatments (Tables 3.6., 3.18., 3.20.). The marked specific ion effect shown by this salt treatment was not therefore due only to reduced calcium uptake. It is suggested that this remaining difference was due partly to some other specific effect of the magnesium ion, possibly a toxic effect (Hayward and Wadleigh, 1949). Beeson et al. (1944) has shown that a high level of magnesium in the treatment solution produced a high level of magnesium in the leaves of the tomato. A specific effect of the sulphate ion would very likely have also been involved, but it was not possible to distinguish between these two possibilities.

4.3.4. Chloride

Smith and Warren (1957) reported that KCl decreased the dry weight of plant top more than KNO_3 when compared on an equal molar basis. A similar result was obtained here (Table 3.18.), which suggests that the chloride ion produces greater depressions of vegetative growth than the nitrate ion. The reverse appeared to be the case for the total fresh weight of fruit and mean weight of fruit (Tables 3.2., 3.14.). Such responses can be explained by the reported effect of extra nitrogen in producing excess vegetative growth in the tomato plant, at the expense of reproductive growth (Hooper and Young, 1957; Nightingale, 1937).

In the present investigation, comparisons of isosmotic

concentrations of KCl and K_2SO_4 showed that the sulphate treatment had the lower dry weight of plant top and was the least succulent (Tables 3.16., 3.22.). This was in agreement with the findings of Hayward and Long (1941) for isosmotic concentrations of NaCl and Na_2SO_4. Due to the unequal number of like cations and unlike anions in these isosmotic solutions, conclusions cannot be made regarding the specific effects of the chloride and sulphate ions.

By using a different method of comparison, it is suggested that the sulphate ion depressed total fresh weight of fruit and fruit numbers more than the chloride ion (Tables 3.4., 3.8.), and similar, but not significant, trends were observed for the mean weight of fruit and dry weight of plant top (Tables 3.11., 3.15.). Eaton (1942) reached the same conclusion, reporting that 100 me. of sulphate reduced the dry weight of vines and total fresh weight of fruit more than 50 me. of chloride. The 100 me. sulphate treatment was obtained by averaging the 50 and 150 me. sulphate treatments. The cations used were of the same kind, but of unequal concentrations, as also must have been the osmotic pressures of these two treatments. Thus, Eaton did not satisfactorily exclude cation and osmotic effects when comparing these two anions. Magistad et al. (1943) concluded that, at equal osmotic pressures, most of the species tested were more tolerant of sulphates than chlorides. Such a statement is quite correct, providing it is not used to suggest that the chloride ion depresses plant performance more than the sulphate ion, as the cation contents of such solutions are not comparable, and the concentration of the chloride ion is in excess of the sulphate ion. In this investigation, it is considered that, for the first time, these problems have been adequately met by the experimental design and

method used in comparing the results of the chloride and sulphate treatments [2.6.2.(c)].

In Experiment II, after spraying with $CaCl_2$, the KCl treatment still produced a lower total fresh weight of fruit and number of fruit, and a lower dry weight of plant top than did the control 2 atmosphere treatment (Tables 3.6., 3.10., 3.18.). The mean weights of fruit for these two treatments were then similar (Table 3.13.). It is possible that the difference remaining after spraying was due mainly to the effect of the chloride ion, as was suggested with the NaCl treatment (4.3.1.). Kidson (1963b) has suggested that luxury absorption of potassium may take place in the tomato plant, so the toxic effect of this cation would not be great. The specific effect of chloride is thought to be of a toxic nature (Bernstein and Hayward, 1958).

4.3.5. Nitrate

The comparative effects of the nitrate and chloride ions on the growth and development of the tomato plant have been discussed (4.3.4.). When investigating the fertilizer requirements of glasshouse tomatoes, van der Kloes (1953) found that high applications of nitrogenous fertilizers reduced yields. A similar response was obtained in these experiments (Tables 3.2., 3.4., 3.6.).

Figures for number of fruit for the KNO_3 treatments were generally high, and the data for numbers of flowers in the third truss clearly indicated a beneficial effect of nitrogen on flower formations (Table 3.25.). The control 2 atmosphere also showed some response, although not significant, to the extra nitrogen available in the treatment solution, and these effects were in accordance with those reported by Wittwer and Teubner (1957).

This response to nitrogen in Experiment II was obtained with the third truss only, as the first and second trusses would have been initiated, and have started to develop, prior to the application of the treatments. It is not necessarily assumed that the nitrogen increased flower number in the third truss by increasing the number of flowers initiated, as it may have been an effect of encouraging the development of flowers already initiated (Calvert, 1962).

In Experiment II, after spraying with $CaCl_2$, the KNO_3 treatment still had a low mean weight of fruit (Table 3.13.). This could not have been accounted for by lack of calcium, nor could it have been due to the potassium ion, as otherwise the KCl treatment would have shown a similar response. It can only therefore be attributed as an effect of the nitrate ion. Thus, it is suggested that the mechanism whereby excess nitrogen increases vegetative growth, at the expense of reproductive growth (4.3.4.), is one where nutritive materials, otherwise available for increasing the size of the fruit, are diverted to vegetative growth.

4.3.6. Sulphate

The comparative effects of the sulphate and chloride ions on the growth and development of the tomato plant have been discussed (4.3.4.). It is suggested that the sulphate ion depressed plant growth and development because of excess accumulation of the sulphate ion (Hayward and Long, 1943), which produced toxic effects in the tomato plant.

4.3.7. Mixture of ions

Meyer et al. (1957) has suggested that a mixture of anions is more favourable to plant growth and development than a single anion,

and other workers have reported that control treatments produce better plants than salt treatments of similar osmotic pressure (Meyer et al., loc cit.; Heimann, 1958; Heimann and Ratner, 1961). The latter observation is supported by the performance of the plants grown in the control 2 atmosphere treatment solutions of Experiment II. Attention should be drawn to the fact that the salt treatments used in the present investigation were all single salt solutions, and therefore the effects of individual ions were more pronounced than if a mixture of salts had been used.

The discussion of the effects of the ions contained in the various salt treatments, on the growth and development of the tomato plant, has clearly established the existence of specific ion effects. The magnitude and type of response produced in the tomato, by an ion of high concentration, depended on the nature of the ion involved and its concentration.

In the experiments reported here, the cations depressed plant performance mainly by reducing calcium uptake. The potassium ion exhibited this tendency more than the sodium ion. The magnesium ion also appeared to have some marked specific effect on growth and development other than that due to reducing calcium uptake. It was suggested that this was a toxic effect.

Calcium deficiency appeared to reduce total fresh weight of fruit by reducing fruit size, and, in one instance at least, the nutritive materials otherwise available for fruit growth were diverted to vegetative growth. Thus, the potassium ion produced a lower yield of fruit but a higher dry weight of plant top, than the sodium ion. As the total yield of fruit is an important factor in tomato crop

production, it can be stated that high concentrations of the potassium ion were more detrimental than similar concentrations of the sodium ion.

The anions also exhibited specific ion effects, the chloride ion reducing yields of fruit less than either the nitrate or the sulphate ions. It appeared that the sulphate ion depressed both growth and development more than the chloride ion. The nitrate ion depressed fruit yields more than the chloride ion, at the same time producing more vegetative growth. This extra vegetative growth, it is suggested, was produced by limiting fruit size, and thus making more nutritive materials available for vegetative growth. The extra nitrogen contained in the KNO_3 and control 2 atmosphere treatment solutions had a beneficial effect on flower production in the third truss.

4.4. Calcium Deficiency

4.4.1. The influence of the salt treatments on the incidence of blossom-end rot and the percentage Ca/SSS ratio

Blossom-end rot of tomatoes has been established by a number of workers as a symptom of calcium deficiency. In the previous section it was concluded that a disturbance in the calcium nutrition of the tomato plant was a major specific ion effect of the salt treatments. Further evidence of this is given by the fact that, with the five salt treatments, the treatments producing the lowest yield of fruit (Tables 3.2., 3.4., 3.6.) had also the highest percentage of blossom-end rot infected fruit (Table 3.28.).

On calculating the percentage Ca/SSS ratio of Geraldson (1957), it was found that the K_2SO_4 and $MgSO_4$ treatments had the lowest ratios, and the NaCl treatment had the highest ratio of the five salt treatments, at any particular level of osmotic pressure (Table 3.26.).

The control and control 2 atmosphere treatments, in which no blossom-end rot occurred, had ratios close to the 15-20 range, considered by Geraldson (loc cit.) to be satisfactory for calcium deficiency control.

These Ca/SSS ratios of the salt treatments can be arranged in order from the least to the greatest, and this order corresponds very closely to those for reduction in yield of fruit and increase in percentage of blossom-end rot infected fruit (Table 4.1.).

TABLE 4.1.

Comparison of the Ca/SSS ratio, fresh weight of fruit and percentage blossom-end rot of the salt treatments

Ca/SSS ratio for level 2	$MgSO_4$	K_2SO_4	KNO_3	KCl	NaCl
	2.0	2.7	3.2	4.1	4.8
Reduction in fresh weight of fruit	$K_2SO_4 > MgSO_4 > KNO_3 > KCl > NaCl$				
Increase in percentage of blossom-end rot	$K_2SO_4 > MgSO_4 > KNO_3$, KCl, NaCl				

From the comparisons made in this table it would appear that the Ca/SSS ratio suggested by Geraldson (loc cit.) would give a reasonably accurate assessment of the extent to which calcium deficiency may be expected in a particular growing medium.

The effects of the individual ions on the calcium nutrition of the tomato have been discussed (4.3.). After considering the evidence presented in Table 4.1., it is suggested that isosmotic solutions of the five salts interfere with the calcium metabolism of the tomato plant in the following descending order:

K_2SO_4, $MgSO_4$, KNO_3, KCl, NaCl.

4.4.2. The effects of the calcium chloride spray on the growth and development of the tomato plants in Experiment II

The spraying of the tomato plants with calcium produced an increase in yield of fruit which was accompanied by a decrease in dry weight and fresh weight of plant top [3.1.2.(a), 3.4.2.(a), 3.5.(a)]. This response indicated that calcium deficiency affects fruit development more than vegetative growth, which is in accordance with the conclusions of Spurr (1959).

Previously, in section 4.3.7., it was concluded that calcium applications increased the yield of fruit by increasing fruit size [3.3.2.(a)]. The decrease in number of fruit, observed in certain of the treatments [3.2.2.(a)], was attributed to the increase in fruit load slowing down the development of the later formed fruit. Spraying also decreased the dry matter percentage [3.6.(a)]. This higher dry matter percentage of plant top shown by the calcium deficient plants may have been due to starch accumulation (McIlrath, 1950; Kalra, 1956).

The responses to calcium applications referred to above, with the exception of the NaCl treatment for all factors of growth and development and the K_2SO_4 treatment for numbers of fruit, were all significant at the .01 level. The lack of significant responses by the NaCl treatment was to be expected, as this treatment produced the smallest amount of calcium deficiency.

Due to the lack of apparent effect of calcium deficiency in reducing flower [3.7.1.(a)] and fruit numbers, it is suggested that the role of calcium in fruit development is one affecting the growth of the component cells of the fruit.

4.5. Inter-relationship between Vegetative Growth and Fruit Development in the Tomato Plant

Calcium deficiency affects fruit development to a greater extent than it does vegetative growth (Spurr, 1959). Thus the application of calcium chloride sprays in Experiment II, in remedying this deficiency, increased the yield of fruit at the expense of vegetative growth (4.4.). On comparing the chloride ion with the nitrate ion, and the sodium ion with the potassium ion, it was found that where one ion produced a greater yield of fruit, the other ion produced the greatest amount of vegetative growth (4.3.4., 4.3.1.). A similar comparison was made between the control and the control 2 atmosphere treatments (Tables 3.5., 3.17.). It is apparent from these results that vegetative growth and fruit development are inter-related, a conclusion also reached by other workers (Salter, 1958; Cooper, 1961). There is disagreement in the literature, however, on the nature of this relationship.

Salter (loc cit.) concluded that under sub-optimal conditions the fruit were able to monopolise the food resources of the plant. Cooper (loc cit.) however, disagreed with this, and suggested the existence of a regulatory mechanism which maintains a balance between vegetative growth and fruit development.

The results reported here do not support the conclusions reached by Salter (loc cit.), as fruit development was retarded to a greater extent than vegetative growth by calcium deficiency, and it is certain that the conditions which produced this deficiency were sub-optimal. These results, however, could be explained in terms of the mechanism suggested by Cooper (loc cit.).

Such a mechanism presumably operates so that, under any

particular set of environmental conditions, the appropriate balance between vegetative growth and fruit development is attained. The direction in which this particular regulatory mechanism would operate would depend on whether the prevailing environmental conditions favoured vegetative growth or fruit development.

CHAPTER 5

SUMMARY

An investigation was made into the effects of an excess of certain salts on the growth and development of tomato plants grown in nutrient culture. Particular attention was paid to the specific ion effects of the excess salt treatments.

Two experiments were carried out. The first experiment was designed to establish the existence of, and make comparisons between, the specific ion effects of the salt treatments. The second experiment was designed to study the importance of calcium deficiency as a specific ion effect of the salt treatments used in the first experiment. Both experiments supplied information on the osmotic effects of the treatments.

Increases in osmotic pressure of the treatment solutions produced reductions in the yield and size of fruit and, in most instances, in vegetative growth. It is concluded that these reductions in growth and development were due to reduced availability of water to the plants.

The existence of specific ion effects of the salt treatments was established. Interference in the availability of calcium to the tomato plant was the major specific effect of the cations. The anions also exhibited specific effects. It is considered that the specific effects of the chloride and sulphate ions were successfully compared, a comparison which has not previously been carried out with any degree of certainty.

Blossom-end rot and other symptoms of calcium deficiency were

completely controlled in the second experiment by the use of calcium chloride sprays. The inter-relationship between vegetative growth and fruit development is discussed. The suggestion is made that some mechanism exists to maintain a balance between vegetative growth and fruit development.

As these experiments were conducted in nutrient culture, it is emphasized that the responses obtained were more marked than those likely to be obtained with similar treatments applied to tomato plants grown in soil.

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ACKNOWLEDGEMENTS

Grateful acknowledgement is made to Mr. M. Richards, of the Department of Horticulture, and Dr. C.V. Fife, of the Soil Science Department, Massey University of Manawatu, for their continued interest, assistance and guidance in this project.

Thanks are also due to Mr. A.C. Glenday, of the Applied Mathematics Laboratory, Department of Scientific and Industrial Research, for advice on the statistical procedures used, to the staff of the Massey University Library for their assistance with bibliographical problems, and to Miss M. Marriott, who typed this thesis.

APPENDICES.

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APPENDIX 1.

Nutrient stock solutions

The concentrated nutrient solution was prepared in 160 litre batches. This solution was prepared from nutrient stock solutions of the following composition:

Salt	Composition of stock solution.	To prepare 160 litres of conc. nutrient solution use:
KNO_3	40.4 grams/litre	1 litre
$Ca(NO_3).4H_2O$	188.8 " "	1 "
$NaH_2PO_4.2H_2O$	41.6 " "	1 "
$MgSO_4.7H_2O$	73.8 " "	1 "
Ferric citrate	4.9 " "	1 "
*$MnSO_4.4H_2O$	.892 grams)	
*$CuSO_4.5H_2O$	.096 ") per	
*$ZnSO_4.7H_2O$	.116 ") 250	125 mls.
*H_3BO_3	.744 ") mls.	
*$(NH_4)_6Mo_7O_{24}.4H_2O$	.014 ")	

* These salts were combined as one stock solution.

APPENDIX 2.

Calculation of relationship between osmotic pressure and concentration (p.p.m.) of the salt treatments used to enrich the ½ atmosphere nutrient solution.

Using the data available in Vol. 4 of International Critical Tables (1929), freezing point depressions were converted to osmotic pressures using the formula (Richards et al., 1954):

O.P. = 12.06 ΔT - 0.021 ΔT^2, where ΔT is the freezing point depression in ^{o}C. A particular value of ΔT corresponds to a particular number of moles of solute per litre of water. By converting moles/litre to p.p.m. it was possible to plot p.p.m. against osmotic pressure for the five salts.

The results of the above calculations are presented on the following page. The number of p.p.m. of the appropriate salt, necessary to raise the osmotic pressure from ½ atmosphere to the required level of osmotic pressure, was obtained from graphs prepared from this data.

NaCl	ΔT	3.66	3.65	3.64	3.62	3.60	3.57	3.53	3.50	3.48	3.42	
	O.P.*	.04	.09	.17	.30	.43	.86	1.69	2.94	4.17	8.21	
	m/l*	.001	.002	.004	.007	.010	.02	.04	.07	.10	.20	
	p.p.m.	58	117	234	409	585	1,169	2,338	4,092	5,846	11,692	
KCl	ΔT	3.66	3.65	3.61	3.57	3.50	3.45	3.39				
	O.P.*	.04	.22	.43	.85	2.10	4.14	8.14				
	m/l*	.001	.005	.01	.02	.05	.10	.20				
	p.p.m.	75	373	746	1,491	3,728	7,456	14,912				
KNO_3	ΔT	3.66	3.64	3.59	3.54	3.43	3.31	3.15				
	O.P.*	.09	.22	.43	.85	2.06	3.97	7.57				
	m/l*	.002	.005	.01	.02	.05	.10	.20				
	p.p.m.	202	505	1,011	2,022	5,055	10,111	20,222				
K_2SO_4	ΔT	5.28	5.26	5.15	5.01	4.77	4.56	4.32				
	O.P.*	.06	.16	.31	.60	1.43	2.73	5.17				
	m/l*	.001	.0025	.005	.01	.025	.05	.10				
	p.p.m.	174	435	871	1,742	4,356	8,713	17,426				
$MgSO_4$	ΔT	3.38	3.24	3.18	3.08	3.02	2.94	2.85	2.60	2.42	2.25	2.09
	O.P.*	.04	.08	.10	.15	.18	.25	.34	.78	1.45	2.71	5.02
	m/l*	.001	.002	.0025	.004	.005	.007	.01	.025	.05	.10	.20
	p.p.m.	120	240	300	481	601	842	1,203	3,009	6,019	12,038	24,076

O.P.* = O.P. measured in atmospheres.

m/l* = moles/litre

APPENDIX 3.

Treatment stock solutions

Treatment		p.p.m. required (from graphs - appendix 2)	Composition of stock solns. (wt. in grams to be dissolved in 2 litres distilled water)
Salt	Level		
NaCl	2	2,085	20.85
"	3	3,485	34.85
"	$4\frac{1}{2}$	5,675	56.75
KCl	2	2,670	26.70
"	3	4,590	45.90
"	$4\frac{1}{2}$	7,290	72.90
KNO_3	2	3,710	37.10
"	3	6,320	63.20
"	$4\frac{1}{2}$	10,280	102.80
K_2SO_4	2	4,700	47.00
"	3	8,290	82.90
"	$4\frac{1}{2}$	13,530	135.30
$MgSO_4$	2	6,780	138.83*
"	3	11,790	241.41*
"	$4\frac{1}{2}$	19,370	396.62*

* $MgSO_4.7H_2O$ was used - not the anhydrous form.

APPENDIX 4.

Preparation of control 2 atmosphere treatment solution

One litre of the control 2 atmosphere treatment solution was prepared as follows:

800 mls.	concentrated nutrient solution.	
15 mls.	KNO_3	nutrient stock solution.
15 mls.	$Ca(NO_3)_2.4H_2O$	" " "
15 mls.	$NaH_2PO_4.2H_2O$	" " "
15 mls.	$MgSO_4.7H_2O$	" " "
140 mls.	tap water	
1,000 mls.		

APPENDIX 5.

Analyses of variance of fresh weight of fruit harvested in Experiment I.

5.1. Fresh weight of fruit on first truss.

Source	S.S.	d.f.	M.S.	F.	Result
Block	1,110	5	222	1.39	n.s.
Treatment	27,235	14	1,945	12.19	**
Error	11,163	70	160		
Total	39,508	89			

5.2. Total fresh weight of fruit harvested from level 2.

Source	S.S.	d.f.	M.S.	F.	Result
Block	44,027	5	8,805	1.70	n.s.
Treatment	1,710,024	4	427,506	82.31	**
Error	103,889	20	5,194		
Total	1,857,940	29			

5.3. Total fresh weight of fruit harvested from levels 3 and $4\frac{1}{2}$ (blocks II, IV and VI).

Source	S.S.	d.f.	M.S.	F.	Result
Block	9,778	2	4,889	3.04	n.s.
Treatment	316,562	9	35,174	21.90	**
Error	28,916	18	1,606		
Total	355,256	29			

APPENDIX 6.

Analysis of variance of total fresh weight of fruit harvested in Experiment II.

Source	S.S.	d.f.	M.S.	F.	Result
Block	244,766	5	48,953	2.53	*
Treatment	16,999,540	11	1,545,413	79.9	**
Error	1,063,177	55	19,330		
Total	18,307,483	71			

APPENDIX 7.

Analyses of variance of total number of fruit harvested in Experiment I.

7.1. Total number of fruit harvested from level 2.

Source	S.S.	d.f.	M.S.	F.	Result
Block	293.6	5	58.7	.41	n.s.
Treatment	2,918.2	5	583.6	4.12	**
Error	3,510.1	25	140.4		
Total	6,721.9	35			

7.2. Total number of fruit harvested from levels 3 and 4½ (blocks II, IV and VI).

Source	S.S.	d.f.	M.S.	F.	Result
Block	70	2	35.0	1.34	n.s.
Treatment	3,751	10	375.1	14.32	**
Error	523	20	26.2		
Total	4,344	32			

APPENDIX 8.

Analysis of variance of total number of fruit harvested in Experiment II.

Source	S.S.	d.f.	M.S.	F.	Result
Block	235	5	47.0	1.61	n.s.
Treatment	2,600	11	236.4	8.08	**
Error	1,609	55	29.3		
Total	4,444	71			

APPENDIX 9.

Analyses of variance of mean weight of fruit harvested in Experiment I.

9.1. Mean weight of fruit harvested from level 2.

Source	S.S.	d.f.	M.S.	F.	Result
Block	16.8	5	3.36	1.35	n.s.
Treatment	552.6	4	138.15	55.70	**
Error	49.6	20	2.48		
Total	619.0	29			

9.2. Mean weight of fruit harvested from levels 3 and $4\frac{1}{2}$ (blocks II, IV and VI).

Source	S.S.	d.f.	M.S.	F.	Result
Block	12.2	2	6.1	2.54	n.s.
Treatment	188.0	9	20.9	8.71	**
Error	43.4	18	2.4		
Total	243.6	29			

APPENDIX 10.

Analysis of variance of mean weight of fruit harvested in Experiment II.

Source	S.S.	d.f.	M.S.	F.	Result
Block	85.3	5	17.1	.91	n.s.
Treatment	11,468.6	11	1,042.6	55.5	**
Error	1,033.2	55	18.8		
Total	12,587.1	71			

APPENDIX 11.

Analyses of variance of dry weight of plant top in Experiment I.

11.1. Dry weight of plant top in level 2.

Source	S.S.	d.f.	M.S.	F.	Result
Block	481	5	96.2	.88	n.s.
Treatment	13,992	5	2,798.4	25.70	**
Error	2,722	25	108.9		
Total	17,195	35			

11.2. Dry weight of plant top in level 3 (blocks I, III and V).

Source	S.S.	d.f.	M.S.	F.	Result
Block	48	2	24.0	4.29	n.s.
Treatment	367	4	91.8	16.39	**
Error	45	8	5.6		
Total	460	14			

11.3. Dry weight of plant top in level $4\frac{1}{2}$ (blocks I, III and V).

Source	S.S.	d.f.	M.S.	F.	Result
Block	63	2	31.5	3.88	n.s.
Treatment	648	4	162.0	20.00	**
Error	65	8	8.1		
Total	776	14			

11.4. Dry weight of plant top in levels 3 and $4\frac{1}{2}$ (blocks II, IV and VI).

Source	S.S.	d.f.	M.S.	F.	Result
Block	169	2	84.5	1.52	n.s.
Treatment	7,698	10	769.8	13.87	**
Error	1,110	20	55.5		
Total	8,977	32			

APPENDIX 12.

Analysis of variance of dry weight of plant top in Experiment II.

Source	S.S.	d.f.	M.S.	F.	Result
Block	2,334	5	466.8	4.59	**
Treatment	45,009	11	4,091.7	40.19	**
Error	5,598	55	101.8		
Total	52,941	71			

APPENDIX 13.

Analysis of variance of fresh weight of plant top in Experiment II.

Source	S.S.	d.f.	M.S.	F.	Result
Block	81,930	5	16,386	3.50	**
Treatment	2,432,890	11	221,172	47.26	**
Error	257,381	55	4,680		
Total	2,772,201	71			

APPENDIX 14.

Analysis of variance of percentage dry matter of plant top in Experiment II.

Source	S.S.	d.f.	M.S.	F.	Result
Block	9.3	5	1.860	3.21	*
Treatment	95.0	11	8.636	14.89	**
Error	31.9	55	.580		
Total	136.2	71			

APPENDIX 15.

Percentage soluble solids of expressed sap of tomato fruit in Experiment II.

Treatment (% soluble solids)						
NaCl	KCl	KNO_3	K_2SO_4	$MgSO_4$	$C_{\frac{1}{2}}$	C_2
6.2	6.8	6.5	6.6	6.6	4.4	5.8
6.7	6.8	6.7	7.1	7.2	4.9	7.7
6.6	7.0	8.2	6.8	7.5	4.9	7.7
7.5	7.2	8.0	7.1	8.0	4.5	
7.5	7.6	8.0			5.0	
		9.6				

APPENDIX 16.

Analyses of variance of flower number on the first three trusses in Experiment II.

16.1. Flower number on first truss.

Source	S.S.	d.f.	M.S.	F.	Result
Block	147	5	29.40	3.13	*
Treatment	72	11	6.55	.70	n.s.
Error	517	55	9.40		
Total	736	71			

16.2. Flower number on second truss.

Source	S.S.	d.f.	M.S.	F.	Result
Block	87	5	17.40	1.25	n.s.
Treatment	143	11	13.00	.93	n.s.
Error	769	55	13.98		
Total	999	71			

16.3. Flower number on third truss.

Source	S.S.	d.f.	M.S.	F.	Result
Block	79	5	15.80	.55	n.s.
Treatment	806	11	73.27	2.55	*
Error	1,582	55	28.76		
Total	2,467	71			

APPENDIX 17.

Total number of leaves up to the third truss
in Experiment II

Block	Treatment (number of leaves)							
	Series	NaCl	KCl	KNO_3	K_2SO_4	$MgSO_4$	$C_{\frac{1}{2}}$	C_2
I	Unsprayed	16	20	17	17	19	16	16
II	"	17	17	15	16	16	17	16
III	"	18	16	16	16	17	16	16
IV	"	17	18	16	16	17	15	16
V	"	17	16	19	16	15	17	16
VI	"	17	16	16	17	16	17	16
I	Sprayed	18	16	15	16	16		
II	"	17	15	16	16	15		
III	"	16	16	19	16	17		
IV	"	17	16	16	16	16		
V	"	17	16	17	16	16		
VI	"	15	18	16	16	16		

APPENDIX 18.

Calculation of the percentage calcium/total soluble salts ratio of the treatment solutions in both experiments.

Total p.p.m. of salt dissolved in the nutrient solution	1,227
Total p.p.m. of calcium dissolved in the nutrient solution	160
Total p.p.m. of salt dissolved in the control 2 atmosphere treatment solution	4,821

The total p.p.m. of salt dissolved in a particular salt treatment is the sum of the number of p.p.m. given in Appendix 3 for that salt treatment, and the total number of p.p.m. of salt dissolved in the nutrient solution.

The percentage Ca/SSS ratio was calculated for a particular salt treatment solution by use of the formula:

$$\frac{160}{\text{total p.p.m. in treatment soln.}} \times \frac{100}{1}$$

APPENDIX 19.

Analysis of covariance of the percentage of blossom-end rot infected fruit for the salt treatments of level 2, Experiment I.

Source	d.f.	x	xy	y	y'	d.f'	M.S.	F.	Result
Total	29	5,811.9	-2,811.9	6,938.2					
Block	5	175.5	-10.0	235.8					
Treatment	4	2,915.6	-2,508.1	6,074.1					
Error	20	2,720.8	-293.8	628.3	596.6	19	31.4		
Treat. + Error	24	5,636.4	-2,801.9	6,702.4	5,309.6	23			
Difference					4,713.0	4	1,178.3	37.5	**

Comparison	Level of significance	
	.05	.01
NaCl and KCl	7.2	9.9
" " KNO_3	7.2	9.9
" " K_2SO_4	7.5	10.2
" " $MgSO_4$	7.2	9.8
KCl " KNO_3	6.8	9.3
" " K_2SO_4	8.9	12.1
" " $MgSO_4$	6.8	9.3
KNO_3 " K_2SO_4	8.8	12.0
" " $MgSO_4$	6.8	9.3
K_2SO_4 " $MgSO_4$	8.8	12.0