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.

K.J. FISHER

1964

TABLE OF CONTENTS

Chapter		Page
	Introduction.	1
1.	Review of Literature.	
	1.1. Osmotic Effects of Excess Soluble Salts.	4
	1.2. Specific Ion Effects of Excess Soluble Salts.	7
	1.3. Blossom-end Rot of Tomatoes.	11
	1.4. Inter-relationship between Vegetative Growth and Fruit Development in the Tomato Plant.	14
2.	Materials and Methods.	
	2.1. The Experiments.	16
	2.2. Experimental Design.	17
	2.3. Composition and Preparation of the Solutions used in Experiments I and II.	20
	2.4. Technique used in Growing the Tomato Plants.	22
	2.5. Measurements Made on Tomato Plants.	24
	2.6. Methods of Comparing Salt Effects and Specific Ion Effects, and of Determining the Presence of Osmotic Effects of the Salt Treatments.	26
3.	Results.	
	3.1. Fresh Weight of Fruit.	29
	3.2. Total Number of Fruit Harvested.	33
	3.3. Mean Weight of Fruit Harvested.	36
	3.4. Dry Weight of Plant Top.	38
	3.5. Fresh Weight of Plant Top in Experiment II.	41
	3.6. Percentage Dry Matter of Plant Material in Experiment II.	42

Chapter Page

3.7. Flower Number in the First Three Trusses and Leaf Number up to the Third Truss in Experiment II. 44
3.8. Calcium Deficiency. 46

4. Discussion.

4.1. Introduction. 48
4.2. Osmotic Effects of Excess Soluble Salts. 48
4.3. Specific Ion Effects of Excess Soluble Salts. 52
4.4. Calcium Deficiency. 61
4.5. Inter-relationship between Vegetative Growth and Fruit Development in the Tomato Plant. 64
5. Summary. 66
References. 68
Acknowledgements.
Appendices.

LIST OF FIGURES

Figure		Facing page
1.	Comparison of plants of the calcium sprayed and unsprayed $MgSO_4$ treatments in Experiment II.	33
2.	Comparison of plants of the control 2 atmosphere and control treatments in Experiment II.	38

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.