Massey University Library
Thesis Copyright Form

Title of thesis:

(1) (a) I give permission for my thesis to be made available to readers in Massey University Library under conditions determined by the Librarian.

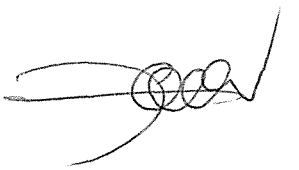
(b) I do not wish my thesis to be made available to readers without my written consent for . . . months.

(2) (a) I agree that my thesis, or a copy, may be sent to another institution under conditions determined by the Librarian.

(b) I do not wish my thesis, or a copy, to be sent to another institution without my written consent for . . . months.

(3) (a) I agree that my thesis may be copied for Library use.

(b) I do not wish my thesis to be copied for Library use for . . . months.

Signed  Fadallan, E.F.

Date 12 MAY 1993

The copyright of this thesis belongs to the author. Readers must sign their name in the space below to show that they recognise this. They are asked to add their permanent address.

NAME AND ADDRESS	DATE
Edgardo Fadallan Romblon State College Odiongan Romblon Philippines 5505	12 MAY 93

THE EFFECTS OF HIGH CONDUCTIVITY LIQUID FEEDS ON THE YIELD AND QUALITY OF OUTDOOR GROWN TOMATOES

A Thesis Presented in Partial Fulfilment of the Requirements
for the Degree of Master of Horticultural Science in
Vegetable Production at Massey University
Palmerston North, New Zealand

EDGARDO F. FADALLAN

Department of Plant Science

1993

ABSTRACT

Studies were conducted to evaluate the effects of high conductivity liquid feeds applied using drip irrigation on the yield and quality of outdoor grown tomatoes. Seed of the tomato cv. *Extase* were propagated in cell trays. During propagation the seedlings were fed using a stock solution containing 100 ppm nitrogen, 34 ppm phosphorous and 100 ppm potassium. The transplants were planted out on 3 December 1991 in the Karapoti Sandy Loam soil at the Plant Growth Unit, Massey University. The spacing used was 150 cm between the rows and 60 cm 2 in the row. A base maintenance dressing of Nitrophoska (12-10-10) fertilizer was applied at a rate of 500 kg per hectare banded 20 cm on either side of the row prior to planting.

There were 3 conductivity treatments of 2, 4, and 6 mS cm^{-1} and a control treatment. A randomized complete block design was used with 4 blocks and 12 plants per plot. The 3 conductivity treatments were based on a standard greenhouse liquid feed, while the control plant received water only. Irrigation requirements were calculated based on a crop factor, area per plant and potential evapotranspiration. Conductivity treatments commenced at the stage were 50% of the plants had commenced flowering on the first truss. Conductivity treatments were applied every 2 days for 2 hours regardless of rain, while control plants were irrigated with tap water when soil moisture deficits exceeded 28 mm day^{-1} except when rainfall immediately followed the scheduled irrigation.

Plants were trained to 2 stems. The second stem was produced from the leaf axil immediately below the first inflorescence. The Otaki system of training and supporting tomato plants was used with the first support attached 25 days after planting and thereafter every 30 cm. Plants were delateraled regularly and stopped by removing the terminal buds at 2 metres high.

Leaf analysis was carried out on 2 occasions, 30 and 55 days after planting, while the conductivity of the soil solution was determined at final harvest. Yield data was collected for each truss on a per stem basis per plant. Fruit were weighed individually and also size graded to the accepted commercial standard. From these data the number and weight of marketable and reject fruits were determined. Fruit samples were taken for 6 consecutive weekly harvests for compositional analysis. Firmness, total solids, titratable acidity and total soluble solids were measured from sample fruits from each treatment.

Increasing the conductivity of the liquid feed increased the concentration of nitrogen and potassium in the leaves 30 days after planting, while phosphorous and magnesium were not affected by the treatments. Calcium fell with each increase in conductivity. At the reproductive stage (55 days after planting) the nitrogen, phosphorous and potassium content fell with increasing conductivity over the range of control to 4 mS cm^{-1}. Calcium and magnesium content also fell with increasing conductivity of the liquid feed. The conductivity of the soil solution increased as the conductivity of the liquid feed increased. As the distance from the dripper increased the conductivity of soil solution decreased.

Tomato plants in this study supported an average of 13 trusses. There were 18 harvests where fruits were harvested at a commercial acceptable stage of maturity and a 19th harvest was used to remove all the remaining fruit on the plant . The main stem carried approximately 65% of the fruit load. Conductivity treatments had no effect on the number and weight of fruit of individual trusses on the main stem except for the 4 mS cm^{-1} treatment which had a higher number and yield of fruit in the third truss. No explanation can be offered for this effect. There were no differences between treatments in the number or yield of fruit per truss on the lateral stem.

Neither the number or yield of marketable fruit or the total number or total yield of fruit at final harvest were affected by the conductivity treatments. There was however a trend for yield to decrease with the 6 mS cm^{-1} treatment. It is possible that if the experiment had been continued for a longer period a treatment effect on the number and yield of fruit may have been obtained. It was suggested that the heavy rain experienced during the experiment may have delayed the occurrence of a yield reduction. Although there was no significant effect of conductivity on fruit size, the number of fruit in the two largest size grades tended to be highest for the control plants, while the 6 mS cm^{-1} treatment had the smallest number of fruit in these size grades. This is further evidence that the conductivity treatments tended to have an effect on fruit size and thus yield.

The main cause for fruits to be rejected was due to fruit cracking, which usually occurred when harvesting preceded heavy rainfall.

The occurrence of blossom end rot was low since both rainfall and the regular application of liquid feeds did not place the plants under a fluctuating moisture stress. Overall there were very few rejects.

The conductivity treatments increased titratable acidity above that of control plants, but there were no difference between the conductivity treatments. Over time titratable acidity of the fruit declined and this may have been associated with either a seasonal effect or the position of the fruit on the stem. Total solids was increased as the concentration of the liquid feeds increased. The percentage of total solids allocated to structural material fell as the concentration of the liquid feed increased. This suggests that the increase in the total solids was due to an increase in the soluble solid component. There was no effect of conductivity on fruit firmness, however firmness fell from an initial value at harvest 1. Total soluble solids of the fruit increased with each increase in conductivity. Over time the trend was for soluble solids to fall slightly up to harvest 5 with a marked decline occurring at harvest 6.

As improvements in fruit flavour are associated with increases in titratable acidity, total solids and total soluble solids the conductivity treatments used in this experiment were successful in improving this aspect of fruit quality. This was achieved without any decrease in yield. As suggested however, a trade off between quality and yield may have occurred if the experiment had been continued for a longer period of time.

This research suggests that the use of trickle irrigation to supply high conductivity liquid feeds to field grown tomatoes has the potential to significantly improve fruit flavour.

ACKNOWLEDGEMENTS

Writing this thesis is an enormous task. As others know well, to bring a thesis from an image to reality requires a sustaining force. For me this had been achieved through the combination of prayers and graces of good health from our Almighty and support from those who are involved at various stages of the study.

My indebtedness goes to Dr. Keith James Fisher, my chief supervisor for his expertise, guidance and constructive suggestions. He was very generous and patient spending much time editing, reviewing and proofreading the manuscript.

I am grateful to Dr. Michael A. Nichols my second supervisor for his confidence and camaraderie during the entire course of this work. He was very kind and helpful looking after most of my statistical analysis.

I also wish to express my heartfelt thanks and gratitude to the staff of Plant Growth Unit for their unceasing support during my experimental work.

It also gives me a great pleasure to record my appreciation to the New Zealand government through the Ministry of External Relations and Trade for financing my study at Massey University .

My profound gratitude is also extended to the Executive Board of Romblon State College for giving me the opportunity to pursue my postgraduate degree under the Overseas Development Assistance Programme.

My special thanks to fellow ROSCOFEANS for wishing me good luck and success in my studies. I hope I have come close to living up to their expectations.

The support and encouragement I received from all Filipino students at Massey University had been of paramount importance and to all of them I wish to express my sincere thanks. The help and moral support of the Carambas and Baker families during my stay in New Zealand is here most gratefully acknowledged.

My special thanks to all staff and graduate students in Plant Science (Horticulture) for their friendship, humour and help to unravel some of the mysteries in computers.

My heartfelt thanks are due to my parents, brothers and sisters, in-laws and relatives for their help in many ways.

Finally, my deepest gratitude to my wonderful wife Eden and son Jake for their moral support and encouragement. Their love and patient understanding are the backbone of my success.

To anyone whose help during my study I have failed to acknowledge, please forgive the oversight and accept my heartfelt thanks.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF PLATES

LIST OF APPENDICES

GENERAL INTRODUCTION

The tomato is a highly valued outdoor crop in New Zealand. It is grown commercially whenever environmental conditions permit an economic yield to be obtained. Consumers continue to use large amounts of this product, but increasingly there has been publicity which suggest that tomatoes are not what they used to be. This is so because plant breeders and producers in their attempt to produce high yields have, according to a widely held view, sacrificed fruit quality.

Up until recently the important quality attributes of the tomato were perceived to include size, shape, colour and firmness of the fruit. At the present time however consumers are increasingly suggesting that fruit flavour should be added to this list. It is well established that the quality of tomato fruit can vary in response to both genetic and environmental factors. It is likely that tomato breeding programs for both greenhouse and outdoor tomatoes will now start to consider improvements in fruit flavour as an important goal. Research has established that there is a close relationship between acid and sugar levels in tomato fruit and fruit flavour. Recent developments with greenhouse tomatoes has shown that increases in titratable acidity and total soluble solids can be achieved by the use of high conductivity liquid feeds. These improvements in quality have been associated with some loss of yield.

Drip irrigation refers to the application of irrigation water and fertilizer nutrients through small emitters placed on or in the soil near the plants. One of the advantages of drip irrigation is its ability to conserve water and fertilizer compared with other irrigation and fertilizer systems. With drip irrigation water is not applied to plant foliage maintaining drier plants and reducing susceptibility to disease outbreak with an associated reduction in the need for fungicides. Drip irrigation has been widely used with field vegetable crops in the USA.

The objective of the research discussed in this thesis was to use drip irrigation to examine the potential of using high conductivity liquid feeds to improve the flavour of field grown fenced tomatoes. Of particular interest was the likely trade off between fruit quality and yield.

CHAPTER 1

REVIEW OF LITERATURE

1.1 Introduction

Production of tomatoes has dramatically increased due to the increasing popularity of the commodity both for fresh consumption and processing. Despite the large improvement in yield that has taken place over the years, fruit quality in terms of composition has received more lip-service than the actual research effort to improve it.

Consumers are becomingly concerned about the quality of the fruit they buy. As we begin to understand more of the quality attributes that consumers demand of this product, there is a necessity to develop production technologies appropriate to meet this demand without sacrificing marketable yield. It is a general observation that an important quality problem with some cultivars is the lack of flavour. This may be alleviated by means of the production system used.

Part of the tomatoes success as a crop is attributed to its ability to acclimate to different environments (Rick,1978). There are numerous environmental factors that determine wether the tomato plant live up to its potential. According to Brice (1978), tomato plants require major elements and trace elements to maintain normal growth and development.

Adams (1986) and Stanley and Geraldson (1991) suggest that in order to achieve high yields and good quality fruits, proper nutritional conditions must be maintained. Regardless of the system used in the application of nutrients, the primary concern must be to provide tomatoes with the nutrients they require at each stage of growth (Stanley and Geraldson, 1991).

1.2 Plant Nutrition

1.2.1 Responses of Tomato Plant to Essential Nutrients

1.2.1.1 Nitrogen

Nitrogen is readily absorbed by plants and easily leached from the soil. Winsor *et al.* (1967) reported that nitrogen fertilizer should be applied with care since excessive nitrogen is detrimental particularly during the reproductive stage. The response of tomatoes to nitrogen application, as with other plants, varies with the source (Adams, 1986), water availability, mode of application and how will the plant is supplied with other nutrients (Mengel and Kirkby, 1987).

Pill and Lambeth (1977) reported that when tomato plants received NO_3-N the fresh and dry weight of above ground parts increased comparably with NH_4-N. The observation of Mengel and Kirkby (1987) regarding the response of various plants to NH_4-N and NO_3-N was that when plants received NH_4-N, the uptake takes place best in a neutral medium, but was depressed as the pH fell.

Absorption of NO_3-N on the other hand is more rapid at low pH. Uptake of nitrogen is also temperature dependent. The most important difference between NO_3-N and NH_4-N was that NH_4-N is absorbed more readily at lower temperatures than NO_3-N. It was further suggested that since photosynthesis in young tomato seedlings was low during winter it maybe safer to apply NO_3-N than NH_4-N. This is because plants with low carbohydrates often show toxicity when NH_4-N is high.

In the field fertilizer can be applied banded, broadcast or injected as in trickle irrigation. In order to stabilise nitrogen removal from soil be it as plant product, leaching or denitrification, it must be supplied in adequate amounts to the soil. During high rainfall or excessive irrigation nitrogen content around the roots is reduced particularly NO_3-N, which does not react with the soil (Bar-Yosef and Sheikholslami, 1976) and NO_3-N will then move with water below the root zone (Goldberg *et al.*, 1971).

The leaching problem with nitrogen can be alleviated by the introduction of trickle irrigation. According to Elfving (1982) following the application of the fertilizer through trickle irrigation roots of plants will have easy access to nitrogen. The emission ports are directed towards the base of the plant, and precise application of nitrogen in the plant rooting zone is possible (Stanley and Geraldson, 1991). By this means, nitrogen content in the soil at any one time will result from an equilibrium between addition by trickle irrigation and removal by plants plus any losses from leaching or denitrification.

1.2.1.2 Phosphorous

Phosphorous concentration in soil solution is very dilute. It is used less by tomatoes than nitrogen and potassium, but at a steady rate throughout the life of the crop (Brice, 1978). When plants have high demand for phosphorous, the rate of absorption by the roots is high and the soil solution in the direct root vicinity is depleted of phosphorous (Olsen and Watanabe, 1970). Phosphorous in contrast to nitrogen is readily fixed in many soils (Kalkafi and Bar-Yosef, 1980). Thus, if the fertilizer is not mechanically worked deeply into the soil, most phosphorous will remain near the surface where availability will be limited. With frequent irrigation total phosphorous uptake was increased (Hedge and Srinivas, 1990). This was enhanced by movement of phosphorous towards root by diffusion, however its availability depends on soil water status. When soils are deficient in phosphorous, tomatoes become dwarfed and spindly with purple veins and leaf stalks. This deficiency normally occurs when tomato plants are grown in soils with a high capacity to fix phosphorous (Adams, 1986; Brice, 1978).

1.2.1.3 Potassium

Of the macronutrients essential for growth and development of tomatoes, potassium is the most unusual since it has no direct contribution to the cellular structure of the plant (Adams, 1986). The function of potassium appears to be that of a regulator for many of the metabolic processes in cells including protein synthesis.

Potassium is more readily exhausted than many other nutrients. Brice (1978) estimated that tomato plants over a season can utilize 680 kg of potassium per hectare twice as much as nitrogen. Potassium has considerable influence on fruit quality and yield (Adams and Grimmett, 1986). Winsor (1979) and Adams *et al.* (1978) showed that although low levels of potassium is sufficient for yield, higher levels have been shown to improve all aspects of fruit quality. Dry matter and titratable acid of the fruit generally increase with an increase in potassium level (Davies and Winsor, 1967). Winsor *et al.* (1961) reported that potassium improves fruit shape while Shafshak and Winsor (1964) showed that fruit firmness was also improved.

Potassium deficiency is most likely to occur on heavy clay soils or on light sandy soils inadequately supplied with potassium (Adams, 1986). Symptoms exhibited by tomato plants grown in potassium deficient substrate include yellowing of the leaf margin, uneven ripening, hollowness, irregular shapes, softness and insipid flavours due to lack of acidity (Brice, 1978).

1.2.1.4 Calcium

The potential uptake of calcium is very much lower compared to potassium despite its concentration in the soil which is ten times higher than that of potassium (Mengel and Kirkby, 1987). The low potential uptake of calcium according to Ferguson *et al.* (unpublished) arise because calcium can be absorbed only by young roots in which the endodermis are still unsuberized.

Apart from this uptake mechanism, the presence of other cations which are easily absorb and translocated within the plant tend to depress the uptake of calcium (Mengel and Kirkby, 1987). This partly illustrates that although soils hold comparable amounts of calcium its concentration in the plant is still low due to its controlled uptake. Ferguson *et al.* (unpublished) recommended that levels of other cations should be kept comparably low but above deficiency levels if the site is known to give rise to plants with calcium deficiency problems. Maynard (1991) added that apart from cation restriction, calcium uptake can also be depressed by salinity of the soil solution, low temperature, dry soil and high humidity. Calcium uptake appear mainly to be a passive process. Calcium that is absorbed by the plant roots is distributed throughout the plant principally along with water.

In tomatoes once calcium has been assimilated in the leaves, it can no longer be translocated to actively growing parts with low transpiration surface (Adams, 1986). Calcium plays a critical role in maintaining cell membrane integrity. Since actively growing parts of the plant are deprived of their calcium requirement they are the first to exhibit calcium deficiency. Maynard (1991) reported that tomato plant deficient in calcium exhibit undeveloped leaves at the growing points, interveinal yellowing in young leaves and blossom end rot in the fruit (Adams, 1986; Brice, 1978).

1.2.1.5 Magnesium

Magnesium is more abundant in soils than potassium, but its uptake rate is comparably much slower than potassium. Magnesium transport is passive moving against the electrochemical gradient (Mengel and Kirkby, 1987). Adams (1986) clarified that in tomato plants magnesium acts as an activator for certain enzymic reactions. Potassium, NH_4 and calcium may play a primary role in magnesium uptake. This competition can lead to magnesium deficiency in tomato plants.

Research work reported by Brice (1978) show that the average magnesium uptake over a season is 290 kg ha^{-1}. Although high levels of potassium often depress total magnesium uptake, increase potassium supply affects magnesium content of different plant organs to a varying extent. For example, increasing potassium supply reduced magnesium content of tomato leaves and roots respectively, but the magnesium content in fruit according to Viro as cited by Mengel and Kirkby (1987), can be increased by higher levels of potassium in the nutrient solution. Magnesium is very mobile in the phloem and can be translocated from older to younger leaves. Since developing fruits are highly dependent on the phloem for their mineral supply they are thus higher in potassium and magnesium.

Magnesium inadequacy in tomatoes is usually due to the plants failure to assimilate magnesium from the soil (Brice, 1978). Tomato plants deficient in magnesium show interveinal yellowing on the lower leaves and gradually which

spreads to all foliage. The disorder is very prevalent when plants are carrying their heaviest fruit load.

1.2.2 The Effect of Salinity on the Vegetative Growth of Tomato

The development of salinity tolerance species according to Shannon *et al.* (1987) is an agronomic approach to the exploitation of large areas of saline soils and the efficient use of relatively abundant saline water supplies that currently have little agricultural value.

As more and more land is brought into crop production through the development of irrigation, Jones (1986) has predicted the widening problem of salinity. Soils affected by salinity represent an important limitation to crop production particularly for crops that are sensitive. For tomato production, this does not pose a threat provided salinity levels do not exceed tolerable levels.

Tomato plants are particularly sensitive to salinity at seedling the stage. Indications of stress in tomato were reported by Zerbi *et al.* (1991) as reductions in photosynthetic activity and leaf water potential which resulted later in reduced yield. Charbonneau *et al.* (1988) studied the effect of salinity of liquid feeds and they reported that raising the conductivity of the solution from 2 to 10 mS cm^{-1} decreased linearly the shoot dry weight by 30%, a clear demonstration that raising salinity reduced vegetative growth.

This finding confirmed the work of Papadopoulos and Rendig (1985) who used NaCl and CaCl to raise the salinity of the nutrient base solution.

Dalton and Poss (1990) suggested that salinity tolerance is controlled not only by the inherent genetic characteristics of plant, but also by some yet to be determined processes in the plant. Tomato plants that were able to withstand salinity exhibited lower growth rates and had a slightly darker green colour than the less tolerant cultivars (Rush and Epstein, 1976).

1.3 Flower Development

1.3.1 Introduction

One of the major events in the life of a tomato plant is the transition from vegetative (non-flowering) state to reproductive (flowering) state. The first signs of the transition from vegetative to reproductive state, which is termed flower initiation occur at the apical stem. Once flower initiation is started, particularly in indeterminate cultivars, it continues throughout the life of the plant. Flowers whose growth and development become arrested may senesce prematurely before flower opening can occur. This pre-mature loss is known as flower abortion.

1.3.2 Flower Formation

The vegetative period of tomato seedling lasts for about 11-31 days depending on the light conditions after pricking out (Brice, 1978). Whenever the vegetative phase is reduced, Atherton and Harris (1986) predicted early fruit production, while extended vegetative growth allows the formation of more leaves preceding the inflorescence and then delay fruiting. Hurd and Cooper (1970) suggested monitoring of leaves as an indicator of flower initiation. They suggest that 3 weeks after cotyledonary leaf expansion, most if not all tomato cultivars start to initiate flowers. This coincides with the third leaf reaching a length to just in excess of 10 mm,

Inflorescence development in tomatoes require substantial amount of photoassimilate in excess of the amount required for growth. Hurd and Thornley (1974) reported that before tomato plants are set to initiate inflorescence, they have to initiate at least 6-8 leaves. This number of leaves is enough to intercept enough light needed for a sufficient production of photoassimilate for development of good quality flowers and fruits on the first truss. The hypothesis of Sachs and Hacket (1969) is in accord with the findings of Hurd and Thornley. According to this theory, the amount of photoassimilate available to the apex must reach a certain level before the transition can take place.

1.3.3 The Influence of Environment on Flower Formation

The effects of environment can be both on flower initiation and subsequent flower development. Since flowering is determined by the appearance of visible flowers or buds, the data are sometimes insufficient to be sure which developmental stage is being affected by environmental factors. Environmental factors associated with fruit set and development in tomatoes were mostly identified under controlled environments, where such factors are subject to relatively close control.

For most cultivars, the ideal day temperature for vegetative growth is about 18 to 25^{0}C (Hussey 1973). Temperatures below this range are damaging as it reduce vegetative growth more than flower development, whereas higher temperature favour vegetative growth at the expense of flowering. Studies of Abdul and Harris (1978) show that young leaves excised from plants grown at low temperature contain low levels of diffusible gibberellins that promoted an increase in number of flowers initiated in the first truss. Leaves excised from plants exposed to high temperature contain high levels of a gibberellic acid-like diffusible substance thus giving them more advantage for attracting assimilate.

Following the exposure of plants to high temperatures, Dinar *et al.* (1983), suggested that leaves restricted the amount of photoassimilate exported to sink organs particularly apex due to high maintenance respiration. Mofo and La Malfa (1986) while studying the relationship between flowering and pre-planting

temperature found that once plants were exposed to low day and night temperature treatments, the number of leaves preceding the inflorescence were significantly reduced along with vegetative growth. One important result from these studies shows that inflorescence was initiated at low temperatures because the apex was able to assimilate with young leaves as their growth is restricted due to low temperatures. Koning (1991) reviewed the relationships between flowering temperature and flowering and found that at 17^{0}C and for every 2^{0}C rise in temperature, flowering was advanced by 0.1 truss per week .

High irradiance is necessary to produce photosynthates required for flowering. As light integral increases, the number of leaves before the inflorescence decrease as does the time of truss appearance (Kinet, 1977). It appears that since the number of days to flower initiation was reduced along with a reduced number of leaves, the inflorescence is placed in a more competitive position for attracting photoassimilate over the young expanding leaves.

The number of flowers in the first inflorescence tend to increase as the light integral is increased. For example, when solar radiation levels were high, flower opening occurred about 40 days after cotyledonary expansion irrespective of total radiation received (Atherton and Harris, 1986). Initial reductions in light had a greater effect than the subsequent light reductions. Flower initiation and development according to Calvert (1969) is adversely affected more than vegetative growth whenever the carbohydrate supply is insufficient. These mechanisms clearly show that when photoassimilate is limiting, the plant

sustainsvegetative growth in preference to other sink organs by diversion of photoassimilate from leaves and away from the inflorescence.

Some cultivars are regarded as qualitative short day plants (Kinet, 1977a). Experimental evidence suggests that at the same light integral an eight hour daylength reduced the number of subtended leaves and time to initiation of the inflorescence compared to plants exposed to sixteen hour daylength.

There is no question that carbon dioxide enrichment increases yield primarily by increasing fruit set and the final size of the fruits. Additional carbon dioxide increases the carbohydrate status of the plant through an increase in net photosynthesis. Thus from the studies conducted by Hand (1968) it was reported that carbon dioxide enrichment increases the rate of leaf initiation slightly and decreased the time to flower initiation. The effect of carbon dioxide is greater when there is an increase in light integral.

Reproductive growth and fruitfulness of tomatoes relies on the correct balance between carbohydrate and fertilizer supply. Tomato plants exhibit growth retardation and flower abortion due to inorganic nutrient deficiency in the growing medium. When the macro-elements are in short supply, tomatoes tend to slow down flower induction, an indication that the plant is under nutrient stress.

The size of the first inflorescence is affected by the supply of inorganic nutrients in the rooting medium when it was initiated.

Of the major elements supplied nitrogen is the most important. When its supply is limiting vegetative growth and flower induction is severely affected .

Earliest reported effect of nitrogen on flower induction was that of Wittwer and Teubner (1957) who found that the number of flowers in the first inflorescence can be increased by increasing supply of nitrogen. The most profound effect was apparent when plants were exposed to 10-13^{0}C when branching of inflorescence was more prevalent. Low supply of nitrogen in the growing medium increases the incidence of flower abortion.

Fisher (1969) reported that low levels of nitrogen in the solution decreased flower number. The same observation were reported by Adams *et al.* (1973) when growing single truss plants.

1.3.4 Pollen Production and Development

When the daytime temperature is at 20^{0}C and under high light conditions, Picken (1984) observed that sexual reproduction in mother cells took place nine days before fruit set. In most instances the quality of viable pollen formed is the most important criteria in pollen production. Between 5-7 days before anthesis, damage caused by high temperature on pollen grain is even more severe than on the ovules because at this stage fruit set can be improved only by the application of untreated pollen.

Tomatoes are generally self pollinated (Ho and Hewitt, 1986). Mature pollen is ready for transfer at the time of anthesis while the stigma is receptive about two days previously and remains up to four days or more (Ho and Hewitt, 1986). Adherence of the pollen grains into the stigma is vital to allow germination to take place. The adherence of pollen grains into the stigma is greatly reduced when the relative humidity is 70% or if the temperature is outside the range of 17 to 24^{0}C (van Ravestijn, 1970 cited by Ho and Hewitt, 1986). Successful transfer of pollen grains to the stigma is also dependent on the length of the style and the nearness of the stigma to the anther cone for self pollination (Rick and Dempsey, 1969).

Rick and Dempsey (1969) observed that tomato cultivar whose stigma is within the anther cone set fruit easily whereas in cultivars with exerted stigma or elongated style, pollination and fruit set are seriously affected. The length of the style determines the degree of insertion or exsertion of the stigma and is generally influenced by external growing conditions. Hannah and Hernandez (1984) studied the response of six cultivars grown in summer and spring conditions and found that high temperature influence exsertion while low temperature induce insertion. The observation of Munoz and Cuartero (1991) on the effects of temperature on stigma position is in agreement with the previous report.

Fertilization has been first observed 18 hours after the adherence of pollen grains to the stigma and most ovules would be fertilized within 30 hours.

The extent of fertilization is dependent upon the number of viable pollen grains reaching the stigma, environment, physiological factors and the process of pollination and fertilization (Picken, 1984).

Pollen germination is temperature dependent (Ho and Hewitt 1986). The degree of germination is greatly reduced when the temperature is below 5^0C or when it exceeds 37^0C. Tomato cultivars grown in the field exhibit some heat sterility specially during summer and this accounts for a reduction of yield. The most commonly accepted explanation to this has been that it was due to the abortion of pollen grains at extreme temperatures.

Shelby *et al.* (1978) cited the study of Schaibe and reported that when night temperature reaches 32^0C tomato fruit set is limited. In the same year Kuo *et al,*(1979) found that most failures in tomato fruit set was due to immediate exposure of the flowers to high temperatures, but observed that if such exposure was done 5 to 8 days after anthesis the flowers tend to tolerate the temperature level.

Viability of pollen grains vary with different times of the day. When the stigma of the male sterile plants were hand pollinated with viable pollen it took 6 hours to reach the stylar end, but when pollinated early in the morning it took 12 hours (Picken, 1984). The growth rate of the pollen tube increases when the temperature is between 10^0C and 35^0C and decreases if the temperature is outside this range.

1.4 Fruit Development

1.4.1 Introduction

Fruit set is a crucial factor that influences yield. Normal fruit growth requires two important processes namely, pollination of the flower, and the steady supply of assimilates. Understanding the mechanisms in these processes will enable us to manipulate and improve yield as well as the sensory qualities of the fruit (Archbold *et al.*, 1982).

Fruit number and individual fruit weight are two important components of yield. Together with sensory attributes like size and shape these are influenced by the number of seeds produced, based on the quality of viable pollen that germinates in the stigma (Picken, 1984).

1.4.2 Physical Changes in Developing Tomato Fruit

Fruit growth is part of an integrated development of the plant. Fruit growth is determined by the interaction between growing conditions and morphological characters as well as physiological activities of the whole plant. It has long been recognized that the improvement of the fruit is dependent upon understanding the factors controlling assimilate production in the leaves and the enzymatic activities that determine sink strength. The key to understanding the factors that

regulate fruit growth is to identify how the morphological factors respond to environment and how the metabolic processes inside the fruit interact with the rest of the plant.

Fruits are reversible storage sinks as the imported assimilates are either used for growth or stored as reserves (Ho, 1988). It is indeed important to understand how the supply and the competition for assimilates for each fruit is regulated.

Fruit yield in terms of dry matter production is related to assimilate supply and hence to the radiation levels intercepted by the crop. This relation however does not imply that any increase in fruit yield is entirely determined by the improvement of photosynthesis. Fruit yield can also be improved by changing the dry matter partitioning and by manipulating the factors that determine the sink strength of the fruit (Gilford and Evans, 1981; Ho, 1988). Before fertilization, the dry matter accounts for 17% of the ovary weight. As the fruit grow, the dry matter content of the ovary as a percentage of fresh weight declines as the amount of water accumulated increases (Ho and Hewitt, 1986). The rate of dry matter accumulated declines to less than 10% after 10 days and 5% to 7% by day 20 and remains at this level until maturity.

The rate of growth and development of tomato fruit is divided into 3 periods. First, there is a slow growth for 2 to 3 weeks when the gain in weight is less than 10% of the final weight (Ho and Hewett, 1986). The growth of the ovary ceases at anthesis and then resumes after fertilization.

Two days after pollination the growth of the ovary is sustained by the importation of assimilates from the nearby leaves. Thus the rate of dry matter accumulation in fruits of the same potential size will relate to the concurrent photosynthesis in the leaves. According to Ho *et al.* (1983), fruits accumulate as much as 30 to 50 mg of dry matter after two weeks of growth. It was subsequently observed that from twenty to twenty five days after anthesis, there was a period of rapid growth. While the growth rate increases during this period, the daily import rate of carbon diminish from 140 mg to approximately one half as the fruit increases from 20% to 90% of its carbon content. The decrease in carbon accumulated by the fruit is due to the formation of an abscission layer between the calyx and the fruit (McCollum and Skok as cited by Ho and Hewitt, 1986).

When the fruit is mature green, Ho and Hewitt (1986) observed that fruits undergo slow growth marked by little addition in weight for almost 2 weeks. However intensive metabolic changes occur. The slow growth was the result of initial cell division and enlargement, while the rapid growth was entirely due to cell enlargement.

Enlargement of pericarp is positively related to the auxin activity in the fruit (Asahira and Hosoki, 1977), while the shape of the fruit results from the differential growth of the ovary at the polar and equatorial dimension before anthesis. Locular cavities which vary from two and above occur as a gap in the pericarp. The locules contain seeds located in the homogenous gelatinous mass of thin walled parenchyma like cells that fill the locular cavities (Varga and

Bruisnma, 1986). These tissues appear very early and are thought to be formed by an outward growth from the placenta surrounding the seeds.

The number of locules in the ovary is dependent on the flower position within the truss. Ovaries of the first flower on the first truss may have more locules than subsequent fruit. If this is the case, then the first fruit is larger than the rest, particularly those at the distal section of the truss.

Since fruit size is of economic significance, increasing the locule number will enhance the size of the fruit. Introduction of genes to increase the locule number have paved the way to increasing the size of the fruit. Aside from the genes, Sawhney *et al.* (1971) confirmed that by applying gibberellic acid to pre-floral plants stimulated an increase in the number of carpels and locules in the ovary. In addition to these observations, the style of the treated flowers were thicker, contained more vascular bundles and there was an increase in ovary size.

Reducing sugars at the onset of fruit growth account for 0.1% of the ovary fresh weight and there was a gradual increase to 1.2% within 2 weeks and 3.5% thereafter until ripening occurred (Ho and Hewitt, 1986). Sucrose accounts for 1% of the dry matter or in a range of 0.1 to 0.2% of the fresh weight. Although lower in percentage, it is important for fruit growth (Walker and Ho, 1979). After pollination, reducing sugars and starch increase sharply, but sucrose reduces to 1% to 0.2% of the fresh fruit weight within 8 days. Although sucrose is the principal sugar imported by the fruit, its content remain low throughout.

According to Ho *et al.* (1983), the highest dry matter gain by fruits daily is 370 mg per day in the proximal fruit while dry matter increment in the distal fruit is approximately 170 mg. The major or principal part of the fruit receiving more starch per fresh weight are the locular tissues and the placental tissues.

Starch which is about 1% of the dry matter when the fruit is mature green, starts to breakdown upon reaching maximum growth (Ho *et al.*, 1983). This concentration was further reduced to approximately 0.03 % of the fresh fruit weight at the time of ripening (Hobson, 1967). The breakdown of starch is associated with the accumulation of hexoses hence a correlation exists between the starch content of a mature green fruit and the reducing sugars of ripe fruits (Dinar and Stevens, 1971).

The concentration of organic acids expressed as percentage of the fruit fresh weight was reported by Ho and Hewitt (1986) to increase during fruit development. This concentration varies according to fruit section, thus locules is more acid compared to pericarp wall and placenta. During early growth malic acid is predominant (13 %), whereas citric acid account for 25 % of the total acidity.

1.4.3 Factors Affecting Fruit Growth

Tomato is a high yielding crop with fruits representing a large fraction of the total dry matter of the plant (Ho and Hewitt, 1986).

The reason for such a high proportion of dry matter allocated to fruit production is the high demand for sugars by the growing fruit. Developing fruit should be able to import high levels of sucrose from the leaves in order that at ripening, the fruit will contain high sugar and organic acids such that both the taste and texture of the fruit will be satisfactory.

Tomato plants has a 2/5 phyllotaxy (Russell and Morris, 1983). Ho and Hewitt (1986) indicated that once the first inflorescence develops on one side of the plant, all succeeding trusses are on the same side of the stem with often 3 leaves in between trusses. The first two leaves below each truss are at angle 90^0 on either side of the truss, while the first leaf above the truss is on the opposite side. The assimilate supplied to the truss at flowering comes from the subtended leaves below the truss and not the leaves above the truss. At fruit initiation however, the assimilates are supplied from the leaves below the truss and the leaves above the truss (Ho and Hewitt,1986).

Tomato plants have a well structured system for distribution of assimilates and minerals to the various growing regions. The pattern of assimilate allocation to respective sinks is effective due to the arrangement of their vascular system (Russel and Morris, 1983; Yoshihiro *et al.*, 1988). There are two main conducting tissues that sustains the growth of the fruit. The phloem, primarily conveys water and sugars from the leaves, while the xylem carries water and salts from the roots (Ho and Grimbly, 1990). In the dark, both phloem and xylem sustains the growth of the fruit, but higher growth rate in the daytime is mainly the result of an

increase in phloem flow bringing in sugar to the fruit.

Most of the dry matter accumulated in the fruit is derived from assimilates imported from the leaves, thus fruit growth is mainly determined by the import rate of assimilates. Once carbon is fixed in a mature leaf, 20 to 30% can be exported to the developing fruits within 2 hours and approximately up to 45-50% within 2 days. The principal labile assimilate exported is in the form of sucrose making up 90% of the assimilate (Ho and Hewitt, 1986).

At any one time when the supply of assimilate is limited, the fruit is sustained by both assimilates from the leaves and that remobilized from the reserves. Although the developing fruit is sustained by the leaves below the truss, transitory patterns occur depending upon the growth conditions of the fruit within the truss. Studies conducted by Bonemain according to Ho and Hewitt (1986) showed that at the peak of fruit growth large amounts of assimilate is required to sustain the needs of the developing fruits. The additional assimilate is supplied by re-mobilization of the carbon reserved in the roots and this can be re-exported within 3 hours in the form of amino or organic acids.

The degree of competition for assimilate between vegetative and reproductive organs depend on their spatial and temporal relationships. In tomatoes, competition for assimilates between reproductive and vegetative organs is very localized, that is for every truss there are 3-5 leaves that act as source for assimilates (Ho and Hewitt, 1986).

As the developing fruits are stronger than flowers and vegetative organs, the competition for assimilates by a fruit is mainly with adjacent fruits within a truss as they derive their assimilates from the same group of leaves. The mechanisms involved in the regulation of competition between fruit is at present not fully understood. Ho (1984) elaborated that fruit growth may be determined by its inherent capacity to attract assimilate and its ability to compete with other fruits for assimilates. Most studies conducted to determine the strength of the fruit to attract assimilates involve sink size and activity as regulatory factors.

Cell numbers contained in the fruit is at present considered a good measure of potential sink size. As the whole fruit mass is determined by cell number, cell size and cell content, while the final volume of the fruit is determined by the extent of cell enlargement (Coombe, 1976).

Factors determining cell number in fruits have not been studied seriously. Ho (1988) stated that in tomato pericarp, the cell number appears to be associated with cambial activity of the vascular bundles . Although most cells of a fruit are derived from cell division following pollination (Mapelli *et al.*, 1978), the difference in cell number of a fruit at various positions in the same truss already exists in the pre-anthesis of the ovary. The duration of cell division after anthesis varies from less than 2 weeks in tomatoes.

Sucrose has been found directly or indirectly to be the predominant mobile assimilate in tomatoes (Walker and Ho, 1979).

At ripening, hexose account for about half of the fruit dry weight hence the hydrolysis of sucrose and subsequent storage of hexose may be important factors in regulating the import rate of carbon (Walker *et al.*, 1978; Ho, 1988). If the partitioning of assimilates is motivated by the metabolic activities within the fruit, then the sink activity is a more primary determinant of sink strength than sink size. The strength of the developing fruit to attract assimilate has been thought to be the product of its dry weight.

Winsor *et al.* (1967) studied the effect of light and carbon dioxide on fruit growth and found that although the addition of carbon dioxide increased yield by increasing the number and weight of the fruit, the chemical composition of the fruit was not improved. The most accepted explanation why fruit composition was not improved, despite carbon dioxide enrichment, was that according to Ho and Grimbly (1990), although the number and size of the fruit was boosted as a result of carbon dioxide enrichment, the amount of assimilate imported by the fruit was accompanied by a similar amount of water, thus fruit weight is increased rather than the dry matter content.

Both size and total soluble solid content of the fruit are influenced by the amount of light absorbed by the leaves. If light level are low during early growth the proportion of hollow fruits in the first truss is 80-100%, while dry matter content of the early yield is low. When the solar radiation is high both dry matter and sugar is high. This was demonstrated by Ho and Grimbly (1990), when they compared tomatoes imported from tropical countries with that produced in

Europe. Ho and Grimbly (1990) confirmed the previous observation that the amount of sugars imported by the fruit as a result of carbon dioxide enrichment is accompanied by the similar amount of water taken up by the fruit. They further explained why fruit weight increased rather than boosting the dry matter content of the fruit. The effect of light on the dry matter content of the fruit is different from the effect of carbon dioxide. Increases in light levels is accompanied by increases in temperature causing slight water stress. The fruit in return benefits from water stress by importing more sugars as the result of increased photosynthesis. High amount of light absorbed, slight water stress and a large leaf area are possible effective ways in increasing the sugar content of fruit.

An efficient way of improving the quality of the fruit is the use of saline media and using the potential tolerance of tomato to salinity. As discussed by Shannon *et al.* (1987), the continued breeding of tomatoes to tolerate salinity has become an agronomic tool in the exploitation of saline soil not only in the field but also in controlled environment with considerable improvement in quality. Mizrahi *et al.* (1988) concluded that among the environmental factors responsible for the improvement of fruit quality, soil water availability and quality can readily be controlled and manipulated to increase the soluble sugar and acid concentration, thereby improving the quality of the fruit. With an increasing awareness of the effect of salinity on fruit quality, the search for materials to increase the electrical conductivity of the solution without prejudicing the growth of the plant should have priority. In the NFT system several experiments have been conducted using different salt combinations to raise the conductivity of the solution.

Shalhevet and Yaron (1973) added NaCl to the base nutrient solution and were able to increase the soluble solid content of the fruit by 24%.

At high salinity both the uptake of water by the plant and the subsequent accumulation of water by the fruit is severely reduced, therefore the promoting effect of salinity is not on fruit density, but on the percent of fruit dry matter and sugar concentration in the fruit juice. This observation was confirmed by the results obtained by Ehret and Ho (1986), when they observed the dry matter of the fruits from salinized plants to increase as the conductivity of the solution increased. During rapid growth, Ehret and Ho (1986) observed that a high proportion of dry matter was stored in the fruit in the form of starch rather than sugars. The advantage of accumulating carbohydrates in fruits in the form of starch rather than hexoses according to Mitchell *et al.* (1991) is that it ensures continued sink activity therefore the accumulation of starch is maintained at a reduced tissue water level. These studies clearly demonstrate that when the assimilate supply is not limiting the amount of assimilate being imported by a fruit is not at all affected by the water relations in the plant. Although size of the fruit is reduced (Ho and Grimbly, 1990) the fruit have a higher percentage of dry matter. If for instance the purchase of the produce is based on the total solid content there would be no economic loss.

When sugars are not limiting, fruit growth is regulated by temperature and water supply. Restricted watering and high salinity can be used to adjust fruit number, fruit size and improve taste. The effect of such reduction is not to reduce

phloem sap supply, but to increase the concentration of the sap without a reduction in the usual amount of sugar being imported by the fruit. Although less water is accumulated, the dry matter accumulated increase with high sugar concentration in the fruit.

The effect of macro and micro elements has been discussed by Uexcull (1979). Adequate nitrogen improves fruit quality, while excessive application tend to decrease the size of the fruit, keeping quality, colour and taste. Phosphorous on the other hand in combination with potassium improves peel and pulp coloration, taste, firmness, vitamin C content and hastens maturity. Potassium tends to increase fruit size and plays a key role in the process of fruit pigmentation. It also influence acid metabolism. Inadequacy of calcium in the growing media will result to a number of physiological disorders, while magnesium deficiency can be induced by high rates of potassium or ammonium nitrogen application.

1.4.4 Maturity and Ripening of Tomato

1.4.4.1 Structure of Tomato Fruit

Davies and Hobson (1981), botanically classified tomato fruit as a berry since the seeds are formed within the fleshy mesocarp. Tomato fruit is composed of flesh (pericarp wall, skin and pulp), placenta and locular tissue including seeds. Generally, less than a third of the fruit fresh weight is made up of pulp (Ho and Hewitt, 1986).

The skin is made up of 4 to 5 layers of cell under a thin cuticle. The epidermal layer is heavily cutinized on the surface. The epidermis is covered by a thin cuticle that thickens as the fruit matures (Varga and Bruinsma, 1986). The cutin may surround the epidermal walls below and between the first layer of collenchyma. The importance of cutin is enhanced resistance of the fruit to cracking during ripening. This is very important particularly when tomatoes are grown purposely for processing and mechanically harvested and transported for long distances (Voisey *et al.*, 1970).

Vascular strands radiate from the stem end of the fruit to the pericarp down to the columella and to the blossom end. Cross connection in the pericarp are more common in the distal half of the fruit. A major vascular bundle, the centre line of each carpel, is developed extending from the stem scar to the blossom end of the fruit (Ho and Hewitt, 1986). In green fruits, the epidermal cells tend to have less starch than the inner parenchymatous cells. Most of the cell division in the pericarp takes place during the first week after anthesis, further division occur during the second week (Asahira *et al.*, 1965 cited by Ho and Hewitt 1986). The number of cell layers increase from 8 to 10 during this period however cell development was observed throughout fruit development.

In mature fruits, the placental tissue is firm, but as it approaches maturity, the walls of these parenchymatous cells become thin and wavy and contain large but diminishing numbers of starch grains (Grierson and Kader, 1986). The appearance of jelly like material in the locular cavity provides an excellent

criterion whereby fruit may be designated mature green. The placental tissue at incipient ripening appears pink in colour. Two major groups of pigment in tomato fruits are chlorophyll and carotenoid. Prior to ripening chloroplasts lose starch and chlorophyll from the grana, followed by the production of osmophilic globules and the formation of lycopene within the swollen granum compartment.

1.4.4.2 Maturation and Ripening

The fruit of tomato requires approximately 40-60 days from flowering to full ripeness. After the initial phase of slow growth, Rick (1978) observed that the fruit undergo major increase up to full size in about half of the ripening period. As the fruit matures, cells in the pericarp become very large, thin walled and the parenchymatous cells around the seeds are reduced to semi-liquid immediately prior to ripening (Ho and Hewitt, 1986). The starch content reaches a peak halfway through development, when it makes up about 20% of the dry matter. This figure falls to 1% at the mature green stage and is followed by a declining growth rate during which maturation and ripening usually occur. During this period, the fruit (Varga and Bruinsma, 1986) stores large amounts of reserve materials accumulated either through synthesis of sugars or elaborated in the nearby source leaves.

Early ripening is marked by the completion of starch hydrolysis at which point reducing sugars are present in maximum concentration. At almost the same time malic acid, which was initially an important organic acid decreased gradually after

fruit maturity and is replaced by citric acid. The turnover in acid concentration in favour of citric acid causes the ratio of malate to citrate acid to fall during the later stages of maturity. Hobson and Harman (1986) elaborated that at maturity, the sugar content in the fruit, in particular reducing sugars, tends to be more concentrated in the locular walls while acids are more concentrated in the locular cavities. An increase in moisture content was also observed in the fruit, which accounts for 90-95% of fresh weight as the fruit develops.

Aside from compositional changes, a series of structural changes are known to occur. Following a decline in growth rate, Bathgate *et al.* (1985) noticed gradual structural changes including membrane disintegration, chlorophyll breakdown and starch disappearance. Gradual chlorophyll degradation at this stage results in the whitening of the fruit which serves as a useful determinant of ripening. The following week is marked by destruction of the remaining chlorophyll when Harris and Spurr (1969) observed the transformation from chloroplast to chromoplast. During this transition, there was an increase in carotenoid content and synthesis of lycopene in the cytoplasm. Grierson (1987) noted that the mechanism of change was structured so that it took place at the same time that other ripening processes such as cell wall degradation, tissue softening and accumulation of sugars and organic acids were occurring.

Ripening of tomato fruit involves a number of chemical and physical changes which convert the fruit from a relatively inedible state to one of optimal quality (Babitt *et al.*, 1973). It is also a complex developmental process involving

changes in the biochemistry, physiology and gene expression of the fruit and an active process characterized by changes in all cellular compartments as well (Smith *et al.*, 1989). It has been suggested by Saccher (1973) that the loss of cell membrane integrity, removal of permeability barrier and increase in free space serve as major factors in ripening and senescence. One of the early events that heralds the onset of ripening is the beginning of the respiratory climacteric, the rise in breakdown of proliferated cells that surround the seeds in the locules (Rabinowitch *et al.* 1975), the partial solubilization of the cell wall components leading to softening of the texture (Speirs and Brady, 1991), alterations in metabolism and composition of all major cell compartments (Grierson, 1987) and progressive changes in colour, texture, flavour and aroma in each tissue (Brecht, 1987). All these changes are highly synchronized appearing in close succession in a variety of distinct processes during the relatively short period which fruit ripens.

The mechanisms by which fruit ripening changes are initiated and synchronized remains largely unknown. It therefore seems appropriate to look into factors that triggers the initiation and coordination of these changes.

Essential to the initiation of ripening is the resistance of the fruit tissues to the effects of hormones that would trigger metabolic changes within the cells. Resistance of tissues to ripening hormones is a feature of most unripe tissues (Hobson and Harman, 1986). Once their resistance has been overcome by ripening hormones their evolution gradually rise from a low basal level.

The rate at which tissue sensitivity towards the ripening hormone occur determines the onset of ripening.

One important and much studied process occurring during fruit ripening is softening. This involves changes in the structure and solubility of the fruit cell wall. The processes involved in fruit ripening has been extensively studied. The main issue under investigation here is the occurrence of ripening enzymes that eventually lead to metabolic degradation of fruit cells. Previous efforts to determine the enzyme that initiated ripening was made by Sacher (1973). Accordingly, there are numerous enzymes that have been shown to change their activities as the fruit ripens, and some of these show clear physiological relevance. For example, when Brecht (1985) measured the concentration of various enzymes in tomato fruit tissues, he found that during maturation the concentration of ACC increased in the locule tissue of green fruit coincident with gel formation. Brecht (1987) clarified that locular tissue was derived from the placenta of the fruit then overgrowing the seeds, which later on fill the locules, but not fusing with either the seeds or pericarp. At maturity, the cell walls become progressively thin and fragile eventually rupturing to produce the typical liquid jelly like consistency of mature ripe fruit. The activity of ACC synthase is not only centred on the locular tissues but is spread out to nearby tissues like columella and placenta, where synthase begins to increase at the mature green stage (Brecht, 1985). Similar increases also occur on radial and outer pericarp following the breaker stage.

ACC and ACC synthase continue to increase in columella and pericarp tissues beyond the breaker stage while levelling off (ACC) or falling (ACC synthase) in the gel as the tissue is degraded. The expansion and separation of cells and the cell wall fragments released at this stage may act as elicitors of ethylene production (Brecht, 1985). The locular contents of tomatoes contributed 20% to the total fresh weight of the fruit thus a small increase in ethylene production observed in the whole fruit at the mature green stage probably represent a significant increase in the locule tissues rate of ethylene production. The relationship between ethylene production rate and maturity stage is a good index to determine physiological maturity of the fruit.

1.5 Quality of Tomatoes

1.5.1 Introduction

Tomato quality has received attention only after the improvement of yield has been achieved. Consumer preference for fresh tomatoes is no longer limited to how they appear, but they are also demanding quality attributes based on flavour and nutritional value. It is generally accepted that ripe tomatoes purchased in supermarkets nowadays lack the desired aroma and flavour that there used to be when fruits were vine ripened.

U.S.D.A. legislation regarding product information requires the inclusion of nutritional value of the product. This move will change the purchasing attitude

of consumers as they can compare product composition. The impact will not end where the product is being sold, instead growers will be obliged to do their part by changing their production practices so that their product will be competitive on the market.

1.5.2 The Composition of Ripening Tomatoes

Tomato fruits ripening either on or off the vine show compositional changes. It is at maturity that the ultimate quality of the fruit can be judged based on the perception of consumers.

Tomato fruits during ripening contain a wide range of compounds and show considerable variation in composition and structure. The presence of many compounds that constitute the flavour of the fruit is the result of interactions with season, nutrition, environmental and physiological status of the fruit.

The composition of present day tomato varieties is the result of combined efforts of research work to determine the factors that comprise fruit flavour in particular sugar, acid, and volatile compounds.

1.5.3 Flavour as a Quality Attribute of Tomato

Flavour is one of the most important constituents of quality, but at present has little effect on the initial sale of the product due to our failure to identify its

components. Tomato fruit are sensed differently by different individual and often impressions are affected by other non-flavour quality attributes. The unique flavour of tomato is a composite of taste smell and touch or mouth feel (Bezar, 1989) and is a product of sugars, acids and aromatic volatiles contributing to 60 % of the dry matter Hobson (1988). If the proportion of sugar in the fruit is low, the consumer will react to their sharp and biting taste, but if the fruit acid is low the unbalanced sweetness can be disturbing to the taste. Weight for weight acids affects the taste more than the sugars. Of the sugars that are used to balance acidity fructose has more sweetening power than glucose due to its higher concentration.

Volatile compounds are not only important to aroma, but also to the overall flavour of tomatoes. Frenkel and Jen (1989), reported research work and concluded that although several hundred aromatic volatiles have been catalogued, there are still new compounds being discovered and added to the existing ones as research for other volatile compounds continue. Only a limited number of these are important to the aroma of the tomato fruit. Improving the sugar and acid ratio of the fruit requires effective combination of factors that influence the chemical composition of the fruit. Studies conducted by Ehret and Ho (1986) and Mizrahi *et al.* (1988) revealed that among the environmental factors that influence the quality of the fruit, nutrient and water availability and quality can be readily controlled and manipulated to increase the total soluble solids and acid concentration. Mizrahi (1982) reported that increasing the concentration of the liquid feed increases the total soluble solids and acid of the

fruit. By imposing a range of salinity regimes, water uptake is regulated thus increasing the concentration of mineral ions in the fruit. The concentration of cations in the fruit varies with the kind of salts used to raise the conductivity of the nutrient base solution. Thus, when Ehret and Ho (1986) imposed a range of salinity using potassium nitrate or calcium nitrate, potassium becomes the predominant cation in the fruit.

An important factor in understanding the determinants of flavour is to know how to balance the acid and sugar content of the fruit. Bezar (1989), pointed out that fruit walls contain at least 20 % more sugar than the juice around the seeds, while the juice contain more acid than the pulpy part of the fruit. Hobson (1988) elaborated that if consumers wanted to derive a biting taste they should choose those fruits with bigger locular contents in contrast to pulpy fruits which gives a sweeter taste.

1.5.4 Sugar as a Component of Flavour

After water, sugars form the next most important constituent of the tomato fruit contributing almost 50% of the total dry matter of the fruit of commercially grown varieties (Winsor, 1966). Ripe fruit contain free sugars in the form of reducing sugars consisting of glucose and fructose in approximately equal amounts, but usually with a preponderance of fructose at late stage of ripeness (de Bruyn *et al.*, 1971; Davies and Hobson, 1981). On equal weight basis fructose is sweeter than glucose.

Hobson and Kilby (1985) and Baldwin *et al.*, (1991) indicated that tomato fruit of normal size contain very little sucrose. Initially, Davies and Kempton (1975) reported that as the fruit develops there is a progressive increase in both glucose and fructose concentration and then they show a dramatic increase during the stage of cell enlargement where the ratio of glucose to fructose decreases rapidly. The pronounce rise in sugar concentration in the fruit coincides with the first appearance of yellow pigment in the walls accompanied by changes occurring in the whole fruit, locular juices and pericarp.

Environmental and production practices greatly influence the sugar concentration of tomato fruits. Davies and Hobson (1981) pointed out that of the known environmental factors affecting the composition of the fruit it is probable light level has the most profound effect on sugar concentration. Thus seasonal trends in sugar levels reflect differences in the intensity and duration of light. Growers have limited opportunity to manipulate the sugar content of the fruit except for morphological modifications to improve light interception and agronomic practices to maintain the vigour of the plants and to increase the rate of photosynthetic production. Since fruits of most typical tomato cultivars contain 95% water the dry matter therefore constitute a very small fraction of the fruit. Ho and Grimbly (1990) estimated that the dry matter of the fruit comprises 8% minerals and the rest consists of carbon products. To increase the proportion of dry matter growers have to restrict the water uptake of the fruit by increasing the osmotic potential of the nutrient base solution and in order to maintain the osmotic

gradient the plants accumulating more solutes in the fruit (Mizrahi, 1982; Hobson, 1988; Adams, 1991).

1.5.5 Organic Acids as a Component of Flavour

Organic acids are one of the major taste components of tomato fruit. The acid content of the fruit is an important characteristics of processing tomatoes. To avoid problems with thermophilic organisms, Stevens (1972) suggested that the acid content of the fruit must be high enough to provide a pH of not less than 4.4. High ph values however necessitate longer processing times increasing the difficulty of obtaining high quality product.

There is a continual change in the acidity of the tomato fruit during development and maturation. The concentration of acids increase during development and reach maximum near incipient colour and then decrease until well beyond maturity (Stevens, 1972). When fruits are still immature malic acid is predominant, whilst citric acid forms only about 25% of the total acidity (Stevens, 1972). Maximum acidity during ripening coincides with the first appearance of pink colour, when malic acid concentration decreases rapidly in locular juices and in the outer fruit walls (Davies and Hobson, 1981). As a result of different rates of change during ripening, malic to citric acid ratio rapidly declines. Thus citric acid makes a greater contribution to sourness than malic because it occurs at a higher concentration (Stevens *et al.*, 1977). Titratable acidity of the outer fruit wall is relatively low compared to that of locular contents.

Should there be any particular change in titratable acidity, it has always been attributed to citric acid alone or to changes in both citric and malic acids.

The relationship between potassium and acidity in tomato fruits is very close and highly significant (Varga and Bruinsma, 1986). Potassium accounts for 85% of the total cations in the fruit (Davies and Hobson 1981). This relationship varies according to the level of the potassium supplied and the growing conditions (Besford and Maw, 1975). At high potassium supply, the acidity increases (Davies and Winsor, 1967) and the colour and shape improves (Winsor *et al.*, 1961). At low potassium supply, the growth period of a tomato fruit is shortened (Besford and Maw, 1975) and the maximum climacteric respiration is enhanced. Mengel and Viro (1974) reported that the potassium concentration affected the metabolism of the fruit.

The form of nitrogen applied influences the acidity of the fruit. With ammonium nitrogen Varga and Bruinsma (1986) observed the fruit to be less acid in composition than with nitrate nitrogen. When high potassium and nitrogen is applied the combined effect is particularly favourable to fruit acidity, while magnesium and calcium have little effect. Calcium when combined with increased potassium lowers the acid content of the fruit.

Tomato fruit is a valuable source of vitamin C. Typical values of Vitamin C vary from 16-25 mg/100 g fresh weight. Extensive literature reported by Hobson and Davies (1981) is no doubt a reflection of its importance to human nutrition and

the contribution that tomato fruit can make. Ascorbic acid content of tomato fruit varies. The wide variation is probably attributable to differences in light conditions during growth. It is not surprising to note that fruits harvested from plants grown outdoor were found to contain more ascorbic acid than fruits grown under glass.

Similar effects of light on ascorbic acid content can be found on fruit positioned in the plant depending on their relative exposure to sunlight. Thus, a rise in ascorbic acid content with ascending truss position was probably due to increasing light intensity.

1.5.6 Aromatic Volatiles

The demise of the tomato like flavour is not only associated with the imbalances between sugars and acid, but also due to the lack of a desirable aroma in ripe fruits. Volatile compounds responsible for the odour of tomatoes are present in a relatively small amounts. The odour of freshly picked tomatoes comes from the calyx, sepals and in the stalk rather from the fruit *per se*. The skin of tomato fruits has no pores or lenticels so that volatile compounds cannot escape. It is only by means of cutting the fruit that we can smell the aromatic compounds. There have been extensive studies conducted to identify the volatile compounds of fresh tomatoes, but inspite of these trials the actual quantitative concentrations has not been reported. Hobson (1988) reported that there are 400 substances that make up the odour of tomatoes, but not even one of them has a smell

reminiscent of a ripe tomato. The flavour of tomatoes is a combination of aroma and the taste components modified by the texture of the tissues and its juiciness. Buttery *et al.*, (1988) showed that the pulp and skin had the highest concentration of the volatile aroma compounds and no significant contribution related to the seeds.

1.5.7 Appearance as a Quality Attribute of Tomato

The quality of tomato fruits is determined among other factors by their size and shape (Favarro and Pillatti, 1987). Size and shape are quality attributes important in marketing tomatoes because it is the first attribute perceived by consumers. Size and shape is standard criterion for grading and packaging. Bangerth and Ho (1984), reported that fruits within the same truss generally differ in their final size, thus, larger fruits develop at the proximal end compared with the distal fruits. The differential growth based on their position in the truss is not entirely due to competition, because if the number of fruits is reduced, the remaining distal fruits still remain smaller. Bangerth and Ho (1984), demonstrated that the final size of the fruit can be manipulated by the induction sequence in the truss, that is by inducing the growth of the fruit in the distal end of the truss ahead of the proximal fruits, a much larger fruit can be produced. As discussed previously, ovule number influence fruit size therefore a large many seeded fruit is likely to originate from an ovary containing many ovules.

According to Mizrahi *et al.* (1988), saline treated plants produce small sized fruits

as they contain less water and more soluble solids.

Colour which depends primarily on the content of total carotenoids and ratio of lycopene to carotene is another quality attribute of tomato fruit. Most consumers prefer deep uniform red coloured tomatoes as a basis for selection. At the ripening stage, temperature has a great influence on the rate and extent of colour change. Lower than normal temperatures lead to an increase in beta-carotene and decrease in lycopene. When tomato fruits are exposed to temperatures between 30-40^{0}C they remain yellow rather than red (Davies and Hobson ,1981). Different morphological regions of tomato fruit vary in chemical composition. Total carotenoids are found to be highest in the outer pericarp whereas carotene is highest in locular region. Mizrahi *et al.*, (1988) observed that fruits from salinized plants were redder in colour than the normal fruits. The effect was intensified as the conductivity of the nutrient solution was increased. Increasing the concentration of potassium in the solution has been found by Dangler and Locasio (1990), to reduce the severity of blotchy ripening.

1.5.8 Firmness and Shelf Life of the Tomato Fruit

Firmness is a quality factor that determines the shelf life of the fruit. Firm fruited cultivars show a great advantage hence fruits can be allowed to ripen on the vine until almost 100% of the fruits is ripe. This practice according to Stevens (1980) can increase the viscosity of the fruit which provides tomato products with increased consistency. Changes in fruit firmness are due to the activity of

softening enzymes. Since firm fruits have reduced amount of locular tissues, they exhibited lower rates of respiration and ethylene production during ripening. One disadvantage of firm fruited cultivars is that they contain less acid thereby lowering their acid to sugar ratio Stevens (1977). Firmness of the fruit show variations along the morphological regions of the fruit. Adegoroye *et al.*, (1989) showed that there is a progressive decrease in deformation from stylar end of the fruit to the calyx, whilst the shoulder part of the fruit is found to be the weakest point. Both epicarp strength, locular resistance and firmness decrease, while deformation and compliance increase with ripeness. Mizrahi (1988) reported a contrasting effect of salinity on the shelf life of tomato. It was observed that saline treated plants produce fruits that are slightly firmer, but deteriorated somewhat faster than the normal fruits in contrast with their other observations showing that the shelf life of the fruit was extended due to a reduce amount of water in the fruit.

CHAPTER 2

THE EFFECTS OF HIGH CONDUCTIVITY LIQUID FEEDS ON THE YIELD AND QUALITY OF OUTDOOR GROWN TOMATOES

2.1 Introduction

High yielding good quality outdoor tomato crops are traditionally grown on fences in the Otaki district of New Zealand. Crops are harvested from summer through to late autumn and are irrigated by using overhead sprinklers. Nutrients are applied as a base dressing along with a number of side dressings.

Trickle or drip irrigation has been used for some time with vegetable crops in Israel and is under investigation in the USA with an extensive range of crops (Hochmuth, 1992). It has not been used to any extent with outdoor vegetable crops in New Zealand.

Research with greenhouse tomatoes has shown that fruit flavour can be improved by the use of high conductivity feeds. The effect of these treatments has been to increase the concentration of sugars and acids in the fruit (Anon, 1992). In Israel, Pasternak *et al.* (1986) have shown that total soluble solids of trickle irrigated tomatoes was increased by the use of saline water, while Cornish and Nguyen (1989) in Australia have shown that high soil electrical conductivity was found to increase total soluble solids comparable to that of hydroponic systems reported by Hobson (1988).

The following study was designed to use trickle irrigation to apply high conductivity feeds to fenced tomatoes to determine the effects of such treatments on fruit yield and quality.

2.2 Materials and Methods

2.2.1 Plant Propagation and Transplanting

On 21 October 1991, seeds of the tomato cultivar ***Extase*** were sown in cell trays at one seed per cell and placed on a heated bench (24^{0}C). The trays held 54 plants and 85 mls of growing media per cell. A 50 : 50 peat sand media was used (Appendix 1). At emergence the seedlings were removed from the heated bench and grown on in a greenhouse with a minimum temperature of 16^{0}C and ventilation at 22^{0}C.

Thirty days after germination, and thereafter twice a week until the plants were ready for planting, the seedlings were fed using a stock solution containing 100 ppm N, 34 ppm P and 100 ppm K. On 27 November, one week before transplanting, the seedlings were moved out of the glasshouse and hardened off outside.

2.2.2 Land Preparation

The experiment was conducted during summer of 1991 on Karapoti Sandy Loam soil at the Plant Growth Unit at Massey University. The experimental block was sheltered and the land was ploughed, rotovated and levelled to prepare a planting out tilth to a depth 20 cm. One hundred and fifty soil samples from the top 15 cm were collected at random from the 225 m^2 experimental area using a soil core borer and a sub-sample was submitted to the MAF Laboratory for analysis. Ten fences, 1.5 m apart and 15 m long were then erected based on the system used in the Otaki district. (Appendix 2). The post were 2 m above the ground and were placed 3.75 m apart in a row.

2.2.3 Base Fertilizer Application and Transplanting

The result of the MAF soil test and target values based on the recommendation of Clarke *et al.* (1986) are presented in Table 1. As the soil test data were satisfactory, a base maintenance dressing of Nitrophoska fertilizer (12-10-10) was applied at a rate of 500 kg per hectare before transplanting. The fertilizer was applied in band 20 cm. on either side of the row and push hoed into the soil.

Table 1. MAF soil test results and target levels.

	pH	Ca	P	K	Mg	Na
Soil Test	6.1	12	41	11	27	7
Target Values	5.3-6.7	10	33-45	13	15	-

On 3 December 1991, forty days after germination,the plants were transplanted and watered in while the guard plants were planted a day later. The plants were in rows 1.5 cm. apart and 60 cm. apart in the row.

2.2.4 Treatments and Experimental Design

There were four treatments, control and three conductivity treatments. The control treatment receive no further nutrients and was watered as required. The three conductivity treatments were 2, 4 and 6 mS cm^{-1}. These treatments were applied from 31 December and were based on a standard nitrogen-potassium greenhouse liquid feed (Table 2) .

A randomized complete block design was used. A block consisted of 2 rows of plants with 2 plots per row (Appendix 3). The experimental plot was 7.2 m long

and contained ten plants with 2 guard plants at the end of each row and between adjacent plots. There were two guard rows at each side of the planting.

2.2.5 Trickle Irrigation System

The trickle irrigation system used in this experiment was connected to the Palmerston North City Corporation Water Supply. A valve and pressure gauge on the main line controlled the delivery to the system. The main line was split into 4 submains to deliver the four treatments (Appendix 3). Inline diluters (Dosatron 1501) were connected to the 3 submains to supply the conductivity treatments and the fourth sub-main supplied water to the control treatment. The four sub-mains were laid across the centre of the experimental block.

In each replicate lateral pipes were connected to the sub-mains according to treatment. Typhoon 25 dripper-line with a water inlet 60 cm apart were used for the conductivity treatments, while pvc pipe with microsprinklers was used for the control plants. The microsprinklers were spaced 1.2 m apart.

Each microsprinkler was set to water 2 plants, one on each side. The four lateral pipes were fixed in place by tying them to wires attached to the posts. The layout of the diluters, nutrient tanks, submains and lateral pipes is detailed in Appendix 3.

2.2.6 Preparation of Liquid Feed

The three conductivity treatments used provided conductivities of 2, 4, and 6 mS cm^{-1}. The liquid feeds for these treatments were based on a standard greenhouse stock solution (Table 2). A series of test dilutions were prepared using the above stock solution to determine the right amount of the fertilizer required to be dissolved to provide conductivities of 2, 4 and 6 mS cm^{-1}.

Figure 1 presents the relationship between the dilution rate and conductivity derived from the test solution prepared.

Table 2. Standard greenhouse tomato stock solution and resulting liquid feed (Clarke *et al.*,1986).

Fertilizer	Composition (grams $litre^{-1}$)	Dilution 1:200			
		N (ppm)	K (ppm)	Mg (ppm)	S (ppm)
Potassium Nitrate	150	105	285	0	0
Urea	30	57.5	0	0	0
Magnessium Sulphate	50	0	0	60.75	80

The dilutions of the standard stock solution (Table 2) that provided the desired conductivities were read off the graph (Figure 1) and then used to determine the stock solutions that when diluted 1:100 would produce the three treatment conductivities (Table 3).

Figure 1. Relationship between dilution rate and conductivity of liquid feed.

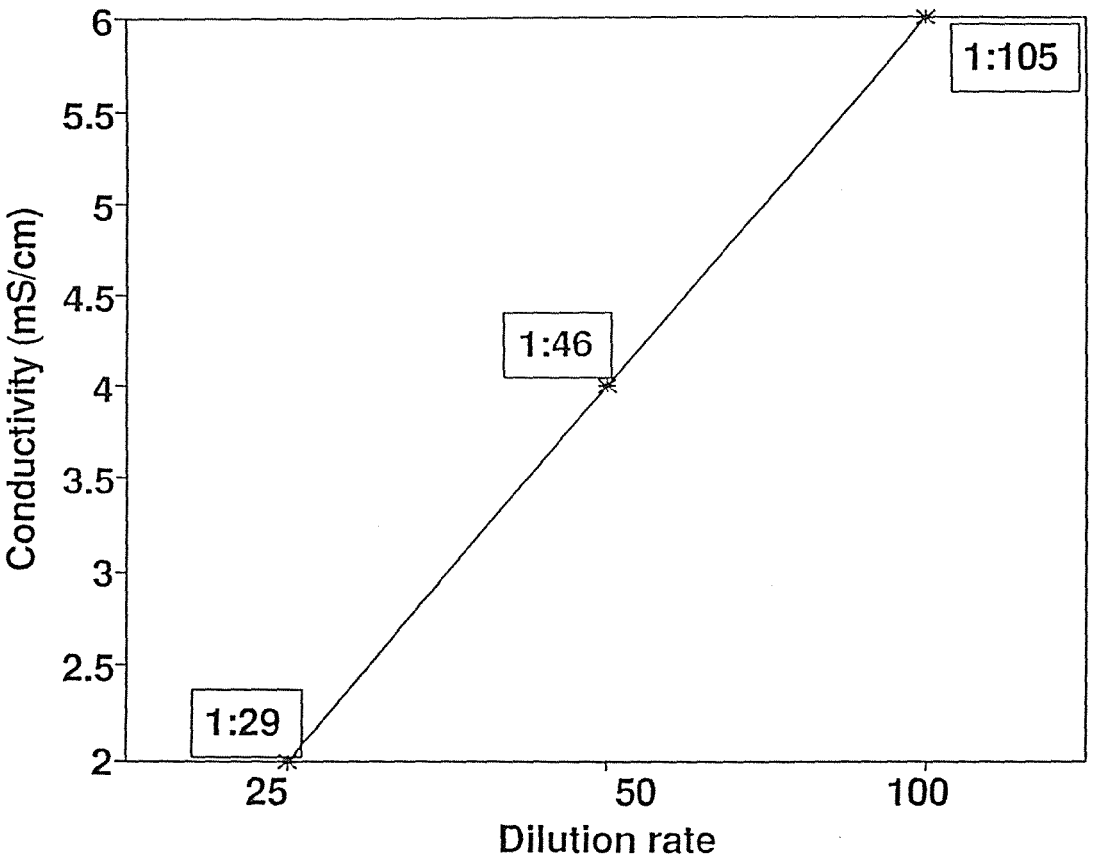


Table 3. Determination of stock solution (1:100) dilution required for three conductivity treatments.

Treatment (mS cm^{-1})	Dilution required (read off from graph)	Potassium Nitrate	Urea	Magnesium Sulphate
		Amount required grams $litre^{-1}$ (Dilution 1:100)		
2	1:105	142.85	28.60	47.20
4	1:46	326.10	65.22	108.70
6	1:29	517.50	103.50	172.50

Stock solution were then prepared which when diluted 1:100 provided the treatment solutions detailed in Table 3. Since the weight of potassium nitrate required to provide the 6 mS cm^{-1} treatment exceeds its solubility two stock solutions each capable of supplying 3 mS cm^{-1} were used .

2.2.7 Irrigation Schedule

Irrigation requirement of the plants was calculated based on a crop factor, area per plant and potential evapo-transpiration. Assuming that the area per plant is 50% of the true area, each plant occupied 0.45 m^2. The crop factor for greenhouse tomatoes of this size is 1.2 (White, 1989). Thus for every millimetre of evapotranspiration, 0.54 litres of water is required by each plant. As the average potential evapotranspiration is 4mm day^{-1}, each plant will require 2.16 litres of water daily. The water requirements for control plants was based on soil moisture deficit. If the estimated soil moisture deficit did not exceed 28 mm per week no irrigation was applied to the control plants.

Information regarding soil moisture deficit were taken from rainfall data from DSIR, Grasslands Division and potential evapo-transpiration (4 mm day^{-1}). Based on this information, there were only four occasions from January to April when the soil moisture deficit exceeded 28 mm. However control plants were irrigated only twice as on two of the occasions that the deficits exceeded 28 mm there was heavy rain before the irrigation could be applied (Appendix 4). Water was applied for two hours on the two occasions irrigation was supplied.

2.2.8 Conductivity Treatments

The conductivity treatments were applied from 31 December 1991. At this stage setting in the first truss had commenced on 50 % of the plants. The conductivity treatments were irrigated every 2 days thereafter for a duration of two hours. This applied 3.6 L of liquid feed per day. The conductivity of the treatment solutions was monitored after irrigation at different locations using a CF meter.

2.2.9 Plant Training and Protection

The Otaki system of training and supporting tomato plants was used. This was done by erecting 4 posts (15 cm in diameter and 2.5 m long) in a row set 3.75 m apart to a depth of 60 cm. End row posts were angled to take the strain once the wire supports were stretched the length of the rows. The rows were 15 meters long.

A pair of wire was attached to the posts at 30 cm intervals from the ground. Plants were trained between pairs of wires which were laid out as the plants required support. Plants were trained to two stems. The second or lateral stem was produced from the axil of the leaf immediately below the first inflorescence. The first pair of wires was attached 25 days after planting. The two stems were delateraled at regular interval and the plants were stopped by removing the top of the plants with a knife at two meters.

A push hoe was used once every two weeks to control weeds. A regular weekly spray programme was carried out for disease and pest control. Details are presented in Appendix 5. This programme was repeated every three weeks.

2.2.10 Harvesting and Grading

To provide details and information about the position on the plant were the fruits were harvested, each truss was labelled using different colour tags according to their position on the individual stems. Fruits were harvested once they reached a red orange colour. There were two harvests per week for the first two weeks and three harvests per week thereafter. Harvesting commenced on March 9 with the final harvest on May 1, 1992.

Fruits were harvested on an individual truss basis for each treatment. Each fruit was weighed individually and graded according to size (diameter) with reject fruits being allocated to 5 classes .

Fruit sizes were classified using the grading chart recommended and issued by New Zealand Fresh Tomato Industry (Plate 1). Fruit were therefore graded to the following diameters; 70+, 60-70, 50-60, 40-50, 40 mm and below. These sizes were coded as grades 1-5. For fruits to be considered marketable they were free from physical damage and uniform in shape and colour. Rejected fruits were indexed as cracked, rough, blossom end rot, blotchy and diseased.

Fruit weights were determined by weighing the fruit individually using a Mettler scale, interfacing with a laptop computer and printer to record the weight along with the information on fruit size and grade (Plate 2). Total yield was computed as combined weights of marketable and rejected fruit. This however did not include the fruits that abcissed from the trusses before they were ripe and those that were damage by birds, as it was difficult to identify where on the plant such fruit originated.

2.2.11 Assessment of Fruit Quality

Ten sample fruits were chosen at random from the fruit harvested from each treatment plot once a week for six consecutive weekly harvests starting from March 19, 1992. Sample fruits were of the same size and maturity with diameters ranging from 50-60 mm. Since the fruits were harvested when orange red, they were ripened at ambient room temperatures until the red ripe stage was reached before quality assessments were made. All quality assessments were carried out on the same day.

2.2.11.1 Fruit Firmness

Firmness of sample fruits were measured by using a penetrometer. Measurements were taken from the equatorial surface of the fruit, one opposite the other. The force required to break the fruit tissue was measured in newtons.

2.2.11.2 Reducing Sugars

After the firmness test, fruit samples were cut into pieces and homogenized in a Waring commercial blender shifting from low to high speeds over two minutes. Ten grams of the homogenate, three samples from each treatment per block, were placed in test tubes and centrifuged in a Clemens GS 200 Centrifuge for five minutes at 300 rpm. An aliquot was pippetted to determine the concentration of reducing sugars using a refractometer.

2.2.11.3 Titratable Acids

Titratable acidity was measured by adding 1.0 gram of homogenate to 40 ml of distilled water. Three samples were taken from each treatment per block. The solutions were titrated with 0.1N NaOH using a Mettler DL21 titrator standardized by using buffer solutions with pH 4 and 7. Acidity of the homogenate was expressed as percent citric acid (Appendix 6).

2.2.11.4 Total Solids

Total solids of the sample fruit was determined by weighing 50 grams of the homogenate. Three samples from each treatment per block were dried in a Watvic oven at 80^{0}C until constant (48 hours). Total solids was determined from the ratio of fresh and dry weights expressed as a percentage.

2.2.12 Leaf Analysis

Young mature leaves were taken from experimental plants 30 and 55 days after transplanting. Leaf samples were placed in labelled bags and oven dried for 24 hours at 75^{0}C. Ground samples were submitted to the Department of Soil Science for mineral analysis.

2.2.13 Soil Conductivity and Percent Soluble Salts

Soil samples were taken after the final harvest at the dripper and at sites 15 and 30 cm from the dripper at soil depths of 5 and 10 cm. These samples were taken from each of the 4 treatments in each block. Each sample consisted of 10 individual cores, which were air dried, ground and thoroughly mixed. A 10 gram of sub-sample was taken from each bulk sample of soil and placed in a 100 ml beaker containing 50 ml deionized water and shaken for 1 hour. The solution was allowed to clarify before conductivity was determined. The conductivity was measured by using Jenway 4010 conductivity meter set to a range of 20 mS

cm^{-1}. The procedures used in determining conductivity of the soil solution and soluble salts was based on the recommendation of Conforth (1980). Percent soluble salts were determined as this expression is widely used to describe salinity levels in soils growing greenhouse tomatoes.

2.2.14 Statistical Analysis

Data was analyzed by using ANOVA and the MSTAT-C Statistical package.

2.3 RESULTS

2.3.1 Nutrient content of the Leaves

The content on a % dry matter basis of the major nutrients 30 days after planting is presented in Table 4. Nitrogen, potassium and magnesium were supplied in the liquid feed. Nitrogen content increased over the range control to 4 mS cm^{-1} and potassium content increased with each increase in conductivity. There was no effect of treatment on the phosphorus and magnesium content of the leaves, while the calcium content fell with each increase in conductivity.

Table 4 . Nutrient analysis of the youngest mature leaf 30 days after planting.

Treatments	Elements (% dry matter basis)				
	N	P	K	Ca	Mg
Control	3.012	0.324	3.291	2.730	0.388
2 mS cm^{-1}	3.278	0.350	3.990	2.313	0.441
4 mS cm^{-1}	3.483	0.303	4.160	1.988	0.381
6 mS cm^{-1}	3.485	0.322	4.315	1.722	0.386
Significance	$p<0.05$	ns	$p<0.01$	$p<0.01$	ns
S.E (9 D.F)	0.150	0.031	0.184	0.236	0.032

The content on a % dry matter basis of the major nutrients 55 days after transplanting is presented in Table 5. At this stage fruits had been harvested for 2 weeks. Nitrogen and potassium content of the leaves increased over the range of control to 4 mS cm^{-1}.

The phosphorus content of the 4 mS cm^{-1} treatment was higher than any other treatment, while again the calcium content fell with increasing conductivity. There were no treatment effects on magnesium content of the leaves.

Nitrogen, phosphorus, calcium and magnesium content of the leaves fell over the time period 30 - 55 days (Table 4 and 5), whereas no changes were apparent in potassium content.

Table 5. Nutrient analysis of the youngest mature leaf 55 days after planting.

Treatments	Elements (% dry matter basis)				
	N	P	K	Ca	Mg
Control	2.472	0.123	3.318	2.400	0.155
2 mS cm^{-1}	2.520	0.118	3.650	1.825	0.178
4 mS cm^{-1}	2.870	0.146	3.933	1.715	0.174
6 mS cm^{-1}	2.735	0.127	3.937	1.475	0.140
Significance	$p<0.01$	$p<0.05$	$p<0.01$	$p<0.01$	ns
S.E (9 D.F)	0.032	0.008	0.15	0.207	0.022

2.3.2 Soil Conductivity and Percent Soluble Salts

The conductivity of the soil solution based on a 1:5 soil water extract and the percent soluble salts are presented in Tables 6 and 7 respectively. In all cases, except the samples taken at 5 cm depth 30 cm from the dripper, the conductivity of the soil solution increased as the concentration of the liquid feeds increased.

The trend was for the conductivity of the soil solution, at particular sampling depth, to fall the further the sample was taken from the dripper. No trend was apparent with respect to depth of sampling. As the percent soluble salts were determined by multiplying the appropriate conductivity by a constant value (0.3) identical conclusions were reached with respect to the treatments and site of sampling and soluble salts as were reached with the conductivity of the soil solution

Table 6. Percent of soluble salts.

Treatment	5 cm Depth			10 cm Depth		
	Dripper	15 cm from Dripper	30 cm from Dripper	Dripper	15 cm from Dripper	30 cm from Dripper
Control	0.062	0.051	0.049	0.060	0.047	0.043
2 mS cm^{-1}	0.092	0.057	0.049	0.082	0.055	0.052
4 mS cm^{-1}	0.135	0.062	0.063	0.141	0.066	0.056
6 mS cm^{-1}	0.208	0.070	0.059	0.203	0.110	0.069
Significance	p<0.01	p<0.01	ns	p<0.01	p<0.01	p<0.01
S.E (9 D.F)	0.011	0.003	0.001	0.011	0.010	0.004

Table 7. Conductivity of soil solution (mS cm^{-1}).

Treatment	5 cm Depth			10 cm depth		
	Dripper	15 cm from dripper	30 cm from dripper	Dripper	15 cm from dripper	30 cm from dripper
Control	0.207	0.170	0.165	0.200	0.155	0.143
2 mS cm^{-1}	0.307	0.190	0.162	0.273	0.183	0.172
4 mS cm^{-1}	0.450	0.205	0.210	0.470	0.220	0.185
6 mS cm^{-1}	0.693	0.232	0.197	0.675	0.367	0.230
Significance	$p<0.01$	$p<0.01$	ns	$p<0.01$	$p<0.01$	$p<0.01$
S.E (DF 9)	0.037	0.010	0.021	0.038	0.034	0.014

2.3.3 Fruit Quality Characteristics

The effects of the high conductivity liquid feeds on fruit quality characteristics are presented in Table 8, while the change in these characteristics that occurred over the 6 week period that samples were taken is presented in Table 9.

Table 8. Fruit quality attributes in response to treatments.

Treatment	Quality Attributes			
	Acidity (% Citric Acid)	Total Solids (%)	Fruit Firmness (Newtons)	Total Soluble Solids (°BRIX)
Control	0.59	4.88	13.83	4.14
2 mS cm^{-1}	0.65	5.14	13.54	4.41
4 mS cm^{-1}	0.66	5.08	13.24	4.47
6 mS cm^{-1}	0.68	5.23	13.24	4.73
Significance	$p>0.01$	$p<0.05$	ns	$p<0.01$
S.E (9 D.F)	0.05	0.23	0.086	0.116

Table 9. Quality attributes of tomato fruit during harvest.

Harvest	Quality			
	Acidity (% Citric Acid)	Total Solids (%)	Firmness (Newtons)	Total Soluble Solids (^{0}Brix)
1	0.68	4.89	17.56	4.98
2	0.01	4.89	12.65	4.65
3	0.73	5.04	13.93	4.51
4	0.49	5.04	12.46	4.40
5	0.48	5.36	12.26	4.49
6	0.48	5.26	11.87	3.89
Significance	$p<0.01$	$p<0.01$	$p<0.01$	$p<0.01$
S.E (9 D.F)	0.14	0.17	0.09	0.15

The titratable acidity of the fruit was increased by the high conductivity liquid feeds above that of the control plants, but there were no differences between the conductivity treatments (Table 8). Titratable acidity decreased over time (Table 9 and Figure 2), apart from a peak at harvest 2 to level off at harvest 4. The peak at harvest 2 may have been due to a titration error.

The trend was for total solids (%) of the fruit to increase with increasing conductivity (Table 8), while with time total solids increased to harvest 5 and then fell (Table 9 and Figure 3).

There was an interaction between conductivity and time with respect to fruit firmness (Figure 4). Fruit firmness was high at harvest 1 for all treatments except for the 4mS cm^{-1} treatment and then firmness fell markedly at harvest 2 to remain fairly steady at this level for all treatments.

Total soluble solids (^{0}Brix) of the fruit increased with each increase in conductivity (Table 8). Over time the trend was for soluble solids to fall slightly up to harvest 5 with a marked decline occurring at harvest 6 (Table 9 and Figure 5).

Figure 2. Effect of salinity on titratable acids during harvest.

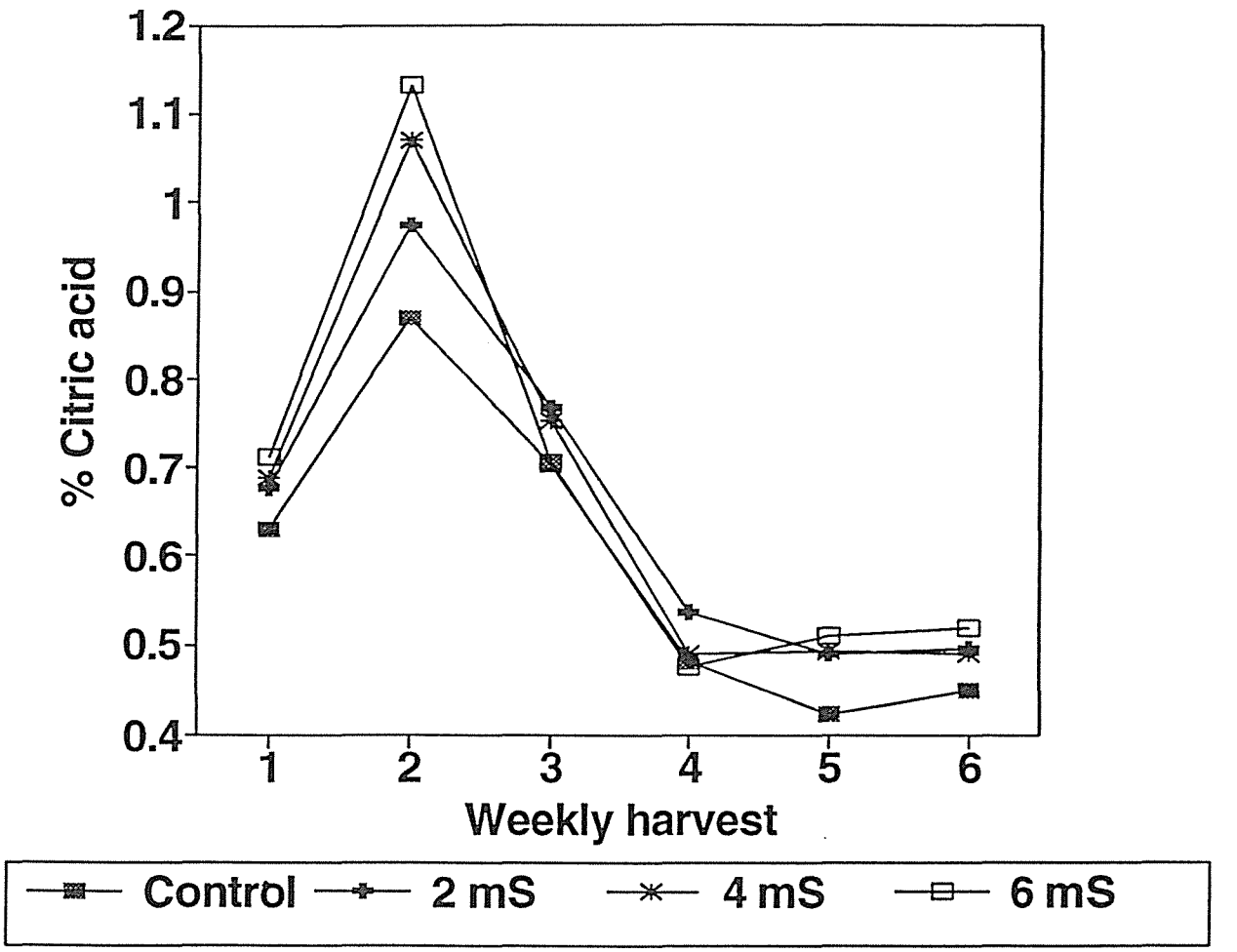


Figure 3. Effect of salinity on accumulated total solids by weekly harvest.

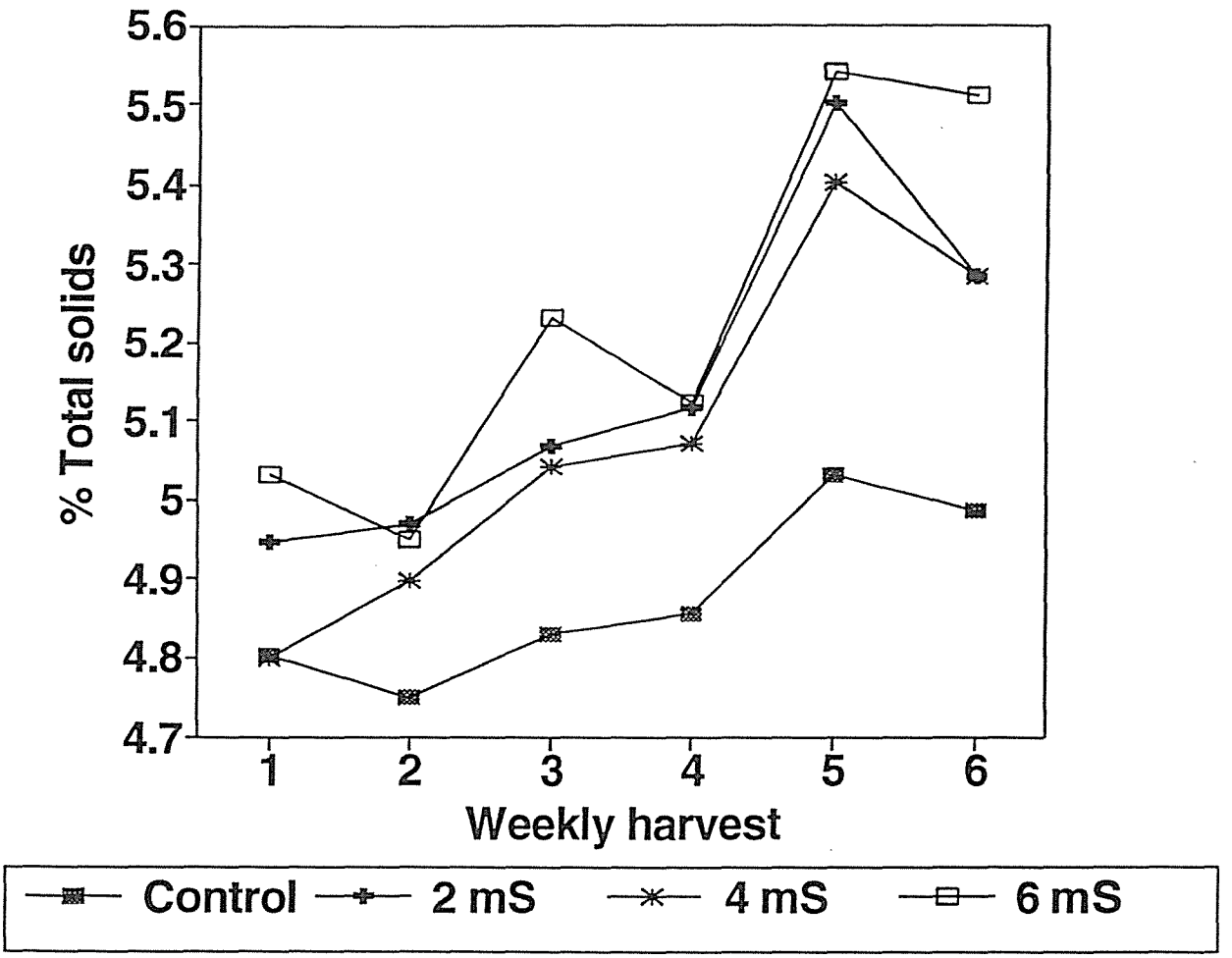


Figure 4. Effect of salinity on fruit firmness by weekly harvest.

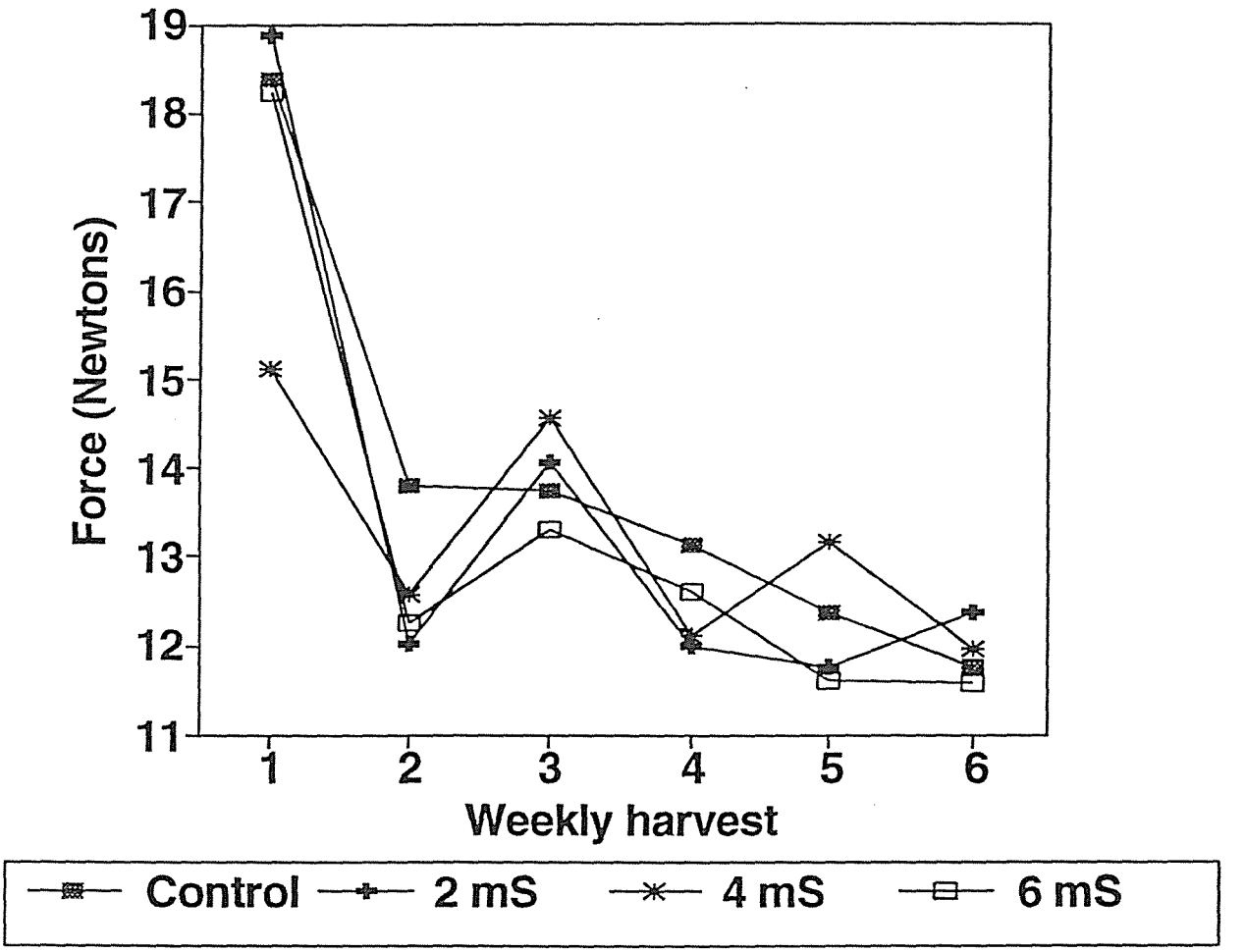
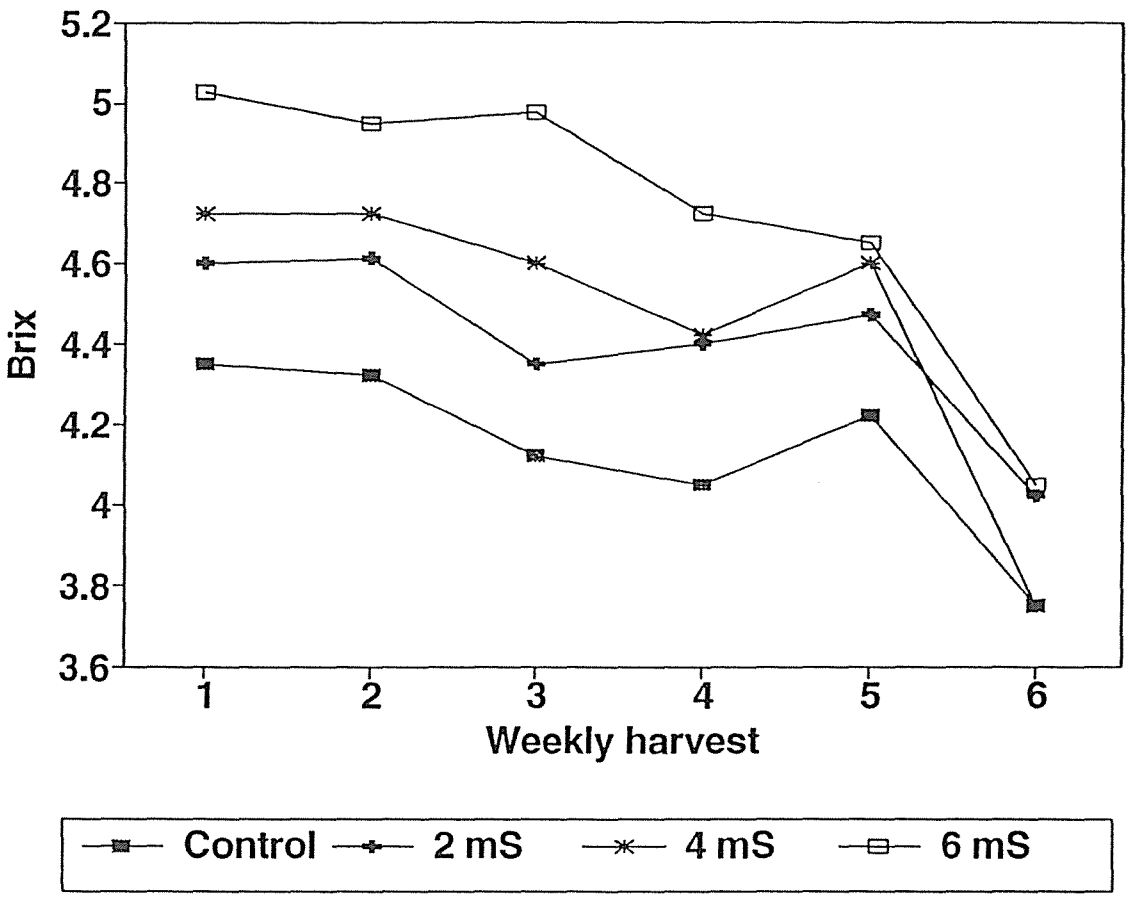


Figure 5. Effect of salinity on the percentage of total soluble solids by weekly harvest.



2.3.4 Total Number and Yield of Fruit

There were 18 harvests where fruit was harvested at a commercial acceptable stage of maturity. There was no significant difference in the total number and total yield of fruit per plant for these harvests (Table 10).

Table 10 . Total fruit number and weight of fruit per plant (Harvest 1-18).

Treatment	Fruit number	Fruit weight (kg)
Control	61.85	7.03
2 mS cm^{-1}	64.25	7.14
4 mS cm^{-1}	64.65	7.21
6 mS cm^{-1}	60.87	6.54
Significance	ns	ns
S.E (9 D.F)	3.72	0.348

The tomato plants in this study supported on average 13 fruit trusses per plant at the time of the final harvest. After the final commercial harvest, harvest 19 was made of all the remaining fruit on the plant. This did not include fruit which had fallen from the plant due to disease or bird damage. The fruit number per plant (harvest 1-19) is presented in Table 11. The 4 mS cm^{-1} treatment had the greatest number of fruit.

Table 11. Fruit number per plant (Harvest 1-19).

Treatments	Fruit number
Control	77.78
2 mS cm^{-1}	76.82
4 mS cm^{-1}	90.48
6 mS cm^{-1}	82.32
Significance	$p<0.05$
S.E (9 D.F)	3.90

The data is not shown, but with both harvests 1-18 and harvest 19 approximately 65% of the fruit were carried on the main stem.

2.3.5 Marketable Fruit

2.3.5.1 Number and Yield of Marketable Fruit

Marketable fruit were those remaining after the reject fruit had been graded out. There were no significant differences in marketable fruit number or yield per plant (Table 12).

Table 12. Marketable number and weight of fruit per plant.

Treatment	Fruit number	Fruit weight (kg)
Control	48.10	5.44
2 mS cm^{-1}	53.50	5.82
4 mS cm^{-1}	56.85	6.23
6 mS cm^{-1}	48.95	5.15
Significance	ns	ns
S.E (9 D.F)	3.79	0.34

2.3.5.2 Distribution of Number and Yield of Marketable Fruit

The distribution of where on the plant the marketable fruit (number and weight) was harvested on a truss-stem basis is presented in Tables 13,14,15 and 16. On the main stem treatment 4 mS cm^{-1} had a higher number (Table 13) and yield (Table 15) of fruit in truss 3 than the other treatments. There were no differences in number or yield of marketable fruit per truss on the lateral stem (Tables 14 and 16 respectively).

Table 13. Number of marketable fruit on the main stem per plant.

Treatment	Truss number					
	1	2	3	4	5	6
Control	10.42	9.60	6.50	4.18	1.60	0.10
2 mS cm^{-1}	12.85	9.80	7.98	4.68	1.50	0.10
4 mS cm^{-1}	10.05	11.48	9.15	5.15	2.18	0.20
6 mS cm^{-1}	10.20	9.40	6.20	4.32	1.70	0.20
Significance	ns	ns	$p<0.01$	ns	ns	ns
S.E (9 D.F)	1.30	1.44	0.70	0.82	0.47	0.14

Table 14. Number of marketable fruit on the lateral stem per plant

Treatment	Truss number			
	1	2	3	4
Control	7.02	5.72	2.58	0.38
2 mS cm^{-1}	8.12	5.72	2.48	0.28
4 mS cm^{-1}	9.18	6.18	2.95	0.35
6 mS cm^{-1}	8.05	5.98	2.32	0.62
Significance	ns	ns	ns	ns
S.E. (9 D.F)	0.78	0.68	0.30	0.31

Table 15. Weight of marketable fruit on the main stem (kg per plant).

Treatment	Truss number					
	1	2	3	4	5	6
Control	1.216	1.134	0.719	0.440	0.139	0.006
2 mS cm^{-1}	1.419	1.159	0.842	0.474	0.130	0.005
4 mS cm^{-1}	1.095	1.323	1.043	0.526	0.207	0.016
6 mS cm^{-1}	1.141	1.039	0.667	0.409	0.145	0.009
Significance	ns	ns	$p<0.01$	ns	ns	ns
S.E (9 D.F)	0.139	0.153	0.055	0.074	0.039	0.001

Table 16. Weight of marketable of fruit on the lateral stem (kg per plant).

Treatment	Truss number			
	1	2	3	4
Control	0.825	0.678	0.249	0.032
2 mS cm^{-1}	0.919	0.610	0.237	0.023
4 mS cm^{-1}	1.039	0.657	0.288	0.033
6 mS cm^{-1}	0.865	0.618	0.207	0.057
Significance	ns	ns	ns	ns
S.E (9 D.F)	0.077	0.045	0.032	0.022

2.3.5.3 Size of Marketable Fruit

Marketable fruit were size graded according to the diameter of the fruit (mm) based on the recommendations of the New Zealand Fresh Tomato Industry. The number of fruit per plant in each size grade for various treatments is presented in Table 17. The only significant differences was with the 60-70 mm size grade where the 6 mS cm^{-1} and the smallest and the 4 ms cm^{-1} had the largest sized fruit. There was a trend however for the control treatment to have high numbers of the fruit in the largest size grades and low numbers of fruit in the other size grades and the reverse was apparent with the 6 ms cm^{-1} treatment.

Table 17. Size of Marketable fruit (New Zealand Fresh Tomato Industry).

Treatment	Size (mm)				
	Number of fruit per plant				
	70+	60-70	50-60	40-50	40 and below
Control	1.92	23.30	16.45	6.25	0.68
2 mS cm^{-1}	1.68	23.12	19.30	8.25	1.15
4 mS cm^{-1}	1.52	26.85	19.88	7.48	1.15
6 mS cm^{-1}	0.65	20.82	19.10	7.38	0.95
Significance	ns	$p<0.01$	ns	ns	ns
S.E (9 D.F)	0.47	1.32	2.01	1.48	0.33

2.3.5.4 Reject Fruit

There was no difference between treatments with respect to the number or yield of reject fruit. Data on the number and yield per plant of reject fruit according to 4 classes of reject is presented in Table 18. This data is presented on a per stem basis with the data average across all treatments.

The main stem carried the most of the rejects, but it also carried most of the fruit. Cracking of fruit was the main cause of rejecting fruit, while the incidence of blossom end rot was low.

Table 18. Number and weight (kg) of reject fruit per plant.

Stem	Cracked fruit		Diseased fruit		Rough fruit		Blossom end rot	
	No.	Wt.	No.	Wt.	No.	Wt.	No.	Wt.
Main	5.17	0.62	1.18	0.11	0.73	0.68	0.82	0.01
Lateral	2.64	0.36	0.63	0.16	0.26	0.02	-	-

2.4 DISCUSSION

2.4.1 Nutrient Content of the Leaves

2.4.1.1 Nitrogen

With trickle irrigation, applied water and the fertilizer components are confined to a small volume of soil just below the dripper. This enhanced the development of a profuse root system in the wetted volume of soil (Plate 3). The extensive development of the feeder roots observed in this study confirms the observation of Cook and Sanders (1991). From the studies conducted by Kirkby and Mengel (1967), tomato plants receiving NO_3-N in precise amounts develop an extremely large root system. Determining the effects of NO_3-N is beyond the scope of this study, it is possible however that NO_3-N enhanced the formation of the root system. The development of this kind of root system improves the recovery of the fertilizer elements like nitrate and potassium which do not react with the soil exchange sites (Bar-Yosef and Sheikholslami, 1976). If too much water has been applied into the soil in the form of rainfall or surface irrigation, then fertilizer elements which do not react with soil exchange sites are likely to be leached below the root zone (Goldberg *et al.*,1971). Such situations result in the inability of the surface root to absorb sufficient nutrients (Rolston *et al.*, 1986).

At both sampling dates (Tables 4 and 5) the nitrogen content increased with the increased amounts of nitrogen applied in the liquid feeds up to a conductivity of 4 mS cm^{-1}. The lack of any further response to nitrogen may have been due to the nitrogen concentration being close to the optimum level at 4 mS cm^{-1} for this particular management system. Maynard (1991) suggested that leaf nitrogen range of 2.50 to 3.00% is a sufficient level for the normal growth of tomato plants. The nitrogen content of the leaves at the first sampling date was more than adequate. Results from studies conducted by Mason and Wilcox (1982), indicates that the capacity of tomato plants to accumulate and store nitrogen during their development stage is in fact of great importance when tomato plant is at the fruiting stage as nitrogen is transported from the leaves and stems to meet the nitrogen needs of the developing fruit. The nitrogen content during the fruiting stage was also adequate. Distinctive changes observed during this stage was the colour of the leaves. Tomato plants that were fed with a concentration of 6 mS cm^{-1} had leaves of darker green colour compared to the other treatments. This was probably due to the N and or K content of the leaves.

In this experiment the possibility of dilution of the liquid feed by rain, may have brought about alterations in the conductivity levels of the liquid feed in the soil and the likelihood of fertilizer being leached. According to Papadopoulos *et al.*, (1985), nitrogen uptake was three times greater from the compartment with the lowest salinity level. Presumably in the present investigation nitrogen was absorbed by the roots from areas in the trickle core of lower salinity. It can be assumed that due to the frequency of irrigation nitrogen concentration will be high

near the dripper point and uptake will be determined by the uptake rate of roots and leaching. Digging out sample roots from each treatment in this experiment showed that dense root growth was only found in the vicinity of the nozzle and farther away from this point root growth become sparse. Our observation in this study was in agreement with the observation of Goldberg *et al.* (1971) who found that 76 % of the total root mass was located in the upper 10 cm of the soil with the major part being in the 3 cm to 10 cm layer.

2.4.1.2 Phosphorous

Apart from the high level of phosphorus in the leaves at 4 mS cm^{-1} at the second sampling, there were no significant differences in phosphorus level (Tables 4 and 5). No explanation can be offered for this difference. As phosphorus was not applied in the liquid feed and it has not been reported as being reduced in plant tissue with the applications of high rates of other nutrients it is perhaps not surprising that there was no other effects of the treatments on phosphorus content of the leaves. Phosphorus content fell with time to a level below the range required for optimum growth. Optimum level of phosphorous range from 0.4-0.7% (Brice 1978).

Tomato plants generally need phosphorous early in its growth (Brice, 1978; Adams, 1986). Thus any increase in phosphorous increases the fresh weight of young tomato plants particularly at higher pH (Massey and Winsor, 1969). Unlike nitrogen, phosphorous according to Kalkafi and Bar-Yosef (1980) is readily fixed

in many soils. However with frequent irrigation phosphorous uptake could be high (Hedge and Srinivas, 1990). Results from our experiment show that 30 days after planting tomato plants accumulated sufficient phosphorous to support normal growth. This might have been the result of enhanced mobility of phosphorous toward the roots as a results of trickle irrigation and rainfall. The amount of phosphorous accumulated however depends upon the extent of the wetted volume of soil. There are other reports that correlate temperature to the rate of phosphorous uptake. For example Martin and Wilcox (1963) had observed that when the temperature increases from 13.3^{0}C to 15.5^{0}C uptake of phosphorous generally increase. The average soil temperature at 20 cm for the month of January was 19.7^{0}C (Ministry of Transportation-NZMS). This temperature range might have enhanced the increase of root growth and been favourable for phosphorous uptake by the roots.

2.4.1.3 Potassium

Potassium is an important plant nutrient required in relatively large amounts to produce good quality fruit. Adams and Grimmett (1986) reported the considerable influence of potassium on fruit quality, particularly acid content (Adams *et al.*,1978) and yield. Accumulation of potassium is also important as it more or less balances organic acid in the fruit. Increasing the concentration of potassium via the liquid feed increased the percentage in leaf tissues at both sampling dates. Only with the 6 mS cm^{-1} at 55 days after transplanting was there no further increased in potassium content.

2.4.1.4 Calcium

The calcium content of the leaf tissues declined at both sampling as the concentration of the liquid feed increased up to 6 mS cm^{-1} (Table 4 and 5). Evidence from this study suggests that despite the decline in the proportion of calcium with increasing the conductivity, the amount accumulated in leaf tissues reached the level necessary for healthy growth of the plants similar to the values (1.2-2.0%) reported by Brice (1978). The fall in calcium content with increasing conductivity can be explained as a result of competition between cations. The competing cation in this case was the potassium supplied in the liquid feed. The calcium content fell with time which was to be expected.

2.4.1.5 Magnesium

There were no treatment effects on the magnesium content in the leaves which fell with time. Experience with greenhouse tomatoes has shown that magnesium uptake is often reduced by high levels of potassium (Welte and Werner, 1963). The application of magnesium in the liquid feed in this experiment can be expected to have counteracted this effect and maintained magnesium content in the leaves at acceptable levels. Mengel and Kirkby (1987) observed that potassium affects magnesium content of different parts of tomatoes in varying ways. Thus although potassium reduced magnesium content of tomato leaves and roots, the magnesium content in fruits is enhanced by higher levels of potassium in nutrient solution.

2.4.2 Soil Conductivity and Percent Soluble Salts

This study shows that by using drip irrigation to apply nutrients to field grown tomatoes, salts accumulated in the upper 10 cm of soil layer below the dripper and around the wetted zone (Table 6). This observation agrees with the work of Goldberg *et al.* (1976) and Rolston *et al.* (1986) that under drip irrigation salts accumulate in the upper layers of the soil and at the periphery of the wetted zone. The movement of certain nutrients, particularly NO_3-N can result in concentration of NO_3-N, which are lower below the dripper and higher at the edge of the wetted zone, while strongly adsorbed ions such as potassium remain in the region below the dripper (Winsor and Adams,1987). Most salts (Bowman and Nakamaya, 1986) however move through the soil profile with irrigation water. Results from this study suggest that the conductivity of the soil solution was lower than that of the liquid feed. This was probably due to the dilution of the liquid feed since soil samples were taken early in May when irrigation preceded rainfall.

The conductivity of the soil solution increased as the conductivity of the treatment feed increased and declined as the distance from the dripper increased. The retention of potassium close to the dripper (Winsor and Adams,1987) may have contributed to the latter effect.

None of the tomato plants grown under any of the treatments outwardly showed any signs of physiological stress due too the high conductivity liquid feeds applied.

This is not surprising as the percent soluble salts at any of the sample sites (Table 6) did not exceed the acceptable level reported by Clarke *et al.* (1986) for greenhouse tomatoes of 0.2%

2.4.3 Fruit Quality Attributes

2.4.3.1 Acidity

The treatment solutions increased the titratable acidity of the fruit, but there was no difference in acidity between the conductivity treatments. Acidity is one of the major taste components of tomato fruit and plays an important role in processing and storability of products. Commercially grown tomatoes contain an average of 3328 mg of citric acid per litre of juice (Davies and Hobson, 1981).

Increases in the acidity of tomato fruit has been associated with either water stress due to the removal of irrigation or due to an increase in the salinity of the irrigation water by increasing the concentration of major nutrients (Adams, 1991; Mitchell et al, 1991). In the field Cornish and Nguyen (1989) reported that increasing the concentration of potassium chloride in the liquid feed resulted in an increase in the percentage of titratable acids. Thus in the present study the high conductivity of the liquid feeds would have increased the acidity of the fruit due to water stress.

In other studies potassium status in the soil and in the plant (Adams et al., 1978) were found to be highly correlated to the concentration of fruit acid. Potassium is the predominant ion accounting for more than 80% of the positive ions in the fruit (Hobson, 1988). The uptake of potassium is vital as it more or less balances the accumulation of organic acids in the fruit. As the concentrated liquid feeds were high in potassium, as shown by leaf analysis data (Table 4 and 5) then the increase in titratable acidity could also be partially explained by the increase in uptake of potassium by the plant.

Over time titratable acidity of the fruit fell (Table 9). The high figure obtained at harvest 2 is hard to explain. Otherwise the level of acidity in the fruit fell until harvest 6 when it was maintained at the same level. As all the fruit were harvested at the same maturity this fall must have been associated with either a seasonal effect or due to the position of the fruit on the plant.

2.4.3.2 Total Solids

The trend was for total solids to increase as the concentration of the liquid feed increased (Table 8). An important factor in tomato fruit quality is total solids content. Normally, total solids (represented as total dry matter of commercial tomato fruit) varies from 4 % to 7.5% of the fruit fresh weight (Davies and Hobson, 1981). From these values, 75 % is normally attributed to soluble solids and 25 % to structural material (Berry and Uddin, 1991).

At harvest 6 (Table 9) the percent of total solids attributed to structural material was 26% which is similar to this reported figure although over the period of the 6 harvests it had increased from 4-26%. Based on the data presented in Table 8 the percent of total solids allocated to structural material in the present study (15%, 14%, 12% and 10% for treatments control to 6 mS cm^{-1} respectively) fell as the concentration of the liquid feeds increased. This suggests that the structural component of the fruit was not greatly effected by the treatments used and that the increase in total solids that occurred was due to an increase in the soluble solids component. Total solids in tomato fruits can be increased by suspending irrigation prior to harvesting (Mitchel *et al.*, 1991) or by raising the osmotic potential of the solution to 12 mS cm^{-1} (Adams, 1991; Ehret and Ho, 1986). Most of these results however relate to glasshouse tomatoes where growers have a relatively good control of growth factors. In the field few studies have been conducted to increase total solids aside from irrigation cut off and the use of brackish water as experienced in Israel. Studies were conducted by Cornish and Nguyen (1989) in Australia by using trickle irrigation and saline solution but failed to achieve a satisfactory response of total solids to salinity due to frequency of leaching and the sandy soil.

In the present investigation with field grown tomatoes increases in total solids of 4.88% to 5.23% were achieved despite the regular occurrence of heavy rain. The frequency of application of the treatment solutions may have however been able to maintain a solution of increased conductivity in the root zone despite leaching.

Results from other studies suggest that the response of total solids to salinity (12 mS cm^{-1}) can be explained by restricted water uptake in fruits imposed by the osmotic potential of the solution that resulted in the accumulation of starch rather than reducing sugars (Adams, 1991).

Total solids increased with time until harvest 5 and then fell at harvest 6. The structural component of total solids also increased over this period from 4-26% (calculations based on Table 9). As with titratable acidity these changes could have been due to either seasonal effects such as rainfall or a stem position effect.

2.4.3.3 Fruit Firmness

Firmness of the fruit depend on weather condition during fruit growth, water supply, degree of ripeness and size. When tomato plants were grown with a complete mineral fertilizer, the total content of pectic substances and protopectin content increased in ripe fruit and firmness was enhanced (Lukyanenko, 1991). In NFT, firmness of the fruit has been improved by intermittent circulation of the liquid feed (Graves and Hurd, 1983).

The interaction effect obtained with fruit firmness cannot be explained (Figure 3). The most reasonable conclusion to make is that there was no effect of the conductivity treatments on fruit firmness (Table 8) and that apart from peaks at

harvests 1 and 3 (Table 9 and Figure 3) measurements made over time were similar.

2.4.3.4 Total Soluble Solids

Increasing the salinity of the liquid feed from 2 to 6 mS cm^{-1} enhanced the accumulation of total soluble solids from 4.41 to 4.73 ^{0}BRIX comparable to fruits from control plants which accumulated 4.14 ^{0}BRIX. This study demonstrates with field grown tomatoes that fruit composition particularly total soluble solids, can be improved despite possible leaching by rainfall of concentrated amounts of nutrients applied in solution via trickle irrigation.

Similar effects were observed by Ehret and Ho (1986) in tomatoes grown in rockwool where increasing the concentration of the liquid feed to 17 mS cm^{-1} by applying potassium and nitrogen increased the percentage of sugar concentration in the fruit, but this level declined with time of harvest. It is interesting to note, that Adams and Grimmet (1986) suggest, that the accumulation of starch was related to the high potassium level in the liquid feed.

In the present investigation there was an increase in potassium concentration in the leaves with increased conductivity and this may have increased the total soluble solids and total solids in the fruit. Although the concentration of potassium in the fruit sap was not tested it is probable that it was high and may have enhanced synthesis of starch into reducing sugar.

Total soluble solids fell with time of harvest (Table 9). These fluctuations are expected to occur and can be explained based on the moisture content of the soil. Julian (1990) observed major fluctuation of total soluble solids in processing tomatoes whenever rainfall was significant a week before harvest. A fall in total soluble solids with harvest has been reported by Ehret and Ho (1986).

2.4.4 Total Number and Yield of Fruit

There were no differences in total fruit number and yield per plant between any of the treatments after the 18th harvest (Table 10) whilst fruit number slightly increased in 4 mS cm^{-1} at 19th harvest (Table 11). It could be suggested that the heavy rainfall during the experiment leached nutrients from the root zone so lowering the conductivity of the soil solution in this area. However improvements in fruit quality (Table 8) that are associated with high conductivity feeds were obtained. Thus in this experiment the reduction in yield associated with improvements in fruit quality from the application of liquid feeds that has been reported for greenhouse tomatoes (Ehret and Ho, 1986; Ho and Grimbly, 1990; Massey *et al.*, 1984) and field tomatoes (Lapusner *et al.*, 1986; Pasternak *et al.*, 1984; Shalhevet and Yaron, 1973) was not obtained.

High numbers of fruit remained on all plants after the completion of harvesting of commercially mature fruit with no differences between treatments. Approximately 65% of the fruit number were carried on the main stem.

2.4.5 Marketable Fruit

As with total number and total yield of fruit there were no significant differences in the number and yield of marketable fruit. Again the trend was for the yield of 6 mS cm^{-1} treatment to be lower than any of the other treatments. This may be an indication that if fruit had been harvested for a longer period then a reduction in yield would have been obtained. For example, Massey *et al.* (1984) have reported that increasing the salinity of the liquid feed will eventually reduce the number of fruit set.

No explanation can be offered as to why the number and yield of the 4 mS cm^{-1} treatment was higher for truss 3 on the main stem than the other treatments. The data for number and yield of fruit for the various trusses on the main and lateral stems provides an insight into how fruit yield is distributed on double stem plants. The main stem appears to be a very successful competitor for assimilates.

2.4.5.1 Size of Marketable Fruit

The only significant differences was for the 6 mS cm^{-1} treatment which had the smallest number of fruit per plant in the 60 - 70 size grade. This is not an unexpected as result as Ehret and Ho (1986) have reported the effects of high conductivity feeds reducing water uptake by fruit, so improving quality attributes, while at the same time reducing fruit size.

The number of fruit in the two largest size grades tended to be highest for the control plants, which again is evidence that the conductivity feeds tended to reduce fruit size.

The evidence presented here suggests that the conductivity treatments tended to reduce fruit size. It is possible that if the experiment had been conducted for a longer period these conductivity treatments may have had a significant effect on fruit size and thus a reduction in yield would have accompanied the improvements in fruit quality. A similar suggestion was made in the section 2.4.3 with respect to the possible effects of the conductivity treatments on fruit number over a longer time period than the present experiment. The occurrence of a reduction in yield may been delayed by the wet growing season.

2.4.5.2 Reject Fruit

The main cause of reject fruit was due to cracking. This was perhaps nor surprising, again due to the heavy rainfall. The very low level of blossom-end rot was possible due to the fact that both the rainfall and the regular application of the liquid feeds via trickle system did not place the plants under conditions of fluctuating moisture stress.

CHAPTER 3

SUMMARY

The quality of field grown tomatoes is of utmost importance to the successful marketing of the crop. Techniques for using concentrated liquid feeds to improve the quality of and in particular the flavour of greenhouse tomatoes are under development. The application of these techniques to field grown tomatoes have not been examined. The use of drip irrigation would be essential to the development of such technology.

In this study the variety *Extase*, was grown o the Karapoti Sandy Loam soil and drip irrigated using liquid feeds having conductivities of 2, 4 and 6 mS cm^{-1} to determine the effects of such treatment on yield and quality of the fruit. Of particular interest was quality attributes relating to fruit flavour. Irrigation requirements were based on the use of a crop factor and daily evapo-transpiration, while the liquid feeds were based on recommendations for glasshouse tomatoes.

The concentration of soluble salts in the top 5-10 cm of soil increased with the conductivity of the liquid feed. As the distance from the dripper increased the percentage of soluble salts decreased. At no point however did the soluble salts reach a level considered excessive for greenhouse tomatoes. Recovery of nutrients based on leaf analysis was high 30 days after planting where fruit load

was still low and enhanced by growth and development of a profuse root system below the dripper. As the distance from the dripper increased root growth become sparse.

Increasing the conductivity of the liquid feed has been shown to improve fruit quality by increasing the acidity, total solids and soluble solids, while firmness of the fruit was maintained. Total and marketable yields and size of the fruit were not affected by the conductivity treatments. This may have been due to the wet season and it is possible that the concentrated feeds would have reduced yield if the experiment had been continued for a longer period of time

Results from this study were encouraging. Based on this research liquid feeds of 4 and 6 mS cm^{-1} will improve flavour. Further work is required however to determine more exactly the most appropriate feed. Future research should also include sensory evaluation of the fruit to confirm that consumers relate to the improvements in fruit flavour achieved in this study. Research is also necessary to determine the keeping quality of fruit produced using this technology. The trade off between fruit yield and quality which was not found in the present investigation needs to be further examined as in the present investigation it may have been an artifact of the weather condition.

REFERENCES

Abdul, K. S. and Harris, G. P. (1978). Control of flower number in the first inflorescence of tomato (*Lycopersicon esculentum* Mill.): The role of gibberellins. Annals of Botany 42: 1361-1367.

Adams. P. (1986). Mineral nutrition, pp.281-324. In: J. G. Atherton and J. Rudich (eds.). The Tomato Crop. Scientific Basis for Improvement. Chapman and Hall London.

Adams, P. (1991). Effects of increasing the salinity of the nutrient solution with major nutrients or sodium chloride on the yield, quality and composition of tomatoes grown in rockwool. Journal of Horticultural Science 66(2):201-207.

Adams, P., Davies, J. N. and Winsor, G. W. (1978). Effects of nitrogen, potassium and magnesium on the quality and chemical composition of tomatoes grown in peat. Journal of Horticultural Science 53: 115-122.

Adams, P. and Grimmett, M. M. (1986). Some responses of tomatoes to the concentration of potassium in recirculating nutrient solutions. Acta Horticulturae 178: 29-35.

Adams, P., Winsor, G. N., and Donald, J. D. (1973). The effects of nitrogen, potassium and sub-irrigation on the yield, quality and composition of single truss tomatoes. Journal of Horticultural Science 48:123-133.

Adegoroye, A. S., Jolliffe, P. A. and Tung, M. A. (1989). Textural characteristics of tomato fruits affected by sunscald. Journal of Science, Food and Agriculture 49: 95-102.

Anonymous (1992). Quality and flavour. New Zealand Commercial Grower August/September pp. 15-16.

Archbold, D. D., Dennis, F. C.Jr. and Flore, J. A. (1982). Accumulation of ^{14}C labelled material from foliar applied ^{14}C sucrose by tomato ovaries during fruit set and initial development. Journal of American Society for Horticultural Science 107: 19-23.

Asahira, T. and Hosoki, T. (1977). *In vitro* studies of controlling tomato puffiness by growth regulators. Scientia Horticulturae 7: 319-328.

Atherton, J. G. and Harris, G. P. (1986). Flowering pp. 167-194. In: Atherton and Rudich (eds.) The Tomato Crop: A Scientific Basis for Improvement. Chapman and Hall, Cambridge Great Britain.

Babbitt, J. K., Powers, M. J. and Patterson, M. E. (1973). Effect of growth regulators on cellulase, polygalacturonase, respiration, colour and texture of ripening tomatoes. Journal of American Society for Horticultural Science 98: 77_80.

Baldwin, E. A., Nisperos-Carriedo, M. O. and Moshonas, M. G. (1991). Quantitative analysis of flavour and other volatiles and for certain constituents of two cultivars during ripening. Journal of American Society for Horticultural Science 116 (2): 265-269.

Baldwin, E. A. and Pressey, R. (1988). Tomato polygalacturonase elicits ethylene production in tomato fruit. Journal of American Society for Horticultural Science 113(1): 92-95.

Bangerth, F. and Ho, L. C. (1984). Fruit position and fruit set sequence in a truss as factors determining final size of tomato fruits. Annals of Botany 53: 315-319.

Bar-Yosef, B. and Sheikholslami (1976). Distribution of water and ions in soil irrigated and fertilized from a trickle source. Journal of Soil Science Society of America 40: 575-582.

Bathgate, B., Purton, M. E., Grierson, D. and Goodenough, P. W. (1985). Plastid changes during conversion of chloroplasts to chromoplasts in ripening tomatoes. Planta 165(2):197-204.

Berry, S. Z. and Uddin, M. R. (1991). Breeding tomato for quality and processing attributes, pp 197-206. In: G.Kallo (ed.) Genetic improvement in tomato. Springer-Verlag, Germany.

Besford, R. T. and Maw, G. A. (1975). Effect of potassium nutrition on tomato plant growth and fruit development. Plant and Soil 42: 395-412.

Bezar, H. (1989). Tomato flavour: Have we lost our best marketing asset? New Zealand Commercial Grower May 1989 pp. 8-10.

Bowman, R.S. and Nakayama, F.S. (1986). Design Principles: Salt distribution pp. 117-141. In: Nakayama and Bucks (eds.). Trickle Irrigation for Crop Production, Design, Operation and Management. Elsevier, New York.

Bretch, J. K. (1985). Location of development of ethylene biosynthesis during tomato fruit maturation. Proceedings of Florida State Horticultural Society 98: 184-187.

Bretch, J. K. (198?). Locular gel formation in developing tomato fruit and the initiation of ethylene production. HortScience 22(3) : 476-479.

Brice, I. (1978). Nutrition of tomatoes, pp.33-39. In: Proceedings of the 1978 Glasshouse Tomato Growers Short Course. Massey University.

Buttery, R. G., Teranishi, R. Ling, L. C., Flath, R. A. and Stern, D. (1988). Quantitative studies on origins of fresh aroma volatiles. Journal of Agriculture and Food Chemistry 36: 1247-1250.

Calvert, A. (1969). Studies on the root initiation development of flower buds of tomato (*Lycopersicon esculentum* Mill.). Journal of Horticultural Science 44: 117-126.

Cerda, A., Bingham, F.T. Hoffman, G.S. and Huszar,K.C. (1979). Leaf water potentials and gaseous exchange of wheat and tomato as affected by sodium chloride and potassium levels in the root medium. Agronomy Journal 71: 27-31.

Charbonneau, J. Gosselin, A. Trudel, M.J. (1988). Influence of electric conductivity and intermittent flow of the nutrient solution on growth and yield of greenhouse tomato in nutrient film technique. Soilless Culture 1(1): 19-20.

Clarke, C. J., Smith, G. S., Prasad, M. and Cornforth, I. S. (1986). Fertilizer Recommendation for Horticultural Crops. MAF, Wellington, New Zealand.

Cook, W. P. and Sanders, D. C. (1991). Nitrogen application frequency for drip irrigated tomatoes. HortScience 26 (3): 250-252.

Coombe, B. G. (1976). The development of the fleshy fruit. Annual Review of Plant Physiology and Plant Biology 27:207-228.

Cornish, P. S. and Nguyen, V. Q. (1989). Use of high solution electrical conductivity to improve the quality of fresh market tomatoes from coastal New South Wales. Australian Journal of Experimental Agriculture 29: 893-900.

Dalton, F. F. and Poss, J.A. (1990). Water transport and salt loading: A unified concept of plant response to salinity. Acta Horticulturae 278 : 187-194.

Dangler, J. M. and Locasio, S. J. (1990). External and internal blotchy ripening and fruit elemental content of trickle irrigated tomatoes as affected by nitrogen and potassium application time. Journal of American Society for Horticultural Science 115(4) : 547-549.

Davies, J. N. and Hobson, G. E. ((1981). The constituents of tomato fruit: The influence of environment, nutrition,and genotype. CRC Critical Reviews in Food, Science and Nutrition 15: 205-280.

Davies, J. N. and Kempton, R. J. (1975). Changes in the individual sugars of tomato fruit during ripening. Journal of Science, Food and Agriculture 26 : 1103.

Davies, J. N. and Winsor, G. W. (1967). Effects of nitrogen, phosphorous, potassium magnesium and calcium on the composition of tomato fruit. Journal of Science, Food and Agriculture 18: 459-466.

De Bruyn, J. W., Garretsen, F. and Kooistra, E. (1971). Variation in taste and chemical composition of the tomato (*Lycopersicon esculentum* Mill.). Euphytica 20: 214-227.

Dinar, M. Rudich, J. and Zamski, E. (1983). Effects of heat stress on carbon transport from tomato leaves. Annals of Botany 51: 97-103.

Dinar, M. and Stevens, M. A. (1971). The relationship between starch accumulation and soluble solids content of tomato fruits. Journal of American Society for Horticultural Science 106: 415-418.

Ehret, D. L. and Ho, L. C. (1986). The effects of salinity on dry matter partitioning and fruit growth in tomatoes grown in nutrient film culture. HortScience 61(3): 361-367.

Elfving, D. C. (1982). Crop response to trickle irrigation, pp.1-49. In: J.Janick (ed.) Horticultural Review. Vol. 4. Avi Westport Connecticut.

Favarro. J .C. and Pilatti, R. A. (1987). Influence of the number of flowers upon the growth of the first cluster fruits in tomato. Scientia Horticulturae 33: 49-55.

Ferguson, I. B., Harker, F. R. and Drobak, B. K. (unpublished). Calcium and apple fruit. DSIR Auckland.

Fisher, K. J. (1969). Effects on nitrogen supply during propagation on flowering and fruiting of glasshouse tomatoes. Journal of Horticultural Science 44:407-411.

Frenkel, C. and Jen, J. J. (1989). Tomatoes pp. 53-75. In: N. A. Skin (ed.). Quality and Preservation of Vegetables CRC Boca Raton, Florida.

Gilford, R. M. and Evans, L.T. (1981). Photosynthesis, carbon partitioning and yield. Annual Review of Plant Physiology and Plant Molecular Biology 32: 485-509.

Goldberg, D., Gornat, B. and Bar, Y. (1971). The distribution of roots, water and minerals as a result of trickle irrigation. Journal of American Society for Horticultural Science 96(5): 645-648.

Graves, G.J. and Hurd, R. G. (1983). Intermittent solution circulation in the nutrient film technique. Acta Horticulturae 133: 47-52.

Grierson, D. (1987). Senescence in fruits. HortScience 22(5) :859-862.

Grierson, D. and Kader, A. A. (1986). Fruit ripening and quality, pp. 241-275. In: J. G. Atherton and J. Harris (eds.). The tomato crop: A Scientific Basis for Improvement. Chapman and Hall, New York.

Grierson, D. and Tucker, G. A. (1983). Timing of ethylene and polygalacturonase synthesis in relation to the control of tomato fruit ripening. Planta 157: 174-179.

Hand, D. W. (1982). Carbon dioxide enrichment, the benefits and problems. Scientia Horticulturae 33:14-43.

Hannah, H. Y. and Hernandez, T. P. (1982). Response of six tomato genotypes under summer and spring weather conditions in Louisiana. Hort Science 17: 758-759.

Harris, W. M. and Spurr, A. R. (1969). Chromoplasts of tomato fruits. II. The red tomato. American Journal of Botany 56:380-389.

Hedge, D.M. and Srinivas, K. (1990). Effect of irrigation and nitrogen fertilization on yield, nutrient uptake and water use of tomato. Gartenbauwissenchaft 55(4):173-177.

Ho. L. C. (1984). Partitioning of assimilate in fruiting tomato plants. Plant Growth Regulation 2: 277-285.

Ho, L. C. (1988). Metabolism and compartmentation of imported sugars in sink organs in relation to sink strength. Annual Review of Plant Physiology and Plant Molecular Biology. 39: 355-378.

Ho, L. C. and Grimbly, P. (1990). The physiological basis for tomato quality. Grower February 22, 33-36.

Ho,L. C. and Hewitt, J. D. (1986). Fruit development, pp. 201-231. In: Atherton and Rudich (eds.) The Tomato Crop: A Scientific Basis for Improvement. Chapman and Hall, Cambridge Great Britain.

Ho, L. C. Sjut, V. and Hoad, G. V. (1983). The effects of assimilate supply in fruit growth and hormone level in tomato plants. Plant Growth Regulation 1: 55-171.

Hobson, G. E. (1967). Starch in tomato fruits. Annual Report of Glasshouse Crops Research Institute 130-134.

Hobson, G. E. (1988). How the tomato lost its taste. New Scientist 29: 46-50.

Hobson, G. E. and Harman, J. E. (1986). Tomato fruit development and the control of ripening. Acta Horticulturae 190: 167-172.

Hobson, G. E. and Kilby, P. (1985). Piecing together the flavour of cheery types. Grower June 20 pp. 27-29.

Hochmuth, G. J. (1992). Fertilizer management for drip-irrigated vegetables in Florida. HortTechnology 2(1):27-32.

Hurd, R. G. and Cooper, A. J. (1967). Increasing flower number in single truss tomatoes. HortScience 42: 181-188.

Hurd, R. G. and Cooper, A. J.(1970). The effect of early low temperature treatment on the yield of single inflorescence tomatoes. Journal of Horticultural Science 45 : 19-27.

Hurd, R. G. and Thornley, J. H. M. (1974). An analysis of growth of young tomato plant in water culture at different light integrals and carbon dioxide concentrations. I. Physiological aspects. Annals of Botany 38: 375-388.

Hussey, G. (1963). Growth and development in the young tomato. I. The effect of temperature and light intensity on growth of the shoot apex and leaf primordia. Journal of Experimental Botany 14: 316-325.

Jones, R. A. (1986). The development of salt tolerant tomatoes: Breeding strategies. Acta Horticulturae 190: 95-102.

Julian, A. P. (1990). Flower and fruit development in processing tomatoes. M.S. Thesis, Massey University, New Zealand.

Kalkafi, U. and Bar- Yosef, B. (1980). Trickle irrigation and fertilization of tomatoes in highly calcareous soils. Agronomy Journal 72: 893-897.

Kinet, J. M. (1977). Effect of defoliation and growth on the development of the inflorescence in tomato. Scientia Horticulturae 33: 27-35.

Kinet J. M. (1977a). Effect of light conditions on the development of the inflorescence in tomato. Scientia Horticulturae 6: 15-26.

Kinet, J. M. (1979). The effects of light conditions on the development of the inflorescence in tomato. Scientia Horticulturae 6: 27-35.

Kirkby, E. A. and Mengel, K. (1967). Ionic balance in different tissues of the tomato plant in relation to nitrate, urea or ammonium nutrition. Plant Physiology 42: 6-14.

Koning, A. N. de (1991). Tomatoes. higher temperature gives fewer trusses. Groenten en Fruit,Glasgroenten (1991)1(5).[Horticultural Abstract 62: 262.].

Kou. C. G., Chen, B. W., Chou, M. H.,Tsai, C. L. and Tsay, T. S. (1979). Tomato fruit set at high temperatures, pp.. In: A. Cowell (ed.). Proceedings of the First International Symposium on tropical tomatoes.

Lapushner, D., Frankel, R. and Fuchs, Y. (1986). Tomato cultivar response to water and salt stress. Acta Horticulturae 190: 247-252.

Lukyanenko, A. N. (1991). Breeding tomato for mechanized harvesting, pp. 213-229. In: G. Kallo (ed.). Genetic improvement of tomato. Springer-Verlag, Germany.

Mapelli, S., Frova, C., Torti, G. and Soresi, G. P. (1978). Relationship between set, development and activities of growth regulators in tomato fruits. Plant Cell Physiology 19:1281-1288.

Martin, G. C., Wilcox, G. E. and Langston, R. (1962). Root zone temperature and phosphorous treatment effects on tomato seedlings grown in soil and nutrient solutions. Proceedings of the American Society of Horticultural Science 80: 522-529.

Mason, S. C. and Wilcox, G.C. (1982). Nitrogen status evaluation of tomato plants. Journal of American Society for Horticultural Science 107 (3):483-486.

Massey, D. M., Hayward, A. C. and Winsor, G. M. (1984). Some responses of tomato to salinity in nutrient film culture. Annual Report of the Glasshouse Crops Research Institute for 1983 pp. 60-62.

Massey, D. M. and Winsor, G. W. (1969). Tomato nutrition: responses to phosphorous and lime. Annual Report of the Glasshouse Crops Research Institute pp.70-71.

Maynard, D. N. (1991). Nutritional diseases,pp 60-63 In: Jones and Jones (eds.). Compendium of Tomato Diseases, APS Press Minnesota.

Mengel, K. and Kirkby, E. A. (1987). Nitrogen, pp. 347-384. In: Principles of Plant Nutrition. International Potash Institute, Switzerland.

Mengel, K. and Viro, M. (1974). Effect of potassium supply on the transport of photosynthates to the fruits of tomatoes (*Lycopersicon esculentum* Mill.). Physiologia Plantarum 30: 295-300.

Mitchell, J. P., Shennan, C., Grattan, S. R., May, D. (1991). Tomato fruit yields and quality under water deficit and salinity. Journal of American Society for Horticultural Science 16(2): 215-221.

Mizrahi, Y. (1982). Effect of salinity on tomato fruit ripening. Plant Physiology 69:966-970.

Mizrahi, Y., Taleinsik, E., Kagan-Zur, V., Zonar, Y., Offenbach, R., Matan, E. and Golan , R. (1988). A saline irrigation regime for improving tomato fruit quality without reducing yield. Journal of American Society for Horticultural Science 113(2):202-205.

Mofo, G. and La Malfa, G. (1986). Flowering of tomato in relation to ,pre-planting low temperatures. Acta Horticulturae 191: 275-280.

Munoz-Fernandez, R. and Cuartero, J. (1991). Effects of temperature and irradiance on stigma exsertion, ovule viability and embryo development in tomato. Journal of Horticultural Science 66 (4): 395-401.

Olsen, S. R. and Watanabe, F. S. (1970). Diffusive supply of phosphorous in relation to soil texture variations. Soil Science 110: 318-327.

Papadopolous, I. and Rendig, V.V. (1983). Tomato response to soil salinity. Agronomy Journal 75: 696-700.

Papadopoulos, I. Rendig, V. V. and Broadbent, F. E. (1985). Growth, nutrition and water uptake of tomato plants with divided roots growing in differentially salinized soil. Agronomy Journal 77: 21-26.

Pasternak, D., De Malach, Y. and Borovic, T. (1986). Irrigation with brackish water under desert conditions VII. Effect of time of application of brackish water on production of processing tomatoes (*Lycopersicon esculentum* Mill.). Agricultural Water Management 12: 149-158.

Picken, A. J. F. (1984). A review of pollination and fruit set in the tomato (*Lycopersicon esculentum* Mill.). Journal of Horticultural Science 59(1) 1-13.

Pill, W. G. and Lambeth, V. N. (1977). Effects of NH_4 and NO_3 nutrition with and without pH adjustment on tomato growth, ion composition and water relations. Journal of American Society for Horticultural Science 102 : 78-81.

Rabinowitch, H. D, Budowski, P. and Kedar, N. (1975). Carotenoids and epoxide cycles in mature green tomatoes. Planta 122: 91-97.

Rick, C. M. (1978). The tomato. Scientific American 239: 66.

Rick, C. M. and Dempsey, W. H. (1969). Position of the stigma in relation to fruit setting of the tomato. Botanical Gazette 130: 180-186.

Rolston, D. E., Miller, R. J. and Schulbach, H. (1986). Fertilization, pp.317-344. In: Nakayama and Bucks (ed.). Trickle irrigation for crop production, design, operation and management. Elsevier, New York.

Rothan, C. and Nicholas, J. (1989). Changes in acidic and basic peroxidase activities during tomato fruit ripening. HortScience 24(2) : 340-342.

Rush, D. W. and Epstein, E. (1976). Differences between salt sensitive and salt tolerant genotypes of the tomato. Plant Physiology 57: 162-166.

Russell, C. R. and Morris, D. A. (1983). Patterns of assimilate distribution and source and sink relationships in young reproductive tomato plant (*Lycopersicon esculentum* Mill.). Annals of Botany 52 :353-363.

Saccher, J. A. (1973). Senescence and postharvest physiology. Annual Review of Plant Physiology and Molecular Biology 24: 197-224.

Sachs, R. M. and Hacket, W. P. (1969). Control of vegetative and reproductive development in seed plants. HortScience 4: 103-107.

Sawhney, V. K. and Greyson, R. I. (1971). Induction of multilocular ovary in tomato by gibberellic acid. Journal of American Society for Horticultural Science 96: 196-198.

Shafsak, S. A. and Winsor, G. W. (1964). A new instrument for measuring the compressibility of tomatoes and its application to the study of factors affecting fruit firmness. Journal of Horticultural Science 39: 284-297.

Shalhevet, J. and Yaron, B. (1973). Effect of Soil and Water salinity on tomato growth. Plant Soil 39: 285-292.

Shannon, M. C., Gronwald, J. W. and Tal, M. (1987). Effects of salinity on growth and accumulation of organic and inorganic ions in cultivated and wild tomatoes. Journal of American Society for Horticultural Science 112(3): 416-423.

Shelby, R. A., Greenleaf, W. H. and Peterson, C. M. (1978). Comparative floral fertility in heat tolerant and heat sensitive tomatoes. Journal of American Society for Horticultural Science 103(3): 778-780.

Shishido, Y. and Hori, Y. (1991). The role of leaf as affected by phyllotaxis and leaf histology on the development of the fruit in tomato. Journal of Japan Society for Horticultural Science 60(2): 319-327.

Smith, C. J. S., Watson, C. F., Ray, J., Bird, C. R.,Morris, P. C., Schuch, W. and Grierson, D. (1989). Antisense RNA of polygalacturonase gene expression in transgenic tomatoes. Nature, U.K. 334 (6184) 724-726 (1988). FSTA 21(1): 1989).

Speirs, J. and Brady, C. J. (1991). Modification of gene expression in ripening fruit. Australian Journal of Plant Physiology 18: 519-532.

Stanley, C. D. and Geraldson, C. M. (1991). Cultural practices pp.6-10. In: Jones et al. (eds.). Compendium of Tomato Diseases. APS Press Minnesota USA.

Stevens, M. A. (1972). Citrate and malate concentrations in tomato fruits: Genetic control and maturational effects. Journal of American Society for Horticultural Science 97: 655-658.

Stevens, M. A. (1980). Processing tomato cultivars with firmness, long vine storage and high viscosity potential. Acta Horticulturae 100: 363-364.

Stevens, M. A., Kader, A. A. and Albright-Holton, M. (1977). Intercultivar variation in composition of locular and pericarp portions of fresh market tomatoes. Journal of American Society for Horticultural Science 102:689-692.

Stevens, M. A., Kader, A. A., Albright,-Holton, M. and Algazi, M. (1977). Genotypic variation for flavour and composition in fresh market tomatoes. Journal of American Society for Horticultural Science 102: 680-689.

Su, L. Y., Mckeon, T., Grierson, D., Cantwell, M. and Yang, S.F. (1984). Development of aminocyclopropane 1- carboxylic acid (ACC) synthase and polygalacturonase activities during maturation and ripening of tomato fruits in relation to their ethylene production rates. HortScience 19: 576-578.

Tigchelaar, E. C., McGlasson, W. B. and Buescher, R. W. (1978). Genetic regulation of tomato fruit ripening. HortScience 13: 508-513.

Ueskull, H. R. von (1979). Tomato: Nutrition and fertilizer requirements in the tropics, pp. 65-78. In: R. Cowell (ed.). Proceedings of the First International Symposium on Tropical Tomatoes. AVRDC Taiwan, ROC.

Varga, A. and Bruinsma, J. (1986). Tomato pp.461-481. In: Shaul P. Monselise (ed.) CRC Handbook of Fruit Set and Development Boca Raton, Florida.

Voisey, P. W., Lyall, L. H. and Klock, M. (1970). Tomato skin strength- its measurement and relation to cracking. Journal of American Society for Horticultural Science 95:485-488.

Walker, A. J., Ho, L. C. and Baker, D. A. (1978). Carbon translocation in the tomato: Pathway to carbon metabolism in the fruit. Annals of Botany 42: 901-909.

Walker,A. J. and Ho, L. C. (1979). Carbon translocation in the tomato, import and fruit growth. Annals of Botany 41: 813-823.

Welte, E. and Werner, W. (1963). Potassium-magnesium antagonism in soils and crops. Journal of Science, Food and Agriculture 14: 180-186.

White, R.A.J. (1989). Production systems I. Proceedings of Greenhouse Vegetable Crops Short Course. Massey University, February 1989, 98-107.

Winsor, G. W. (1966). Some factors affecting the composition flavour and firmness of tomatoes. Scientia Horticulturae 18: 27-35.

Winsor, G. W. (1979). Some factors affecting the quality and composition of tomatoes. Acta Horticulturae 93: 335-346.

Winsor, G. W. and Adams, P. (1987). Diagnosis of Mineral Disorders in Plants. Glasshouse Crops Volume 3 pp. 52-71.

Winsor, G. W., Davies, J. N. and Long, M. I. E. (1961). Liquid feeding of glasshouse tomatoes: The effects of potassium concentration on fruit quality and yield. Journal of Horticultural Science 36: 254-267.

Winsor, G. W., Davies, G. N., Long, M. I. E. (1967). The effects of nitrogen, phosphorous, potassium magnesium and lime in factorial combination on the yields of glasshouse tomatoes. Journal of Horticultural Science 42: 277-288.

Witter, S. H. and Teubner, F. G. (1957). The effects of temperature and nitrogen nutrition on flower formation in the tomato. American Journal of Botany 44:125-129.

Yoshihiro, K. and Kuniyoshi, K. (1988). Morphological characteristics of tomato plants grown in nutrient solution in comparison with those grown in soil. Journal of Japanese Society For Horticultural Science 57 (3): 408-417.

Zerbi, G., Lecain, D. R. and Morgan, J.A. (1990). Concurrent action of salinity and water stress on leaf gas exchange and water relations in tomato. Journal of Horticultural Science 65(6): 675-681.

PLATES

Plate 1

Grading Chart

Plate 2

Set-up for Weighing the Fruit

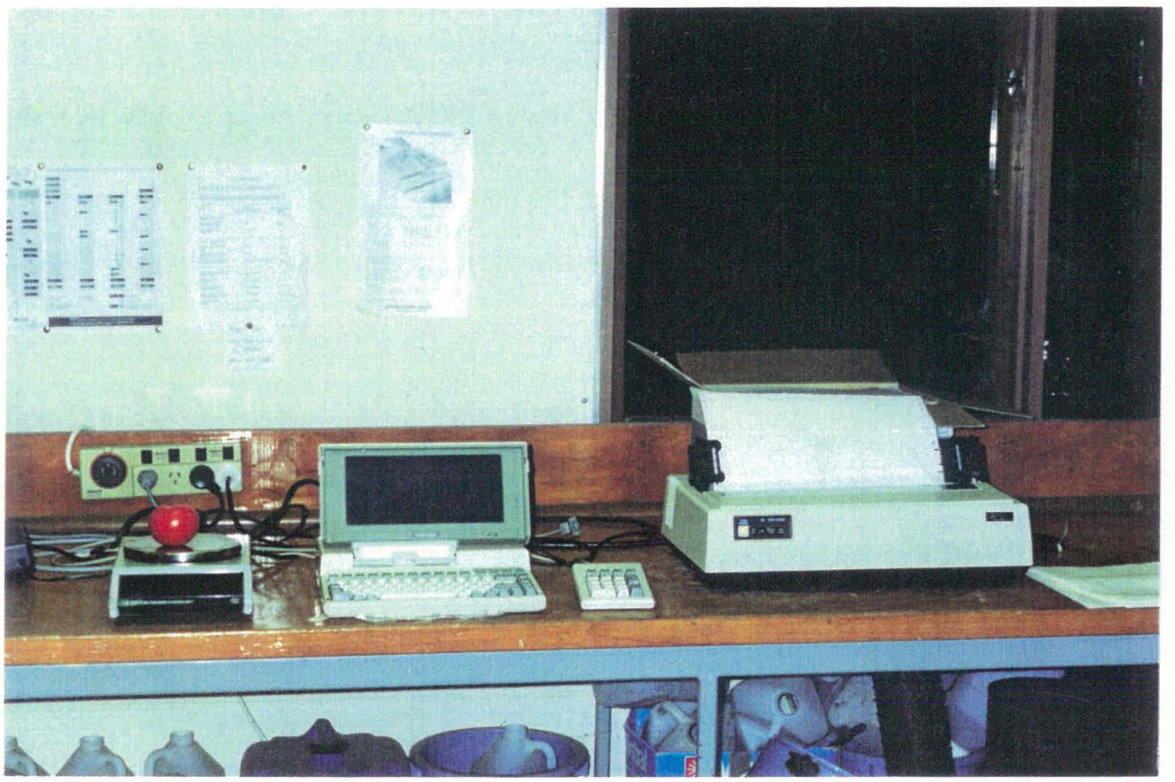
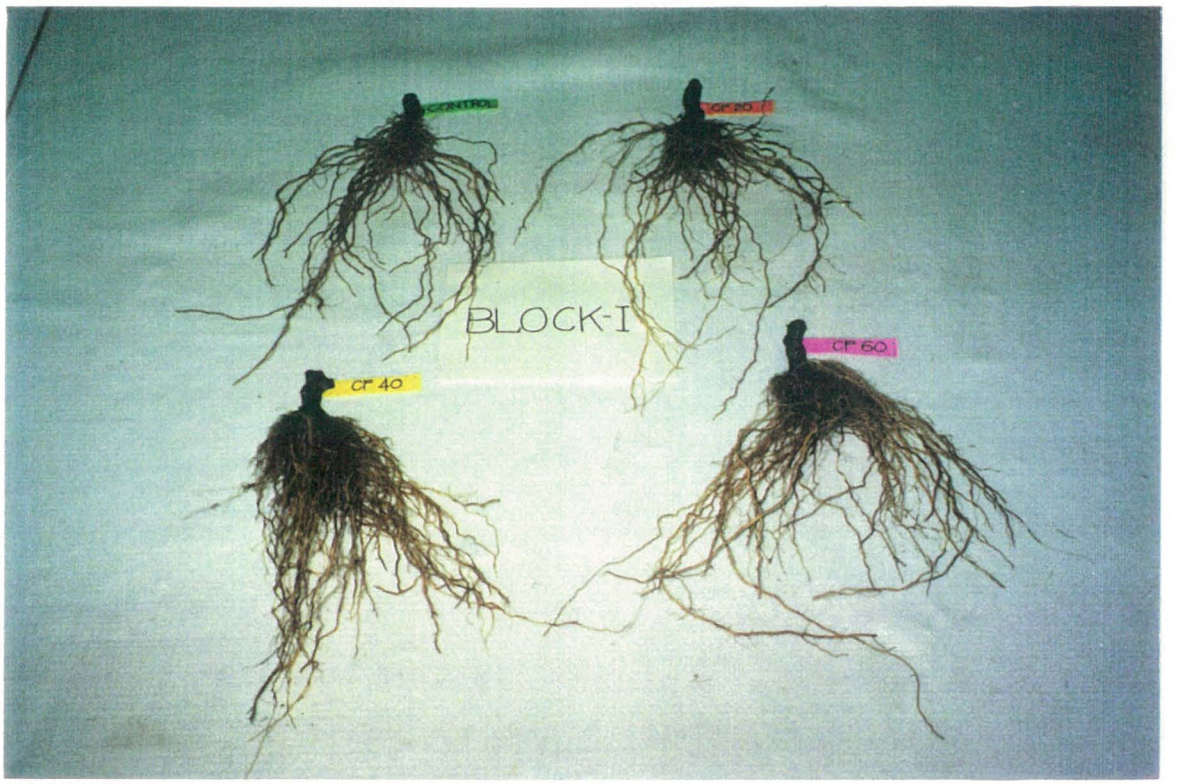


Plate 3

Tomato Root System



APPPENDICES

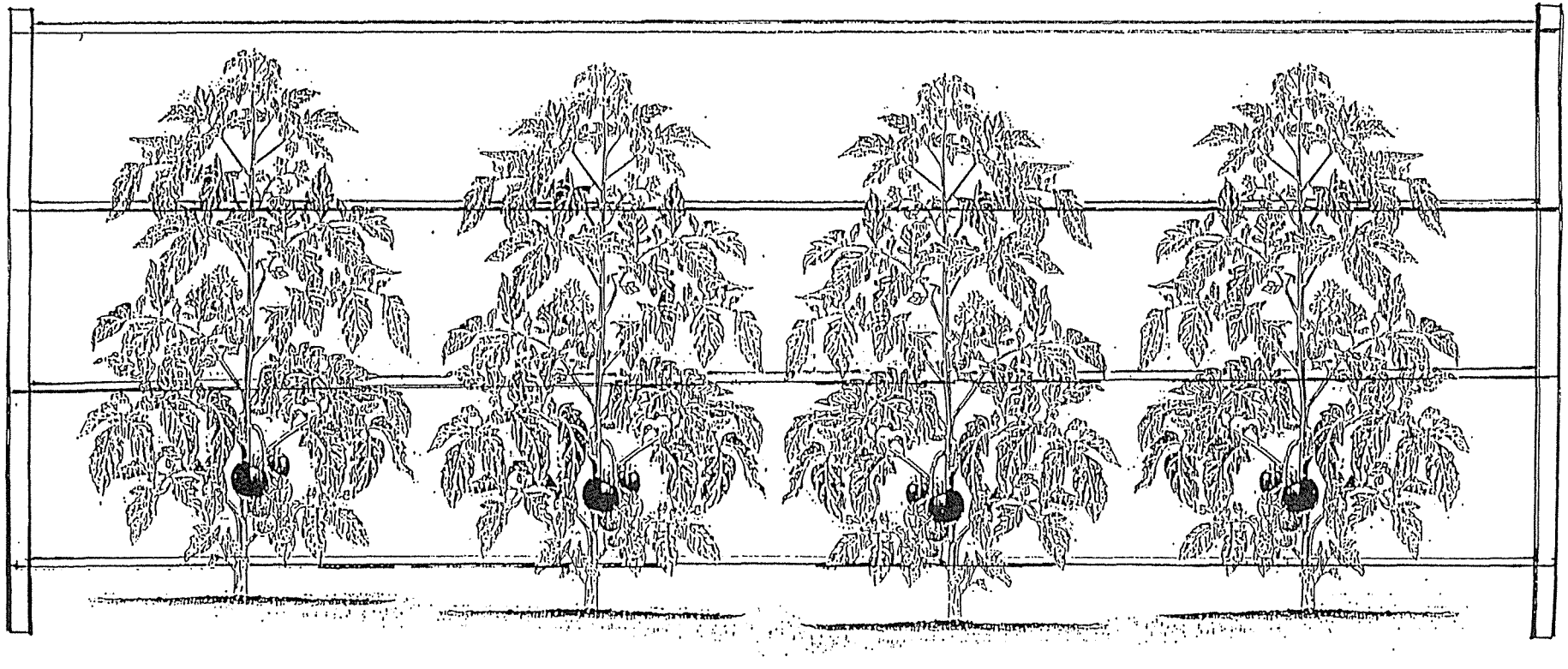
Appendix 1

Growing media 50% peat and 50% sand by volume

Fertilizer	kg per 0.08 m^3
Osmocote (3 month)	0.18
Lime	0.12
Dolomite	0.24
Superphosphate	0.12
Micromax	0.048

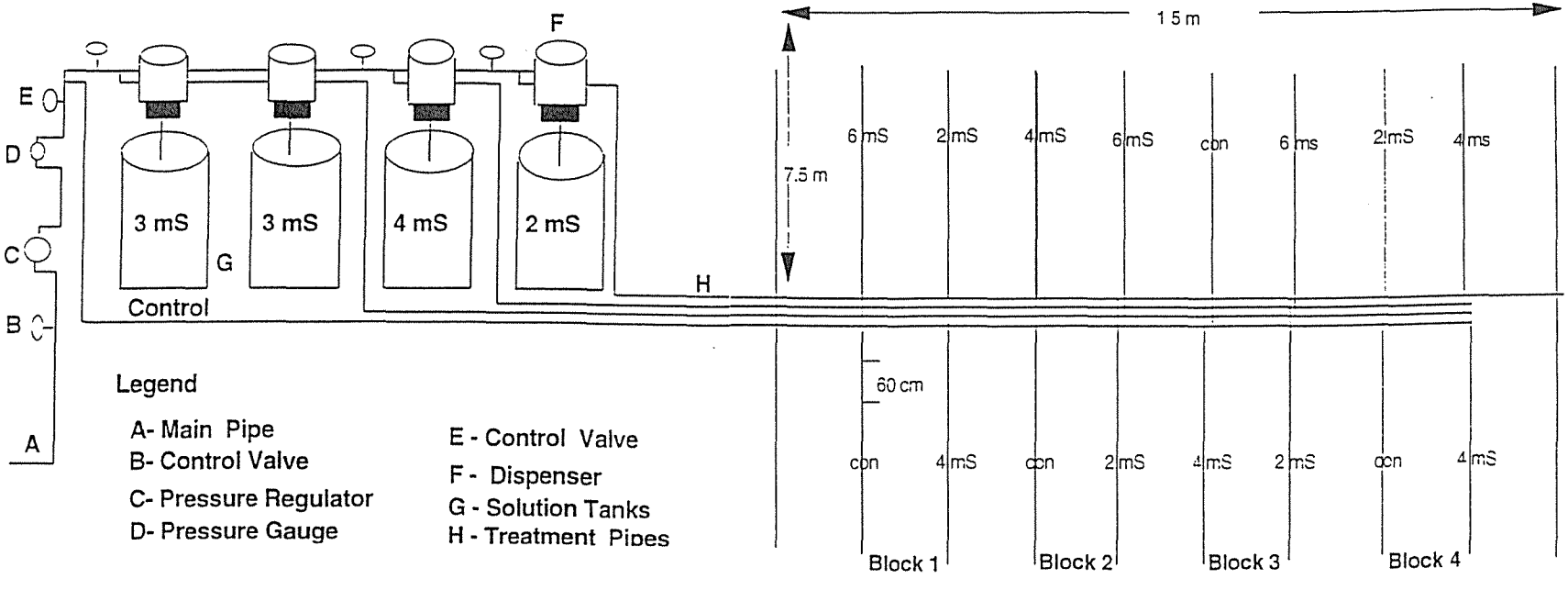
Appendix 2

The Otaki System of Tomato Fencing (Diagramatic)

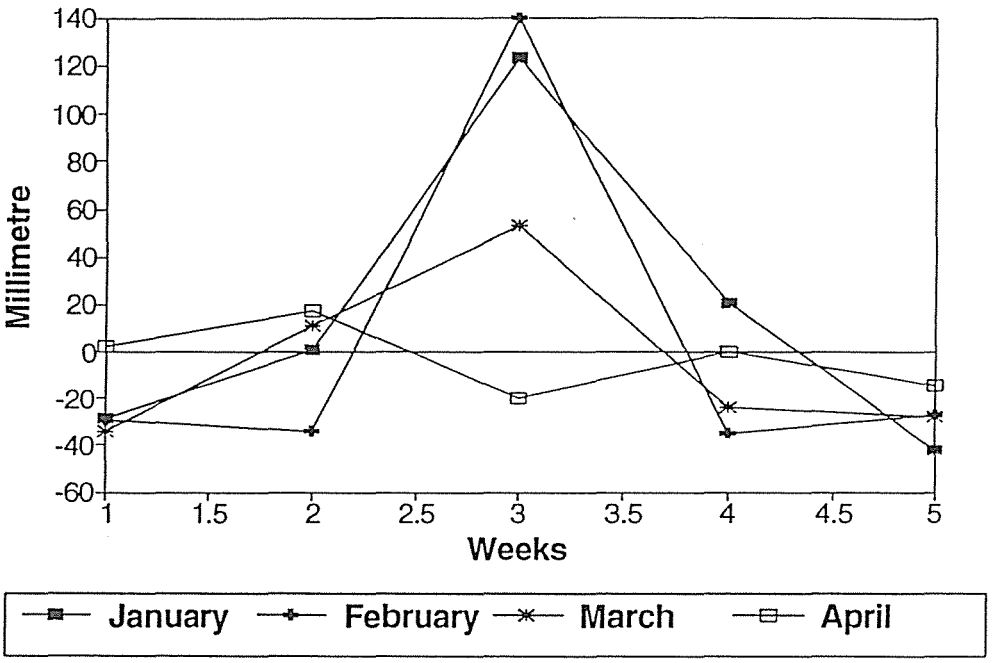


Appendix 3

Experimental Design



Appendix 4
Soil Moisture Deficit
(January to April)



Appendix 5

Spraying Programme

Pesticides	Schedule of Application	Recommended Rate of Application	Diseases and Pest To Control
Dithane Z-78	First 2 weeks	150-200 grams per 100 litres	Anthracnose, early and late blight and leaf mould
Kocide	Third week	150-300 grams per 100 litres	Early and late blight, bacterial speck and spot
Karate	First 2 weeks combined with Dithane Z-78	200 ml per 1000 litres	Fruit worm

Appendix 6

Formula in Determining the Titratable Acidity of Tomato

$$\% \text{ Citric Acid} = \text{ml NaOH} \times (0.1N) \frac{(\text{molecular weight of citric acid})/3}{\text{mls. of juice} \times 10}$$