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**EFFECTS OF NUTRIENT SOLUTION CONDUCTIVITY
ON YIELD AND QUALITY OF TOMATO (*Lycopersicon
esculentum* Mill) GROWN WITH NFT**

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By
BUSSAKORN S. MPELASOKA

Massey University

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ABSTRACT

The effects of electrical conductivity (EC) of nutrient solution on yield and some quality characteristics of tomato (*Lycopersicon esculentum* Mill) were studied. Two fresh market tomato cultivars, Concordia (a long shelf life cultivar) and Rondello (a standard greenhouse tomato) were grown in a greenhouse with NFT at four EC levels of nutrient solution (2.0, 4.0, 6.0, and 8.0 mScm⁻¹). Two experiments were conducted, one in the summer and the other in the winter. Increasing EC significantly improved fruit quality in terms of total soluble solids (TSS), titratable acidity (TA) and dry matter concentration (% DM) in both experiments. Results from the taste test indicated that the changes in fruit compositions at high EC resulted in taste improvement that could be recognised by consumers. Fruit (picked at breaker stage) from plants grown at 6 and 8 mScm⁻¹ had redder skin colour on Day 3 to 11 during storage at 20 °C.

During the summer experiment, EC 6.0 and 8.0 mScm⁻¹ reduced fruit yield mainly due to a reduction in fruit size and an increase in the incidence of blossom-end rot (BER). Generally, increasing EC also decreased vegetative growth, and the effects were clearer during the summer experiment.

The effects of increasing EC levels on growth, yield and quality observed could be because increasing EC decreased water potential of nutrient solution leading to less water uptake and lower plant water status. Both plant water uptake and plant water status were found to decrease with increasing EC levels.

Results from this study showed a clear effect of season. Vegetative growth and yield were substantially lower during the winter experiment. The effect of increasing EC levels on fruit quality (fruit compositions and taste) was significant during both experiments, but their effect on yield was significant only during the summer experiment.

In general, both cultivars responded to EC levels similarly in terms of vegetative growth, yield and fruit quality except that Rondello was much more susceptible to BER at EC

higher than 4 mScm⁻¹ during the summer experiment.

The levels of EC used in this study had no effect on time of maturity but Rondello appeared to mature slightly earlier than Concordia. The levels of EC used in this study did not have any effect on rate of water loss of the fruit during storage at 20 °C but Concordia had higher rate of water loss than Rondello.

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GLOSSARY OF ABBREVIATIONS

ANOVA	- Analysis of variance
BER	- Blossom-end rot
CV	- Cultivar
DM	- Dry matter concentration
EC	- Electrical conductivity
H	- Hue angle (°)
L	- Lightness (%)
MPa	- Mega Pascal (1 MPa = 10 bars)
mS	- Milliseimens
NFT	- Nutrient film technique
RCBD	- Randomized complete block design
RH	- Relative humidity (%)
RWC	- Relative water content
SEM	- Standard error of the mean
TA	- Titratable acidity (% citric acid)
TSS	- Total soluble solids
Ψ	- Leaf water potential

CHAPTER ONE

INTRODUCTION

Tomato (*Lycopersicon esculentum* Mill) is a vegetable fruit crop in the family Solanaceae. The fruit contain vitamin A and C, though not in a large amount. It ranks number one in term of its contribution of nutrients to the diet in U.S.A. due to its large per capita consumption (Wills et al., 1989). Tomato is also an important research tool as it easily grown, short-season, and useful mutant lines are available.

In New Zealand, tomato can only be grown outdoors during the warm summer months (November - March). Because of this, a greenhouse tomato industry has developed to supply tomato during the winter months (Nichols et al., 1994). Nowadays, much of the greenhouse tomato is grown in soilless substrate. The Nutrient Film Technique (NFT) is one of the soilless culture system and a commercially accepted method of growing high values protected crops (Grave and Hurd, 1983). The NFT system, though requiring high establishment and management costs, provides several advantages such as the effective use of water and fertilizers, improved control of weed and soil-borne diseases and pests and improved control of the below ground environment eg. nutrient, water and O₂. The uptake of nutrients is usually proportional to the availability of nutrients to the roots. In soil, this may be limited by moisture content and pH, which affect the solubility of various nutrients. With the NFT system, the amount of nutrients and pH can be monitored and adjusted continuously.

High yield is preferred by tomato growers. However, as tomato production continues to expand, the market value of the fruit is also determined by fruit qualities such as size, shape, colour, taste and keeping quality. Improvement of fruit quality, generally, can be done through breeding programmes. Nevertheless, water stress has been reported to be beneficial in increasing the quality of various crops including tomato (Behboudian and Lawes, 1994; Chalmers, 1989; Mills et al., 1994; Rudich and Lukinsky, 1986). Efforts have been made in various studies to investigate and utilize the effects of water stress on plant growth, yield and quality, however, in many previous studies, it has been

difficult to achieve the desirable level of water stress through treatments like regulated deficit irrigation (Durand, 1990; Arzani, 1994). As tomato is one of the crops that can tolerate quite high salinity, water stress conditions can be introduced to the NFT tomato simply by increasing the electrical conductivity (EC) of the nutrient solution (increasing the concentration of the nutrient solution). The more exact and uniform level of water stress can be achieved more easily with the NFT as the EC levels can be monitored continuously. Furthermore, there is no local depletion of water around the root surface, as in soil or soilless substrate, because the roots are constantly bathed in a continuously flow solution (Adams, 1994).

The method of increasing EC levels of the nutrient solution to improve tomato fruit quality appears to be promising. Similar results of improving tomato fruit flavour with increasing EC levels were obtained from various studies, for example increasing sugars and total soluble solids (Adams and Ho, 1989; Mizrahi, 1982; Mizrahi et al., 1988) and increasing acids content (Gough and Hobson, 1990). However, the effect of increasing EC levels can also be detrimental as the quality improvement is usually accompanied by reduced yield. Moreover, there is still a variation in the findings in terms of vegetative growth, keeping quality and the degree of yield reduction. The variation in the findings could have been due to the difference in EC levels used, and the difference in response among different cultivars in different weather conditions. Understanding the effects of EC levels on tomato is necessary in order to identify the appropriate EC levels that will improve fruit quality with minimum yield loss.

The purpose of this study is to investigate the response of two tomato cultivars, Rondello and Concordia, in terms of vegetative growth, yield and some fruit quality attributes to different EC levels when grown with NFT in two different seasons, summer and winter.

CHAPTER TWO

LITERATURE REVIEW

2.1 THE TOMATO CROP

Tomato (*Lycopersicon esculentum* Mill) is a perennial vegetable fruit crop belonging to the family Solanaceae. Tomato plants can be divided, with respect to their growth habit, into two types i.e. determinate and indeterminate. Plants of determinate type may grow up to about 2 m in height. They have an erect and bushy stem with a restricted flowering and fruiting period. Indeterminate plants, on the other hand, may grow indefinitely, flowering and fruiting regularly (Picken et al., 1986). A tomato plant is constructed of sympodial shoots, each consisting of a stem section with three leaves and a terminal inflorescence (truss) (Russell and Morris, 1983). Generally, in glasshouse-grown indeterminate tomato cultivars, only the main sympodium is allowed to develop and other lateral shoots are removed (de Koning, 1994).

2.1.1 Vegetative growth

Vegetative growth, following germination, proceeds at first alone and then coincident with reproductive growth. Vegetative growth includes leaves, stem, shoot and root.

Leaves are arranged alternatively and produced regularly (Coleman and Greyson, 1976). Rate of leaf growth and development varies among seasons. Coleman and Greyson (1976) reported that tomato grown in the greenhouse initiated new leaves every 2 days in summer and every 2 to 5 days in winter.

Stem elongation is dependent on the level of daily irradiance. Reduced daily irradiance below $2 \text{ MJm}^{-2} \text{ d}^{-1}$ increases the rate of stem elongation (Hurd and Thornley, 1974). The rate of stem elongation is also affected by temperature, and generally increases with

increasing temperature (Calvert, 1964).

The shoot/root dry weight ratio increases as the plant grows (Picken et al., 1986). Rate of root growth decreases and the shoot/root dry weight or fresh weight ratio increases at high temperature (Kristofferson, 1963). The shoot/root dry weight ratio increases more slowly and reaches lower values in higher irradiance (Kristofferson, 1963). High humidity may encourage aerial adventitious root growth and promote root extension (Picken et al., 1986).

2.1.2 Reproductive growth

2.1.2.1 Flowers and flowering

Tomato flowers are perfect and are generally self-pollinated (Atherton and Harris, 1986). The flower cluster is a short, forked racemose cyme, usually with several flowers open at the same time so that buds, open flowers, and young fruit all occur together on the same truss (Davies and Hobson, 1981).

The number of developing fruit is the overall result of the flowering rate, the number of flowers initiated per truss and the incidence of abortion of flower buds, flowers and fruit (de Koning, 1994). Similar to many other developmental processes, flowering rate of tomato is strongly affected by temperature (Klapwijk and Buitelaar, 1977). Flowering is significantly delayed by low temperature (Bakker, 1989). In general, flower bud abortion is enhanced by low assimilate supply during development (Atherton and Harris, 1986), while the number of flowers that become young fruit (fruit set) depends strongly on the flower and pollen quality and prevailing environmental conditions (Picken, 1984). Low irradiance levels limit the production of assimilates by photosynthesis (Picken, 1984) and consequently induce flower abortion.

In indeterminate tomato cultivars, flower initiation once started continues through the life of the plant (Atherton and Harris, 1986). Generally, inflorescence is developed at

intervals of 3 leaves (Picken, 1984).

2.1.2.2 Fruit, fruit set and fruit development

Tomato fruit is a berry, composed of flesh (pericarp walls and skin) and pulp (placenta and locular tissue including seeds) (Fig. 2.1) (Ho and Hewitt, 1986).

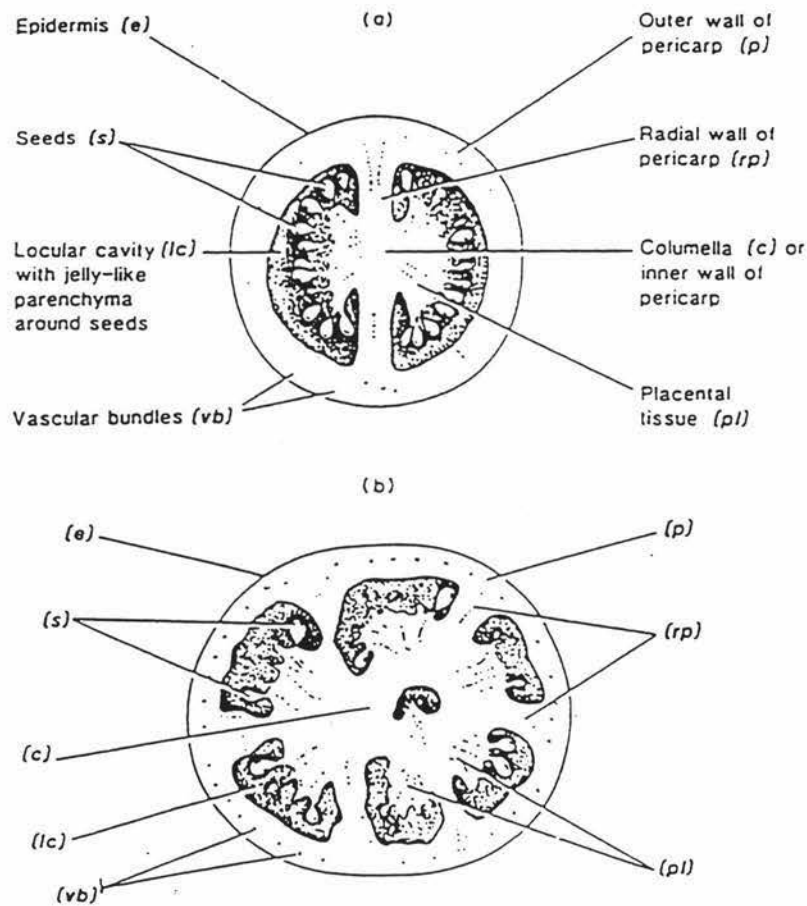


Figure 2.1: Anatomy of tomato fruits with (a) bilocular or (b) multilocular structure shown as transverse sections. (From: Ho and Hewitt, 1986)

Fruit set denotes the proportion of flowers which appear to reach anthesis normally and which subsequently set fruit of a marketable size (over 37 mm diameter in the UK) (Picken, 1984). Fruit increases in size by cell division which occurs during the first 7

to 14 days of fruit development and thereafter by cell enlargement (Davies and Hobson, 1981). Growth of a tomato fruit follows a sigmoid pattern (Monselise et al., 1978) in which growth rate slows down toward ripening (Mizrahi et al., 1988). The time required for a fertilised ovary to develop into a red ripe fruit is between 7 to 9 weeks, depending on cultivar, position on a truss and environment (Ho and Hewitt, 1986). The fruit is climacteric, showing a characteristic respiratory peak (Wills et al., 1989). Climacteric fruit show a drop in respiration to a pre-climacteric minimum, prior to ripening. At the onset of ripening, respiration increases, rises to a minimum, called the climacteric peak, and subsequently declines slowly (Grierson and Kader, 1986). In addition to a stimulation of respiration, climacteric fruit also inhibit an increase in ethylene synthesis during ripening. Many characteristic ripening changes begin to occur at about the same time as the increases in respiration and ethylene production (Fig. 2.2) (Grierson and Kader, 1986).

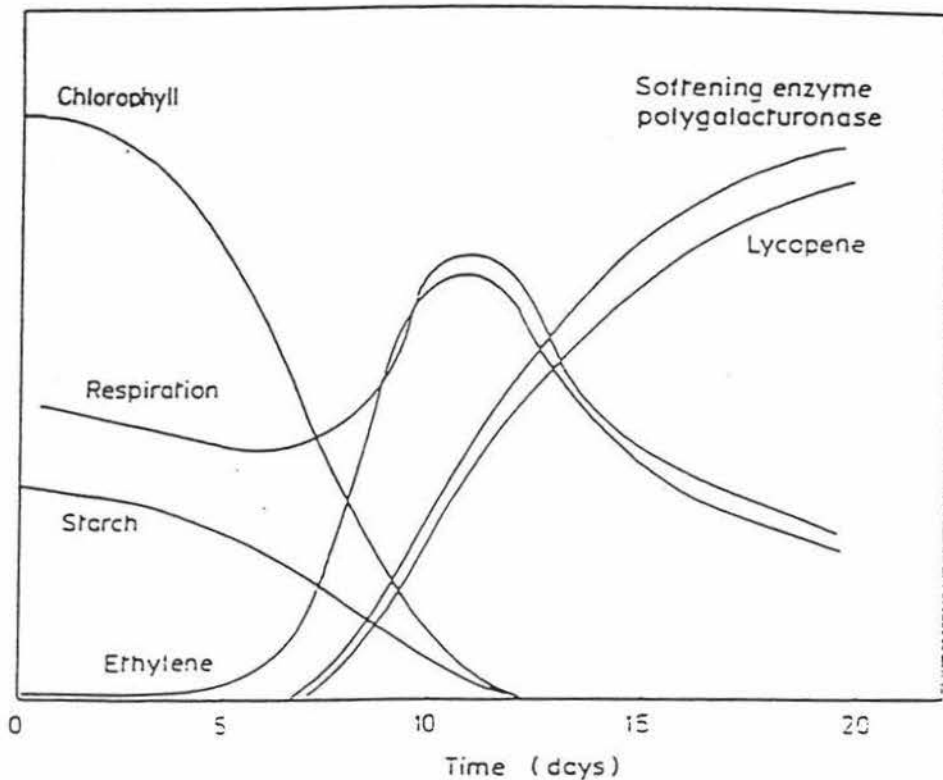


Figure 2.2: Changes in metabolism and composition during ripening. (From: Grierson and Kader, 1986)

2.2 QUALITY ATTRIBUTES OF TOMATO

The quality of tomato fruit may be considered in terms of external quality and compositional quality attributes. External quality attributes include size, shape, colour, and physiological disorders or mechanical damage. Compositional quality attributes which determine taste, flavour and nutritive value of the fruit include sugars, total soluble solids, acids, vitamins, etc.

2.2.1 External quality attributes

2.2.1.1 Size

Tomato fruit size varies among cultivars. Preference for a given size of tomato varies among consumers and depends, to some extent, on the intended use of the fruit. For example, the U.K. fresh salad market prefers tomato fruit size in the range of 47-57 mm in diameter. Such fruit weigh between 60 and 90 g (Cockshull and Ho, 1995). However, cherry tomato which is one of the most popular tomatoes in many parts of the world are relatively small, typically weighing between 10 and 35 grams (Hobson and Grierson, 1993). The potential size of tomato fruit is dependent on their position within a truss and on cultivar. But the actual size is dependent also on the amount of assimilates produced by the foliage and the number of fruit competing for the assimilates (Cockshull and Ho, 1995). The amount of assimilates produced by the foliage is regulated by photosynthesis, which, in turn, is dependent on the quality of solar radiation incident on the crop, the area of foliage available to intercept solar radiation, and the average CO₂ concentration by day (Cockshull and Ho, 1995). The number of fruit competing for assimilates is related to the rate of truss initiation, the number of fruit set on each truss, the number of plant per m², and the duration of fruit development (Ho and Hewitt, 1986). The availability of water for fruit growth can also influence fruit size because more than 90% of the fruit weight is water (Ehret and Ho, 1986b; Ho et al., 1987). Fruit weight and diameter are generally used to determined fruit size and these are generally strongly

correlated (Gough and Hobson, 1990).

2.2.1.2 Colour

Colour is one of the most important quality attributes associated with the evaluation of most food products and is the first aspect noticed by consumers (Gould, 1974). The external colour of tomato fruit is the result of both flesh and skin pigmentation. For example, a pink tomato has a colourless skin and red flesh whereas a red tomato has a yellow skin and red flesh (Grierson and Kader, 1986). Most consumers prefer deep, uniformly red-coloured tomato (Grierson and Kader, 1986).

The two major groups of pigments found in tomato fruit are chlorophyll and carotenoids. The production of the normal red colour of ripe fruit is a result of the destruction of chlorophyll and the extensive accumulation of carotenoids as the chloroplasts are transformed into chromoplasts (Grierson and Kader, 1986). Chromoplasts are plastids specialized to accumulate high levels of carotenoids and are responsible for the bright yellow and red colours of many fruits (Giuliano et al., 1993). In modern cultivated varieties, chlorophyll, which is located in the chloroplast thylakoids, reaches a peak in concentration relatively early in the growth of the fruit (Fraser et al., 1994). Fruit ripening, which occurs towards the end of development when growth has slowed down or ceased (Davies and Hobson, 1981) involves the conversion of chloroplasts into chromoplasts (Giuliano et al., 1993). During ripening process, chloroplasts differentiate into chromoplasts, chlorophyll content declines to undetectable levels, and carotenoid content increases (Giuliano et al., 1993). Changes from chloroplasts to chromoplasts start initially in the locular jelly surrounding the seeds and then in the pericarp, progressively from the blossom-end of the fruit to the stem-end (Davies and Hobson, 1981). Carotenoids are yellow, orange, and red pigments. Carotenoids include phytoene, a colourless compound and the first carotenoid in the pathway; ζ -carotene, a pale yellow compound; lycopene, a red compound; β -carotene, an orange compound; and xanthophylls or hydroxylated carotenoids, a yellow compound (Giuliano et al., 1993). Lycopene is the main pigment in ripe tomato fruit with β -carotene being the second

most prevalent pigment (Davies and Hobson, 1981). Lycopene is more concentrated in pericarp tissue whereas β -carotene is more concentrated in locular tissue (Thompson et al., 1965). Colour is an indicator of tomato ripeness. Table 2.1 shows ripeness classes of tomato as determined by skin colour.

Table 2.1 Ripeness classes of tomato (From: Grierson and Kader, 1986)

Score	Class	Description*
1	Green	Entirely light-to dark-green, but mature
2	Breaker	First appearance of external pink, red or tannish-yellow colour; not more than 10%
3	Turning	Over 10% but not more than 30% red, pink or tannish-yellow
4	Pink	Over 30% but not more than 60% pink or red
5	Light-red	Over 60% but not more than 90% red
6	Red	Over 90% red; desirable table ripeness

* All percentages refer to both colour distribution and intensity

2.2.1.3 Physiological disorders

One of the common physiological disorders found in tomato fruit is blossom-end rot (BER). Blossom-end rot is characterised by rotting of the tissue at the distal end of the tomato fruit (Ehret and Ho, 1986). Symptoms begin as a small, water-soaked spot at or near the blossom scar of green tomato. As the spot enlarges the affected tissues dry out and become light brown to dark brown. Then, the lesion develops into a well-defined sunken spot with the affected tissues collapsed and leathery (Grierson and Kader, 1986). Incidence and severity of blossom-end rot are influenced by calcium deficiency in these tissues (Ehret and Ho, 1986). Grierson and Kader (1986) have reported that the incidence of BER increases markedly when the concentration of calcium in the fruit falls below 0.08% (on dry weight basis) while at 0.12% calcium, BER seldom occurs. Adams

and Ho (1993) found that the lowest percentage of calcium was found in the distal placenta and locular tissues where BER first develops. Calcium is taken up to the plant by plant roots and inside the plant calcium travels with water along the transpiration stream through a system of xylem vessels (Ho et al., 1993). Thus leaves, the major organ for transpiration, are stronger sinks for calcium than fruit and generally, less than 3% of the calcium absorbed by a tomato plant enters into the fruit (Clover, 1991). After calcium is taken up into the plant, it is important that a sufficient amount of calcium reaches the young fruit during rapid growth. The critical period is about 2 weeks after anthesis when rate of fruit growth is very high and the BER symptoms usually appear during this early stages of active fruit growth (Belda and Ho, 1993). Possible factors that promote the incidence of BER are summarised in Figure 2.3.

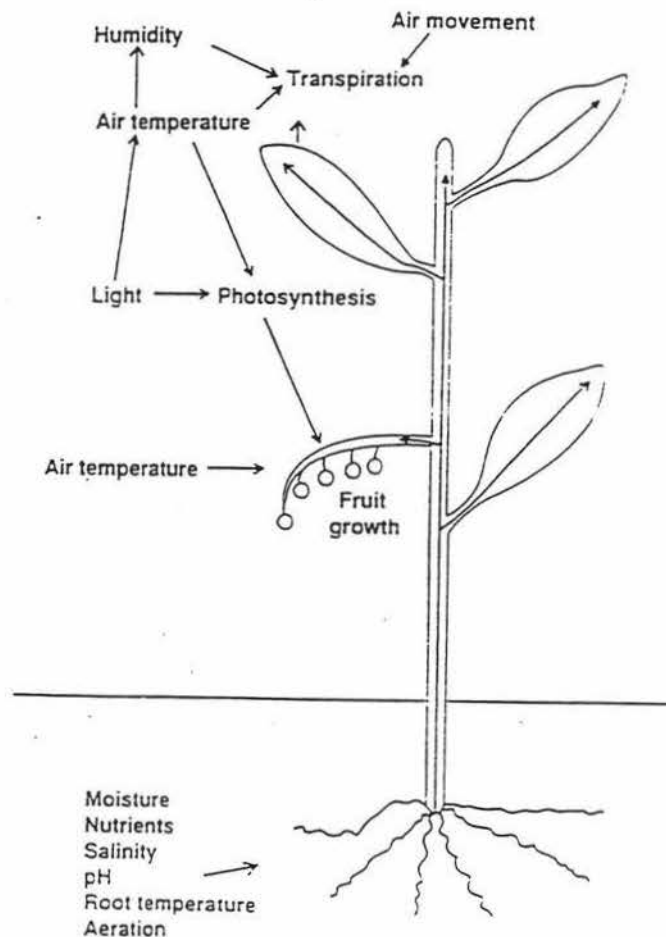


Figure 2.3: A diagram showing environmental factors that affect the uptake and internal distribution of water and nutrients by a tomato plant. (From: Adams, 1994)

Possible factors that promote the incidence of BER include:

A. Conditions that reduce uptake of calcium by the roots such as

- 1) restricted water supply (van Goor, 1974)
- 2) high salinity in the root zone (Adams and El-Gizawy, 1986; Adams and Ho, 1989; Ho et al., 1993; Ho and Adams, 1989)
- 3) low temperature in the root zone (Adams and Ho, 1993),
- 4) inadequate calcium nutrition and excessive use of ammonium-nitrogen, which is more competitive than calcium ion and can be taken up by plant roots more readily (Hobson and Grierson, 1993).

B. Conditions that encourage rapid fruit growth such as high temperatures, high light intensity, high CO₂ concentration. As a result, the fruit's calcium demands may not be met by the supply (Ho et al., 1993).

C. Conditions that stimulate transpiration such as high temperatures and low humidity. High transpiration causes a diversion of too much calcium to leaves instead of fruit (Adams and Ho, 1993; Clover, 1991), and the accumulation of calcium by fruit is inversely related to the transport of calcium to the leaves (Adams and Ho, 1993).

Incidence of BER differs substantially among cultivars (Adams and Ho, 1992). According to Ho et al. (1993), the susceptibility to BER is directly related to the capacity of calcium uptake by plant roots and the capacity of calcium transport into the fruit particularly in the distal part of the fruit which regulate the calcium supply, in relation to rate of fruit growth which regulates calcium demand.

The other common physiological disorder found in tomato are fruit cracking and blotchy ripening. Cracks may occur in circles around the stem scar (concentric cracking) or radiating from the stem scar (radial cracking) (Grierson and Kader, 1986). Cracks decrease the attractiveness of the fruit, increase an entry point for insects and decay organisms (Peet and Willits, 1995) and increase susceptibility of affected fruit to water loss (Grierson and Kader, 1986). Cracking is genetically control (Abbot et al., 1986) and appears to be related to skin strength and stretching ability (Grierson and Kader, 1986). Cracking is less observed when fruit is harvested at the mature-green or breaker stage,

on the other hand, its incidence increases when fruit is harvested at the pink or later stages (Peet and Willits, 1995). The proposed factors that cause fruit cracking in tomato include rapid fluctuation in soil moisture during maturation (Abbot et al., 1985) and rapid movement of water and solutes into the fruit (Peet and Willits, 1995). According to Peet and Willits (1995), fruit are particularly susceptible to cracking if physiological changes in the tomato skin during ripening or under certain soil moisture conditions reduce the strength and the ability of the tomato skin to stretch. For field-grown tomato, this most likely occurs when low soil-moisture levels are suddenly relieved by rain (Peet and Willits, 1995). In greenhouse tomato, Abbot et al. (1985) reported that cracking was decreased by 22% in tomato irrigated every day, compared to those irrigated only when needed. In the soil treatment, raising the irrigation frequency significantly decreased cracking in the susceptible cultivar. In the soilless treatment, on the other hand, frequent irrigation increased cracking in both susceptible and resistant cultivars. This could be because of high water retention in soilless treatment, frequent irrigation might therefore be overwatering and adversely affecting the plants' water relations (Abbot et al., 1985). Increase cracking in greenhouse tomato as a result of increasing the amount of water applied was also observed in the studies of Peet and Willits (1995). Soil water potential was found to be less negative in the treatments receiving more water. And this likely increased root pressure and seems the most likely explanation for increased fruit cracking (Peet and Willits, 1995).

The incidence of blossom-end rot is inversely proportional to cracking such that when the amount of water was increased, cracking increased, but blossom-end rot decreased (Peet and Willits, 1995). Good calcium nutrition has been implicated in preventing blossom-end rot and also in controlling fruit cracking (Peet, 1992).

Blotchy ripening (or irregular ripening) is characterized by green, greenish-yellow areas on apparently normal red fruit. Usually, it is confined to the outer walls, but in extreme cases radial walls can also be affected (Grierson and Kader, 1986). The exact cause of blotchy ripening is not yet known although there is a relationship between the concentration of potassium and inorganic nitrogen in the soil and the even ripening of

the fruit (Grierson and Kader, 1986).

2.2.2 Compositional quality

Fresh tomatoes provide a satisfactory amount of vitamin A and C, however they have little calorific value because of their low dry matter and fat content (Hobson and Grierson, 1993). Generally, the dry matter content of ripe fruit is within the range 5-7.5% and 100 g of raw tomato contains about 20 calories (Grierson and Kader, 1986). The ratio of sugars to acids plays a major role in determining the taste of a tomato, with high sugars and high acids being favoured (Hobson and Grierson, 1993).

2.2.2.1 Total soluble solids

In the water soluble portion of the fruit dry matter, about half is in the form of reducing sugars (fructose and glucose) and a quarter in the form of citric, malic and dicarboxylic amino acids, lipids and minerals (Davies and Hobson, 1981). Because sugars and organic acids (which are the important taste components of tomato fruit) account for the major portion of total soluble solids (TSS), TSS is often used as one of the quality parameters and as a parameter that reflects sugar status of the fruit. High TSS and a favourable TSS:acid ratio are essential to good quality tomato (Stevens, 1972). According to Davies and Hobson (1981), the refractive index of tomato fruit sap measured by a refractometer is closely correlated with the total solids content.

2.2.2.2 Acids

Fruit acidity increases from the immature-green to a maximum at the appearance of yellow pigmentation, followed by a progressive decrease as ripening continues (Winsor et al., 1962). Acid content in tomato fruit is higher in the locules than in the pericarp wall and placental tissues (Ho and Hewitt, 1986). The major acids are malic and citric (Hobson and Grierson, 1993). Although malic acid is the predominant acid in immature green fruit, it decreases with increasing maturity and declines rapidly during ripening

(Davies and Hobson, 1981). Citric acid content is more stable throughout the ripening period (Hobson and Grierson, 1993). As a result of their different rates of synthesis and turnover during ripening, the malic to citric ratio was found to decrease rapidly throughout the development of tomato fruits (Davies, 1966). In ripe fruit, citric acid accounts for between 45% and 66% of the total acidity of the English cultivars, and between 40% and 90% for the American cultivars (Davies and Hobson, 1981). According to Davies and Hobson (1981), titratable acidity is closely correlated with citric but not malic acid. The titratable acidity increased from the immature-green through the breaker stage, followed by a decrease up to the red-ripe stage (Young et al., 1993).

2.2.2.3 Dry matter content

Fruit dry matter content as percentage of fruit fresh weight is a measure of the total solids, consisting of the water soluble (Section 2.2.2.1) and insoluble solids. Although the dry matter of tomato fruit can vary from below 5% to nearly double that amount, for most modern varieties it lies between 5 and 7.5%. Of this dry matter, about half is in the form of reducing sugars, with slightly more fructose than glucose. A further quarter of the dry matter consists mainly of citric, malic and dicarboxylic amino acids, lipids, and most of the minerals. The composition of the remaining quarter is alcohol-insoluble solids i.e. protein, pectic substances, cellulose and hemicellulose (Davies and Hobson, 1981). Figure 2.4 shows the composition of tomato fruit in terms of the dry matter in the fresh tissue.

The level of the dry matter depends to a considerable extent on season, nutrition and environment (Davies and Hobson, 1981). The percent dry matter decreases throughout the maturation of the fruit when expressed on a fresh weight basis. This decrease in the percent dry matter may be due to respiration and a dilution in concentration resulting from fruit water uptake (Young et al., 1993). Factors that may influence the dry matter content of tomato fruit include a high leaf area : fruit ratio, the rate of assimilates export

from leaves, rate of import of assimilates by fruit, and fruit carbon metabolism (Hewitt et al., 1982).

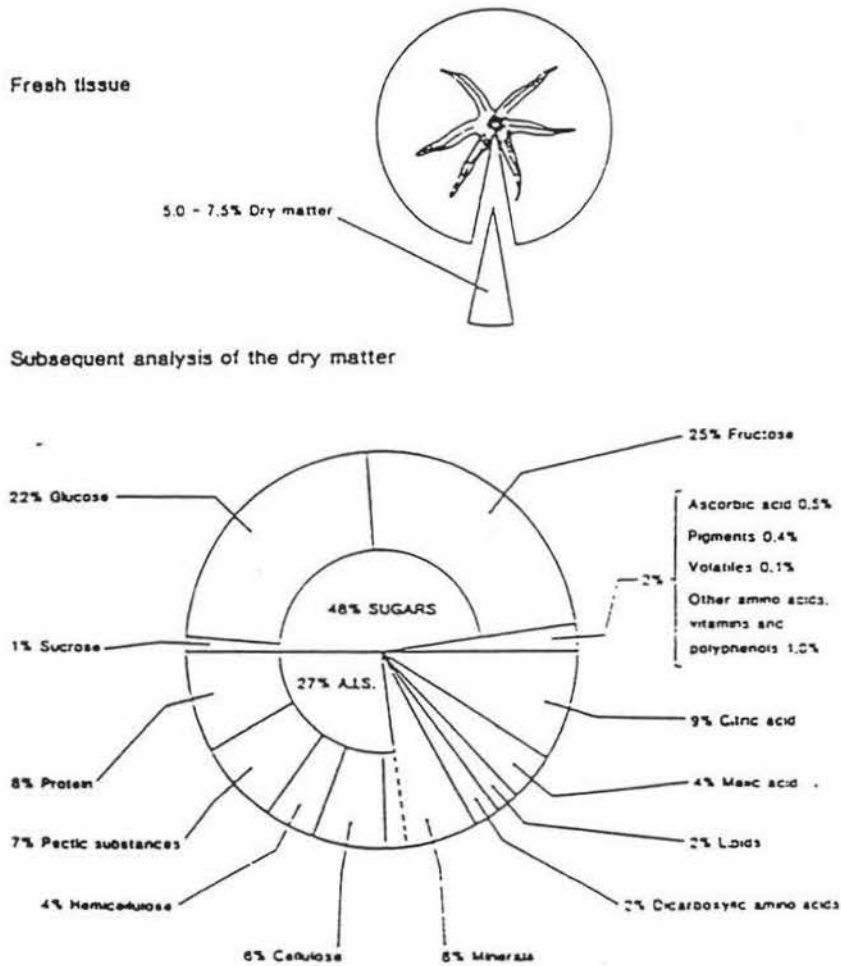


Figure 2.4: Composition of tomato fruit in terms of dry matter in the fresh tissue, and the subsequent balance of constituents in the dry matter fraction. (From: Davies and Hobson, 1981)

2.2.3 Susceptibility to weight loss

Besides visual appearance and composition of the fruit the other fruit quality which is important not only to consumers but also to market distributors is the shelf life of the fruit.

Gough and Hobson (1990) defined shelf life as the length of time that a uniform batch of fruit of a particular colour stage can reasonably be expected to remain in a saleable condition. A 'shelf-life index', however, still needs to be developed. Gough and Hobson (1990) proposed that the index can be derived by obtaining the rate of change in colour and firmness of the fruit. Nevertheless they also mentioned that this would have to be calibrated subjectively by experienced personnel to define a firmness and colour coefficient for each cultivar studied at which the shelf life is considered to be exceeded.

All fruits and vegetables lose water after they are harvested. Water loss is a major cause of deterioration in storage and leads to undesirable characteristics such as loss of marketable weight; poor appearance of the product as it wilts and shrivels; changes in the texture due to reduction in cell turgor e.g. loss of succulence; undesirable changes in colour and palatability; early ripening and senescence; and increased susceptibility to diseases (Grierson and Wardoski, 1978; Woods, 1990). Water contributes more than 90% of tomato fruit weight (Ehret and Ho, 1986b). The susceptibility of the fruit to water loss is therefore one of the important factors affecting keeping quality and shelf life of tomato fruit.

2.3 NUTRIENT FILM TECHNIQUE

The nutrient film technique (NFT) is a hydroponic method of growing plants in a thin film of aerated nutrient solution which is continuously recirculated (Tregidga and Lewthwaite, 1986). The basic features of a system for nutrient film technique are: (1) a tank of nutrient solution; (2) a pump to deliver the solution, via pipes, to the upper end of (3) the sloped gullies in which the plants are grown; and (4) a means of collecting the solution as it flows from the lower ends of the gullies and returning it to the tank for recirculation (Adams, 1981). The main features of NFT are shown in Figure 2.5. The gullies may be made of almost any water proof material that is not phytotoxic. The nutrient solution is corrosive and so iron fittings cannot be used, as their corrosion leads to problems with iron and zinc concentrations (Tregidga and Lewthwaite, 1986).

Doublesided black and white polythene sheet (Panda film) is often used with the black layer inside and the white layer outside to reduce heat absorption and increase the reflection of light (Adams, 1981). The length of the gullies should not exceed 30 m, as aeration decreases with length, and growth towards the end of the gully may be inhibited. The gullies should be sloped at not less than 1:100 (Adams, 1981). Slopes of 1:60 to 1:75 are commonly used. Flow rate of nutrient solution should be about 2-3 litres per minute (Adams, 1981). As a plant matures it takes up nutrients at different rates to match its changing requirements. In order to adjust these changing conditions, circulating solution and leaf nutrient concentrations should be tested monthly. However, small scale growers, who cannot justify the cost of analysis, have successfully replaced the circulating solution every 4-6 weeks.

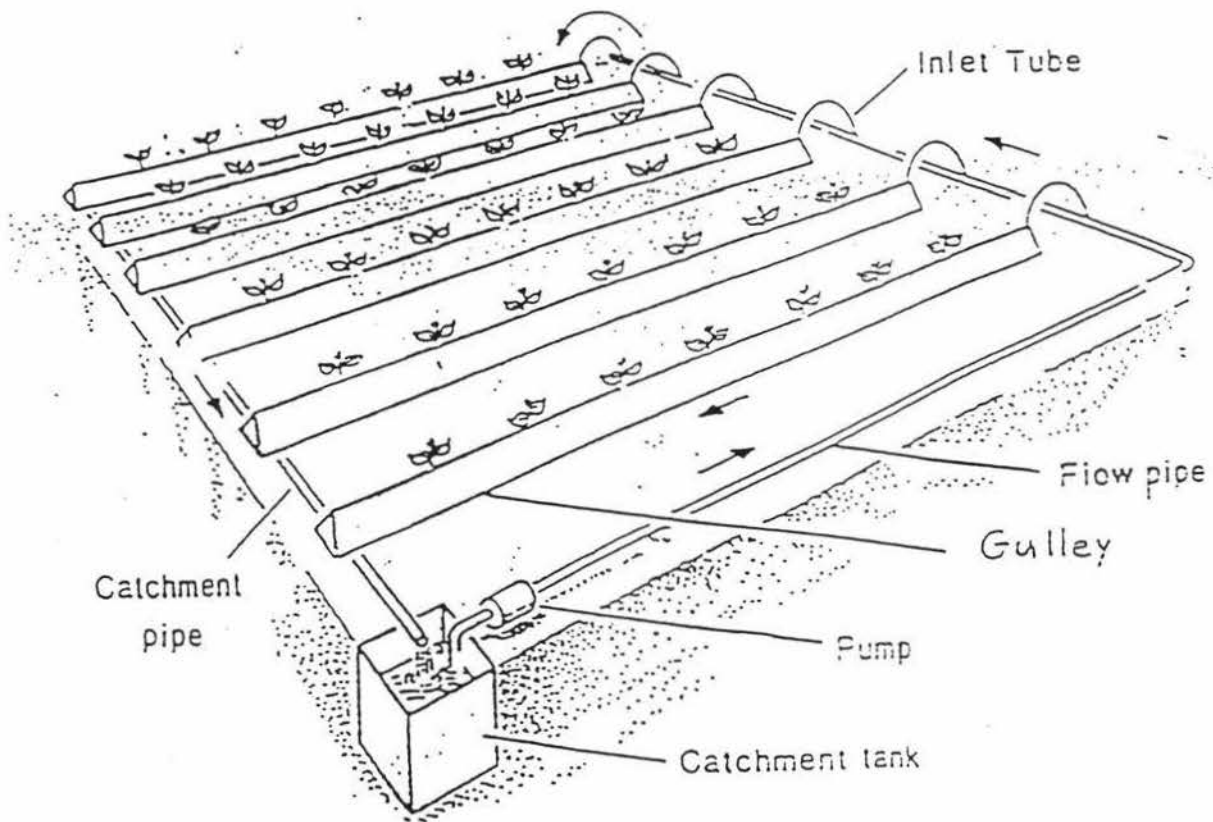


Figure 2.5: The main feature of a nutrient film technique (NFT).

The advantages of NFT include (Adams, 1981):

- a) Effective use of water and fertilizer
- b) Improved control of weed and soil borne diseases and pests
- c) Improved control of the below ground environment e.g. nutrient, water, O₂
- d) Maximum potential of the cropping space may be achieved as very little time is needed between crops

The disadvantages of NFT are (Adams, 1981):

- a) High cost
- b) The absence of a solid substrate may result in rapid wilting of the crop when the nutrient solution is interrupted by, for example, a pump or power failure.

2.4 EFFECTS OF EC ON PLANT WATER STATUS

Conductivity or electrical conductivity (EC) is the measurement of the amount of electrolyte which is directly related to the amount of nutrient ions that are dissolved in the nutrient solution. The unit of measurement is milliseimens per cm (mScm⁻¹). The nutrient solution conductivity used depends on crop. For tomatoes, most commercial growers in New Zealand use a conductivity ranging between 1 and 3.5 mScm⁻¹. Changes in EC of nutrient solution affects water potential of the solution and therefore affect plant water uptake and plant water status.

2.4.1 Water potential

Water potential indicates the energy status of water. It may be defined as the difference in chemical potential per unit volume between a given water sample and pure free water at the same temperature (Mengel and Kirkby, 1987). The relationship is expressed as:

$$\Psi_w = (\mu_w - \mu^{\circ}_w) / V_w$$

Where: Ψ_w is the water potential; μ_w is the chemical potential of the water under consideration (Jmol^{-1}); μ°_w is the chemical potential of pure free water at the same temperature (Jmol^{-1}); and V_w is the partial molal volume of water in the system ($\text{m}^3 \text{mol}^{-1}$). The international standard unit of water potential is Pascal (Pa) ($\text{Pa} = \text{Nm}^{-2}$). The water potential of pure water is by definition zero.

Water potential can be partitioned into various components (Jones et al., 1985):

$$\Psi_w = \Psi_p + \Psi_s + \Psi_g + \Psi_m$$

Where: Ψ_p is the turgor potential, Ψ_s is the osmotic potential, Ψ_g is the gravitational potential, and Ψ_m is the matric potential. Turgor potential (Ψ_p) is numerically equal to the hydrostatic pressure. Increasing the hydrostatic pressure increases the water potential and therefore turgor potential is always positive (Mengel and Kirkby, 1987). Osmotic potential (Ψ_s) is the potential resulting from the presence of solutes and is sometimes called solute potential. The introduction of solutes into water reduces the water concentration or more precisely the activity of the water molecules. This decreases the water potential. The osmotic potential is always a negative value as it is always lower than zero, the water potential of pure water (Mengel and Kirkby, 1987). The gravitational potential (Ψ_g) increases by only 0.01 MPa for each 1 m increase in height and hence it is usually ignored (Jones et al., 1985). Matric potential (Ψ_m) represents suction. It is made up by the effects of solid surfaces on the water phase. Water can be bound to large molecules such as proteins and polysaccharides by means of H bonding. Besides this adsorptive effect, water is also held in capillaries by surface tension effects. As these forces restrict the mobility of water, they tend to lower the water potential. The sign of matric potential (Ψ_m) is therefore negative (Mengel and Kirkby, 1987). In plants, matric potential is often ignored as, in fresh plant material, the proportion of matric bound water is usually very low (Mengel and Kirkby, 1987).

2.4.2 Water movement up the plant

A difference in water potential is the driving force for water movement. Water moves from a higher to a lower water potential (Salisbury and Ross, 1992). Plants generally have a high tissue water potential, mostly greater than -2 MPa whereas the atmosphere usually has a relatively low water potential (-95.6 MPa at 25 °C and 50% RH) (Hinckley and Braatne, 1994). Similarly, the water potential of the soil solution is usually much higher than the water potential of the plants. Thus a very large energy gradient exists within the soil-plant- atmosphere continuum. This gradient is the driving force that causes the translocation of water from the soil solution through the plant to the atmosphere (Mengel and Kirkby, 1987).

2.4.3 Plant water status

Several methods have been used to estimate plant water status. The common methods are total water potential (Ψ), osmotic potential (Ψ_s), turgor pressure (Ψ_p), and relative water content (RWC) (Rudich et al., 1981). The leaf/xylem water potential, Ψ , is a widely accepted parameter for the measurement of plant water status. Leaf water potential can be determined by a 'Scholander pressure chamber'. The unit measured by 'Scholander pressure chamber' is the bar which can be converted to pascal (Pa) as 1 bar = 10^5 Pa (Mengel and Kirkby, 1987). Lower leaf/xylem water potential indicates a lower water status of the plant.

The nutrient solution used in NFT system is comparable with the soil solution. The difference in water potential between nutrient solution and a plant is the driving force of water movement from the solution into the plant. Increasing EC (solutes) of the nutrient solution decreases the osmotic potential (becomes more negative) and therefore decreases the water potential of nutrient solution. This in turn decreases the gradient between water potential of the nutrient solution and the plant, resulting in less water movement up the plant and thus lower plant water status. It has been observed that at high EC both the uptake of water by plants (Ehret and Ho, 1986b; Papadopoulos and

Rending, 1983) and the accumulation of water by fruit (Ehret and Ho, 1986b) were reduced. Water potential of fruit grown at 2 mScm⁻¹ was found to be higher than those at 17 mScm⁻¹ (Ehret and Ho, 1986b). Similarly, Mitchell et al. (1991a) reported a lower water content in fruit (at maturity) from plants grown at higher EC.

2.5 EFFECTS OF EC ON GROWTH, YIELD AND QUALITY

Water is an important structural component in plants. Water is a solvent for many substances such as inorganic salts, sugars, and organic anions. It is the medium in which all biochemical reactions take place. It is also essential for the translocation and distribution of nutrients and metabolites throughout the entire plant (Mengel and Kirkby, 1987 p.193). Plant water status, therefore, plays a major role in various physiological and developmental processes and affects growth, yield, and quality. Changes in nutrient solution conductivity have the potential of affecting plant water status (Section 2.4) and therefore growth, yield and quality.

2.5.1 Vegetative growth

Growth usually implies permanent increase in size. It results from cell division followed by enlargement and differentiation, and all these processes are affected by plant water status (Kozlowski et al., 1991). Water is essential for cell turgor and a minimum degree of cell turgor is necessary for cell expansion. Cell enlargement is a complex process that requires simultaneous intake of water, extension of cell walls, and a sustained supply of solutes necessary to maintain turgor in the expanding cells (Boyer, 1985). Cell enlargement is generally regarded to be more sensitive to water deficit than cell division. Cell size, however, affects cell division because cells do not divide until they have attained a certain size (Kozlowski et al., 1991). According to Chalmers (1989) shoot growth is usually more sensitive to water deficit than fruit growth. Decreased vegetative growth in terms of both fresh and dry weight as a result of increasing the EC was

observed (Charbonneau et al., 1988; Hayward and Long, 1943). Vegetative growth in response to EC varies among cultivars. Charbonneau et al. (1988) reported a decrease of plant height by 6% for 'Carmello' cultivar and by 14% for 'Vendor' cultivar when plants were grown at 10 mScm⁻¹ EC. Mitchell et al. (1991a), however, reported that high EC did not affect tomato plant growth.

The variation in the findings may be due to different levels of EC, tomato cultivars, and growing conditions used in the experiments. Charbonneau et al. (1988) conducted the experiment in a hydroponic system using rockwool. Two cultivars, Carmelo and Vendor, and three levels of EC, 2, 6, and 10 mScm⁻¹ were used. Mitchell et al. (1991a), on the other hand, conducted the experiment in soil (field condition) using 'UC82B' processing tomato cultivar. Raising EC was done by saline irrigation. The EC levels achieved varied greatly at different soil depth and different times of crop development, ranging from 1.72 to 6.63 mScm⁻¹ at 30 cm depth and lower at the greater depths.

2.5.2 Yield

The results from many studies found that yield, in terms of fruit fresh weight, is adversely affected by increasing EC beyond a certain level (Adams, 1989; Adams and Ho, 1989; Cornish, 1992; Gough and Hobson, 1990; Mizrahi et al., 1988). Previous work done by Adams (1989) in NFT showed that EC of 5.5 mScm⁻¹ did not reduce yield but further increases in EC reduced yield significantly. In the study by Gough and Hobson (1990), fruit yield was reduced at EC of 8 mScm⁻¹ but no significant differences in fruit yield were observed at the lower levels of EC (3 and 5 mScm⁻¹). The decreased yield is mainly due to reduced fruit size (Mizrahi et al., 1988; Cornish, 1992; Gough and Hobson, 1990; Hobson, 1988). However at very high EC fruit number may also be reduced. In the study by Adams (1991), the lower yield at 8 mScm⁻¹ were due to a decrease in fruit size only, whereas at 12 mScm⁻¹ both the number and size of the fruit were reduced. A similar insensitivity of fruit set in tomato to EC levels was observed by Mitchell et al. (1991a).

2.5.3 Fruit quality

The results from various studies indicate that increasing EC of nutrient solution has the potential of improving tomato fruit quality particularly in terms of TSS, acidity, percentage dry matter content and colour. However, the improved quality resulting from increasing the conductivity is often accompanied by reduced fruit size and increased incidence of physiological disorders especially blossom-end rot.

2.5.3.1 Size

Various studies found that increasing EC decreases individual fruit fresh weight resulting in decreased fruit size (Adams, 1991; Cornish, 1992; Ehret and Ho, 1986; Gough and Hobson, 1990; Mizrahi et al., 1988). Reduction in individual fruit fresh weight at high EC may be due to a depression in fruit growth and development as a result of a low plant water status. Mizrahi et al. (1988) suggested that if high EC is applied at a late stage of plant development and when many fruit have already formed and some completed the main stage of growth, reduction in size can be minimised. This may probably be a useful method in application of high EC to determinate type tomatoes which are source limited. For indeterminate cultivars, as new trusses develop, flowering and fruit set is continuous, therefore application of high EC during flowering and fruit set cannot be totally avoided. However, indeterminate cultivars have excess foliage, usually with more photosynthetic area than the fruit needs (Rudich and Luchinsky, 1986).

2.5.3.2 Colour

Mizrahi (1982) reported that fruit from plants grown under high EC conditions were redder (as confirmed by pigment concentration measurement) than those from plants grown under low EC conditions. Janse and Aalbersberg (1984) reported that high EC levels slightly accelerated fruit coloration. According to Paz et al. (1982), ethylene increases carotenoid concentration of tomato fruit. Ishida et al. (1993) also reported that

the peak lycopene formation coincided with the peak of ethylene production. More ethylene production was found in tomato fruit harvested from plants grown with high EC conditions (Mizrahi, 1982; Hobson, 1988). It is therefore possible that the redder colour of fruit at high EC levels was a result of the higher ethylene production of these fruit. Both colour and ethylene production are parameters that indicate maturation and ripening stages of tomato fruit. Mizrahi et al. (1982) found that various parameters of fruit ripening process include colour, activity of pectolytic enzymes, and ethylene and CO₂ evolution increased in fruit from plants grown at high EC. It is therefore possible that high EC accelerate fruit maturation and ripening resulting in more advance in colour.

2.5.3.3 Physiological disorders

Many studies have observed that the incidence of blossom-end rot (BER), a common physiological disorder of tomato, increases with increasing EC. (Adams and El-Gizawy, 1986; Adams and Ho, 1993; Charbonneau et al., 1988; Ho et al., 1993). The most likely causes of the disorder are poor calcium uptake by the roots and/or inadequate distribution of calcium to the fruit at a period of high calcium demand (Section 2.2.1.3). According to Adams and Ho (1993), the uptake of calcium ion is reduced by osmotic stress or by cation competition in the root zone. High EC in the nutrient solution or soil solution causes osmotic stress in the root zone resulting in restricting water uptake and thus reduces calcium ion uptake. Besides reduced uptake of calcium by the roots, osmotic stress may also reduce the capacity of calcium transport to the distal fruit tissue through reduced xylem tissue development in the fruit (Ho and Adams, 1989a; Ho, et al., 1993).

Incidence of BER differ greatly among cultivars in response to salinity (Adams and Ho, 1992). And the incidence of BER of the same cultivar changes during plant development and is closely related to seasonal changes (Ho et al., 1993). The physiological basis of the susceptibility to BER (Section 2.2.1.3) is the interaction between fruit growth habit and the growing environment (Ho et al., 1993). High light intensity increases

photosynthesis in the leaves and thus increase the import of sucrose for fruit growth (Ho et al., 1993). In addition, irradiance increases the ambient temperature. This increased temperature stimulates cell enlargement, resulting in a higher import rate of assimilate as well as greater rate of fruit enlargement (Walker and Ho, 1977). Moreover, canopy transpiration would be enhanced by irradiance as well as by lower relative humidity due to higher ambient temperature in the glasshouse (Aikman and Houter, 1990), enhancing transport of calcium to the leaves rather than to the fruit (Section 2.2.1.3).

2.5.3.4 Total soluble solids

Results from many studies show that increasing EC increases total soluble solids of tomato fruit (Adams and Ho, 1989; Cornish, 1992; Ho and Grimby, 1990; Mitchell et al., 1991a; Mizrahi, 1982; Mizrahi et al., 1988). Ehret and Ho (1986b) explained that the promoting effect of high EC on TSS was due to the fact that, at high EC, the accumulation of water by fruit was reduced while the accumulation of assimilates was unaffected. Dinar and Steven (1981) found a positive association between the level of starch in early stages of fruit development and TSS of ripe fruit in several tomato cultivars. Starch and structural materials are the only forms of storage of imported carbon. Starch levels increase in early stages of fruit development followed by a decrease to virtually zero by ripeness due to subsequent conversion to sugars (Davis and Cocking, 1965). Upon ripening, starch hydrolysis occurs and starch are converted to sugars which is the major component of soluble solids (Dinar and Steven, 1981). Therefore, starch accumulation at early fruit development and starch hydrolysis at ripening appear to play an important role in determining the amount of TSS in ripe fruit. Starch levels during the early stages of fruit development appeared to be increased at high EC (Ehret and Ho, 1986; Mitchell et al., 1991a and 1991b). The increase in TSS at high EC could also be due to enhanced conversion of starch to sugars which occurs as a result of water deficit (Kramer, 1983).

2.5.3.5 Acids

Titrateable acidity was found to increase in the sap of tomato fruit grown at high EC levels (Adams, 1991; Adams and Ho, 1989; Cornish, 1992; Cornish and Nguyen, 1989; Gough and Hobson, 1990; Hobson, 1988; Mitchell et al., 1991b; Mizrahi, 1982). The coupling of increased organic acid concentrations with increases in the ratio of inorganic cation:anion uptake has been proposed by Davies (1964) as a means to maintain electro-neutrality in tomato fruit tissue. An increase in total cation and a decrease in total anion accumulation per unit dry weight in mature fruit at high EC were reported (Mitchell et al., 1991b). Mitchell et al. (1991b) explained that higher titrateable acidity level and organic acid accumulation of fruit from plants grown at high EC levels resulted from an increase in the fruit cation:anion ratio.

2.5.3.6 Dry matter content

One of the main effects of high EC in the nutrition of tomato is on the dry matter content as a percentage of the fruit fresh weight. Various studies found that percentage dry matter of the fruit markedly increased by increasing EC (Adams, 1991; Adams and El-Gizawy, 1986; Ehret and Ho, 1986b; Ho and Grimby, 1990). According to Ho and Grimby (1990), water stress reduced the quantity of phloem sap entering the fruit but it also increased the phloem sap concentration. Therefore although less water accumulated in the fruit, the dry matter still accumulated to the same level as normal fruit. The result is a high percentage of dry matter in the fruit.

CHAPTER THREE

MATERIALS AND METHODS

3.1 EXPERIMENTAL SITE

The experiments were carried out at the Plant Growth Unit, Massey University, Palmerston North, New Zealand (Lat.40 ° 23'S, Long.175 ° 37'E). Two experiments were conducted, one in the summer and the other in the winter.

3.2 CLIMATE

The climatic data of the area during the experimental period (November 1994 to October 1995) is shown in Figure 3.1. The parameters recorded monthly included pan evaporation, air temperature, air relative humidity (RH) and sunshine hours. These meteorological data were recorded in a standard electronic weather station (AgResearch Grasslands, Crown Research Institute (CRI), Palmerston North) located approximately 1 km from the experimental site.

a) Pan evaporation

A large variation in pan evaporation is recorded in the area during the experimental period, ranging from 17.8 mm to 181.4 mm. The lowest mean monthly pan evaporation is recorded in June 1995 and the highest in January 1995.

b) Temperature

Mean monthly temperatures recorded during the experimental period range from 4.6 °C in July 1995 to 14.5 °C in February.

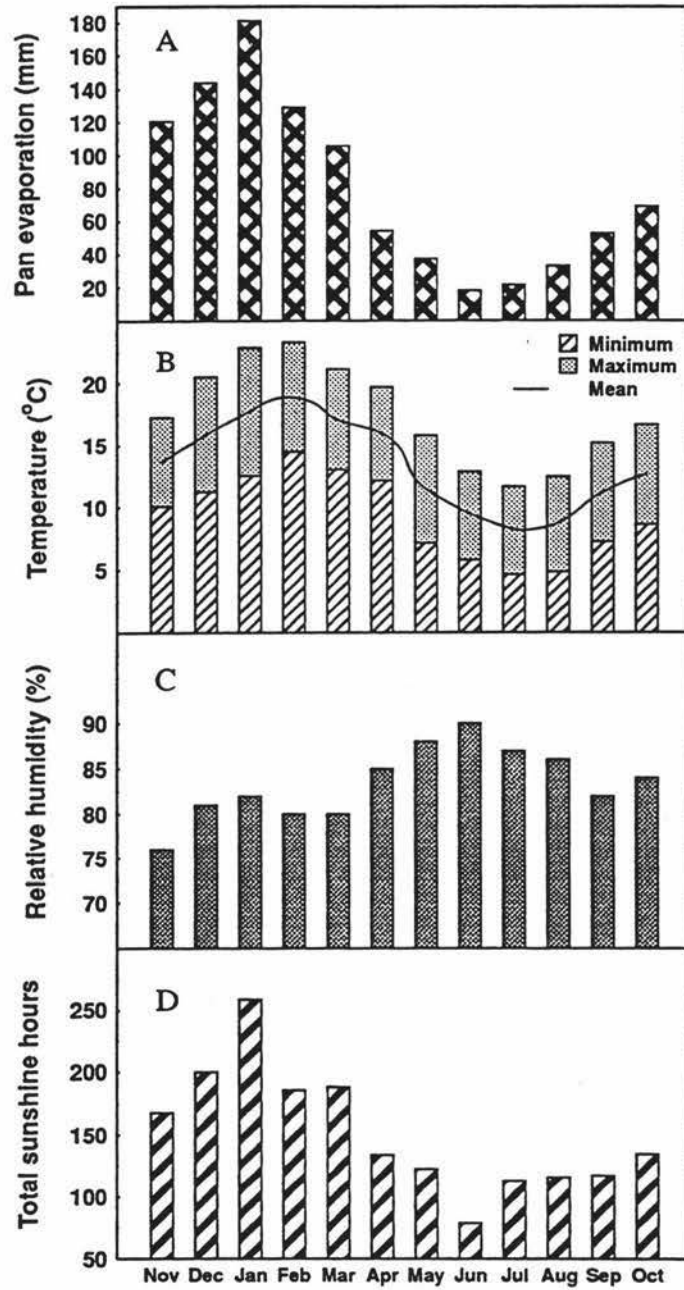


Figure 3.1: Summary of the climatic data during the experimental period (November 1994 to October 1995) for the Manawatu region.

c) Relative humidity

The area experiences a high RH throughout the year in the range of 76.0% to 90.0% with the highest mean monthly RH occurring in June and the lowest in November.

d) Sunshine hours

The highest mean monthly sunshine hours is recorded in January (188.4 hours) and the lowest is recorded in June (79.2 hours).

3.3 PLANT MATERIAL

Two fresh market tomato cultivars, Concordia (a long shelf life cultivar) and Rondello (a standard greenhouse tomato) were used in the experiments. Both are indeterminate type.

3.4 SOWING AND TRANSPLANTING

Seeds were sown on 3 October 1994 for the summer experiment and 13 March 1995 for the winter experiment. Sowing was done in plug trays using bark-based seed germination media made up of dolomite 300 g per 100 litres, agricultural lime 300 g per 100 litres, PG mix 200 g per 100 litres and 100% bark. Seedlings were transplanted 10 days after sowing into 8 cm-diameter plastic pots filled with bark-based growing media for short term (less than 4 months) greenhouse crops composed of dolomite 300 g per 100 litres, agricultural lime 300 g per 100 litres, iron sulphate 50 g per 100 litres, osmocote plus (15-4.8-11.3) 450 g per 100 litres and 100% bark. Plants were transferred in the plastic containers to the Nutrient Film Technique system on 3 November 1994 for the summer experiment and 14 April 1995 for the winter experiment. The bottom of the plants containers were cut off before placing the plants into the NFT system. A nutrient solution with 2 mScm^{-1} was used for all plants until the treatments were applied.

3.5 GROWING CONDITIONS

In order to protect the NFT gullies from direct contact with soil, double sided (black and white) polythene sheet (Panda film) was placed over the floor. The white side was placed on top to reflect the light into the greenhouse, and the black side faced the floor to cut out the light and prevent weed growth. The gulleys consisted of a metal base (width = 24 cm) with Panda film on top. The black layer of the polythene sheet was inside and the white layer was outside to reduce heat absorption and increase the reflection of light. The two edges of the polythene sheet were clipped together to form a gully, minimise evaporation and exclude light, which would otherwise encourage the growth of algae. A photograph of the NFT construction is shown in Figure 3.2. The 100-litre capacity tanks of nutrient solution were placed below ground level with the top of the tanks being lower than the gully level. The tanks were cover with removable wooden boards to exclude light and reduce contamination. The solution was continuously pumped to the upper end of each gully at a rate of approximately 2 litres per minute. The solution then flowed down the gullies and back to the tanks by gravity.

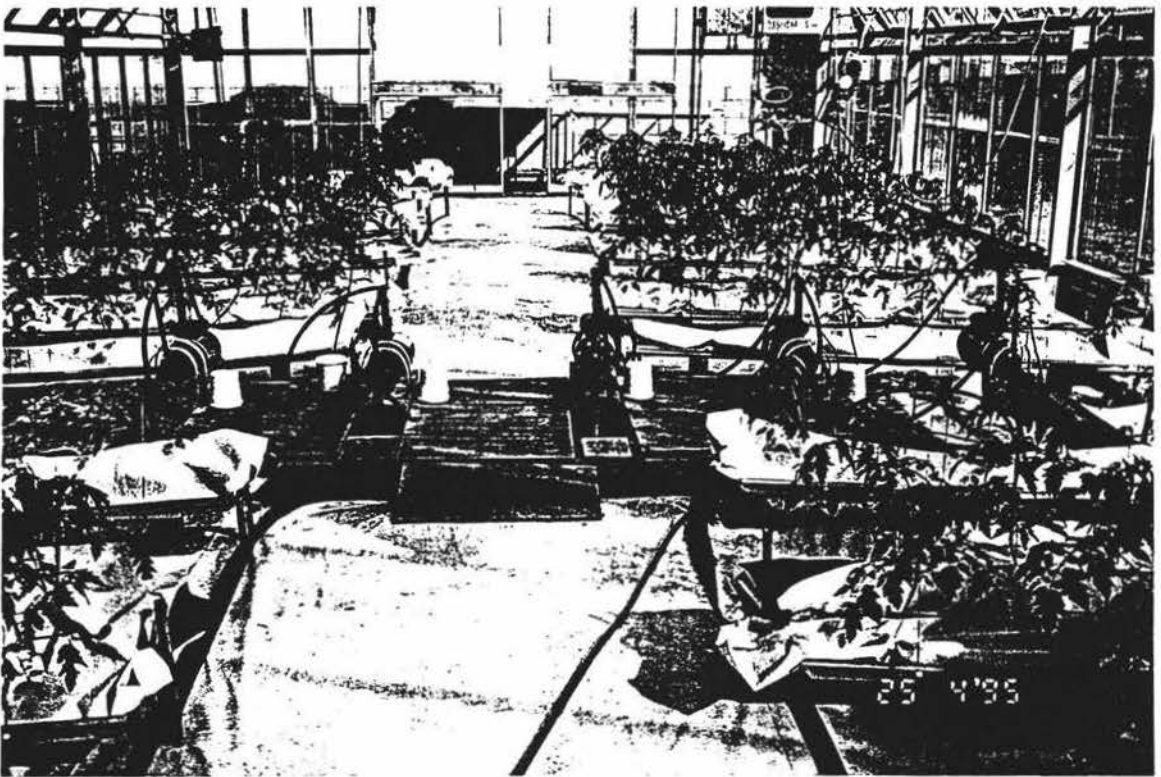


Figure 3.2: A diagram of the NFT construction in the current experiment.

Temperatures in the greenhouse were partly controlled via a heating system when temperatures fell to 16°C and ventilating when temperatures reached 25°C. A 'Standard Greenhouse Tomato Solution' was used as the nutrient solution (appendix A). The pH of nutrient solution was kept between 5.5 and 6.5. Phosphoric acid ($H_2(PO_3)^{2-}$) was used to lower the pH and potassium hydroxide (KOH) was used to raise the pH.

3.6 TREATMENTS AND EXPERIMENTAL DESIGN

The design of the experiment was a split plot design with three replications. The treatments consisted of four levels of nutrient solution at conductivities 2, 4, 6, and 8 $mScm^{-1}$, as main-plots and two tomato cultivars, Rondello and Concordia, as split plots. Each replication consisted of four plots with the four levels of nutrient solution conductivity as a double row, with one row of each cultivar, in each plot. The rows were 48 cm apart with the plants 35 cm apart in the row and a 80 cm path between the double rows. Guard plants were grown in double rows at the end of each replication facing the greenhouse wall, and in single rows at the end of each replication facing the nutrient solution tanks area. Five tanks were used, four of them were for the four levels of nutrient solution conductivity and the fifth for the guard plants. Each tank had its own pump (Type CP 11 MONO, Model MPE 524-HHG 3-90, 180 Watt, rpm 1425).

Increased levels of conductivity were achieved by adding macronutrients. The conductivity and pH level of the nutrient solution were monitored and adjusted twice a day for the summer experiment and once a day for the winter experiment. Conductivity levels were measured using a cF meter and pH by a pH meter. The nutrient solution in each tank was totally replaced every two weeks for the summer experiment and every three weeks for the winter experiment. Treatments were started when approximately half of the first flowers of the first trusses were opened.

3.7 NUTRIENT SOLUTIONS AND CONDUCTIVITY ADJUSTMENT

3.7.1 Nutrient solutions

Stock solutions were prepared and stored in four separate containers. The four stock solutions were:

- A. Chelate iron (Fe Na) 0.158 kg in 20 litres of water
- B. Calcium nitrate ($\text{CaNO}_3 \cdot 4\text{H}_2\text{O}$) 1.976 kg in 20 litres of water
- C. Potassium nitrate (KNO_3) 1.316 kg, Mono potassium phosphate (KH_2PO_4) 0.544 kg and Magnesium sulphate ($\text{MgSO}_4 \cdot 7\text{H}_2\text{O}$) 0.993 kg in 20 litres of water.
- D. Trace elements i.e. Manganous sulphate ($\text{MnSO}_4 \cdot \text{H}_2\text{O}$) 12.3 g, Boric acid (H_3BO_3) 3.42 g, Copper sulphate ($\text{CuSO}_4 \cdot 5 \text{H}_2\text{O}$) 0.55 g, Ammonium molybdate [$(\text{NH}_4)_6\text{Mo}_7\text{O}_{24} \cdot 4\text{H}_2\text{O}$] 0.184 g, and Zinc sulphate ($\text{ZnSO}_4 \cdot 7\text{H}_2\text{O}$) 0.62 g in 20 litre of water.

3.7.2 Conductivity adjustment

- a) Conductivity 2 mScm^{-1} : Equal amounts of all the above solutions were added to raise the conductivity.
- b) Conductivity 4 mScm^{-1} : Equal amounts of solutions B and C were added, but only half of that amount was added for solutions A and D.
- c) Conductivity 6 mScm^{-1} : Equal amounts of solutions B and C were added, but only one third of that amount was added for solutions A and D.
- d) Conductivity 8 mScm^{-1} : Equal amounts of solutions B and C were added, but only one quarter of that amount was added for solutions A and D.

3.8 CROP MANAGEMENT

The plants were trained up strings according to normal commercial practice and stopped at two leaves above the top wires. Lateral shoots were regularly removed. A truss vibrator was used to enhance pollination every other day at midday. Fruit were thinned to maintain six fruit per truss. White flies were the only insects problem observed and insecticide was sprayed in the greenhouse when necessary. No fungal diseases were found during the summer experiment but *Botrytis* and *Pythium* root rot were found during winter experiment with increasing intensity as the plants grew larger. No fungicide was used to control *Pythium* root rot but *Botrytis* was controlled by cutting the infected part and painting the cut area with a fungicide (Benlate).

3.9 DATA COLLECTED

3.9.1 Plant water uptake

Plant water uptake was measured as the amount of water added to each tank of nutrient solution each day. The measurement was done only during summer experiment for a total period of 14 days from 17/12/94 to 31/12/94. Evaporation was assumed to be nil as all the nutrient solution tanks were covered and the solution was recirculated in a closed system. The average values of plant water uptake per plant per day were calculated for cloudy and sunny days.

3.9.2 Plant water status

Plant water status in terms of leaf water potential was measured at mid-day by using a Scholander pressure chamber (Soil moisture Equipment Corp., Santa Barbara, California). The measurement was done approximately two times a week during the period of 15/12/94 and 30/1/95 during the summer experiment and from 25/5/95 to 10/7/95 during the winter experiment. A fully expanded mature leaflet per plant was

chosen from well exposed leaves in the middle of the plant. Two plants per split-plot were measured each time. The average values of xylem water potential were calculated for cloudy and sunny days.

3.9.3 Vegetative growth

The vegetative growth i.e. leaf area, leaf fresh weight, leaf dry matter concentration and stem fresh weight were determined after the last harvest. For the winter experiment stem dry matter concentration was also determined.

3.9.3.1 Leaf fresh weight and leaf dry matter concentration

Total leaf fresh weight of each plant was determined using a balance (Mettler Model PM 4800 Delta Range). The leaves were then sampled from each plant for dry weight determination. Fresh weight of each leaf sample was recorded before placing in the oven (60-80°C) until completely dry. Dry weight of each sample was determined and percentage dry matter was calculated.

3.9.3.2 Stem fresh weight and stem dry matter concentration

Total stem fresh weight of each plant was collected with the use of a balance (Mettler Model PM 4800 Delta Range). The stem were then sampled from each plant for the dry weight determination. The stem samples were cut into shorter pieces and weighed. Thereafter they were placed in the oven (60-80°C) until completely dry. The dry weight was determined and percentage dry matter calculated.

3.9.3.3 Leaf area

Two plant per split-plot were used to measured total leaf area. Total leaf area per plant was determined by LI-COR Model 3100 Area Meter.

3.9.4 Reproductive growth and yield

3.9.4.1 Number of trusses and length between trusses

The total number of trusses per plant were recorded in both experiments. For the winter, the distance between the first and the last trusses of each plant was also recorded.

3.9.4.2 Fruit yield and yield components

Fruit harvesting commenced on 14 January 1995 and continued until 30 March 1995 for the summer experiment and commenced on 16 July 1995 and continued until 6 October 1995 for the winter experiment. Fruit were harvested at the pink, light-red and red stages except fruit samples for quality evaluation which were harvested at the breaker stage. During the last harvest a few fruit still remained green.

The weight of each fruit were recorded for each truss and each split plot. Fruit with disorders e.g. blossom end rot and cracking were recorded separately as non-marketable yield. A balance (Mettler Model PM 4800 Delta Range) was used and the data were directly recorded from the balance into a computer spreadsheet.

3.9.5 Fruit quality

3.9.5.1 Fruit composition

Five fruit from each split plot of approximately the same size and free from defects and injury were used. Fruit were picked from the same truss at breaker stage and stored at 20°C until they reached the red stage. During the summer experiment, fruit from Truss 2 were chosen for the early trusses determination and from Truss 8 for the late trusses determination. During the winter experiment fruit from Truss 1 were chosen for the early trusses determination and from Truss 6 for the late trusses determination. For fruit dry matter concentration, only fruit from Truss 8 were determined during summer

experiment. Fruit samples were then washed, dried, cut into quarters and put through a blending machine. The resulting extract was filtered and the clear solution was used to determine TSS and titratable acidity.

a) Total soluble solids

The concentration of total soluble solids was determined by using an Atago refractometer (0-20% Brix; ATC-1; Atago, Tokyo). Measurements were made by placing a few drops of the clear solution of the tomato juice on the refractometer plate and recording the brix reading. The refractometer was adjusted to zero with distilled water after each reading. The prism surface and the sunlight plate were thoroughly washed with distilled water and dried with soft tissue paper after each reading. Three brix readings were taken for each sample and the average brix value for each sample was calculated.

b) Titratable acidity

One ml of the clear solution of the tomato juice was placed in a small beaker with 50 ml of distilled water. The resulting solution was then titrated with 0.1 NaOH using an automatic titrator (model DL 21; Mettler, Greifensee, Switzerland) up to an endpoint of pH 8.1. The values of titratable acidity of the tomato samples expressed as % citric acid were calculated from the following equation:

$$\% \text{ citric acid} = \text{ml NaOH} * \text{Normality of NaOH} * 192.1/30$$

The value 192.1/30 resulted from [molecular wt. of citric acid anhydrous/3]/[mls of tomato juice (1 ml) * 10]

c) Dry matter concentration

Each fruit sample was weighed and then cut into quarters and placed in the oven (60-

80°C) until completely dry. Dry weight of each sample was then recorded and percentage dry matter calculated.

3.9.5.2 Skin colour

Fruit skin colour was determined only during winter experiment. Three fruit from each split-plot of approximately the same size and free from defects and injury were used. Fruits were picked from the same truss (Truss 2) at breaker stage. Each fruit was numbered and marked using a felt pen with two circle of about 1.5 cm in diameter approximately at the equatorial line of the fruit. These marks would be the area for colour determination. The skin colour was determined daily for 14 days using a chroma meter (CR-2800; Minolta, Osaka, Japan).

The chroma-meter utilizes a xenon arc lamp which gives a spectral energy distribution similar to that of daylight in the range which the human eye responds. The results are reported as L and H values. The L (lightness) value is a brightness/darkness factor ranging from 0 (black) to 100 (white) (Fig. 3.3).

The H (hue angle) value describes a major colour family such as red and green and is calculated as:

$$H = \tan^{-1} a/b$$

The a and b values are chromaticity coordinates, being red-green and yellow-blue factors respectively (Fig. 3.3). Thus pure red colour has a hue angle of 0 ° whilst green 180 °.

Fruit skin colour measurements were made by placing the 8-mm-diameter measuring area of the chroma-meter at the middle of each circle mark and recording the L and H values.

The meter was calibrated at illuminant condition C (6774 K) with the manufacturer's green standard tile before use. During the period of colour determination fruit were stored at 20°C. Mean values for lightness and hue-angle were calculated.

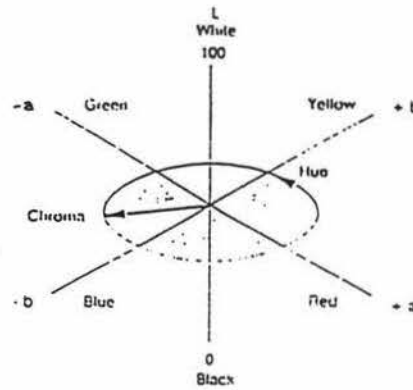


Figure 3.3: Colour space diagram. L^* axis indicates lightness of a colour; a^* axis is the ratio of redness:greenness; b^* axis is the ratio of blueness:yellowness. The ratio of the a^* value and the b^* value defines an angle which quantifies one of the hue (e.g., red, orange, green) (Van Eck, 1994).

3.9.5.3 Weight loss

Six fruit from each split plot of approximately the same size and free from defects and injury were used. Fruit were picked from the same truss (Truss 4 for the summer experiment and Truss 2 for the winter experiment) at breaker stage. Each fruit was washed in cold water, dried, and numbered. Fruit were individually weighed to two decimal places using a balance (Mettler Model PM 4800 Delta Range). Six fruit of the same sample were placed apart from each other into a cardboard shallow tray and then placed in a temperature controlled room at 20 °C. High relative humidity in the room was maintained by placing two pans of water in the room. The fruit were reweighed every two days for a total of 14 days and weight loss calculated as the percent reduction from the original weight.

3.9.5.4 Taste test

Fruit samples of approximately the same size and free from defects and injury were

used. Fruits were picked from the same truss (Truss 5 for the summer experiment and Truss 3 for the winter experiment) at breaker stage and stored at 20°C until they reached the red stage. Fruit were then washed, dried and cut into pieces. Pieces from both the blossom and stem ends were discarded. Each piece chosen contained all fruit components i.e. fruit skin, pericarp, seeds and jelly. Ten tasters from different nationalities were chosen. The tasters gave scores ranking from 1 (worst) to 4 (best) in terms of preference in taste within each cultivar and indicated their preference among the two cultivars.

3.10 STATISTICAL ANALYSIS

Analysis of variance (ANOVA) was performed using Statistical Analysis Systems (SAS) software (SAS Institute, Cary, N.C.). Mean comparisons were carried out using the Duncan's multiple range test at 5% level of significance. All data unless otherwise, specified, were analyzed as a randomized complete block design (RCBD) for Factor A, with factor B a split plot on A.

CHAPTER FOUR

RESULTS

4.1 PLANT WATER UPTAKE

The average values of water uptake per plant per day on both sunny and cloudy days during the summer experiment are shown in table 4.1. At high EC levels (6 and 8 mScm⁻¹), plants took up less water than at the lower EC levels (2 and 4 mScm⁻¹). The highest water uptake, however, occurred at 4 mScm⁻¹. The amount of water taken up by plants was lower in cloudy compared with sunny days at all EC levels.

Table 4.1. Average water uptake per plant per day at different conductivity level of nutrient solution during summer experiment.

	Average water uptake/plant/day (litre)			
	2 mScm ⁻¹	4 mScm ⁻¹	6 mScm ⁻¹	8 mScm ⁻¹
Sunny days	1.84	1.92	1.73	1.43
Cloudy days	0.95	1.26	0.90	0.83

4.2 PLANT WATER STATUS

Leaf water potential (Ψ) measured at midday during both experiments are shown in Table 4.2.

Table 4.2. Leaf water potential (Ψ) measured at midday on sunny and cloudy days of two tomato cultivars grown with NFT at different conductivity levels during the summer and winter experiments.

EC and CV	Leaf water potential (MPa)			
	Summer		Winter	
	Sunny	Cloudy	Sunny	Cloudy
Conductivity (EC)				
2 mScm-1	-0.84	-0.52	-0.54	-0.38
4 mScm-1	-0.90	-0.61	-0.61	-0.41
6 mScm-1	-0.96	-0.69	-0.68	-0.40
8 mScm-1	-1.20	-0.84	-0.79	-0.48
S.E.(df=6)	0.05	0.04	0.06	0.04
Cultivar (CV)				
Rondello	-1.00	-0.67	-0.66	-0.44
Concordia	-0.96	-0.66	-0.65	-0.39
S.E.(df=8)	0.02	0.01	0.01	0.02
Significant				
EC	**	***	*	ns
CV	ns	ns	ns	*
EC * CV	ns	ns	ns	ns

ns, *, **, *** Nonsignificant or significant at P = 0.05, 0.01 or 0.001 respectively.

Summer experiment

Different EC levels of nutrient solution significantly affected plant water status measured as leaf water potential (Ψ) both during sunny days ($P = 0.01$) and cloudy days ($P = 0.001$). Generally, plants grown at higher EC levels had lower Ψ . However, during sunny days, there were no significant differences in Ψ in plants grown at 2, 4, and 6 mScm^{-1} . But plants grown at 8 mScm^{-1} had a significantly lower Ψ . The average values of Ψ were lower during sunny days compared to those during cloudy days at all EC levels. The average values of Ψ ranged from -0.52 MPa at 2 mScm^{-1} to -0.84 MPa at 8 mScm^{-1} during cloudy days and from -0.84 MPa at 2 mScm^{-1} to -1.20 MPa at 8 mScm^{-1} during sunny days. There was no significant differences in Ψ between Rondello and Concordia either during sunny days or cloudy days.

Winter experiment

During the winter experiment, unlike summer experiment, the reduction in Ψ at high EC levels was observed only during sunny days ($P = 0.05$). During cloudy days though the values of Ψ tended to decrease with increasing EC, the decreases were not significant. Similar to those of summer experiment, the average values of Ψ were lower during sunny days at all EC levels. There were no significant differences in Ψ between the two cultivars during sunny days but Rondello had significantly lower Ψ than Concordia during cloudy days. The average values of Ψ during winter experiment were lower than those during summer experiment at all EC levels and both during sunny days and cloudy days. The average values of Ψ during winter experiment ranged from -0.38 MPa at 2 mScm^{-1} to -0.48 MPa at 8 mScm^{-1} during cloudy days and from -0.54 at 2 mScm^{-1} to -0.79 MPa at 8 mScm^{-1} during sunny days.

4.3 VEGETATIVE GROWTH

Vegetative growth was measured one day after the last fruit harvest. Leaf area per plant, leaf fresh weight per plant, leaf dry matter content as percent of leaf fresh weight, and stem fresh weight per plant were determined for both experiments. Stem dry matter content expressed as percent of stem fresh weight was recorded only during the winter experiment.

Summer experiment

Different nutrient solution conductivity levels affected most aspects of vegetative growth. Leaf area was not affected by EC levels (Fig. 4.1A). Leaf fresh weight was highest in plants grown at 2 mScm⁻¹ and decreased at high EC levels being lowest at 8 mScm⁻¹ (Fig. 4.1B). There were no significant differences in leaf fresh weight between 2 and 4 mScm⁻¹ and between 6 and 8 mScm⁻¹. Leaf fresh weight per plant (kg) for the various conductivity levels were: 2.79, 2.73, 2.36, and 2.17 for 2, 4, 6, and 8 mScm⁻¹ respectively. The highest leaf dry matter concentration (%) was also achieved from plants grown at 2 mScm⁻¹. At 4 mScm⁻¹, leaf dry matter concentration was slightly lower, however, the difference was not significant. Leaf dry matter concentration was significantly decreased when the conductivity levels were raised to 6 and 8 mScm⁻¹ (Fig. 4.1C). Stem fresh weight were affected by EC levels in the same way as leaf dry matter concentration in that it decreased at high EC levels (6 and 8 mScm⁻¹) (Fig. 4.2A). Again, there was no significant difference in stem fresh weight between plants grown at 2 and 4 mScm⁻¹.

There were no cultivar effects in all aspects of vegetative growth (Tables 4.3 and 4.4) except in leaf dry matter concentration, in which Concordia had higher leaf dry matter concentration than Rondello.

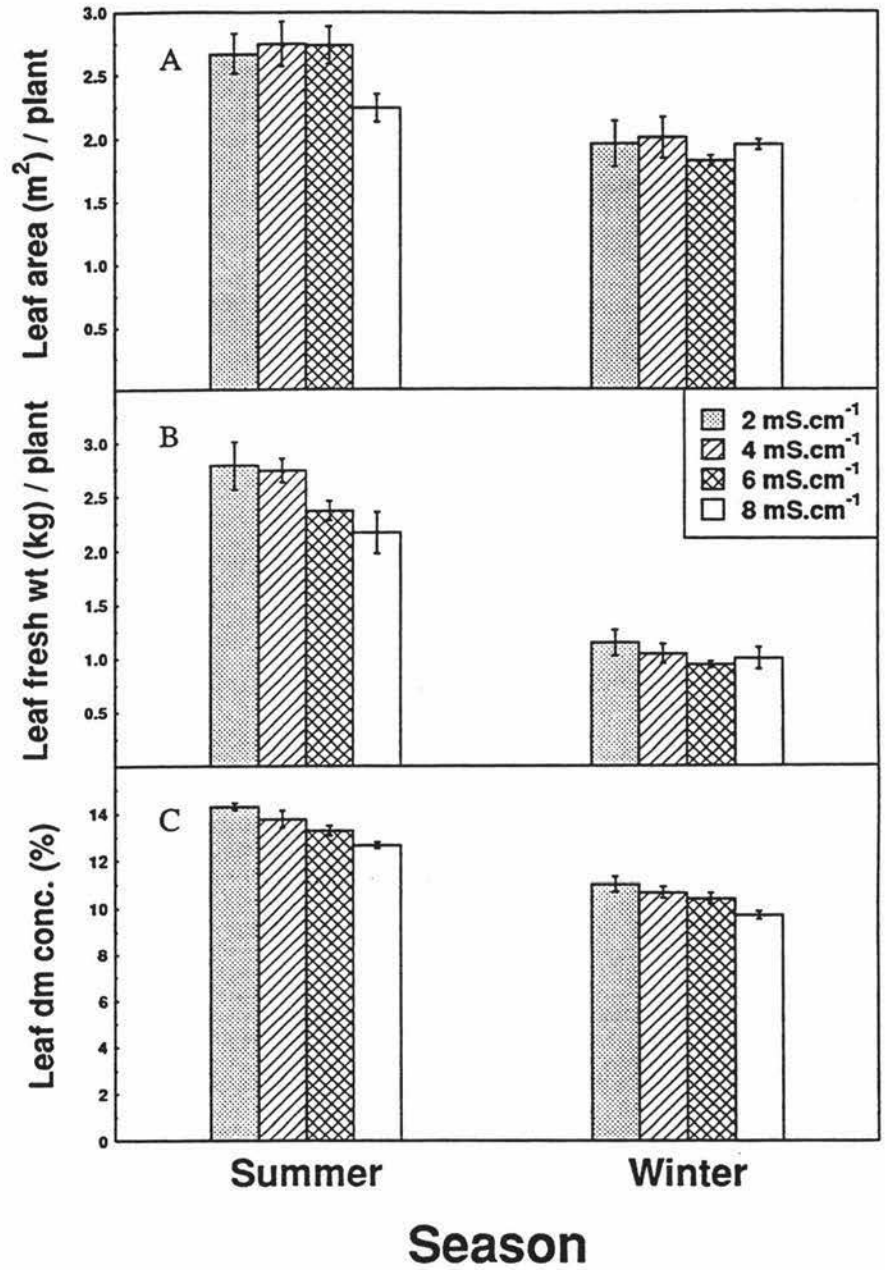


Figure 4.1: Leaf area (m²) / plant (A), leaf fresh weight (kg) / plant (B) and leaf dry matter concentration (%) (C) of tomato grown with NFT at different conductivity levels. Vertical bars represent SEM.

Table 4.3 Leaf area (m²) per plant, leaf fresh weight (FW) (kg) per plant and leaf dry matter (DM) concentration (%) of two tomato cultivars grown with NFT during the summer and winter experiments.

Cultivar	Leaf area (m ²) / plant		Leaf FW (kg) / plant		Leaf DM conc. (%)	
	Summer	Winter	Summer	Winter	Summer	Winter
Rondello	2.47	1.78	2.42	1.00	13.19	10.49
Concordia	2.73	2.09	2.61	1.06	13.81	10.44
S.E.(df=8)	0.14	0.10	0.14	0.10	0.18	0.17
Significance	ns	*	ns	ns	**	ns

ns,*,** Nonsignificant or significant at P = 0.05 or 0.01 respectively

Table 4.4 Stem fresh weight (FW) (kg) per plant and stem dry matter (DM) concentration (%) of two tomato cultivars grown with NFT during the summer and winter experiments.

Cultivar	Stem FW (kg) / plant		Stem DM conc. (%)	
	Summer	Winter	Summer	Winter
Rondello	0.73	0.38	n.a.	15.49
Concordia	0.70	0.38	n.a.	16.41
S.E.(df=8)	0.02	0.02	n.a.	0.27
Significance	ns	ns	n.a.	**

^{n.a.} Not applicable

^{ns,**} Nonsignificant or significant at P = 0.01 respectively

Winter experiment

Different conductivity levels of the nutrient solution did not affect leaf area and leaf fresh weight in the winter experiment (Fig. 4.1A and 4.1B respectively). Leaf dry matter concentration tended to decrease with increasing EC levels (Fig. 4.1C), however, the differences were not significant. There were significant effects of EC levels on both stem fresh weight and stem dry matter concentration (%). Stem fresh weight was highest at 2 mScm⁻¹ (Fig. 4.2A).

They then decreased at the higher EC levels. The differences in stem fresh weight among plants grown at 4, 6, and 8 mScm⁻¹ were, however, not significant. The values of stem fresh weight per plant (kg) were 0.43, 0.39, 0.35, and 0.36 for the conductivity levels of 2, 4, 6, and 8 mScm⁻¹ respectively. Though there was no significant difference in stem dry matter concentration between plants grown at 2 and 4 mScm⁻¹, a further increase in EC levels significantly decreased stem dry matter (Fig. 4.2B). The values of stem dry matter concentration (%) at different EC levels were 16.47, 16.53, 15.10, and 15.69 respectively.

A cultivar effect was observed only on stem dry matter where Concordia had a higher value than Rondello (Table 4.4). Leaf area, leaf fresh weight, and leaf dry matter concentration (Table 4.3), and stem fresh weight (Table 4.4) of the two cultivars were not significantly different.

All the attributes of vegetative growth studied in the current experiments were lower during winter compared with summer at all EC levels (Fig. 4.1, 4.2) and in both cultivars (Tables 4.3 and 4.4) especially in leaf fresh weight and stem fresh weight. There were no interaction effects between EC levels and cultivars in any aspects of vegetative growth in the study during both experiments.

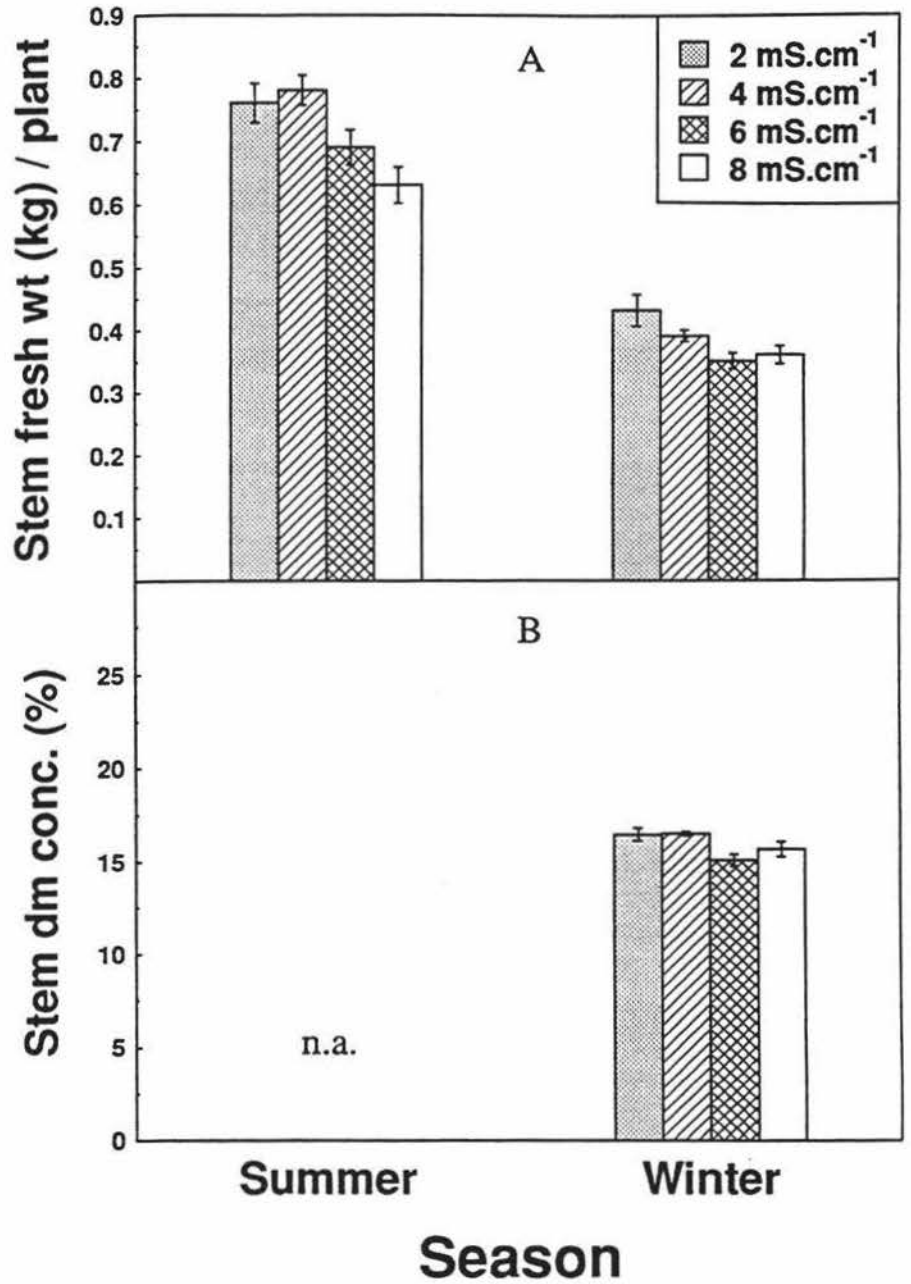


Figure 4.2: Stem fresh weight (kg) / plant (A) and stem dry matter concentration (%) (B) of tomato grown with NFT at different conductivity levels. Vertical bars represent SEM.

4.4 NUMBER OF TRUSSES AND LENGTH BETWEEN TRUSSES

There were no significant differences in total number of trusses per plant between different EC levels (Fig. 4.3A) or between the two cultivars (Table 4.5) during both experiments. Similarly, length between trusses which were determined only during winter experiment were not significantly different either at different EC levels (Fig. 4.3B) or between the two cultivars (Table 4.5), however the number of trusses per plant during the winter were lower than those during the summer.

Table 4.5 Total number of trusses per plant and length between trusses of two tomato cultivars grown with NFT during the summer and winter experiments.

Cultivar	No.of trusses/plant		Length between trusses	
	Summer	Winter	Summer	Winter
Rondello	9.07	5.80	n.a.	23.75
Concordia	9.22	6.29	n.a.	21.53
S.E.(df=8)	0.14	0.10	n.a.	1.85
Significance	ns	**	n.a.	ns

n.a. Not applicable

ns,** Nonsignificant or significant at P = 0.01 respectively

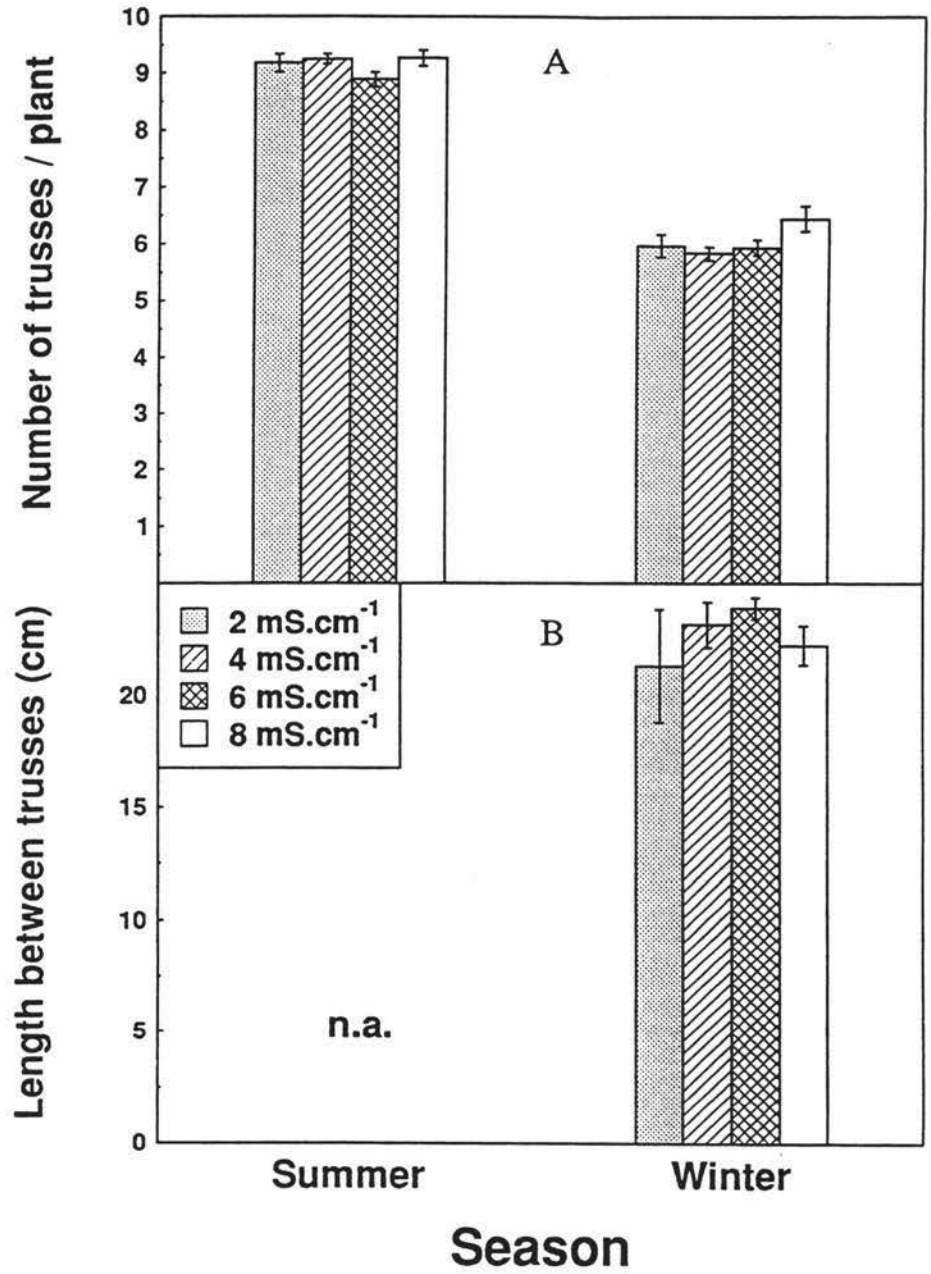


Figure 4.3: Number of trusses per plant (A) and length between trusses (B) of tomato grown with NFT at different conductivity levels during summer and winter. Vertical bars represent SEM.

4.5 YIELD, YIELD COMPONENTS AND TIME OF MATURITY

4.5.1 Yield and yield components

Summer experiment

Yield measured as fruit fresh weight per plant from the summer experiment are shown in Table 4.6. Marketable yield decreased at EC higher than 4 mScm⁻¹ at which marketable yield was slightly higher than those at 2 mScm⁻¹, however, the difference was not significant. There was no significant difference in non-marketable fruit fresh weight per plant among 2, 4, and 6 mScm⁻¹ but it increased markedly at 8 mScm⁻¹ where the non-marketable yield was about five times as much as those achieved at 2, 4, and 6 mScm⁻¹.

Number of fruit per plant and fruit size (mean fruit fresh weight) of the summer experiment are shown in Table 4.7 and 4.8 respectively. Total number of fruit per plant was unaffected by EC levels but the number of non-marketable fruit was substantially higher at 8 mScm⁻¹ where the amount of non-marketable fruit was almost 10 times of those at 2, 4, and 6 mScm⁻¹. The number of marketable fruit per plant was significantly lower at 8 mScm⁻¹ compared to those at 2, 4, and 6 mScm⁻¹. There were no significant differences in the number of both marketable and non-marketable fruit per plant at 2, 4, and 6 mScm⁻¹.

There was no significant difference in mean fruit fresh weight among marketable fruit from plants grown at 2 and 4 mScm⁻¹. However, further increased in EC levels significantly decreased mean fruit fresh weight. Non-marketable fruit generally had much less mean fruit fresh weight than marketable fruit.

Table 4.6 Yield (fruit fresh weight) (kg) per plant of two tomato cultivars grown with NFT at different levels of nutrient solution conductivity during the summer experiment.

EC and CV	Marketable	Non-marketable	Total
Conductivity (CV)			
2 mScm ⁻¹	6.19	0.08	6.27
4 mScm ⁻¹	6.34	0.07	6.41
6 mScm ⁻¹	4.89	0.10	4.99
8 mScm ⁻¹	3.14	0.49	3.63
S.E.(df=6)	0.27	0.03	0.27
Cultivar (CV)			
Rondello	5.26	0.35	5.61
Concordia	5.02	0.02	5.04
S.E.(df=8)	0.22	0.04	0.23
EC * CV			
2 mS cm ⁻¹			
Rondello	6.51	0.13	6.64
Concordia	5.86	0.04	5.90
4 mS cm ⁻¹			
Rondello	6.66	0.14	6.80
Concordia	6.02	0.01	6.03
6 mS cm ⁻¹			
Rondello	5.23	0.20	5.43
Concordia	4.55	0.00	4.55
8 mS cm ⁻¹			
Rondello	2.64	0.94	3.58
Concordia	3.63	0.04	3.67
S.E.(df=3)	0.83	0.38	0.45
Significance			
EC	***	***	**
CV	ns	***	*
EC * CV	ns	**	ns

ns,*,**,*** Nonsignificant or significant at P = 0.05, 0.01 or 0.001 respectively

Table 4.7 Total number of fruit per plant of two tomato cultivars grown with NFT at different levels of nutrient solution conductivity during the summer experiment.

EC and CV	Marketable	Non-marketable	Total
Conductivity (CV)			
2 mScm ⁻¹	49.88	1.06	50.94
4 mScm ⁻¹	52.79	0.85	53.64
6 mScm ⁻¹	48.08	1.61	49.69
8 mScm ⁻¹	37.59	9.64	47.23
S.E.(df=6)	2.38	0.43	2.34
Cultivar (CV)			
Rondello	44.17	6.26	50.43
Concordia	50.00	0.32	50.32
S.E.(df=8)	1.93	0.48	2.06
EC * CV			
2 mS·cm ⁻¹			
Rondello	49.86	1.68	51.54
Concordia	49.89	0.44	50.33
4 mS·cm ⁻¹			
Rondello	50.64	1.60	52.24
Concordia	54.93	0.11	55.04
6 mS·cm ⁻¹			
Rondello	47.26	3.23	50.49
Concordia	48.89	0.00	48.89
8 mS·cm ⁻¹			
Rondello	28.9	18.55	47.45
Concordia	46.28	0.72	47.00
S.E.(df=3)	7.89	7.97	2.00
Significance			
EC	**	***	ns
CV	*	***	ns
EC * CV	*	***	ns

ns,*,**,*** Nonsignificant or significant at P = 0.05, 0.01 or 0.001 respectively

Table 4.8 Fruit size (mean fruit weight) (g) of two tomato cultivars grown with NFT at different levels of nutrient solution conductivity during the summer experiment.

EC and CV	Marketable	Non-marketable	Total
Conductivity (CV)			
2 mScm ⁻¹	124.23	52.13	123.18
4 mScm ⁻¹	120.67	74.16	119.98
6 mScm ⁻¹	101.89	31.67	100.40
8 mScm ⁻¹	85.06	48.99	76.85
S.E.(df=6)	3.29	17.93	3.00
Cultivar (CV)			
Rondello	116.31	74.88	110.77
Concordia	99.62	28.60	99.44
S.E.(df=8)	1.79	9.78	1.73
EC * CV			
2 mS·cm ⁻¹			
Rondello	131.00	75.38	129.18
Concordia	117.45	28.88	117.17
4 mS·cm ⁻¹			
Rondello	131.93	110.65	130.66
Concordia	109.42	37.68	109.31
6 mS·cm ⁻¹			
Rondello	110.88	63.35	107.88
Concordia	92.90	0.00	92.91
8 mS·cm ⁻¹			
Rondello	91.44	50.13	75.35
Concordia	78.69	47.84	78.35
S.E.(df=3)	4.50	31.30	10.32
Significance			
EC	***	ns	***
CV	***	**	***
EC * CV	ns	ns	**

ns, **, *** Nonsignificant or significant at P = 0.01 or 0.001 respectively

Rondello had significantly larger marketable fruit size than Concordia. Rondello also had lower marketable fruit number per plant due to higher non-marketable fruit number per plant than Concordia. Considering marketable fruit fresh weight per plant, there was no significant difference between the two cultivars. Concordia had much less non-marketable yield than Rondello and the majority of non-marketable fruit were due to fruit cracking while the majority of non-marketable fruit in Rondello were due to BER.

There were interaction effects between EC levels and cultivars in number of non-marketable fruit and non-marketable fruit fresh weight per plant in such a way that at increasing EC especially at 8 mScm^{-1} the number of non-marketable fruit and non-marketable fruit fresh weight substantially increased in Rondello while this did not occur in Concordia.

Winter experiment

Yield measured as fruit fresh weight per plant, number of fruit per plant and fruit size (mean fruit fresh weight) of the winter experiment are shown in Tables 4.9, 4.10 and 4.11 respectively. Fruit number per plant and fruit fresh weight per plant were not affected by EC levels. Mean marketable fruit fresh weight were, however, decreased significantly at 8 mScm^{-1} at which a reduction of 17% in size was observed.

There was no significant difference in marketable fruit fresh weight per plant among the two cultivars. Marketable fruit number per plant of the two cultivars was not significantly different but Rondello had significantly higher number of non-marketable fruit than Concordia. Rondello also had larger marketable fruit size than Concordia.

Unlike in the summer experiment, there was no interaction effect between EC levels and cultivar in any yield and yield components during the winter experiment.

Table 4.9 Yield (fruit fresh weight) (kg) per plant of two tomato cultivars grown with NFT at different levels of nutrient solution conductivity during the winter experiment.

EC and CV	Marketable	Non-marketable	Total
Conductivity (CV)			
2 mScm ⁻¹	2.42	0.00	2.42
4 mScm ⁻¹	2.55	0.00	2.55
6 mScm ⁻¹	2.35	0.01	2.36
8 mScm ⁻¹	2.06	0.01	2.07
S.E.(df=6)	0.16	0.00	0.16
Cultivar (CV)			
Rondello	2.52	0.01	2.53
Concordia	2.18	0.00	2.18
S.E.(df=8)	0.19	0.00	0.19
EC * CV			
2 mS·cm ⁻¹			
Rondello	2.80	0.00	2.80
Concordia	2.04	0.00	2.04
4 mS·cm ⁻¹			
Rondello	2.96	0.01	2.97
Concordia	2.13	0.00	2.13
6 mS·cm ⁻¹			
Rondello	2.21	0.02	2.23
Concordia	2.49	0.00	2.49
8 mS·cm ⁻¹			
Rondello	2.09	0.02	2.11
Concordia	2.03	0.00	2.03
S.E.(df=3)	0.54	0.01	0.53
Significance			
EC	ns	ns	ns
CV	ns	ns	ns
EC * CV	ns	ns	ns

^{ns} Nonsignificant

Table 4.10 Total number of fruit per plant of two tomato cultivars grown with NFT at different levels of nutrient solution conductivity during the winter experiment.

EC and CV	Marketable	Non-marketable	Total
Conductivity (CV)			
2 mScm ⁻¹	28.59	0.00	28.59
4 mScm ⁻¹	30.96	0.07	31.03
6 mScm ⁻¹	30.26	0.19	30.45
8 mScm ⁻¹	29.65	0.12	29.77
S.E.(df=6)	1.62	0.07	1.60
Cultivar (CV)			
Rondello	29.93	0.15	30.08
Concordia	29.80	0.04	29.84
S.E.(df=8)	1.82	0.04	1.84
EC * CV			
2 mS·cm ⁻¹			
Rondello	30.71	0.00	30.71
Concordia	26.47	0.00	26.47
4 mS·cm ⁻¹			
Rondello	32.83	0.08	32.91
Concordia	29.10	0.05	29.15
6 mS·cm ⁻¹			
Rondello	28.62	0.33	28.95
Concordia	31.90	0.05	31.95
8 mS·cm ⁻¹			
Rondello	27.58	0.19	27.77
Concordia	31.72	0.06	31.78
S.E.(df=3)	4.46	0.12	4.35
Significance			
EC	ns	ns	ns
CV	ns	*	ns
EC * CV	ns	ns	ns

ns,* Nonsignificant or significant at P = 0.05

Table 4.11 Fruit size (mean fruit weight) (g) of two tomato cultivars grown with NFT at different levels of nutrient solution conductivity during the winter experiment.

EC and CV	Marketable	Non-marketable	Total
Conductivity (CV)			
2 mScm ⁻¹	83.64	0.00	83.64
4 mScm ⁻¹	81.94	23.66	81.92
6 mScm ⁻¹	77.74	47.73	77.70
8 mScm ⁻¹	69.51	37.19	69.52
S.E.(df=6)	3.30	20.38	3.36
Cultivar (CV)			
Rondello	83.31	35.89	83.29
Concordia	73.10	18.40	73.10
S.E.(df=8)	3.37	13.34	3.33
EC * CV			
2 mS cm ⁻¹			
Rondello	90.53	0.00	90.53
Concordia	76.75	0.00	76.75
4 mS cm ⁻¹			
Rondello	90.48	27.12	90.49
Concordia	73.40	20.20	73.36
6 mS cm ⁻¹			
Rondello	77.08	68.01	76.97
Concordia	78.40	27.45	78.42
8 mS cm ⁻¹			
Rondello	75.17	48.41	75.16
Concordia	63.85	25.96	63.87
S.E.(df=3)	8.04	18.02	8.12
Significance			
EC	*	ns	*
CV	*	ns	*
EC * CV	ns	ns	ns

ns,* Nonsignificant or significant at P = 0.05

Comparing between the two seasons, marketable fruit number and fruit fresh weight per plant and mean fruit fresh weight were much lower during winter experiment compared to the summer experiment. The number and fresh weight per plant of non-marketable fruit were also much lower during the winter experiment and the majority of the non-marketable fruit were due to fruit cracking rather than BER.

4.5.2 Time of maturity

Summer experiment

The levels of nutrient solution conductivity did not affect the time of maturity (Fig. 4.4). The total harvest period was 76 days. Half of the total yield per plant (50% of the cumulative yield per plant) at different EC levels were harvested at similar periods of about 30 days from the first harvest.

Rondello appeared to mature slightly earlier than Concordia (Fig. 4.5). Fifty percent of the cumulative yield were harvested at about 28 days and 32 days in Rondello and Concordia respectively.

Winter experiment

The effect of nutrient solution conductivity on time of maturity was not consistent (Fig. 4.6). The total harvest period was 83 days. Fifty percent of the cumulative yield of plants grown at 2 and 4 mScm⁻¹ were harvested at similar period of about 45 days from the first harvest. In plants grown at 6 mScm⁻¹, half of the total yield were harvested earlier (about 38 days). Whereas at 8 mScm⁻¹, fruit matured much later such that half of the total yield were harvested at about 52 days from the first harvest. Half of the total yield of Rondello and Concordia were, however, harvested at the same period of about 43 days from the first harvest (Fig. 4.7).

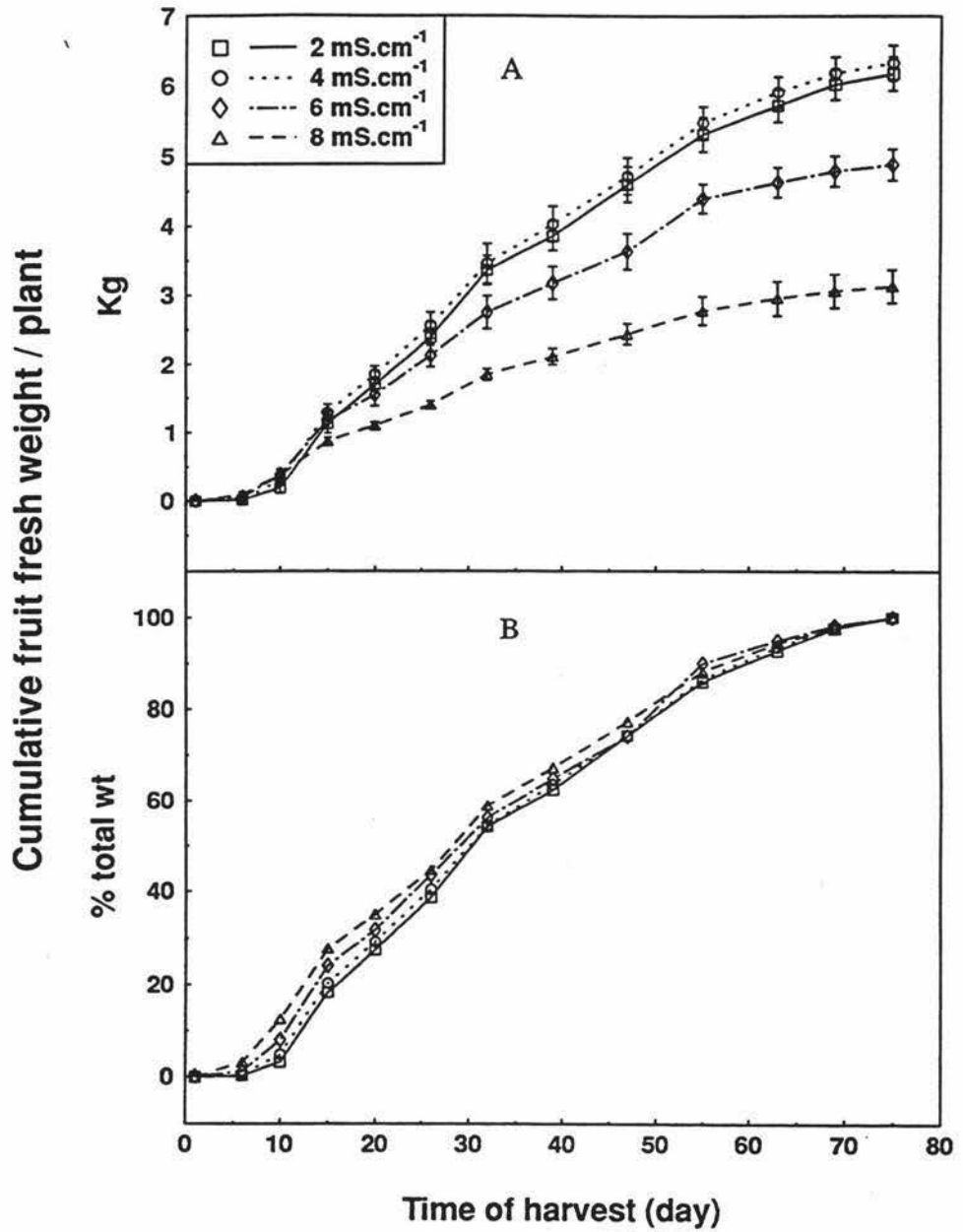


Figure 4.4: Cumulative yield expressed as fruit fresh weight (kg) per plant (A) and % of total fruit fresh weight per plant (B) of tomato grown with NFT during summer experiment. Vertical bars represent SEM.

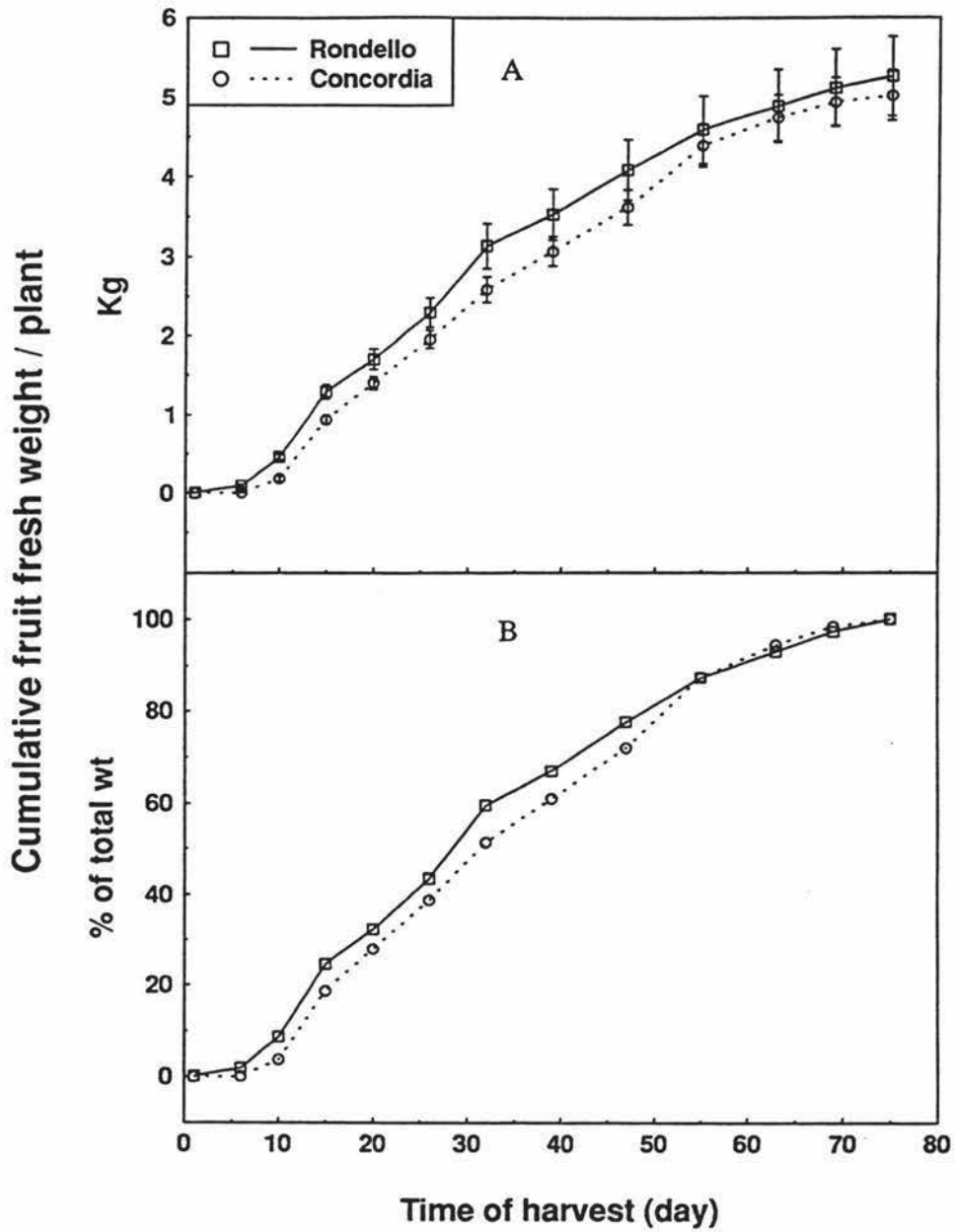


Figure 4.5: Cumulative yield expressed as fruit fresh weight (kg) per plant (A) and % of total fruit fresh weight per plant (B) of two tomato cultivars grown with NFT during summer experiment. Vertical bars represent SEM.

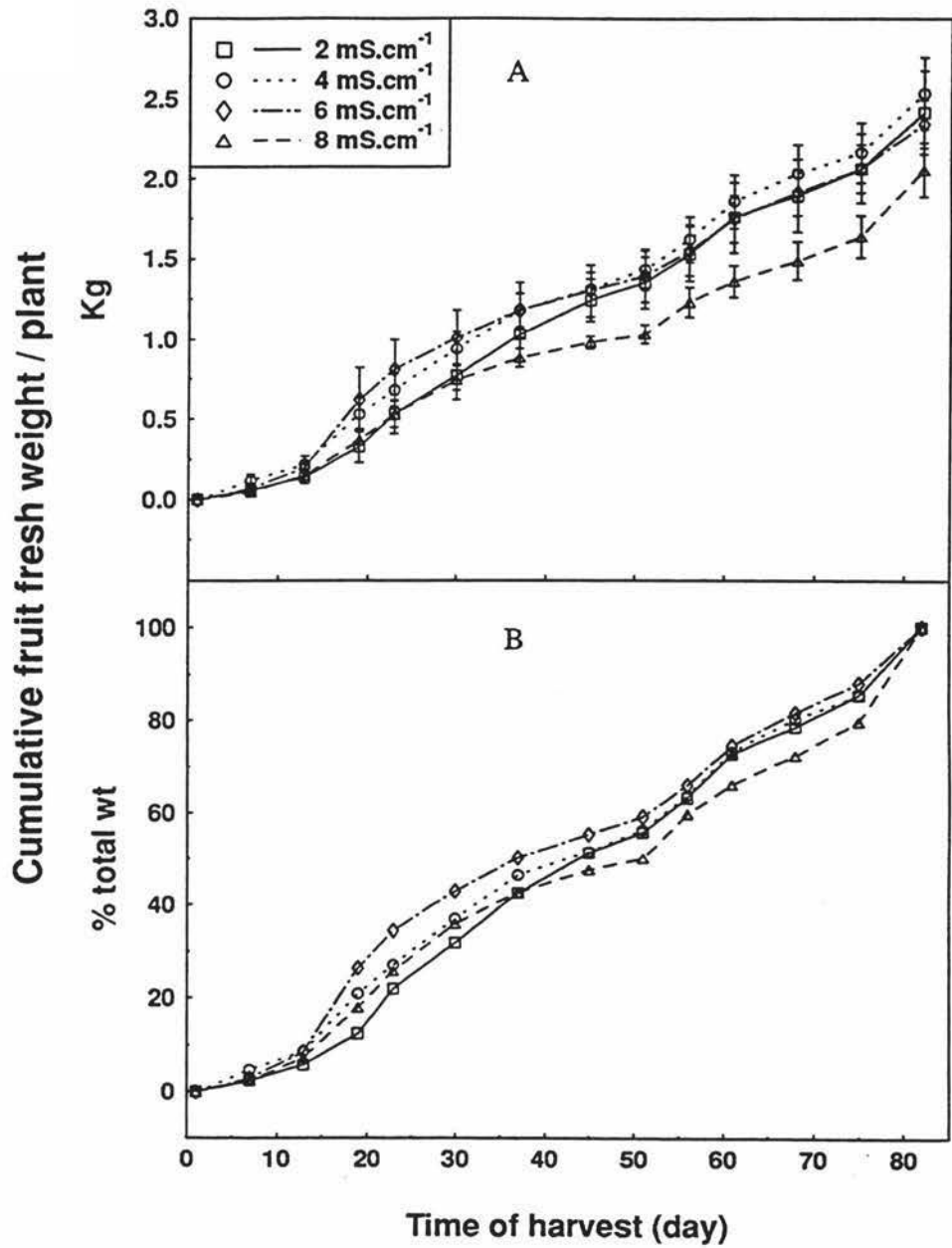


Figure 4.6: Cumulative yield expressed as fruit fresh weight (kg) per plant (A) and % of total fruit fresh weight per plant (B) of tomato grown with NFT during winter experiment. Vertical bars represent SEM.

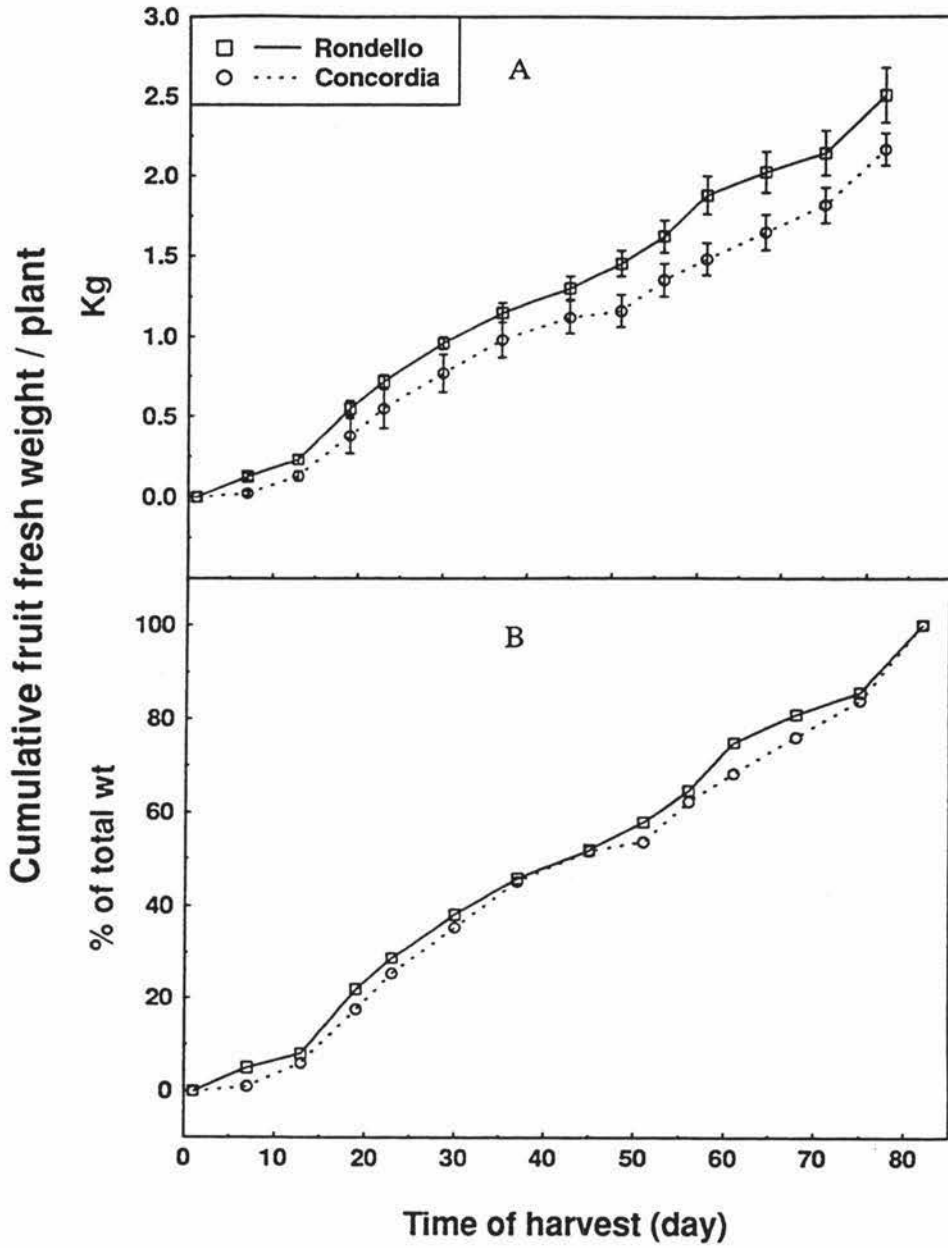


Figure 4.7: Cumulative yield expressed as fruit fresh weight (kg) per plant (A) and % of total fruit fresh weight per plant (B) of two tomato cultivars grown with NFT during winter experiment. Vertical bars represent SEM.

4.6 FRUIT QUALITY

4.6.1 Size (see Section 4.5.1)

4.6.2 Skin colour (determined only during the winter experiment)

a) Hue angle

Changes in hue-angle of fruit from different EC levels and from each cultivar are shown in Figures 4.8A and 4.9A respectively. At the start of colour measurements (breaker stage), there was no significant difference in hue-angle either between fruit from plants grown at different EC levels or between the two cultivars. Thereafter the values of hue-angle decreased with time in storage in both cultivars and at all EC levels. The decrease in hue-angle of fruit from plants grown at high EC (6 and 8 mScm^{-1}) were greater than those at the lower EC (2 and 4 mScm^{-1}) such that from Day 3 to Day 11 fruit from plants grown at 6 and 8 mScm^{-1} had significantly lower hue-angle than those at 2 and 4 mScm^{-1} . However, there was no significant difference in hue-angle between 6 and 8 mScm^{-1} and between 2 and 4 mScm^{-1} for most of the time in storage. On Day 13 and 14 there were no significant differences in hue-angle among fruit from plants grown at different EC levels. Hue-angle of Rondello and Concordia remained the same until Day 12. From there on Concordia fruit had significantly lower hue-angle than Rondello.

b) Lightness

Changes in lightness values of fruit from different EC levels and from each cultivar are shown in Figures 4.8B and 4.9B respectively. At the start of the measurements, lightness values of fruit from plants grown at 6 and 8 mScm^{-1} were higher than those at 2 and 4 mScm^{-1} .

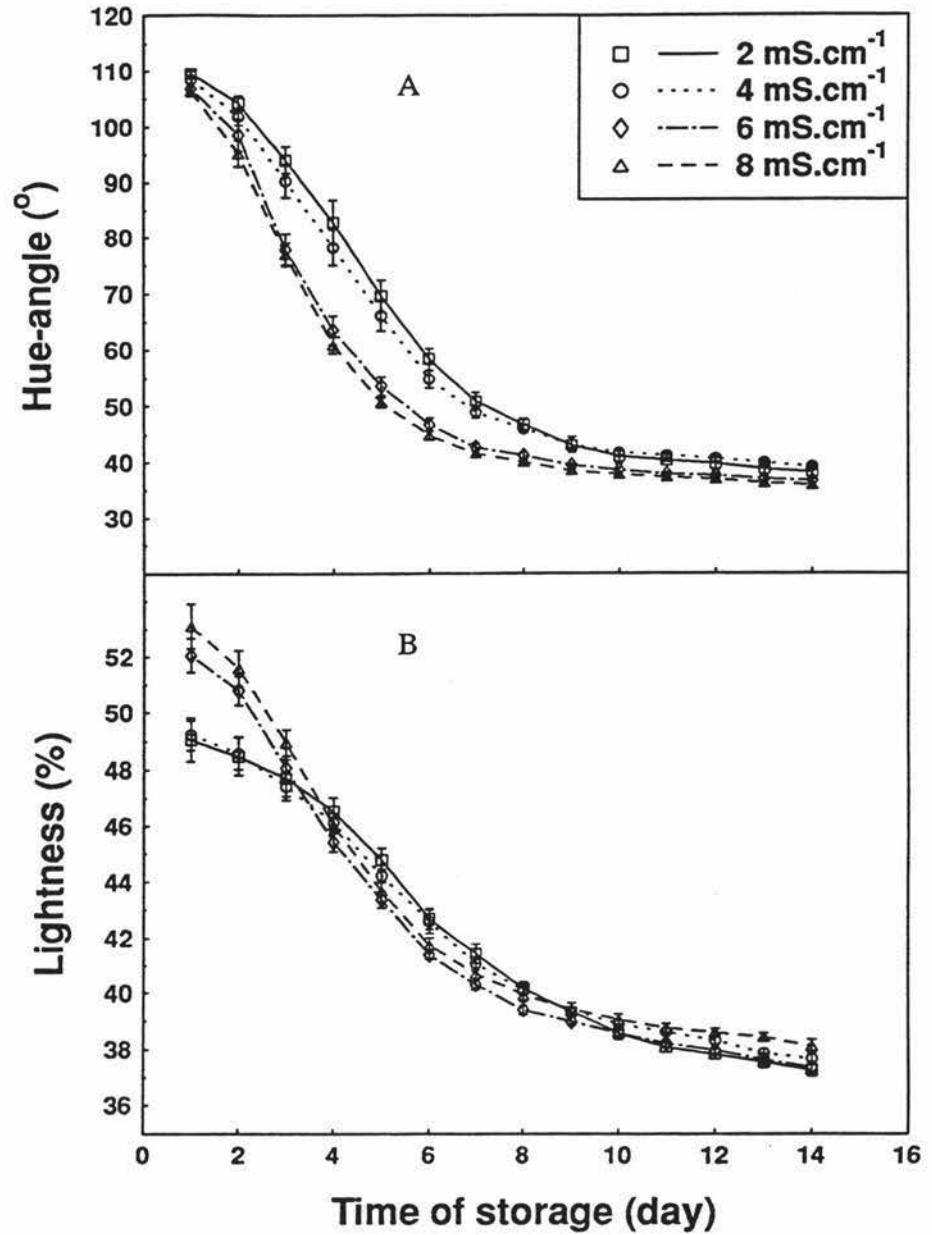


Figure 4.8: Changes in Hue-angle (°) (A) and Lightness (%) (B) of tomato fruit during storage at 20 °C as influenced by different conductivity levels. Vertical bars represent SEM.

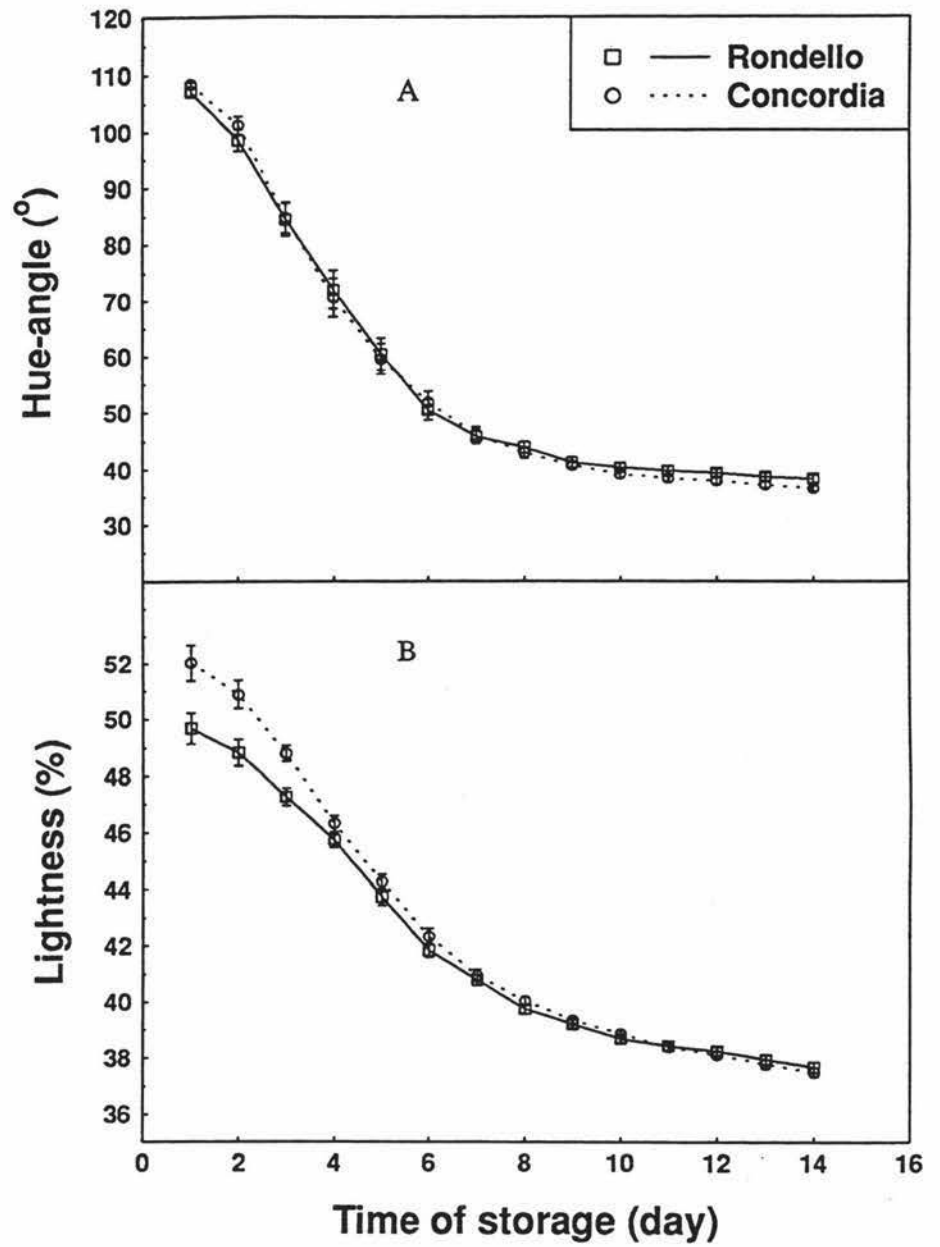


Figure 4.9: Changes in Hue-angle ($^{\circ}$) (A) and Lightness (%) (B) of two tomato cultivars during storage at 20°C . Vertical bars represent SEM.

The lightness values was higher in 'Concordia' than in 'Rondello'. Thereafter, lightness values decreased in all cases. At the early stages (from Day 1 to Day 3) the decrease in lightness values of fruit at 6 and 8 mScm⁻¹ were greater than those at 2 and 4 mScm⁻¹. Thereafter, the decrease continued at a similar rate. From Day 3 onwards, there were no significant difference in lightness values among fruit from different EC levels. Similarly the decreases in lightness values of 'Concordia' was greater at the early stage (from Day 1 to Day 4) and then the decreases continued at a similar rate. From Day 4 onwards, there were no significant difference in lightness values between the two cultivars.

4.6.3 Physiological disorders

Summer experiment

Two types of physiological disorders, blossom-end rot (BER) and cracking were found. The incidence of physiological disorders was highest at 8 mScm⁻¹ being about five times of that at 2 mScm⁻¹. There were no significant differences in incidence of physiological disorders among fruit at 2, 4, and 6 mScm⁻¹ (Tables 4.6 and 4.7).

The incidence of physiological disorders was more than three times higher in Rondello than in Concordia. Most of the affected fruit were due to BER in Rondello and cracking in Concordia.

There was an interaction effect between EC levels and cultivars on the incidence of physiological disorders in such a way that Rondello was more affected by BER at high EC levels.

Considering truss distribution in number of BER fruit in Rondello (Fig. 4.10), fruit from early trusses especially Truss 1 and 2 were subjected to BER at all EC levels. The amount of BER fruit on Truss 3 at 2, 4 and 6 mScm⁻¹ decreased substantially.

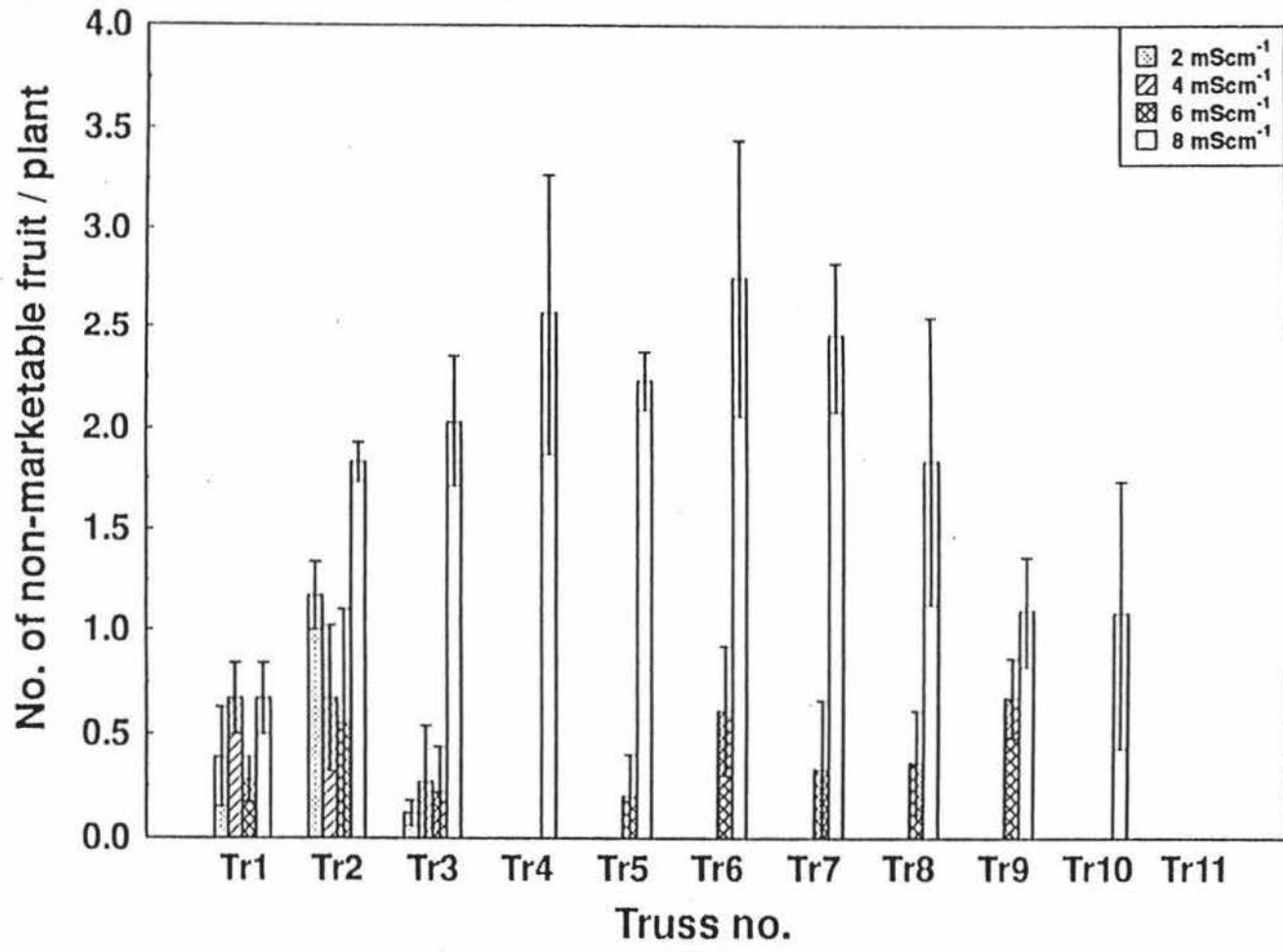


Figure 4.10: Truss distribution in number of non-marketable fruit per plant of 'Rondello' tomato grown with NFT during summer experiment. Vertical bars indicate SEM.

From Truss 4 onwards BER fruit were found only in plants grown at 8 mScm⁻¹ and 6 mScm⁻¹ (in some trusses and at a lower amount). The number of BER fruit at 8 mScm⁻¹ was very high on Truss 4 to Truss 8 then decreased in Truss 9 and 10. No BER fruit was found on Truss 11.

Winter experiment

There were no significant differences in the incidence of physiological disorders (in terms of fruit fresh weight per plant) among plants grown at different EC levels and between the two cultivars (Tables 4.9 and 4.10). The majority of the affected fruit were due to cracking.

The incidence of physiological disorders was much less during the winter experiment than in the summer experiment at all EC levels and in both cultivars.

4.6.4 Total soluble solids

Fruit total soluble solids (TSS) concentration from both experiments are shown in Figure 4.11 for the four different levels of conductivity and Table 4.12 for the two cultivars.

Summer experiment

There was a highly significant effect of EC levels on TSS ($P = 0.001$). Increasing EC resulted in increased TSS in both the early truss (Truss 2) and late truss (Truss 8). However there were no significant difference in TSS between fruit from plants grown at 2 and 4 mScm⁻¹ in early truss. There was no effect of cultivar on TSS of early truss fruit but in late truss, Concordia had higher TSS than Rondello. There was no interaction effect between EC levels and cultivars on TSS.

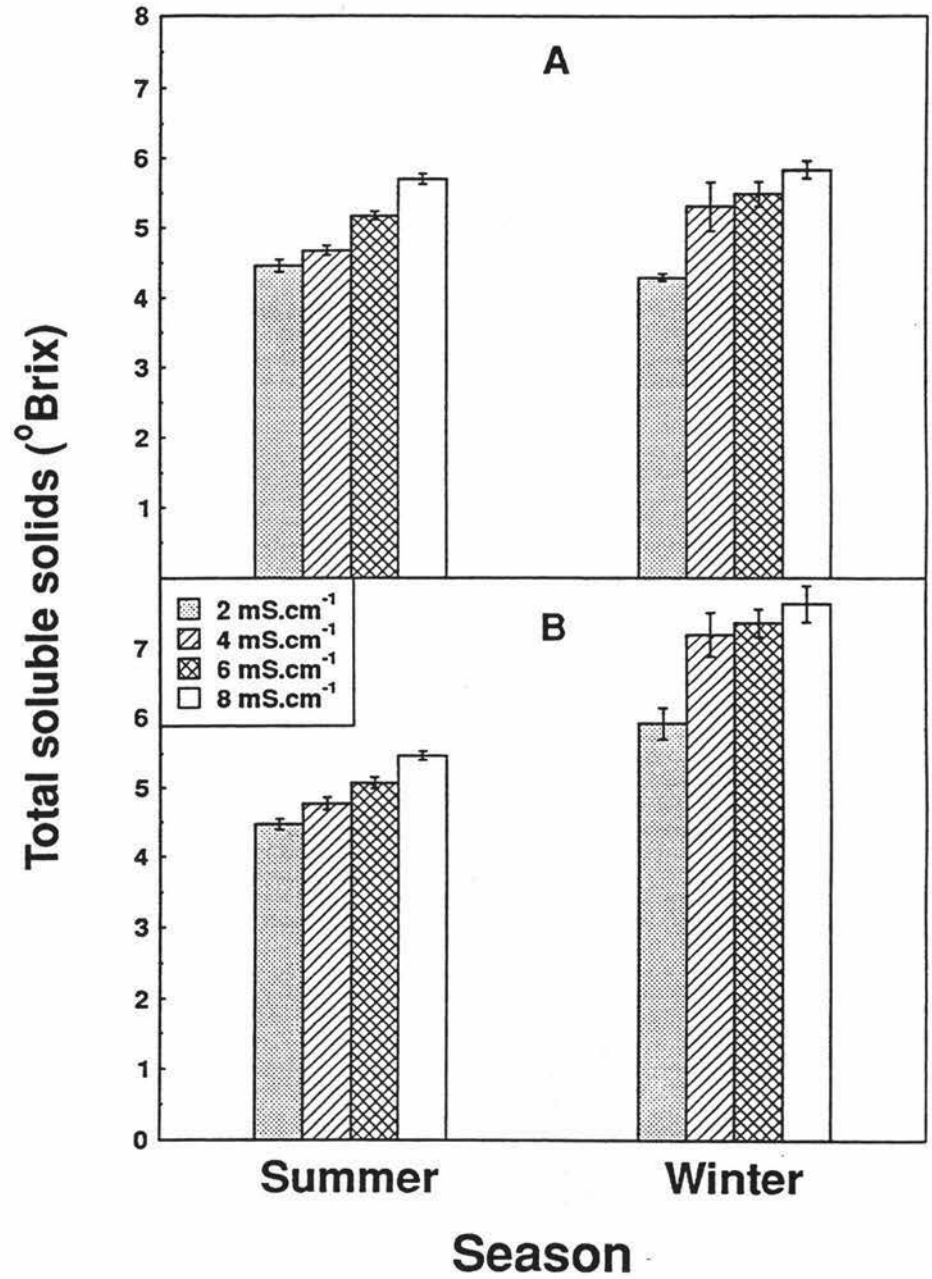


Figure 4.11: Fruit total soluble solids of tomato grown with NFT as influenced by conductivity level and season. A = Early truss fruit (Truss 2 for summer and Truss 1 for winter), B = Late truss fruit (Truss 8 for summer and Truss 6 for winter). Vertical bars represent SEM.

Table 4.12 Total soluble solids (TSS) (° Brix) of two tomato cultivars grown with NFT. Fruit from Trusses 2 and 8 during the summer experiment and from Trusses 1 and 6 during the winter experiment were chosen for early and late trusses determination respectively.

Cultivar	TSS (° Brix)			
	Summer experiment		Winter experiment	
	Early truss	Late truss	Early truss	Late truss
Rondello	4.99	4.86	4.87	6.15
Concordia	5.00	5.02	4.99	6.61
S.E.(df=8)	0.06	0.07	0.06	0.04
Significance	ns	*	ns	*

ns,* Nonsignificant or significant at $P = 0.05$ respectively

Winter experiment

Similar to summer experiment, TSS was significantly increased at increasing EC both in early truss (Truss 1) ($P = 0.001$) and late truss (Truss 6) ($P = 0.01$). However, there were no significant differences in TSS between late trusses fruit from plants grown at 6 and 8 mScm^{-1} . In the early trusses, TSS was unaffected by cultivar, whereas in late trusses, Concordia had higher TSS than Rondello. There was no interaction effect between EC levels and cultivars on TSS.

In early trusses, TSS of fruit from plants grown during summer and winter experiment were similar when compare at the same EC level of 4, 6 and 8 mScm^{-1} . But at 2 mScm^{-1} , TSS was much lower during winter compared to summer. In late

trusses, TSS values were higher during winter than summer experiment at all levels of EC.

4.6.5 Titratable acidity

Titrateable acidity (TA) measured as % citric acid for both experiments as influenced by the four different EC levels are shown in Figure 4.12 and from the two cultivars are shown in Table 4.13.

Summer experiment

There was a clear effect of EC levels on TA in both the early and late trusses fruit. The values of TA were slightly higher at 4 mScm⁻¹ compared with 2 mScm⁻¹ especially in early trusses fruit, however, the differences were not significant. Further increase in EC levels increased TA significantly. At 8 mScm⁻¹, TA value was about 1.4 times of that at 2 mScm⁻¹.

There was no cultivar effect on TA in early trusses fruit whereas in late trusses fruit, Concordia had significantly higher TA than Rondello. The TA values (%) were 0.53 and 0.49 for Concordia and Rondello respectively.

Winter experiment

As in the summer experiment, EC levels affected TA in that TA increased with increasing EC. In early truss fruit, however, the increase in TA at 4 mScm⁻¹ compared with 2 mScm⁻¹ was not significant.

There was no cultivar effect on TA in late truss fruit. In early truss fruit, on the other hand, Concordia had higher TA than Rondello.

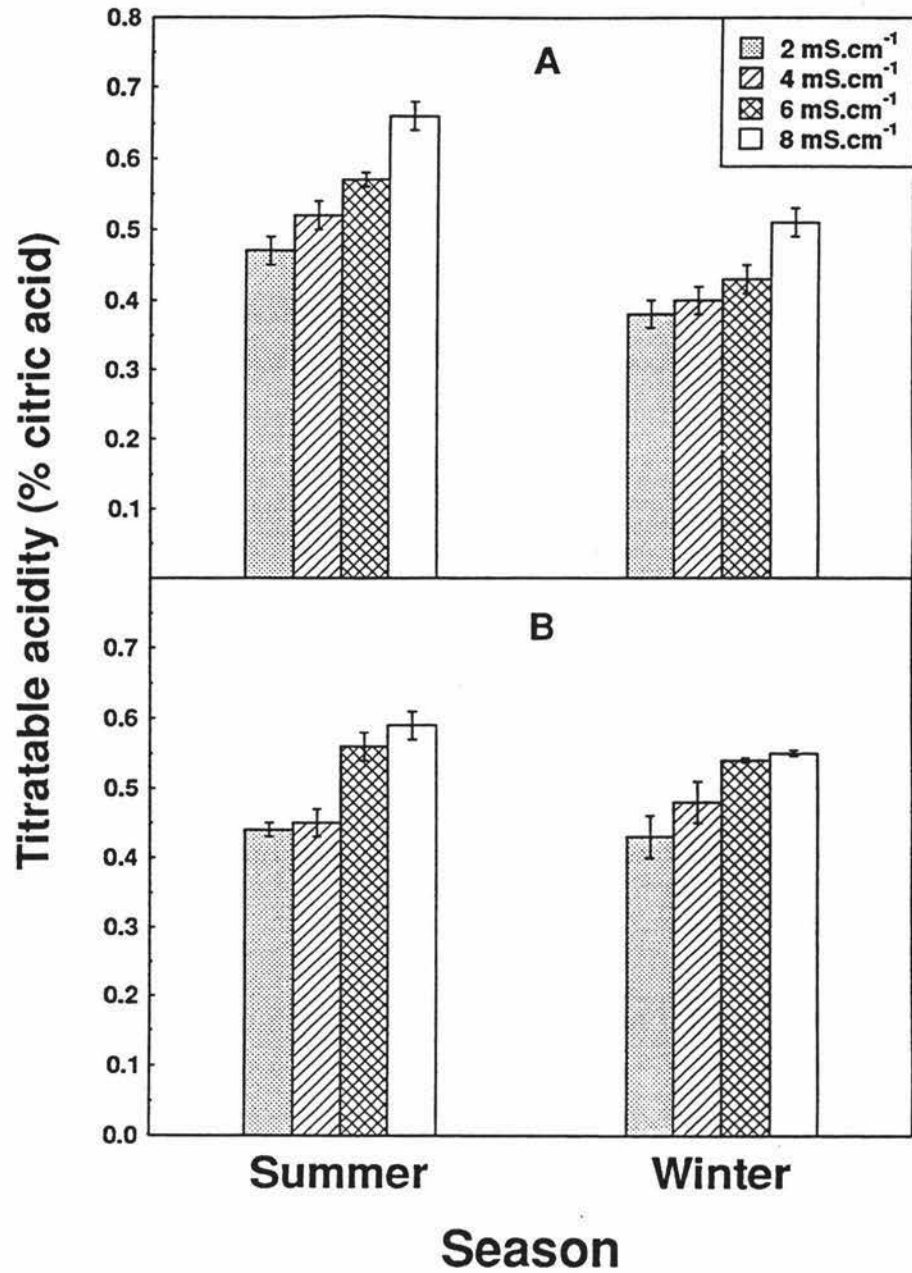


Figure 4.12: Effects of conductivity level and season on fruit titratable acidity of tomato grown with NFT. A = Early truss fruit (Truss 2 for summer and Truss 1 for winter), B = Late truss fruit (Truss 8 for summer and Truss 6 for winter). Vertical bars represent SEM.

There was no interaction effect between EC levels and cultivars on TA in both experiments. The TA values for early truss fruit were much lower during the winter compared with the summer at all EC levels and in both cultivars. Whilst in late truss fruit, the TA values were, in general, similar when compared at the same EC levels and in each cultivar.

Table 4.13 Titratable acidity (TA) measured as % citric acid of two tomato cultivars grown with NFT. Fruit from Trusses 2 and 8 during the summer experiment and from Trusses 1 and 6 during the winter experiment were chosen for early and late trusses determination respectively.

Cultivar	TA (% citric acid)			
	Summer experiment		Winter experiment	
	Early truss	Late truss	Early truss	Late truss
Rondello	0.54	0.49	0.41	0.48
Concordia	0.58	0.53	0.45	0.52
S.E.(df=8)	0.02	0.01	0.01	0.02
Significance	ns	*	*	ns

ns,* Nonsignificant or significant at P = 0.05 respectively

4.6.6 Dry matter concentration

The dry matter concentration (%) from both experiments are shown in Figure 4.13 for the for levels of conductivity and Table 4.14 for the two cultivars.

Summer experiment

Only dry matter concentration (%) of late trusses fruit were determined during summer experiment. Dry matter (%) increased significantly at increasing EC ($P = 0.01$). There were neither effect of cultivars nor interaction effect between EC levels and cultivars on dry matter concentration (%).

Table 4.14 Dry matter concentration (%) of two tomato cultivars grown with NFT. Fruit from Trusses 2 and 8 during the summer experiment and from Trusses 1 and 6 during the winter experiment were chosen for early and late trusses determination respectively.

Cultivar	Dry matter conc.(%)			
	Summer experiment		Winter experiment	
	Early truss	Late truss	Early truss	Late truss
Rondello	n.a.	6.88	5.03	6.90
Concordia	n.a.	6.93	5.43	7.15
S.E.(df=8)	n.a.	0.18	0.15	0.18
Significance	n.a.	ns	*	ns

^{n.a.} Not applicable

^{ns,*} Nonsignificant or significant at $P = 0.05$ respectively

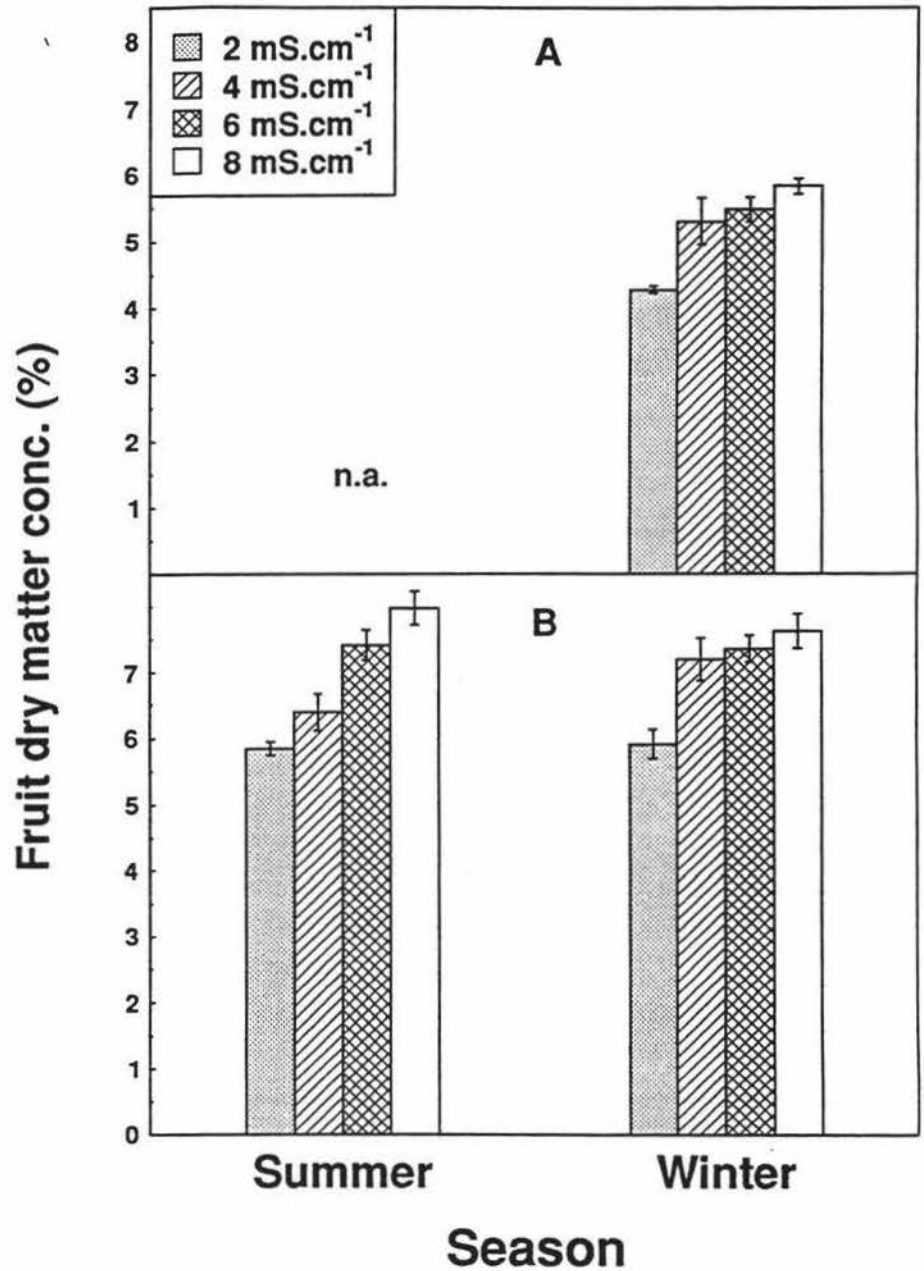


Figure 4.13: Effect of conductivity level on fruit dry matter concentration (%) of tomato grown with NFT. A = Early truss fruit (Truss 2 for summer and Truss 1 for winter), B = Late truss fruit (Truss 8 for summer and Truss 6 for winter). Vertical bars represent SEM.

Winter experiment

Increasing EC levels significantly increased fruit dry matter concentration (%) in both early trusses ($P = 0.05$) and late trusses ($P = 0.01$). In early trusses, 'Concordia' had higher % dry matter than Rondello. Whereas in late trusses, dry matter (%) were unaffected by cultivars. There was no interaction effect between EC levels and cultivars on % dry matter of the fruit.

4.6.7 Fruit taste

Results of taste tests performed on ripe tomato fruit are presented in table 4.15. In general, the fruit from plants grown at high EC levels (6 and 8 mScm^{-1}) tasted better than those at lower EC levels in both experiments. According to the results from the taste test, the difference in taste of fruit from 2 and 4 mScm^{-1} was not clear. Comparing between the two cultivars, about 75% and 63% (during summer and winter experiments respectively) of the tasters preferred the taste of Rondello than Concordia (data not shown).

Table 4.15 Effect of conductivity level on taste of tomato fruit.

Season	Fruit taste, score *							
	Rondello				Concordia			
	Conductivity (mScm^{-1})				Conductivity (mScm^{-1})			
	2	4	6	8	2	4	6	8
Summer	2.1	2.5	3.2	3.3	2.3	2.1	2.5	2.9
Winter	2.4	2.0	2.9	3.3	2.2	2.4	3.0	3.1

* Taste score ranking from 4 = best to 1 = worst.

Numbers are the average of ten tasters.

4.6.8 Weight loss

Summer experiment

Fruit weight loss was dependent on time in storage. There was a tendency for decreasing weight loss when EC levels increased from 2 mScm⁻¹ to 4 mScm⁻¹ and from 4 mScm⁻¹ to 6 mScm⁻¹ (Fig. 4.14A). The highest percent weight loss, however, resulted from fruit at 8 mScm⁻¹. Nevertheless, the differences in percent weight loss among fruit from different EC levels were not significant. Surprisingly, percent weight loss of Concordia, the long shelf life cultivar, was higher than Rondello (Fig. 4.15A). On day 14, weight loss were 3.3% and 2.9% for Concordia and Rondello, respectively.

Winter experiment

Fruit weight loss was dependent on time in storage. There were no significant differences in weight loss among different EC levels (Fig. 4.14B). Concordia appeared to lose weight more than Rondello, however, the differences were not significant (Fig. 4.15B).

Percent weight loss was higher during the winter experiment. On day 14, the percent weight loss at 2, 4, 6, and 8 mScm⁻¹ were 4.20%, 3.71%, 3.21%, and 3.32% during winter experiment and 3.27%, 3.10%, 2.73%, and 3.30% during summer experiment. And the percent weight loss for Concordia and Rondello were 3.90% and 3.32% during winter experiment while they were 3.30% and 2.90% during summer experiment.

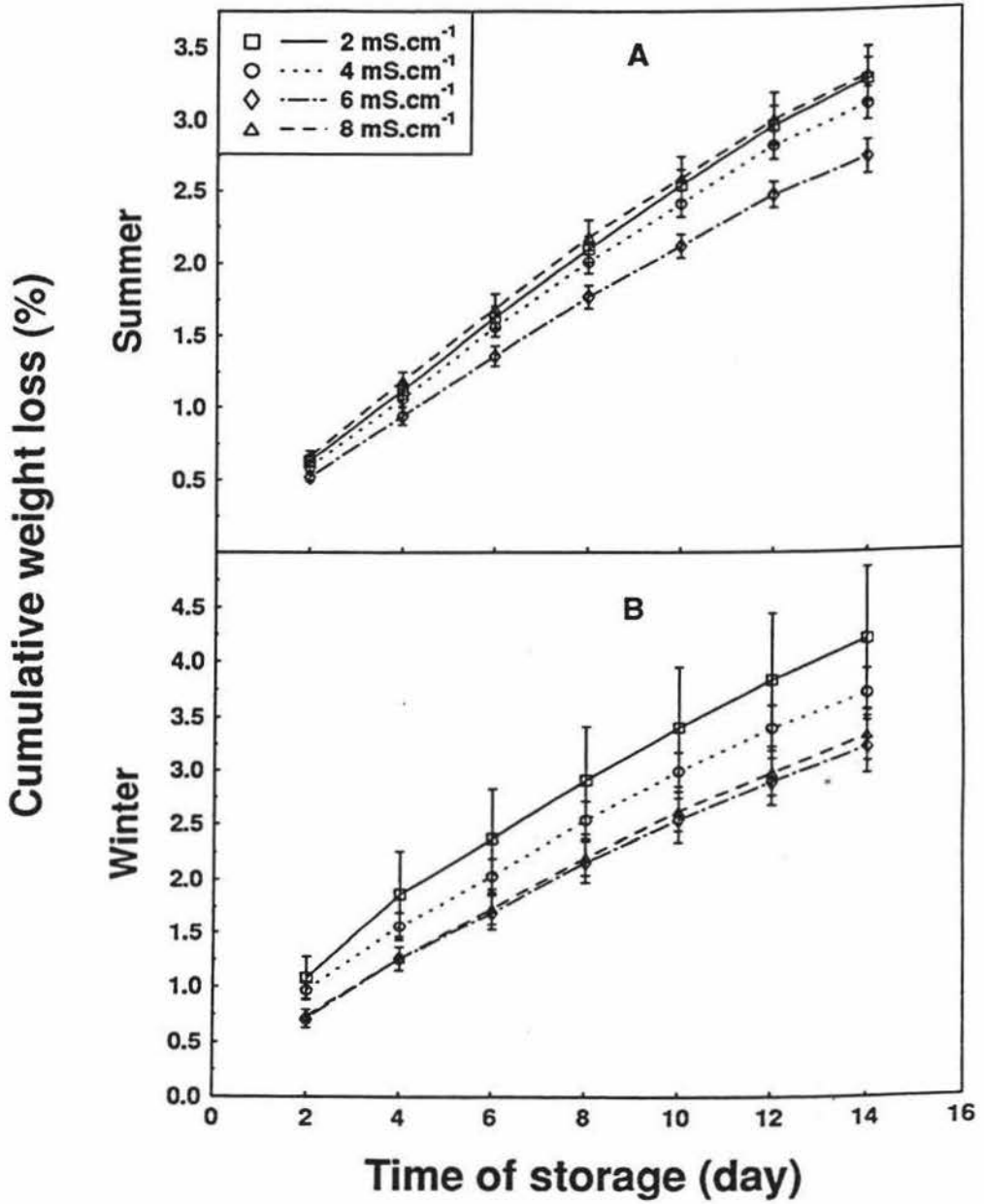


Figure 4.14: Cumulative weight loss (%) of tomato fruit (during storage at 20 °C) at different conductivity levels during summer (A) and winter (B). Vertical bars represent SEM.

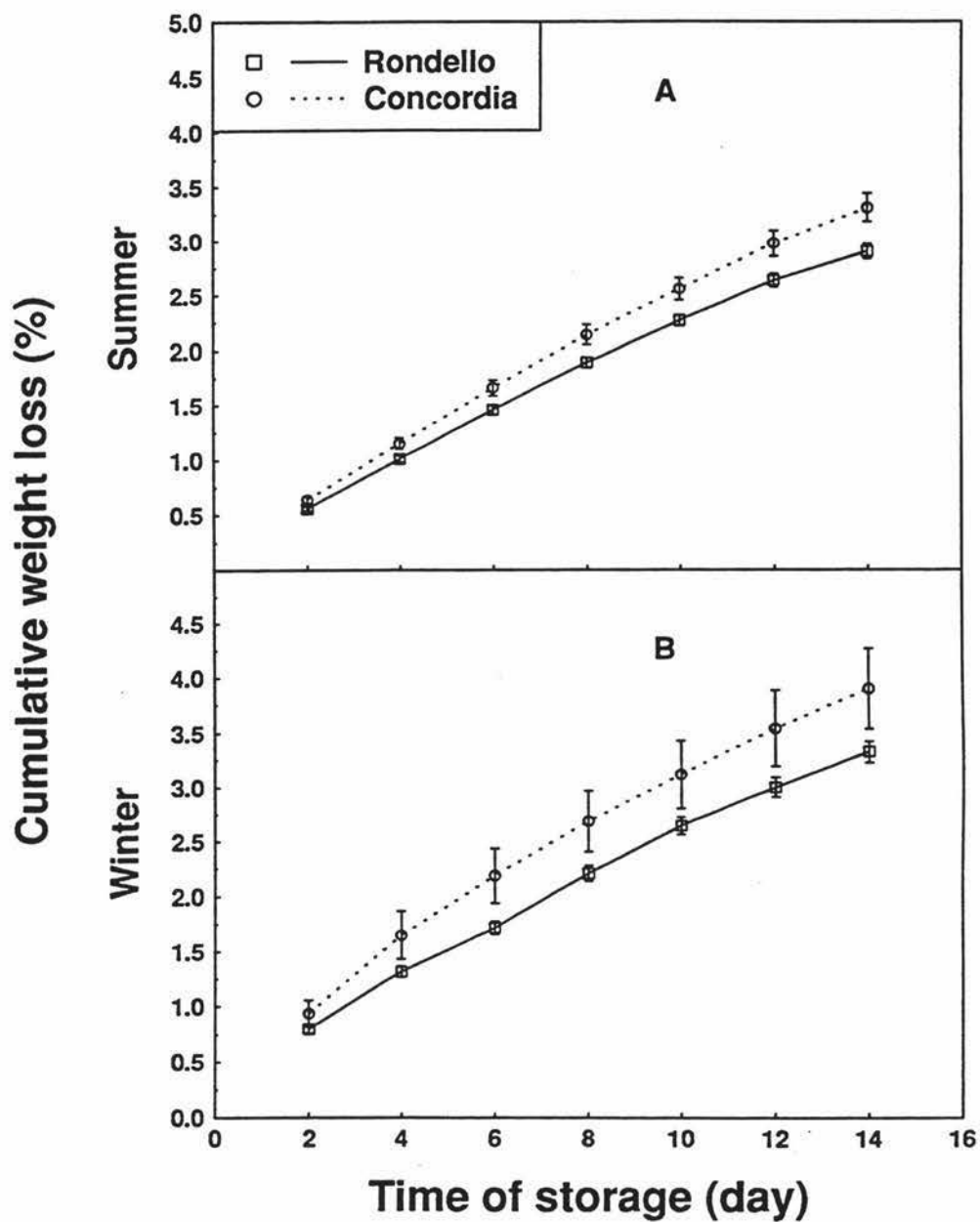


Figure 4.15: Effect of cultivar on cumulative weight loss (%) of tomato fruit during storage at 20 °C in the summer (A) and winter (B) experiments. Vertical bars represent SEM.

CHAPTER FIVE

DISCUSSION

5.1 PLANT WATER UPTAKE AND PLANT WATER STATUS

Leaf and/or xylem water potential, Ψ , has received wide acceptance as a measurement of plant water status (Boyer, 1967; Kaufman and Hall, 1974). During the summer experiment, decreasing Ψ at increasing EC levels indicated that levels of nutrient solution conductivity had significant effects on the plant water status. Other studies also reported a decrease in Ψ as a result of increasing salinity (high EC levels in the root zone) (Alarcon et al., 1994; Atta-aly et al., 1992; Mitchell et al., 1991b) and water stress (Mitchell et al., 1991b; Torrecillas et al., 1995). Bruggink et al. (1987) observed the lower stem water potential in tomato plants grown with NFT at 6 mScm^{-1} compared with those grown at 2 mScm^{-1} . Though the design of the experiment prevented statistical inferences to be drawn from the data, plant water uptake appeared to decrease at EC levels higher than 4 mScm^{-1} . Increasing EC levels decrease the water potential of the nutrient solution as the increased solutes decrease the osmotic potential, a component of water potential (Mengel and Kirkby, 1987). This leads to a decrease in the water potential gradient between the nutrient solution and the plant roots resulting in decreased plant water uptake and consequently plant water status. Many workers have reported a decrease in tomato plant water uptake at high EC levels (eg. Adams, 1994; Ehret and Ho, 1980b; Papadopoulos and Rending, 1983). The average values of plant water uptake resulted from the current study were, however, higher at 4 mScm^{-1} compared to 2 mScm^{-1} on both sunny and cloudy days. Adams (1994) also reported a higher water uptake in tomato at 4.8 mScm^{-1} than at 3 mScm^{-1} . However, the reason was not given. According to the concept of soil-plant-atmosphere continuum (Section 2.4.2), the higher uptake of water by plant roots on sunny days compared with cloudy days and during the summer experiment compared with the winter experiment could be caused by higher water loss

from plants through transpiration due to the higher evaporative demand.

Similarly the lower Ψ during sunny days compared to cloudy days in both experiments and the lower Ψ during the summer experiment compared to winter experiment were likely due to differences in evaporative demand. In many plant species, there is a diurnal variation in Ψ (Jones et al., 1985). Dramatic diurnal changes in Ψ also exists in tomato plants. The highest Ψ is found during the early morning and late night hours and the lowest during the afternoon (Rudich et al., 1981). Diurnal changes in Ψ indicate that, in addition to the water availability in the root zone, Ψ is also dependent on the evaporative demand of the atmosphere (Rudich et al., 1981) which is dependent on radiation, temperature and relative humidity. Increased transpiration at high evaporative demand due to higher solar radiation and higher temperature during sunny days compared to cloudy days and during summer compared to winter could therefore explain the lower value of Ψ during sunny compared to cloudy days and during summer compared to winter.

5.2 VEGETATIVE GROWTH

Reduction in vegetative growth as a result of reduced plant water status has been reported previously in many plant species such as apples (Higgs and Jones, 1991); peaches (Chalmers et al., 1984); pears (Mitchell et al., 1984). In tomato, decreased vegetative growth in terms of both fresh and dry weights as a result of an increase in EC level was reported (Charbonneau et al., 1988; Hayward and Long, 1943). Atta-Aly et al. (1992) observed vegetative growth reduction, as indicated by reduced plant height, leaf fresh weight and leaf size, in saline-treated tomato plants. From the current study, increasing EC levels of nutrient solution caused substantial decrease in vegetative growth in terms of leaf fresh weight, leaf dry matter concentration and stem fresh weight during summer experiment. For the winter experiment, only stem fresh weight and stem dry matter concentration reduced at high EC levels. Leaf area, on the other hand, was unaffected by EC levels in both experiments.

Results from earlier studies are conflicting in some aspects of vegetative growth as influenced by plant water status. For example, Alarcon et al. (1994) observed reduced leaf dry weight at high salinity whereas Torrecillas et al. (1995) found no reduction in leaf dry weight from the water stressed plants. Several authors have observed reduced leaf area in plants grown in conditions leading to a reduced plant water status such as deficit irrigation (Torrecillas et al., 1995) and salinity (Alarcon et al., 1994). Bruggink et al. (1987), however, observed no significant difference in leaf area between plants grown at 2 and 6 mScm⁻¹. The different findings could have been due to differences in plant water status achieved from various treatments, differences in cultivars used, and differences in weather conditions during the experiments.

In the current study, during the winter experiment, there was a trend of decreasing leaf dry matter concentration with increasing EC levels though the differences were not significant. In the case of leaf fresh weight, there might have been an experimental error during the winter experiment because, as a means to control *Botrytis*, some of the affected leaves were cut off. The values of total leaf fresh weight per plant collected at the end of the experiment were, therefore, not the actual values. In general, we may conclude from the current study that low plant water status as a result of high EC levels reduced vegetative growth. Since leaf area was unaffected by EC levels, a decrease in leaf dry matter concentration and/or leaf thickness might have accounted for the decrease in leaf fresh weight at high EC levels.

There were no cultivar effects in most aspects except Concordia had higher leaf area and stem dry matter concentration than Rondello during the winter experiment and higher leaf dry matter concentration during the summer experiment.

Lack of interaction effect between EC levels and cultivars suggested that both cultivars responded, in terms of vegetative growth, to EC levels in the same way.

5.3 NUMBER OF TRUSSES AND LENGTH BETWEEN TRUSSES

From the current study, the conductivity level of the nutrient solution did not affect either the total number of trusses per plant or length between trusses. However, plants grown during the winter experiment had fewer trusses per plant than those grown during the summer experiment. All plants were stopped at 2 leaves above the top wires which means that the differences in total number of trusses per plant could be a result of differences in internode length. However, this cannot be concluded from this study because length between trusses was recorded only during the winter and not in the summer experiment. During the winter experiment, the absence of any effect of EC levels on length between trusses corresponded with the absence of effect of EC levels on number of trusses. From the literature, Hurd and Thornley (1974) reported an increase in the rate of stem elongation at reduced daily irradiance. Koning (1994) observed that there were fewer trusses available at low temperatures than at high temperatures due to differences in plant development. Lower daily irradiance and temperatures were recorded in winter than in summer (Section 3.2).

5.4 YIELD, YIELD COMPONENTS AND TIME OF MATURITY

5.4.1 Yield

During the summer experiment the yield of both cultivars were reduced significantly at high EC levels (6 and 8 mScm⁻¹) due to a decrease in fruit size (mean fruit weight) and a decrease in marketable fruit due to the incidence of BER especially in Rondello. In both experiment, yield was slightly higher at 4 mScm⁻¹ compared to 2 mScm⁻¹, however, the difference was not significant. Adams (1994) reported the higher yield (by 6%) at 4.8 mScm⁻¹ compared to 3 mScm⁻¹ corresponded to more water and nutrients uptake.

There were no significant differences in marketable yield between Rondello and Concordia in both experiments. The total number of fruit set in both cultivars were not significantly different. Rondello though was more subjected to physiological disorders than Concordia and so it had less number of marketable fruit, this was compensated by the larger fruit size (higher mean fruit fresh weight).

5.4.2 Fruit number

In my study, fruit were thinned to maintain six fruit per truss. There were less than six fruit formed in some trusses especially during the winter experiment. Nevertheless, there were no significant differences in total number of fruit per plant at different EC levels in both experiments. Adams (1991) observed that the conductivity level of up to 8 mScm⁻¹ did not affect the number of fruit produced, whereas at 12 mScm⁻¹ the number of fruit produced was significantly reduced. Adams and Ho (1989) observed no reduction in fruit number of tomato plants grown with NFT at 8 mScm⁻¹ during a short-term crop but a decrease in fruit number of about 12% was found in a long season crop. The less sensitive response in terms of number of fruit set due to water deficit was reported by Cannel and Asbell (1974); Mitchell et al. (1991a); and Wolf and Rudich (1988).

There was a clear seasonal effect on number of fruit obtained. The number of fruit set were much less during the winter experiment. Total number of fruit per plant during winter experiment were 56%, 58%, 61%, and 63% of those during summer experiment at 2, 4, 6, and 8 mScm⁻¹, respectively. The reduced number of fruit produced during winter experiment could be as a result of the lower number of trusses developed (Section 4.4). However, when comparing the same truss, the number of fruit were still less in winter than in summer experiment in some trusses, especially from Truss 4 (Fig.

No. of non-marketable fruit / plant

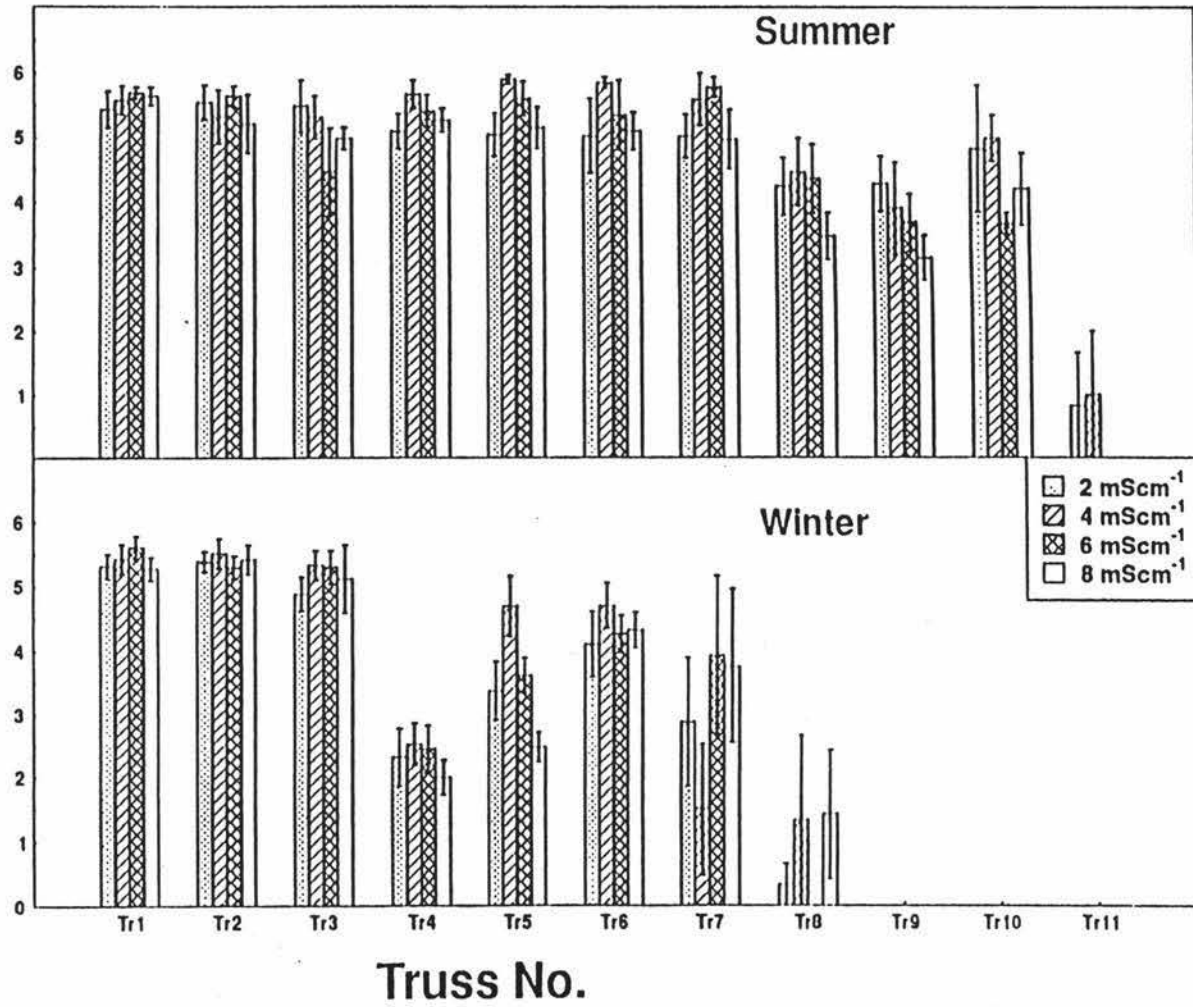


Figure 5.1: Truss distribution in number of marketable fruit of tomato grown with NFT at different conductivity level during summer and winter. Vertical bars represent SEM.

5.1). The probable reason for less fruit in winter could be the occurrence of flower abortion and/or reduced fruit set due to low irradiance during winter. However, this cannot be concluded from this study. Flower abortion is defined as the loss of flowers prior to their opening (Atherton and Harris, 1986). In the studies of Atherton and Othman (1983), total irradiance of 150 MJm^{-2} over a 30 day period from macroscopic bud visibility caused 50% flower abortion in the first inflorescence. Complete truss abortion occurred when plants received less than 75 MJm^{-2} over the same period. And no flower abortion occurred when plants received over 300 MJm^{-2} . Limitation of fruit set in the low light conditions during winter was reported by Picken (1984). Extreme temperatures (below $10 \text{ }^{\circ}\text{C}$ or above $30 \text{ }^{\circ}\text{C}$) also limit fruit set (Picken, 1984). However, such extreme temperatures were unlikely to have occurred in this study as the temperature in the glasshouse was partly controlled (Section 3.4).

5.4.3 Fruit size

The results obtained in the current study showed that the levels of nutrient solution conductivity had clear effects on fruit size (measured as mean fruit fresh weight) in both experiments. During the winter experiment, though EC levels had no effect on fruit fresh weight per plant and number of fruit per plant they had significant effects on mean fruit weight. Fruit size of both cultivars responded to EC levels in the same way that the size decreased when the conductivity level was raised to 6 and 8 mScm^{-1} . At the same level of nutrient solution conductivity, Concordia had a smaller fruit size than Rondello. This could be a genotypic effect as it is known that fruit size varies among cultivars.

Reduction in fruit size at high EC levels has been reported in many studies (eg. Adams, 1991; Adams and Ho, 1989; Ehret and Ho, 1986b; Gough and Hobson, 1990). Adams and Ho (1989) indicated that high EC levels affect fruit size by a reduction in fruit water content than in dry matter accumulation. The total number of fruit set (fruit load) also affects fruit size due to mutual competition for assimilate between fruit (Koning, 1994). However, this effect is negligible in this study as fruit were thinned to maintain six fruit per truss.

The further reduction in fruit size during winter compared to summer which occurred in all trusses (Fig. 5.2) indicates the seasonal effects on fruit size. Fruit growth depends upon its ability to accumulate assimilates (Wolf and Rudich, 1988). Seasonal effects on fruit size are largely through direct effects of solar radiation on crop photosynthesis (source of assimilates) and on glasshouse air temperature (Cockshull and Ho, 1995). The other possible reason for smaller fruit size obtained during winter experiment could be as a result of poor pollination under low light conditions in winter. Weight of individual fruit appears highly correlated with number of seeds (Imanishi and Hiura, 1975). Poor pollination reduces seed number and therefore fruit weight. Number of seeds per fruit were not determined in the current experiments. The smaller number and size of fruit obtained during winter experiment, however, may suggest poor pollination.

5.4.4 Time of maturity

From this study, the effect of EC levels on time of maturity was not clear. Half of the total yield from plants grown at different EC levels were harvested at similar period during the summer experiment. During the winter experiment, half of the total yield from plants grown at 6 mScm⁻¹ were harvested earliest while at 8 mScm⁻¹ they were the latest being harvested. Alarcon et al. (1994) observed that fruit from plants grown in saline conditions matured and reached the harvest stage earlier than those of the control. The shortened tomato fruit life span under saline conditions was also reported in the study by Mizrahi (1982) as an adaptation to stress, which enables the plant to disperse its seeds faster when exposed to stress.

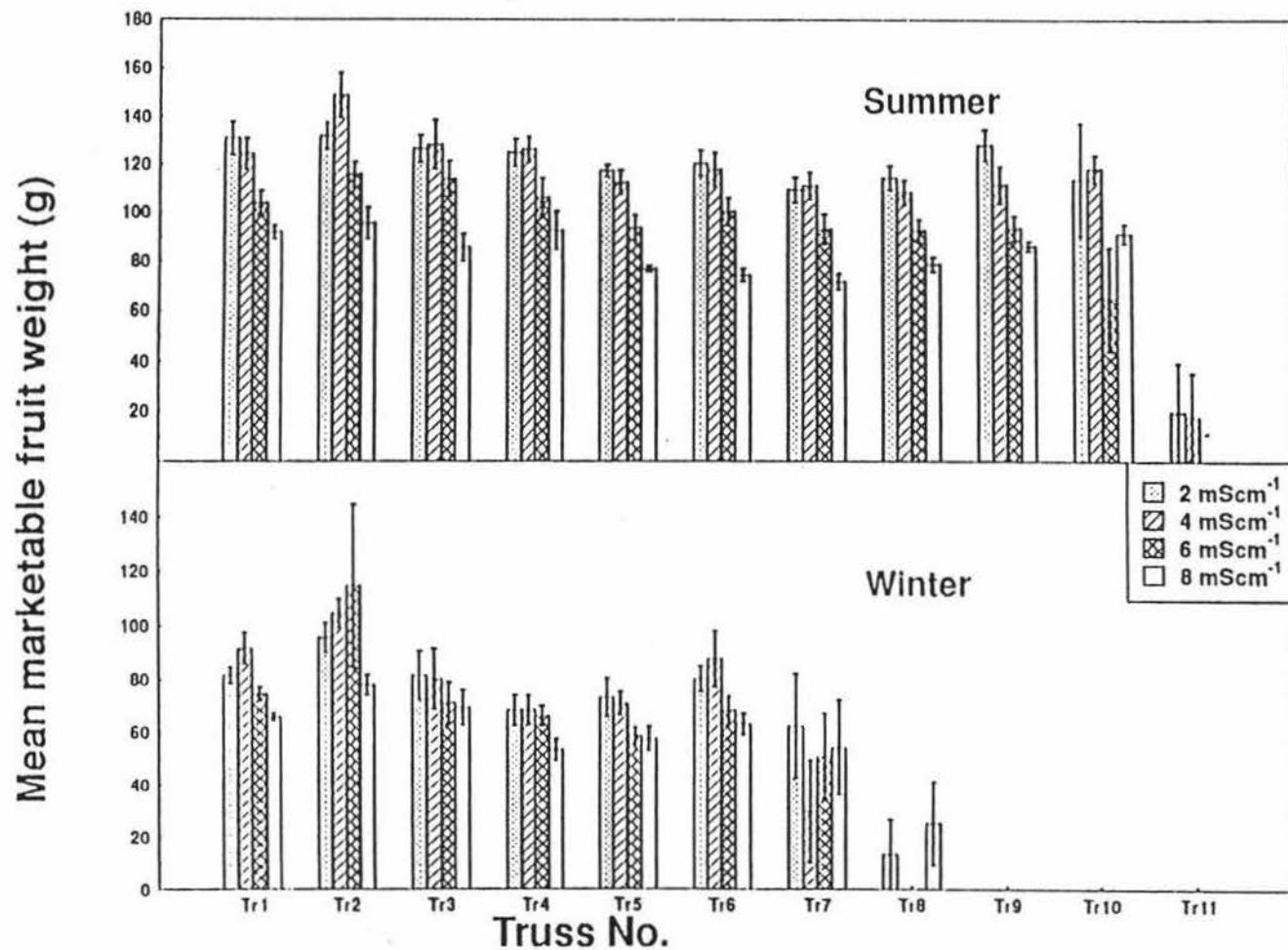


Figure 5.2: Fruit size (mean fruit fresh weight) in each truss of tomato grown with NFT at different levels of conductivity during summer and winter. Vertical bars represent SEM.

5.5 FRUIT QUALITY

5.5.1 Fruit size (see Section 5.4.3)

5.5.2 Skin colour

The colour of tomato is a result of a blend of various amounts of different pigments. Lycopene synthesis is primarily responsible for the red colour of tomato ripe fruit (Davies and Hobson, 1981). Lower values of H and L indicate a redder and darker skin and these correspond with a higher lycopene concentration (Ishida et al., 1993). From the current study, though L values appeared to be unaffected by EC levels, fruit from high EC levels (6 and 8 mScm⁻¹) had lower H values than fruit from low EC levels (2 and 4 mScm⁻¹) in most of the measurements (day 3 to 11). Therefore, the results obtained indicate that fruit from plants grown at higher EC levels (6 and 8 mScm⁻¹) developed a higher lycopene content than those from lower EC levels (2 and 4 mScm⁻¹) at an earlier stage.

The values of H and L of Rondello and Concordia were, in general, not different except during the first 3 days where Rondello had lower L values and the last 3 days where Concordia had lower H values. We may conclude that both cultivars had similar skin colour but Concordia developed a redder colour 11 days after storage. Lack of interaction effect suggested that both cultivars responded to EC levels in the same way in terms of changes in skin colour during ripening.

The current study did not investigate the physiological basis of the differences observed in skin colour. Accumulation of lycopene is a result of the destruction of chlorophyll as chloroplast are transformed into chromoplast (Grierson and Kader, 1986) and this occurs during the ripening process (Fraser et al., 1994; Giuliano et al., 1993). Colour is often used as an indicator of tomato ripeness (Grierson and Kader, 1986). The redder colour

of fruit on Day 3 to 11 from plants grown at high EC (6 and 8 mScm⁻¹) could have been as a result of more advanced ripening. Several workers (eg. Alarcon et al., 1994; Mizrahi, 1982; Sharaf and Hobson, 1986) have observed that high conductivity in the root zone enhanced fruit maturation and ripening (fruit ripen more quickly). Mizrahi (1982) found, in various tomato cultivars, more ethylene and more CO₂ evolved from fruit harvested from plants grown at higher conductivity levels.

5.5.3 Physiological disorders

Results from the summer experiment indicate that there were effects of EC levels on the incidence of physiological disorders. The incidence of physiological disorders started to increase when the EC level was raised to 6 mScm⁻¹ and they increased markedly when the level of EC was raised to 8 mScm⁻¹. The results also indicated the interaction effects between EC levels and cultivars in such the way that at increasing EC levels, Rondello was more susceptible to physiological disorders.

Moreover, the results obtained suggested that there were seasonal effects. The incidence of physiological disorders was much higher during the summer experiment (39% of total yield in Rondello grown at 8 mScm⁻¹), whereas during the winter experiment, the incidence of physiological disorders was negligible (about 1% of total yield in Rondello grown at 8 mScm⁻¹). Rondello yielded much more fruit with physiological disorders than Concordia. Most of physiological disorder found in Rondello was BER whilst in Concordia was cracking.

Blossom-end rot

Several studies have observed an increase in BER incidence at high EC levels (eg. Adams and El-Gizawy, 1986; Adams and Ho, 1993; Ho et al., 1993). From the current study, the incidence of BER was high only in Rondello plants grown at high EC levels especially at 8 mScm⁻¹ during the summer experiment. During the winter experiment, BER was negligible. Blossom-end rot generally results from a combination factors that

affect Ca movement and/or rate of fruit growth (Adams, 1994). High EC levels restrict water and thus Ca uptake. Reduced Ca uptake as a result of high EC Levels in the root zone was reported by many workers (eg. Adams and El-Gizawy, 1986; Belda and Ho, 1993; Ehret and Ho, 1986a; Ho et al., 1993). According to Ho and Adams (1989a), besides a reduction in Ca uptake by the roots, a direct and short term effect, high EC levels also have an indirect, long term effect on the xylem tissue development in the fruit. Ho et al. (1993) found that the density of vascular bundles per cross-sectional area of fruit tissue which is a measure of the relative capacity of transport in both phloem and xylem was only slightly reduced at high EC levels, but the number of stained vascular bundles, a measure of the relative capacity of xylem transport, in both the proximal and distal fruit tissue was reduced substantially at high EC levels.

The high incidence of BER during the summer experiment could be as a result of the high solar radiation integral as well as high average daily temperature. Increase in light intensity enhance fruit growth rate as it increases the rate of photosynthesis and hence the supply of assimilates to the fruit (Adams, 1994). The rate of fruit growth is also controlled by air temperature (Pearce et al., 1993). Increase in temperature increases fruit growth rate. In the study of Koning (1994), fruit growth period varied from about 73 days at 17 °C to only 42 days at 26 °C. As the growth rate increases, the demand for Ca of the fruit increases since Ca is widely involved in bonds which hold the cell structure together (Adams, 1994). This increase in Ca demand without a corresponding increase in Ca supply enhances the incidence of this disorder. Moreover, increases in light and temperature also enhance transpiration result in a preferential distribution of Ca to the leaves, the major organ through which most water is lost via transpiration.

Fruit with BER were found even at low EC levels on early trusses especially Truss 1 and 2. Growth and development of fruit on these trusses occurred mainly in January when the total sunshine hours, air temperature and pan evaporation were all high. It is speculated that the incidence of BER which occurred even at low EC levels could be as a result of high growth rate of the fruit on these trusses and less Ca distributed to the fruit as more Ca was distributed to the leaves due to high transpiration. In

February and March, though the air temperatures were still high, there were less total sunshine hours and pan evaporation. It is therefore suggested that the high BER in fruit from Truss 4 to 8 at 8 mScm^{-1} was as a result of the long stress period. Decreasing in BER incidence from Truss 9 could be because there were less fruit remained on the plant hence less competition for Ca.

The results from this study indicated that Rondello was more susceptible to BER than Concordia especially at high EC levels. Adams and Ho (1992) reported that the incidence of BER differs substantially among cultivars in response to salinity. The capacity of the susceptible cultivars to import and distribute $^{45} \text{Ca}$ to the distal half of the fruit was substantially reduced at high salinity (Adams and Ho, 1992). According to Ho et al. (1993), the susceptible cultivars have poorer xylem development as indicated by the reduction of stained vascular bundles in the distal layer of the placenta and higher rate of cell enlargement than the less susceptible cultivars. Rondello has larger fruit size than Concordia and this could also be another reason why Rondello is more susceptible to BER than Concordia. Though fruit growth rate was not determined in this study, Rondello appeared to have higher fruit growth rate than Concordia as both cultivars started flowering and setting fruit at similar periods but Rondello though having larger fruit size reached the harvest stage slightly earlier than Concordia during the summer experiment.

5.5.4 Fruit composition

The effects of EC levels on fruit composition could be seen clearly in both cultivars and during both the experiments. Fruit total soluble solids (TSS), titratable acidity (TA) and dry matter content (%) all increased with increasing EC levels.

Large differences in fruit dry matter content were found among fruit from plants grown at different EC levels. Increasing the EC from 2 mScm^{-1} to 8 mScm^{-1} increased dry matter concentration (%) of harvest ripe fruit from 5.85 to 7.98% in late truss during the summer experiment, from 4.28 to 5.84 and from 5.92 to 7.63 for early and late truss,

respectively, during winter experiment. Adams (1991) found an increase in fruit dry matter concentration (%) in tomato grown in rockwool when the conductivity level of nutrient solution was raised from 3 to 8 and 12 mScm^{-1} . Fruit dry matter content is determined not by assimilate supply alone but also by the fruit's water accumulation (Ho, 1988b). Ehret and Ho (1986b) reported that, at high EC, the accumulation of water by fruit was reduced while the accumulation of assimilates was unaffected. Results from the studies of Mitchell et al. (1991b) were in agreement with that of Ehret and Ho (1986b) in that, under moderate levels of water deficit or salinity, fruit water accumulation was reduced, whereas net dry matter accumulation was less affected. This resulted in increased fruit dry matter content (% of fruit fresh weight) and TSS as soluble solids contribute a major portion of fruit dry matter.

Along with an increase in fruit dry matter content (%), many workers have observed increases in TSS (eg. Adams, 1991; Adams and Ho, 1989; Mitchell et al., 1991a; Mizrahi, 1982; Mizrahi et al., 1988) and TA (Adams, 1991; Adams and Ho; 1989; Gough and Hobson, 1990; Mitchell et al., 1991b; Mizrahi, 1982). In this study, fruit TSS and TA increased significantly at 4 mScm^{-1} and higher during the winter experiment and at EC higher than 4 mScm^{-1} during the summer experiment. The increase in TA appeared to be slightly higher than the increase in TSS. However, the ratios of TSS:TA (Table 5.1) of fruit grown at different EC levels were not significantly different. The TSS:TA ratios of Rondello and Concordia were not significantly different either.

As in the case of fruit dry matter concentration (%) the increase TSS with increasing EC could be as a result of a reduction in fruit water accumulation. Another possible reason for the increase in TSS at high EC levels is the positive correlation between the level of starch accumulation at early stages of fruit development and TSS of ripe fruit which has been observed in many tomato cultivars (Dinar and Steven, 1981). The current study did not determine starch accumulation in the fruit. However earlier studies have observed that, during the early stages of fruit development, starch levels appear to be increased by irrigation cutoff and salinity treatments (Mitchell et al., 1991a and 1991b). Ehret and Ho (1986b) also observed an increase in starch levels during early stages of

Table 5.1 The fruit TSS:TA ratios of two tomato cultivars grown at different EC levels during summer and winter. Fruit from Trusses 2 and 8 during the summer experiment and from Trusses 1 and 6 during the winter experiment were chosen for early and late trusses determination respectively.

EC and CV	TSS:TA ratio			
	Summer experiment		Winter experiment	
	Early truss	Late truss	Early truss	Late truss
Conductivity (EC)				
2 mScm ⁻¹	9.457	10.171	10.380	12.615
4 mScm ⁻¹	9.043	10.588	12.348	12.510
6 mScm ⁻¹	8.991	9.153	12.317	12.568
8 mScm ⁻¹	8.678	9.261	11.324	13.497
S.E.(df=6)				
Cultivar (CV)				
Rondello	9.346	10.061	11.897	12.845
Concordia	8.739	9.526	11.288	12.750
S.E.(df=8)				
Significance				
EC	ns	ns	ns	ns
CV	ns	ns	ns	ns
EC * CV	ns	ns	ns	ns

^{ns} Nonsignificant

fruit development for plants grown under concentrated macronutrient stress (high EC conditions).

The increase in TA could also be caused by increase in acids concentration in the fruit juice due to less water accumulation of the fruit at high EC levels. Davies (1964) proposed that an increase in organic acids concentrations was as a result of an increase in the ratio of inorganic cation:anion uptake as a means to maintain electro-neutrality in tomato fruit tissue. Mitchell et al. (1991b) reported higher organic acid levels throughout fruit development in plants grown at high EC conditions and this correlated with increased inorganic cation rather than anion accumulation in these fruit.

5.5.5 Fruit taste

Overall flavour intensity of tomato fruit is mainly determined by the concentrations and ratio of sugars and acids (Hobson and Kilby, 1982). High sugars and relatively high acids are required for the best flavour (Stevens et al., 1979). Results obtained from the taste tests indicated that fruit from plants grown at high EC levels tasted better than those at lower EC levels. These results corresponded with the analyses results in fruit composition in that TSS (reflects sugar status of the fruit) and TA increased significantly with increasing EC levels. Previous studies also reported the taste improvement, as a result of increasing EC levels in the root zones, in accompanied with increasing in sugars and TSS (Adams and Ho, 1986; Mizrahi et al., 1988; Mizrahi, 1982).

5.5.6 Weight loss

The major loss of horticultural produce after harvest occurs due to moisture loss through transpiration. This reduces saleable weight and quality of fresh produce during postharvest storage and handling (Shirazi and Cameron, 1993). Mizrahi et al. (1988) reported a lower water loss in fruit from saline treated plants compared with control. According to Mizrahi et al. (1988), the possible reason could be due to a lower water potential in the fruit from salinated plants. Epicuticular waxes and the cuticle play an

important role in weight loss as they act as a partial barrier to water vapour movement from inside the fruit to the environment (Gaffney, 1978). Crisosto et al. (1994) observed a thicker cuticle and a higher density of trichome on the skin surface of peaches from deficit irrigation treatment. The less rate of water loss of fresh produce grown under water deficit conditions could, therefore, be a result of cuticle modification. Results from the current study, however, indicated that weight loss of tomato fruit during storage at 20 ° C was not affected by conductivity level of nutrient solution.

CHAPTER SIX

GENERAL DISCUSSION AND CONCLUSION

Two tomato cultivars, Rondello and Concordia, were grown in the glasshouse with NFT at four levels of nutrient solution conductivity during summer and winter. Responses of the two tomato cultivars to different conductivity levels in terms of vegetative growth, yield and yield components and some quality attributes of the fruit were evaluated. The hypothesis of the studies was that increasing conductivity levels of the nutrient solution, though often reduce yield, improve fruit quality. This occurs through modification in water availability of the nutrient solution and so water uptake and water status of the plants. The degree of responses varies according to the level of conductivity, weather conditions and cultivars. This chapter summarizes and further discuss some of the main points of this thesis.

6.1 WATER RELATIONS, GROWTH AND YIELD

Increasing the level of nutrient solution conductivity, generally, reduced plant water uptake and plant water status in both tomato cultivars. The effectiveness of increasing EC levels on reduced plant water status was, however, not significant on cloudy days during the winter experiment. Factors such as light, temperature and R.H. in the aerial environment and conductivity levels in the root zone, interact with plant water uptake (Adams, 1991). Water uptake generally increased with evaporative demand which is determined by light intensity, temperature and relative humidity. Plants also lose more water to the atmosphere through transpiration under conditions of high evaporative demand (soil-plant-atmosphere continuum) (Mengel and Kirkby, 1987).

Reduced water status in plants affects various physiological processes and organs (Kozlowski et al., 1991). However, different tissues, organs, and processes have different sensitivities to water stress (Chalmers, 1989). This phenomenon was well manifested in

the current study. For example, flowering and fruit set were not affected by EC levels whereas most of vegetative growth reduced significantly at high EC levels.

Though the total number of trusses and total number of fruit obtained were not significantly different, fruit from plants grown at EC higher than 4 mScm⁻¹ were significantly smaller. The smaller fruit size at high EC levels was due to a reduction in fruit water content rather than in dry matter accumulation (Adams and Ho, 1989). Besides a reduction in fruit size, the increase in BER incidence at EC levels higher than 4 mScm⁻¹ especially at 8 mScm⁻¹ was also a major cause of marketable yield reduction in Rondello during the summer experiment.

The reduction in vegetative growth with increasing EC levels was clearer during the summer experiment. During the winter experiment, only stem fresh weight and stem dry matter concentration decreased. Similarly, the reduction in yield at high EC levels was significant only during the summer experiment whereas during the winter experiment, though fruit size decreased, yield was not affected. The smaller effect of increasing EC levels on vegetative growth and yield during winter experiment corresponded with their smaller effect on reduced plant water status (on cloudy days).

6.2 FRUIT QUALITY

In general, fruit from both cultivars developed increased TSS, TA and DM with increasing EC levels during both experiments. At increasing EC levels, the fruit received less water but received similar photoassimilate levels compared to the fruit grown at the lower EC levels (Ehret and Ho, 1986b; Mitchell et al., 1991b). This resulted in increased dry matter content of the fruit hence the concentration of TSS and acids in the fruit juice were increased. In some instance, however, there may be an active uptake of sugars or increased conversion of starch to sugars as a result of water stress (Kramer, 1983). During the summer experiment, though the values of TSS, TA and DM in fruit grown at 4 mScm⁻¹ tended to be higher than that at 2 mScm⁻¹, the difference was not significant. But during the winter experiment, TSS and DM of fruit at 4 mScm⁻¹ were

significantly higher than that at 2 mScm⁻¹. The more pronounced effect on increased fruit TSS observed in late truss fruit during the winter experiment compared to those from the summer experiment could be as a result of higher water stress due to root damage caused by *Pythium* root rot. Note that the value of TSS in late truss fruit during the winter experiment was also high. This is, however, only a speculation as plant water status during the late growth stage was not determined.

The results from the taste test indicated that the increased fruit composition found in the laboratory analysis did improve the taste of the fruit that could be recognised by the consumers. This occurred in both cultivars. The flavour of Rondello was more preferred than Concordia though in most cases their TSS and TA were not significantly different and in some cases Concordia had significantly higher TSS and TA than Rondello for example in late truss fruit during the summer experiment. The TSS:TA ratios of the two cultivars were not significantly different in either early or late trusses fruit during both experiments. Though sugars and acids play a major role in tomato flavour, other fruit components such as volatile substances, firmness, juiciness may also contribute in consumers' preference. In the studies by Mizrahi et al. (1988), superior flavour was obtained in some saline-treated fruit without a significant change in sugar and/or TSS values. Kopeliovitch et al. (1982) also suggested that tomato flavour is not always a function of total sugars but could also be due to other fruit constituents.

Conductivity levels of 6 and 8 mScm⁻¹ resulted in redder fruit on Day 3 to 11 during storage. In this study, colour determination was done in fruit harvested at breaker stage and stored at 20 ° C. The increased in red skin colour of tomato grown at high EC conditions was also observed in the studies by Mizrahi (1982). This could be because fruit grown at high EC had more advanced maturation and ripening as observed in previous studies (Alarcon et al., 1994; Mizrahi, 1982).

Increasing EC levels did not affect the rate of weight loss of the tomato fruit. Concordia, the long shelf life tomato, however, had higher rate of weight loss than Rondello. Though rate of water loss plays an important role in keeping quality of the fresh

produce, other fruit quality such as changes in firmness are also important in determining postharvest life of the produce. Firmness of the fruit was not determined in this study due to limitation in equipment and time.

Results from this study showed a clear effect of season (weather conditions). Vegetative growth was substantially lower during the winter experiment and so was the yield. The fruit compositions in terms of TA and DM were slightly lower in the winter whereas TSS was similar in early trusses fruit but was higher during the winter experiment in late trusses fruit. The effect of increasing EC levels on fruit quality (fruit compositions and taste) improvement was significant during both experiment (from EC 4 mScm^{-1} during the winter and from 6 mScm^{-1} during the summer). Their effect on yield was, however, significant only during the summer experiment.

In general, both cultivars responded to EC levels similarly regarding vegetative growth, yield and fruit quality except that Rondello became much more susceptible to BER at EC levels higher than 4 mScm^{-1} especially at 8 mScm^{-1} during the summer experiment. The method of increasing EC levels to improve fruit quality if applied in Rondello or other BER susceptible cultivars, should incorporate with other method such as calcium spray to reduce the BER incidence.

Success of a tomato grower used to be measured in terms of yield, however, quality had become equally important to the expanding tomato industry. Increasing EC levels of the nutrient solution appears to be a potential method for NFT tomato quality improvement. And the effects appears to occur through a reduction in plant water status. As the beneficial effects of increasing EC level are often accompanied by reduced yield and too high EC levels may cause injury and death to plants, the level of EC has to be determined promptly to maximise the beneficial effects with minimum yield loss or any other adverse effects. Because plant water status depends on the combined effects of the soil, atmosphere and plant itself (Rudich and Lukinsky, 1986), the EC level to be used should be determined from the combination of various factors such as cultivars, stage of the plant and the environmental conditions.

The current study raises a number of suggestions through which future research may be directed. This include:

- * There is a need for studies aimed at a more precise recommendation of the most appropriate EC levels to be used at each stage of plant growth in each cultivar and at each time of the year and the threshold levels of plant water status that is beneficial in terms of improved fruit quality without or with minimum adverse effects eg. on marketable yield and fruit size.
- * The study of the physiological basis of the skin colour as affected by EC levels observed in the current experiment.
- * The studies aimed at effective and non health-hazard methods that can control root diseases without interfering the beneficial effects of the EC levels.
- * To improve the popularity of Concordia, studies on factors that cause lower taste preference though having satisfactory TSS and TA values and factors that cause high rate of weight loss could be useful.

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