STUDIES OF THE FACTORS AFFECTING THE YIELD AND QUALITY OF SINGLE TRUSS TOMATOES

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ABSTRACT

This research was conducted to evaluate the potential of the single truss system of tomato production to produce high yields of quality fruit under New Zealand conditions. The NFT hydroponic system was used to grow the plants so that nutrient solution conductivity could be maintained close to predetermined levels.

In the first experiment three cultivars were compared. At the time of fruit set of the first truss four conductivity treatments (2, 4, 6 and 8 mS cm^{-1}) were applied. Yield and fruit quality data was obtained from each of six crops over an 18 month period. Yield (fruit size) decreased with increasing conductivity for all three cultivars. Season also had a significant effect on yield, with an April harvested crop having the highest yield. Both fruit brix and titratable acidity were increased at the higher conductivity levels. There were also cultivar and seasonal differences in fruit quality, with the cherry cultivar 'Cherita' consistently producing the highest brix and titratable acidity levels. Brix levels were found to be low in the December harvested crop, while acidity was highest in the December, April and July harvested crops. Season, solution conductivity and cultivar influenced plant leaf area and leaf area index. Solution conductivity also effected foliar mineral levels, as did cultivar.

Three successive multi truss crops were grown in a pumice media system to provide fruit quality data for sensory evaluation and comparison with single truss and commercial compositional fruit quality. The same three cultivars as were compared in the single truss crop experiment were grown at three conductivity levels (2, 4 and 6 mS cm^{-1}) applied at the time of fruit set of the first truss. Fruit samples were taken from the 5th and 6th trusses for quality evaluation. Season and solution conductivity had an effect on fruit dry matter percentage and brix. Fruit shelf life was affected by season, conductivity and cultivar, with a longer shelf life obtained from fruit grown at the higher conductivity levels. The December harvested crop had the lowest overall shelf life. Fruit firmness was only affected by solution conductivity, with the fruit from the higher

conductivity treatments being firmest. Sensory evaluation of Rondello fruit on three separate occasions showed that the higher conductivity treatment scored highest for most attributes, and that these sensory scores correlated well with brix and titratable acidity levels.

A second single truss crop experiment focused on manipulation of the source/sink relationship (fruit and leaf number combinations) of three successional crops and the effect of spring and winter CO_2 enrichment on two of the three crops. The summer crop also evaluated the effect of crop shading and source/sink relationship on fruit yield, as high fruit temperatures were suspected to have reduced yield in the previous summer single truss crops. Yield and fruit quality data was collected from all three crops, along with fruit and environmental temperature recordings from the summer crop. It was found that season and fruit number effected yield, with the 8 fruit per plant treatment resulting in the greatest yield. Leaf number (either 2 or 3) and season affected fruit dry matter percentage, brix and leaf area, while fruit number influenced brix levels. CO_2 enrichment (1000 ppm) had no effect on either spring or winter fruit yield, but did advance crop maturity allowing an extra crop per year to be produced. Thus yearly yield was increased by CO_2 enrichment. CO_2 enrichment improved fruit quality in the spring crop, but had no effect on the winter crop. Shading of the summer crop resulted in an increase of 10% in total fruit yield and 19% in marketable fruit yield, due to the presence of smaller fruit and heat induced ripening disorders in the unshaded crop. Both leaf number and shading treatments affected titratable acidity, with unshaded fruit having greater percent citric acid levels. Shelf life and fruit firmness was greater in the shaded crop. Air, canopy and fruit temperatures were reduced under shade, with exposed fruit often reaching extreme temperatures (above 40°C).

Having established that leaf and fruit temperatures were reaching extreme levels during the summer in a single truss cropping situation, the effect of these temperatures on photosynthesis and fruit respiration was examined. The effect of leaf age on photosynthesis was also examined as single truss plants do not continue to produce young foliage to maintain photosynthesis levels. After harvest, net photosynthesis and the light compensation point, which had been increasing began to fall rapidly at all light

levels. It was found that after an initial drop as leaves matured, leaf age did not effect net photosynthesis. Plants exposed to 800 PAR showed maximum net photosynthesis at temperatures between 25 - 27°C. Net photosynthesis ceased at 43°C.

Fruit truss respiration rates were determined at 4 temperatures (25, 30, 35 and 40°C), on 3 occasions (18, 26, 36 and 40 days after fruit set). 5 different tissue sample combinations were assessed comprising, the whole truss with sealed and unsealed cut surfaces, fruit only with sealed and unsealed calyx scar and calyx, peduncles and plant stem only. It was found that temperature, truss portion assessed and stage of fruit maturity all affect fruit respiration rate, with the fruit only (calyx scar unsealed) resulting in the greatest CO_2 efflux. It was concluded that while the fruit epidermis is relatively impermeable to gas escape, the main route for CO_2 is through the calyx scar. Mature green fruit had the greatest response of increased CO_2 production with increasing temperature, while temperatures above 25°C disrupted the climacteric pattern of CO_2 evolution. It was concluded that in single truss plants, when temperatures were above 30°C, net photosynthesis is reduced, while fruit respiration begins to increase rapidly, both responses having a detrimental effect on yield.

The single truss system was shown to produce yields and fruit quality equal to those of good multi truss commercial tomato producers in New Zealand. This was achieved by CO_2 enrichment for crop advancement and summer crop shading, while moderate levels of solution conductivity produced good quality fruit. However, there is the possibility of further improving these yields by utilisation of other technologies such as a movable bench system and manipulation of plant density, timing of conductivity application, and different cultivars. The potential of this system for high quality, high yielding tomato fruit production warrants commercial evaluation.

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INTRODUCTION

The single truss system of tomato production was first proposed by Cooper (1964b) in the U.K. In this system the plants are stopped two leaves above the first inflorescence so that each plant only produces one truss of fruit. The plants were produced in either a capillary bed system or in tiered troughs and grown at a high density. The concept behind the development of this system was to produce 3-4 crops per year per greenhouse and attempt to increase the efficiency of tomato production. The system was not developed further at this time as the yield over a 12 month period did not equal that of a conventional long term crop. This was probably because the number of single truss crops grown over 12 months was not high enough and the mid winter crop performed poorly under U.K conditions. More recently research into other aspects of the single truss system has been carried out in the USA. This research has reexamined methods to achieve continuous and predictable yields with a moveable bench system (Fischer et al, 1990), and has also studied the role of supplemental lighting and computer modelling to plan and predict yields (Mc Avoy and Janes, 1989; Giniger and Mc Avoy, 1986). The yield and quality potential of such a production method has required evaluation under New Zealand conditions and growing systems.

An initial decision was made in the present study to examine single truss tomato production using the NFT (nutrient film technique) system. This was decided because of the potential of NFT to provide good control of the below ground environment. Of particular importance to this investigation was the ability of NFT to provide close control of solution conductivity and so fruit quality and to minimise moisture stress.

In the past, tomato producers directed crop management towards obtaining the highest possible yields from their crops. However, over recent years there has been an increasing demand for quality produce. This is now of particular importance in New Zealand as strong competition has developed on the domestic market as a result of Australian fruit imports and larger volumes are being exported overseas. There is also an increasing demand for high quality lines from supermarkets. An important aspect of fruit quality is flavour and it is believed that this will become a significant fruit

quality factor in the future. The role of solution conductivity, cultivar and season on the compositional, organoleptic and keeping quality of the fruit produced is an important feature of the research described in this study.

The second important objective of the study was to evaluate methods of increasing single truss yield, while maintaining fruit quality, by examining the use of technology commonly applied to multi truss crops. The importance of CO_2 enrichment, manipulation of the source/sink relationship and summer crop shading were treatments studied in an attempt to increase the yield of successional crops over a 12 month period.

Since the single truss plant is physiologically different from a multi truss plant, due to the removal of the growing point and lack of new foliage, the effect of temperature, light levels and leaf age on net photosynthesis were evaluated. Fruit respiration rates in response to increasing temperature were also examined as it became apparent that as single truss fruit are more exposed to radiation, and therefore prone to heat stress during the summer months. The research concluded with a study on the effects of high temperatures on photosynthesis and respiration.

The present study was the first of its kind in New Zealand. It was carried out at a time when the New Zealand greenhouse tomato industry is under economic pressure. The industry is responding to this pressure by going "high tech" to increase production and quality. It seemed therefore timely to assess the single truss system in a climate where cropping is possible over the winter months. It is hoped that the findings of this study will provide the basis for more commercially orientated studies in an industry setting.

REVIEW OF LITERATURE

1.1 TOMATO PRODUCTION

1.1.1 Introduction

The tomato *(Lycopersicon esculentum)* is a fruit that is almost universally treated as a vegetable. It is the focus of a large, worldwide agricultural industry with both field and greenhouse crops being produced. Although the tomato does not rank high in the concentration of any dietary component, the large volumes consumed means it is the major contributor of vitamins and minerals in the US diet (Rick, 1978). The popularity of the tomato is readily explained in terms of its attractive colour, flavour and its versatility (Rick, 1978).

1.1.2 New Zealand greenhouse tomato industry.

The New Zealand tomato industry has a market floor value of over $40 million a year. Domestic greenhouse production supplies approximately two thirds of the tomatoes for the fresh market. These supplies are predominantly during autumn, winter and spring when prices are greatest. During summer, returns are lower as outdoor produced fruit becomes available. Small quantities are currently being exported by producers or packhouses such as PANZ (Packhouse Association of New Zealand), however the domestic market remains the major outlet. The majority of greenhouse tomato production occurs in the Auckland area and has developed due to the close proximity to a large domestic market and the mild climate. There are currently over 600 greenhouse tomato producers in the Auckland region.

Over recent years, the New Zealand industry has been facing a major problem in the form of competition from imported Australian tomatoes. Queensland crops are produced outdoors on a extensive scale and can therefore arrive on the NZ market at a price below those produced domestically under cover. As a result of this competition many NZ growers come under considerable economic pressure as profitability became dependent on producing high yields of premium quality fruit.

In an effort to recoup sales lost to imported fruit, the New Zealand industry adopted a

'taste the difference' campaign which claimed that NZ produced tomatoes were superior in flavour to the imports. However the quality demanded of the New Zealand product was not achieved by the majority of tomato producers (Anon, 1990). The best option open to the New Zealand greenhouse tomato growers is to produce a high quality product and take advantage of the fact that consumers are becoming increasingly quality conscious (Hobson, 1988).

A typical New Zealand crop has a nine month long season, with March and April being the most popular months for planting (White, 1978). A significant number of greenhouse crops are now produced in soilless systems, either NFT or pumice bags which allows a greater control over plant nutrition. The average Auckland crop yields nearly 30 Kg m^2 per year (Anon, 1995). On the other hand some growers are achieving yields close to 50 Kg/m^2 year (Anon, 1995). These yield variations are the result of variations in crop management practices used by growers. The highest yields can only be achieved by intensive management of the crop and this requires some understanding of the physiology of the plant (White, 1978).

1.2 PHYSIOLOGY OF THE TOMATO CROP

1.2.1 Growth form

The tomato is a perennial plant with both indeterminate and determine growth habits. For greenhouse production it is the indeterminate cultivars which are grown, while determinate varieties are used largely for outdoor processing crops. In indeterminate cultivars the main stem grows indefinitely, reaching more then 10m in a year's growth under greenhouse conditions (Atherton and Rudich, 1986). Such cultivars require layering for a long season crop but have the advantage of flowering and fruiting regularly and evenly. All lateral shoots which develop from the axils of the leaves are removed as they develop and the main stem is supported by training wires.

Between 7 and 11 leaves are formed before the apex is transformed into the first inflorescence (Atherton and Rudich, 1986). Thereafter 3 - 4 leaves are produced between inflorescences in indeterminate crops. Flower and fruit numbers vary between cultivars, the average being 6 - 8 for large fruited varieties and up to 30 for the cherry

cultivars. Typically the fruit at the stem end of the truss will be largest, though when there are only a few fruit on the truss there may be little variation in fruit size (White, 1978).

1.2.2 Nutrient uptake

The total uptake of nutrients varies with many factors such as light intensity, temperature, humidity, aeration and the health of the plant, particularly the root system (Adams, 1986). Thus for indeterminate cultivars grown under glass, the average rate of mineral uptake is determined by the environmental conditions (Adams, 1986). Potassium is the element which responds to fruit load. The K:N ratio increases from 1.2:1 during the vegetative phase to about 2.5:1 when the plants are carrying a heavy crop load (Adams and Winsor, 1979).

The response to nutrients generally declines when the temperature of the air and substrate fall appreciably below the optimum, since low temperatures inhibit growth and nutrient uptake. High air temperatures increased the nitrogen content of tomato plants at all levels of N (Abdella and Verkerk, 1970). Grosselin and Trudel (1983), found that high air temperature at night (21°C) increased the Ca and Na contents of the leaves, but reduced the P content. Locascio and Warren (1960) found that there was a 15 fold increase in the total uptake of phosphorus when the soil temperature was increased from 13 to 21°C, much of this response being attributed to stimulation of root growth by the higher temperature. Chu and Toop (1975), stated that the total uptake of K, Ca and Mg were depressed at a root temperature of 13°C, and the P, K, Ca, Mg, Cu, Fe, and Mn contents of the leaves increased as the temperature of the nutrient solution increased (Maher, 1978).

Rates of nutrient uptake vary during the day. The uptake rates of N and K are highly correlated with light intensity and air temperature, and hence with water uptake (Winsor et al, 1980). Rates of water, N and K uptake increased with light intensity between 6.30 and 14.00 hours and subsequently declined (Adams, 1986). Winsor et al (1958), found that N and K were also reduced under shade as compared to fully exposed crops. Tremblay et al (1984), reported that supplementary

lighting increased the uptake of N, K, Ca, Mg and Mn content of the leaves and the yield of fruit. P uptake is more closely related to solution temperate and reaches a maximum later in the day than the rates for N and K (Winsor et al, 1980).

The uptake of elements is depended not only on the stage of growth and environmental conditions, but also on the mineral composition and concentration of the nutrient solution. Winsor and Massey (1978) showed that the ratio of nutrients absorbed to water used increased with the concentration of N and P supplied in the solution. The uptake of both N and K increased markedly with the concentration supplied in solution (Winsor and Massey, 1978). However, total uptake of Ca is depressed by 85 - 88% at high solution conductivities (17 ms cm^{-1}), even when this is achieved by adding high levels of Ca and K nitrate to the basic solution (Adams, 1986). Very low levels of P in the substrate induces an increase in the rate of P uptake (Adams, 1986). Besford (1979) observed that the total uptake of P and K increased with the concentration of N supplied.

High levels of N and K in solution culture can exacerbate Mg deficiency which is the most common nutritional disorder of tomatoes (Adams, 1986). For example, a loss in yield due to Mg deficiency of 5% occurred at a very low level of N, but increased to 20% where heavy N dressings were applied (Adatia and Winsor, 1971). At low K levels, the incidence of ripening disorders was increased by intermediate and high levels of N (Adams, 1986). High concentrations of ammonium-nitrogen reduce the uptake of certain nutrients - notably Ca and Mg (Kafkafi et al, 1971).

Increasing salinity by addition of sodium chloride to the nutrient solution increased the phosphorus content of the leaves and depressed the Ca and nitrate-nitrogen contents, but had little effect on the K, Mg and total N contents (Cerda and Bingham, 1978).

Several interactions between Cu, Fe, Mn and Zn have been reported. Increasing levels of Mn depressed the Fe content of leaves (Gerloff et al, 1959), and high levels of Mg, Cu and Zn each reduced the amount of Fe released from tomato roots into the stem

exudate (Tiffin, 1967).

1.2.3 Distribution of nutrients

A large proportion of the nutrients absorbed by mature tomato plants are found in the fruit (Adams, 1986). 56% of the N, 63% of the P and 63% of K taken up in crops grown under glass end up in the fruit (Winsor et al, 1958). Fruit also contains 5% of the Ca and 35% of the Mg absorbed by greenhouse grown plants (Ward, 1964). In young plants the distribution of nutrients depends on the stage of development (Adams, 1986). For example, in plants that were 7 weeks old, approximately 50% of the K absorbed was found in the leaves, 25-30% in the stems and less then 10% in the roots, the rest being in the developing flowers and fruit (Besford and Maw, 1974). When carrying a full fruit load, 63% of the K uptake can be found in the fruit (Winsor et al, 1958).

The concentration of nitrogen in the dry matter is generally higher in leaves (laminae plus petioles) than in fruit and about twice that in stems. The potassium content is higher in the fruit; although the potassium content of the stems is slightly lower it is still twice that of the leaves. The concentrations of Ca and Mg are highest in the leaves and lowest in the fruit (Kidsen et al, 1953). The roots generally contain lower concentrations of macronutrients than the aerial parts of the plant (Ward, 1964).

1.2.4 Flowering

Flowers are initiated in the growing point and develop, while surrounded by relatively young leaves near the top of the stem. These young leaves use assimilate for their own continued growth and export assimilate to the initiating and developing flower trusses (White, 1973).

Both the timing of initiation of the first inflorescence and the stage of growth at which initiation first occurs may be affected by environmental treatments given to the plant shortly after seedling emergence (Atherton and Harris, 1986). During the later stages of initiation of the first inflorescence, initiation of the second inflorescence begins.

It is well established that low irradiance experienced during early seedling growth delays inflorescence initiation (Calvert, 1959) and that the effect of low light was greater at high temperature (25°C) than at lower temperatures (15°C). Solar radiation may influence flowering time through effects on the time of inflorescence initiation and on the rate of development of the flowers. Calvert (1964b) reported that differences in leaf number to flower found in tomatoes grown in greenhouses at different times of the year are largely attributable to differences in daily light integral rather than to photoperiod.

The number of flowers initiated can vary widely and can be affected by the environment of the shoot. The phase in tomato development during which flower number in the first inflorescence may be affected begins about 8 days after cotyledon expansion and continues for 1 to 2 weeks (Calvert, 1964a; Hurd and Cooper, 1967). Branching of the inflorescence was promoted when plants experienced low temperatures during inflorescence initiation.

The number of flowers that are initiated, as reported above, have been shown to be influenced by the environmental conditions supplied to the seedlings during the floral initiation phase. There have been several studies to determine methods by which the number of fruits on the first truss can be controlled. The objective foremost is to increase the flower number.

Hurd and Cooper (1967) were the first to investigate the use of low temperatures to manipulate seedling development. They found that the flower number in the first truss of glasshouse tomatoes was increased by growing the seedlings at low temperatures shortly after pricking out. It was stated that, in summer, flower number could be doubled, but in winter only a 30 - 40% increase could be obtained. However, as a side effect, chilling delayed anthesis by up to 10 days, with the delay being proportional to the duration of chilling (Hurd and Cooper, 1967). This increase in flower numbers was attributed to an increase in the number of branched trusses as these carried appreciably more flowers than occur on unbranched trusses. The degree of branching depended on the chilling conditions. The most branching occurred when the cold period started 15 days from sowing rather than only 11 days. The temperatures used for such chilling

treatments ranged from 10/10 °C to 16/4°C, both having similar effects on flowering and resulted in similar delays to growth and anthesis.

Temperature is of primary importance in determining the rate of development of the flowers after initiation. Calvert (1964a) showed that under natural daylight conditions in a greenhouse, flowers developed more rapidly at mean air temperatures of 20°C than at 16°C; an advance of up to 20 days was recorded for first anthesis in the first inflorescence.

Although high temperatures generally hasten floral development, they may also produce increases in the incidence of flower bud abortion under certain conditions (Atherton and Harris, 1986). Abortion of the flower buds is most likely to occur where photosynthetically active radiation is severely limiting to growth of the whole plant (Atherton and Harris, 1986).

Calvert and Slack (1975), examined the effect of different levels of CO_2 enrichment on floral abortion and found that 53% abortion occurred at ambient levels, 26% at 600ppm and 15% at 1000vpm and 11% at 1400 ppm, under winter light condidtions in the U.K. The large increase in fruit production due to CO_2 enrichment was largely attributable to an increased number of flowers reaching anthesis in the early inflorescences.

Advancement of the date of first anthesis in the first inflorescence by as much as seven days may occur in response to CO_2 enrichment of the atmosphere to 800 - 2000 vpm (Hand and Postlethwaite, 1971). There is no evidence that CO_2 enrichment also acts to reduce the interval between the development of successive inflorscences higher on the plant.

Mineral deficiencies generally retard flower development and may even cause flower abortion. Fisher (1969) found that low levels of N in solution culture resulted in delayed opening of the flowers. Flowering may also be retarded by water stress, high temperatures, low K and P levels, low radiation levels and root zone warming (Abdella and Verkerk, 1970; Menary and Van Standen, 1976; Morgan and O'Haire, 1978). Floral

development may also be inhibited by both vegetative and reproductive parts of the shoot system (Atherton and Harris, 1986). Leopold and Lam (1960) showed that floral development could be promoted by the removal of young developing leaves.

It is a well known occurrence for the number of flowers per inflorescence to decline with increasing temperature. Rylski (1979) reported that as day temperature increased from 17 to 27°C, the number of flowers per inflorescence from the 2nd to 5th truss declined. Abdalla and Verkerk (1968) investigated the effects of high temperature (35°C day, 25°C night) on flower and fruit development. It was found that compared to normal temperature conditions of 22°C day and 18°C night, at high temperature, stem growth was twice as fast, giving thin stems and many trusses with weak flowers, increased flower shedding and slow pollen growth. Abdalla and Verkerk (1968) explained this phenomenon by claiming that the supply of assimilates for the optimal development of all the different organs of the plant was limiting at high temperatures. Hence optimal flower size was often not maintained and usually only the first few flowers of the first two trusses developed into fruits (Abdella and Verkerk, 1968).

1.2.5 Pollination

All modern tomato cultivars are self pollinated (Ho and Hewitt, 1986). Although the mature pollen is ready for transfer at the time of anthesis the stigma becomes receptive about 2 days previously and remains so for up to 4 days or more (Smith, 1935). Once pollen grains adhere to the stigma, pollen tubes start to grow within an hour; so that most ovules would be fertilised within 30 hours at 20°C (Iwahori, 1966).

In unheated glasshouses, temperatures lower than 10°C together with low light result in low pollen viability and poor fruit set (Ho and Hewitt, 1986). Crops may also be over heated in summer if ventilation is insufficient. Temperatures over 40°C at the critical stages of gametogenesis can adversely affect the viability of ovules and the production, dehiscence and transfer of pollen (Rudich et al, 1977).

1.3 PHOTOSYNTHESIS

1.3.1 Introduction

Photosynthetic rates within any crop are influenced by many factors: water, CO_2, light, nutrition and temperature as well as plant age, species and cultivar. In the greenhouse environment the producer is concerned with the factors which limit production, and the manipulation of the environmental conditions to maximise yield.

In the greenhouse environment, water and nutrition are usually in plentiful supply and thus do not act to inhibit photosynthesis. Temperature, radiation and carbon dioxide levels can be manipulated within greenhouse structures, but are often not maintained at the optimum levels for maximum photosynthesis and plant development.

1.3.2 Effect of radiation levels

In the greenhouse environment, a certain percentage of the solar radiation reaching the earths surface is lost due to the transmittance properties of the greenhouse covering and structures. Improvements to the insulation of modern greenhouses are generally accompanied by a reduction in the quantity of light transmitted to the crop (Cockshull, 1985).

As with any crop environment, the irradiance varies with season, time of day, elevation and also within the plant canopy. Of the external solar energy, some is reflected by the glass or intercepted by opaque structures and only 60% is incident on the crop within the glasshouse (Aikman, 1989). External light intensity incident perpendicularly onto an inclined surface can be close to 500 W m^{-2} PAR, even after allowing for an attenuation of 20% by the glass (Aikman, 1989)

Approximately 80% of the PAR reaching the crop is absorbed by a representative leaf, although this value varies considerably with leaf structure and age. The remainder (mostly green wavelengths) is transmitted to lower leaves or the ground below or is reflected to the surroundings. Of that absorbed and potentially capable of causing photosynthesis, more that 95% is usually lost as heat; thus less then 5% is captured during photosynthesis. As a result the tomato plant converts about 7.6% of the

intercepted PAR energy into dry matter energy (Aikman, 1989).

Mature crop canopies of cucumber and tomato intercept about 76% of the light incident on their upper surfaces, with about 18% lost through gaps between the rows (Warren Wilson et al, 1992). Further to this, if the light is transmitted through the entire depth of the canopy and is reflected back by white plastic on the ground, the lower surface of the canopy will receive 13 % of the light incident on the upper surface (Warren Wilson et al, 1992).

1.3.3 Light compensation point and saturation levels

The irradiance level at which photosynthesis just balances respiration (net CO_2 exchange is zero) is called the light compensation point. This light compensation point is usually less than 2 percent of maximum sunlight. Only when the irradiance is above the light compensation point can dry weight increases occur (Salisbury and Ross, 1989). At the other end of the scale the photosynthetic response of a particular plant becomes saturated when photosynthesis no longer increases with increasing light levels. Between these points the rate of photosynthesis depends on light intensity. Experiments on individual leaves show that increased light intensity results in higher rates of carbon fixation for radiation up to 200 W m^{-2} (Warren Wilson et al, 1992), although there is a saturation effect that results in a progressive decrease in the efficiency of increasing light levels (Aikman, 1989). Warren Wilson et al, (1992) reported that light saturation in tomato crops occurs at 150 W m^{-2} for exposed leaves and 550 W m^{-2} within the canopy.

Individual leaves of C3 plant species show photosynthetic light saturation at irradiance one fourth to one half full sunlight (300 - 400 W M^{-2}). However, this response of single leaves to light levels differs for that of whole plants or groups of plants representative of a cropping situation. The reason for differences in light responses of single leaves and cropping situations is that the upper leaves absorb much of the incident light, leaving less for the lower leaves. In this situation, exposure to a higher irradiance may saturate the upper leaves, but more light is then transmitted and reflected toward the shaded leaves below that are not saturated (Salisbury and Ross, 1989).

Aikman (1989) also stated that leaves on the shaded side of a plant row or lower in the canopy, will be exposed to light levels well below those that would cause saturation. Thus an appreciable fraction of the solar PAR radiation is being used at much reduced efficiency. It is therefore beneficial if upper leaves were orientated to intercept a lower proportion of the incident light and the lower leaves to intercept a greater proportion, the plant would thus achieve a more uniform interception of light over the foliage (Aikman, 1989).

However, another possibility is the retrieval of light passing though the foliage by the use of reflective ground covers (dispersive white plastic) which confer a positive effect on tomato plants and grain crops, and could increase productivity by an estimated 17% (Aikman, 1989).

For a mature tomato crop, the net photosynthetic rate of the canopy was found to be almost directly proportional to light flux density at least up to 200 W m^{-2}, under commercial glasshouse conditions (Warren Wilson et al, 1992).

Warren Wilson et al (1992) summarized tomato (cultivar Kingley Cross) crop light response curves and light conversion efficiency (see below).

Light flux density compensation point (W m^{-2}).	5
Optimum light flux density for light conversion efficiency (W m^{-2})	110
Leaf area index	8.6
Light intercepting efficiency	0.99
Maximum light conversion efficiency (g CO_2 J^{-1})	7.3
(%)	8.4
Maximum light utilizing efficiency (g CO_2 J^{-1}).	7.4
(%)	8.6

Hurd and Thornley (1974), stated that not only does high light intensity produce higher growth rates and net assimilation rates of young tomato plants, but in low light

conditions leaf area ratios are five times larger than those in high light conditions, attributable mainly to a difference in leaf dry weight/area. This phenomenon was also found earlier by Cooper (1961), who reported that plants grown in the winter months had a longer period of increasing leaf area and attained a larger total maximal leaf area then plants sown in the summer months. Calvert (1964b) concluded that in winter growth is limited by and is therefore proportional to, the amount of available photosynthetic light, while in summer the young tomato plant is light-saturated and growth is limited by factors other then light.

As well as effecting rates of photosynthesis, light intensity can also benefit fruit set and development. Kinet (1977) concluded that inflorescence development is far better in short days with high light intensity then in long photoperiods with low light. It has long been known that during periods when light intensities are low, winter grown greenhouse tomatoes have a large percentage of misshapen fruit (Marr and Hillyer, 1967). It has been concluded that a reduction in the amount of carbohydrates under low light conditions reduced the quantity of fruit due to plant respiration utilising most of the daily carbohydrate production (Marr and Hillyer, 1967). Marr and Hillyer (1967) reported that shading treatments reduced the yield of greenhouse grown fruit simply due to this reason. Warren Wilson et al (1992) stated that the fruit yield of glasshouse tomatoes has been shown to be directly dependent on the solar energy received and on the total hours of bright sunshine; a 10% reduction in sunshine hours results in 10% less yield.

Cockshull et al (1992) also investigated the effects of plant shading on yield of glasshouse tomatoes. They reported that yield was accumulated in direct proportion to solar radiation received and regardless of treatment, 2.01 Kg of fresh weight of fruit were harvested for every 100 M J^{-1} of solar radiation incident on the crops from the onset of harvest, so that there was a yield loss of 0.5 to 3.1% yield loss for each 1% light lost. A positive correlation between yield and cumulative radiation has also been observed with successive sowings of single truss tomatoes (Mc Avoy et al, 1989b). Cockshull et al (1992) also reported that fruit number per truss was positively correlated with solar radiation received, as was the reduction in fruit size due to shading treatments.

Mc Avoy et al (1989b), working at Rutgers University in the USA carried out a similar investigation on single truss tomato crops. They reported a strong positive correlation between the total yield and total photosynthetic photon flux received in the period from anthesis to harvest. Total PPF in the seedling stage (emergence to anthesis) was strongly correlated with timing of anthesis (McAvoy et al, 1989b). Supplementing the naturally available radiation with 6.48 moles m^{-2} day^{-1} resulted in a 50 to 100% increase in PPF available at crop level, (Mc Avoy et al, 1989b). Fresh weight of tomato yield showed a direct, positive response to this increase in PPF (Mc Avoy et al, 1989b), so the decrease due to natural depressed mid winter PPF conditions could be reduced in severity if supplementary lighting was used.

Mc Avoy et al (1989b) also reported an effect of PPF onseedling development. The PPF environment affects both vegetative and reproductive tomato seedling development by influencing the amount of photosynthate available for growth (Ho, 1976). In a high PPF environment, there is an early and rapid canopy development and rapid seedling growth ensues, and flower initiation and expression occur at a lower node. High PPF during flower development and fruit set results in larger ovaries with more locules and a greater fruit set (Kinet, 1977), and thus a steady net carbohydrate flux from the source leaves.

Not only does light intensity have an effect on crop growth and development, but photoperiod also plays a role. Morgan and Clarke (1976) reported that tomato plants grown in a photoperiod of 12 versus 16 hours resulted in substantially increased leaf area, dry weight per unit leaf area, plant height, dry weight per unit height, plant spread and flower bud numbers.

It can be concluded that the seasonal pattern of development of tomato leaves and fruit appears to not only be determined by the inter relationship between leaf and fruit development but also by changes in light intensity and duration

1.3.4 Effect of leaf age on crop photosynthesis

As leaves develop, their ability to photosynthesize increases for a time then, often even

before maturity, begins to slowly decrease (Salisbury and Ross, 1989). It has been stated that net photosynthesis of leaves reaches a maximum when leaves are about 30 - 50% expanded depending on the CO_2 concentration (Ludwig and Withers, 1984). This was also reported by Tanaka et al (1974b), who stated that the apparent photosynthetic rate of a leaf attains a peak (33 - 46 mg CO_2 dm^{-1} hr^{-1}) at a very early stage of its development, decreases rapidly and then maintains a low constant value (5mg CO_2 dm^{-1} hr^{-1}).

There are differences in net leaf photosynthetic rates due to leaf age and position (Picken et al, 1986). Maximum net photosynthetic rates of single leaves decreases rapidly with the age of the leaf, so that by the time leaves are beginning to yellow the maximum leaf photosynthetic rate has dropped to less then one tenth.

The reason proposed by Tanaka et al (1974b), for this rapid decline in photosynthetic activity of a leaf with age, is that the surplus of photosynthates of young upper leaves is considered to depress the photosynthetic activity of old, lower leaves even with full illumination. Old, senescent leaves eventually become yellow and are unable to photosynthesize due to chlorophyll breakdown and the loss of functional chloroplasts.

1.3.5 Effect and availability of CO_2.

During summer crop production insufficient CO_2 is a common cause of suboptimal photosynthesis of C3 plants, especially in leaves exposed to bright light (Salisbury and Ross, 1989). In greenhouse conditions this is further complicated by the fact that these crops usually lack sufficient CO_2 for maximal growth in winter due to the greenhouses remaining closed to conserve temperature. Even slight breezes can enhance photosynthesis by replacing CO_2 depleted air in the boundary layer around the leaf for crops grown in the field (Salisbury and Ross, 1989).

Ambient CO_2 levels are usually around 340ppm, however within crop canopies CO_2 levels as low as 170 ppm have been recorded in summer, even with the ventilators open (Drakes, 1984), principally as the result of its utilisation in photosynthesis.

Photosynthetic rates are enhanced not only by increased irradiance levels but also by higher CO_2 concentrations, unless stomates are closed by drought (Salisbury and Ross, 1989). Hand and Postlethwaite (1971) found that measurements of CO_2 assimilation rate with widely spaced (LAI 0.8), single truss (cultivar Graigella) tomatoes became light saturated at a solar radiation level of approximately half the summer greenhouse maximum when grown at 400ppm CO_2. By contrast, the rate of CO_2 uptake of closely spaced plants (LAI 2.6) grown in a similar concentration of CO_2 continued to increase with increasing solar radiation up to a level of two thirds the summer greenhouse maximum, indicating that the denser plant canopy resulted in less light being available for each plant.

In order to saturate photosynthesis a higher CO_2 concentration is required at high rather than at low irradiance levels. This was demonstrated by Hand and Postlethwaite (1971), who concluded that for single truss tomatoes CO_2 enrichment results in an increase in the rate of CO_2 fixation by tomato plants that is greatest in strong light but also evident in weak light. Therefore CO_2 enrichment in greenhouse environments is more beneficial at higher irradiance levels, but helps substitute for lower light levels. It should also be mentioned that as a result of the beneficial increases in photosynthesis due to CO_2 enrichment, increased fruit yields have also been reported (Slack et al, 1988).

CO_2 enriched multi truss crops result in increases in both the number and size of fruits developed on individual trusses (Hand and Postlethwaite, 1971; Calvert, 1972). The increases in yield of ripe, marketable fruit after four and twenty weeks of harvesting amounted to 300% and 35% respectively, this increase in early yield was largely due to CO_2 reducing the proportion of plants with complete abortion of the first truss owing to dull UK light conditions (Calvert and Slack, 1975; Calvert, 1972). White (1978) reported an average yield increase of 19% with a CO_2 enrichment of 900 - 1000 ppm from multi truss crop studies carried out in New Zealand.

CO_2 enrichment also provides benefit when used to avoid depletion below ambient levels. Slack (1983) found a yield increase of 17% by preventing CO_2 depletion in the spring and summer period. While CO_2 enrichment does have a beneficial effect on

multi truss crop yields, fruit quality remains unaffected (Davies and Winsor, 1967a).

In a greenhouse cropping situation it is both CO_2 and light that are the limiting factors in photosynthesis. The upper canopy area containing the more illuminated leaves will usually respond to increases in CO_2 while the lower leaves may be CO_2 saturated, but will respond to additional light. Thus an increase in either factor increases CO_2 fixation of a whole plant or crop (Salisbury and Ross, 1989).

Cockshull (1985), reported that the rate of net photosynthesis of leaves increases almost linearly with increasing CO_2 concentration from about 100 vpm to 400 vpm, or more under high irradiance conditions. Any reduction below the outdoor ambient level of approximately 335 ppm CO_2 gives a corresponding reduction in net photosynthesis which is usually seen as a reduction in yield (Hand, 1984).

Another effect of CO_2 enrichment in greenhouse situations is the ability of plants to adapt to changes in CO_2 concentration. Frydrych (1984) reported that long term exposure of plants to the increased CO_2 concentration generally causes adaptation changes in the photosynthetic apparatus which may result in a decrease in net photosynthetic rates of leaves exposed to normal CO_2 concentration in comparison with plants grown in normal atmosphere. This adaptation to elevated CO_2 levels took the form of slightly increased specific leaf mass in both sweet pepper and tomato plants.

1.3.6 CO_2 fixation and carbohydrate translocation

As well as many environmental conditions, there is also internal control of photosynthesis in the form of the rate at which photosynthetic products such as sucrose are translocated from the source to the sink organs.

It has been found that the removal of developing sinks inhibits photosynthesis after a few days, particularly in adjacent leaves that would normally translocate to these organs. Furthermore, species that have high photosynthetic rates also have high translocation rates, consistent with the idea that effective transport of photosynthetic products maintains rapid CO_2 fixation (Salisbury and Ross, 1989).

One phenomenon which has been discovered in some CO_2 enriched crops is the build up of starch grains in chloroplasts when translocation is slow and photosynthesis is fast. Such starch grains press thylakoids unusually close together in chloroplasts and physically prevent light from reaching the thylakoids and thus reducing photosynthesis (Salisbury and Ross, 1989).

1.4 TEMPERATURE

1.4.1 Effects of temperature on tomato crop photosynthesis

The effect of temperature on photosynthesis depends on the species, cultivar, the environmental conditions under which the plant was grown and the environmental conditions during measurement. Increases in temperature usually increase photosynthetic rates until enzyme denaturation and photosystem destruction begin (Salisbury and Ross, 1989). However, respiratory CO_2 loss also increases with temperature, and this is especially pronounced for photorespiration, largely because a temperature rise increases the ratio of dissolved O_2 to CO_2 (Salisbury and Ross, 1989). As a result of O_2 competition, net CO_2 fixation in C3 plants is not promoted by increased temperature as much as would be expected.

The promoting effect of a temperature rise is nearly balanced by increased respiration and photorespiration over much of the temperature range at which C3 plants normally grow, so a flat and broad temperature response curve between 15 and 30°C often occurs.

There is also evidence that at high temperatures ATP and NADPH are not produced fast enough in C3 plants to allow increases in CO_2 fixation, so formation of ribulose biphosphate becomes limiting (Salisbury and Ross, 1989). Lipton (1970), reported that high greenhouse humidity can aggravate the effects of high air temperatures, as the leaves can not transpire efficiently enough to cool the plant. It was found that with air temperatures reaching 30 to 35 °C, the actual temperature of the leaves was close to 35 to 45 °C, temperatures that approach those lethal to young cells of higher plants (Lipton, 1970).

The optimum temperature of leaf photosynthesis is dependent to a certain degree on

light and CO_2 levels. This is further complicated by the fact that different cultivars exhibit different response curves to light, CO_2 and temperature due to different net photosynthetic rates and photochemical and carboxylation efficiencies (Augustine et al, 1976). Although genotypes vary in the temperature response of leaf net photosynthesis, most show an optimum between 25 and 30 °C.

Many responses to different day/night temperatures have been reported. de Koning (1988) concluded that for young plants a high day/low night temperature regime seems most suitable to achieve a greater increase in light interception and maximum growth. However, great differences between day and night temperature will give elongated weak plants. Later, a low day/high night temperature regime is preferred to produce the maximum yield without loss of fruit quality (de Koning, 1988).

1.4.2 The effect of solution temperature on tomato plant growth and development

Tomato root system heating has been investigated for at least 30 years and has shown to generally increase vegetative growth with only limited effects on tomato yield at either normal or sub normal air temperature (Hurd and Graves, 1985). An advantage of the NFT system is the ease at which root temperatures can be maintained or modified with much more flexibility then is possible with soil. A further energy related advantage of NFT is that the running costs for heating NFT solutions are low since all the heat subsequently lost from the gullies contributes to heating the air (Hurd and Graves, 1985).

It is recommended that solution temperature be maintained in the range 18 - 20 °C, as high solution temperatures early in the season especially with reduced air temperatures results in poor fruit quality (Drakes et al, 1984). Temperature of nutrient solution, however, should not fall below 15 °C, and it has been shown that roots regenerate faster after root death where the solution is warmed. In situations under warm conditions, solution temperatures in excess of 30 °C have been recorded in exposed return pipes, and this resulted in poor fruit quality (Drakes et al, 1984).

Takano (1988), reported that there was a close relationship between plant growth and root zone temperature in NFT systems, and that heating the solution can supplement greenhouse air heating. It was found that at a solution temperature of 27 °C, dry matter production and mineral uptake were relatively high, even though the air temperature fell to 5 °C at night in winter. It was concluded that this temperature results in higher photosynthetic and transpiratory efficiency due to the maintenance of lower resistance of water and ion uptake by the root system (Takano, 1988). It has also been found that in tomato plant roots grown at 20 °C compared to 8 °C, the chloroplasts were rounded with clearly visible grana and large osmiophilic granules at 20 °C, whereas the lower temperature resulted in disintegration in the chloroplasts.

The effect of solution temperature on plant growth and nutrient uptake was studied by Moorby and Graves (1980) who stated that the rate of water uptake was a positive function of root temperature as was the rate of nutrient uptake and that the response curve shows a broad optimum in the region of a solution temperature of 25 - 30 °C.

In this investigation by Moorby and Graves (1980), it was also found that heating the roots led to initially faster rates of growth of seedlings and larger mature plants with larger leaf areas. Devonald (1987) also found that plant height, fresh weight and dry weight were all affected by solution temperature. The production of larger plants at high root temperatures implies that a greater rate of carbon fixation is occurring, as a result of the increased leaf area in the warmer solution temperatures (25 - 30 °C). Hurd and Graves (1985) concluded that the beneficial effects of high solution temperatures on leaf growth and fruiting may be due to increase in water or nutrient uptake by the roots

As well as larger mature plants, it was found that there was a larger fruit yield at higher root temperatures resulting from both an increased number of fruit and the production of larger fruit (Moorby and Graves, 1980). This was also reported by Cooper (1973). Although varying the root temperature for a short period did not appear to affect tomato yields, it was found that continuous solution temperatures in the optimum range of 30 - 35 °C increased fruit number, fruit size and fruit yield. However other researchers found the optimum temperature range for increased yield due to a larger fruit size

(Chong and Ito, 1982; Giacomelli and Janes, 1986; Hurd and Graves, 1985) or an increased number of fruits (Moss, 1983) was in the range 20 - 25°C. Maher (1980) reported that raising the solution temperature to 25 °C did not affect the development of early fruit or the yield, however, by the end of the experiment, the heated solution produced 3Kg more fruit then the unheated solution.

In another investigation Hurd and Graves (1985) stated that increasing root temperatures of up to 12 °C above the ambient of 15 °C, resulted in small reductions in yield and quality of early fruit. During the fruiting phase however, root heating increased final yield by about 10% over 20 weeks of harvesting. Hurd and Graves (1985) also reported that high root temperatures (25 °C) gave overall increases in yield and crop value, despite their detrimental effects on early yield and fruit quality. However, by delaying root heating until after fruit set, the detrimental effects on early fruit quality could be avoided.

Maher (1980) found that heating the nutrient solution to 25 °C resulted in increased shoot vigour and root size particularly at lower night air temperatures (13 and 5 °C). This was also reported in a review by Cooper (1973), who demonstrated that shoot dry weight increases with root temperature up to 30 °C. Maher (1980) also found that a solution temperature of 25 °C produced a large increase in root size and raised the levels of minerals in the leaf. It was also noted that total leaf area increases with solution temperature to a maximum of 30 °C then fell off steeply in the 30 - 40 °C range (Cooper, 1973).

It can therefore be concluded that raising the nutrient solution temperature to 25 - 30 °C has a beneficial effect on several plant processes. These beneficial effects of solution heating include increased transpiration and mineral uptake, increased seedling growth, the development of larger mature plants and increased final leaf area, resulting in increases in net photosynthesis and carbon fixation. As a result increases in fruit yield may be expected.

1.4.3 Summary

The growth, development and yield of the tomato crop is influenced by both the genetic potential of the plant and the environment it is exposed to. Process such as nutrient uptake, distribution and photosynthesis provide the basis for plant growth and effect the subsequent growth rate, flowering and fruit development. Environmental factors such as radiation levels, temperature and CO_2 all influence crop growth and management of these factors is aimed at maximising assimilate production to obtain the greatest yields.

1.5 THE SOURCE SINK RELATIONSHIP OF THE TOMATO PLANT

1.5.1 Introduction

The source sink concept describes the relationship between the leaves as the source of assimilates and the sinks, or importers of these assimilates. The predominant sink organs in the tomato plant are the root system, the stem, the developing inflorescence, the fruit and the shoot apex (Russell and Morris, 1983). However, in the tomato plant it is the fruit which are the economic sink and are of most concern to the producer. We are therefore interested in determining the roles that source and sink strength play in determining yield at the various stages in the life of the tomato crop.

Source strength and sink strength have been defined as (Warren Wilson, 1972):

Source strength = source size x source activity.

Rate of assimilation/plant (g/plant/day) = leaf area/plant (m^2/plant) x rate of assimilation/unit leaf area (g/m^2/day).

Sink strength = sink size x sink activity.

Absolute growth rate (g/day) = dry weight (g) x relative growth rate (g/g/day)

In the young tomato plant, the first truss becomes the dominant sink and the pattern of assimilate distribution is in the direction of this truss (Anon, 1989). As this first truss

matures, the second truss begins to take over this pattern and it is then continued with subsequent trusses. The leaves closest to the developing fruit are the major suppliers of assimilate. If these leaves are removed, the truss will import assimilates from further away (Anon, 1989).

Tanaka et al (1974a) proposed a concept for the source/sink unit. They stated that except for several leaves at the base of the stem which send their photosynthates to the roots, a tomato plant is composed of several units, each of which is composed of 3 leaves, a truss and a bud. In this investigation, Tanaka et al (1974a) found that the photosynthates of the leaves of a unit go preferentially to the sinks within the unit. However, this source-sink unit is not an absolute one. There is an inter-unit translocation of photosynthates and the extent of it depends on the condition (removal of leaves or the truss of a particular unit) of the plant (Tanaka et al, 1974a).

However, the availability of assimilate is determined by its rate of production or mobilisation in the source (source strength) and its rate of utilisation of storage in the sink (sink strength) (Ho et al, 1983). When either supply of or demand for assimilate is limiting, the sink strength and source strength change to create a new equilibrium. Thus the photosynthetic rate is either reduced by low sink demand or enhanced by high sink demand (Ho et al, 1983). This is supported by Tanaka et al (1974a), who stated that the net assimilation rate increases when the leaves are partially removed and decreases when the fruits are partially or completely removed, the net assimilation rate is under the control of the sink size. The rate decreased with a decrease of the sink size due to the removal of the fruits and it increased with increases in sink size per leaf area due to the partial removal of leaves (Tanaka et al, 1974a).

1.5.2 Stems, buds, leaves and roots as sinks

The leaf itself is one of the most important sinks for the photosynthate of the leaf. The translocation percentage of the photosynthates of a leaf is about 15% when it is developing rapidly and is about 50% even when it is transporting its photosynthate most actively (Tanaka et al, 1974b).

The bud receives photosynthates from the leaves on the main stem, especially from the leaf at which the bud is closest. However, a bud has a positive apparent photosynthesis from early in its development, and sends some photosynthates to the main stem (Tanaka et al, 1974a).

The function of several leaves, generally 6 leaves at the base of the stem is different from that of the upper leaves (Tanaka et al, 1974a). These leaves are more closely linked in the source-sink relationship with the roots. Russell and Morris (1983) disagree with this, finding that the root system received assimilate principally from leaf 5 and higher leaves, and the stem apex from the four lowest leaves in 47 day old tomato plants. This unusual pattern of transport is interpreted in terms of the complex bicollateral arrangement of the phloem in the tomato and in other members of the Solanaceae. It was found that in detailed autoradiographic studies, the downward transport of C from a leaf supplied with radioactive CO_2 occurred in the external phloem, whilst upward transport took place predominantly in the internal phloem (Russell and Morris, 1983).

However, both Russell and Morris (1983) and Tanaka et al (1974a), are in agreement that the developing first inflorescence received assimilate mainly from the leaves closest to it. Russell and Morris (1983) further quantified this to state that the developing first inflorescence received assimilates mainly from the two orthostichies adjacent to the radial position of the inflorescence on the vertical axis of the plant; these included leaves which were major contributors of assimilate to the root system (leaves 6 and 8) and the shoot apex (leaves 1 and 3).

Tanaka et al (1974a) found that when the major sink of a leaf (the fruits) are removed, the translocation percentage becomes as low as 10%. Some of the photosynthates moved out from the leaf accumulate in the leaves and in the stem, which do not act as sinks under ordinary conditions, and the weight of these organs becomes heavier. Under such conditions, the leaves become curled, pigmented and die early in fruiting plants.

It is well known (Russell and Morris, 1983) that under low photon flux densities during winter months in the UK, the developing first inflorescence is a weak sink which competes poorly with vegetative sinks for the limited supplies of photosynthates available, and that a number of cultural treatments have been shown to stimulate the growth and development of this inflorescence and to reduce flower abortion. Russell and Morris (1983) used this explanation to explain why root restriction treatments and removal of young leaves in the shoot apex can reduce the extent of flower bud abortion in the first inflorescence under conditions of reduced photoassimilate availability.

Other treatments that are known to stimulate the growth and development of this first inflorescence are techniques which increase total availability of photoassimulate such as CO_2 enrichment, increased levels of irradiation and wider spacing (Russel and Morris, 1983), all of which is well documented. Fisher (1979) found that the yield of individual trusses of single truss plants can be increased by increases in source strength due to CO_2 enrichment and that it appears that this is not a case of more assimilates all round for the fruit appears to get proportionally more of the increased supply mainly at the expense of the leaves.

However, it is possible to stimulate the development of the first inflorescence by techniques which reduce the demand for assimilates by competing vegetative sinks, such as root restriction (Cooper and Hurd, 1968), removal of young leaves at the shoot apex (Leopold and Lam, 1960) and exposure of the whole plant to low temperatures during inflorescence development (Hurd and Cooper, 1970).

Root restriction is in fact a commercial practice in the U.K where it is generally accepted that the longer a tomato plant from a winter sowing is kept in a pot before being planted out, the better is the development of the first inflorescence (Cooper, 1972). The beneficial effect on inflorescence development by such root restriction practices is often attributed by tomato growers to an influence on competition between root growth and inflorescence development. Cooper (1972) suggested that this improved inflorescence development produced by these root restriction techniques is at the expense of leaves and not at the expense of roots as commonly thought.

1.5.3 Competition within a sink

Not only is there competition between reproductive and vegetative growth and between the trusses or sinks of a plant, but also within the sinks. Tomato fruits within the same truss generally differ in their final size with the larger ones developing at the proximal position (Bangerth and Ho, 1984).

In the study by Bangerth and Ho (1984), the theory that distal fruits have a lower potential sink strength then proximal fruits was investigated. It is known that the amount of assimilate imported by a fruit (sink strength) is determined by both the ability of fruit tissues to import and the fruit size, but it is not certain what determines the higher potential sink strength in proximal fruit. Bangerth and Ho (1984) suggested that by having a greater number of cells (high potential sink size) together with more auxin to attract assimilates (higher sink activity) the proximal fruits have the potential to grow bigger. It was also suggested that the lower sink activity of the later induced fruits may be due to an inhibition from the first induced fruits.

The two ways in which these fruit which are induced first may inhibit the growth of the later induced ones are:

1. By limiting the supply of assimilates to the later induced fruits by monopolising the mobile assimilates en route or

2. By suppressing the rate limiting processes of fruit growth (e.g unloading of assimilates) in the later induced fruits.

This inhibition may be caused by the release of IAA and other inhibitors from the first induced fruits (Bengerth and Ho, 1984). So not only is final fruit size of tomato fruit determined by potential sink strength (determined before fruit set), but also the competition for assimilate supply determined by the sequence of fruit set.

1.5.4 Competition between trusses

In a multi truss tomato crop, for most of the plant's life there will be a number of

trusses developing at the same time. These fruit trusses must compete with each other for the available assimilates. The one truss that develops with minimal competition from the other trusses is the first truss (Anon, 1989). Slack and Calvert (1977) found that removal of a truss resulted in yield increases on some of the remaining trusses both above and below the one removed, the largest increases occurring on the trusses adjacent to the one removed and smaller increases occurring on the more distant ones.

Fisher (1977) supports these findings, by claiming that the largest amount of competition comes from the truss immediately above the truss under consideration, although data did indicate that a truss as distant as truss 6 still had a competitive role to play with respect to truss 2. Fisher (1977) also stated that the existence of such competition effects demonstrates that yield is being limited by assimilate supply (source strength). From this evidence it can be concluded that in a tomato plant under ordinary commercial cultivation the sink exceeds the source, and the growth rate of the plant is under the control of the sink size (Tanaka et al, 1974b).

Thus, although the tomato is source limited, increases in sink strength can stimulate photosynthesis. Data presented by Fisher (1977) suggests that the net assimilation rate in the tomato plant can be reduced due to lack of fruit load and that fruit yield can be limited simultaneously by lack of both source and sink strength. Ho et al (1983) also state that the photosynthetic rate is either reduced by low sink demand or enhanced by high sink demand. Fisher (1977) stated in a later study that the yield of individual trusses can be increased by increases in both source and sink strength and that increases in sink strength can stimulate photosynthesis particularly in the young plant. Slack and Calvert (1977) stated that the removal of a truss resulted in apical and basal movement of the available assimilate to the remaining trusses, perhaps via the internal and external phloem. These results also indicated that there was greater export of assimilates to the remaining trusses in an upward direction as it was found that increases in yield on trusses above the one removed were somewhat larger then the increases on the lower trusses.

Other researchers (Khan and Sager, 1966) stated that the pattern of export from the

leaves changed with continuing development of the plant. The two important aspects they considered likely to have effected this change were the removal of the lower leaves as part of normal cultural practice and the changing sink strengths of the trusses; the demand from the younger trusses increasing and that from the older ones lessening as they reached maturity and fruits were removed on ripening.

However, it remains that in a multi truss tomato crop, under normal cultural conditions, yield is source limited rather then sink limited, and the yield of individual trusses can be increased by increases in source strength with the use of such techniques as CO_2 enrichment and supplementary lighting - both of which amount to increased photosynthesis and thus a greater amount of assimilates available for sink growth and development.

1.5.5 Partitioning of dry matter in the tomato plant

In an investigation into the partitioning of dry matter by tomato plants, Cooper (1972) found that partitioning between the component organs was controlled on a proportional basis that was independent of the growth rate of the plant. The evidence that supports this claim was that despite plants grown in winter and summer having very different growth rates, the partitioning between component organs was initially very similar.

Cooper (1972) stated that the control of partitioning initially increased the proportion of dry matter going to the leaves and stem and reduced the proportion going to the cotyledons and roots. Immediately after flower initiation this pattern of distribution was altered, in that the proportion going to the leaves ceased to increase further and began to decrease slowly.

Subsequent changes that occurred in the control of partitioning coincided with the onset of rapid ovary swelling. Firstly, the proportion of dry matter going to the stem began to decline, secondly the slow decrease in the proportion of dry matter going to the leaves became much more rapid. The dry weight of the stem and leaves continued to decline until a weight was reached which subsequently remained constant (Cooper, 1972).

Cooper (1972) investigated the influence of container volume, solution concentration, pH and aeration on dry matter partitioning by tomato plants in water culture. In this investigation it was found that the volume of containers had little influence on dry matter partitioning as did solution pH or aeration. However, reducing the concentration of the nutrient solution reduced the proportion of the total dry matter in the roots during the first 2 weeks of seedling growth but subsequently increased it slightly. This increase in the proportion in the roots was achieved initially at the expense of the leaves and subsequently at the expense of the stem (Cooper, 1972).

Hurd and Thornley (1974) found that conditions favouring high rates of photosynthesis also resulted in plants with thicker leaves having a large dry weight per unit area, whilst low rates of assimilation were associated with thin leaved plants.

1.5.6 Summary

With the tomato plant it is the fruit which are the economic sink. It is therefore important to establish the relationship between the vegetative and reproductive processes in order to maximise sink size. The production and distribution of assimilates in a multi truss tomato plant is complicated by many factors; source strength produces the pool of assimilates and sink strength determines the demand for these. However, there are numerous source sites and several sinks at different developmental stages on the same plant at any one time. This has lead to the development of the source-sink unit concept (Tanaka et al, 1974b), where each truss is associated with 3 leaves which provide it with assimilates. This concept is not an absolute one as stems, buds, leaves and roots also act as sinks. This concept is further complicated by the fact that there may be competition within a sink (between the fruit on the same truss), and competition between trusses on the same plant, all of which may be influenced by environmental factors which effect dry matter partitioning. Although yield is dependent on both source and sink strength, the environmental factors which influence source activity play the major role in assimilate production and thus final sink size.

1.6 FRUIT GROWTH AND DEVELOPMENT

1.6.1 Fruit growth and development - physical changes

The most obvious physical change that occurs during tomato fruit development is an increase in fruit size, although some changes in shape also occur in some cultivars, particular the 'pear shaped' varieties. The shape of the fruit results from the differential growth of the ovary at the polar and equatorial dimension prior to anthesis (Houghtaling, 1935).

Fruit of modern tomato cultivars develop from an ovary weighing 5 - 10 mg to a final weight between 15 g (e.g cherry tomatoes) to 450 g (e.g beefsteak type); thus their growth rates differ substantially (Ho and Hewitt, 1986).

This increase in size is due to the importation of leaf assimilates to the ovary. It has been found that by the middle of the growth period the rate of daily growth increases to a maximum in fresh weight of 7g, or in dry weight 0.37 g or in volume 2.2 ml (Ho and Hewitt, 1986). Most of the fruit weight is accumulated by the mature green stage, until finally there is a period of slow growth for 2 weeks when there is little gain in fruit weight, but in which intensive metabolic changes take place. The cessation of assimilate import occurs about 10 days after the first change of colour is caused by the formation of the abscission layer between the calyx and the fruit (Mc Collum and Skok, 1960).

Another physical change which occurs as fruit develop and mature is the development of colour. The first colour change occurs 2 - 3 days after the mature green stage and progressively develops from yellow, orange and to red (Ho and Hewitt, 1986).
These changes in colour are attributed to chlorophylls a and b which continue to increase with the size and maturity of the fruit, but begin to decrease as fruit start acquiring a pink colour (Dalal et al, 1986).

1.6.2 Physiological changes

The major physiological changes that occur during tomato fruit development and maturity relate to the processes of photosynthesis and respiration.

Green tomato fruits contain chlorophyll and fix carbon dioxide. However, even at light saturation the net photosynthetic rate is only 0.064 mg CO_2 $g.fwt^{-1}.h^{-1}$ for very young fruit and no net photosynthesis can be detected in older, mature fruits (Ho and Hewitt, 1986).

The rate of respiration of a tomato fruit falls from 0.4 - 0.6 mg CO_2 $gf.wt^{-1}$ h^{-1} in a 2 week old fruit to 0.05 - 0.07 in a mature green fruit and then doubles its minimal rate during the climacteric at the orange stage (Tanaka et al, 1974b). On a whole fruit basis, the amount of carbon respired per day increases from 7 to 20 mg in fruits of 20% to 90% final size accounting for 5% and 25% of the imported carbon respectively (Walker and Ho, 1977a).

1.6.3 Biochemical and compositional changes

The major constituents of the tomato fruit are listed in Table 1.1. Note the high proportion of sugars and organic acids which make a major contribution to the taste of the fruit.

Table 1.1 Composition of ripe tomato fruit (% dry matter)

Sugars	
Glucose	22
Fructose	25
Sucrose	1
Alcohol insoluble solids	
Protein	8
Pectic substances	7
Hemicellulose	4
Cellulose	6
Organic acids	
Citric acid	9
Malic acid	4
Minerals	
Mainly K , Ca, Mg, P	8
Others	
Lipids	2
Dicarboxylic amino acids	2
Pigments	0.4
Ascorbic acid	0.5
Volatiles	0.1
Other amino acids, vitamins, polyphenols	1.0

(Source; Davies and Hobson, 1981).

Some of the important compositional changes effecting these constituents during development, ripening and senescence are listed in Table 1.2.

Table 1.2 Changes in composition during ripening

Degradation of starch and production of glucose and fructose.
Loss of chlorophyll
Synthesis of pigments such as β-carotene and lycopene
Increase in soluble pectins resulting from wall softening and degradation.
Production of flavour and aroma compounds
Increase in ratio of citric acid to malic acid
Increase in glutamic acid
Breakdown of the toxic alkaloid α-tomatine

(Source: Grierson and Kader, 1986).

Many of these can be shown to take place when mature green fruit are detached from the plant and allowed to ripen. It therefore follows that at least some aspects of ripening depend on the metabolism of components already existing in the fruit and are not dependent on the import of materials from the parent plant.

The most consistent change found in the composition of tomatoes during ripening was a decrease in the content of alcohol insoluble solids (Craft and Heinze, 1954).

Baldwin et al (1991), found that some of the flavour volatiles increased in concentration, peaking at the turning stage or red stage of maturity. The trend of other volatiles followed the increased production of ethylene and lycopene and the climacteric rise in respiration during ripening.

Syamal (1990) stated that during ripening and senescence of 12 tomato cultivars at room temperature, there was observed a decrease in total juice per cent, chlorophyll content and acidity. There was also an increase in lycopene content, total soluble solids and reducing sugar per cent. It is thought that the reduction in acidity might be due to rapid utilization of organic acids in respiration (Syamal, 1990).

Rigney and Wills (1981) reported that cell wall calcium level increased during fruit development to the fully grown, immature stage, but dropped just prior to the onset of ripening.

The biochemical processes occurring during fruit growth and maturation, are due to the RNA polymerase enzymes in the nucleus transcribing many different genes to produce messenger RNA molecules, transfer RNAs and ribosomal RNAs. These molecules are transported through the nuclear pores to the cytoplasm where they form polyribosomes, synthesizing a range of enzymes and structural proteins required in the cytoplasm, membranes, cell organelles and cell walls (Grierson and Kader, 1986). These all result in the physiological and physical changes that occur during development and maturation.

During fruit growth, the dry matter content, as a percentage of fruit fresh weight declines, as increasing amounts of water are accumulated. Before fertilization, dry matter accounts for 17% of the ovary weight. Once the fruit starts to grow, the dry matter content is reduced to less than 10% by day 10 and then to 5 - 7% by day 20, remaining at this level to maturity (Gustafson, 1926). Sugars, mainly glucose and fructose account for about half of the dry matter or 65% of the total soluble solids of a ripe tomato fruit.

Sucrose accounts for only 1% of dry matter or in the range of 0.1 - 0.2% fruit fresh weight, but the metabolism of sucrose is important for fruit growth. After pollination, the content of reducing sugars and starch increase sharply, but that of sucrose reduces from 1% ovary fresh weight to 0.2% fruit fresh weight within 8 days (Marre and Murneek, 1953). During the initial stages of development the fruit contains twice as much glucose as fructose, but with the onset of ripening the glucose/fructose ratio declines. Total reducing sugars (% fresh weight or per fruit) increase markedly between the mature green and green yellow stages with a tendency to decrease with subsequent ripening (Davies and Kempton, 1975).

The rate of starch accumulation increases during the rapid growth period and has great influence on the final content of total soluble solids. The rate of starch accumulation

rises to a peak and accounts for 30% of the daily accumulated dry matter at day 20. Starch starts to break down when the fruit absolute growth reaches its maximum and the starch content is about 1% dry matter at the mature green stage or 0.03% fruit fresh weight at ripening. Since the breakdown of starch is associated with a rapid accumulation of reducing sugars, there is a high correlation between the starch content in green fruits and the total soluble solids contents of ripe fruits among cultivars (Dinar and Stevens, 1981).

The organic acids in a tomato fruit consist mainly of citric and malic acids and account for 13% of dry matter. During early growth, malic acid is the predominant acid whereas citric acid accounts for only 25% of the total acidity (Ho and Hewitt, 1986).

It was also found by Dalal et al (1986) that total pectic materials increased up to the large green size and declined as the fruit began to ripen, while water soluble pectins showed a steady increase.

1.6.4 Changes that occur during ripening and senescence

1.6.4.1 Introduction

The conversion of a tomato fruit from the mature green stage to fully ripe stage involves dramatic changes in colour, composition, aroma, flavour and texture. Ripening used to be thought of simply as the result of a series of degradative processes, probably because some of the more obvious changes require the action of hydrolytic enzymes. However it is now clear that ripening is dependent on a wide range of separate synthetic as well as degradative reactions. These include alterations in metabolism and gene expression which have a dramatic effect on fruit quality. Hall et al (1986) stated that senescence in a higher plant is clearly a programmed process that is, its timing, form and duration are laid down in the genome. The changes are highly coordinated; they occur in the majority of the cells of the fruit and involve every subcellular compartment. The various facets of ripening appear to be coordinated and regulated by plant hormones but may be modified by genetic and environmental factors (Grierson and Kader, 1986).

During ripening tomatoes show the climacteric pattern of respiration usually observed

with fleshy fruits. The gas exchange of tomato fruit takes place almost exclusively through the stem scar, the skin being quite impermeable to oxygen and carbon dioxide (Workman et al, 1956).

1.6.4.2 Physical changes

The obvious physical changes that occur during ripening and senescence are a change in colour from orange at ripening, through to a deep red during senescence. During senescence a reduction in size (and possible shrivelling of the fruit) occurs as a result of water loss or a decrease in the total juice content per cent (Syamal, 1990).

1.6.4.3 Physiological changes

Ripening used to be thought of essentially as a degenerative process, involving senescence and the general breakdown of the cell, leading ultimately to cell death. Although it is certainly true that the cells of ripening fruit will eventually die if left for long enough, the process takes several weeks. During all this time, the nucleus, mitochondria, chromoplasts, plasmalemma and polyribosomes all remain intact and active. In some cases they even increase their metabolic activity. A more correct interpretation of the ultrastructural evidence is that various parts of the cell are simply transformed in appearance as the composition of the cells becomes modified. The cells may become more fragile as a result of cell wall degradation and possibly other changes, so that the fruit are more easily damaged during postharvest operations (Grierson and Kader, 1986).

1.6.4.4 Biochemical and compositional changes

The major events that occur during ripening and senescence have been well documented for many fruits, but the factor(s) that control the onset of natural ripening are still uncertain (Rigney and Wills, 1981). Ethylene, once considered to be the ripening hormone, is now generally not regarded as the only endogenous control factor. PG activity has been proposed as a key control factor for the ripening of tomatoes (Rigney and Willis, 1981). In the ripening of the tomato fruit, it is clear that ethylene is involved in controlling the synthesis of the ripening associated enzymes, notably endopolygalacturonase (Hall et al, 1986).

Tomato fruits are resistant to ethylene before the mature green stage and this suggests that they are not competent to respond until a certain stage in development is reached (Hall et al, 1986). Not all ripening events are dependent on ethylene production. Ethylene has little effect on sugar and acid levels in ripening, nor do these changes rely on PG induced wall degradation. However, lycopene synthesis and PG activity with a number of subsequent events are greatly dependent both on presence of ethylene and on tissue sensitivity (Hobson and Harman, 1986).

1.7 RESPIRATION

1.7.1 Introduction

A simplified scheme of carbon metabolism in the fruit comprises initial hydrolysis of imported sucrose and subsequent utilisation of hexoses in respiration or in further conversions: starch and insoluble residue are the major products, representing partitioning into storage and structural components respectively (Walker and Ho, 1977a). A rough estimate indicates that the materials used for the growth of fruits consist of 10 - 15% of their own photosynthates and 90 - 85% of translocated materials from the leaves. Of these materials 75% become fruit constituents; the remainder is consumed in respiration. In other words the growth efficiency of the fruit is about 75% (Tanaka et al, 1974b).

The rate of respiration of a tomato fruit falls from 0.4-0.6 mg CO_2 $g.fwt^{-1}.h^{-1}$ in a 2 week old fruit to 0.05-0.07 in a mature green fruit then doubles its minimal rate during the climacteric at the orange stage. On a whole fruit basis the amount of carbon respired per day increases from 7 to 20 mg in fruits of 20 to 90% final size, accounting for 5% and 25% of the imported carbon respectively. Since the rate of respiration is related to the relative growth rate of the fruit and the high starch accumulation rate is associated with high growth rates among cultivars, both the rates of starch accumulation and of respiration may partially regulate import. This was also found by Walker and Ho (1977a), who stated that only 5% of the carbon imported by the smallest fruits was respired compared with 26% of that imported by the largest fruits. However, in all cases the respiratory loss of carbon was less then 2% of the fruits initial carbon content.

When measured over a 24 hour period, fruit respiration rates were found to be at a maximum at midday, followed by a decline to a minimum at 21:00 - 22:00 hours and a subsequent rise in rate just after midnight (Bunce, 1990).

1.7.2 Effect of temperature on respiration rates in tomato fruit

Respiration is an essential plant process, it may be divided into two components within a plant system:

(i) Constructive or growth respiration which supplies energy for the synthesis of new dry matter from carbohydrates and minerals and

(ii) Maintenance respiration, which is connected with the permanent turnover of certain organic compounds and the maintenance of ionic gradients (Gary, 1989).

Of these two, maintenance respiration is highly temperature dependent (Walker and Thornley, 1977). Temperature has the effect of altering the rates of respiration and starch synthesis in the fruit, therefore the rate of assimilate import is changed by fruit temperature.

The rate of deterioration of fruits is closely correlated with their rate of respiration (Southwick and Lachman, 1953). Gosiewski, et al (1982) reported that both net photosynthesis and dark respiration rates of 4 genotypes at ambient temperatures of 10, 18, 20 and 26°C illustrated that in general, net photosynthesis and respiration increased with an increase in temperature. Walker and Ho (1977b) also stated that there was a net loss of reserve material due to the breakdown of starch at a temperature of 35°C. Gary (1989), found that the exhaustion of leaf sucrose during a dark period occurred more rapidly at higher temperatures of 20-25°C. Lurie and Klein (1992) found that harvested mature green tomatoes showed an increase in respiration when stored at 38°C for a period of 3 days. In this investigation, it was found that fruits held at 38°C had a CO_2 production rate 50% greater then fruit kept at 12°C. Gale (1982) stated that the increase in the rate of CO_2 efflux at higher temperatures could result from an increase

in maintenance respiration in order to supply the energy required to cope with higher rates of protein turnover and the damage resulting from these high temperatures (38°C).

Smillie (1992) stated that the photosynthetic system in leaves is especially vulnerable to heat stress, becoming inactivated at temperatures several degrees below those damaging respiration and several other cellular process. Temperatures above 45°C are generally needed to inactivate respiration in plant tissue. Thus a plant under high temperature stress would rapidly loose reserves from the fruit as photosynthesis would be inhibited, while respiration would be continuing at a high rate.

1.7.3 Fruit respiration after harvest

Workman et al (1956) measured the respiration and ripening of tomato fruits harvested at the mature green stage. During ripening tomatoes show the climacteric pattern of respiration usually observed with fleshy fruits. The gas exchange of the tomato fruit takes place almost exclusively through the stem scar, the skin being quite impermeable to O_2 and CO_2.

The pattern of respiration was that the rate dropped from a relatively high initial rate of a pre-climacteric minimum, then rose to the climacteric peak, and then again dropped. It appears from this data that tomatoes go through the climacteric peak while still unripe (Workman et al, 1956).

Workman et al (1956) stated that differences in behaviour of tomatoes with regard to respiration pattern and ripening may result from several factors. For example, variations in the length of time between an initial reading and the pre-climacteric minima, the maturity of the fruit when harvested and to the position of fruit in the cluster.

Fruit respiration rates differ or are effected by:

(i) Fruit size
(ii) Relative growth rate of the fruit
(iii) Onset of the climacteric changes/ripening

(iv) Possible position in the truss

(v) Temperature

(vi) Time of day

1.7.4 Measurement of tomato fruit respiration

As a green tomato matures, the permeability of the outer epidermis decreases (Smillie, 1992), so that by the time a fruit is harvested, the gas exchange of the fruit is taking place almost exclusively through the stem scar, the skin being quite impermeable to O_2 and CO_2 (Workman et al, 1956). This was shown when various research workers waxed the stem scars in order to prevent decay, but observed anomalous respiratory behaviour as a result of a modified internal atmosphere which varied with the degree of stem-scar sealing (Workman et al, 1956). In the most severe cases fruit breakdown as a result of anaerobic conditions occurred as the internal CO_2 concentrations rose to detrimental levels.

The fact that the tomato fruit epidermis is relatively impermeable to gas exchange was also shown by Smillie (1992), who suggested that maturing tomato fruit continue to fix CO_2 photosynthetically utilising accumulated CO_2 from respiration. This was later demonstrated when intact fruit were exposed to CO_2 free air, the loss of activity was slow, indicating that most of the CO_2 fixed photosynthetically in the fruit was derived from CO_2 accumulated within the fruit.

This reduction in the permeability of the outer epidermis as the green tomato fruit matures is a result of the reduction in stomatal frequency along with a decrease in the number of functional stomata. Guard cells become inactive as the walls subsequently thicken and become covered with wax. Substomatal cells with suberized walls divide and grow, transforming the stomata into lenticels which resist gas exchange (Smillie, 1992). Decreasing permeability of the outer epidermis of the fruit arising from the combined effects of decreasing stomatal frequency and function leads to a build up of CO_2 within fruit cavities, in apple as much as 5% (v/v), a 150 fold increase in concentration as compared with the external ambient [CO_2] (Smillie, 1992).

The evidence obtained by Smillie (1992) and Workman et al (1956) all strongly indicated that CO_2 released during respiration is not escaping through the fruit epidermis, but is either being released through the stem scar after harvest, or being utilised in fruit photosynthetic activity. However, since mature green tomato fruit have a low rate of photosynthesis, being 1 to 10% of that occurring in the leaves due to the sparsely distributed chloroplasts in fruit tissue, the CO_2 released from respiration may be either accumulating in the fruit, or forced back out along the truss stalk, and into the plant stem. If between 5% (small fruit) and 26% (large fruit) of the imported carbon in a fruit is respired, this would result in concentrations of CO_2 far above what could be utilised in the low rate of photosynthesis maintained by green fruit. This was shown by Czarnowski and Starzecki (1990), who found that net photosynthesis in green fruits, irrespective of their size, occurred below the gas exchange compensation point and that in orange fruit, no photosynthetic CO_2 assimilation was observed.

Since internal CO_2 tissue damage is not usually seen on tomato fruit, it is likely that respiratory CO_2 is being forced back into the plant. This CO_2 could be released at a number of points, through the fruit calyx, truss stalk tissue, or the plant stem and leaves. Another possibility is that if fruit respiratory CO_2 is escaping back into the plant tissue, it could be utilised in photosynthetic activity in the leaf tissue. If this is the case then any measurement of the CO_2 released from fruit respiration needs to include all tissue and the point of release of this CO_2, not just the fruit surface itself. However, previous researchers have concentrated in recording the CO_2 evolved from the fruit surface not considering that the tomato fruit epidermis is relatively impermeable to gas exchange.

1.7.5 Experimental measurement of tomato fruit respiratory activity

The earliest measurement of fruit respiration were carried out by Phillips (1937). To obtain measurements of the CO_2 output, tomato fruit were placed in individual gas-tight chambers immersed in a constant temperature bath. A CO_2 free air stream was passed over the fruit in the chamber and the CO_2 evolved was collected by absorption in Ba(OH) in Pettenkoffer tubes. Measurements were made by titrating the contents of each tube every 24 hours. The resulting rates were expressed in mg of CO_2 per Kg of fruit.

Walker and Ho (1977a) determined the rate of fruit respiration by removing all but 2 fruit on the second truss of the plant. Plants were stopped two leaves above this second truss. Entire plants were then removed to the laboratory 24 hours before the start of the experiment and the sepals were removed so that only fruit respiration was measured. The individual attached fruits were enclosed in perspex chambers with expanded polystyrene bungs fitted around the peduncles. The fruits were then maintained at a constant temperature by circulating water between a controlled temperature bath and the measurement chamber. Fruit respiration was determined by measuring the CO_2 enrichment of a stream of air passing through a chamber enclosing the fruit. Outside air was drawn through three 86 litre mixing drums by a diaphragm pump and passed at a controlled rate (0.41 l min^{-1}), via a flow regulator and needle values, to the individual chambers. On leaving the chambers the air streams were bubbled through columns containing 100 ml standard NaOH solution to absorb CO_2. At the end of the experiment the amounts of CO_2 absorbed by the various units were determined by titrating aliquotes of the absorbtion solutions against 0.5 N HCl after precipitating the carbonate with 25% barium chloride solution. This method was also used by Walker and Ho (1977 b), and Walker and Thornley (1977).

Workman et al (1956), used much the same method to determine post harvest respiration rates. Fruit samples for respiration measurements were placed in respiration chambers (18 inch pyrex jars), and air from a compressor was passed through the jars at a known rate (generally 18 to 22 l per hour) such that the final CO_2 concentration in the out flowing air would be 0.3 to 1.2 per cent. In this situation, CO_2 released from respiration would be escaping through the stem scar.

Other researchers, have monitored plant respiration often in combination with photosynthesis on a whole plant basis usually by placing the entire plant in an air tight chamber and monitoring the gas exchange over a 24 hour period (Gosiewski et al, 1982; Bunce, 1990). Gosiewski et al (1982) reported that for the cultivar Sonatine, respiration rates increased with temperature from 0.081 to 0.138 mg CO_2 m^{-2} s^{-1} per unit leaf area over the temperature range 10-26°C.

Ahrens and Huber (1990), determined the respiration rate of ripening tomato fruit after harvest by placing individual fruit in 500ml glass containers with lids fitted with rubber septa. One-half ml samples were drawn from the container atmosphere after 30 minutes and analyzed for CO_2 using a Fisher gas-partitioner. Ahrens and Huber (1990) reported that the four cultivars measured all differed in their respiration rates at each stage of maturity from mature green to fully red. The rate of respiration for the cultivar Rutgers, for the maturity stages mature green, breaker, turning, pink, light red and red were 18, 21, 32, 30, 28 and 27 ml Kg^{-1} h^{-1} respectively (Ahrens and Huber, 1990).

1.8 FRUIT QUALITY.

1.8.1 Introduction

Fruit quality is influenced by several interacting factors. The genetic background of the variety determines the basic fruit character and has a profound effect on all aspects of fruit quality; other factors can only modify the fruit character (Hobson and Adams, 1989). Considerable effort has been directed by plant breeders toward developing improved cultivars with enhanced yield and quality characteristics (Mitchell et al, 1991).

Numerous management techniques have been proposed to increase yields and improve the flavour and quality components of tomato fruit. Growers in recent years have attempted to develop water management practices that maintain yields, but impose controlled moderate levels of stress to improve fruit quality and restrict vegetative growth. Thus practices which involve increasing the interval between irrigations (in the field) or increasing the concentration of the nutrient solution (greenhouse) both have the effect of imposing a water stress on the plant.

These techniques have improved fruit quality by increasing total and soluble solids concentrations in the fruits, both in the field and under protected cultivation. The improvements gained by water deficit or saline water irrigation are, however often accompanied by reduced yields (Mitchell et al, 1991).

The best quality fruits have a high content of both sugars and organic acids. Where low acidity is combined with a high sugar content the taste is sweet, but to most people, insipid. With high acidity and low sugar content the taste is rather sharp and thin. When both acidity and sugar content are low, the taste is watery and unattractive (Winsor, 1966). Examples are presented in Table 1.3.

Table 1.3. Some analysis of juices expressed from ripe tomatoes. (Winsor, 1966)

Variety	Titratable acidity m.e/100ml juice	Sugars g/100ml	Total solids g/100ml	Comments
Potentate	8.1	3.09	4.81	A good sample of this variety
Potentate	7.9	2.19	3.80	Acidity satisfactory sugars low
Potentate	5.8	3.18	4.46	Acidity low, sugars satisfactory
Potentate	4.4	4.02	5.18	Acidity very low, sugars very high

Kavanagh and McGlasson (1983), stated that for normally grown commercial cultivars, total soluble solids range from 4 to 6%, pH from 3.9 to 4.6 and titratable acidity from 9.7 to 14.6 m.e./100ml of juice. However, although there is a highly significant negative correlation between pH and titratable acidity, there is a wide range in the $[H^+]$/titratable acidity ratio. It has been suggested that differential buffering is primarily responsible for this variation and that phosphate content of the fruit is a prime factor in differential buffering (Stevens, 1972b).

Fruit conductivity has been established as a predictor of potassium levels in sap which,

in turn is related to the titratable acidity (Stevens, 1972b). However, Hobson and Kilby (1984), found that titratable acidity did not show a good correlation with fruit sap conductivity. It is likely that conductivity measurements only give an indifferent indication of the titratable acidity, although probably a better one with total acidity (Winsor, 1966). The consumer responds most to titratable acidity levels (Hobson and Kilby, 1984).

1.8.2. Comparison of different tomato varieties

The main compositional characteristic that differs with variety is fruit acidity (Winsor, 1966). Davies and Winsor (1969), reported that fruit of tomato varieties grown under comparable conditions can differ markedly in acidity. They suggested that the fruit walls show considerably lower acidity than the locular contents, large fruited varieties might be expected to show relatively low acidity and vice versa.

Varieties having an average acidity of 8.5 - 9 milliequivalents or more of acidity per 100ml of expressed juice were regarded as highly satisfactory where the fruit is to be eaten fresh (Winsor, 1966). Acidity of the fruit depends upon the interplay of varietal characteristics and environment or cultural factors, such as fruit shading or exposure to sunlight, nutrition and season (Winsor 1966).

Differences in dry matter production between cultivars often result in variation in shelf life between varieties (Richardson and Hobson, 1987). Table 1.4 shows this relationship with the cultivars Ailsa Craig and Sonatine.

Table 1.4 The relationship between dry matter and shelf life for two tomato cultivars (Richardson and Hobson, 1987).

	Ailsa Craig	Sonatine
Shelf Life in Days	28.1	18.4
Dry matter (g 100 g^{-1})	6.48	5.67

1.8.3 Comparison of different production systems

Granges (1980) reported that fruits from plants grown in soil were more acid, but had lower reducing sugar and ash contents than those grown in NFT. The method of culture had no effect on dry matter content. He also found that the β-Carotene content of the fruit was 70% higher in fruit grown in soil than in those grown in nutrient film culture, but there was no difference in vitamin C content.

Gormley and Egan (1982) carried out an investigation into the quality of fruit from NFT, soil and peat growers. Peat was the growing medium that gave fruit with the highest soluble solids content, and it was the peat medium that also resulted in the highest fruit puree conductivity values followed by soil and NFT (Table 1.5).

Table 1.5. Soluble solids, acidity, conductivity and firmness or tomato fruit from UK commercial growers 1981 (Gormley and Egan, 1982)

	Soluble solids %	Acidity meq/100g puree	Conductivity mhos	Firmness mg per 5 mm compression
NFT	4.6	9.5	667	2910
Soil	4.3	9.2	679	2925
Peat	4.7	10.2	717	3044

In comparison, Benoit and Ceustermans (1987), found that fruit from NFT grown tomatoes were firmer, higher in Vitamin C and also contained more sugar, acid and sodium (which gave a more pronounced taste) than soil grown tomatoes. The nitrate content of NFT grown fruits was considerably lower, while the phosphorus, potassium, calcium and magnesium content were practically identical with tomatoes grown in soil.

Adams and Winsor (1976) compared fruit produced in peat bags and NFT. It was found that there was little overall difference in firmness of fruit grown by these two methods, though those from peat-grown plants were softer at the first date of sampling. They also reported that dry matter content of the fruit was 11 percent higher and the sugar content was 17 percent higher in NFT, than those grown in peat bags (Table 1.6). Factors which may have contributed to the superior quality of fruit from solution culture include less vigorous plant growth and some reduction in yield compared with the plants in peat bags.

Table 1.6. The composition of tomatoes cv. Sonato grown in peat bags compared with that of fruit grown in nutrient-film culture (Adams and Winsor, 1976)

	Peat	NFT
Dry matter (%)	5.60	6.22
Sugars (g/100ml)	2.50	2.93
Titratable acidity (meq/100ml)	7.9	8.7
Potassium (meq/100ml)	5.80	6.00

In all these studies of fruit quality from different production systems, it should be taken into consideration that the different nutritional programmes, seasonal conditions and differing grower skills all play a role in quality determination. Thus the differing management techniques used with the systems may have a greater influence on fruit quality than the systems themselves.

1.8.4. Nutrition and fruit quality

Of all the plant nutrients, potassium plays the most important role in fruit quality. The acidity of fruit juices was found to increase with the level of potassium in the soil (Winsor, 1966). Potassium is an important constituent of tomato fruit and is the

dominant cation present. Potassium accounts for 85% of the total cations removed by ion exchange from tomato puree, and increases in fruit acidity are usually accompanied by substantial increases in potassium content (Winsor et al, 1961).

With the tomato applications of potassium in excess of that which is required for maximum yields are necessary for good fruit quality (Fisher, 1989). It has been demonstrated by numerous researchers that hollow fruit and ripening disorders are decreased, fruit shape and firmness improved and the acid concentration of the fruit increased by high potassium concentrations.

1.8.5 Salinity level

It is well known that when salt tolerant, edible crops are grown under saline conditions, the flavour of the product is improved, although often at the expense of marketable yield (Gough and Hobson, 1990). Salt tolerance seems to be linked with an ability to increase the concentration of solutes in plant tissues (Gough and Hobson, 1990). Mitchell et al (1991) stated that the effect of water deficit or salinity in improving fruit quality results from a reduction in water accumulation and not because they promote the accumulation of solutes.

Since over 90% of the fruit is water, the concentration of sugars can be increased by reducing the water content. This is achieved by restricting the supply of water to plants grown in soil or peat and by making the feed of plants grown in rockwool or NFT more saline (Hobson and Adams, 1989).

Gough and Hobson (1990), investigated the effects of salinity on fruit compositional quality and shelf life. It was found that with NFT solutions having an EC of 3, 5 and 8 dS m^{-1}, the dry matter content of the fruit as a percentage of fresh weight increased at the higher conductivity levels. It was also found that the sodium content and titratable acidity in the fruit sap were significantly raised when plants were grown at the higher conductivities. No significant increase in sugar levels was found in this investigation, suggesting that irradiance fluctuations were playing a major role in sugar determination, it should be noted that sugar levels in tomato fruit are notoriously

variable (Davies and Winsor, 1969).

In contrast, Petersen and Willumsen (1991) stated that it is possible to increase the sugar content by up to 28 percent and the acid content by 21 percent by raising the salinity of the solution from 2.2 to 4.8 mS cm^{-1}. However, this increase in solution salinity resulted in yield loss of up to 20% in rockwool systems.

There was some evidence of greater resistance to physical damage by fruit grown at 6 dS m^{-1} compared to those grown at lower conductivity levels (Gough and Hobson, 1990). Storage characteristics of fruit from plants grown at salinity levels above normal were not impaired (Gough and Hobson, 1990). Fruit from different salinity treatments showed slightly different rates of pigment formation, with fruit grown at high salinity tending to colour more slowly than those grown at lower salinity levels.

Mizrahi et al (1988) reported that saline-treated fruit (irrigated with sea water) were slightly firmer than control fruit, but deteriorated somewhat faster, and that salinity tended to reduce the percentage of fruit with colour flaws as compared to the control. Mizrahi (1982), had previously reported that fruits of salt exposed plants were redder than those of control fruit as confirmed by pigment concentration measurement. Sharaf and Hobson (1986), also reported that salt treated plants (irrigated with sea water) speeded up the ripening of normal cultivars. It was also found that high salinity partially overcomes the inhibition of ripening that certain mutant alleles induce (Sharaf and Hobson, 1986).

In an earlier investigation by Mizrahi (1982) it was reported that salinity treated fruit (6 g per litre NaCl in half strength Hoagland solution), resulted in higher rates of ethylene and CO_2 evolution during ripening as well as increased activity of pectin methyl esterase, polymethylgalacturonase and polygalacturonase, resulting in a much shortened shelf life.

Mizrahi et al (1988) indicated that salinity may have affected shelf life by two opposing mechanisms. In one case, water loss in fruit from salinated plants was lower than in the

control due to a lower water potential in the fruit, leading to a longer shelf life. In the second case, fruit from salinated plants exhibited increased polygalacturonase activity which enhanced softening and caused shorter shelf life (Mizrahi et al, 1988).

Mizrahi et al (1988) also stated that taste of control fruit deteriorated after 1 and 2 weeks storage, whereas saline treated fruit did not. One of the main effects of salinity increases on the growth of tomato plants is on the dry matter content as a percentage of the fruit fresh weight. Within this dry matter, which is mainly sugars, are increases in titratable acidity, and in the sodium and potassium content of the fruit sap (Gough and Hobson, 1990). Potassium particularly improves visual and compositional fruit quality, generally also reducing fruit size (Gough and Hobson, 1990).

1.8.6 Conductivity level (Solution CF)

Many investigations have shown that an increased concentration of the nutrient solution results in fruits with a higher percentage of dry matter, sugar and acid and consequently a better taste and greater firmness (Petersen and Willumsen, 1991; Mizrahi et al, 1988; Gough and Hobson, 1990). This is the case for both large-fruited tomatoes and cherry tomatoes.

In an investigation by Hobson and Adams (1989), a range of conductivity treatments were applied to cherry tomatoes. Table 1.7 shows the effect of a conductivity of 2.5 compared with 10.0 mS cm^{-1}, on compositional quality of the cherry cultivar Gardener's Delight. This table shows how both fruit sugars and acidity increase with higher conductivity probably as a result of the reduction in water content at 10 mS cm^{-1}. The increase in potassium along with the higher acidity suggests that this ion is playing a role in acidity levels. In a later investigation by Gough and Hobson (1990) cherry tomato fruit in an NFT system were grown with an EC of 3, 5 or 8 dS m-1. The dry matter content, sodium content and titratable acidity of the fruit increased at the higher conductivity levels, but the reducing sugar and potassium contents were less affected. A taste panel revealed a general preference for the 5 dS m-1 fruit (Gough and Hobson, 1990).

Similar findings have been reported for beefsteak and round varieties. For round tomato cultivars (e.g Mercator), analyzed by taste panels in the UK, it was found that the lowest conductivity level tested (4.0 mS cm^{-1}) resulted in significantly lower overall tomato flavour and sweetness. Increases in conductivity made the fruit significantly more acidic (Anon, 1989) (Table 1.8).

Table 1.7. Relation between conductivity of recirculating nutrient solution and fruit composition (Hobson and Admas, 1989)

	Conductivity mS cm^{-1}	
	2.5	10.0
Sugars (g/100ml expressed sap)	3.52	6.21
Titratable acidity (% citric acid)	0.61	0.80
Potassium (meq/100ml expressed sap)	6.40	7.40
Water Content (%)	93.4	89.6

Table 1.8. Round tomato cultivar Mercator, taste panel evaluation of fruit grown at a range of salinity levels (Anon, 1989). Scored on a four-point scale with 1=none, 2=weak, 3=moderate and 4=strong (mean scores for each attribute)

	Conductivity (mScm^{-1})		
	4.0	6.0	9.0
Overall tomato flavour	2.1	2.8	2.6
Sweetness	1.9	2.6	2.6
Acidity	1.9	2.7	3.1

Sonneveld and Welles (1988) found that tomato fruit grown on rockwool at an EC of 3.5 compared to 2.6 mS cm^{-1}, had increased brix levels from 4.8 to 5.0, acids (m $mol.l^{-1}$

in the sap) from 75 to 84 and increased fruit shelf life from 17.5 to 19.2 days. This was also found by Ho and Ehret (1983) who reported that when tomato plants were grown in recirculating solution at EC of 10 mS cm^{-1}, the dry matter content, sugars and potassium increased compared to fruit grown at 2 mS cm^{-1}. Massey et al (1983b) found similar results in a recirculating system. Increasing conductivity from 2 to 10 mS cm^{-1} increased fruit dry matter from 5.7 to 7.0 and reducing sugars from 2.7 to 3.2 g per 100ml of juice. Titratable acidity content of the fruit juices also increased with conductivity from 9.0 to 12.6 meq per 100ml of juice and potassium from 7.3 to 9.2 meq per 100ml of juice (Massey et al, 1983b). In an investigation by Ehret and Ho (1986), tomato plants were grown in an NFT system at conductivities of 2-17 mS cm^{-1}. The percentage dry matter of the fruit and sugar levels were markedly increased by an EC of 10 mS cm^{-1} compared to those grown at 2 mS cm^{-1} (Ehret and Ho, 1986).

An obstacle to improving the sugar content of the tomato fruit via increased conductivity is the inverse relationship between yield and the dry matter content (Ho and Grimbly, 1990). Using cultivation techniques such as increasing conductivity to increase the dry matter content of the fruit also reduces the rate of water accumulation and thus cell enlargement, so that a loss in yield is inevitable (Ho and Grimbly, 1990). Ehret and Ho (1986) reported that the fresh weight of fruit was 40% less at 17 mS cm^{-1} than that of fruit grown at 2 mS cm^{-1}. Massey et al (1983b) found that yield declined progressively with EC over the range 6-10 mS cm^{-1}, and that high quality fruit could only be obtained at the expense of some loss in yield. Massey et al (1983b) claimed a compromise between yield and quality is necessary and an EC of 4 mS cm^{-1} had little effect on yield and improved both dry matter and acidity of the fruit. Sonneveld and Wells (1988) reported that higher EC values (above 2.5 dS m^{-1}) decreased yield by 5 to 7 % per dS m^{-1}. In contrast, Gough and Hobson (1990) working with cherry tomatoes stated that no significant losses in yield were observed until the conductivity reached 8 dS m^{-1}.

With solid growing media, only coarse control over the conductivity levels to which the plants are exposed is usually possible since the substrates drain freely and then dry out between waterings. The only systems in commercial use capable of maintaining salinities within a narrow range throughout the entire life of a crop involve NFT,

rockwool and perlite systems (Gough and Hobson, 1990).

1.8.7 Partial defoliation

The tomato plant is normally trained to a single stem, and some of the lower foliage is removed as the fruit ripens. This process of 'leafing' is sometimes taken to excess, and the possible effects of such treatments have been investigated (Winsor, 1966). Table 1.9 shows the effects of partial defoliation on the content of sugars and soluble solids in the expressed fruit juices:

Table 1.9. The effect of different numbers of leaves on the content of sugars and total solids in the expressed fruit juices (Winsor, 1966)

Treatment	A	B	C	D	E
Leaves retained per truss	1	2	3	all	+2
Sugars g./100ml	3.04	3.29	3.50	3.60	3.79
Total solids g./100ml	3.96	4.14	4.31	4.49	4.68

+2 = one lateral shoot with two leaves retained between successive trusses.

Removal of leaves significantly reduced the content of sugars and total solids in the juices. In further studies it was shown that restricting the number of fruits per truss increased their sugar content. Thus ratio of foliage to fruit has a considerable bearing on fruit composition (Winsor, 1966).

McCollum (1946a) reported an inverse relationship between the amount of foliage and ascorbic acid content. He suggested that exposure of the fruits to sunlight might be an influencing factor.

Hewitt and Stevens (1981), stated that an increase in fruit solids with increasing leaf area would be expected only when the photosynthetic surface is limiting solids accumulation. It has been suggested that in multi truss tomato crops source strength is often a limiting factor in tomato production, although this may be more due to lack of light or CO_2 rather than leaf area (Fisher, 1979).

1.8.8 Fruit and truss position

One factor affecting fruit size and both the dry matter and sugar contents is the position of the fruit on the truss. The largest fruit having the highest dry matter content (and therefore sugar content) are found nearest the main stem, with small fruit towards the end of the truss being inferior (Hobson and Adams, 1989). Sugars are thought to be related to the starch levels built up during fruit growth, and this is influenced by truss position (Richardson and Hobson, 1987).

Benoit and Ceustermans (1987) found that for NFT grown tomatoes, the fruit of the first few trusses were firmest, with little differences being found in later trusses (Table 1.10). However, despite trusses 1 to 9 being harvested in a period from June to August, the detrimental effect of progressively deteriorating seasonal conditions can not be ruled out.

Table 1.10. Effect of truss number on fruit composition for the cultivar Duranto grown in NFT and soil (Benoit and Ceustermans, 1987)

Truss No	Firmness Newtons		Vitamin C (mg/100g FW)		Sugar (Brix) Refractometer (%)		Acid (ml NaOH 100ml)	
	NFT	Soil	NFT	Soil	NFT	Soil	NFT	Soil
1	5.4	4.3	13.5	10.0	4.4	3.7	10.0	7.1
2	5.5	2.8	9.2	11.3	4.4	3.4	8.0	7.0
3	3.2	2.1	14.8	-	3.9	-	6.8	-
7	2.6	1.9	16.7	18.8	3.9	3.7	3.2	3.5
9	2.6	2.6	13.9	-	3.8	-	3.2	-

1.8.9 Light and temperature effects on fruit quality

Light is the chief factor that determines the photosynthetic capability of plants and thus the amount of sugars and dry matter available for the fruit. Poor light results in low sugar and dry matter contents, by limiting photosynthate production (Hobson and Adams, 1989). Sinnadurai and Amuti (1970) reported that the soluble solids of 6 tomato cultivars increased significantly under 16 hour as compared to 12 hour day length, but fruit pH was not affected.

The effect of season is linked to variations in radiation and temperature, both of which can have a major influence on fruit quality. Both temperature and light affect pigment formation of tomato fruit, while soluble solids are known to increase with a reduction in available soil moisture and with periods of high temperatures (Orzolek and Angell, 1975).

It has often been stated that high greenhouse temperatures in summer tend to produce poorer fruit quality and lower yields (Slack et al, 1988). In an investigation by Slack et al (1988), it was found that raising the temperature at which ventilation commenced

by 5°C (i.e from 21 to 26°C) reduced total fruit yield substantially. This reduction in total fruit yield at higher venting temperature resulted in fruit temperatures in excess of the actual air temperature. The temperature as measured at the fruit surface often reached 30°C. In an investigation by Lipton (1970) fruit temperatures of above 40°C were recorded on fruit exposed to the sun at normal humidity (maximum air temperature of 27°C), shaded fruit reached a maximum surface temperature of 28.5°C.

It has been suggested that not only are high air temperatures detrimental to fruit yields and quality but that fruit must also be protected from short-wave radiation if defects in coloration are to be minimized, particularly in areas of high light intensity (Lipton, 1970). Several investigations have reported that a temperature of 23°C as compared to lower greenhouse temperatures results in improved fruit quality. Buitelaar and Janse (1990) reported that the cultivar Calypso grown at 23°C resulted in firmer fruit, improved fruit shape and fruit flavour as compared to lower greenhouse temperatures. Yakir et al (1984) reported that temperatures in excess of 30°C for an average of 9 hours per day resulted in a significant reduction in fruit quality as measured by colour, total soluble solids and acidity. A reduction in fruit pH with low night temperatures towards the end of the harvesting season has been reported by Orzolek and Angell (1975).

It has been found that fruits grown in the shade contain less ascorbic acid, total sugars and total solids than similar fruits that are unshaded (Forshey and Alban, 1954). This was also reported by McCollum (1946b), who found a striking increase in ascorbic acid of unshaded over shaded fruits. Forshey and Alban (1954) also reported that titratable acidity, reducing sugars and total pectic substances all increased with increasing hours of sunlight, indicating that low quality might be due to restricted photosynthetic activity.

1.8.10 Seasonal trends in fruit composition

Successive samples of fruit taken throughout the cropping period usually show certain trends in composition. In the northern hemisphere, acidity was high in July, declining subsequently in late August/September (Winsor 1966). Sugar content of the fruit was low at first, rose to a maximum in July to August and decreased slightly towards the end of the season. Exceptions undoubtedly occur, probably due to prevailing weather

conditions (Winsor, 1966). Fruit quality tends to fall towards the end of the life of the crop and the approach of winter.

In an investigation carried out in the UK, tests on tomato fruit from the Dublin Market indicated that values for sugars acids and conductivity, which are essential for good flavour, were on the low side especially towards the end of the growing season (Gormley and Egan, 1982).

Petersen and Willumsen (1991), found that sugar and acid content of fruit varied according to harvest date. The acid content tended to drop during the season. However, the sugar content was highest in the middle of the season or almost constant. This was also found by Gormley and Egan (1982), who stated that fruit acidity fell significantly as the growing season progressed and this would influence flavour adversely. It was suggested that this fall off in acidity as the season progressed could be reduced by modifying the nutritional programme in order to boost the end of season values. Gormley and Egan (1982) also noted that fruit conductivity values fell during the season and this also suggests a fall off in fruit flavour.

Orzolek and Angell (1975), stated that seasonal variation of 20% in the ascorbic acid content of tomato cultivars can be expected. In fact ascorbic acid in tomato cultivars is irregular and inconsistent and is sensitive to minor variation in the environment, it has however been concluded that the amount of ascorbic acid in tomato fruit was directly affected by sunshine and temperature (Orzolek and Angell, 1975).

Forshey and Alban (1954), found that greenhouse tomato fruits harvested at the end of fall crops deteriorated more rapidly than fruits harvested at the beginning of that crop. With spring crops, the opposite trend was observed (Forshey and Alban, 1954).

1.9 SUGARS/ACIDS/VOLATILES AND SENSORY EVALUATION

1.9.1 Fruit composition and flavour

The organoleptic (taste or flavour), properties of tomato fruits are determined largely by the amount of solids, particularly sugars and organic acids, and the volatile compound composition (Stevens, 1972a). Many volatile compounds have been identified (and many remain unidentified) in tomato fruit and the concentration of certain of these varies among cultivars. It is suggested however, that only a few of the volatiles contribute to the characteristic aroma of the tomato.

Sugars and acids not only contribute to the sweetness and sourness of tomatoes, but are also major factors influencing overall flavour intensity (Stevens et al, 1979). Hobson and Bedford (1989) stated that consumers preferred fruit with a balanced sugar-acid ratio. Fruit sourness, titratable acidity and pH, are all highly correlated with each other (Stevens et al, 1979).

1.9.2 Sensory evaluation of horticultural products

For the consumer, the taste of a fruit or vegetable is of as much importance as the appearance and firmness (Hobson and Bedford, 1989). While some of the quality attributes of horticultural produce such as colour and texture can be measured by objective methods, flavour cannot be measured directly by instruments as it is an interaction between consumer and product (Piggott, 1990). Quality is generally evaluated on the basis of measurements of composition and assessment by taste tests. Although a well defined taste test with experienced panellists can produce very reliable information, it is difficult to compare taste panel evaluations obtained at different times or by different workers around the world (Kavanagh and Mc Glasson, 1983). The reason for this is that these tests are performed under differing conditions with many cultivars and can employ a number of different methods of testing and analysis.

Sensory evaluation involves the measurement, quantification, and interpretation of the sensory characteristics of foods through the use of human subjects acting as judges (Heintz and Kader, 1983). The attributes of a food item tend to be perceived in the following order: appearance, odour/aroma/fragrance, consistency and texture, flavour

(aromatics, chemical feelings, taste). However, in the process of perception, most of the attributes overlap i.e the subject receives a jumble of near simultaneous sensory impressions and he/she will not without training be able to provide an independent evaluation of each (Meilgaard et al, 1986).

1.9.3 The sense of taste and flavour chemistry

The sense of taste is commonly modelled as being composed of four basic components: sweet, salty, sour and bitter. The one missing taste from this model is 'umami' a sensation for which there seems to be no satisfactory word in English, though 'delicious' has been suggested informally. These four (or five) tastes can be relatively easily linked to food components causing them, and hence the perception can be explained. Sweetness in the food is usually due to sugar, though in some cases other materials such as proteins can be involved. However, complications arise when the tastes interact with each other, so it is not necessarily a simple matter of linking flavour notes to compounds or groups of compounds. Inspection of the volatiles in food data shows that many fruits for example contain broadly the same components, yet have quite distinct flavours (Piggott, 1990).

The sensations perceived through the taste buds can be very important components of the flavour of a vegetable, but are really not so important as those sensations which are the result of odoriferous compounds. The materials which are ordinarily responsible for the characteristic flavour of vegetables (and fruit), appear to be ones which are volatilized in the mouth and detected by the olfactory epithdium located in the upper part of the nasal cavity (Hartman, 1954).

Foods contain a wide variety of volatile materials which give rise to a variety of odours when the food is tasted or eaten. The number of volatiles found in any particular food is limited only by the money and skill available to find them (Piggott, 1990).

Like olfactation, gustation is a chemical sense. It involves the detection of stimuli dissolved in water, oil or saliva by the taste buds which are located primarily on the surface of the tongue as well as in the mucosa of the palate and areas of the throat

(Meilgaard et al, 1986). We can only taste differences in the concentration of many substances, not absolute concentrations, as our sensitivity to levels that are lower than those in saliva is low and ill defined.

Therefore flavour includes:

1. The aromatics i.e olfactory sensations caused by volatile substances released from a product in the mouth via the posterior nares.

2. The tastes i.e gustory sensations (salt, sweet, sour, bitter), caused by soluble substances in the mouth.

3. The chemical feeling factors, which stimulate nerve endings in the soft membranes of the buccal and nasal cavities (astringency, spice, heat, cooling, bite etc) (Meilgaard et al, 1986).

1.9.4 The sensory evaluation of tomato fruit

Reducing sugars and acids contribute to the taste of fresh tomatoes but simple measurements of total soluble solids, pH, titratable acidity and electrical conductivity do not provide an adequate measurement of sensory quality. A complex mixture of volatile (aroma) compounds interacts with the sugars and acids to give a characteristic tomato flavour. Since volatile compounds are so important in the flavour of fresh tomatoes, they influence taste panel evaluation. There is no single volatile compound which gives a typical tomato aroma, but instead, a complex interaction of tomato components are involved (Kavanagh and Mc Glasson, 1983).

One consideration however, is the lack of definition as to what quality components are actually reflected in compositional measurements. For example, total soluble solids are used to estimate sugar content, but sugars account for only 60 - 80% of the variation in tomato soluble solids. Similarly, titratable acidity, used to indicate free acid concentrations, has been reported to correlate with potassium or total anion contents and with citric acid, but not malic acid or pH. Several components influence these individual measurements so it is difficult to know which of the tomato constituents

affects eating quality (Kavanagh and Mc Glasson, 1983).

Kavanagh and Mc Glasson (1983) found that the composition measurements for 14 cultivars of tomatoes tested did not appear to closely reflect the sensory quality as determined by a taste panel. In particular, no relationship between the measurements of TSS and eating quality were evident.

Other investigations have found a significant correlation between sensory evaluation scores and compositional analysis. Bisogni et al (1976), found that soluble solids content, locular material content and reduced ascorbic acid content were significant in a multiple linear regression equation for predicting flavour scores, with soluble solids content weighted most heavily. Bisogni et al (1976) stated that while further testing needed to be performed, the significance of this regression demonstrates that these quality measurements may be useful in characterizing tomato eating quality.

Other investigations have also found this type of correlation. Kader at al (1977), found that pH correlated with sourness, the reducing sugar content with sweetness and the volatiles with 'off flavours' in tomato fruit. Stevens et al (1977) reported that large percentages of the variations of sensory attributes could be accounted for by volatile and non volatile components.

Dirinck et al (1976) found that flavour quality of different samples of fresh tomatoes, evaluated by a panel, could be related to the occurrence and concentration of n-hexanal, trans-2-hexenal, cis-3-hexen-1-ol, 2-isobutylthiazole and some unidentified compounds in the fruit's essential oils. Hobson and Bedford (1989) found that the acceptability of cherry tomatoes was found to be closely linked with the total soluble solids content and reducing sugar levels in the fruit. Hobson et al (1976), found that the panellists reacted more favourably towards fruit that were generally high in total solids; reducing sugars and acids. These studies indicate that sensory attributes can be quantified by objective measurements.

Watada (1980) found that sweetness did not correlate with the soluble solids content,

this is in contrast to the findings of Bisogni et al (1976) and Kader et al (1977). However, both investigations analyzed several cultivars that gave a wider range of values for both subjective and objective measurements than did Watada (1980). Therefore the reasons why different investigators are in conflict as to whether compositional analysis is an indicator of sensory evaluation are due to a number of different cultivars being tested, different methods of analysis and sensory evaluation techniques, the growing conditions and maturity of the fruit samples tested.

1.9.5 Volatiles and flavour

Although sugar-acid ratios and concentrations play a major role in flavour quality, attention must be paid to the volatile organic compounds which determine aroma. Dirinck et al (1976) obtained tomato fruit essential oils by steam distillation continuous extraction and by head-space condensation. These volatiles were identified and evaluated organoleptically. It was found that flavour quality of different samples of fresh tomatoes, evaluated by a panel could be related to the occurrence and concentration of n-hexanal, Trans-2-hexenal, cis-3-hexen-1-ol, 2-iosbutylthiazole and some other unidentified compounds.

Dimethyl sulphide and hydrogen sulphide were recognised to be important to 'cooked tomato' flavour. Several compounds have been suggested as being important to fresh tomato flavour: trans-2-hexenal, n-hexanal, cis-3-hexen-1-ol, trans trans 2, 4 decadienal and especially 2-isobutyl-thiazole and cis-3-hexenal (Dirinck et al, 1976).

There are further complications in evaluating the contribution of individual volatiles to overall flavour and sensory quality. For example, in aqueous solution, 2-isobutylthiazole was reported to taste spoiled, vine like, and objectionable, but when added to a tomato product it gave an intense fresh tomato-like flavour. Similarly, other volatiles act unpredictably in combination with tomato components, by for example, improving the mouthfeel, blending out harsh notes, flattening the overall flavour and producing different flavour effects at different concentrations.

Kazoniac and Hall (1970) also carried out investigations into tomato fruit volatiles.

They stated that organoleptic evaluation of the flavours of volatile compounds in fresh fruits and vegetables is very difficult because of the many possible flavour interactions of the compounds. It was found that the volatiles isolated for identification can differ grossly from those present when the fresh fruit or vegetable is actually consumed.

1.10 POSTHARVEST

1.10.1 Changes in fruit composition during ripening on the plant and postharvest

The conversion of a tomato fruit from the mature green stage to fully ripe involves substantial changes in colour, composition, aroma, flavour and texture. Ripening used to be thought of simply as a series of degradative processes, probably because some of the more obvious changes require the action of hydrolytic enzymes. However, it is now clear that ripening is dependent on a wide range of separate synthetic as well as degradative reactions. These include alterations in metabolism and gene expression which have a dramatic effect on fruit quality (Winsor, 1966). The various facets of ripening appear to be coordinated and regulated by plant hormones, modified by genetic and environmental factors.

The changes occurring during development, in general act to determine final fruit quality. For example, colour and composition in fruit are determined during the growth and developmental stages when sugars, acids and pigments are accumulated. These increases in sugars, acids and fruit volatiles all determine the final flavour of the fruit. (Winsor, 1966).

This growth and development stage is followed by ripening and senescence, during which further changes occur, some of which act to reduce fruit quality. These include a drop in the levels of calcium which increases softening and hence fruit firmness. This in turn makes the fruit more susceptible to physical and pathological damage. The changes induced by ripening enzymes and ethylene also act to reduce fruit firmness.

During senescence the fruit quality deteriorates to a stage when it is no longer consumable. This is characterised either by severe shrivelling of the fruit due to excessive water loss, or rotting induced by pathogens or by anaerobic respiration inside

sealed packaging. Senescence is also characterised by the development of a deep red colour, and the eventual collapse of fruit structure.

Tomatoes often show severe losses and damage during handling, transportation and marketing (Morris and Kader, 1986). Losses of fruit between harvesting and their eventual consumption have been put at between 5% for intensively grown crops under protection to 50% for crops grown in the tropics. Therefore it is important that correct handling procedures are implemented to reduce postharvest wastage in the most cost effective way (Hobson, 1988).

1.10.2 Postharvest effects on fruit quality

Tomato fruit quality encompasses a wide range of physical and compositional variables. The tomato fruit is composed of a large number of compounds - sugars, acids, and volatiles, all of which influence the taste component of a particular fruit (Stevens, 1972a). Fruit firmness, shelf life, ripening defects, postharvest damage and physiological disorders all effect the visual and physical appearance of the fruit (Kader, 1986).

Final fruit quality is influenced by a number of interacting factors. Before the crop is even sown, the choice of cultivar has a major influence on the final fruit quality, as can the environmental conditions after planting. Once the crop is planted into the greenhouse a range of cultural and management factors also effect the developing fruit, and play a role in the final quality of the fruit.

Once the fruit reaches the mature green stage, a range of postharvest handling procedures can also have a detrimental effect on fruit quality. Since a harvested tomato is a living commodity subject to continuing changes and rapid deterioration, every effort should be made to maintain fruit quality for as long as possible after harvest (Kader, 1992).

Tomatoes respond to their environment, especially temperatures, relative humidity and composition of the atmosphere. Control of these factors gives the best tool to slow

down deterioration. Since the tomato fruit is mostly water (about 95%) they are therefore subject to physical damage and water loss. Fruit are also subject to pathological breakdown and this will depend upon the quality of the fruit, the environment that exists and the presence of physical injury and of course pathogens (Kader, 1986).

The postharvest handling procedures which influence fruit quality are:

(i) Harvesting at the incorrect stage of maturity.

(ii) Physical injury during harvest, in the packhouse, during transportation and at the point of sale, including cuts, bruises and abrasions.

(iii) Lack of sanitation leading to infection by pathogens.

(iv) Undesirable temperatures resulting in chilling injury or high temperature damage, and delays in precooling or suboptimal precooling, incorrect storage temperatures.

(v) Lack of proper relative humidity control.

(vi) Exposure to ethylene gas.

(Markey, 1991).

It is essential that if a high quality product is to be produced that both the pre and postharvest management of the crop is directed towards maximising and maintaining good fruit quality. Although the grower may be responsible for the initial product, a high percentage of fruit are lost though the handling and transportation procedures after harvest. It is therefore important to not only produce fruit of good quality, but to maintain that quality throughout the distribution chain and at the consumer level in order to meet the increasing demand for better quality produce (Kader, 1992).

1.10.3. Firmness, ripening and shelf life of tomato fruit

During ripening tomatoes show the climacteric pattern of respiration usually observed with fleshy fruits (Workman et al, 1956). Gas exchange of the tomato fruit takes place almost exclusively through the stem scar, the skin being quite impermeable to oxygen and CO_2 (Workman et al, 1956).

The textural quality of tomatoes is influenced by flesh firmness, the ratio between

pericarp and locular tissue, and skin toughness (Kader et al, 1978). Fruit firmness decreases during ripening on the plant, and continues quite rapidly during storage (Winsor, 1966). Softening of fruit during storage may be due to several factors, including loss of moisture, the breakdown of insoluble pectic substances and respiration (Shafshak and Winsor, 1964).

Marked differences in compressibility have been found between varieties (Winsor, 1966). It has also been stated that the firmness of fruits increases with number of locules per fruit (Shafshak and Winsor, 1964), and that high fruit acidity is associated with a high degree of firmness (Davies and Winsor, 1969). Mizrahi et al (1988) reported that increased fruit firmness can be obtained in fruit grown at high conductivity levels which results in less fresh weight (water) to be lost from the fruit, so fruit remains firm longer.

Feigin et al (1980), found that application of 10 - 15% NH_4-N to the nutrient solution markedly increased the percentage of high quality (firm) fruits. This increase in fruit firmness can probably be explained by differences in the chemical composition of the fruit, with the NH_4-N stimulating organic anion synthesis and cation accumulation (Feigin et al, 1980).

Temperature may prove to be the most important of the environmental factors affecting fruit firmness (Winsor, 1966). Sharshak and Winsor (1964), reported that fruits grown at a day temperature of 29.3 °C were 30% softer than those grown at 18.3° C. Heavy watering has also been reported to result in softened fruit, particularly under hot, shaded conditions (Shafshak and Winsor, 1964).

Ayres and Peirce (1960), reported that an increase in the pH of fruit was correlated with excessive softness, darkening or appearance of rot spots, and that storage life was correlated with the percentage of total solids. Fruit with a solids content of 6.7% had a 3 week longer storage life than those with a solids content of 6.0%.

1.10.4 Fruit water loss during storage.

The skin of the tomato fruit is practically impermeable to gases and water vapour, and any exchange of gas in connection with respiration is made almost entirely through the stem scar. Water is lost from the fruit largely due to transpiration and to a lesser extent from respiration (Syamal, 1990).

Since the tomato fruit is largely composed of water, when the weight loss due to moisture evaporation exceeds 5 - 6%, the fruit begins to shrivel and becomes unsalable. Rapid drying occurs if the relative humidity surrounding the fruit drops anywhere below 96% under normal conditions. However, reduction of moisture loss can be achieved by packing fruit in moisture proof films. For this purpose the package must be relatively impermeable to water vapour (Robertson, 1989).

However, there is a limit to the extent of moisture protection that can be provided. If the package is too moisture proof, it can cause sufficient internal condensation to impair the visibility of the product by fogging (Robertson, 1989). Maintaining a high relative humidity in the package can also cause rotting by decay organisms.

A good package should therefore allow, some but not too much vapour transmission. It should also be sufficiently permeable to oxygen to allow normal respiration of the product to continue for as long as possible. The level of oxygen permeability required for this purpose can vary over a wide range, depending on the rate of respiration, which is in turn dependent on the storage temperature.

No film of practically usable thickness has sufficient permeability to carbon dioxide, oxygen and water vapour at normal storage temperatures to prevent anaerobic spoilage of tomato fruit. The necessary permeability therefore has to be achieved artificially either by incomplete sealing or by perforating the film material (Roberston, 1989). The most common method of perforation is to punch holes or perforations according to the weight and the respiration of the fruit.

1.11 SINGLE TRUSS SYSTEM OF TOMATO PRODUCTION

1.11.1 Introduction

Traditionally greenhouse tomato plants are grown as a multi truss crop with the potential for each plant to bear an indefinite number of fruit trusses. This system allows maximum use of greenhouse space and a continuous harvest as successive trusses develop and ripen up the plant.

In the 1960's Dr A J Cooper of the Glasshouse Crops Research Station in the UK led an investigation into a system of single truss tomato production. In this system the plants were stopped two leaves above the first truss so that each plant only produced one truss of fruit. The plants were produced in either a capillary bed system or in tiered troughs and grown at a high density (Cooper, 1961).

The concept behind the development of this system was to produce 3 - 4 crops per year per greenhouse and to also increase the efficiency of tomato production. This increase in efficiency was later defined by Hand and Postlethwaite (1971) as:

1. Being able to provide the optimum environment for each stage of development as single truss plants will all bear fruit of the same age and are not complicated by having multiple trusses of different maturity stages.

Mc Avoy et al (1989a) later stated the potential to control closely and predict crop response and the potential to adapt the crop to existing greenhouse automation were further attractive features of the single truss system.

2. Allow producers to programme fruit production for specific periods of the year when profit margins are greatest.

It is known that market demands place a premium on dependability and continuity of supply, so continuity of production is important for retaining a competitive edge in the market (Mc Avoy et al, 1989a). The single truss system allows winter production when prices are highest to be targeted but production difficulties occur due to low radiation

levels. In response to low photosynthetic photon flux (PPF), tomato production and quality are often drastically reduced in some regions (Cooper, 1961; Mc Avoy et al, 1989b; Hand and Postlethwaite, 1971).

3. Reduce annual labour costs by avoiding the need to train plants up and over cropping wires.

4. Provide better flexibility in cropping, for example, efficient use of such technology as supplementary lighting (Hand and Postlethwaite, 1971).

From a research point of view, the single truss system of production offers further advantages. It allows for a straight forward examination of the source sink relationship of the tomato plant and can also be utilised in investigations into the use of such technology as supplementary lighting, CO_2, nutrition, and temperature on the separate developmental stages of the plant as well as computer modelling of harvest predictions.

Other researchers followed Coopers early work to examine such factors as the effects of light integral and CO_2 (Hurd and Thornley, 1974; Janes and Mc Avoy, 1989; Hand and Postlethwaite, 1971; Mc Avoy et al, 1989; Janes and Mc Avoy, 1991), plant density, and season (Hand and Postlethwaite, 1971), and the temperature response of single truss tomatoes (Lake, 1967; Hurd and Cooper, 1970).

Investigations have also looked at other forms of plant manipulation and source sink relationships of the single truss plant. Thus Cooper (1964a) studied the development of the first inflorescence of the glasshouse tomato and Fisher (1975) examined the effect of the amount and position of leaf tissue on yield. Other research involved the development and validation of a computer model for planning production so that a continuous harvest could be obtained from sequential crops (Mc Avoy et al, 1989b; Giniger and Mc Avoy, 1986; Mc Avoy et al, 1989a; Santos, et al 1992).

1.11.2 The physiology of single truss tomato crops

The relationship between vegetative growth and fruit yield in the tomato is essentially

a source sink relationship, with the leaves as the source and the fruit as the sink for assimilates (Fisher, 1975). The physiology and the source sink relationship of a single truss plant is different to that of a multi truss plant because of the presence of only one truss. Fisher (1977) stated that fruiting on one part of a tomato plant can influence fruiting elsewhere on the plant and that a reduction in yield of a particular truss is due to the presence of subsequent trusses. This reduction in yield caused by subsequent trusses can be ascribed to competition for available assimilates.

The existence of such competition effects demonstrates that yield is being limited by assimilate supply (source strength) (Fisher, 1977). The single truss crop overcomes this competition effect by only producing one truss, thus a higher yield of larger fruit can be expected on the first truss than would normally be obtained in trusses from a multi truss plant.

Slack and Calvert (1977) reported similar findings to that of Fisher (1977). In this investigation it was stated that removing a truss resulted in yield increases on the remaining trusses both above and below the one removed. The possible mechanism for this is that the removal of a truss sink results in apical and basal movement of the available assimilate to the remaining truss. Thus by removing the apical meristem in the single truss crop, we are stopping the development of further sinks which would compete for assimilates with the fruit of the first truss. This assimilate production has proven to depend on the amount rather then position of leaves in the single truss crop (Fisher, 1975). The leaves as producers of assimilates (or source) for fruit production determine fruit growth. Yield has been shown to be related to leaf dry weight (Fisher, 1975). Fisher (1975) suggested that single truss yields could have been increased if more leaves were allowed to develop by later stopping of the plants. It was also stated that to increase yield, the optimal LAI should occur at flowering and be maintained for as long as possible after this.

1.11.3 Nutrition of single truss crops

Adams et al (1973) studied the effects of nitrogen and potassium on the growth of single truss tomatoes with particular emphasis on fruit yield and quality. It was found that the

growth and yield of single truss plants in this trial was determined largely by the concentration of N applied. This study also confirmed the results of Fisher (1969) who found that for tomatoes grown in nutrient culture, the concentration of N applied before initiation of the first truss was of crucial importance in determining the yield. These findings suggest that a high concentration of N in the solution feed would appear to be necessary during the early stages of growth.

Adams et al (1973) found that plant height and leaf length increased markedly with N concentration, as did the number of flowers and marketable fruits per plant, the mean weight per fruit and total yield, and that low N levels delayed harvesting. The proportion of unevenly ripened fruit decreased with increasing concentrations of both N and K. It was also found that the titratable acidity of the fruit juice significantly increased with N concentration, but was little affected by K.

Thus nutrition of a single truss crop allows another opportunity to increase yields and reduce the time to harvest by manipulating the levels of essential elements such as N and K.

1.11.4 Temperature

Lake (1967) examined the effect of combinations of high temperature (17, 20 and 23°C) and low winter light intensity on single truss crops in an investigation aimed at determining the best temperature for each stage of fruit development. It was found that the start of harvest was delayed slightly by high day temperatures in the period before flower initiation, but in subsequent periods high day temperatures greatly advanced the date of harvest (Lake, 1967). Lake (1967) also stated that for commercial production of single truss tomatoes it is desirable to have a short stem and this could be achieved with use of equal day and night temperatures during the period between flower initiation and anthesis.

Temperature may also be used to manipulate flower numbers on the first truss. Increasing single truss flower numbers can be achieved by cooling the plant below the normal growing temperature for a short period during early growth. The resulting plants

tend to have branched trusses with appreciably more flowers then occur on unbranched trusses (Hurd and Cooper, 1970). Hurd and Cooper (1967) found that the flower number in summer could be doubled, but in winter only 30 to 40% increases were obtained from low temperatures applied shortly after pricking off. Chilling delayed anthesis by up to 10 days, with the delay being proportional to the duration of chilling. Day/night temperatures of either 10°C/10°C or 16°C/4°C during chilling had similar effects on flowering, and resulted in similar delays to growth and anthesis (Hurd and Cooper, 1967).

In a later investigation by Hurd and Cooper (1970) it was found that an average temperature of 10°C during early growth increased flower number and resulted in 25% greater yield than unchilled plants. Fruit number was increased, average fruit weight diminished, and thus there were fewer very large fruit of low market value. In this investigation chilling delayed harvesting by 4 days in summer sowings, but had little effect on the duration of the harvesting period (Hurd and Cooper, 1970).

1.11.5 Supplementary lighting

Low winter radiation is the major limiting factor preventing the year round production of greenhouse tomatoes, since winter light is often inadequate for production (Janes and Mc Avoy, 1989b). Mc Avoy et al (1989b) were working in New Jersery which has a latitude of 41° compared to 40° in Palmerston North.

Supplementing the naturally available PPF with additional photosynthetically active radiation (PAR) will alleviate some of the problems encountered during winter tomato production (Mc Avoy et al, 1989b). However, the use of additional lighting is expensive and must result in sufficient yield increases to maximize such an investment.

The use of supplementary lighting on a traditional multi truss crop has the disadvantage that light uniformity is not easy to maintain and since there are many different stages of plant growth and development occurring concurrently, it is difficult to achieve a specific crop response.

Research has shown that similar yields can be expected from tomato crops produced according to both traditional multi truss cropping methods and alternative production methods when lighting is used (Mc Avoy et al, 1989b). The single truss method of production with plants cropped at high densities is one such alternative method.

Mc Avoy et al (1989b) reported the following effects of PPF levels on tomato growth and development:

1. The PPF environment affects both vegetative and reproductive tomato seedling development by influencing the amount of photosynthate available for growth.
2. Changes in vegetative and reproduction development are affected by the PPF environment immediately following seedling emergence.
3. At emergence, high light leads to early rapid canopy development and rapid seedling growth.
4. In response to high light, flower initiation and expression occur at a lower node.
5. High PPF over a full leaf canopy also favours increased yields.
6. High light during flower development and fruit set results in larger ovaries with more locules and a greater fruit set, thereby increasing sink strength.

In the investigation by Mc Avoy et al (1989b), it was found that the effects of increasing the available PPF were rapid canopy development, good fruit set, and a steady net carbohydrate flux from the source leaves. As a result of these findings it was possible to develop an equation which predicted yields based on expected natural radiation and supplementary lighting, so that a schedule could be developed to produce a continuous yield throughout the year.

In a further study by Janes and Mc Avoy (1991), it was found that the date of harvest was inversely correlated with the amount of light the crop received during the seedling phase of growth, while fruit weight was positively correlated with light during the production phase. It was also found that the most effective period for the addition of supplementary lighting was between 15 and 45 days after flowering.

Mc Avoy et al (1989b) stated that by varying the sowing dates based on available PPF,

a number of crop blocks can be accurately timed to produce a continuous supply of fruit. This type of prediction model was further developed by Janes and McAvoy (1991), who stated that by using expected light inputs, expected plant responses and a desired production starting date, it was possible to schedule a series of overlapping crops that will provide nearly continuous production during the growing season with an expected yield for each crop. Therefore the singe truss production method allows not only efficient use of supplementary lighting by applying it only to those growth stages which will benefit the most, but PPF levels can be used as the basis of a model to predict harvest dates and yields so that production can be accurately scheduled.

1.11.6 CO_2 enrichment of single truss crops

As with supplementary lighting, single truss plants provided a relatively convenient means of studying the response of greenhouse tomatoes to CO_2 supplementation since investigations of multi truss plants are complicated by the presence of many different growth stages. Hand and Postlethwaite (1971) found that CO_2 enrichment advanced the date of first anthesis, promoted earlier cropping and shortened the duration of harvest for single truss tomatoes sown in winter and to a lesser extent for those sown in summer. It also prevented arrested development of flowers in the winter sown crop due to low light levels. It was further found that increases in total marketable fruit weight caused by CO_2 resulted from an increase in the number of fruits attaining marketable size and an increase in the average weight for individual fruits. These suggest that increased CO_2 levels result in more efficient conversion of incident light energy to chemical energy when days were longer or additional lighting supplied. Thus there exists the potential to further manipulate single truss plant growth with the combination of supplementary lighting and CO_2 enrichment.

1.11.7 Yields obtained from single truss crops

Although no data is available for single truss crops grown in New Zealand, overseas researchers have reported that the quantity of fruit produced from single truss cropping over a 12 month period is similar to that of conventionally grown tomatoes (Mc Avoy et al, 1989b).

Mc Avoy et al (1988, 1989) reported average yields of 700g per plant with a range of 250 -850 g/plant in single truss crops produced in the USA, at a density of 12 plants per square meter. Cooper (1979) reported yields of 100-800 g/plant depending on season in the first single truss trials carried out in the UK (density was not stated). In a single truss trial in Japan, Kobayashi (1992) produced yields of 60-80 tonnes per hectare at a plant density of 130 000 plants per hectare with production of 5 crops per year. Lake (1967) reported yields of 30 tons per acre at a spacing of 12" by 12" allowing paths of 20% of the growing area. Lake (1967) claimed yields of 45 tons per acre could be obtained if the need for paths was eliminated.

A density of approximately 12 plants per square meter is commonly used in single truss investigations (Mc Avoy et al, 1989a; Giniger and Mc Avoy, 1986; Roberts, 1988). One investigation cropped single truss plants at densities of 10 and 25 plants per square meter where it was found that 25 plants m^2 produced 41% less marketable yield then 10 plants m^2 under UK conditions (Hand and Postlewaite, 1971).

Thus the annual yields of single truss crops are determined by the density per square meter and the number of crops grown a year per greenhouse. It must also be considered how this yield is divided into first and second class fruit, reject fruit and different size grades.

Mc Avoy et al (1989b), stated that the removal of the apical meristem from the plant prior to anthesis reduced the competition between sink organs during fruit development favouring fruit set and development. As a result more assimilates are available for the single truss and the fruit attains a larger size than fruit from a plant with multiple trusses competing for these assimilates. Lake (1967), stated that in the January grown single truss crop, most of the fruits were too large for the best market grades.

Yield per square meter of available growing area is also determined by the percentage of area in actual production and that assigned to path space. A fixed bench system with paths around each bench for crop access utilises between 59 and 70% of greenhouse space (Aldrich and Bartok, 1992). Moveable bench systems which utilise 90% of the

growing area have been developed for single truss crops at Rutgers University in the USA (Kabala and Giacomelli, 1989). The concept of a movable bench system is to convert all but one aisle to growing space. Access to crops is created by rolling aside neighbouring benches creating a temporary aisle (Kabala and Giacomelli, 1989). The moveable bench system maximised greenhouse space utilisation, allowed more plants to be grown and produced a higher yield.

1.11.8 Modelling of single truss crops

Giniger and Mc Avoy (1986) working at Rutgers University in the USA developed a model for computer simulations of single truss cropping systems. This model was further investigated and validated by Mc Avoy et al (1989a), Giniger (1988) and Santos et al (1992).

The simple planning model using accumulated radiation was produced by Giniger and Mc Avoy (1986) for the management of single truss tomato production systems (McAvoy et al 1989a). Being able to schedule individual crops to meet desired harvest periods and predicting crop yields were the two most important functions of this model which was based on crop response equations developed from data obtained from 20 single truss crops.

The model assumed that the time required for a tomato to develop following flowering would remain constant. The timing of flowering then governed when cropping would occur. Using this, by accurately scheduling anthesis, the timing of harvest could be controlled. Individual crops were scheduled by predicting the number of days required for an emerging seedling to reach anthesis with the following equation.

(1) $D = 86 - (0.09X)$

Where D = days to anthesis, and X = PPF (mol/m^2) available at canopy level between seedling emergence and anthesis (McAvoy et al 1989a).

In this model Mc Avoy et al (1989a) assumed that:

1. Photosynthetically active radiation (PAR) was available daily
2. Day/night set points were 21/17°C

3. Initial fruit harvest would occur 45 days after anthesis
4. The period of time from seedling emergence to anthesis was between 35 and 38 days and
5. A 14 day harvest interval for each crop

The final harvest date was used as a reference point for determining the cropping schedule in this model. From this, the assumed 45 day fruit development and 14 day harvest periods were subtracted to establish the date of anthesis. The PPF available prior to anthesis was then totalled and entered into equation (1) to generate a predicted time interval from seedling emergence to anthesis (Mc Avoy et al 1989a).

Finally, the model subtracted two days from the date of emergence to identify what date osmotically primed seeds were to be sown so that the seedlings would emerge on the date specified by the model.

To predict fresh weight fruit yields the total PPF available from anthesis until the fruit reached maturity were used. The following equation was used for the fresh weight production.

(2) $Y = (0.82 X) - 194$

where Y = yield in g/plant and X = PPF in mol/sq m available at canopy level between anthesis and harvest of mature fruit (Mc Avoy et al 1989a).

This model allowed a cropping schedule that resulted in a continuous harvest of tomatoes with the use of sequential crops from single truss plants. This resulted in a prediction model that was impossible to accurately develop for multi truss crops.

Santos et al (1992) further developed this model to predict yield under a wide range of environmental conditions which proved accurate based on field experiments.

CHAPTER 2

THE EFFECT OF PLANTING DATE, SOLUTION CONDUCTIVITY AND CULTIVAR ON THE FRUIT QUALITY OF MULTI TRUSS TOMATO CROPS

2.1 INTRODUCTION

In the past, tomato producers directed crop management towards obtaining the highest possible yields from their crops. However, over recent years there has been an increasing demand for quality produce. This is now of particular importance as strong competition has developed on the domestic market as a result of Australian fruit imports and larger volumes of fruit are being exported overseas. One aspect of fruit quality is flavour. Research has shown that with hydroponic systems increased conductivity can be used to improve fruit quality including flavour (Petersen and Willumsen, 1991; Gough and Hobson, 1990; Hobson and Adams, 1989). A measure of flavour in tomatoes can be determined by estimating the sugar (Brix) content and the acid content (Hobson and Kilby, 1984). However, flavour cannot be measured directly by instruments as it is an interaction of consumer and product (Piggott, 1990). Overall fruit quality needs to be evaluated in terms of compositional fruit tests and assessment by sensory evaluation. Sensory evaluation involves the measurement, quantification and interpretation of the sensory characteristics of the fruit through the use of human subjects acting as judges (Heintz and Kader, 1983). One objective of the present study was to examine the relationship between analytical compositional fruit quality assessment and sensory evaluation scores.

In order to obtain the volume of fruit required for such an evaluation, multi truss crops were grown in a pumice based hydroponic system at a range of conductivity levels. The objective was to determine the effect of conductivity, cultivar and season on the compositional, organoleptic and keeping quality of the fruit produced.

To meet these objectives, three distinctly different tomato cultivars were grown from 3 successive plantings over a 12 month period, with three solution conductivities. This multi truss experiment differed from the single truss NFT cropping system as plants

were grown in a pumice media with nutrient solution applied several times daily.

2.2 MATERIALS AND METHODS

2.2.1 Cultural

Seeds were sown into seedling trays containing a seed sowing media (Appendix 1), and germinated on a heated propagation bed at 18 - 20°C in a temperature controlled greenhouse. After 7 days seedlings were pricked out into 100 mm plastic pots containing a standard media (Appendix 2). Seedlings were grown on in a greenhouse with a minimum temperature of 16 °C via the heating system with ventilation at 22°C. At the appearance of the first inflorescence they were transplanted into PB 18 planter bags containing a course pumice media. Plants were grown in double rows at a density of 2.2 plants per square meter. A standard nutrient solution based on that recommended by Tregidga et al (1986) (Appendix 3) with an EC of 2 mS cm^{-1} was applied a number of times daily to the pumice media. At each watering sufficient solution was applied for a 5 - 10% loss to drainage to occur.

The nutrient solution was applied to each plant via an emitter and excess solution drained to waste. Frequency of irrigation was increased with plant size from 5 times daily at planting to 12 times daily at maturity of the third truss.

All laterals were removed as they developed and the plants were stopped after the production of the 7th truss at the height of the top wire. A truss vibrator was used to assist pollination.

The details of the three crops or planting dates are provided in Table 2.1. In this experiment the various plantings will be designated by the month in which the 5th and 6th trusses were harvested and quality assessment carried out.

Table 2.1 Multi truss tomato crop - significant dates

Crop	Sowing date	Planting date	Flowering 5th truss	Month of harvest/quality assessment of 5th and 6th trusses
1	12/5/92	26/06/92	25/08/92	October 1992
2	2/09/92	6/10/92	15/11/92	December 1992
3	23/12/92	12/01/93	3/02/93	March 1993

2.2.2 Treatments

Three cultivars and three conductivities were combined factorially at each of the 3 planting dates to provide 9 treatments. The three conductivity treatments were applied from the time of setting of fruit on the first truss.

The three cultivars were:

Rondello - a standard commercial variety producing fruit of approximately 110g,

Ophir - a beefsteak variety with a fruit size of 200g,

Cherita - a cherry type with a fruit of approximately 30g.

The three conductivity treatments were:

2 mS cm^{-1}

4 mS cm^{-1}

6 mS cm^{-1}

A standard nutrient formula (Appendix 3) was used for all conductivity treatments. Conductivity was raised by increasing the amount of macro elements. Trace elements remained at normal levels to avoid the risk of toxicity problems caused by high levels of micro elements. Treatment solutions were applied using 2 tanks (A and B solutions) of stock solutions and associated diluters.

2.2.3 Experimental design

The 3 cultivars were combined factorially with the 3 conductivities to give 9 treatments. A complete randomized block design was used with each cultivar having a row of 7 plants for each of the conductivity levels. There were 2 replications, with each replication being a separate greenhouse.

2.2.4 Data collection

2.2.4.1 Fruit dry matter percentage

Fruit from the 4th and 5th trusses free from blemish, and of the 50 - 60mm size grade were used for fruit quality assessment. Samples of 15 fruit per plot were weighed before being cut into quarters and placed in an oven (60 - 80°C) for a minimum of 48 hours, or until completely dehydrated. The dry weight of each sample was then determined and percentage dry weight calculated.

2.2.4.2 Brix

Fruit samples as for fruit dry matter calculation were collected and frozen before Brix assessment. Samples were defrosted at room temperature and then put through a juicer. The resulting extract was left to settle for one hour. A few mls of the clear extract was then placed on the refractometer plate for brix assessment. Three brix readings from each sample were taken and averaged.

2.2.4.3 Titratable acidity

Titratable acidity assessment was determined on an extract prepared for the brix determinations. A 1 ml sample of the clear fraction of the tomato juice was added to 60 ml of distilled water. This was then titrated with 0.10 N solution of NaOH until an endpoint of pH 8.1 was reached. These titrations were carried out using a Metler automated titrator. Three titrations were carried out on each fruit sample. Titratable acidity (ml NaOH) was later converted to percentage citric acid by the following formula.

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

2.2.4.4 Shelf life

Fruit samples from each plot were selected from the 5th and 6th trusses for shelf life assessment. Fruit were harvested at the breaker stage (green/orange), when the fruit were showing the first external signs of colour change. Samples consisted of 20 fruit of the size grade 60 - 70 mm for Rondello and Ophir, over 20 g for Cherita and free from defects. Fruit were washed in cold water, dried and each individual fruit numbered and weighed.

Each sample was placed in a shallow cardboard tray (not touching each other) and then placed into the shelf life room. The shelf life room was maintained at a constant temperature of 20°C. Humidity was maintained as close to 80% as possible. Each shelf life room had a small opening for ventilation to prevent excessive build up of ethylene produced by the ripening fruit.

Fruit were examined daily to determine when the end of acceptable shelf life was reached. As each fruit reached unacceptable market maturity - that is over ripe, dark red, soft and/or evidence of rots, it was removed from the sample.

2.2.4.5 Fruit firmness

Fruit samples in the 60 - 70 mm size grade and free from defects and blemishes of the cultivar Rondello were selected from each plot during the March harvest for firmness assessment. The Massey Firmness meter (developed at Massey University) was used to nondestructively evaluate fruit firmness. Firmness due to skin and flesh resistance of mature (red) fruit was determined. This instrument measures the deformation of the fruit surface over a period of time when a 100g weight was applied via a probe. Measurements (taken 200 times a second) are fed, via a software programme directly into a portable computer, which calculates the softness value and the r^2 value of the reading.

The instrument's probe was positioned over the locule area of each fruit in order to

avoid striking the locule wall surface which would result in a firmer reading. Two determinations on each fruit were made.

2.2.4.6 Sensory evaluation

Sensory evaluation via a trained taste panel was carried on each of the three plantings. Preliminary selection of taste panellists took place in September 1992. 25 staff and students from the Massey University Plant Science Department were invited to attend a panel selection session. This was to determine those people who had the greatest ability to discriminate between tomato samples. Prospective panellists were given three sets of three tomato samples and asked to select the odd sample out. Within each set of three samples, one had been altered by the addition of either sodium chloride (0.1%), sucrose (1.0%) or citric acid (0.01%). This allowed a determination of those panellists that could determine differences in all three flavour components. After analysis of a triangle test, the eight panellists who scored the greatest number of correct answers were asked to participate in fruit evaluation sessions.

All panellists were given details of the main constituents of tomato fruit flavour and the attributes they would be asked to evaluate. Equal numbers of male and female panellists were selected to prevent any bias caused by differences in taste preferences.

Before each tasting session, panellists were retrained to remind them of what attributes they were evaluating. Each was provided with tomato samples to which sodium chloride, sucrose or citric acid has been added to allow a reminder of how each attribute appears to taste in a fruit sample.

Fruit samples of the cultivar Rondello for each tasting session were selected from the 5th and 6th trusses of each conductivity treatment. Fruit were washed, dried and diced into 1 cm cubes after the removal of the blossom and stem ends. Dicing allowed each judged sample to be a composite of several fruits and also to be representative of all the morphological regions of the fruit. It also retained enough intact tissue to represent a

sample prepared for consumption.

A taste panel room was established in a quiet location, and the panellists were isolated from each other via partitions to prevent communication. Surfaces of the partition were painted white and samples masked with red lighting to prevent irregularities of colour influencing the panellists evaluation of each sample. Samples were presented in white containers divided into three sections, labelled A, B and C. Water was provided for panellists to rinse between each sample.

Cubed fruit samples from each conductivity treatment were randomly assigned to be labelled either A, B or C. Panellists were asked to score each sample for the attributes of sweetness, saltiness, acidity, firmness and tomato like flavour intensity. Scoring was carried out by panellists placing a mark on a line scale from 1 to 50 (Figure 2.1) for each sample. Although panellists had been trained to recognise what sweetness, saltiness, acidity were in terms of tomato sample, the firmness and tomato like attributes were left to the preference of the individual panellist. Firmness was determined by texture and resistance to compression in the mouth. Tomato like flavour intensity was entirely determined by the panellists view of what constituts a high flavoured tomato.

Scores for each sample were determined by measuring the distance along the line marked by the panellist. Mean values for each tasting session (for each planting) were calculated. As expected, using human subjects resulted in variation between panellists, and in particular between the tasting sessions which were carried out 3 months apart.

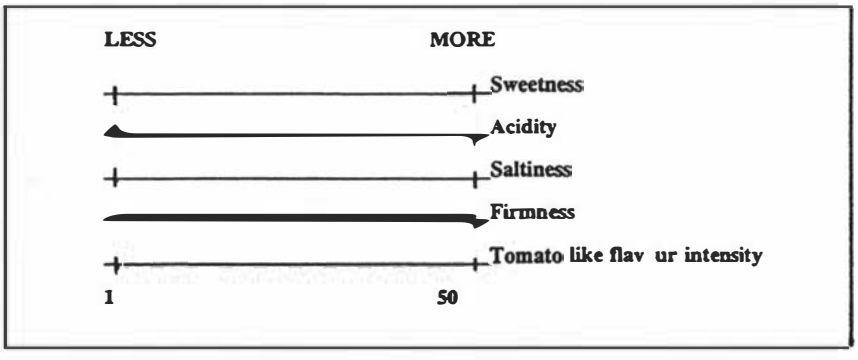


Figure 2.1 Taste Panel score sheet

2.2.4.7 Plant measurements

After full expansion of the leaf subtending the 5th truss, a sample of leaf tissue (a 2 cm^2 section of leaflet) from each plant in each conductivity x cultivar treatment was removed and bulked up for foliar mineral level analysis. Leaves were dried for 3 days at 60°C and finely ground before analysis.

2.2.4.8 Data analysis.

An ANOVA was carried out on the compositional fruit quality data. All three crops were examined collectively for the effect of conductivity, cultivar and season on fruit percentage dry matter, brix, titratable acidity, shelf life and firmness. As the sensory evaluation is a subjective process, it was not appropriate to compare the scores from the three separate evaluation dates due to the time lapses between each session. For the sensory evaluations, means from all panellists were calculated for each attribute.

2.3 RESULTS

2.3.1 Effect of planting date, solution conductivity and cultivar on fruit percentage dry matter, brix and titratable acidity

2.3.1.1 Effect of planting date, solution conductivity and cultivar on fruit percentage dry matter

Planting date, conductivity and cultivar all had a significant effect on fruit dry matter percentage (Table 2.2). The December harvested crop resulted in the greatest fruit dry matter percentage (Figure 2.2), while increasing solution conductivity increased fruit dry matter (Figure 2.3). Cherita was the cultivar with the highest dry matter level, while Ophir had the lowest (Figure 2.4).

Table 2.2. The effects of planting date, solution conductivity and cultivar on fruit dry matter percentage, brix and titratable acidity

	Fruit dry matter %	Fruit brix	Titratable Acidity % citric acid
Planting date	*	**	ns
Solution conductivity	**	**	ns
Cultivar	***	***	***
Planting date x conductivity	ns	*	ns
Planting date x cultivar	ns	***	ns
Conductivity x cultivar	ns	ns	ns
Planting x conductivity x cultivar	ns	ns	ns

* Prob < 0.05
** Prob < 0.001
*** Prob = 0.0000
ns = not significant

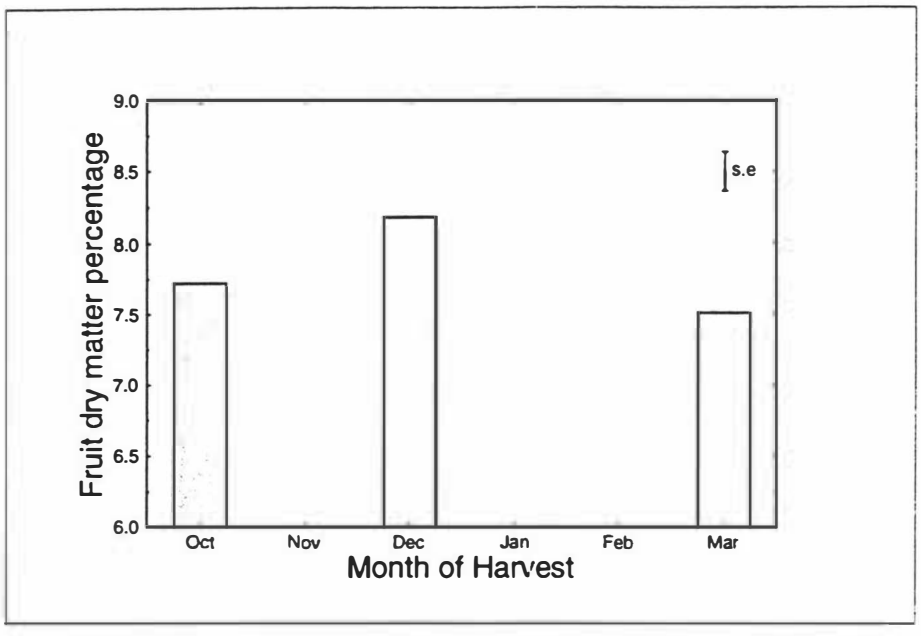


Figure 2.2 Effect of planting date on fruit dry matter percentage

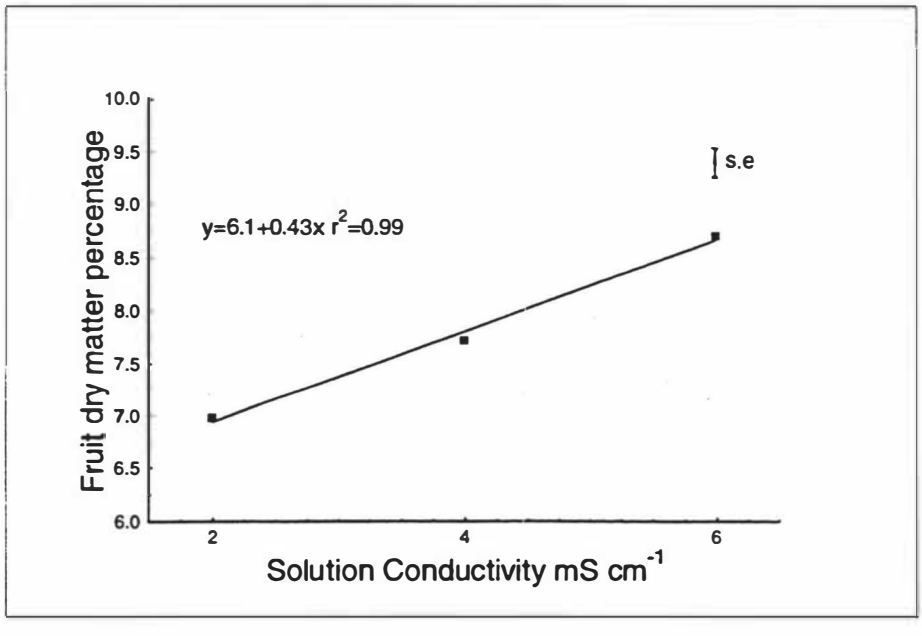


Figure 2.3 Effect of solution conductivity on fruit dry matter percentage

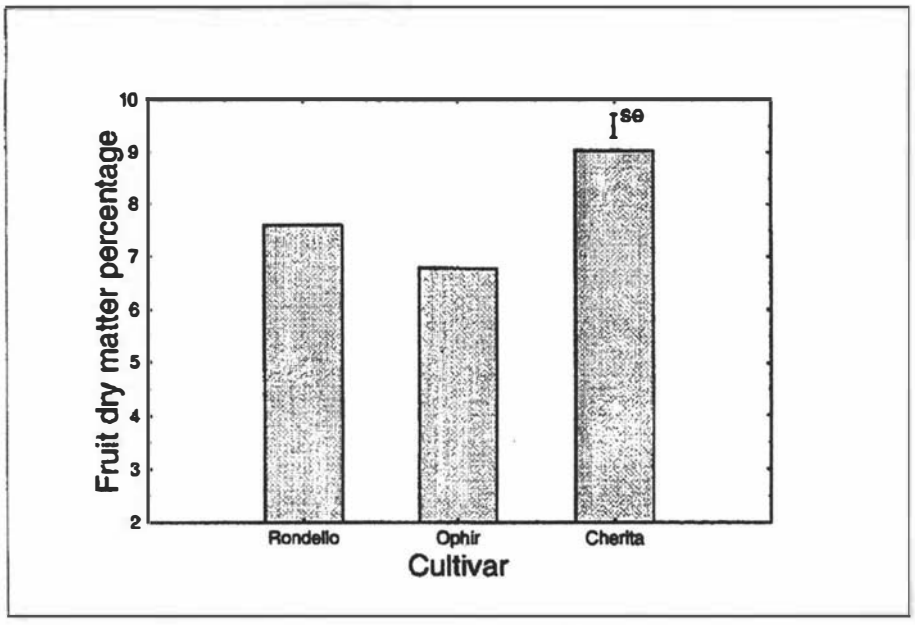


Figure 2.4 Effect of cultivar on fruit dry matter percentage

2.3.1.2 Effect of planting date, solution conductivity and cultivar on fruit brix

There was a planting date x conductivity interaction for fruit brix (Table 2.2). The December harvested crop had a lower brix level compared to the October and March harvested crops, with relative positions of the October and March crops being reversed at the lower and high levels of conductivity. With all plantings fruit brix increased with increasing conductivity (Figure 2.5)

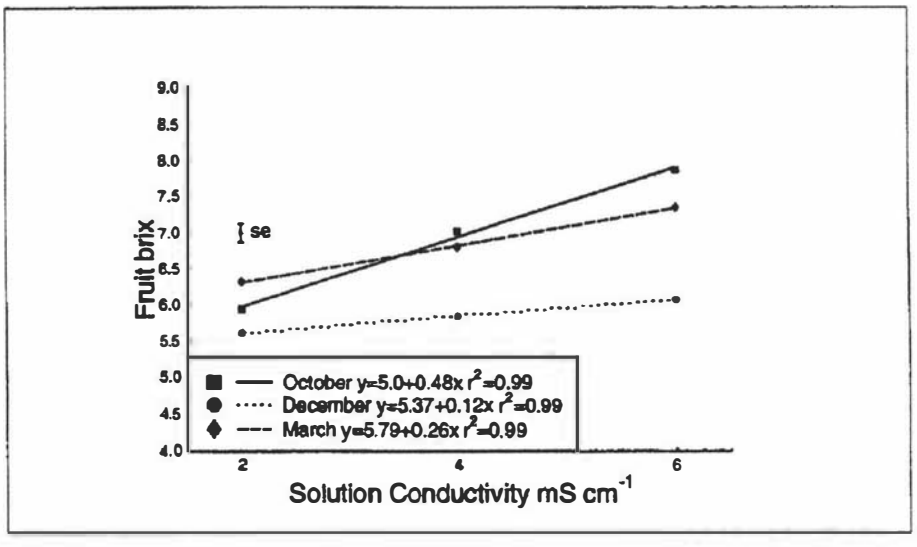


Figure 2.5 Effect of planting date and conductivity on fruit brix levels.

There was a planting date x cultivar interaction for fruit brix (Table 2.2). The effect of season on fruit brix levels for the three cultivars is presented in Figure 2.6. With Cherita brix levels were always high and did not vary greatly with season. In October the levels of all cultivars was similar but in December and March the brix levels for Rondello and Ophir were lower than for Cherita. The relative positions for Rondello and Ophir differed in December and March.

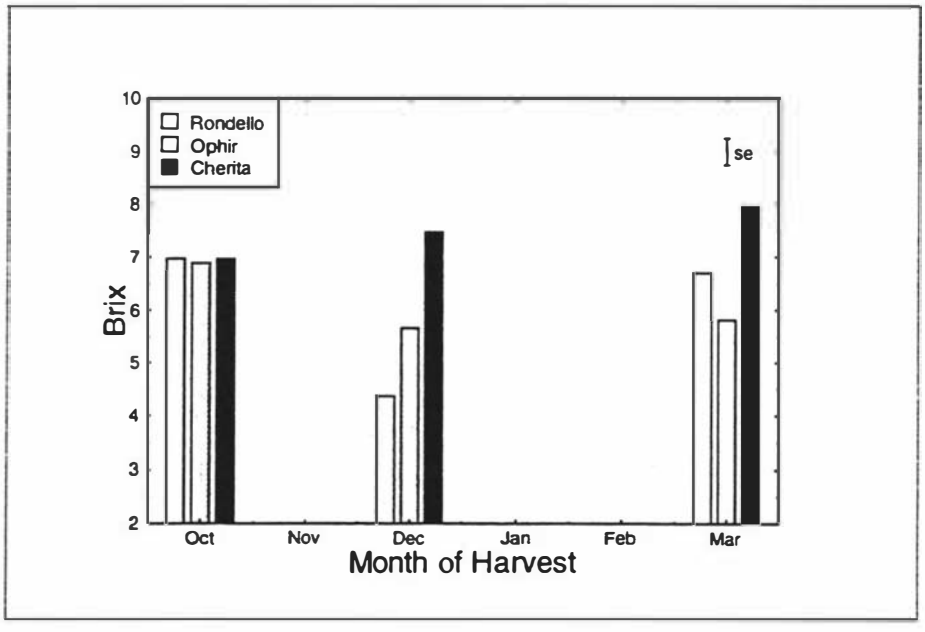


Figure 2.6 Effect of planting date and cultivar on fruit brix.

2.3.1.3 Effect of cultivar on fruit titratable acidity

Cultivar had a significant effect on fruit titratable acidity levels (Table 2.2) expressed as percent citric acid. Cherita had the greatest titratable acidity level, while Rondello and Ophir had similar acidity levels (Figure 2.7).

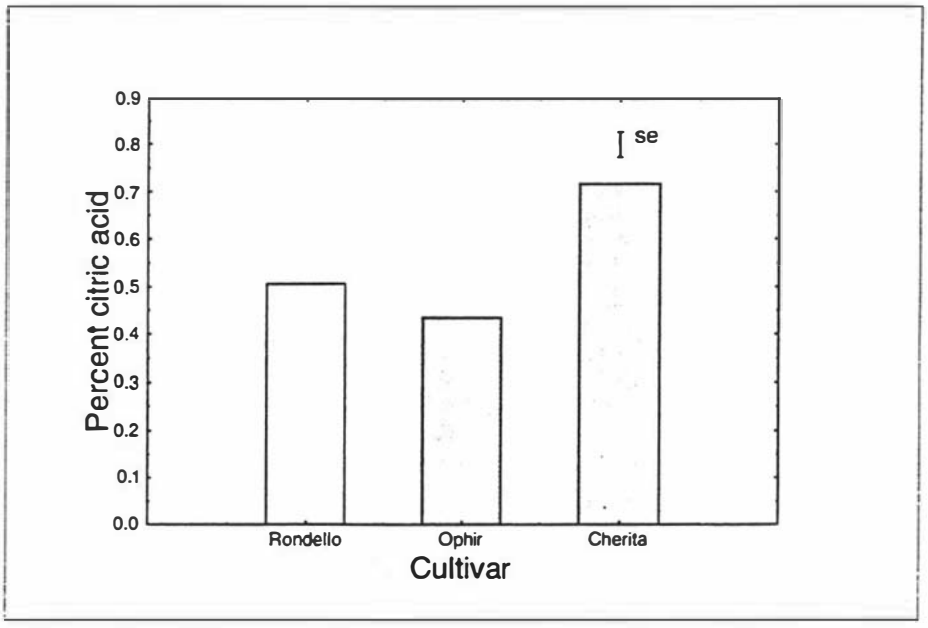


Figure 2.7 Effect of cultivar on fruit titratable acidity levels (Percent citric acid)

2.3.2 Effect of planting date, solution conductivity and cultivar on fruit shelf life and firmness

2.3.2.1 Effect of planting date, solution conductivity and cultivar on fruit shelf life

There was a planting date x conductivity interaction for fruit shelf life (Table 2.3). Shelf life increased with conductivity with the December planting having the lowest shelf life (Figure 2.8). The relative position of the other two plantings was different with the lower and higher levels of conductivity.

Table 2.3. The effect of planting date, conductivity and cultivar on fruit shelf life and firmness

	Shelf life (Days)	Fruit firmness
Planting date	**	ns
Solution conductivity	***	**
Cultivar	**	ns
Planting date x conductivity	*	ns
Planting date x cultivar	**	ns
Conductivity x cultivar	ns	ns
Planting x conductivity x cultivar	ns	ns

* Prob < 0.05
** Prob < 0.001
*** Prob = 0.0000
ns = not significant

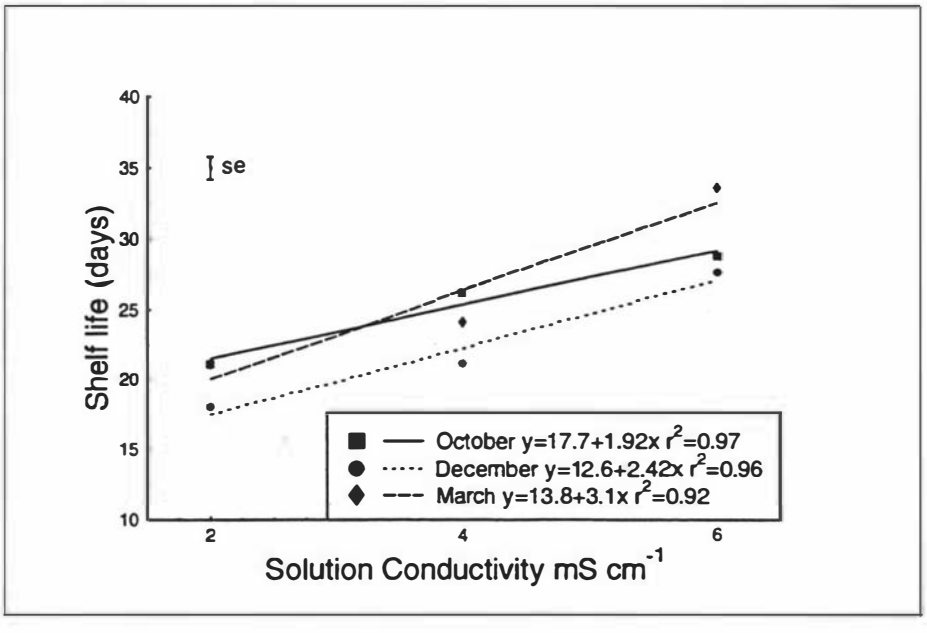


Figure 2.8 Effect of planting date and conductivity and planting on fruit shelf life

There was a planting date x cultivar interaction for fruit shelf life (Table 2.3). Cherita had the longest shelf life irrespective of season (Figure 2.9). Ophir had the lowest shelf life in the October harvested crop.

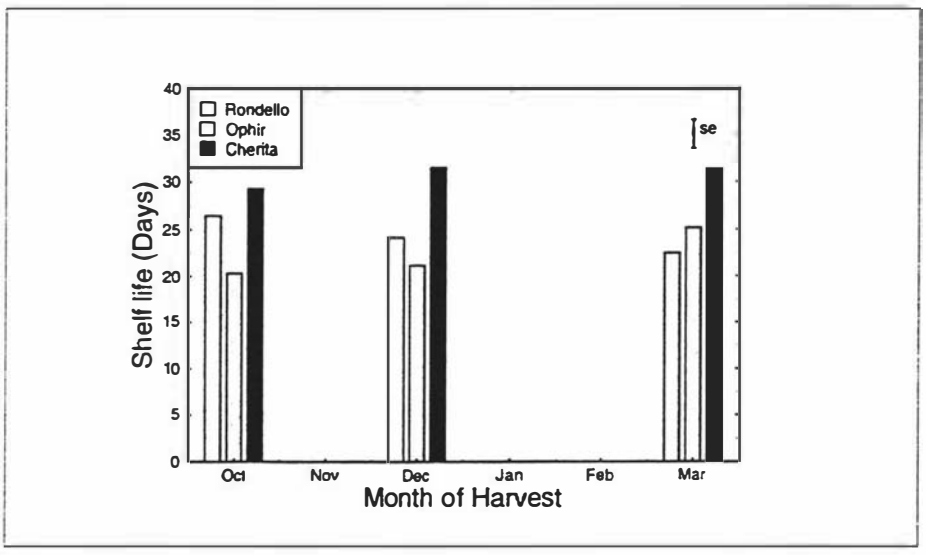


Figure 2.9 Effect of planting date and cultivar on shelf life

2.3.2.2 Effect of solution conductivity on fruit firmness

Solution conductivity had a significant effect on fruit firmness (Table 2.3). Fruit firmness for the cultivar Rondello increased at the highest conductivity level as denominated by a lower firmness reading (Figure 2.10).

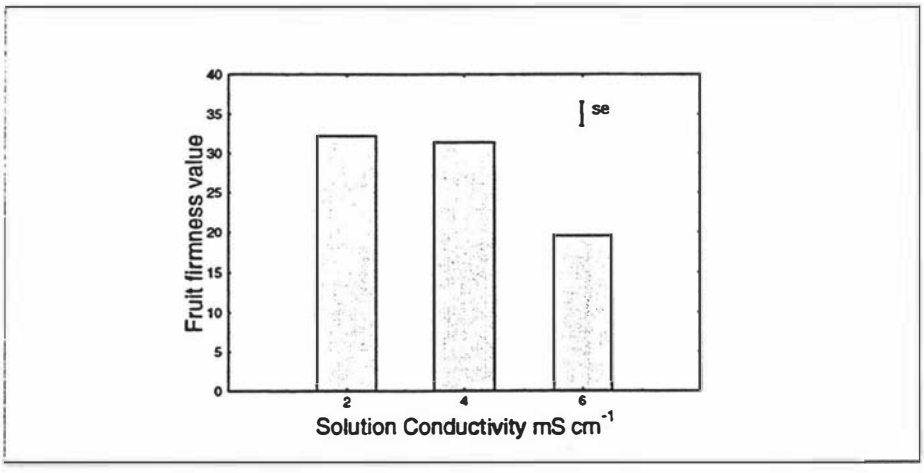


Figure 2.10 Effect of solution conductivity on Rondello fruit firmness (March harvest)

2.3.3 Effect of planting date and solution conductivity on sensory evaluation

2.3.3.1 Introduction

The results of the sensory evaluation for each harvest date are presented in Figures 2.11 (a), (b) and (c). As sensory evaluation is a subjective process it is not appropriate to compare the scores from the three separate evaluation dates due to the time lapse between each session. All taste scores from each panellist were combined for each fruit attribute (total of 8 - 9 trained panellists per evaluation).

2.3.3.2 Effect of planting date and solution conductivity on sensory evaluation

The sensory evaluation scores for the fruit attributes of sweetness, acidity, saltiness, firmness and tomato like flavour intensity for the October harvested crop are presented in Figure 2.11 (a). This evaluation consisted of fruit from only the 2 and 6 mS cm^{-1} conductivity treatments as not enough fruit was available at maturity from the conductivity 4 mS cm^{-1} treatment. For all attributes, apart from the tomato-like attribute, the 6 mS cm^{-1} conductivity fruit ranked higher than the 2 mS cm^{-1} treatment.

The sensory evaluation scores for the December harvested crops are presented in Figure 2.11 (b). For all attributes the 2 mS cm^{-1} conductivity scored lowest, and 6 mS cm^{-1} the highest apart for acidity where conductivity 4 mS cm^{-1} had the highest score and the tomato-like attribute where the 4 and 6 mS cm^{-1} treatments had similar scores.

The sensory evaluation scores for the March harvested crop are presented in Figure 2.11 (c). As with the other two evaluations, the 2 mS cm^{-1} conductivity sample scored the lowest for all attributes. The conductivity 6 mS cm^{-1} treatment resulted in the highest score apart from the tomato like attribute where all conductivities returned similar scores

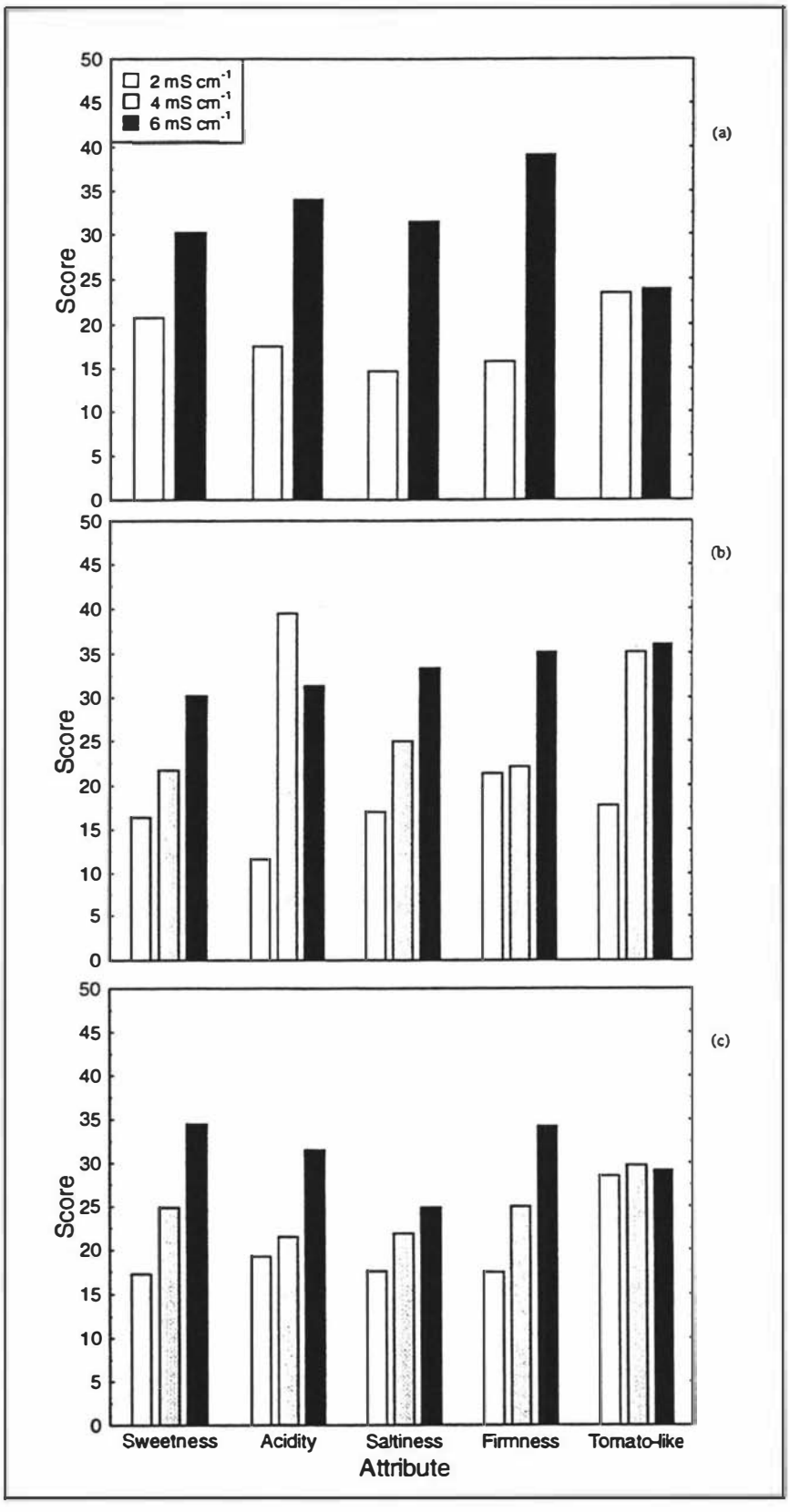


Figure 2.11 Effect of solution conductivity on sensory evaluation scores for the October (a), December (b), and March (c) harvested crops

2.3.3.3 Correlation between analytical compositional analysis and sensory evaluation scores

The correlation between the fruit Brix levels and the Sweetness sensory evaluation score for the 3 conductivity levels is presented in Figure 2.12. This data is for the cultivar Rondello. Both the sensory evaluation score for sweetness and the analytical Brix levels increase with conductivity.

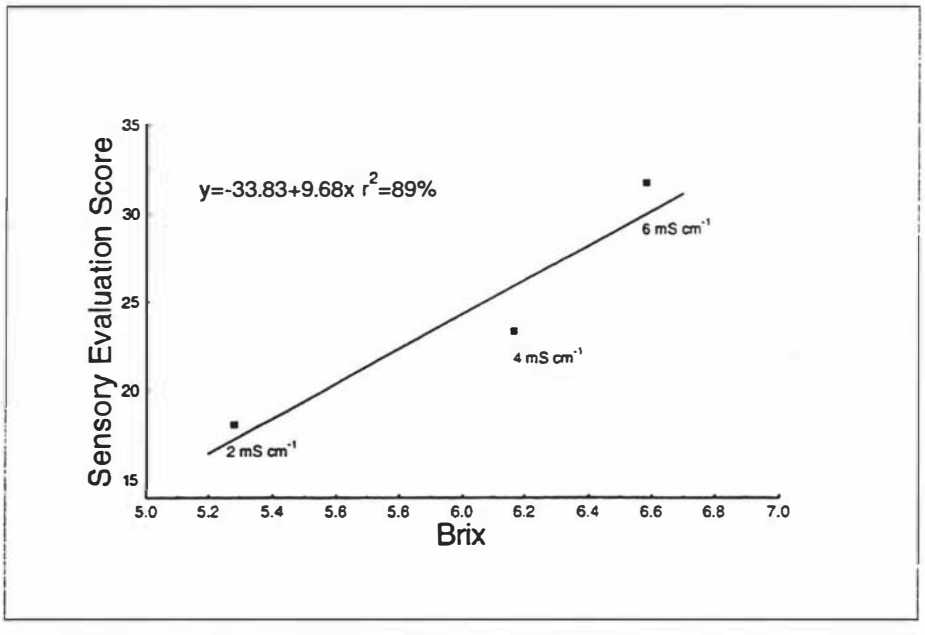


Figure 2.12 Correlation between the effects of solution conductivity on brix levels and sweetness sensory evaluation score.

The correlation between the fruit titratable acidity levels and the acidity sensory evaluation score for the 3 conductivity levels is presented in Figure 2.13. As with the Brix and sweetness scores, both titratable acidity and the acidity attribute increase with conductivity.

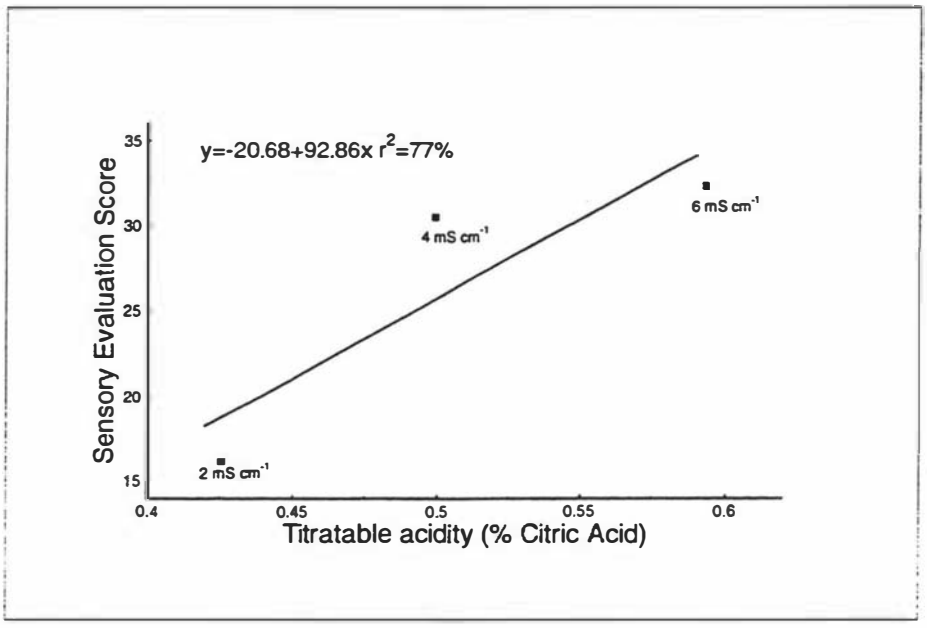


Figure 2.13 Correlation between the effect of solution conductivity on fruit titratable acidity levels (percent citric acid) and acidity sensory evaluation score.

2.3.4 Effect of solution conductivity on leaf mineral leaves

There was no apparent seasonal trends for any of the elements N, K or Ca. Leaf tissue element levels of N, K, and Ca and are presented in Figures 2.14 (a), (b) and (c) respectively. N and K levels increased with conductivity whereas Ca decreased.

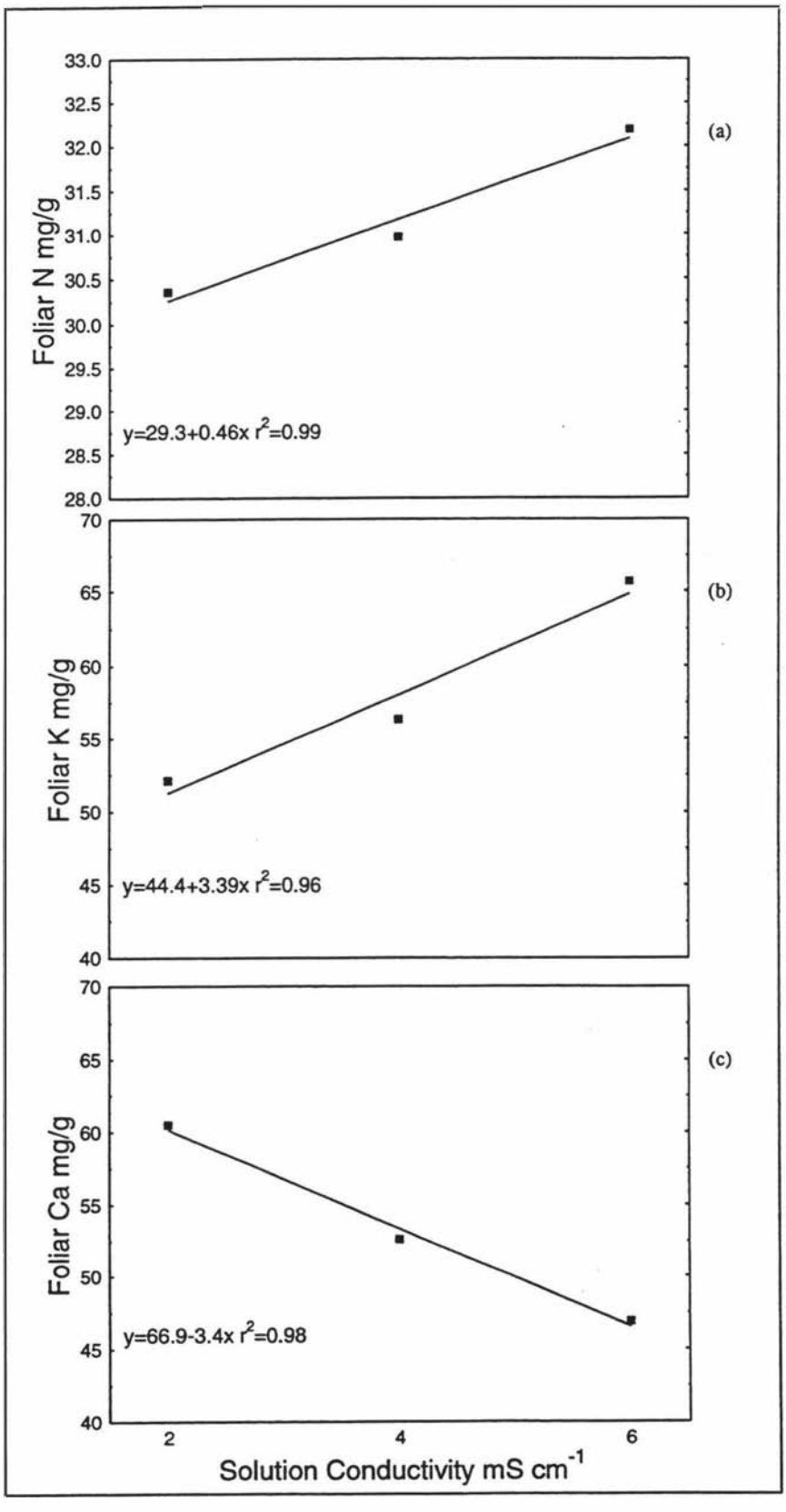


Figure 2.14 Effect of solution conductivity on foliar N (a), K (b), and Ca (c) levels

2.4 DISCUSSION

2.4.1 Effect of planting date, solution conductivity and cultivar on fruit quality

2.4.1.1 Effect of planting date on compositional fruit quality

Fruit composition is influenced by a number of environmental factors. Radiation levels, water stress, leaf area, temperature and rate of photosynthesis all affect compositional fruit quality (Ho and Grimbly, 1990). Brix and percentage dry matter are related not only to the amount of solar radiation and therefore rates of plant photosynthesis, but also to the rate of respiration which utilises reserves. Sinnadurai and Amuti (1970) reported that the soluble solids of 6 tomato cultivars increased significantly under 16 hour as compared to 12 hour day length. The high fruit dry matter percentage obtained in the December harvested crop (Figure 2.2) can be attributed to increased reserves due to greater rates of photosynthesis over the summer months. However if temperatures are high, although a plant may have sufficient light for a high level of photosynthesis, plant reserves may be depleted by the increased rate of respiration. This has been shown by Slack et al (1988) to occur in tomato plants and may account of the drop in fruit brix levels in the December harvested crop (Figure 2.6). However, in the December crop the increased dry matter percentage and reduced brix levels are difficult to explain since we would normally expect a close relationship between these two.

Season affected the Brix levels for the three cultivars differently. Chertia shows a constant increase in Brix from the October harvested through to the March harvested crop (Figure 2.5), which is the expected trend, as increasing levels of solar radiation increase fruit sugar levels (Forshey and Alban, 1954). Rondello and Ophir however, showed the reduction in Brix for the December harvested crop which may be a result of increased respiration rates during December.

2.4.1.2 Effect of solution conductivity on compositional fruit quality

Increasing solution conductivity raised both fruit percentage dry matter and Brix levels (Figures 2.3 and 2.5), while having no significant effect on titratable acidity (Table 2.2). Improved fruit compositional quality in terms of dry matter and Brix is a result of the high osmotic potential of the nutrient solution at the higher conductivity levels,

increasing the concentration of the phloem sap entering the fruit, and reducing the accumulation of water by the fruit. As a result the fresh weight of the fruit is reduced at higher conductivity levels, while the dry matter stays constant, or may even increase slightly (Ho and Grimbly, 1990).

2.4.1.3 Effect of cultivar on compositional fruit quality

Cultivar has a significant effect (Table 2.2) on all the components of compositional fruit quality. Fruit percentage dry matter (Figure 2.4), brix (Figure 2.6) and titratable acidity (Figure 2.7) were all significantly different between the three cultivars. In all cases, the cultivar Cherita had the highest fruit compositional quality values (Figures 2.4, 2.6, 2.7). It has long been known that cherry cultivars have higher sugar and acid levels than normal fruited cultivars (Hobson et al, 1976; Hobson and Kilby, 1984; Hobson and Bedford, 1989; Bezar, 1989). The varieties - Rondello and Ophir had similar fruit compositional values, with Ophir, the larger fruited cultivar being slightly lower than Rondello. This demonstrates that there are genetic variations in fruit quality components of cultivars grown under identical conditions. This was also found by Davies and Winsor (1969), who stated that fruit of tomato varieties grown under comparable conditions can differ markedly in acidity. They suggested that the fruit walls show considerably lower acidity than the locular contents, so large fruited varieties such as Ophir might be expected to show relatively low acidity and smaller fruited cultivars (i.e Cherita) would produce higher acidity.

2.4.2 Effect of planting date, solution conductivity and cultivar on fruit shelf life and firmness

2.4.2.1 Effect of solution conductivity on fruit shelf life and firmness

Increases in solution conductivity increased shelf life by 5 - 10 days over the range 2 - 4 mS cm^{-1}. There are seasonal differences with the March harvested crop showing the greatest response to conductivity level (Figure 2.8). Fruit firmness was also improved at the highest conductivity levels (Figure 2.10). The most likely explanation for both the increased shelf life and firmness is that the higher percentage dry matter of the fruit grown at the higher conductivity levels means there is less fresh weight (water) to be lost from the fruit, so fruit remains firm longer (Mizrahi et al, 1988). Differences in

skin structure or thickness can not be held responsible for fruit firmness as microscopic examination revealed no changes in the epidermis with conductivity level.

Another possibility is that the fruit grown at the higher conductivity values would have received a higher level of nutrition and fruit with a higher nutritional status may remain firm longer.

2.4.2.2 Effect of planting date and cultivar on fruit shelf life

There was a planting date x cultivar interaction with respect to shelf life (Table 2.3). The cultivar Cherita consistently produced fruit with the longest shelf life - often in excess of 25 days (Fig 2.9). Rondello had an average shelf life of approximately 22 days, and Ophir 19 days. These cultivar differences in shelf life can be explained partly by the dry matter levels of the fruit as reported by Richardson and Hobson (1987). Cherita having the greatest fruit percentage dry matter also had the longest shelf life.

Planting date had no effect on the shelf life of Cherita and apart from the October planting where Rondello recorded its highest level of shelf life the shelf life of these two cultivars was not affected by season.

2.4.3 Effect of planting date and solution conductivity on fruit sensory evaluation

When considering fruit quality attributes the human sensory system varies greatly between people. It is less difficult to determine differences in the concentration of sugars and acids than it is to detect 'saltiness' which is masked by the dominant sugar/acid ratios. Fruit firmness is not a chemical sensation but a textural attribute and 'tomato like' flavour intensity involves a complex mixture of volatile compounds (Kavanagh and Mc Glasson, 1983).

The results from the first sensory evaluation session (Figure 2.11), showed that the trained panellists could detect differences between the two conductivity samples for all attributes except 'tomato-like' flavour intensity. Even though panellists detected greater sugar, acidity, saltiness and firmness in the 6 mS cm^{-1} conductivity sample, these

attributes did not constitute a greater tomato like score. This could be due to the fact that a large number of volatiles also affect this attribute, with no single volatile compound giving a typical tomato flavour (Kavanagh and Mc Glasson, 1983).

The most noticeable difference between the two fruit samples in the October evaluation was for fruit firmness. This firmness evaluation is a measure of the amount of force required by the panellist to reduce the fruit sample to a pulp. The higher firmness attribute scores for the sensory evaluation correlate well with the fruit firmness test data shown in Figure 2.10.

The results from the December and March sensory evaluation sessions (Figures 2.11 (b) and (c)), include a sample of 4 mS cm^{-1} conductivity fruit. The inclusion of 3 conductivity fruit samples meant panellist took a greater length of time before scoring each sample, but could still detect flavour differences. It is apparent that there is a marked increase in each attribute between 2 and 6 mS cm^{-1}, and this was also generally true for the 4 mS cm^{-1} conductivity.

From the analytical tests on the same fruit samples it was determined the Brix, fruit dry matter percentage and firmness all increased with conductivity (2.3.1.1, 2.3.1.2 and 2.3.2.2). These three sensory evaluation sessions have shown that the increase in fruit quality with conductivity is of a significant magnitude to improve the flavour of the fruit as determined by human subjects. This conclusion was supported when the analytical quality data was compared with the sensory evaluation scores (Figures 2.12 and 2.13). This type of relationship between taste panel scores and analytical quality assessment has been reported by a number of researchers. Bisogni et al (1976), and Kader et al (1977) both found that soluble solids content and reducing sugar content correlated well with sweetness flavour scores. Hobson et al (1976) found that panellists reacted more favourably towards fruit that were generally high in total solids; reducing sugars and acids. These studies indicate that some sensory attributes can be quantified by objective measurements. In this study the sweetness and acidity attributes correlated well with brix and titratable acidity values (Figures 2.12, 2.13).

2.4.4 Effect of solution conductivity on foliar mineral levels

Foliar N and K levels increased with conductivity, while Ca decreased. Foliar Mg and P levels neither increased or decreased with conductivity.

In general nutrient uptake and accumulation is influenced by a number of factors. The uptake of N and K is closely related to light intensity and air temperature and are also highly correlated with water uptake (Adams, 1987).

It has been consistently reported that the uptake of N increased with the level of N in solution (Winsor and Massey, 1978). The increased N and K foliar levels at higher solution conductivities was likely to be a result of greater concentrations of these elements in the nutrient solution. The data presented in Figure 2.14 is in agreement with several researchers. Adams and Grimmett (1983) found that the total uptake of potassium by tomato plants increased with the concentration of K in the recirculating nutrient solution. Sonneveld and Welles (1988) stated that with increasing EC values, K contents of the leaves were increased and the Ca and Mg contents were decreased. Adams et al (1973) found that the K content of the leaf increased markedly with the N concentration of liquid feeds. The N rather then the K treatment generally controlled both the K content of the leaves and the total uptake of this element.

The most interesting effect of increasing conductivity is on the foliar levels of Ca (Figure 2.14(c)), which fall considerably with the higher conductivity levels. This has been reported by many researchers (Adams, 1986; Adams, 1987; Tachibana, 1991), who are in agreement that the total uptake of Ca by plants can be depressed by 85 - 88% at high salinity levels (17 mS cm^{-1}), even if this was achieved by adding high levels of Ca and K nitrates to a basic nutrient solution (Adams, 1986).

It has also been found that blossom end rot susceptible cultivars grown in high EC solutions develop a lower density of xylem vessels. Since Ca travels in the transpiration stream through the xylem, this has a significant effect on the Ca nutrition of the entire plant (Anon, 1987). This is supported in the findings of Tachibana (1991) who stated

that increased salinity of the rooting medium was also inhibitory to the upward translocation of Ca from roots to shoots in tomato plants.

Apart from the overall influence of salinity on Ca uptake and translocation, there is the possibility of specific ion inhibition of Ca uptake. Fisher (1967) found that interference in the Ca nutrition of the tomato plant was a major specific ion effect of the cations K and Mg, with the sodium ion exhibiting this tendency to a lesser extent.

It can therefore be concluded that not only is the general increase in conductivity causing a reduction in Ca uptake and translocation, but the higher concentrations of other elements, notably K, N and Mg may also be having an inhibitory effect on Ca nutrition.

CHAPTER 3

THE EFFECT OF SEASON, SOLUTION CONDUCTIVITY AND CULTIVAR ON THE YIELD AND QUALITY OF SINGLE TRUSS TOMATO CROPS

3.1 INTRODUCTION

The single truss system was first proposed by Cooper (1964b) in the U.K. In this system the plants are stopped two leaves above the first inflorescence so that each plant only produces one truss of fruit. The plants were produced in either a capillary bed system or in tiered troughs and grown at a high density (Cooper, 1964b). The concept behind the development of this system was to produce 3-4 crops per year per greenhouse and attempt to increase the efficiency of tomato production. Although some research was carried out into nutrition in peat media (Adams et al, 1973), treatments to increase flower number (Hurd and Cooper, 1967, 1970) and the effects of carbon dioxide (Hand and Postlethwaite, 1971), further development of the system did not take place. This was probably because yield over a 12 month period did not compare to multi truss crops, possibly due to poor performance over the winter period. More recently work in the USA has re-evaluated the single truss system, concentrating on developing methods to achieve continuous and predictable yields with a moveable bench system (Fischer et al, 1990). This research also involved an examination of the effect of supplemental photosynthetic lighting (Mc Avoy and Janes, 1989; McAvoy et al, 1989b), and the development of a computer model to plan and predict single truss yields (Giniger et al, 1988; Mc Avoy et al, 1989a).

There is always room for innovative ideas in horticulture. This is particularly relevant in New Zealand where the greenhouse tomato industry is under pressure from Queensland imports (Anon, 1990) and to meet the demands of supermarkets for bulk quality lines. The industry is responding to this pressure by going "high tech" to increase production. It seemed therefore timely to reassess the single truss system in a climate where cropping is possible over the winter months. The NFT system of production was selected not only because of its potential to control the below ground environment and so increase yields, but also because high conductivity nutrient solutions

can be applied to manage fruit quality in a way not possible with a multi truss crop, where fruit trusses are present at widely different stages of development at the one time.

This experiment had 2 objectives:

1. To determine the yield of the single truss tomato system over a 12 month period in New Zealand.
2. To examine the relationship between solution conductivity and fruit quality over a 12 month period.

To meet these objectives, three distinctly different tomato varieties were grown with 6 successive plantings over an 18 month period, using four solution conductivities.

3.2 MATERIALS AND METHODS

3.2.1 Cultural

Seed was sown into rockwool propagation blocks or seedling trays containing a seed sowing media (Appendix 1). The standard seed sowing media replaced the use of rockwool after the third sowing because of a possible boron toxicity problem in the rockwool.

Seeds were germinated on a heated propagation bed at 18 - 20°C in a temperature controlled greenhouse. After 7 days seedlings were transplanted into large (100 mm) rockwool cubes, or 100 mm plastic pots containing a standard media (Appendix 2). A nutrient solution based on that recommended by Tregidga et al (1986) (Appendix 3) with an EC of 2 ms cm^{-1} was applied daily to plants grown in rockwool cubes.

Seedlings were grown on in a greenhouse until the appearance of the first inflorescence when they were planted into the NFT system. Rockwool cubes for the first 3 plantings were placed in the NFT gullies (Plate 3.1). Seedlings in plastic pots had the base cut from the pot before being placed in the NFT system. NFT gullies were covered with black plastic film to prevent light penetration and algae growth. Plants were grown in an environment with a minimum temperature of 16°C via the heating system with ventilation at 22°C.

Plate 3.1 Seedlings 1 day after planting into the NFT gullies

Plate 3.2 Single truss crop at the 50% fruit set stage

All laterals were removed as they developed and the plants were stopped at the second leaf above the first inflorescence (Plate 3.2). A truss vibrator was used to assist pollination. Plants were supported by tying the stem to a wire placed above the NFT gulley. There were 9 plants per 2.8 m NFT gulley with a bench consisting of six gullies, each gully 280mm apart (Figure 3.1). This provided a density of 12.9 plants per m^2.

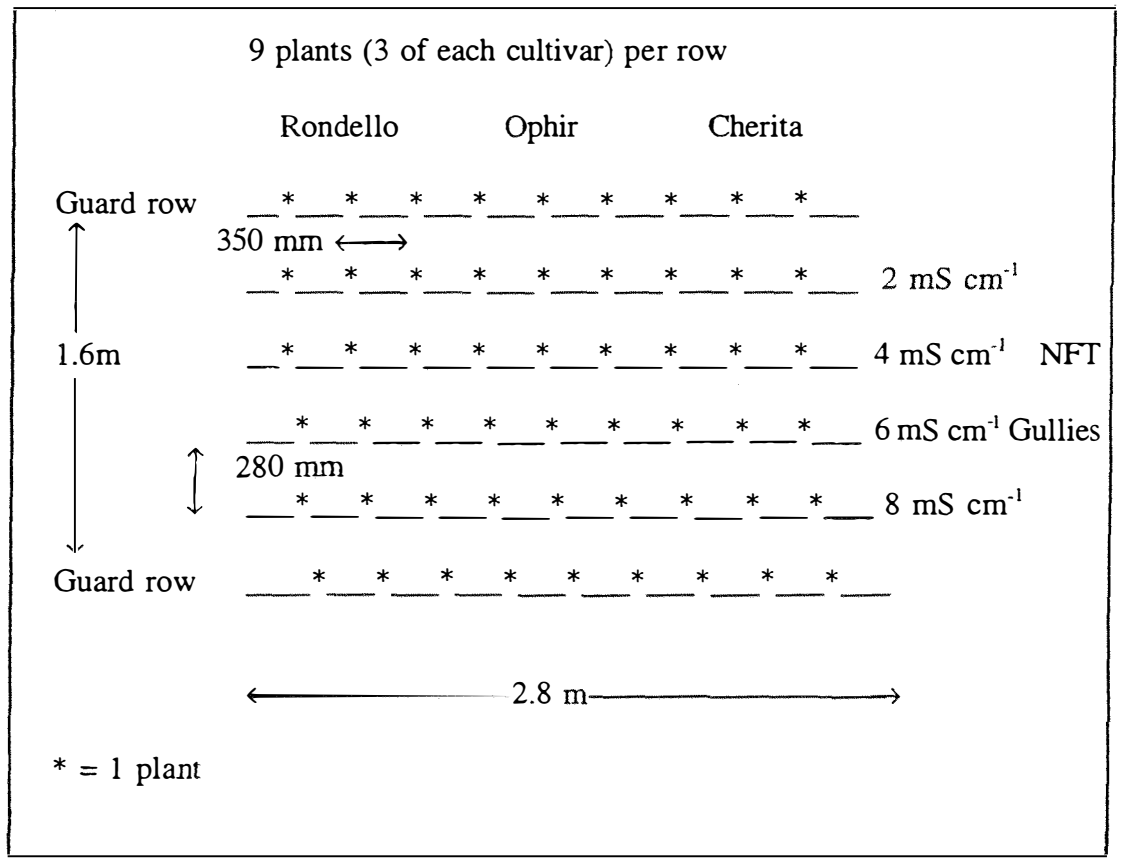


Figure 3.1 Example of an NFT bench

3.2.2 Treatments

Three cultivars and four conductivities were combined factorially at each of the 6 planting dates to provide twelve treatment combinations. At each planting a split plot design was used with the 4 conductivities as the main plots and the cultivars as the sub plots. There were three replications, each consisting of a bench of 6 gullies (Plate 3.3). The four central gullies contained the conductivity treatments, while the two outside gullies were guard rows. Each row (NFT gulley) consisted of 9 plants, 3 for each of

the 3 cultivars.

The three cultivars were:

Rondello - a standard commercial variety producing fruit of approximately 110g,

Ophir - beefsteak variety with a fruit size of 200g

Cherita - a cherry type with a fruit of approximately 30g.

The four conductivity treatments were:

2 mS cm^{-1}

4 mS cm^{-1}

6 mS cm^{-1}

8 ms cm^{-1}.

These were applied from the time of the setting of the first fruit, prior to that a single conductivity of 2 mS cm^{-1} was applied to all plots (Plate 3.4). A standard nutrient formula (Appendix 3) was used for all conductivity treatments. Conductivity was raised by increasing the amount of macro elements. Trace elements remained at normal levels to avoid the risk of toxicity problems caused by high levels of micro elements.

The solution level in each of the four treatment tanks was adjusted daily and the conductivity and pH adjusted. pH was corrected with either phosphoric acid or potassium hydroxide to a level of 5.5 - 6.5. Conductivity was increased by the addition of small amounts of concentrated stock solutions, or lowered with the addition of water. Nutrient solutions were replaced every three weeks to prevent any imbalances in nutrient levels. Between each crop the NFT system was disinfected with a 10% chlorine solution then rinsed with water. Guard rows received 2 mS cm^{-1} solution and had their own holding tank. Rena C40 pumps were used in each of the 5 tanks.

The details of the six crops and the planting dates are provided in Table 3.1. In this experiment the various plantings will be designated by the month in which the majority of the fruit was harvested.

Plate 3.3 Single truss crop showing bench system and nutrient lines

Plate 3.4 Plants at the time of conducivitiy treatment application

Table 3.1 Single truss tomato crop - important dates

Crop	Sowing	Planting	1st anthesis	1st harvest	Final Harvest	Month of Harvest
1	12/5/92	24/6/92	13/7/92	14/9/92	17/10/92	Sept
2	7/7/92	27/8/92	8/9/92	28/10/92	24/11/92	Nov
3	1/9/92	12/10/92	20/10/92	8/12/92	6/1/93	Dec
4	2/10/92	29/11/92	15/12/92	26/1/93	23/2/93	Feb
5	23/12/92	22/1/93	15/2/93	5/4/93	27/4/93	April
6	1/3/93	2/4/93	19/4/93	2/7/93	26/7/93	July

3.2.3 Data collection

3.2.3.1 Yield

All crops were harvested 3 times weekly at the orange-red stage of maturity. Fruit from each plant was harvested and weighed separately. The harvesting period was 3 - 5 weeks depending on the season (Table 3.1).

On harvests three to five, fruit of 50-60 mm diameter for Rondello and Ophir and for Cherita fruit free from blemish and of a weight greater then 20g, were selected for quality assessment (Section 3.2.3.2 - 3.2.3.3). For each cultivar 15 fruit from each sub plot (conductivity x cultivar) were collected and frozen for later assessment of brix and titratable acidity (percent citric acid).

3.2.3.2 Brix

Fruit samples were defrosted to room temperature and put through a juicer. The resulting extract was left to settle for one hour. A few mls of the clear extract was then placed on the refractometer plate for brix assessment. Three brix readings from each sample were taken and averaged.

3.2.3.3 Titratable acidity

Titratable acidity assessment was determined on an extract as for the brix fruit samples. A 1ml sample of the clear fraction of the tomato juice was added to 60ml of distilled water. This was then titrated with 0.10 N solution of NaOH until an endpoint of pH 8.1 was reached. These titrations were carried out using a Metler automated titrator. Three titrations were carried out on each fruit sample and averaged. Titratable acidity (ml NaOH) was later converted to percentage citric acid using the following formula.

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

3.2.3.4 Plant measurements

After full expansion of the second leaf above the first truss, a sample of leaf tissue (a 2 cm^2 section of leaflet) from each plant was removed and bulked up for foliar mineral level analysis. Samples consisted of 9 (one from each treatment plant) $2cm^2$ leaf portions for each conductivity x cultivar treatment. Leaves were dried for 3 days at 60°C and finely ground before analysis.

At the completion of an experiment leaf area measurements on a sub sample of leaf tissue were carried out on one randomly selected plant from each sub plot.

3.2.3.5 Data analysis.

An ANOVA was carried out on the data. All six crops were examined together for the effect of season, solution conductivity and cultivar on crop performance.

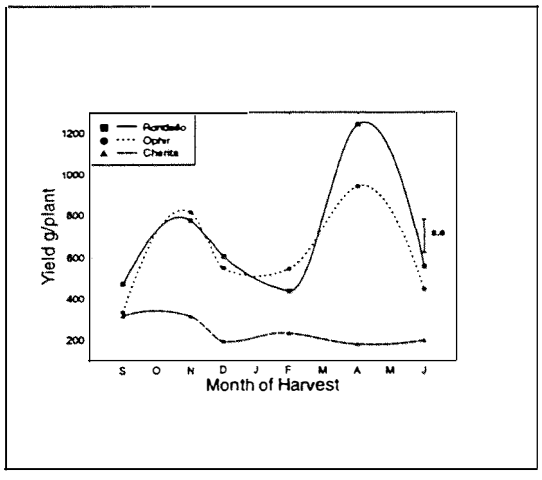
3.3 RESULTS

3.3.1 Effect of season, solution conductivity and cultivar on yield, number and size of fruit

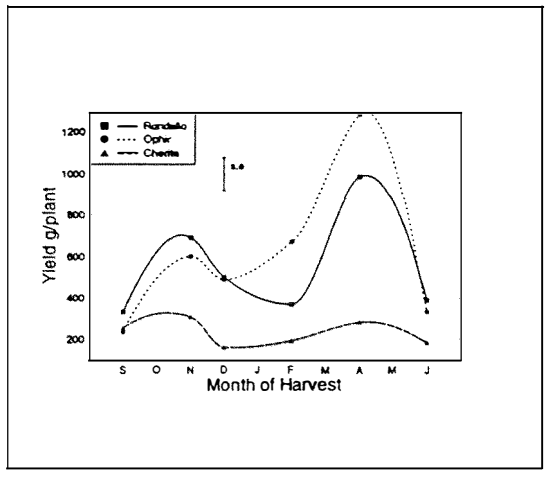
3.3.1.1 Introduction

The raw data for fruit yield for the six plantings (season) and four conductivities for each of the three cultivars is presented in Figure 3.2. The data is presented in this way to provide an overview of the response of the crops to the treatments. The marked effect of season on yield for cultivars Rondello and Ophir is apparent whereas the pattern is less clear for the cherry tomato Cherita. For the two large fruited cultivars yield was decreased for plantings fruiting over the mid-summer period. Yield decreased with increasing conductivity for all three cultivars.

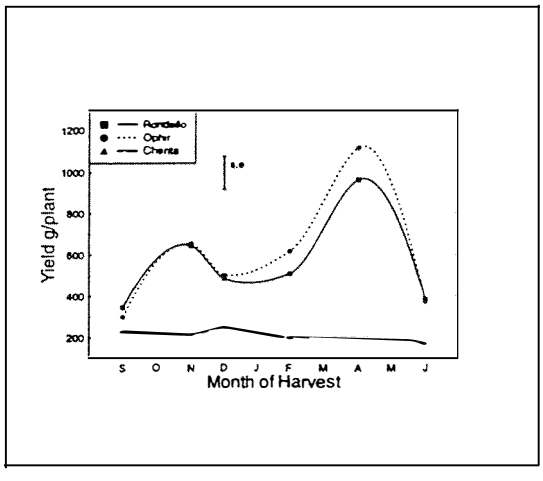
The results of the ANOVA carried out on the data for yield, number and size of fruit is presented in Table 3.2. These results are considered in detail in sections 3.3.1.2 - 3.3.1.4.



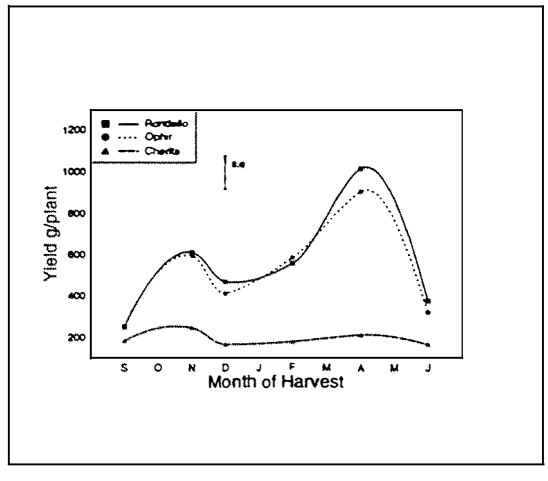
(a) Conductivity 2 mS cm^{-1}



(b) Conductivity 4 mS cm^{-1}



(c) Conductivity 6 mS cm^{-1}



(d) Conductivity 8 mS cm^{-1}

Figure 3.2 Effect of season, conductivity and cultivar on yield (g/plant)

Table 3.2 Effect of season, solution conductivity and cultivar on yield, number and size of fruit

	Yield	Fruit number	Fruit size
Season	***	***	***
Solution conductivity	*	ns	*
Cultivar	***	***	***
Season x Conductivity	ns	ns	ns
Season x Cultivar	***	***	***
Conductivity x Cultivar	ns	ns	ns
Season x Conductivity x Cultivar	ns	ns	ns

* $P < 0.05$
** $P < 0.001$
*** $P = 0.0000$
ns = not significant

3.3.1.2 Effect of solution conductivity on yield and fruit size

There was an effect of conductivity on yield and fruit size (Table 3.2). Increasing solution conductivity decreased yield linearly (Figure 3.3) and fruit size (Figure 3.4) curvilinearly over the range of conductivities applied. Fruit size did not decrease until a conductivity of 6 mS cm^{-1} was applied.

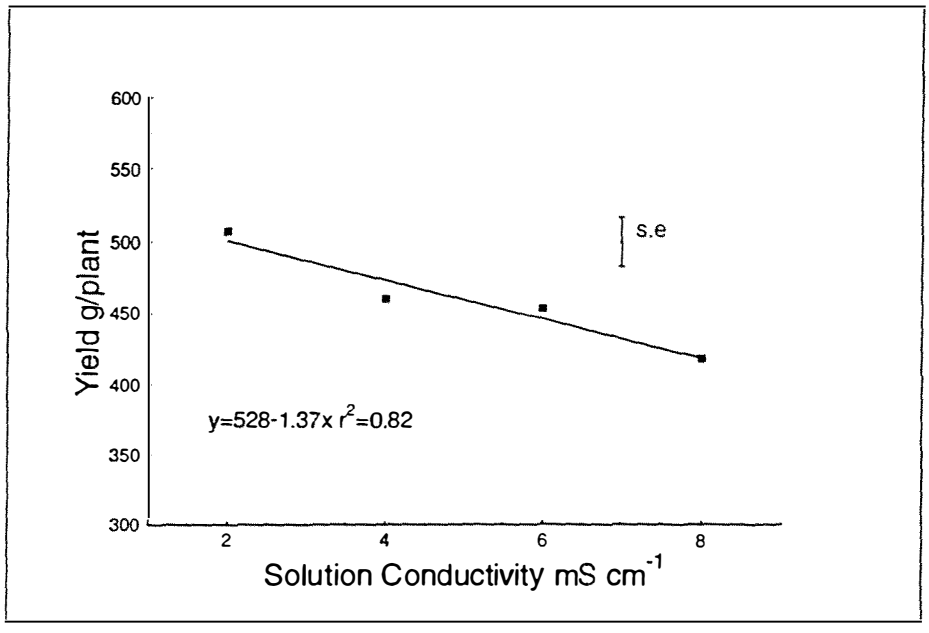


Figure 3.3 Effect of solution conductivity on yield (mean of 3 cultivars and 6 plantings)

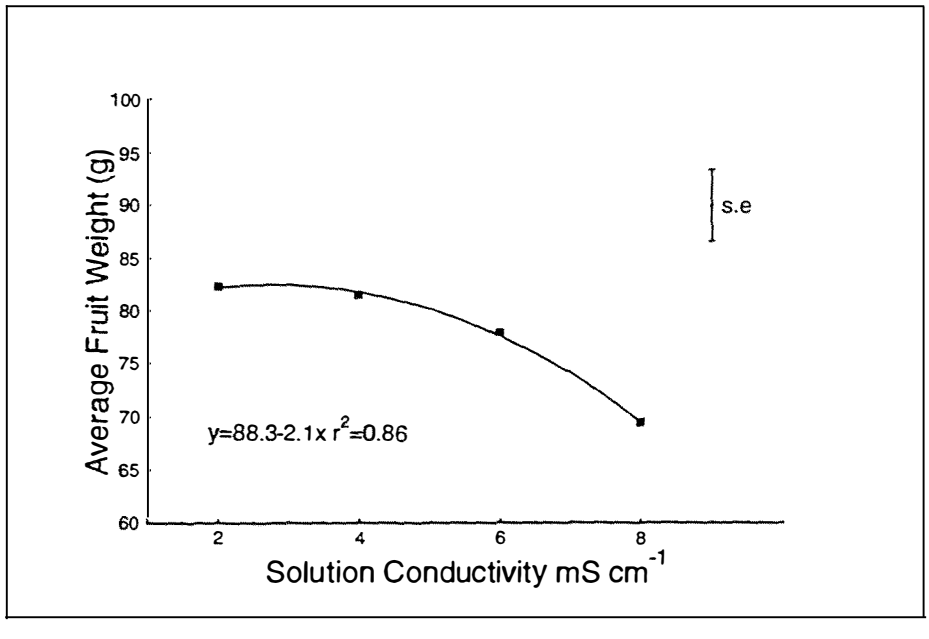


Figure 3.4 Effect of solution conductivity on fruit size (mean of 3 cultivars and 6 plantings)

3.3.1.3 Effect of season and cultivar on yield, number and fruit size

3.3.1.3.1 Introduction

There was a season x cultivar interaction for yield, number and size of fruit (Table 3.3).

3.3.1.3.2 Effect of season and cultivar on fruit yield.

The effect of season on yield for each of the three cultivars is presented in Figure 3.5. Apart from in February the yield of Rondello and Ophir were similar. For these two cultivars the yield for crops that matured in December and February was lower than in November and April, with yields also reaching low levels in July and September. The yield of the cherry cultivar Cherita was lower than the other varieties apart from in September when the yield of all cultivars was similar. The yield of Cherita varied little over the season, although there was also a trend for yield to decrease in December and February.

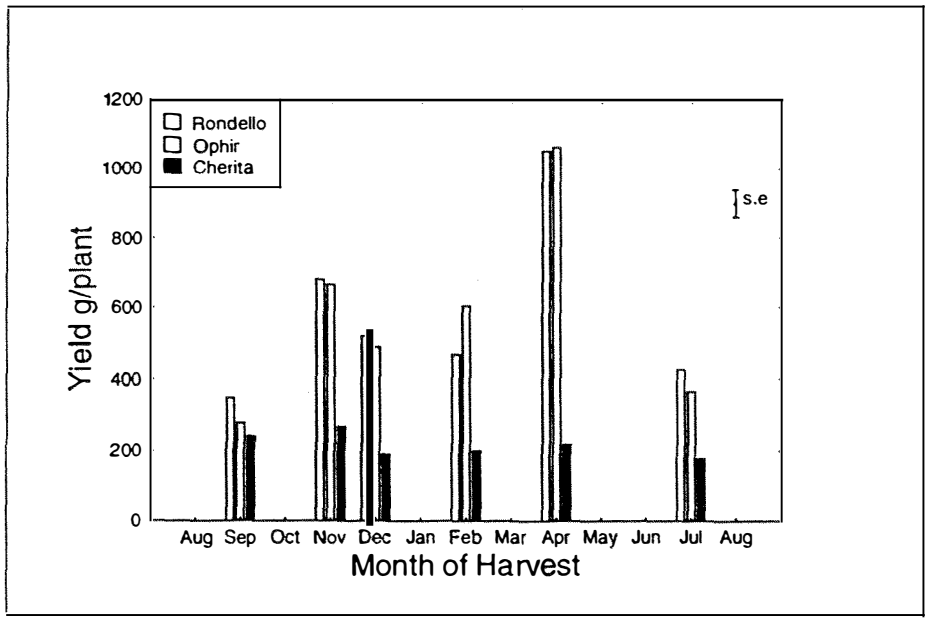


Figure 3.5 Effect of season on yield for the cultivars Rondello, Ophir and Cherita.

3.3.1.3.3 Effect of season and cultivar on fruit number

The effect of season on fruit number for each of the three cultivars is presented in Figure 3.6. The cherry cultivar Cherita had the highest fruit number with numbers falling from September until December and then levelling off. Fruit numbers for Rondello and Ophir were similar throughout the season. Numbers appeared to fall in July, particularly for Ophir.

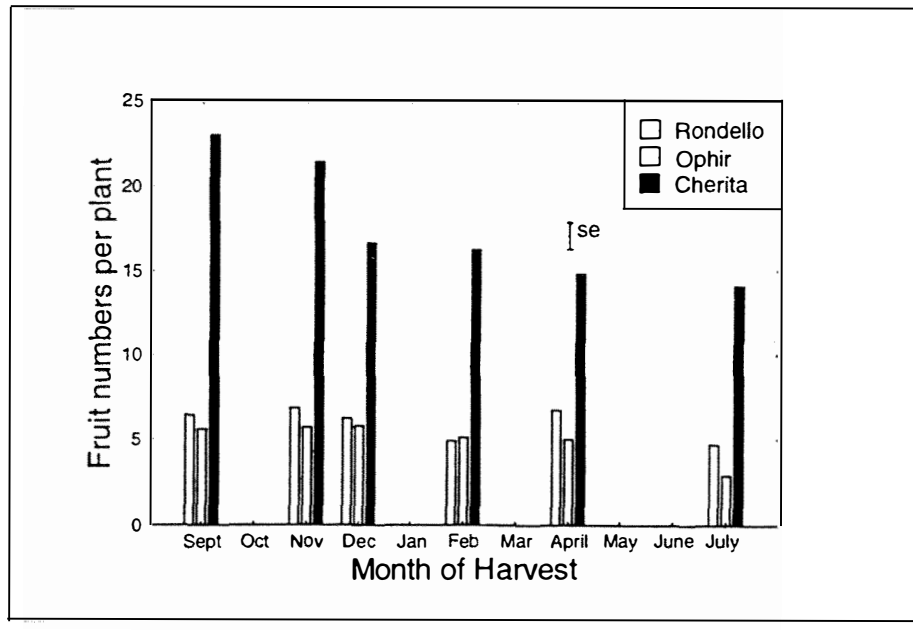


Figure 3.6 Effect of season on fruit number for the cultivars Rondello, Ophir and Cherita

3.3.1.3.4 Effect of season and cultivar on fruit size

The effect of season on fruit size for each of the three cultivars is presented in Figure 3.7. The cherry cultivar Cherita had the smallest fruit size. The trend was for Ophir to have larger fruit than Rondello at most harvest periods. The seasonal variation in fruit size was as for fruit yield, increasing from September to November then falling for December and February to peak in April. Fruit size fell in July, but was not as low as for the crop harvested in September. Fruit size of Cherita varied little throughout the season.

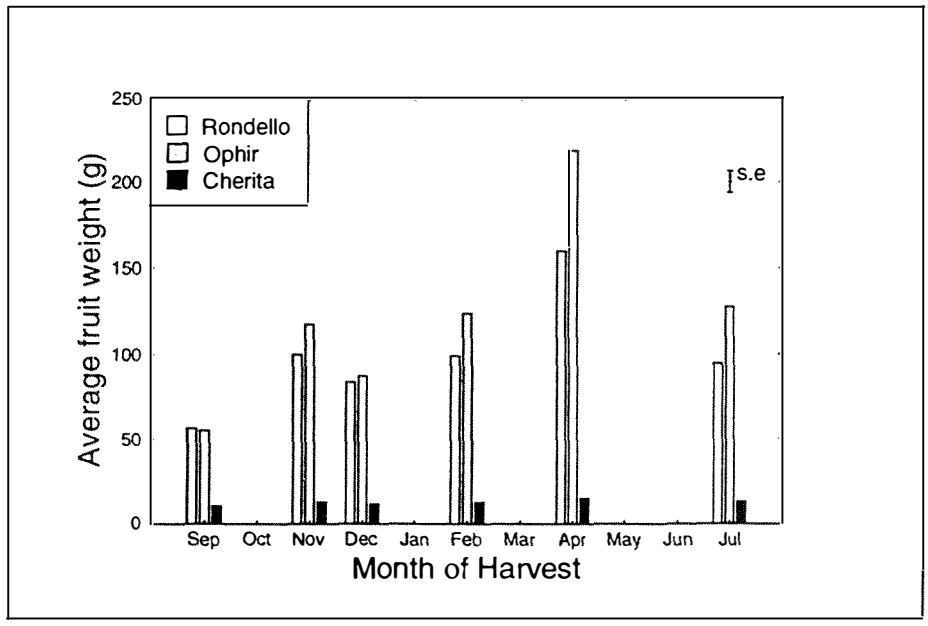


Figure 3.7 Effect of season on fruit size for three cultivars.

3.3.2 The effect of season, solution conductivity and cultivar on fruit quality

3.3.2.1 Brix levels

3.3.2.1.1 Effect of season and cultivar on fruit brix levels

There was a season x cultivar interaction for brix levels (Table 3.3). Cherita had the highest brix level often by a factor of 1.0 - 1.5 units, while Rondello and Ophir had similar brix levels apart from in February and July, when Rondello had the higher value (Figure 3.8). Brix levels were low for all cultivars in December, and for Rondello and Ophir in April and for Ophir in July.

Table 3.3. The effects of Season and solution conductivity on fruit Brix and titratable acidity

	Total soluble solids (Brix)	Percent citric acid
Season	***	***
Solution conductivity	***	***
Cultivar	***	***
Season x Conductivity	ns	**
Season x Cultivar	***	**
Conductivity x Cultivar	*	ns
Season x Conductivity x Cultivar	ns	ns

* Prob < 0.05
** Prob < 0.001
*** Prob = 0.0000
ns = not significant

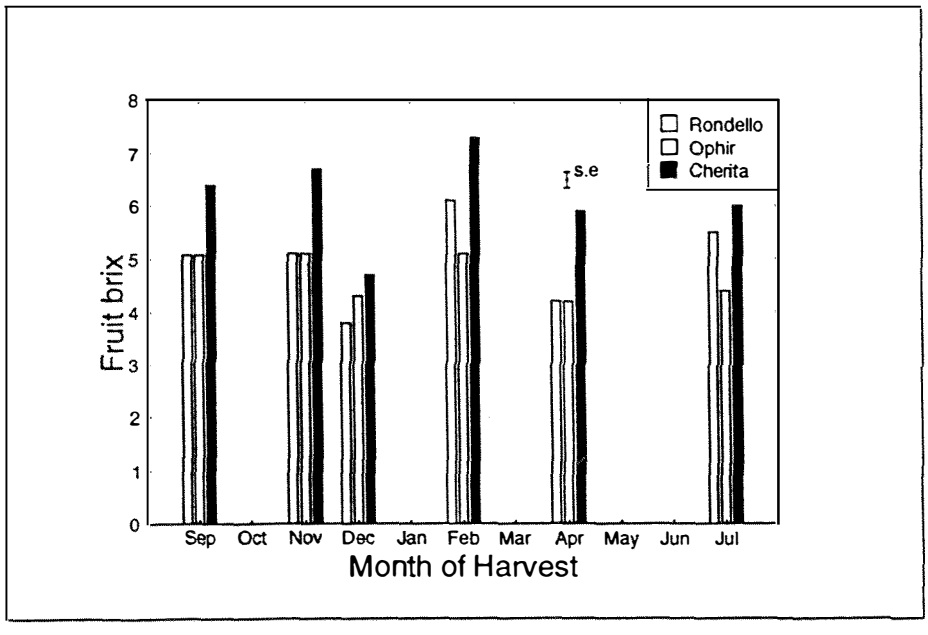


Figure 3.8 Effect of season on brix levels for all three cultivars

3.3.2.1.2 Effect of solution conductivity and cultivar on fruit brix levels

There was a solution conductivity x cultivar interaction for fruit brix levels (Table 3.3). Cherita had the highest brix level by a factor of 1.0 - 1.5 units, while Rondello maintained a slightly higher brix level than Ophir at all conductivity levels (Figure 3.9). With all cultivars fruit brix increased in a linear manner with increasing solution conductivity, with the rate of increase being slightly higher for Rondello.

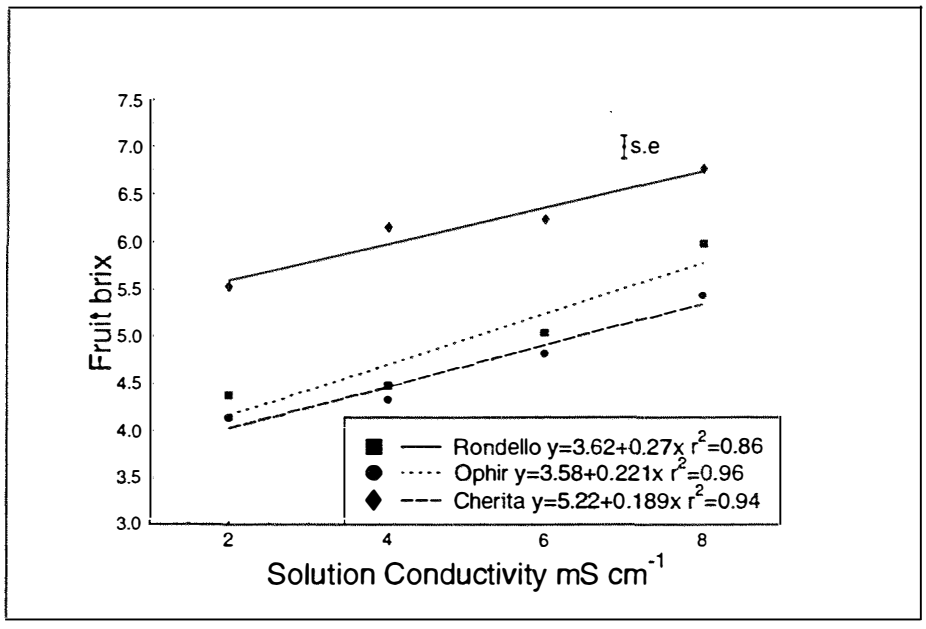


Figure 3.9 Effect of solution conductivity on fruit brix levels

3.3.2.2 Titratable acidity

3.3.2.2.1 Effect of season and conductivity on fruit titratable acidity

There was a season x conductivity interaction for titratable acidity, expressed as percent citric acid (Table 3.3). Percent citric acid for each season showed a positive response to increasing conductivity (Table 3.4). The September and November plantings had a lower level of citric acid throughout, whereas the December, April and July harvested crops generally had higher levels.

Table 3.4 Effect of conductivity on fruit percent citric acid for each planting date

Month of Harvest	Solution Conductivity			
	2 mS cm^{-1}	4 mS cm^{-1}	6 mS cm^{-1}	8 mS cm^{-1}
September	0.48	0.56	0.60	0.64
November	0.47	0.51	0.49	0.58
December	0.60	0.61	0.66	0.69
February	0.54	0.65	0.67	0.86
April	0.60	0.68	0.72	0.76
July	0.63	0.67	0.76	0.86
s.e		0.025		

3.3.2.2.2 Effect of season and cultivar on fruit titratable acidity

There was a season x cultivar interaction for percent citric acid (Table 3.3). The effect of season on titratable acidity for the three cultivars is presented in Table 3.5. Cherita had the highest percentage citric acid often by a factor of 0.3 units. Rondello and Ophir had similar acidity levels except in July when Rondello had the higher figure. Percent citric acid figures were lowest for both these cultivars in September and November, although there was no marked effect of season.

Table 3.5 Effect of season and cultivar on fruit titratable acidity

Month of Harvest	Cultivar		
	Rondello	Ophir	Cheita
September	0.49	0.45	0.77
November	0.39	0.37	0.77
December	0.55	0.57	0.80
February	0.57	0.60	0.87
April	0.58	0.60	0.88
July	0.73	0.57	0.88
s.e		0.031	

3.3.3 Effect of season, solution conductivity and cultivar on leaf growth

3.3.3.1 Leaf area and leaf area index

3.3.3.1.1 Effect of solution conductivity on leaf area and leaf area index

Solution conductivity had a significant effect on leaf area and leaf area index (Table 3.6). Leaf area and leaf area index were lowest at a conductivity of 8 mS cm^{-1} (Table 3.7) followed by the 4 mS cm^{-1} treatment.

Table 3.6. Effect of season and solution conductivity on and leaf area and leaf area index

	Leaf area cm^2	LAI
Season	***	***
Solution conductivity	**	**
Cultivar	ns	ns
Season x Conductivity	ns	ns
Season x Cultivar	**	**
Conductivity x Cultivar	ns	ns
Season x conductivity x cultivar	ns	ns

* Prob < 0.05
** Prob < 0.001
*** Prob = 0.0000
ns = not significant

Table 3.7. Effect of solution conductivity on leaf area cm^2 and leaf area index

	Solution conductivity			
	2 mS cm^{-1}	4 mS cm^{-1}	6 mS cm^{-1}	8 mS cm^{-1}
Leaf area cm^2	2801	2493	2820	2292
s.e		97.51		
Leaf area index	3.6	3.2	3.6	3.0
s.e		0.126		

3.3.3.1.2 Effect of season and cultivar on leaf area and leaf area index

There was a season x cultivar interaction for leaf area and leaf area index (Table 3.6). There was no clear pattern with respect to the cultivars as their relative positions varied for each season (Figure 3.10 and Table 3.8). All cultivars demonstrated a low leaf area and a low leaf area index for crops harvested in November and July.

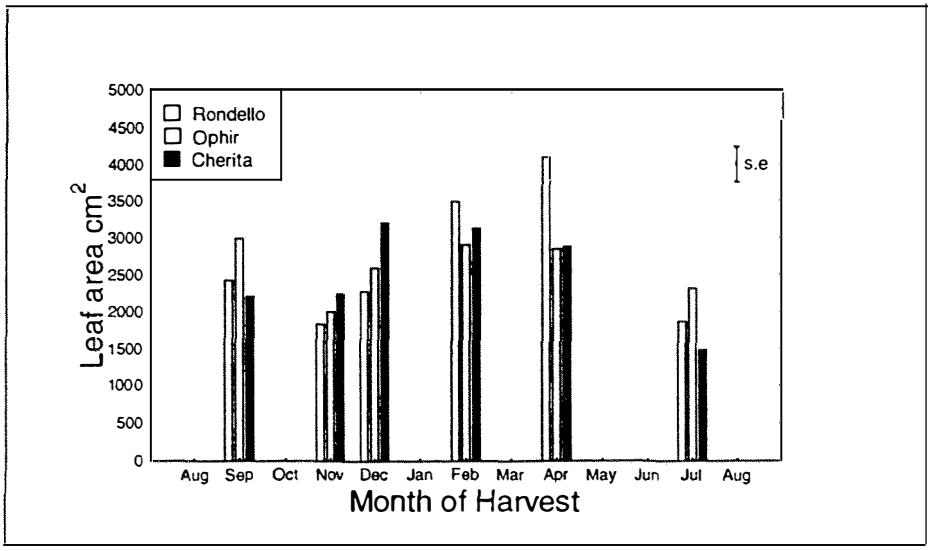


Figure 3.10 Effect of season on leaf area for all cultivars

Table 3.8 Effect of season on leaf area index for all cultivars

Month of Harvest	Cultivar		
	Rondello	Ophir	Cherita
September	3.1	2.9	3.9
November	2.4	2.9	2.6
December	2.9	4.1	3.4
February	4.5	4.0	3.8
April	5.3	3.7	3.7
July	2.4	1.9	3.0
s.e		0.30	

3.3.4 Effect of season, solution conductivity and cultivar on leaf mineral levels

The effect of solution conductivity on leaf mineral levels is presented in Figures 3.11 - 3.14, and cultivar differences in foliar nutrient levels is presented in Figure 3.15. The July harvested crop produced a different response to conductivity then the other planting dates and is therefore reported separately in each graph.

Foliar nitrogen levels increased with conductivity, however this was not the case with the July harvested crop (Figure 3.11), which maintained a higher N level and did not change with changes in conductivity.

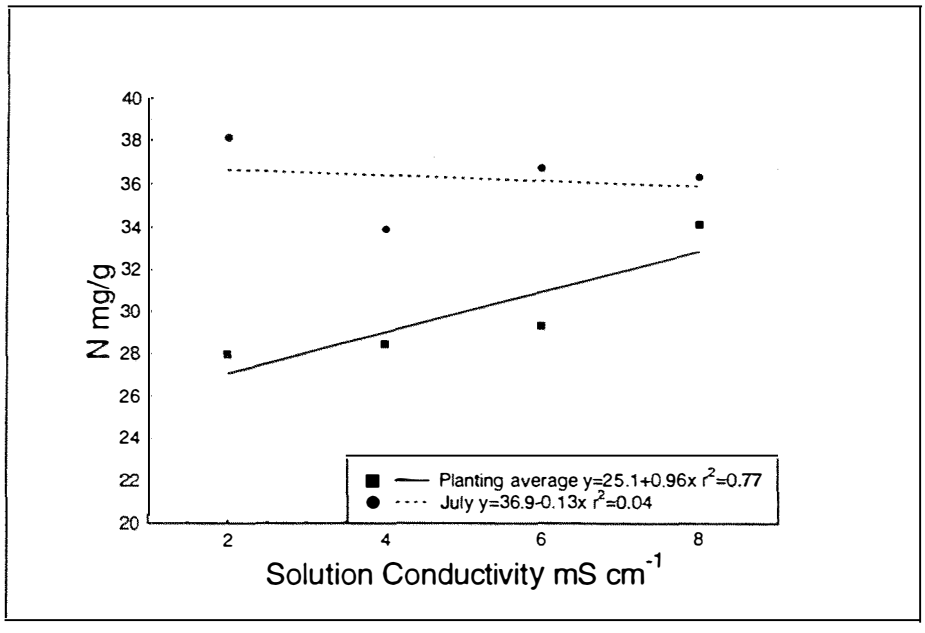


Figure 3.11 Effect of solution conductivity on foliar N levels (5 planting dates averaged with the July crop presented separately).

Foliar P levels decreased with increasing solution conductivity (Figure 3.12). Foliar P levels in the July harvested crop responded the least to the increase in conductivity.

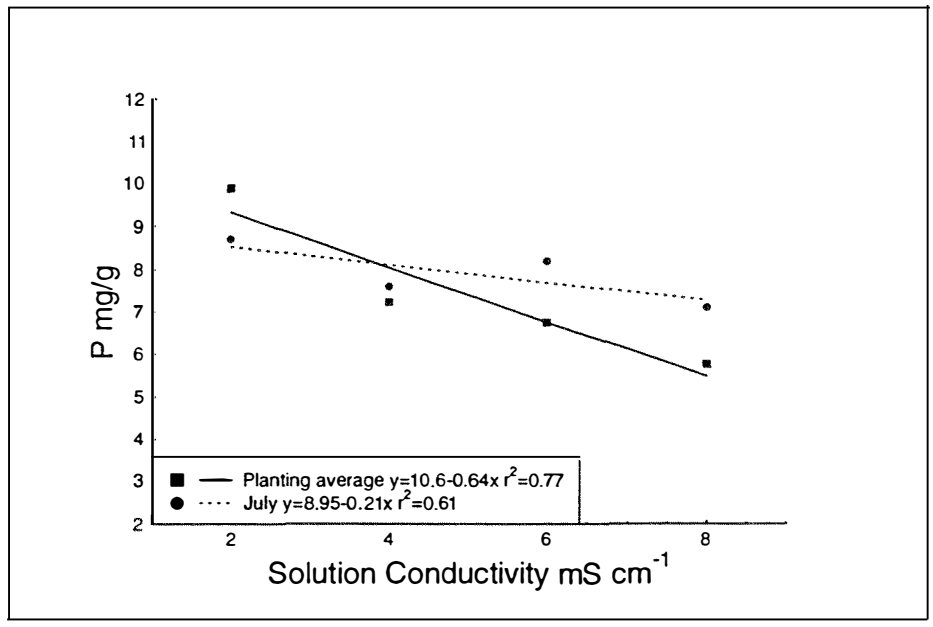


Figure 3.12 Effect of solution conductivity on foliar P levels (5 planting dates averaged with the July crop presented separately)

Foliar K levels increased with conductivity for all harvest dates (Figure 3.13). The response was less with the July planting.

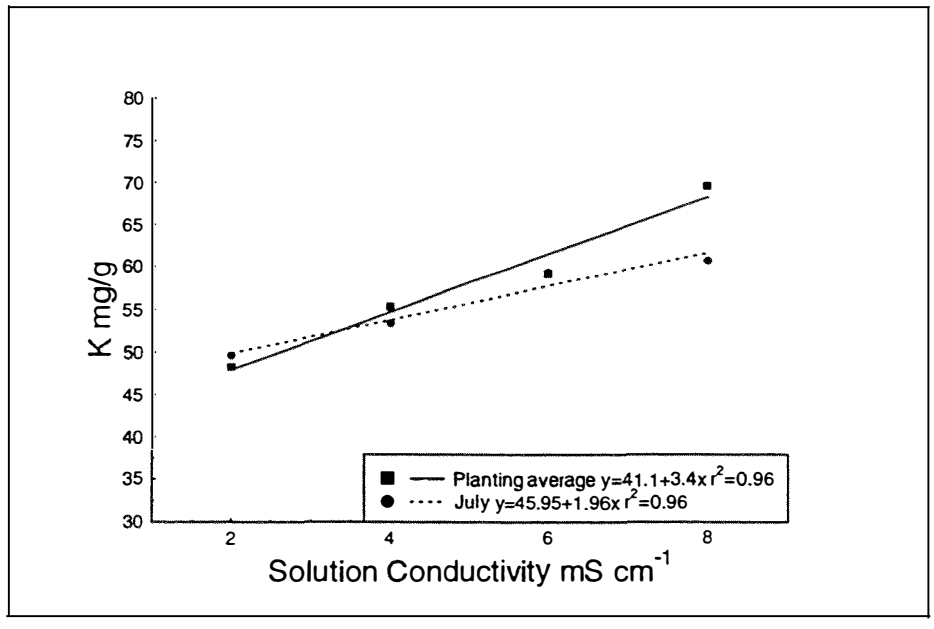


Figure 3.13 Effect of solution conductivity on foliar K levels (5 planting dates averaged with the July crop presented separately)

Foliar Ca levels decreased with solution conductivity (Figure 3.14). The July harvested crop maintained a lower Ca level than the other plantings

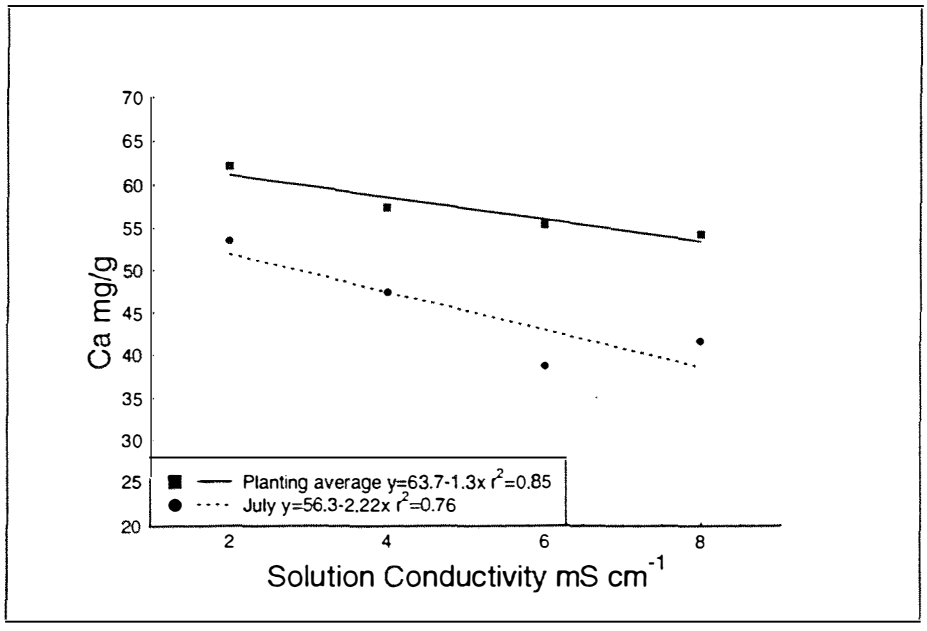


Figure 3.14 Effect of solution conductivity on foliar Ca levels (all planting dates averaged with the July crop presented separately)

The cultivar differences in foliar mineral levels are presented in Figure 3.15. No cultivar consistently had higher or lower leaf nutrient levels, the greatest difference between the cultivars was in K and Ca levels.

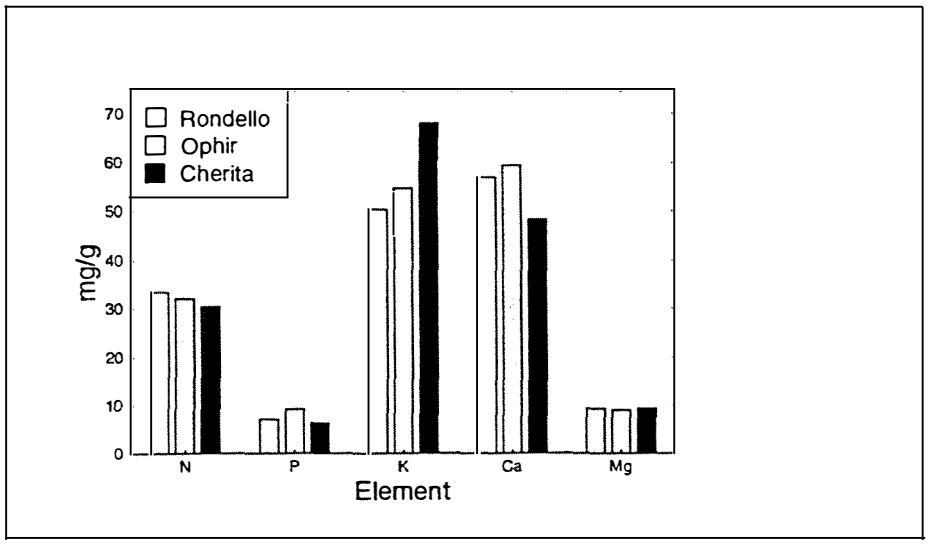


Figure 3.15 Cultivar differences in foliar N, P, K, Ca and Mg levels

3.4 DISCUSSION

3.4.1 Yield, size and number of fruit

3.4.1.1 Effect of season and cultivar on yield, size and number of fruit.

3.4.1.1.1 Effect of season and cultivar on fruit yield

Both Rondello and Ophir had similar yields for each planting (Figure 3.5). Cherita, the lowest yielding cultivar, followed the seasonal trend of the other two cultivars, but to a much lesser degree. The lower yield of Cherita could be explained in terms of a lower sink strength. This lower sink strength of the fruit could result in the yield of such cultivars being effected less by changes in the seasonal levels of solar radiation.

Total yield was lowest in both the winter plantings which were harvested in September and July. This was to be expected due to the lower radiation and temperature levels and hence the reduced production of assimilates for fruit growth. Yield then began to increase with the November harvested crop as radiation levels improved. The seasonal effect of radiation on fruit growth has been well documented by Cooper (1961) who used successional plantings to examine the effects of season on fruit volume production. Fruit volume production was lowest in mid winter and highest in mid summer. In the present study, the two summer plantings, harvested in December and February, had total yields, much lower then expected for this time of the year when the radiation levels are greatest. This reduced summer yield resulted from smaller fruit size (Figure 3.7) and not fruit number (Figure 3.6) which are essentially controlled in a single truss system.

A possible explanation for these low summer yields is that temperature and the effect of direct solar radiation on exposed leaves and fruit increased their temperature and caused yield to be reduced. Another factor here could have been high solution temperatures.

Single truss crops are more effected by direct solar radiation then multi truss crops as they do not have the depth of canopy to shade the leaves and fruit. A single truss plant has a significant proportion of its leaves and fruit exposed. Exposed leaves and fruit would have their temperatures raised by direct solar radiation above that of the

surrounding air temperature. This would then have had detrimental effects on photosynthesis with stomatal closure occurring to prevent excessive water loss. With leaves at temperatures reaching 30 -35°C, the actual temperature of the leaves is close to 35 to 45°C, temperatures that approach those lethal of young cells of higher plants (Lipton, 1970). Smillie (1992), stated that the photosynthetic system in leaves is especially vulnerable to heat stress, becoming inactivated at temperatures several degrees below those damaging respiration and several other cellular process.

However, the most detrimental effect of direct solar radiation could well be on fruit temperature and thus fruit respiration. Fruit respiration rates double for each 10°C increase in temperature (Gale, 1982). Gale (1982) also reported that the increased rate of respiration measured as CO_2 efflux at higher temperatures could result from an increase in maintenance respiration in order to supply the energy required to cope with higher rates of protein turnover and the damage resulting from high temperatures (38°C). It is possible therefore that increased fruit respiration rates and cell and enzyme damage are responsible for the low summer fruit size in the present experiment. Thus yield reduction could be due to the combined effects of low assimilate production and high fruit respiration.

The highest yield was obtained in the April harvested crop, where the plants had grown vegetatively during February and fruit expansion was occurring largely in March and April when temperatures were decreasing. It would have been expected that if high foliage and fruit temperatures were not limiting fruit expansion during summer, then the yield from the December and February harvested crops would have been similar too or greater then the yield obtained from the April harvested crop. In a single truss trial carried out in the UK, Cooper (1979) reported yields of 800g per plant from a summer grown crop, and 100g per plant from winter crops (plant density was not stated). One could postulate therefore that the yield from the December and February harvested crops in the present study would have been between 800 and 1000 g/plant, if fruit growth had not been restricted.

3.4.1.1.2 Effect of season and cultivar on fruit size

The seasonal pattern for fruit size was similar to that of fruit yield. The effects of season on fruit size formed the basis of the explanation in the previous section as to the seasonal effects on yield and do not need to be repeated here.

Unlike Rondello and Ophir, the fruit size of Cherita was not influenced by season. Ophir a beefsteak type tended to have larger fruit then Rondello and this was most noticeable in April, a time of the year when the crop experienced good growing conditions.

The significant cultivar/season interaction demonstrates that each of the three cultivars is effected differently by season in terms of fruit weight. Cherita the smallest fruiting cultivar differs only by 4 - 5 g per fruit throughout the season. However, the larger fruiting cultivars differed greatly in terms of the magnitude of the size difference between seasons. The September harvested crop was one quarter the fruit size of the April harvested crop. This indicates that Rondello and Ophir are more sensitive to environmental conditions then Cherita, preforming well under favourable light conditions and poorly under winter conditions. As previously suggested (3.4.1.1.1), this could be explained in terms of the greater sink strength of the two cultivars.

3.4.1.1.3 Effect of season and cultivar on fruit number

As expected the cherry tomato variety, Cherita, carried markedly more fruit then the other two varieties. Fruit numbers for Cherita fell after the September and December crops. It was observed the September and December crops had a high percentage of branched (double and triple) trusses, while few branched trusses were noted in subsequent crops. It could be possible that environmental conditions at the time of floral initiation favoured the development of branched trusses in these first two crops, but it is difficult to speculate what these conditions were, as the plants had sufficient heating and did not therefore experience the low temperatures that are reported to cause truss branching (Lake, 1967: Hurd and Cooper, 1967).

Fruit numbers for Rondello and Ophir did not vary much during the season except for

July where fruit numbers were low. This could be explained in terms of poor light levels. In these experiments it could be argued that the propagation conditions were not marginal with respect to temperature and light, apart from in July. Stopping the plants would have also removed a strong sink (the growing tip) and this should have aided inflorescence development. Although not significant Rondello appeared to maintain more fruit per plant than Ophir.

The significant season/cultivar interaction demonstrates that all three cultivars have different responses to environmental conditions. Fruit numbers for the cultivar Ophir are more effected by light and temperature conditions during floral/fruit development then Rondello. Ophir develops good fruit numbers in favourable conditions, but in the winter grown crop, flower numbers were reduced to only 2.9 fruit per truss.

3.4.1.2 Effect of solution conductivity on yield, size and number of fruit

3.4.1.2.1 Effect of solution conductivity on fruit Yield

In the present investigation yield and size of fruit both decreased with increases in conductivity over the range 2 - 8 mS cm^{-1} (3.3.1.2) although there was no decrease in fruit size from 2 - 4 mS cm^{-1}. The lack of response in the latter case may be more of a chance result then a real treatment effect. Yield reductions with increasing conductivity have been reported by a number of researchers. Sonneveld and Welles (1988) working in the Netherlands reported a 5 - 7% yield reduction per mS cm^{-1} in multi truss crops grown over a 6 month period in a rockwool/NFT system. Massey et al (1983b), found an average yield loss of 4.13% per mS cm^{-1} increase in conductivity in an NFT, multi truss tomato crop produced in the UK. Charbonneau et al (1988) reported a 19% decrease in total and marketable yield from multi truss, NFT crops when the conductivity was raised from 2 to 10 mS cm^{-1}. Ehret and Ho (1986), found a 40% decrease in fresh weight of mature multi truss fruit grown at 17 mS cm^{-1} compared to fruit grown at 2 mS cm^{-1}. Caro et al (1991), studied the effect of EC (from 2.8 to 21.5 dS m^{-1}) on the yield of several normal sized and cherry cultivars and found that the fruit yield of all cultivars decreased with increasing salinity, and that this response was different for each cultivar.

In this investigation, the cultivar Rondello, Ophir and Cherita had yield losses of 3.3%, 2.5% and 3.2% per mS cm^{-1} respectively over the range 2 - 8 mS cm^{-1}. This is similar to the yield losses obtained from multi truss trials reported above (2.4 - 7% per mS cm^{-1}).

The reason for this yield loss at higher conductivity levels is that the uptake of water by the plants is reduced and so the accumulation of water by fruits is also reduced (Ehret and Ho, 1986). As the conductivity of the nutrient solution increases, less water but the same amount of dry matter accumulates in the fruit so that the fruit dry matter content increases. Ho and Grimbly (1990) stated that using techniques such as high salinity to increase the dry matter content of the tomato fruit by reducing the rate of water accumulation, which then effects cell enlargement means that a loss in yield is inevitable.

3.4.1.2.2 Effect of solution conductivity on fruit size

As with yield, fruit size was reduced with increases in conductivity (Figure 3.4). The reduction in average fruit size with conductivity is well documented. Massey et al (1983b) and Ho and Ehret (1983) both found that a conductivity increase from 2 to 10 mS cm^{-1} significantly reduced the size of fruits. Gough and Hobson (1990) also reported that at high conductivity levels (8 mS cm^{-1}) mean fresh weight and diameter of fruits decreased. Sonneveld and Welles (1988) and Satti et al (1994) both claimed that salinity significantly suppressed fruit fresh weight.

3.4.1.2.3 Effect of solution conductivity on fruit number

In the present study yield reductions were solely due to the effect of conductivity on fruit size, while fruit numbers remained unchanged. There are 2 possible explanations as to why conductivity did not effect fruit numbers:

1. The conductivity treatments applied were not severe enough to have an overall effect on fruit numbers. Other researchers have found that a conductivity of 10 mS cm^{-1} resulted in reduced flower numbers (Ho and Ehret, 1983: Massey et al, 1983b). In these cases multi truss crops were grown.

2. In the present investigations the conductivity treatments were not applied until the 50% anthesis stage when the flower development had been completed. If the conductivity treatments had been applied before floral initiation or soon after floral initiation there may have been a reduction in fruit numbers with the increasing conductivity. This was reported by Dumbroff and Cooper (1974) who stated that budding and flowering were effected most when salt stress was applied during the early stages of development (at budding) and that stress during the later half of the study (at flowering) had only minor effect on the reproductive process.

It can be concluded that by applying the higher conductivity treatments late, after flowering, the effect of salinity on fruit numbers was avoided. Conductivity treatments could be applied later than fruit set (e.g during fruit expansion), which may reduce the loss in yield caused by higher conductivity levels, while maintaining fruit quality. The timing of the application of conductivity increases, for this reason, warrants further investigation.

3.4.2 Effect of season, solution conductivity and cultivar on fruit quality

3.4.2.1 Effect of season on fruit brix and acidity

Fruit composition is influenced by a number of environmental factors. Radiation levels, water stress, temperature and rate of photosynthesis all effect compositional fruit quality (Hobson and Adams, 1989; Orzolek and Angell, 1975; Yakir et al, 1984). Brix and percentage dry matter are related not only to the amount of solar radiation and therefore rates of plant photosynthesis, but also to the rate of respiration which utilises reserves. Therefore if temperatures are high, although a plant may have sufficient light for a high level of photosynthesis, plant reserves may be depleted by the increased rate of respiration. This has been shown to occur in tomato plants (Walker and Ho, 1977b), and may account for the drop in fruit brix levels in the December harvested crop (Figure 3.8). The increased percent citric acid levels in the February and April crops can be explained in terms of higher light levels which have been reported to increase titratable acidity (Forshey and Alban, 1954). No explanation can be offered for the lower brix level in April or the increased percent citric acid level in the July harvested crop.

3.4.2.2 Effect of solution conductivity on fruit brix and acidity

Increasing conductivity increased both brix (Figure 3.9) and percent citric acid (Table 3.4). This improved fruit compositional quality is a result of the increased osmotic potential of the nutrient solution at the higher conductivity levels, so although less water accumulates in the fruit, the dry matter still accumulates to the same level as a normal fruit (Ho and Grimbly, 1990). As a result the fresh weight of the fruit is reduced at higher conductivity levels, while the dry matter stays constant, or may even increase slightly. This was also found by Ho and Grimbly (1990), who stated that the effect of high EC is to reduce the quantity of phloem sap entering the fruit, but by increasing the concentration of the phloem sap the quantity of sugars entering the fruit is maintained at the same level. The result is a high percentage dry matter in the fruit or a higher sugar concentration in the fruit juice.

In this study, brix levels were increased by 4.5%, 4% and 3% per mS cm^{-1} for the cultivars Rondello, Ophir and Cherita respectively while percent citric acid increased by 5.7%, 3.7% and 3% per mS cm^{-1}. Davies and Winsor (1969) also found that the acidity in the fruit sap was increased when plants were grown at higher conductivities (8 mS cm^{-1}). Petersen and Willumsen (1991) reported that it was possible to increase the sugar content by up to 28% and the acid content by 21% by raising the salinity of the solution from 2.2 to 4.8 mS cm^{-1} with tomato crops grown in rockwool. Gough and Hobson (1990) obtained a 19 and 22% increase in titratable acidity and an 11 and 3% increase in reducing sugars from two crops (grown during the first or second half of the season) grown in NFT, with a conductivity increase from 3 to 8 dS m^{-1}. Hobson and Adams (1989) reported a 25% increase in percent citric acid and a 43% increase in sugars in NFT with a conductivity increase from 2.5 to 10.0 mS cm^{-1}. The increase in brix and percent citric acid in the present study resulted in a 27 and 34% increase respectively for the cultivar Rondello over the 2 - 8 mS cm^{-1} range, which suggests single truss plants respond to higher conductivities with greater increases in sugar and acidity than has been reported from most multi truss studies.

Increased fruit acidity levels may be linked to the greater concentration of potassium in the higher conductivity solutions, as potassium plays an important role in fruit quality.

Winsor (1966) found that the acidity of fruit juices was found to increase with the level of potassium in the soil. Increases in fruit acidity are usually accompanied by substantial increase in the potassium content of the tomato puree during compositional quality assessment (Winsor et al, 1961). This may be explained by the fact that potassium accounts for 85% of the total cations removed by ion exchange from tomato puree (Winsor et al, 1961). Thus increases in the fruit cation:anion ratio due to salinity results in significantly higher titratable acidity levels and organic acid accumulation (Mitchell et al, 1991).

3.4.2.3 Effect of cultivar on fruit brix and acidity

Cultivar has a significant effect (Table 3.3) on brix and percent citric acid. In all cases, the cultivar Cherita had the highest fruit compositional quality values (Figures 3.8 and 3.10). This is as expected, as cherry cultivars have established a reputation as high quality fruit, which are quite distinct from conventional tomatoes (Hobson and Adams, 1989). Cherita is likely to have a high leaf/fruit ratio which has been reported by various workers (Winsor, 1966; Hewitt and Stevens, 1981) as increasing brix levels. The varieties Rondello and Ophir had similar fruit compositional values, with Ophir, the larger fruited cultivar having lower brix and acidity values then Rondello on a number of occasions. This demonstrates that there are differences in fruit quality components of cultivars grown under identical conditions.

3.4.2.4 Solution conductivity and the yield/quality relationship

Increasing solution conductivity not only results in improved fruit quality (3.4.2), it also causes a loss in yield (section 3.4.1). This yield/quality relationship for the present study is outlined in Table 3.9.

Table 3.9 Effect of solution conductivity on yield and fruit quality (average of all crops).

	Fruit Yield				Fruit Quality	
Conductivity mS cm^{-1}	Yield g/plant	% Yield Loss	Fruit Brix	% Increase in Brix	Fruit % Citric acid	% Increase in % Citric acid
2	507		4.68		0.55	
4	460	9	4.98	6	0.61	10
6	453	2	5.37	7	0.65	6
8	418	8	6.06	11	0.73	11

As emphasis is placed on obtaining high yields, a yield loss from a conductivity increase from 2 to 4 mS cm^{-1} it is suggested would be acceptable. Any greater loss of yield would not be commercially viable. This conductivity increase from 2 to 4 mS cm^{-1} results in the production of good quality fruit, with a brix increase of 6% and an increase in percent citric acid of 10%. With brix levels of 4.98 at a conductivity of 4 mS cm^{-1}, this equates with the common range of brix levels in the commercial fruit samples analysed in December in the Auckland district (Appendix 4). Percent citric acid levels of 0.61%, at a conductivity of 4 mS cm^{-1}, equates with the top of the range of commercial fruit samples analysed in December (Appendix 4). This increase in percent citric acid level from a conductivity of 2 mS cm^{-1} to 4 mS cm^{-1} would be detectable during a sensory evaluation assessment as was shown in 2.3.3.3 Figure 2.13.

3.4.3 Effect of solution conductivity and season on plant leaf area and leaf area index

3.4.3.1 Effect of conductivity on leaf area and leaf area index

Increasing solution conductivity was not expected to influence leaf area as the conductivity treatments were not applied until the time of fruit set (Table 3.1). Presumably some leaf expansion took place after this date. Foliage from the higher

conductivity treatments appeared to be thicker, and therefore heavier then the lower conductivity plants. No explanation can be offered as to why the 4 and 8 mS cm^{-1} treatments have the lower leaf areas and leaf area index values (Table 3.7).

3.4.3.2 Effect of season on leaf area and leaf area index

Leaf area and leaf area index were lowest in the November and July harvested crops (Figure 3.10 and Table 3.8). Several environmental factors influence leaf area. Light and temperature have been reported as the most important factors influencing leaf development and subsequent leaf area (Hurd and Thornley, 1974). Cooper (1973) found that total leaf area increased with solution temperature to a maximum to 30°C, and then fell of steeply in the 30 - 40°C range. Cooper (1961) also found that plants grown in the winter months had a longer period of increasing leaf area and attained a larger total maximal leaf area then plants sown in the summer months. However, these studies on multi truss plants can not be directly applied to a single truss crop as leaf area in a single truss plant develops only for a short time before vegetative growth is terminated. It is more likely that the environmental conditions for the few weeks during which the young single truss plant is developing influenced the seasonal differences in final leaf area. The poorer leaf areas in November and July may have been associated with environmental stress at that time, which also reduced yield. In July low light and in November, high temperatures may have been involved.

The leaf area index values of the crops produced in this series of experiments varied from 1.9 to 5.3 (Table 3.8), with most values being in the 3 - 3.5 range (Table 3.7). These leaf area index values are higher then the average multi truss leaf area of approximately 2.3 (Warren Wilson et al, 1992). This suggests that the high density of the single truss crops resulted in a canopy where only the upper 2 leaves were activity photosynthesising.

3.4.4 Foliar mineral levels

3.4.4.1 Effect of solution conductivity on foliar mineral levels

Foliar mineral levels can be divided into two separate groupings. Those that increase

with solution conductivity being N (Figure 3.11) and K (Figure 3.13) and those that decrease with increasing solution conductivity, P (Figure 3.12) and Ca (Figure 3.14). Foliar Mg levels neither increased or decreased with conductivity.

In general nutrient uptake and accumulation is influenced by a number of factors. The uptake of N and K is closely related to light intensity and air temperature and are also highly correlated with water uptake (Winsor et al, 1980).

It has been consistently reported that the uptake of N increased with the level of N in solution (Winsor and Massey, 1978: Massey and Winsor, 1980: Hegde and Srinivas, 1990). This was found in this study for all but the July harvested crop (Figure 3.11).

K plays a major role in plant osmotic adjustment, thus we would expect higher foliar levels in plants grown at the higher conductivity levels. This is a likely explanation for the significant K foliar levels over the range of solution conductivities (Figure 3.13). Ho et al (1987) have suggested that K salts regulate the osmotic potential of tomato fruit under high salinity since under these conditions K salts account for 49% of the measured fruit osmotic potential. The data presented in Figure 3.13 is in agreement with several researchers. Adams and Grimmett (1983) found that the total uptake of potassium by tomato plants increased with the concentration of K in the recirculating nutrient solution. Sonneveld and Welles (1988) stated that with increasing EC values, K contents of the leaves were increased and the Ca and Mg contents were decreased. Adams et al (1973) found that the K content of the leaf increased markedly with the N concentration of liquid feeds.

Foliar levels of both P and Ca fell with increasing conductivity level (Figures 3.12 and 3.14). Sonneveld and Welles (1988) stated that high EC values reduced P contents of young leaf parts and fruits but not in older leaf parts. Since the single truss crop data shows P decreasing with conductivity, it might be assumed this is due to the fact that as single truss plants, all leaf tissue was young at the time of sampling.

The most interesting effect of increasing conductivity is on the foliar levels of Ca

(Figure 3.14), which fell considerably with the higher conductivity levels. This has been reported by many researchers (Ho and Ehret, 1983; Sonneveld and Welles, 1988), who are in agreement that the total uptake of Ca by plants can be depressed by 85 - 88% at high salinity levels (17 mS cm^{-1}), even if this was achieved by adding high levels of Ca and K nitrates to a basic nutrient solution (Adams, 1986). It has also been found that blossom end rot susceptible cultivars grown in high EC solutions develop a lower density of xylem vessels. Since Ca travels in the transpiration stream through the xylem, this has a significant effect on the Ca nutrition of the entire plant (Anon 1991). This is supported in the findings of Tachibana (1991), who stated that increased salinity of the rooting medium was also inhibitory to the upward translocation of Ca from roots to shoots in tomato plants.

Apart from the overall influence of salinity on Ca uptake and translocation, there is the possibility of specific ion inhibition of Ca uptake. Fisher (1967) found that interference in the Ca nutrition of the tomato plant was a major specific ion effect of the cations K and Mg, with the sodium ion exhibiting this tendency to a lesser extent. It can be concluded therefore that not only is the general increase in conductivity causing a reduction in Ca uptake and translocation, but the higher concentrations of other elements, notably K, N and Mg may also have an inhibitory effect on Ca uptake.

3.4.4.2 Effect of cultivar on foliar mineral levels

All three cultivars differed in the foliar levels of each element except for levels of Mg (Figure 3.15). The higher potassium concentrations for the cultivar Cherita may be linked to the greater fruit quality of this cultivar, as potassium is linked to fruit acidity and is the major element associated with fruit quality as it accounts for 85% of the total cations present in tomato puree (Winsor et al, 1961).

CHAPTER 4

THE EFFECT OF SPRING AND WINTER CO_2 ENRICHMENT, SUMMER SHADING AND SOURCE/SINK TREATMENTS ON THE YIELD AND QUALITY OF SINGLE TRUSS TOMATO CROPS

4.1 INTRODUCTION

In the previous experiment the effects of season, conductivity and cultivar on the yield and quality of single truss tomatoes was studied. Plant performance of greenhouse crops is also influenced by management of the aerial environment and plant training. Aspects of these relationships were selected for study in the present investigation.

The source sink relationship has an important influence on crop yield (Warren Wilson, 1972). Yield can be limited by lack of source or sink strength. Source strength is defined as source size x source activity (leaf area x NAR), while sink strength is defined as sink size x sink activity (fruit number x sink activity) (Warren Wilson, 1972). Thus source and sink strength can be influenced by leaf area and fruit number respectively. The respective roles of source and sink strength in limiting the yield of single truss tomatoes at different times of the year is not known. In the present experiment the source sink relationship was studied by manipulating leaf and fruit numbers.

It is reported in the literature that the yield of multi truss tomato crops can be increased by the use of CO_2 enrichment (Calvert and Slack, 1975 and 1977; White, 1977; Slack, 1983). With single truss tomatoes, CO_2 enrichment has been shown to increase marketable fruit weight, advance the date of first anthesis, promote earlier cropping and shorten the duration of harvest (Hand and Postlethwaite, 1971). Improvements in yield due to CO_2 enrichment can be explained in terms of its effect on NAR and thus source activity (Cockshull, 1985). CO_2 enrichment was therefore included in this study. Its application however was not possible at times of the year when the demand for ventilation precluded CO_2 enrichment. For this reason only the spring and winter crops received CO_2 enrichment (1000 ppm).

In the previous single truss experiments summer yields were lower then expected

(3.3.1.3.2) due, it was suggested, to heat stress caused by the direct effect of solar radiation. To evaluate this proposition, half of the summer crop was covered with shade cloth in an attempt to reduce greenhouse temperatures. Air and canopy temperatures in both the shaded and unshaded sides of the greenhouse were monitored and fruit temperature readings were also recorded over a range of different weather conditions.

4.2 MATERIALS AND METHODS

4.2.1 Cultural

Seed of the cultivar Rondello was sown in trays containing seed sowing media (Appendix 1) and germinated on a heated propagation bed at 22°C in a greenhouse heated to 16°C with ventilation at 22°C. After 7 days seedlings were pricked out into 100 mm plastic pots containing a standard growing on media (Appendix 2).

Table 4.1 Source sink series - important dates

Planting title	Sowing date	Planting	1st Anthesis	1st Harvest	Last harvest
Spring (CO_2)	2 July 1993	13 Aug 1993	2 Sep 1993	19 Oct 1993	8 Nov 1993
Spring (ambient)	2 July 1993	13 Aug 1994	12 Sep 1993	30 Oct 1993	18 Nov 1993
Summer (shaded)	9 Nov 1993	18 Dec 1993	1 Jan 1994	10 Feb 1994	7 Mar 1994
Summer (unshaded)	9 Nov 1993	18 Dec 1993	28 Dec 1993	10 Feb 1994	7 Mar 1994
Winter (CO_2)	28 Mar 1994	24 Apr 1994	14 May 1994	18 July 1994	11 Aug 1994
Winter (ambient)	28 Mar 1994	24 Apr 1994	23 May 1994	2 Aug 1994	31 Aug

Seedlings were grown on the greenhouse bench until the first inflorescence became visible, when they were planted into the NFT system (Plate 4.1). The base of the plastic pot was cut away before being placed into the NFT system. The NFT system, training of the plants and management of the nutrient solution was as described in 3.2.1.

A density of 13.5 plants per square meter was used for all three planting dates. There were 10 plants per 2.8 m NFT gulley with a bench consisting of six gullies each 260mm apart (Figure 2.1). A standard nutrient formula (Appendix 3) with an EC of

Plate 4.1 Seedlings 1 day after planting into the NFT system (CO_2 enriched crop)

Plate 4.2 Source sink treatment fruit nearing maturity (CO_2 enriched crop)

4.5 mS cm^{-1} was applied to all plants from the time of setting of the first fruit. This solution conductivity level was chosen based on the performance of the previous single truss crop trials, as the EC level which produces good fruit quality without a substantial yield loss.

4.2.2 Treatments

4.2.2.1 Number of crops

Three crops were grown in this series of experiments. They covered the spring, summer and winter growing periods. Sowing, planting and harvesting dates for each of these crops is detailed in Table 4.1.

4.2.2.2 Source sink strengths

Source and sink strengths were manipulated by changes in leaf and fruit number. The 2 levels of source and sink strength were combined factorially for each of the 3 crops.

The 2 levels of source strength were:

2 leaves above the fruit truss

3 leaves above the fruit truss

The 2 levels of sink strength were:

6 fruit per truss

8 fruit per truss

At the 100% anthesis, fruit trusses were thinned to either 6 or 8 fruit depending on treatment (Plate 4.2).

4.2.2.3 Carbon dioxide enrichment

Only the spring and winter crops were enriched. Enrichment of the summer crop was not possible as the regular ventilation of this crop made this impractical. The carbon dioxide was supplied from compressed carbon dioxide cylinders from 9.00 am to 5.00 pm each day unless ventilation was required. A Gas-o-mat carbon dioxide controller was used to monitor and control the CO_2 concentration at 1000 ppm.

4.2.2.4 Crop shading

With the summer crop there was a control (unshaded) and shaded treatment. The shading treatment was applied on days that were judged to have high radiation levels by covering the crops with a 32% shade cloth cover over the outside of the greenhouse. The judgement as to when to apply the shade was purely subjective.

4.2.2.5 Greenhouse compartments

A 6 x 18 m plastic film (EVA) greenhouse was used for the experiment. The greenhouse was divided into two equal sections by a plastic partition half way down the length of the house. These sections allowed one portion of the house to receive CO_2 enrichment or summer shading, while the other was the control (ambient CO_2 or unshaded). Each of the partitions had 3 benches of 6 gullies.

4.2.3 Experimental design

Within a planting the CO_2 and shading treatments were not replicated. The 3 benches in each section of the greenhouse allowed 3 replications of the source sink treatments. Each bench consisted of 2 outside guard rows, with 4 inside treatment rows divided into two plots - one plot for the 3 leaves per plant treatment, the other for the 2 leaf treatment. Each plot consisted of 6 plants for each source/sink treatment plus guard plants (Figure 4.1). A split plot design was used, with the source treatment as the main plot and the sink treatment as the sub plot. This was to avoid shading problems between the 2 source treatments.

4.2.4 Data Collection

4.2.4.1 Yield and fruit quality

All crops were harvested 3 times weekly at the orange-red stage of maturity. The harvesting period was 3 - 5 weeks depending on season (Table 4.1). On harvests three to five, fruit free from blemish were selected for quality assessment. Samples of 15 fruit from each plot (CO_2 x source/sink or shading x source/sink) were collected for dry matter determination and for freezing for later assessment of brix and titratable acidity

levels. Samples were also collected for shelf life assessment of the summer crop only.

Fruit dry matter, brix, titratable acidity and shelf life assessments were carried out as detailed in 2.2.4.1-2.2.4.4.

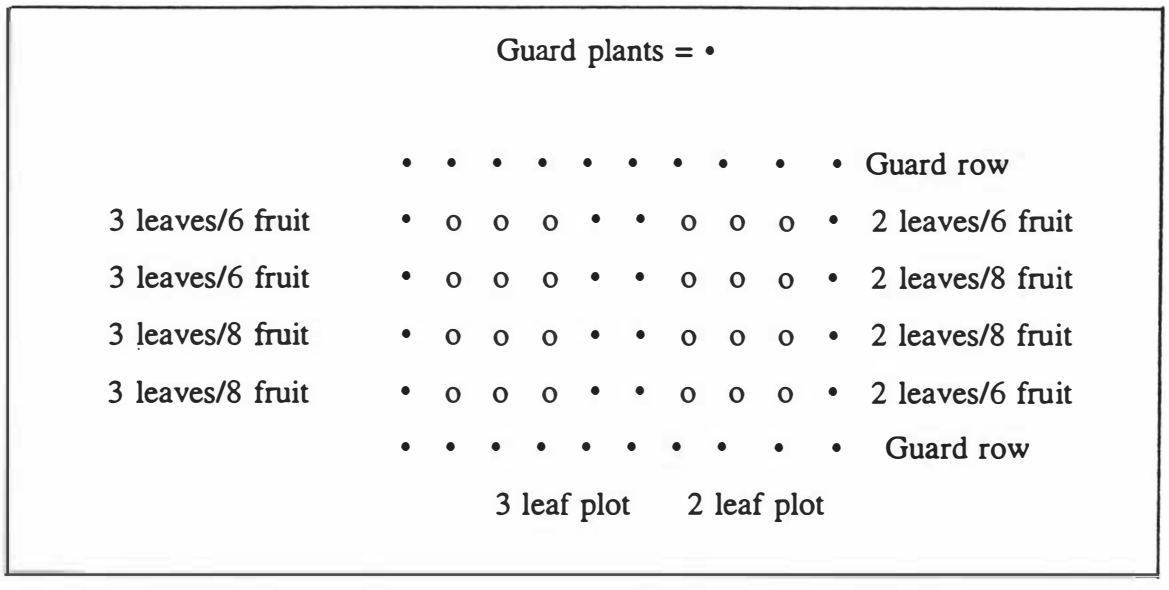


Figure 4.1 Example of a bench layout

4.2.4.2 Plant measurements

At the final harvest, the NFT system was drained of solution and plants cut at the base of the stem. Leaf area measurements on a sub sample of leaf tissue were then carried out.

4.2.4.3 Temperature measurements

Temperature was logged for the entire life of the summer crop in both the shaded and control sections of the greenhouse. Temperature thermocouples (2 in each side of the greenhouse) were placed where they could monitor air and canopy temperature every 15 minutes.

During fruit development of the summer crop, thermocouples were inserted into exposed

and shaded fruit to determine daily temperature fluctuations. Probes were placed just below the fruit surface on the exposed side of the fruit, in the fruit centre and under the skin on the shaded side of the same fruit. 15 shaded and 15 exposed fruit were monitored on each occasion. Temperature was logged for a 24 hour period for each fruit in both the shaded and control sections of the greenhouse. This was done on a number of days which experienced different weather conditions so that data covering a range of radiation levels could be studied.

4.2.5 Data analysis

An ANOVA was carried out on the data. All three crops were examined for the effects of season and the source sink treatment on crop performance using data from the control plants. The spring and winter crops were examined for the effects of season, CO_2 and the source sink treatment on crop performance, while the summer crop was examined for the effects of shading and the source sink treatment on crop performance.

4.3 RESULTS

4.3.1 Introduction

The results are presented in three sections:

(i). Effect of season and source/sink treatment on the performance of the spring, summer and winter crops (4.3.2).

(ii). Effect of season, CO_2 enrichment and source/sink treatment on the performance of the spring and winter crops (4.3.3).

(iii). Effect of shading and source/sink treatment on the performance of the summer crop (4.3.4).

4.3.2 Effect of season and source/sink treatment on the performance of the spring, summer and winter crops

4.3.2.1 Effect of season and source/sink treatment on yield and fruit size

Season and fruit number both had a significant effect on yield and fruit size (Table 4.2). The spring and summer crops produced a higher yield and larger fruit size than the winter crop (Table 4.3), while 8 fruit produced a higher yield per plant but smaller sized fruit then plants with 6 fruit.

Table 4.2 The effect of season and source/sink treatment on yield, fruit size, percentage dry matter, brix, percent citric acid and leaf area

	Yield	Fruit size	% Dry matter	Brix	% Citric Acid	Leaf area cm^2
Season	**	*	*	ns	ns	**
Leaf number	ns	ns	**	*	ns	*
Fruit number	**	**	ns	*	ns	ns
Season x Leaf	ns	ns	*	ns	ns	ns
Season x Fruit	ns	ns	ns	ns	ns	ns
Leaf x Fruit	ns	ns	ns	ns	ns	ns
Season x Leaf x Fruit	ns	ns	ns	ns	ns	ns

* $P < 0.05$
** $P < 0.001$
*** $P = 0.000$
ns = not significant

Table 4.3. Effect of season and fruit number on yield (g/plant) and fruit size (g/fruit)

		Yield (g/plant)	Fruit size (g/fruit)
Season	Spring	794	114
	Summer	800	116
	Winter	633	92
	s.e	23.1	2.9
Fruit number	6 Fruit	692	115
	8 Fruit	805	101
	s.e	15.1	1.9

4.3.2.2 Effect of season and source/sink treatment on fruit quality

There was a season x leaf number interaction for fruit dry matter percentage, while both leaf and fruit numbers had significant effects on brix levels (Table 4.2). There were no treatment effects on percent citric acid. With the 2 leaf series, the spring and summer crops had a higher percentage dry matter than the winter crop, while with the 3 leaf series the spring crop had the highest percentage dry matter (Table 4.4). The 3 leaf series produced a higher fruit percentage dry matter then the 2 leaf series in spring and winter. The 3 leaf series and the 6 fruit series produced fruit with the higher brix levels (Table 4.4).

Table 4.4 Effect of leaf and fruit number on fruit percentage dry matter and brix levels

Fruit percentage dry matter			
Leaf number	Spring	Summer	Winter
2 Leaves	6.08	6.27	5.52
3 Leaves	6.68	6.18	6.22
s.e		0.117	

Brix			
Leaf Number		Fruit number	
2 Leaves	3 Leaves	6 Fruit	8 Fruit
4.70	5.02	4.95	4.77
s.e	0.078		0.044

4.3.2.3 Effect of season and source/sink treatment on leaf area (cm^2) and leaf area index

Season and leaf number had a significant effect on plant leaf area (Table 4.2). The summer crop had the greatest leaf area and leaf area index (LAI) (Table 4.5), while the 3 leaf series had the higher leaf area per plant and LAI (Table 4.5).

Table 4.5 Effect of season and on leaf area (cm^2) and leaf area index (LAI)

		Leaf Area (cm^2)	Leaf area index (LAI)
Season	Spring	3345	4.5
	Summer	4714	6.3
	Winter	3267	4.4
	s.e	191.9	0.26
Leaf number	2 Leaves	3574	4.8
	3 Leaves	3976	5.3
	s.e	116.3	0.16

4.3.3 Effect of season, CO_2 enrichment and source/sink treatments on the performance of the spring and winter crops

4.3.3.1 Introduction

The effect of the CO_2 enrichment and source/sink treatment on the performance of the spring and winter crops are presented in Table 4.7. The effect of season and the source sink treatment on yield and fruit quality were reported in 4.3.2. Where the results from the analysis reported in this section are similar to those in 4.3.2, then they have not been detailed here again.

4.3.3.2 Effect of season and CO_2 enrichment on fruit Yield

Although not significant, the data for the effect of CO_2 enrichment on yield and fruit size is presented here as it is an issue of some practical importance (Table 4.6). The relative positions of control and CO_2 treatments were different for the two seasons.

Table 4.6 Effect of CO_2 enrichment on spring and winter yield and fruit size

	Spring		Winter		
	Control	CO_2	Control	CO_2	s.e
Yield (g/plant)	794	827	633	613	23.6
Fruit size (g/fruit)	114	118	92	87	3.08

4.3.3.3 Effect of season, CO_2 enrichment and source sink treatment on fruit quality

There was a significant season x CO_2 x fruit number interaction for fruit dry matter percentage, and brix (Table 4.6), and also for season x leaf number x fruit number for brix. For titratable acidity there was a season x CO_2 x leaf number interaction.

Table 4.7 Effect of season, CO_2 enrichment and source sink treatment on Spring and winter crops

	Yield	Fruit Size	% Dry Matter	Brix	% Citric Acid	Leaf Area	LAI
Season	***	***	***	ns	ns	*	*
CO_2	ns	ns	**	**	ns	**	**
Leaf number	ns	ns	**	*	ns	**	**
Fruit number	***	**	**	**	ns	**	**
Season x CO_2	ns	ns	**	**	ns	ns	ns
Season x Leaves	ns	ns	ns	ns	ns	ns	ns
Season x Fruit	ns	ns	ns	ns	ns	**	**
Leaves x Fruit	ns	ns	ns	ns	ns	*	*
Leaves x CO_2	ns	ns	ns	ns	ns	ns	ns
Fruit x CO_2	ns	ns	ns	**	ns	**	**
Season x Leaves x Fruit	ns	ns	ns	**	ns	ns	ns
Season x CO_2 x Leaves	ns	ns	ns	ns	**	ns	ns
Season x CO_2 x Fruit	ns	ns	**	*	ns	ns	ns
Season x CO_2 x Leaves x Fruit	ns	ns	ns	ns	ns	**	**

* $P < 0.05$
** $P < 0.01$
*** $P = 0.000$
ns = not significant

With the 6 fruit treatment CO_2 enrichment resulted in lower fruit percentage dry matter with the winter crop and higher dry matter with the spring crop (Table 4.8). The spring crop (general trend) and the 6 fruit series had the higher fruit percentage dry matter.

Table 4.8. Effect of season, fruit number and CO_2 enrichment on fruit percentage dry matter

Season	Fruit number	Control/CO_2	Fruit dry matter percentage
Spring	6 Fruit	Control	6.41
		CO_2	7.14
	8 Fruit	Control	6.34
		CO_2	6.58
Winter	6 Fruit	Control	6.08
		CO_2	5.37
	8 Fruit	Control	5.65
		CO_2	5.42
		s.e	0.09

The trend was for the 3 leaf and the 6 fruit series to produce the highest brix levels (Table 4.9). The only effect of season was for the spring x 3 leaf comparison where the 6 fruit series had the higher brix. CO_2 enrichment resulted in lower brix levels in the winter crop, but increased brix levels in the spring crop for the 6 fruit treatment (Table 4.9). The 6 fruit series had the higher brix levels in the spring enriched and winter ambient crops.

In the spring crop, CO_2 enrichment increased titratable acidity with the 3 leaf treatment and with the enriched 2 leaf series, while the winter crop had the higher titratable acidity (Table 4.9).

Table 4.9 Effect of season, CO_2 enrichment and source sink treatment on fruit brix levels and titratable acidity expressed as percent citric acid

		Brix	
Leaf number	Fruit number	Spring	Winter
2	6	4.73	4.72
2	8	4.55	4.47
3	6	5.15	4.82
3	8	4.67	4.75
	s.e	0.071	

		Brix	
CO_2 level	Fruit number	Spring	Winter
Control	6 Fruit	4.68	5.08
	8 Fruit	4.72	4.75
CO_2	6 Fruit	5.20	4.45
	8 Fruit	4.50	4.47
	s.e	0.07	

		% Citric acid	
CO_2 level	Leaf number	Spring	Winter
Control	2 Leaves	0.49	0.43
	3 Leaves	0.43	0.47
CO_2	2 Leaves	0.39	0.49
	3 Leaves	0.58	0.48
	s.e	0.036	

4.3.3.4 Effect of season, CO_2 enrichment and source sink treatment on plant leaf area and Leaf Area Index

There was a significant season x leaf number x fruit number x CO_2 enrichment interaction for leaf area (cm^2) and leaf area index (Table 4.7).

The spring crop had the higher leaf area apart from the 2 leaf/6 fruit control treatment combination (Table 4.10). With the winter crop enrichment decreased leaf area, while with the spring crop this response occurred only with the 2 leaf/8 fruit and the 3 leaf/6 fruit treatments. The only difference between the 6 and 8 fruit series was for the spring crop 2 leaf control series and the 3 leaf CO_2 treatments. Here the 8 fruit series had the larger leaf area.

Table 4.10 Effect of season, source/sink treatment and CO_2 enrichment on plant leaf area (cm^2) and leaf area index

Season	Leaf/fruit number	CO_2/control	leaf area	L A I
Spring	2 Leaves/6 fruit	Control	1973	2.7
		CO_2	2360	3.2
	2 Leaves/8 fruit	Control	3852	5.2
		CO_2	2855	3.9
	3 leaves/6 fruit	Control	3796	5.1
		CO_2	2965	4.0
	3 leaves/8 fruit	Control	3760	5.1
		CO_2	4002	5.4
Winter	2 Leaves/6 fruit	Control	3071	4.1
		CO_2	1898	2.6
	2 leaves/8 fruit	Control	3302	4.5
		CO_2	2189	3.0
	3 leaves/6 fruit	Control	3290	4.4
		CO_2	2574	3.5
	3 leaves/8 fruit	Control	3402	4.6
		CO_2	2339	3.2
		s.e	194.1	0.26

4.3.3.5 Effect of CO_2 on crop timing

CO_2 had the effect of advancing the time from sowing to flowering, the length of the fruit development period (flowering to harvest) and the harvesting period for both the spring and winter crops (Table 4.11).

Table 4.11 Effect of CO_2 on crop timing (Days)

Crop	Sowing - flowering	Flowering - harvest	Harvest length	Crop length
Spring (CO_2)	67	43	20	130
Spring (control)	73	54	19	140
Winter (CO_2)	48	61	24	133
Winter (control)	57	76	29	162

4.3.4 Effect of shading and source sink treatment on the performance of the summer grown crop

4.3.4.1 Introduction

The effects of shading and source/sink treatment on the summer crop are presented in this section (Table 4.12). The effect of the source sink treatments on yield and quality has been reported in 4.3.2 and 4.3.3. Where the results in this section are similar to those in 4.3.2 and 4.3.3, then they have not been repeated here.

4.3.4.2 Effect of shading and source sink treatment on the performance of the summer grown crop

Total yield, fruit size, marketable yield and fruit size were significantly increased under shade (Table 4.12), with both total and marketable yield being increased by 10 and 19% respectively by the shading treatment (Table 4.13). The effect of fruit number on brix was as detailed in section 4.3.2.

Table 4.12 Effect of source/sink treatment and crop shading on the summer crop

	Total Yield	Marketable Yield	Fruit Weight	% Dry Matter	Brix	% Citric Acid	Shelf Life	Leaf Area	LAI
Shade	**	*	*	ns	ns	ns	*	ns	ns
Leaf number	ns	ns	ns	ns	ns	*	ns	**	**
Fruit number	**	*	ns	ns	**	ns	ns	ns	ns
Shading x leaf number	ns	ns	ns	ns	ns	*	ns	*	*
Shading x fruit number	ns	ns	ns	ns	ns	ns	ns	ns	ns
Leaf no x fruit no	ns	ns	ns	ns	ns	ns	ns	ns	ns
Shading x leaf x fruit	ns	ns	ns	ns	ns	ns	ns	ns	ns

* $P < 0.05$
** $P < 0.001$
*** $P = 0.000$
ns = not significant

Total and marketable yield and fruit size was increased under shading (Table 4.13). Marketable yield was determined by removing fruit effected by blossom end rot, other ripening disorders and undersized fruit. There was a higher incidence of fruit effected by blossom end rot in the unshaded crop.

Table 4.13. Effect of crop shading on total and marketable crop yields and fruit size

Treatment	Total yield g per plant	Fruit size g per fruit	Marketable yield g per plant	Marketable fruit size g per fruit
Shaded	886	127	879	128
Unshaded	800	116	715	103
s.e	3.89	1.15	18.58	3.22
Percentage gain from shading	10%	8.7%	19%	20%

There was a significant shade x leaf number interaction for fruit percent citric acid (Table 4.12). Shaded plants had a lower level of percent citric acid then the unshaded plants (Table 4.14). Fruit from shaded plants with the 3 leaf treatment resulted in lower percent citric acid levels then the 2 leaf treatment. Shading also increased shelf life (Table 4.15).

Table 4.14 Effect of shading, leaf and fruit number on % citric acid

Shading	Leaf number	% citric acid	s.e
Shaded (32%)	2 leaves	0.51	
	3 leaves	0.47	
			0.0124
Unshaded	2 leaves	0.76	
	3 leaves	0.77	

Table 4.15. Effect of shading on fruit shelf life (days)

Shading	Shelf life (days)	s.e
Shaded (32%)	35.6	
		0.57
Unshaded	32.5	

There was a significant shade x leaf number interaction for leaf area. There was no difference in leaf area for the unshaded plants. For the shaded plants the 2 leaf treatment produced the smallest and the 3 leaf treatment the largest leaf area of the 4 treatments (Table 4.16)

Table 4.16 Effect of shading and leaf number on leaf area cm^2 and leaf area index

	Leaf Area		Leaf area index	
Leaf number	Shaded	Unshaded	Shaded	Unshaded
2 leaves	3742	4622	5.0	6.2
3 leaves	5059	4797	6.8	6.5
s.e	136.77		0.18	

4.3.4.3 Summer greenhouse and fruit temperatures

Shading reduced air temperatures in the 30 - 36°C range (Figure 4.2), and canopy temperatures in the 26 - 32°C range (Figure 4.3), over the life of the crop. Shading also resulted in a greater number of hours at the optimum air temperature range of 22 - 27°C, while the unshaded house experienced over 150 hours above 30°C (air temperature).

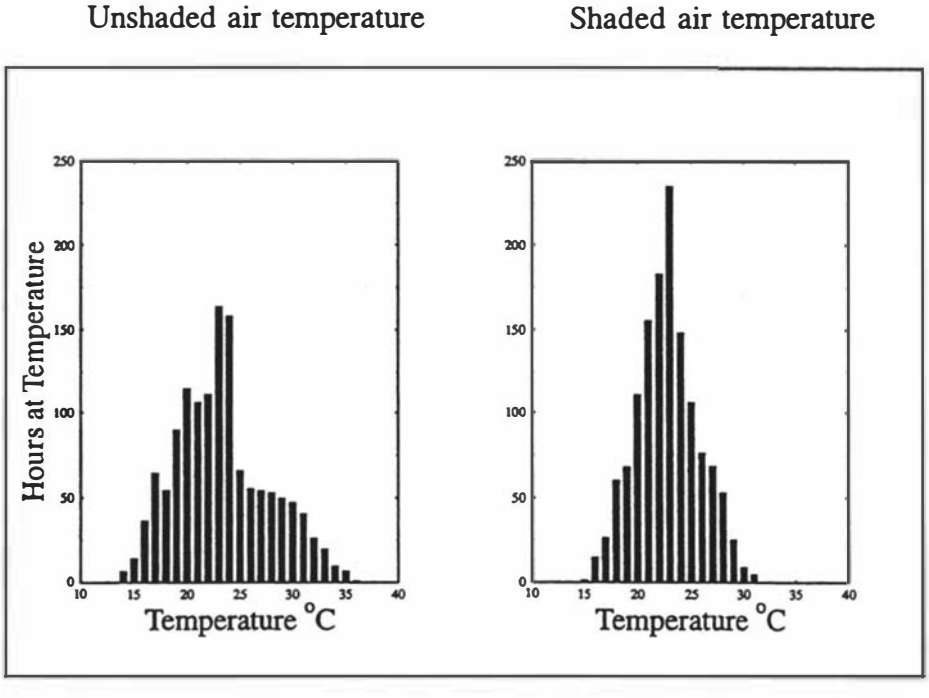


Figure 4.2 Air temperature of unshaded and shaded crops

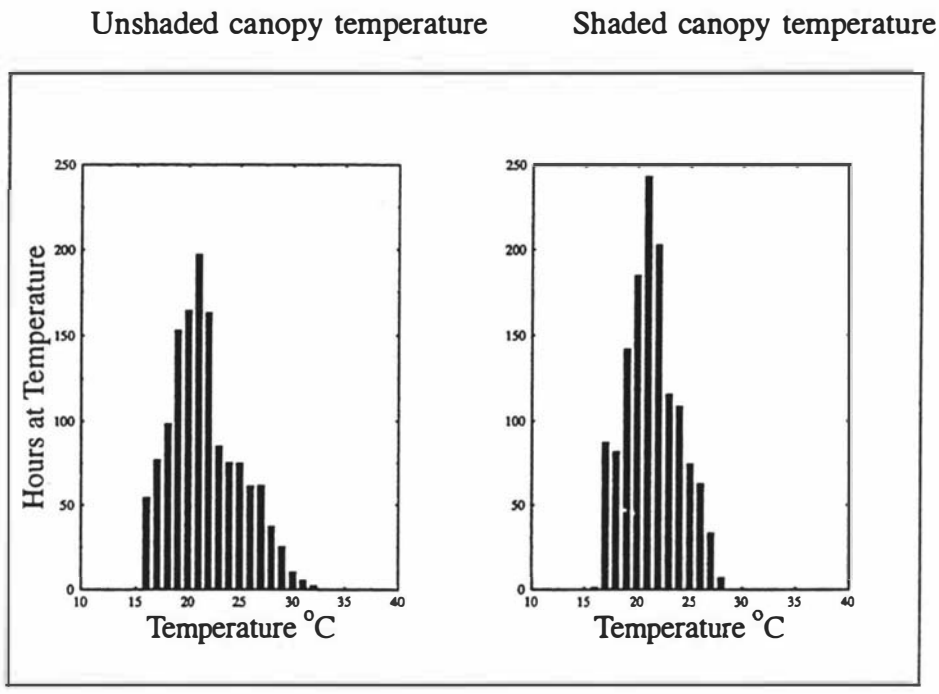


Figure 4.3 Canopy temperature of unshaded and shaded crops

Shading reduced temperature beneath the exposed fruit skin surface by over 10°C from 1pm to 4pm on a day with high radiation levels (Figure 4.4). Fruit reached temperatures of 45° C when exposed to direct solar radiation, but shaded fruit, although warmer then the air temperature did not reach the same extremes.

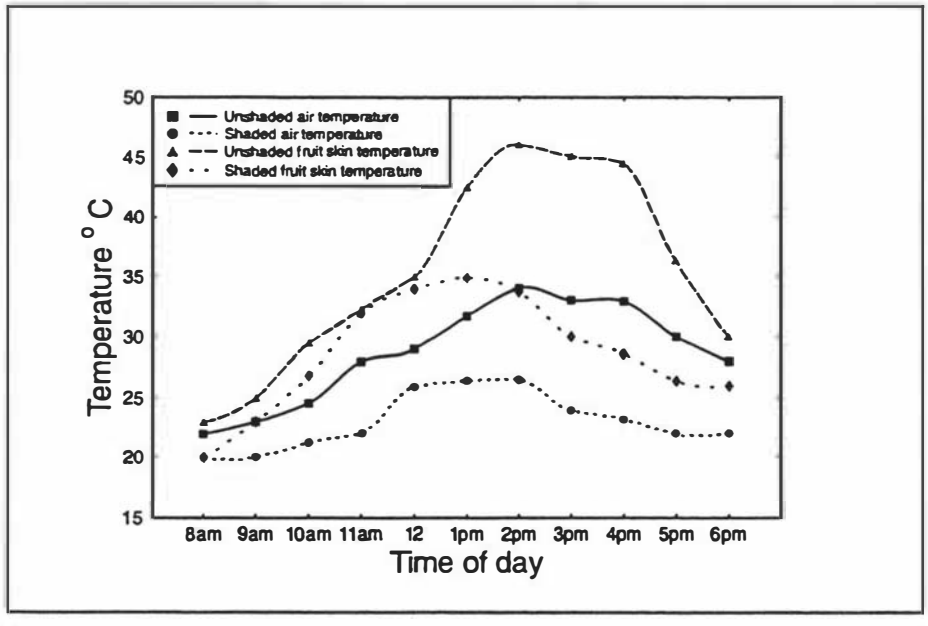


Figure 4.4 Fruit skin and air temperature of unshaded and shaded crops

In the unshaded crop, on a day with high radiation levels, temperature on the fruit surface reached 45 °C, while temperature at the fruit centre did not reach the same extremes it followed the same pattern throughout the day. Temperature on the shaded side of the same fruit remained closer to the actual air temperature (Figure 4.5). On a day with low radiation levels, fruit surface, centre and shaded side temperatures all remained close to the air temperature (Figure 4.6).

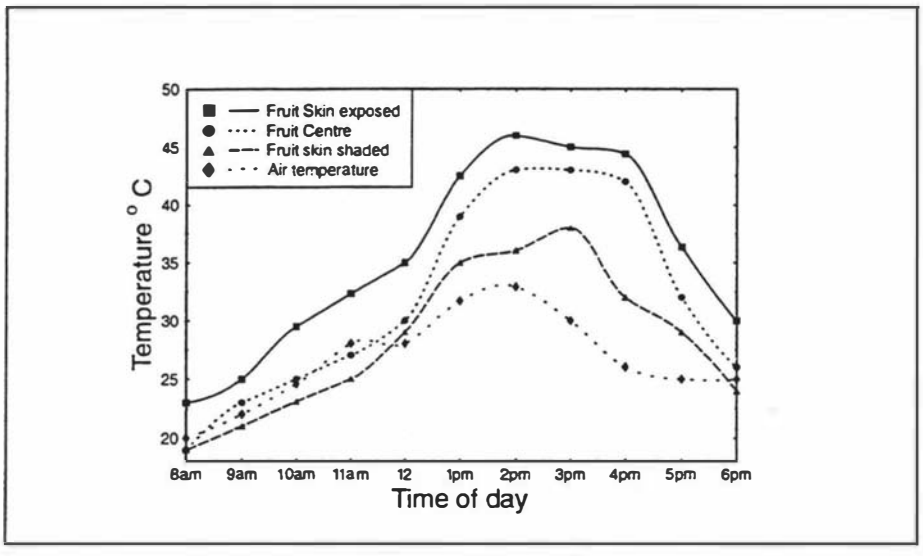


Figure 4.5 Temperature of exposed surface, fruit centre and shaded surface of an exposed fruit on a day with high solar radiation

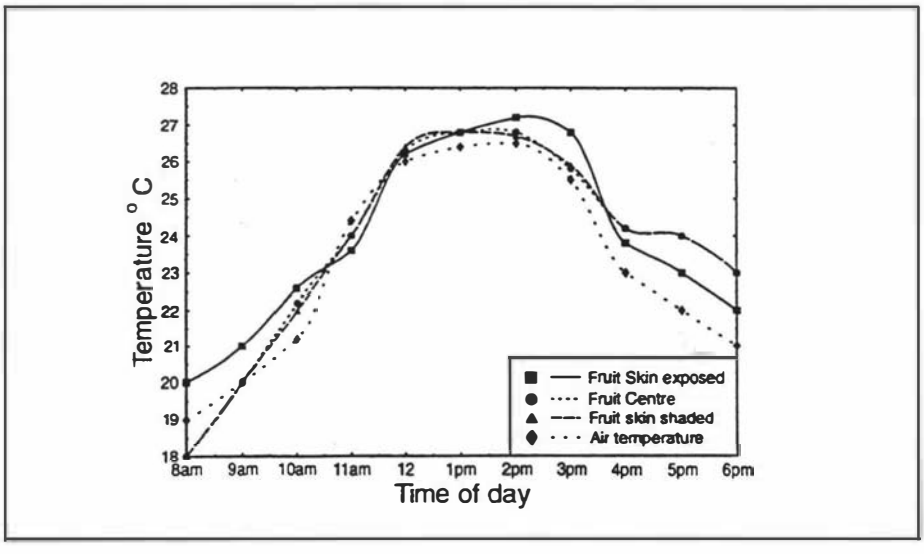


Figure 4.6 Temperature of exposed surface, fruit centre and shaded surface of an exposed fruit on a day with low solar radiation

4.6 DISCUSSION

4.6.1 Yield and fruit size for all three crops

4.6.1.1 Effect of season and source sink treatment on yield and fruit size

In the present investigation both yield and fruit size were significantly effected by season (4.3.2.1). Fruit yields were found to be highest in the summer crop, followed closely by the spring crop, but much lower in the winter crop (Table 4.3). It is suggested that these findings result from the higher light intensities in spring and summer, which cause more rapid growth, higher yields and greater fruit size (Table 4.3) than was obtained in the winter grown crop. Hurd and Thornley (1974) found that high light intensity produces higher growth and net assimilation rates of tomato plants while Cockshull et al, (1992) reported that yield was accumulated in direct proportion to solar radiation received. This has also been reported to be the case with single truss tomatoes (Mc Avoy et al, 1989b).

When the results from the present study are compared to the previous single truss crop experiment (3.3.1), it was found that yields per plant for all three crops were greater then the corresponding single truss crop in the first series of experiments. An average yield of 794, 800 and 633 g per plant was obtained for the spring, summer and winter crops respectively in the present study, while yields of 644, 510 and 384 (cultivar Rondello) were obtained in the first series of single truss crops. These could be a result of seasonal differences between the years in which the crops were grown (1992-1993 and 1993-1994), or a result of the fact that the two experiments were conducted in different greenhouses.

Leaf number had no effect on fruit yield. It can therefore be concluded that the optimum leaf area index had been reached. Source strength is the result of source size (leaf area) and source activity (net assimilation rate). Since yield did not respond to increased leaf area the response to season (radiation levels) suggests that the net assimilation rate is the limiting factor. Radiation and CO_2 levels determine the net assimilation rate. This suggests that the low winter yield was a direct result of lower radiation levels and that single truss tomato crops are source limited at least in the

spring and winter.

The effect of sink size on yield and fruit size follows an inverse pattern. The greatest yield but smallest fruit size was obtained from the 8 fruit treatments, and lowest yield but greatest fruit size from the 6 fruit treatments (Table 4.3). These results show that under the experimental conditions of the present study, the single truss plants are also sink limited. As increasing fruit number 6 to 8 fruit per truss increased yield per plant by 14% (113 g/plant). The fact that fruit size decreased with the 8 fruit series supports the view that source strength is also limiting yield.

Fisher (1979) found that increasing the sink size stimulated photosynthesis and Moorby and Jarmen (1975) also demonstrated this in single truss plants, finding that removing fruits reduced the rate of export of $^{14}CO_2$ labelled products from the leaves. Tanaka et al (1974a) stated that the net assimilation rate is under control of sink size and that leaves have a hidden potential to perform more active photosynthesis if sink size is increased.

This demonstrates a major difference between single truss and multi truss crop physiology. A multi truss plant with a lower leaf area per truss and competition between vegetative and fruit growth is usually seen as source limited. Thus what is limiting yield is not a lack of fruit on the plant (sink strength) but a lack of assimilates. While it is generally accepted that a multi truss plant is source limited, it is still possible to increase the net assimilation rate to a degree by increasing fruit load (Fisher, 1977). This was also found reported by Tanaka and Fujita (1974) who stated that in tomato plants the source exceeds the sink, but that the net assimilation rate is under the control of sink size. This is also true with single truss plants.

4.6.1.2 Effect of season and CO_2 enrichment on yield and fruit size

There was no effect of CO_2 enrichment on yield and fruit size (Table 4.7), this may have been because enrichment advanced crop maturity by 20% (Table 4.11) which allowed less time for fruit growth.

4.6.2 Fruit quality for all three crops

4.6.2.1 Effect of season and source/sink treatment on fruit dry matter percentage and brix levels

There was a season x leaf number interaction for fruit dry matter percentage (Table 4.2 and 4.4). The effect of season on fruit dry matter percentage is complicated by the effect of excessive summer greenhouse temperatures. High summer temperatures would have increased fruit respiration rates which may have resulted in the utilisation of fruit reserves thus reducing the percentage dry matter. Thus the dry matter percentage was not increased in summer as found by Adams and Winsor (1976). Low fruit dry matter in the winter crop was due to the effect of low light levels and reduced photosynthesis resulting in less assimilates for fruit growth. This was reported by Forshey and Alban (1954), who found a highly significant correlation between fruit quality factors and the number of hours of sunlight during the period in which the fruits made the major portion of their growth. This suggests that light levels are one of the major limiting factors influencing fruit quality.

Both fruit brix and percentage dry matter followed the same trend in terms of source/sink treatments (Table 4.4). With all seasons averaged fruit dry matter percentage and brix were highest in the 3 leaf treatments. Fruit brix levels were greatest in the 6 fruit treatment (Table 4.4). This suggests that there is a beneficial effect on compositional fruit quality of having an extra leaf above the truss. This was also found by Hewitt and Stevens (1981), who reported increasing solids levels in tomato fruit with increasing leaf area.

While fruit number had no significant effect on fruit dry matter percentage, brix was found to be highest in the 6 fruit treatments (Table 4.4). This finding is in agreement with Hewitt and Stevens (1981) who claimed that soluble solids content was inversely correlated with yield and is attributable to the inability of the leaves to produce sufficient photosynthate to maintain both high yields and high fruit solids. It was therefore expected that the highest yielding fruit number treatment (8 fruit), would have the lowest fruit solids as found by Hewitt and Stevens (1981).

4.6.3 Leaf Area and leaf area index for all three crops

4.6.3.1 Effect of season and leaf number on leaf area and leaf area index

Leaf area and leaf area index was highest in the summer crop and lowest in the winter crop (Table 4.5). This high leaf area value obtained in summer could have been a result of warmer root temperatures as Gosselin and Trudel (1984) found that leaf areas were generally increased by a rise in root temperatures from 12 to 30°C as might occur under summer conditions. Photoperiod and light intensity may also play a role in the larger summer leaf area per plant. Morgan and Clarke (1976), stated that a longer photoperiod (16 vs 12 hours) gave a 15% increase in leaf area. Therefore, root temperature, photoperiod and light levels all influenced plant growth so that leaf area was significantly increased in the summer crop.

The 3 leaf treatment had the highest leaf area as predicted (Table 4.5), due to the presence of the extra leaf above the fruit truss. The leaf area index values varied from 4.4 to 6.3 between the three seasons (Table 4.5). As with the previous single truss experiments, these leaf area index values are greater then the average multi truss leaf area of approximately 2.3 (Warren Wilson et al, 1992). This suggests that the high density of the single truss crops results in a canopy where only the upper 2 - 3 leaves are activity photosynthesising.

4.6.4 Effect of season, source/sink treatment and CO_2 enrichment on fruit quality

4.6.4.1 Effect of season, source/sink treatment and CO_2 enrichment on fruit percentage dry matter and brix levels

There was a significant effect of leaf number and a season x fruit number x CO_2 enrichment interaction for fruit dry matter percentage and brix levels (Table 4.7).

CO_2 enrichment increased fruit quality slightly in terms of fruit percentage dry matter, and brix in the spring crop, but had the reverse effect in the winter crop (Table 4.8 and 4.9) These results indicate that CO_2 enrichment interacts with season (environmental factors) to influence fruit quality. It is possible that the winter grown crop at ambient CO_2 which took three weeks greater to develop, had a longer period of time to

accumulate dry matter and sugars then the CO_2 enriched crop. However, in the spring crop, the effect of increasing light levels interacted with the CO_2 enrichment to produce more assimilates and improved fruit quality. Other researchers agree that CO_2 enrichment has no significant effect on fruit quality with multi truss tomato crops (Slack et al, 1988: Davies and Winsor, 1969). These findings from the present single truss fruit quality data suggest that single truss plants may respond differently with respect to CO_2 enrichment during the spring and winter seasons.

The fruit number treatments responded differently to CO_2 enrichment, with the differences in dry matter and brix between CO_2 enriched and ambient crops being greatest for the 6 fruit treatments.

4.6.4.2 Effect of season, source/sink treatment and CO_2 enrichment on fruit titratable acidity levels

There was a significant season x leaf number x CO_2 enrichment interaction for fruit titratable acidity levels (Figure 4.6). The pattern of the effect of CO_2 on fruit acidity is not as well defined as was shown to occur in the dry matter and brix level data. CO_2 enrichment interacted with each source treatment differently so that no distinct pattern is evident.

4.6.4.3 Effect of season, source/sink treatment and CO_2 enrichment on plant leaf area (cm2) and leaf area index

There was a significant season x leaf number x fruit number x CO_2 enrichment interaction for plant leaf area and leaf area index (Table 4.6). In the winter crop, ambient CO_2 levels consistently increased leaf area and leaf area index for all source/sink treatments (Table 4.10). The increased leaf area from the non enriched crop may be due to the fact that this crop had a longer developmental period in both the vegetative and reproductive phases and therefore had a longer time to develop a larger leaf area. However this explanation does not hold true for all the source/sink treatments in the spring crop. A more likely explanation is that CO_2 may have acted to cause a thickening of the leaves in the enriched crop as found by Klapwijk and Wubben (1984). Bruggink (1984) also stated that at higher CO_2 concentrations leaf thickness increases

which means a decrease in the leaf area ratio.

In the spring crop there is no pattern for the effect of either CO_2 enrichment or source/sink treatment on plant leaf area and leaf area index.

4.6.4.4 Effect of CO_2 enrichment on crop timing

CO_2 enrichment is known to advance both the date of anthesis and shorten the duration of harvest in both single truss crops (Hand and Postlethwaite, 1971) and in multi truss crops (Calvert, 1972). This was found in both the spring and winter single truss crops in the present study (Table 4.11). The spring enriched crop has a 10 day shorter total crop length, the winter crop a 29 day shorter cropping period then the ambient CO_2 treatments. The major advantage of this effect of crop advancement with CO_2 enrichment is that it would allow an extra crop per year to be produced in the single truss system, thus increasing yearly yield significantly.

4.6.5 Effect of summer shading on the February harvested crop

4.6.5.1 Effect of summer shading on fruit yield and size

Total fruit yield was increased by 10% and marketable yield by 19% in the shaded crop (Table 4.13). This increase in yield under shade was a result of a 20% increase in fruit size as all fruit numbers were set at 6 or 8 fruit per truss. The difference between the total and marketable yields in the unshaded and shaded crops was due to the large numbers of the exposed fruit developing blossom end rot early in the life of the crop. It is also due to fruit being rejected due to scorch, crazing on the fruit surface and uneven coloration (blotch). Although blossom end rot was likely to have been a result of the environmental conditions in the plastic covered greenhouse, it would have been intensified by the high fruit temperatures the exposed crop were subjected to. The incidence of blossom end rot was only slight in the shaded crop, suggesting that the higher temperatures in the exposed crop fruit did play a major role in the development of this condition in the unshaded crop.

Fruit quality problems which reduce marketable yield such as scorch, crazing and uneven ripening are directly attributable to exposed fruit being under heat stress. This

was found by Lagier and Brun (1988), who reported that scorched and split fruit were particularly evident in an unshaded control crop as compared to a 50% shaded crop. Slack et al (1988) also reported that the amount of non-marketable yield in a high temperature regime (venting at 26° C compared to 21°C), was more then four times that in the normal regime.

Apart from the detrimental effects of high fruit temperature on quality and ripening disorders, crop heat stress also reduced fruit size (Table 4.13). This result was also reported in the previous single truss crops when low summer yields occurred in the December - February period (3.3.1.3). This effect of high temperature on single truss yield loss have been confirmed in this trial where shading was shown to reduce temperatures and increase yields. Other researches have reported similar findings. Lagier and Brun (1988), found that plants grown under 50% shade had a higher average fruit weight then the control group. El-Aidy and Moustata (1983), also reported increases in average fruit weight under shade and Russo (1993) found that shade improved total fruit yield at certain times of the year.

The yield loss in the unshaded crop may be attributed to the combined effects of a reduction in photosynthesis at high temperatures and increased fruit respiration rates. The effect of temperature on assimilate importation rates is not clear. Walker and Ho (1977b), reported that carbon import was enhanced by fruit warming at 35°C, but at this temperature there was a net loss of reserve material due to the breakdown of starch. We can therefore assume that although assimilate importation was not restricted at the temperatures the exposed fruit were reaching, there was a net loss of reserves due to higher respiration rates.

There may also have been an inhibition of net photosynthesis during the warmest part of the day when canopy temperatures reach above 30°C. Measurements on single truss plants in growth cabinets indicate that net photosynthesis is restricted at leaf temperatures above 30°C, and completely inhibited at 42°C (5.3.1.1). We might therefore expect that the 2 - 3 leaves above the truss exposed to direct radiation may have had reduced net photosynthesis for a short period during the day, thus reducing

assimilate available for fruit growth. However, this is not considered to be the major reason for yield losses in the unshaded crop as photosynthesis would only have been reduced for a short period each day. The more likely cause of the 20% reduction in fruit size in the control crop is the effect of excessive temperatures on fruit respiration rates.

The rate of fruit respiration is highly temperature dependent (Walker and Thornley, 1977), with a 50% rise in respiration rate for every 10°C increase in temperature recorded (Gale, 1982). Gale (1982) also reported that this increase in respiration rate is in order to supply the energy required to cope with higher rates of protein turnover and the damage resulting from high temperatures (38°C). We would therefore expect that at the temperatures the exposed fruit were reaching, reserve material was being utilised in a high rate of respiration preventing the yield increases that would have otherwise occurred.

4.6.5.2 Effect of summer shading and source/sink treatment on fruit titratable acidity levels

There was a significant shading x leaf number interaction for fruit titratable acidity levels (Table 4.12). The three leaf treatment had a greater acidity level in the exposed plants. This is due to the increased amount of radiation reaching the fruit surface which is known to increase fruit acidity levels. This has been reported in a number of investigations. Forshey and Alban (1954) found that fruits grown in the shade contained less ascorbic acid then similar fruits that were unshaded. McCollum (1946) also stated that there was a striking increase in acidity of unshaded over shaded fruits.

4.6.5.3 Effect of summer shading on fruit shelf life

Fruit shelf life was greater in fruit from the shaded crop then from the exposed crop (Table 4.15). This result of shaded fruit having a greater shelf life then exposed fruit is likely to be due to the different temperatures the fruit experienced during development. The shaded crop, having been grown cooler then the exposed crop would be expected to not only have a greater shelf life but also be firmer. Winsor (1966) stated that temperature was the most important environmental factor affecting fruit

firmness. Sharshak and Winsor (1964) reported that fruits grown at a day temperature of 29.3°C were 30% softer then those grown at 18.3 °C. Since softness is related to the rate of deterioration of a tomato fruit - softer fruit having a reduced shelf life, the exposed crop would therefore produce fruit of a lower shelf life simply because of the higher temperatures experienced during fruit development.

4.6.5.4 Effect of summer shading and leaf number on leaf area and leaf area index

The difference between the leaf area and leaf area index of the 2 and 3 leaf treatments was greater in the shaded crop, with only a 175 cm^2 difference in the unshaded crop between leaf treatments (Table 4.16). The highest leaf area and leaf area index value was obtained in the 3 leaf shaded treatment. This effect of greater leaf area under shade was also found in an investigation by Cockshull et al (1992), who reported that the average area of each expanded leaf was estimated to be 22.1 and 48.8% greater in the light and heavy shade treatments respectively as compared to an unshaded control treatment. A possible explanation for this greater leaf area of shaded crops is that some species have been shown to increase their leaf areas as an adaptation response to low light conditions in order to maintain their relative growth rates (Gosselin and Trudel, 1984).

4.6.5.5 Summer greenhouse air and fruit temperatures

The number of hours at air and canopy temperatures in the late 20s and early 30s °C were reduced under shade (Figure 4.2 and 4.3). On average the effect of shading on a day with high solar radiation levels was to reduce air temperature by 2 - 7°C. This was also found by Lagier and Brun (1988), who reported that the benefit of shading was most evident in extreme temperature conditions above 30°C, when foliage temperature was reduced on average by 2 - 3°C. El-Aidy et al (1983), in a trial conducted in Egypt during late summer, found that the air temperature was always lower under shade.

The most beneficial effect of crop shading was the reduction in fruit temperatures due to the fruit being protected from exposure to direct solar radiation (Figure 4.4). Since in a single truss crop, more then 50% of the fruit are normally exposed to direct solar

radiation, average fruit temperatures are much greater then would be experienced in a multi truss crop which has a developing canopy shading each truss. During the warmest part of the day, fruit temperatures were reduced by 15°C under the fruit skin. At the temperatures the exposed fruit were reaching, often in the range 30 - 45°C, cell damage and rapidly increasing fruit respiration would be occurring. This was also found by Lipton (1970) who reported that fruit exposed to direct solar radiation reached temperatures in excess of 40°C in the fruit wall and 38°C in the fruit centre.

4.6.5.6 Summary

Crop shading increased summer single truss marketable fruit yield by 19% and fruit size by 20%. The major effect of crop shading is to reduce fruit temperatures by preventing fruit being exposed to direct solar radiation. The yield losses in the crop are largely attributed to increased respiration rates of exposed fruit due to excessive temperatures. Exposed fruit also result in a higher incidence of blossom end rot and ripening disorders which reduce marketable fruit yields. Therefore shading is beneficial in summer single truss crops in order to prevent excessive yield losses due to heat stress.

CHAPTER 5

THE EFFECT OF ENVIRONMENTAL CONDITIONS ON PHOTOSYNTHESIS AND RESPIRATION OF SINGLE TRUSS TOMATO PLANTS

5.1 INTRODUCTION

The physiology of the single truss plant differs from that of a multi-truss plant because of the presence of only one truss of fruit. Furthermore, once the plant has been stopped after the production of 2-3 leaves above the truss, there is no further vegetative development and therefore no young leaves to take over photosynthesis from the older foliage. With multi truss crops maximum net photosynthetic rates of single leaves decreases rapidly with the age of the leaf, with maximum photosynthesis occurring when the leaves are about 30 - 50% expanded (Ludwig and Withers, 1984). Tanaka et al (1974b) reported that leaves of different ages have different photo-response curves to radiation intensities. It is therefore important to the present study to determine if the presence of ageing foliage results in net photosynthesis of these leaves falling with time, so reducing the supply of assimilates to the single truss plant. In the present study this issue will be examined by determining the effect of a range of radiation intensities on the net photosynthetic rate of the leaves of different ages. The second objective of this experiment was to determine the temperature response curve of photosynthesis of single truss plants under a constant radiation level. Exposed single truss foliage in a cropping situation may remain at temperatures above the optimum range for photosynthesis for certain periods of the day, thus reducing the amount of assimilates produced for fruit growth. By measuring leaf net photosynthesis over a range of temperatures commonly experienced by the crop in summer, the reduction in net photosynthesis with increasing temperature could be determined.

Another major difference between single and multi-truss plants is that the tall, developing canopy of the multi-truss plant shades the fruit from direct radiation and the fruit remains cooler then in the shallow canopy of the single truss crop. A high proportion of the single truss fruit is exposed to direct solar radiation. Fruit temperatures have been shown to reach extreme temperatures of over 40°C, (4.3.4.3).

Increased temperature results in a higher rate of fruit respiration. Lurie and Klein (1992) reported that tomato fruit showed a 50% increase in respiration with a temperature rise from 12 to 38°C. Walker and Ho (1977b) reported a net loss of reserve material in tomato fruit due to the breakdown of starch at a temperature of 35°C. Lipton (1970) found that with air temperatures reaching 30 - 35°C, the actual temperature of the leaves was close to 35 - 45°C, temperatures that approach those lethal to young cells of higher plants. Both the effect of high fruit and foliage temperature are suspected to have resulted in reduced yields during the summer months in unshaded plants in the present research (4.3.4.2).

In order to support the argument that high summer greenhouse temperatures, particularly direct solar radiation on the fruit surface, reduced summer yields, measurements of single truss fruit respiration over a range of temperatures was carried out. The objective was to determine if high temperature could account for the loss of yield obtained in summer grown single truss crops.

This series of experiments was designed to allow an examination of the physiology of the single truss plant in terms of photosynthesis, leaf age and fruit respiration and the environmental factors which influence these.

5.2 MATERIALS AND METHODS

5.2.1 Cultural

Seeds of the cultivar Rondello were sown into seedling trays containing a seed sowing media (Appendix 1), and germinated on a heated propagation bed at 18 - 20°C in a temperature controlled greenhouse. After 7 days seedlings were transplanted into 100 mm plastic pots containing a standard media (Appendix 2). Seedlings were grown on in a greenhouse until the appearance of the first inflorescence, when they were either planted into PB 18 planter bags containing 11 litres of media for the photosynthesis experiments (5.2.1.1) or transplanted into an NFT system for the respiration experiment (5.2.1.2).

5.2.1.1 Photosynthesis experiments

Seedlings were planted into PB 18 planter bags containing a short term standard media (Appendix 2). Plants also received nutrient solution based on that recommended by Tregidga et al (1986) (Appendix 3) with an EC of 2 mS cm^{-1} twice weekly. Plants were grown in a greenhouse with a minimum temperature of 16°C via the heating system with ventilation at 22°C. All laterals were removed as they developed and the plants were stopped after the production of the second leaf above the first inflorescence. A truss vibrator was used to assist pollination. Plants were supported by tying to a stake in each planter bag.

5.2.1.2 Fruit respiration experiments

Rondello seedlings in 100 mm plastic pots had the base cut from the pot before placing in the NFT system. NFT gullies were covered with plastic film to prevent light penetration and algae growth. Plants were grown in an environment with a minimum temperature of 16°C via the heating system with venting at 22°C.

All laterals were removed as they developed and the plants were stopped after the production of the second leaf above the first inflorescence. A truss vibrator was used to assist pollination. Plants were supported by tying the stem to a wire at a height of 30cm above the NFT gully. There were 13.4 plants per square meter. This consisted of 10 plants per 2.8m NFT gulley with a bed consisting of six gullies each gully 260mm apart.

180 plants were grown on 3 NFT benches with each bench having 2 outside guard rows. Plants on the four inner rows for each bench were assigned a temperature treatment and date of assessment (5.2.3.2).

A standard nutrient formula (Appendix 3) with an EC of 4.0 mS cm^{-1} was applied to all plants. The solution level, conductivity and pH was adjusted daily. pH was corrected with either phosphoric acid or potassium hydroxide to a level of 5.5 - 6.5. Conductivity was increased by addition of small amounts of concentrated stock solution or lowered with the addition of water. The nutrient solution was replaced every three weeks to

prevent imbalances in nutrient levels.

5.2.2 Treatments

5.2.2.1 Photosynthesis experiments

5.2.2.1.1 Effect of leaf age and radiation intensity on net leaf photosynthesis

15 plants were grown on under standard greenhouse conditions (5.2.1.1). At flowering, which was six weeks after sowing of the seed, a uniform line of 10 plants were selected and allocated to 2 groups of 5 plants. This was carried out as 5 plants was the maximum number which could be accommodated in a growth cabinet. The first group of plants was placed in a growth cabinet and allowed to acclimatise for 2 days before the determination of leaf net photosynthesis on the top 2 leaves. Measurement was only carried out on the top 2 leaves as these are the major producers of assimilate for fruit growth. After this the plants were returned to the greenhouse and the second group of plants placed in the cabinet. This procedure was repeated at 10, 12 and 14 weeks after sowing (Table 5.1).

Table 5.1 Plant developmental stages

Treatment period	Plant age (weeks after sowing)	Stage of development
1	6	Full flowering of truss
2	10	50% final fruit size
3	12	2 - 5 days before first harvest
4	14	2 - 5 days after harvest

5.2.2.1.2 Effect of temperature on net leaf photosynthesis

40 plants were grown for this experiment (5.2.1.1). At 10 weeks after seed sowing the temperature effect on leaf net photosynthesis was determined. Further readings over time as the plant aged could not be carried out due to a lack of growth cabinet facilities. Leaf net photosynthesis was determined over a range of temperatures from 25 - 40°C (Table 5.2). Of the 40 plants grown for this experiment, 6 uniform plants were allocated

at random to each of the 5 temperatures, so that 5 of these 6 would be placed in the growth cabinet, the sixth plant being replacement in case of plant death of loss of the fruit truss. The groups of 5 plants were placed in the growth cabinet to acclimatise for 3 hours before determination of leaf net photosynthesis. This process was repeated starting at the lowest temperature until the 5 temperature regimes had been assessed.

Table 5.2 Photosynthesis x temperature treatments - 10 weeks after sowing

Treatment	Number of plants	Temperature °C	Radiation level $\mu mol.m^{-2}.s^{-1}$ Quanta
1	6	25	800
2	6	30	800
3	6	35	800
4	6	40	800
5	6	45	800

5.2.2.2 Effect of temperature on fruit respiration

There were 4 temperature treatments and 4 dates of assessment (Table 5.3). 180 plants were grown on 3 NFT benches (5.2.1.2) with each bench treated as a replicate. Plants on the inner rows of each bench were assigned a date of assessment (5.2.3.2). A four plant plot for each replicate was allocated to each assessment date with 1 plant for each temperature treatment.

Table 5.3 Respiration treatments

Times of assessment:	18 days after fruit set (Truss 30% of full size)
	26 days after fruit set (Truss 50% of full size)
	36 days after fruit set (First fruit mature green)
	40 days after fruit set (Mature fruit - mixed colour)
Temperature treatments:	25, 30, 35 and 40°C

5.2.3 Data collection

5.2.3.1 Leaf photosynthesis experiments

5.2.3.1.1 Leaf net photosynthesis determination

Photosynthesis was measured by the LiCor Li6200 photosynthetic apparatus which has the capacity to measure and record air and leaf temperature, net photosynthesis, stomatal conductance and resistance and internal CO_2 levels. This instrument calculates net photosynthetic rate by measuring the rate of CO_2 uptake from a sealed container surrounding the leaf as a function of time.

5.2.3.1.2 Effect of leaf age and radiation intensity on leaf net photosynthesis

Recordings for the photosynthesis x radiation intensity x leaf age experiment began with the onset of flowering. After acclimatization in the growth cabinets at 25°C, the top 2 leaves of each plant were tagged for net photosynthesis measurement. Net photosynthesis was recorded at full illumination (800$\mu mol.m^{-2}.s^{-1}$ Quanta) and at a range of radiation intensities from 150 to 750 $\mu mol.m^{-2}.s^{-1}$ Quanta. Radiation levels were adjusted with the use of a range of different shade cloth covers. Plants were allowed to adjust to each new radiation intensity for 2 hours before readings were taken. These measurements were repeated every two weeks as the plants aged to determine how the plants response to different radiation intensities changed with leaf age.

5.2.3.1.3 Effect of temperature on photosynthesis

For the photosynthesis x temperature experiment, after acclimatization at each temperature, net photosynthesis was determined by clamping young mature fully exposed leaves in the chamber of the Li-cor. Net photosynthesis was then recorded, along with leaf temperature. Two leaves on each plant were measured for each temperature treatment.

5.2.3.1.4 Fruit respiration experiments

The fruit respiration chamber consisted of two, 100 litre air tight chambers (with a water seal at the base) each with a small fan to circulate air (Figure 5.1). Each chamber had an inlet and outlet to allow for air to be continuously drawn from the chamber, passed through the Binos infra red gas analyser and returned to the chamber. Both respiration

chambers were enclosed in a temperature controlled cabinet in complete darkness.

Before measurement, each plant stem was severed 150 mm either side of the truss stalk (Figure 5.2). The entire truss, stalk and stem portion were placed in the fruit respiration chamber and the cabinet heated to the required temperature (either 25, 30, 35 or 40°C). The time taken to reach the required fruit temperature varied from one hour for small fruit in the first reading to 3 hours for the larger mature fruit at final harvest. When the fruit had reached the required temperature, determined by an extra 'test fruit' with a thermocouple inserted in the centre, the chamber was briefly opened to vent any CO_2 evolved during the heating process. The chamber was then resealed and the CO_2 evolved from the fruit over a 30 minute period was measured by the Binos infra red gas analyser.

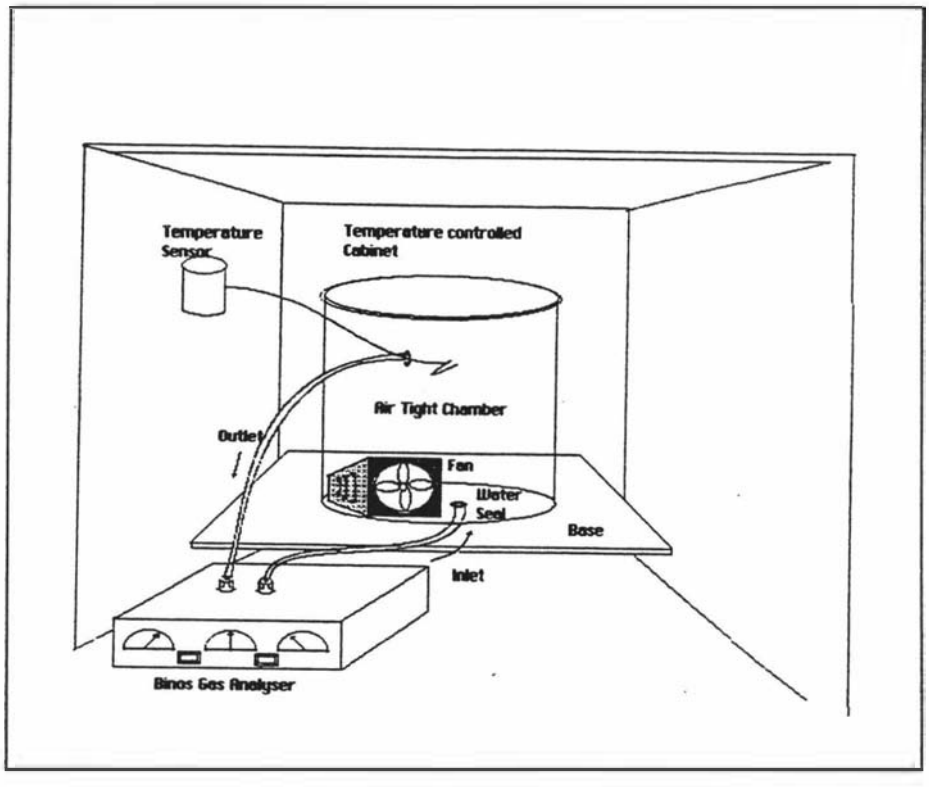


Figure 5.1 Respiration chamber

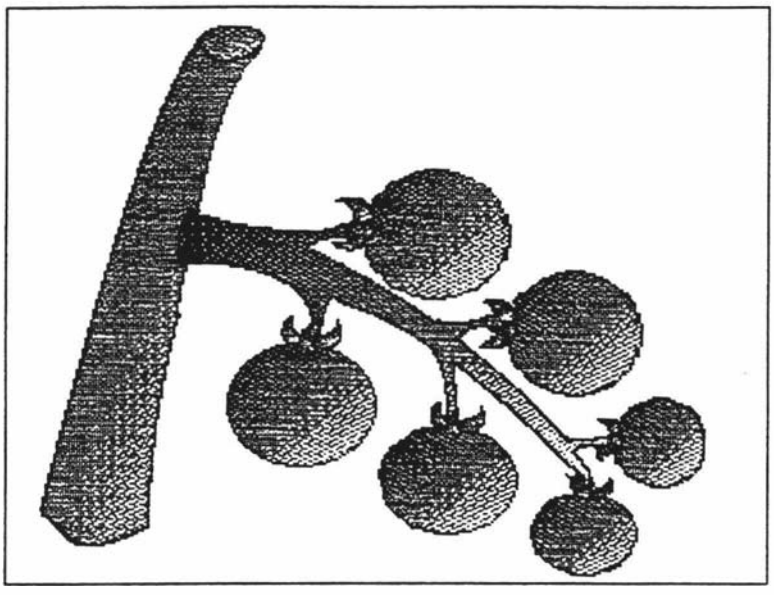


Figure 5.2 Diagram of truss, stalk and portion of plant stem which was severed from each plant and placed in the fruit respiration chamber.

At each measurement date (Table 5.3), 1 plant from each block, for each temperature treatment were cut at the base and taken to the fruit respiration chamber. Fruit for respiration measurement were harvested on this plot basis (Figure 5.3), in order to prevent a lack of competition as successive plants were removed.

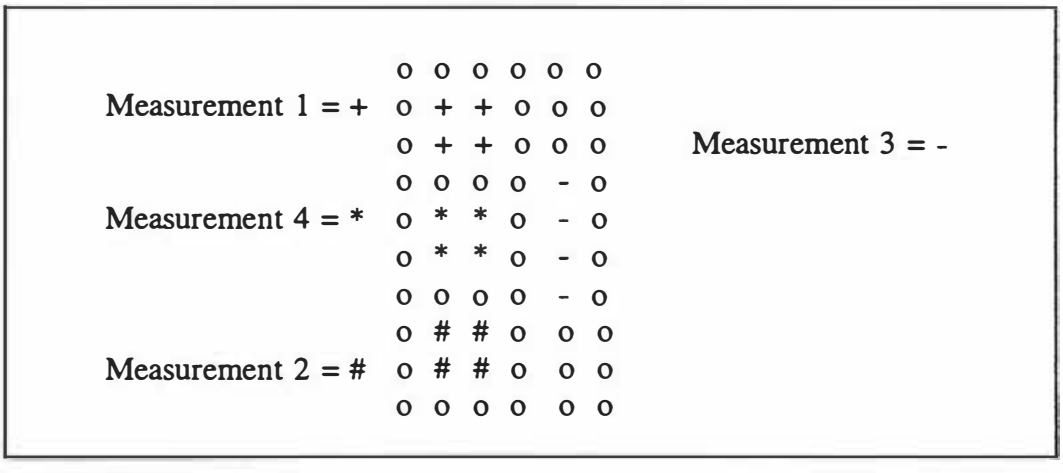


Figure 5.3 Example of a bench - plant selection system for respiration measurement.

Fruit respiration determinations were as in Table 5.4.

Table 5.4 Fruit respiration determinations

Determination	Tissue measured
1	Fruit truss and stem portion
2	Fruit truss and stem portion - stem cuts sealed
3	Fruit only (calyx absent)
4	Calyx, truss and stem - fruit removed
5	Fruit only - stem scar sealed (36 days after fruit set)

It is known that there is little gaseous exchange through the surface of the tomato fruit with most of the exchange taking place through the stem scar (Bergevin et al, 1993). The selection of these combinations of plant tissue were so that respiration of attached and detached fruit could be determined as well as the contribution made by the associated plant tissue to overall respiration. Fruit and stem fresh and dry weights were recorded for later conversion to a per Kg basis.

5.3 RESULTS

5.3.1 Photosynthesis experiments

5.3.1.1 The effect of leaf age and radiation intensity on net photosynthesis

Net photosynthesis at each radiation level declined with plant age from 6 weeks to 12 weeks after sowing (Figure 5.4). Data points are only presented for the 6 week determination. After fruit harvest (14 weeks after sowing), net photosynthesis rates increased above that for 10 and 12 weeks. Light saturation was not reached at the highest light level. The light compensation point (point where net photosynthesis became zero), also shifted with leaf age. The light compensation point increased up until the time of fruit harvest when it began to drop rapidly (Figure 5.5).

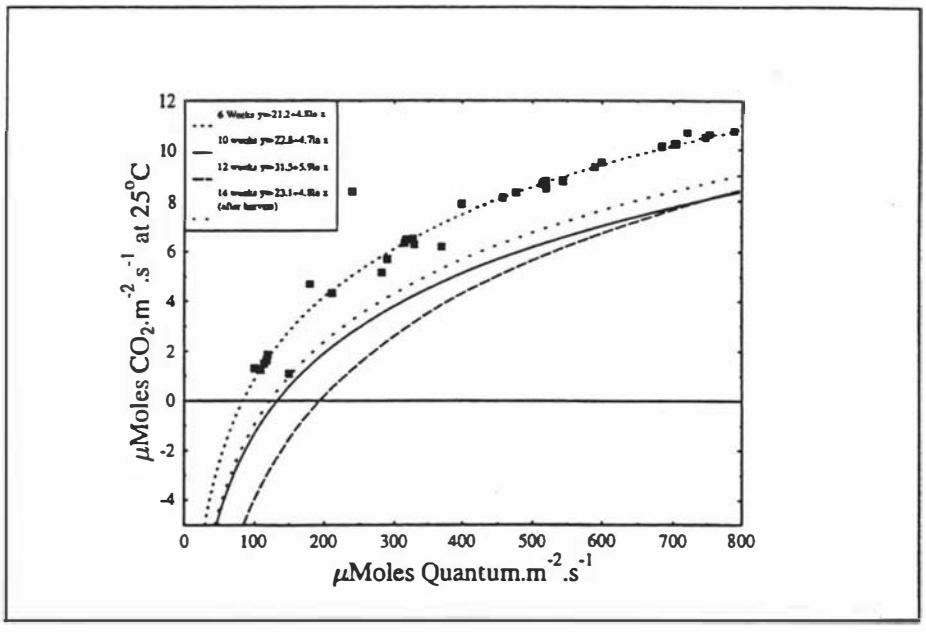


Figure 5.4 Effect of leaf age and radiation level on net photosynthesis

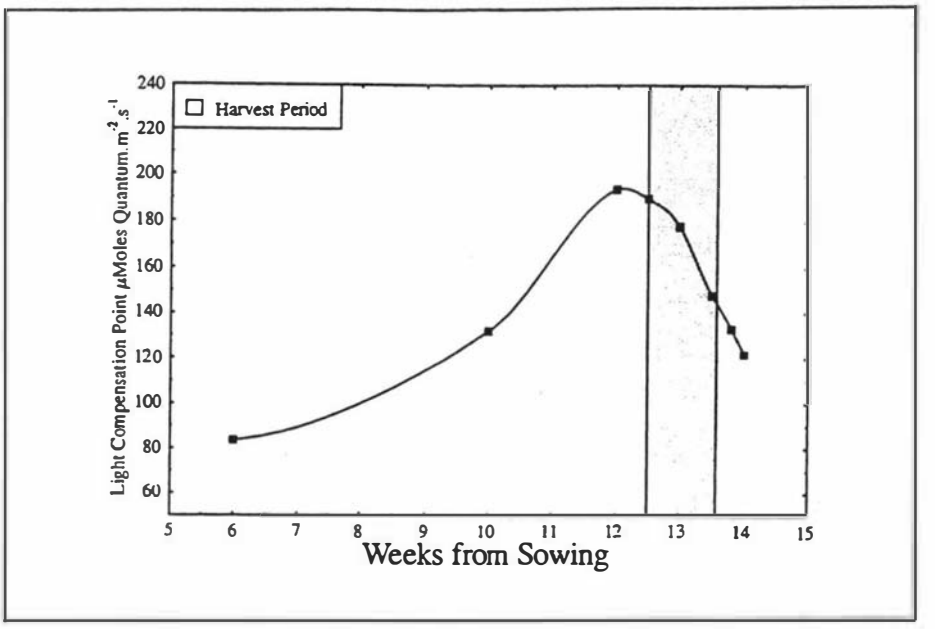


Figure 5.5 Effect of leaf age on the light compensation point for single truss tomato plants

5.3.1.2 Effect of temperature on net leaf photosynthesis

Net photosynthesis reached a maximum at a leaf temperature of 25 - 27 °C and ceased at 42 °C at radiation levels of 800 μmol.m^{-2}.s^{-1} Quanta (Figure 5.6).

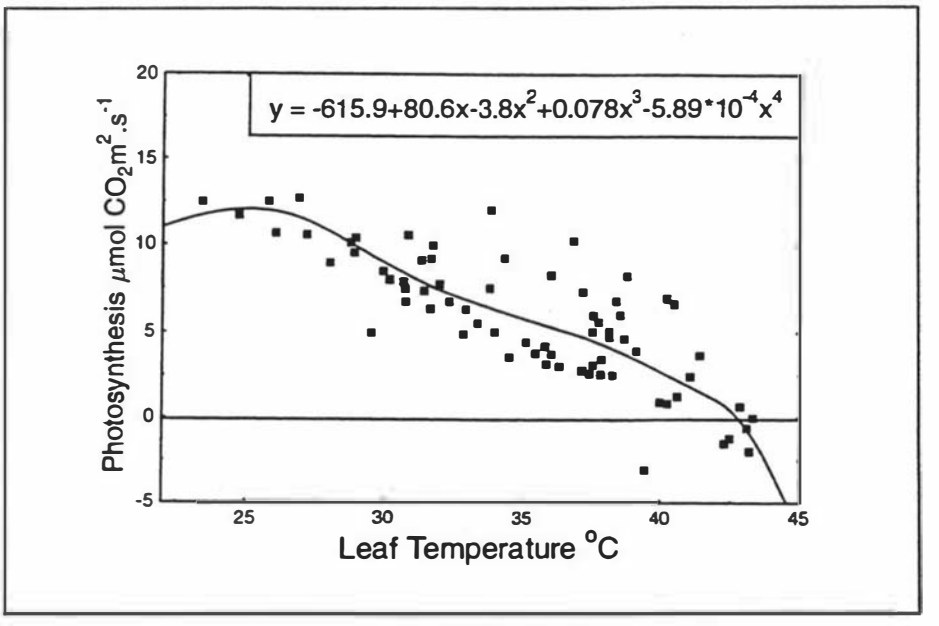


Figure 5.6 The effect of leaf temperature on net photosynthesis at 800 μol.m^{-2}.s^{-1} Quanta, 10 weeks after sowing

5.3.2 Fruit truss respiration experiments

5.3.2.1 Introduction

The results of the ANOVA carried out on the data for fruit truss respiration is presented in Table 5.4. These results are considered in detail in sections 5.3.2.2 - 5.3.2.4.

Table 5.4 Effect of temperature, fruit truss portion, date of assessment and fruit colour (for the final assessment only) on fruit truss respiration rates

	Respiration rate mg $CO_2/Kg^{-1}/hr^{-1}$
Stage of fruit development	ns
Temperature	***
Truss portion assessed	***
Stage of development x temperature	ns
Stage of development x truss portion	ns
Temperature x truss portion	***
Stage x temperature x truss portion	*
Colour (4th assessment only)	***
Temperature x colour (4th assessment)	***

* $P < 0.05$
** $P < 0.001$
*** $P = 0.0000$
ns = not significant

5.3.2.2 Fruit truss respiration during fruit development

There was a significant stage of fruit development x temperature x truss portion interaction (Table 5.4). At each stage of fruit development (18, 26 and 36 days after fruit set) the fruit only sample produced the highest respiration rate and the stems and calyxes only sample, the lowest (Figure 5.7). The whole truss with sealed cut surfaces always had a lower rate of respiration than the whole truss with unsealed cut surfaces.

The position of the whole truss with unsealed cut surfaces did vary relative to the fruit only sample. Thus at 18 days, at 25°C the respiration rate of these two treatments was similar while at 36 days the respiration rates were similar at 40°C. A fruit only sample consisting of individual fruit with the stem scar sealed was measured for respiration rate on the 36th day after fruit set and resulted in an extremely low respiration rate of 5.4 $mgCO_2/Kg^{-1}/hr^{-1}$. Data for comparision made at this time is presented in Figure 5.8.

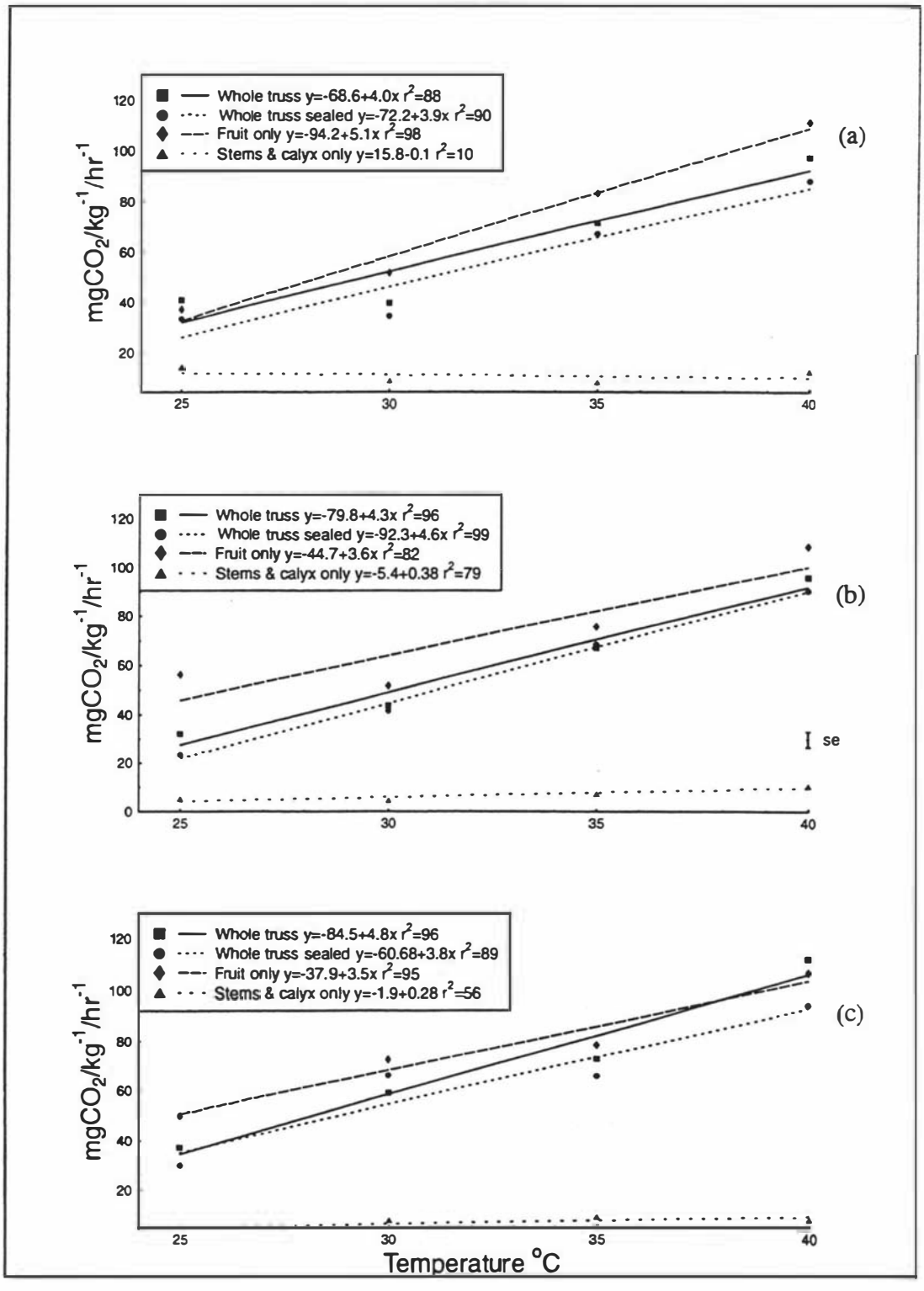


Figure 5.7 Effect of stage of fruit development, truss portion, and temperature on respiration rates at (a) 18 days, (b) 26 days and (c) 36 days after fruit set

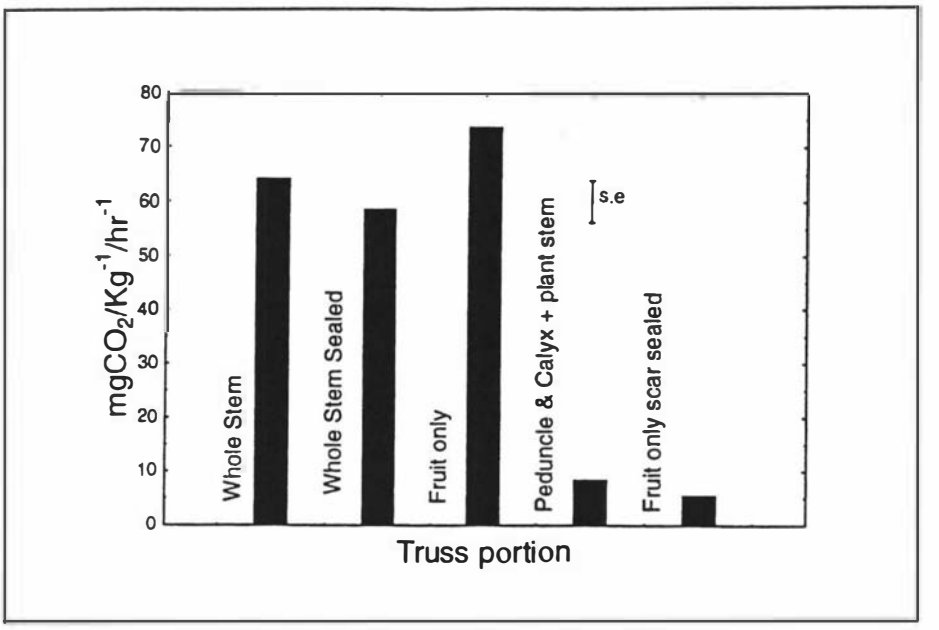


Figure 5.8 Effect of truss portion on respiration rate.

5.3.2.3 Effect of fruit maturity and temperature on respiration rate

At each maturity stage (mature green, first colour, orange and red), 40 days after fruit set, the fruit only respiration rate increased with temperature. The mature green fruit sample had the greatest response of increased respiration with temperature, the orange fruit sample the least. The fruit showing first colour and in the orange stage had the highest overall rates of respiration. Red fruit had the lowest respiration rate.

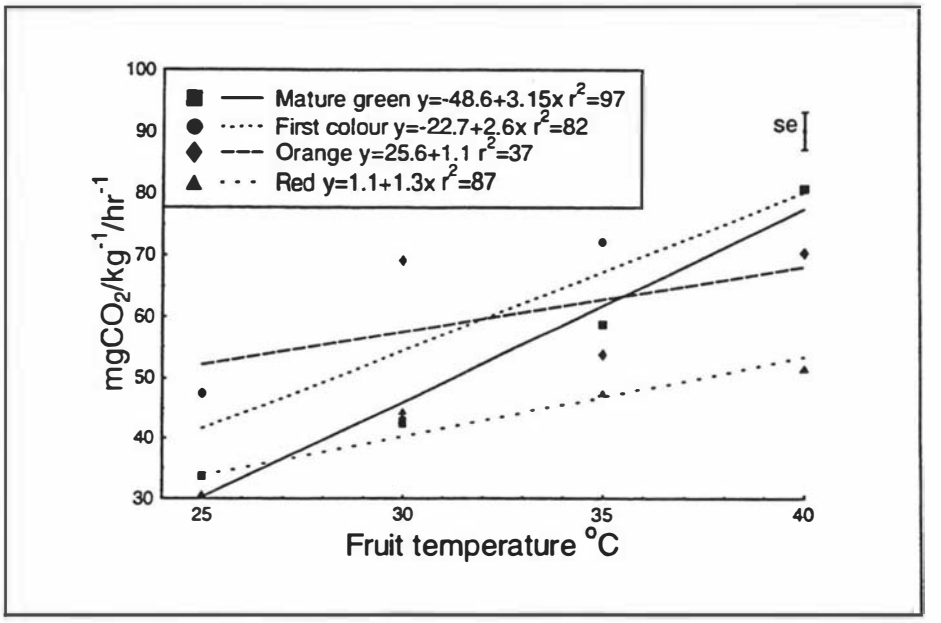


Figure 5.9 Effect of maturity and temperature on fruit only respiration rates.

Increasing temperature had the effect of changing the climacteric pattern of respiration (Figure 5.10). The typical climacteric pattern shown at 25°C was delayed at 30°C and advanced at 35 and 40°C, with the peak in respiration occurring at the mature green - first colour intermediatory range, not the first colour - orange stage as occurs at 25°C.

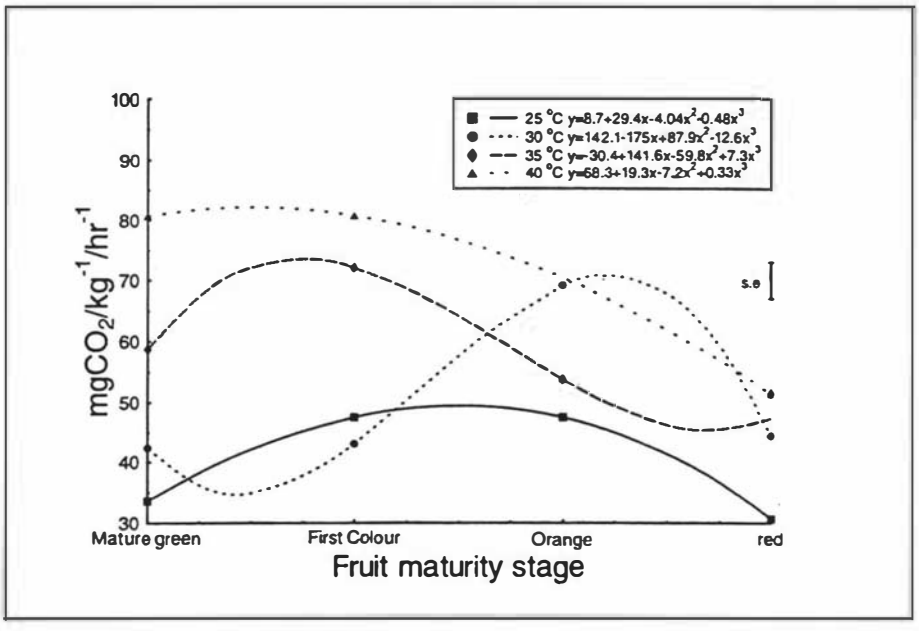


Figure 5.10 Effect of temperature on the climacteric pattern of respiration.

5.3.2.4. Effect of temperature on leaf net photosynthesis and fruit truss respiration.

Increasing temperature has the effect of both reducing net photosynthesis, while increasing the respiration rate of the fruit truss (Figure 5.11). Even at temperatures as low as 30 °C, net photosynthesis is being reduced while fruit respiration had begun to increase rapidly. The response of photosynthesis and fruit respiration to temperature shown in Figure 5.11 was obtained from Figures 5.6 and 5.7 respectively.

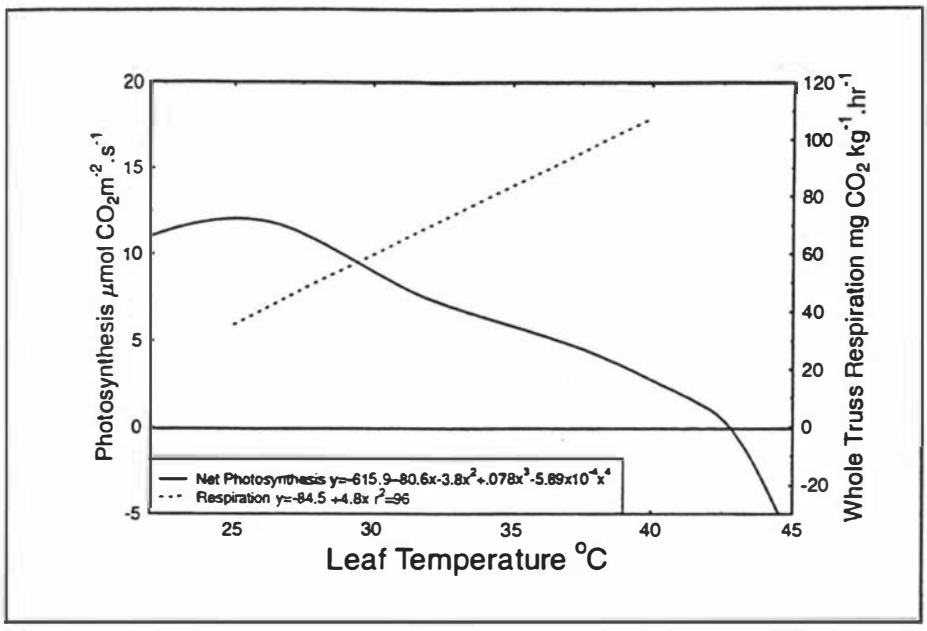


Figure 5.11 Effect of temperature on net photosynthesis and whole truss respiration

5.4 DISCUSSION

5.4.1 Photosynthesis experiments

5.4.1.2 Effect of leaf age and light intensity on leaf net photosynthesis and the light compenstation point.

Leaf age and its effect on net photosynthesis is an important issue for a single truss crop as there is no new developing foliage at the top of the plant to take over photosynthesis as the lower leaves age. By the time the fruit are developing, the youngest mature leaves on a single truss plant are already showing signs of age becoming thickened and curled. From this experiment it appears that increasing leaf age does reduce net photosynthesis slightly (Figure 5.4).

At 6 weeks after sowing, net photosynthesis was presumably at maximum levels as this determination was made just after the top 2 leaves had finished expanding. At 10 weeks after sowing (50% final fruit size), net photosynthesis had dropped for the same two leaves by 1.5 - 2 μmoles CO_2 $m^{-2}s^{-1}$ (at 25 °C). The final reading before fruit harvest at 12 weeks resulted in a further reduction in net photosynthesis for light levels below 650 PAR suggesting that at higher PAR, after an initial drop as leaves mature, leaf age does not significantly reduce net photosynthesis.

Salisbury and Ross (1989), stated that net photosynthesis of leaves reaches a maximum when leaves are about 30 - 50% expanded and then begins to decrease rapidly to a low level (less then one tenth the original rate). Mc Avoy and Janes (1989), working with single truss tomatoes, reported that net photosynthetic activity, µmol CO_2 min^{-1} dm^{-2} was greatest in the canopy during early anthesis and then steadily declined as the canopy aged. Mc Avoy and Janes (1989) also reported that net whole plant photosynthetic activity, µmol CO_2 min^{-1} $plant^{-1}$, increases steadily after the early stage of development to a peak rate during the rapid fruit development stage. Net whole plant photosynthetic activity then declined as the plant approached the mature green and then finally the red-ripe stage of fruit development. When the drop in net photosynthesis as leaves aged in the current experiment (Figure 5.4), is considered, it suggests that net photosynthesis although decreasing slightly with age is in fact maintaining much higher levels then

expected. One reason for this could be that the normally rapid decline in photosynthetic activity of leaves with age is explained as being a result of a surplus of photosynthates from young upper tomato leaves depressing the photosynthetic activity of the older, lower leaves (Tanaka et al, 1974a). Since single truss plants do not have any young upper developing leaves to supply a surplus of photosynthates, which depress the activity of the older leaves, net photosynthesis of the aging top leaves was maintained. Gifford and Evans (1981), stated that even senescent leaves can be rejuvenated to full photosynthetic performance with the sink:source ratio is increased substantially.

Tanaka et al (1974b), also reported that leaves of different ages have different photo-response curves to light intensities. Generally the photosaturation point is higher in young leaves. Although light saturation was not reached in the current experiment, which only reached a maximum of 800 PAR, the light compensation point (irradiance point where photosynthesis just balances respiration), did increase with leaf age up until the first harvest, 12.5 weeks after sowing (Figure 5.5). This data indicates that at lower radiation levels (50 - 200 μmoles quantum), leaf age had a negative effect on photosynthesis and the light compensation point is reached at higher levels of radiation.

After fruit harvest (14 weeks), net photosynthesis rates of the top 2 leaves began to increase (Figure 5.4). This is an unexpected result as fruit removal or removal of sink strength (i.e fruit numbers) is usually reported to reduce the net photosynthetic rate of the leaves as the main assimilate sink is no longer present (Tanaka and Fujita, 1974c). King et al (1967), reported that in wheat, removal of the sink (main shoot ear), reduced net photosynthesis by up to 50% within 3 - 15 hours. Mondal et al (1978) working with soybean, also reported that removal of the sink inhibited leaf photosynthesis and concluded that the presence of a sink stimulates photosynthesis. Although the list of those investigations in which there is a close correlation between sink demand and net photosynthesis is large, some workers listed by Geiger (1976) report no correlation. For example, Austin and Edrich (1975), reported that removal of the sink of a wheat plant (an ear from a tiller), did not result in any marked change in the net photosynthetic rate of the subtending flag leaf. Austin and Edrich (1975) claimed that after removal of the sink, a new pattern of translocation was established within 2-3 days of ear removal and

the tiller exported assimilates to other tillers on the plant and possibly the roots. Geiger (1976) also claimed that the simple, negative feedback mechanism which explains how sink demand influences photosynthesis did not seem to be adequate to bring about the control between sink demand and net photosynthesis. This evidence suggests that the hypothesis that sink removal results in a decline in net photosynthesis does not always hold true.

There are several possible explanations for this observation of increased net photosynthesis after fruit harvest. Ho et al (1983) found that in a 2 truss tomato plant, total truss removal decreased ^{14}C export within a week, but the rate of photosynthesis was not affected until 2 weeks later. This would explain why net photosynthesis rates did not drop at the time of fruit harvest, as net photosynthesis was only measured for 10 days after harvest, but does not offer an explanation as to why net photosynthesis rates increased. Another possibility is that after fruit harvest, other alternative sinks take over the demand for assimilates. If this is the case, the most likely alternative sinks in a single truss plant with no developing foliage, is the root system and the stem. Since the principal suppliers of assimilates for the first flowering truss also supply the roots (leaves 6 and 8), the root system is a likely candidate to become a strong sink when the tomato fruit is removed (Russell and Morris, 1983). In fact it has been reported that as the sink strength increases over the time from flowering to fruiting, the heavy fruit load may be responsible for root death (Hurd and Price, 1977). Thus, if the sink is attracting assimilates at the expense of the root system, when the sink is removed, the root system may become a strong sink. Mc Avoy and Janes (1989), also stated that in single truss plants, once the apical meristem and the axillary shoots were removed, the root system and the fruiting truss were left to compete for available assimilates. Neales and Incoll (1968), claimed that in maize plants, removal of the developing sink by preventing pollination, may have resulted in assimilates which normally moved into the developing cob being diverted to the root system. Tanaka and Fujita et al (1974a) also reported that the even the old portions of stem maintain the potential to act as a sink and continue to gain weight, suggesting that both root and stem could combine to create a sink strong enough to maintain net photosynthesis after fruit harvest. This may be particularly true in a single truss plant where there is no other developing stinks on the

plant at the time of fruit harvest.

Another possibility for the increased rate of net photosynthesis after fruit harvest is that during fruit growth, starch in the leaves was depleted by the fruit so that when the fruit stopped importing assimilates (7 - 10 days before harvest in tomato plants), the leaves increased photosynthesis to replace the lost reserves (Russell and Morris, 1983). Tanaka and Fujita et al (1974a) reported that the ability of a leaf to act as the sink for photosynthates of other leaves becomes very low with age, but it serves as a sink for its own photosynthates for a long period.

It is therefore possible that the combination of root, stem and leaf as sinks resulted in the increased net photosynthesis after the fruit sink was removed. So that assimilates that were being directly imported into the fruit for growth, were now available for the alternative sinks, which had been receiving little assimilate while the plant carried a heavy fruit load.

One further possibility to explain the increase in net photosynthesis after fruit harvest is that while the fruit were developing, the sink was exhibiting a feed back inhibition of leaf photosynthesis. Since the single truss plant appears to be both sink and source limited, the sink may have regulated photosynthesis to produce only the required amount of assimilate to maintain its rate of growth. This type of feedback inhibition could be the result of a lack of a sucrose gradient which controls the translocation of assimilates from the source to the sink (Geiger, 1976). Geiger (1976) reported that the effect of sink demand of photosynthesis may act via decreased phloem loading or decreased flux in the sieve tubes, mediated through the build up of starch and of the accumulation of translocate sugar. Gifford and Evans (1981), stated that the demand by sinks for assimilate can determine photosynthetic supply. Therefore if the sink has sufficient assimilates it could act to lower net photosynthesis. Thus when the sink was removed at harvest, the feedback inhibition of photosynthesis was no longer present, and alternative sinks such as the roots could then receive the assimilate which was not available to them when the fruit was present on the plant and in the process stimulate photosynthesis.

The light compensation point (point where net photosynthesis became zero), also shifted with leaf age. The light compensation point increased up until the time of fruit harvest when it began to drop rapidly (Figure 5.5). Light compensation point values of 80 μmol Quantum.$m^{-2}.s^{-1}$ at 6 weeks from sowing to a maximum of 190 μmol Quantum.$m^{2}.s^{-1}$ immediately prior to harvest are in the range reported by other researchers (Warren Wilson et al, 1992). The increasing light compensation point up until the time of harvest is consistent with the finding that net photosynthesis at each radiation level declined with plant age from 6 to 12 weeks (Figure 5.4). The drop in the light compensation point values after harvest is also consistent with the net photosynthesis findings (net photosynthesis increasing post harvest (Figure 5.4)), but is an unexpected result. Although the reasons for this decrease in light compensation point immediately after harvest are not clear it may be due to differences in leaf respiration. Salisbury and Ross (1986) reported that differences in light compensation points are caused primarily by differences in respiration rates, since the light compensation point is the irradiance at which photosynthesis just balances respiration. Therefore the decreasing light compensation point post harvest could be a result of increased photosynthesis, decreased respiration or a combination of both, but no clear explanation can be offered.

5.4.1.1 Effect of leaf temperature on net photosynthesis

Single truss tomato plants exposed to 800 PAR show maximum net photosynthesis at temperatures between 25 - 27 °C (Figure 5.4). Most tomato genotypes show an optimum level of net photosynthesis between 25 and 30 °C (Augustine et al, 1976).

Generally increases in temperature, increase the rate of actual photosynthesis until enzyme denaturation and photosystem destruction begin. However, leaf respiration also increases rapidly with temperature resulting in net photosynthesis curves such as that shown in Figure 5.4. Salisbury and Ross (1989), stated that the promoting effect of a temperature rise is nearly balanced by increased respiration and photorespiration over much of the temperature range at which C3 plants normally grow.

In the current study, for a 10 °C increase in temperature, from 25 to 35 °C, there was a corresponding reduction of 50% in the level of net photosynthesis (Figure 5.5). Net

photosynthesis reached zero at 43 °C, indicating that at temperatures above 43 °C, some respiration but little photosynthesis is occurring. This is possible since the photosynthetic system in leaves is especially vulnerable to heat stress, becoming inactivated at temperatures several degrees below those damaging respiration and several other cellular processes (Smillie, 1992). Although in the current study, net photosynthesis ceased at 43 °C, respiration continued, since the process of respiration is less susceptible to heat inhibition.

At temperatures above 43 °C, plants would therefore be depleting stored reserves during the process of respiration. The implications of the findings of the current study are that even at commonly attainable greenhouse temperatures of 30 °C and above, some reduction in net photosynthesis would occur at PAR levels of 800. Once temperatures reach 35 °C net photosynthesis would be reduced by half, and above 40 °C very little would be occurring. This has major implications for a summer grown single truss crop where the leaf temperature of the upper leaves of the canopy can be above 30°C, and it is these leaves which are the main providers of assimilate for the developing fruit.

5.4.2 Respiration experiments

5.4.2.1 Effect of temperature on fruit truss respiration rates

At all stages of fruit development each increase in temperature resulted in a rise in the respiration rate of the fruit truss (Figures 5.7 and 5.9). The effect of increasing temperature on fruit respiration of harvested fruit is well documented. Lurie and Klein (1992) found that harvested tomato fruit held at 38 °C for 3 days had a 50% greater respiration rate then fruit kept at 12 °C. In the current study, respiration of the whole intact truss increased by 46%, 39% and 54%, from 25 to 35 °C, for measurements taken 18, 26 and 36 days after fruit set respectively.

Fruit respiration rates in the current experiment continued to increase rapidly with temperature even at 40 °C (Figure 5.7), a temperature at which the photosynthetic system in leaves would have become inactivated (Smillie, 1992). It has been reported that temperatures higher then those given in this study, are required before respiration in plant tissue is inactivated (Alexandrov, 1964).

5.4.2.2 Effect of truss portion on respiration rate.

At all stages of fruit development, the respiration rate of the different truss portions (whole truss, whole truss with cut stem surfaces sealed, fruit only and stem and calyxes only), on a mg $CO_2/kg^{-2}/hr^{-1}$ basis, differed from one another (Figure 5.7).

When respiration rate on a whole truss basis was assessed it was found that when the cut stem surfaces were sealed to prevent gas escape this resulted in only a slight lowering of the truss respiration rate (Figures 5.7 and 5.8). This slight decrease may be a result of prevention of CO_2 from escaping from the place of least resistance (the cut stem). Thus the most likely route of escape of the CO_2 from attached fruit is not through the fruit epidermis due to impermeability, but that the CO_2 diffused out into the calyx and truss tissue (peduncle and plant stem) and is released there where the tissue is more permeable. It is also apparent from this data that when fruit are removed from the truss, the CO_2 from respiration is released through the exposed stem scar. This was demonstrated when the stem scar of the fruit was sealed and respiration rate determined (Figure 5.8). The low rate of CO_2 evolution shows that the main escape route of respiratory CO_2 is the stem scar when the fruit is harvested. This has in fact been shown by other researchers who found that stem scar sealing caused anomalous respiratory behaviour caused by modified internal atmospheres which varied with the degree of stem scar sealing (Workman et al, 1956).

When the respiration rate of the fruit only samples was measured, it was found to be consistently higher then the respiration rate of the entire truss. This may be explained by the resistance to CO_2 escape through truss tissue is higher than through the fruit stem scar.

Workman et al (1956), claimed that at the time the tomato fruit is harvested (i.e calyx was removed), the gas exchange of the fruit was taking place almost exclusively through the stem scar, the skin being quite impermeable to O_2 and CO_2. This was also reported by Mikal (1993) who stated that 97% of gas exchange occurs through the stem scar of harvested tomato fruit and Bertola et al (1990) who reported that the specific resistance of tomato skin was approximately 200 times grater than that of the stem scar and that

two-thirds of the gas diffusing in the fruit passes through the scar. Bergevin et al (1993) reported that the peduncle scar has a greater permeability to gases than the skin and facilitates gas exchange with the external atmosphere. This was also confirmed by Smillie (1992), who reported that the tomato fruit epidermis is relatively impermeable to gas exchange caused by the combined effects of decreasing stomatal frequency and function, and that this causes a build up of CO_2 within fruit cavities by as much as 5% (v/v). Bergevin et al (1993) measured the CO_2 in the internal atmosphere of tomato fruit with and without the peduncle attached, and found that at 20°C, fruit with the peduncle attached accumulated greater concentrations of internal CO_2 then fruit with the peduncle removed, and these high internal CO_2 levels promoted the development of chilling injury symptoms. Czarnowski and Starzecki (1990) also measured the endogenous CO_2 concentration of tomato fruit and reported it to be 2300 cm^3 CO_2/m^3 in young fruits and 2800 $cm^3/CO_2/m^3$ in large green fruits. Thus, temperatures resulting in increased respiration rates would result in an accumulation of CO_2 in the fruit caused by the combination of high levels of respiration and a relatively small escape route (calyx tissue) for this CO_2. As a result, high levels of internal CO_2 could cause tissue damage in heat stressed tomato fruit. A suggested mechanism for injury of fruit caused by high internal CO_2 levels is the aggravation of the cell membrane destabilization, caused by temperature stress (Bergevin et al, 1993). In several CA investigations high CO_2 damage in other crops has been reported to cause a number of symptoms, the most common being impaired ripening, off-odours and flavours (melons) (Lougheed, 1987), prevention of ripening and flesh softening, external and internal browning and changes in susceptibility to disorders (peaches) (Nanos and Mitchell, 1991).

Such a build up of CO_2 in the fruit and the inability of CO_2 to rapidly be released from the fruit skin may explain the higher respiration rate after the calyx is removed with the stem scar presenting a passage of least resistance to CO_2 evolution. It was reported that the internal CO_2 levels of fruit with the pendule removed remained at less then 3%, while the fruit with the pendule accumulated 2.4 to 4% internal CO_2 at 20°C (Bergevin et al, 1993).

Stem and calyx portions only (no fruit) had much lower respiration rates then the whole

truss or fruit only portions (Figure 5.7), and these were relatively unaffected by increases in temperature. This demonstrates that fruit tissue had not only greater initial rates of respiration, but is influenced by temperature to a much greater degree then vegetative plant tissue.

5.4.2.3. Effect of fruit maturity and temperature on mature tomato fruit respiration

At all maturity stages (mature green, first colour, orange and red fruit colour), harvested fruit showed an increase in respiration rate with increasing temperature (Figure 5.9). The rate of respiration increase with temperature was greatest in the preclimacteric mature green fruit, and less in the climacteric (first colour - orange) and post climacteric (red) stages (Figure 5.9). This suggests that respiration of preclimacteric, mature green fruit is more sensitive to increases in temperature then when the climacteric pattern of higher respiration is initiated. This was also found by Lyons and Pratt (1963), who found that the less mature the fruit is at harvest, the greater the response to ethylene and thus the greater the respiration rate.

Initial rates of respiration for each fruit maturity stage, irrespective of temperature follow the normal climacteric pattern of respiration usually observed with fleshy fruits. Respiration rates at 25 °C were lowest in preclimacteric, mature green fruit sample, rose at the sign of first colour, increased again for the orange fruit sample at the climacteric peak and dropped as the fruit reached a mature red colour. This process has been well documented by other researchers. Campbell et al (1990) and Smillie (1992) both reported that CO_2 production increased with the onset of colour change (breaker stage), reached a peak coincidental with the peak rate of colour change and then declined as colour change ceased at the red stage. Saltveit (1993) reported a 2 fold increase in carbon dioxide efflux occurred during the climacteric surge of ripening in detached tomato fruit.

In the current study, while this pattern of climacteric CO_2 evolution occurred at 25 and 30 °C with respiration rates being low at the mature green stage, increasing with colour change and then dropping back to preclimacteric levels at the full orange stage, at

temperatures of 35 to 40 °C, the process is speeded up. At 35 and 40 °C, mature green fruit still show an increase in respiration at the first signs of colour, then peaks instead of increasing through the orange stages of colouration, and then drops rapidly to below mature green levels and drops even more rapidly as the fruit obtains a full red colour. This implies that the higher temperatures (35 and 40 °C as compared to 25 and 30 °C) speed up the climacteric pattern of respiration so that it occurs at a an earlier stage of maturity then normal (Figure 5.10).

Campbell et al (1990) and Ahrens and Huber (1990) stated that the rate of CO_2 production increased two-fold at the climacteric peak from preclimacteric levels. In the current study, this was true at 25 °C, where respiration increased from 30 mg $CO_2/kg^{-2}/hr^{-1}$ at the mature green stage to a peak of 53 mg $CO_2/kg^{-2}/hr^{-1}$ at the orange stage. This is a further effect of high temperature disrupting the climacteric pattern of respiration. This disruptive effect of temperature on climacteric CO_2 evolution was also found by Morris et al (1981), who reported that at 30 °C, there was no definite climacteric pattern on respiratory CO_2 production.

5.4.2.4 Effect of temperature on photosynthesis, respiration and final fruit size

Final fruit size results from a combination of both assimilate supply via photosynthesis and utilisation during respiration, both of which are temperature dependent processes. Tanaka et al (1974b), stated that the growth efficiency of tomato fruit is about 75%. That is, of the photosynthates available to the fruit, 75% become fruit constituents; the remainder is consumed in respiration. If the 25% of assimilates utilised in the respiration process is increased due to the crop being exposed to high temperatures for any length of time, then fruit size would be reduced. If at these increased temperatures, leaf net photosynthesis was also reduced, as was shown to occur in the current experiment, then fruit size would be further effected.

From the data obtained from the photosynthesis and fruit respiration experiments in this study, it was determined that even a 10 °C temperature increase from 25 - 35 °C (which is possible in summer conditions), can reduce net photosynthesis by half while increasing fruit respiration by an average of 50% (Figure 5.11). If these higher

temperatures were maintained for just a few hours each day, fruit size would be significantly reduced as was found in the summer grown single truss crop (3.3.1). In the single truss study of the previous summer it was found that the canopy temperature of the unshaded plants remained above 25°C for a total of 278 hours, while during fruit development, fruit temperature remained above 35°C for an average of 5 hours per day on days with high solar radiation (4.2.4.3 Figure 4.3 and 4.5) Thus, a significant reduction in yield could have resulted from the reduction in net photosynthesis and increase in fruit respiration in this temperature range.

Although a detailed study of assimilate production, importation and utilisation was not conducted, the data from the photosynthesis and fruit respiration experiments provide sufficient evidence to support the view that high greenhouse summer temperatures were partially responsible for the low single truss fruit yields over the December 1992 - February 1993 period. This demonstrates the necessity for some form of temperature control (e.g crop shading) for summer produced crops as single truss plants do not have a tall dense canopy providing self shading as does a multi-truss crop.

CHAPTER 6

POTENTIAL OF THE SINGLE TRUSS SYSTEM

6.1 INTRODUCTION

The objectives of the current investigation into the single truss cropping system were:

1. To examine the growth, development and yield potential of the system over a 12 month period under New Zealand conditions and

2. To assess the relationship between fruit quality and solution conductivity.

The research examined the effect that spring and winter CO_2 enrichment, summer shading for temperature control and different source/sink treatments had on fruit yield.

Techniques that could be used to improve the performance of the crop were developed, but further research is required to examine a number of system variables not covered in this study. These are discussed in section 6.5. The following sections discuss yield, and the fruit quality/yield trade off found in the present research, along with issues such as timing of the application of conductivity, plant densities, cultivars and flower numbers, the environment and crop modelling which all play a role in the potential of the single truss system.

6.2 THE SYSTEM

6.2.1 Description of the system

The single truss crops of the present study were grown in the Manawatu which is not a traditional greenhouse tomato production area. The system consisted of a series of NFT gullies supported by benches (3.2.1). Plants were propagated in a standard media and after pricking out were grown on in 100 mm plastic pots in a heated greenhouse. At the appearance of the first inflorescence seedlings were placed into the NFT system at a density of 12.9 - 13.5 plants per m^2. Plants were grown in an environment with a minimum temperature of 16°C with venting at 22°C. Management of the crop involved

removal of all laterals and stopping the plants at the second leaf stage above the first truss.

6.2.2 Cropping area

A fixed bench system was used which utilised approximately 70% of the greenhouse area. This allowed for aisles between the individual benches for crop access. Greenhouse fixed bench layouts are reported as occupying between 59 and 70% of greenhouse space or growing area (Aldrich and Bartok, 1992). As a fixed bench system, the layout used was at the higher end in terms of efficency of space used.

Another approach is the use of a moveable bench system which increases growing space by 10 - 25% by utilising 81 - 93% of the growing area (Aldrich and Bartok, 1992; Giniger and Mc Avoy, 1986). The concept of a movable bench system is to convert all but one aisle to growing space. Access to crops is created by rolling aside neighbouring benches so creating a temporary aisle (Kabala and Giacomelli, 1989). Because the benches move, connections for nutrient delivery and return are attached to the bench are flexible (Aldrich and Bartok, 1992).

The movable bench system maximises greenhouse space utilisation, allows more plants to be grown and thus produces a higher yield. Although this concept has been largely used in the nursery industry it is ideal for adaption to NFT single truss plant production. The use of movable benches would have increased yields in the experiments of the present study by about 20%.

6.3 YIELD

6.3.1 Number of crops per year

In the current study, plants were placed into the system at the appearance of the first inflorescence, however careful management of the pot grown plants would allow a later planting reducing the time in the system by 1 - 2 weeks. This would require that while seedlings were held in pots until the time of first anthesis, careful control of nutrition, watering and spacing be observed to prevent plant stress. Crop removal in a commercial production situation would normally be carried out when the majority of the fruit had

been harvested (after 10 - 20 days of harvesting). In the present study crop removal was often delayed considerably while the final fruit on each truss matured increasing the cropping period by 1 to 3 weeks. By delaying the time of planting until full flowering and rapid crop removal after the majority of fruit were harvested would allow a maximum number of crops to be produced per year.

Although the time taken from planting to cropping is dependent largely on season, it is also influenced by factors such as CO_2 enrichment. In the current study a summer produced crop took an average of 54 days from planting to first harvest, a winter crop 99 and a spring crop 78 days at ambient CO_2 levels. With CO_2 enrichment (1000 ppm) the cropping time was reduced by 14 and 11 days for a winter and spring crop respectively. The only benefit of CO_2 enrichment is to promote earlier cropping. Hand and Postlethwaite (1971) reported that CO_2 enrichment advanced the date of first anthesis, promoted earlier cropping and shortened the duration of harvest for single truss tomatoes sown in December and July. CO_2 enrichment advanced the date of first anthesis by 4 days at a density of 10 plants/m^2 in a December sown crop (Hand and Postlethwaite, 1971).

An estimate of the total crop time in the system for crops that were planted at the time of first anthesis and removed after the majority of fruit were harvested is presented in Table 6.1. These figures are based on crop timings from the present research and are adjusted to allow for planting at a later stage and earlier crop removal. These figures also assume CO_2 enrichment in winter and spring crops is used for crop advancement.

Table 6.1 Crop timing - number of days from planting to crop removal

Season	Number of days
Summer	59
Winter	79
Spring	65

Using the above estimates of commercial crop lengths, 5.5 separate crops per year could be produced of the cultivar Rondello in the Manawatu region. This assumes that in a year, 1 summer, 1 autumn, 1 early spring, 1 late spring and 1 winter crop could be produced with 35 days left to contribute towards the 6th crop (summer) of the year (Figure 6.1). This assumes 1 - 2 days between each crop for plant removal and replanting.

Single truss studies carried out in the USA did not provide data on the number of individual crops per year as crops were produced as overlapping successive blocks (up to 26 per year) so that a continuous harvest of fruit was possible (Giniger et al, 1988; Mc Avoy et al, 1989b). However, Mc Avoy et al (1989a) stated that 5 crops a year of single truss plants were produced over a 10 month period at a density of 10.8 plants/m^2.

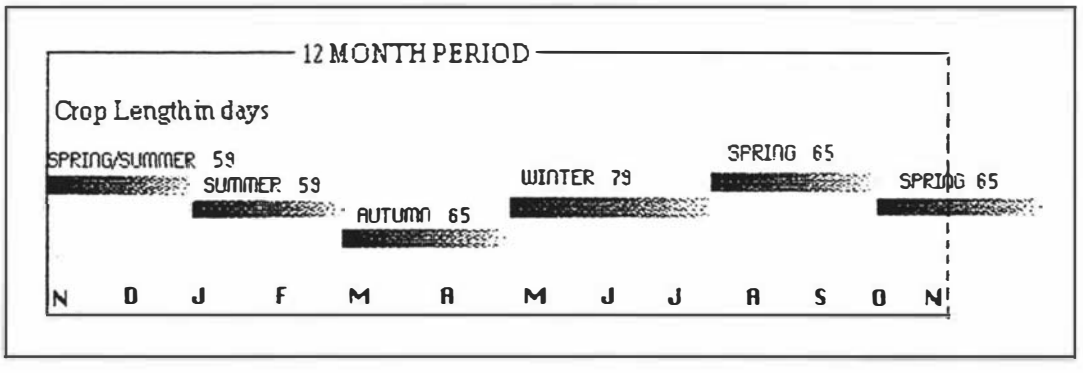


Figure 6.1 12 month crop timing for single truss plantings

6.3.2 Yield potential

In the current investigation yields ranged from 350 - 1019 g/plant, however Table 6.2 details the highest yields obtained and the treatments required to obtain such yields.

Table 6.2 Highest yields obtained at a density of 13.5 plants/m^2 (cultivar Rondello)

Season	Yield g/plant	Growing conditions/treatments
Summer	1019	8 fruit per plant, crop shading
Spring	927	CO_2 (1000 ppm), 8 fruit per plant
Winter	703	CO_2 (1000 ppm), 8 fruit per plant
Yearly average	883	Grown at a conductivity of 4.5 mS cm^{-1}

Mc Avoy et al (1989a, 1989b) reported average yields of 700 g/plant with a range of 250 - 850 g/plant in single truss crops produced in the USA at a density of 12 plants m^2. In the present study the yearly average yield was 883 g/plant where the best technology was used. Cooper (1979) reported yields of 100 - 800 g/plant in single truss trials carried out in the UK. It should be noted that winter light levels would have been higher in New Zealand then in the UK and northern USA.

Using the cultivar Rondello at a density of 13.5 plants/m^2, yielding an average of 883 g/plant with 5.5 crops per year the following yields on a yearly basis per m^2 could be expected (Table 6.3):

Table 6.3 Expected yearly yields utilising different percentage growing areas.

Area cropped (% of total greenhouse area)	Yearly yield Kg/m^2 Manawatu	Yearly yield Kg/m2 Auckland
70% - Current fixed bench system	47.0 Kg	50.5 Kg
75% - Fixed bench system	50.0 Kg	54.1 Kg
90% - Moveable bench system	60.1 Kg	64.9 Kg

The yield figures presented in Table 6.3 are based on a crop produced in the Manawatu and Auckland regions. A crop grown in Auckland might expect to yield 10% more due to improved climatic conditions. If this is the case, the average yield per plant would become 971.3 g.

6.4 FRUIT QUALITY

6.4.1 Fruit quality obtainable with the single truss system.

Single truss fruit quality achievable with an NFT type system is dependent not only on season but also on solution conductivity. The fruit quality obtained for each conductivity level is presented in section 3.3.2. This equated to a 4.5% increase in Brix and 5.7 % increase in percent citric acid per mS cm^{-1} increase in solution conductivity over all crops. This data is compared to fruit samples assessed from New Zealand Commercial Growers (Appendix 4) with traditional multi truss cropping systems (Table 6.4).

Table 6.4 Comparison of single truss and commercial fruit sample quality

Sample	Brix	% Citric acid
Commercial - common range	3.8 - 4.4	0.35 - 0.41
Commercial - top range	5.3 - 5.6	0.56 - 0.59
Single truss - range from 2 - 8 mS cm^{-1}	3.8 - 5.5	0.52 - 0.77

For single truss brix levels, the conductivity 8 mS cm^{-1} sample produced fruit in the top range of commercial growers, while the conductivities 6 and 8 mS cm^{-1} produced fruit with percent citric acid levels in the top range.

6.4.2 The yield/quality trade off.

While the highest conductivity of 8 mS cm^{-1} produced superior single truss fruit quality in terms of brix and acidity, the loss in yield from the higher conductivity levels makes

the production of such high quality fruit unattractive for economic reasons. On average 125 g/plant, 222 g/plant and 180 g/plant yield was lost from the December, April and July harvested crops respectively with a conductivity increase from 2 to 8 mS cm^{-1}. The yield/quality trade off found in the present single truss crops for 3 separate harvest dates is presented in Table 6.5.

Although the lowest single truss conductivity level (2 mS cm^{-1}) produced the highest yields, fruit quality, although within the commercial range was low. Thus it would be more appropriate to consider the 4-6 mS cm^{-1} levels to obtain satisfactory fruit quality without a substantial loss in yield.

Table 6.5 Effect of conductivity on Yield, brix and % citric acid levels in single truss crops

Month of harvest		2 mS cm^{-1}	4 mS cm^{-1}	6 mS cm^{-1}	8 mS cm^{-1}
December	Yield g/plant	604	503	487	479
	Brix	3.3	3.6	3.9	4.6
	% Citric acid	0.50	0.52	0.56	0.62
April	Yield g/plant	1240	987	964	1018
	Brix	3.8	3.9	4.6	4.7
	% Citric acid	0.49	0.56	0.61	0.66
July	Yield g/plant	556	392	384	376
	Brix	4.3	4.7	5.6	7.2
	% Citric acid	0.58	0.57	0.75	1.04

6.5 ISSUES NOT CONSIDERED IN THE PRESENT STUDY

6.5.1 Introduction

The present investigation examined several factors which effected the yield and quality of single truss crops. These included solution conductivity, season, CO_2 enrichment, source/sink relationship, summer crop shading and to a limited degree cultivar (Cherry vs beefsteak varieties). However, there are more factors which should be examined to determine their influence on both fruit quality and yield in the single truss system. These factors are discussed in the following sections.

6.5.2 Timing of increased conductivity

The timing of the application of the increased solution conductivity needs to be examined. In the present study the conductivity was increased from 2 mS cm^{-1} at the onset of 50% fruit set. If the timing of the application had been delayed it is possible that improvements in fruit quality could have been achieved with out significant reductions in yield. The counter argument is that the improvements in fruit quality largely relate to less water in the fruit and this must lead to a loss in yield. Thus delaying the application of the higher conductivity might only produce small improvements in quality and reductions in yield.

6.5.3 Plant density

A factor which has a major influence on the yield of the crops is plant density. Other researchers have grown single truss crops at densities of 10 and 25 plants per/m^2, where it was found that the 25 plants/m^2 density produced 41% less marketable yield then the 10 plants/m^2 (Hand and Postlewaite, 1971). A density of approximately 12 plants/m^2 has been used in other single truss investigations (Mc Avoy et al, 1989a; Giniger and Mc Avoy, 1986; Roberts, 1988).

A fixed density throughout the year may not be the most efficient method of production as light levels vary between seasons. It might be possible to increase yields by use of a higher plant density when radiation levels are high. In the current study fruit size was good in winter (mostly 50 - 70 mm), but was excessive for market requirements in

summer (over 70 mm). A higher plant density in summer may have reduced fruit size to an acceptable level while increasing yield per square meter. The relationship between season, plant density and fruit size/yield warrants further investigation.

6.5.4 Cultivars and flower numbers

Just as plant density may need to change with season, so might the choice of cultivar for the single truss system. 3 distinctly different cultivars were trailed in the present investigation. The one true beefsteak variety used (Ophir) was not suitable for the single truss system due to low fruit numbers in winter and excessive fruit size in summer (250+ g). The cherry cultivar (Cherita) produced excellent fruit quality, but was low yielding. The variety Rondello, produced well under single truss cropping. No data is available on how other standard New Zealand commercial varieties might perform under the single truss system.

Rondello has the advantage of good flower numbers (6 - 8 per truss) but during spring and summer when radiation levels are not limiting, a higher fruit number per plant would have been an advantage to reduce the fruit size. Selection of a cultivar which regularly produces 8 - 10 fruit per truss would be advantageous under such conditions.

A further possibility is to use environmental conditions to increase flower numbers on the first truss of a cultivar such as Rondello. This has been the subject of several investigations (Hurd and Cooper, 1970; Calvert, 1957; Hurd and Cooper, 1967), but relied on the critical timing of the application of low temperatures at the time of floral initiation which varies with season and cultivar. For this reason selection of a cultivar which regularly produces high flower numbers irrespective of the environmental conditions at the time of floral initiation would be the better approach.

6.5.5 Environmental manipulation

The single truss system allows for efficient utilisation of environmental manipulation as only one stage of plant development is present at any one time in a crop block. Nutrition can be precisely controlled for each stage of plant growth. For example, lower conductivities can be given for seedling development which can be increased at a later

stage to ensure high fruit quality. Another possibility is the application of higher rates of N while the plants are growing vegetatively and higher K rages during fruit development. This would not be possible in a multi truss crop where many stages of fruit development are present at any one time on the same plant.

Another approach in regions where winter production is limited by low light quantities, is the use of supplementary lighting to reduce cropping time and increase yields (Mc Avoy et al, 1989b). The even canopy of a single truss crop allows for uniformity and exact timing for the application of additional PPF (photosynthetic photon flux), which is not possible in a large multi truss crop. Although supplementary lighting has shown to increase yields in the Northern USA (Mc Avoy et al, 1989b), and may well do so under New Zealand conditions, the cost of this is considered unecomonic.

CO_2 is another form of environmental manipulation which can be used to full efficiency in a single truss system. Although CO_2 advances the time to harvest and shortens the harvest period, one of its greatest benefits is in preventing floral abortion during winter conditions in the UK (Hand and Postlethwaite, 1971). Thus CO_2 could be used to advantage by application during the critical period where floral abortion occurs.

6.5.6 Plant size and spacing

With the single truss system plant spacing can be adjusted depending on the size of the plant, so that as seedlings increase in size they can be spaced further apart allowing maximum space utilization. For example, Roberts (1988) reported that at 7 days seedling density in 10 cm pots was 97 plants/m^2, after 21 days plants were spaced to 24 plants/ m^2 and after 17 days plants were placed into planter bags at the final density of 12.1 plants/ m^2. With the NFT system, plant spacing could be adjusted in the gullies until the time of full leaf expansion.

The compact and lightweight nature of single truss plants provides further advantages in terms of reduced labour (particularly heavy labour operations such as crop layering and removal) and utilisation of the moveable bench system. Moveable bench systems which utilise 90% of the growing area have been developed for single truss crops at

Rutgers University in the USA. Kabala and Giacomelli (1989) developed a moveable, elevated bench system with a centralised work station where harvesting, transplanting, respacing and other crop operations could be preformed. The main advantage of such a system is the reduction in labour, since much of the labour required in a traditional multi truss system is in the continual lowering of the plant for maintaining access to the fruit (Kabala and Giacomelli, 1989). This moveable bench system was based on an ebb and flood hydroponic system.

The moveable bench system with a centralised work station, although not documented by comparative testing in the study carried out by Kabala and Giacomelli (1989), did result in less arduous work (i.e less extended reaching, bending and walking) for the worker. This should reduce fatigue, maintain more consistent performance and potentially improve worker productivity when compared to the requirements of the traditional multi truss tomato production systems.

Fischer et al (1990) carried out a similar study on movable bench system for single truss plants, again using the ebb and flood system with plants grown on a bench in bags containing a substrate with trickle irrigation. Further adaption of this type of movable bench system needs to include the utilisation of solution culture (NFT) which would allow for a greater degree of control of nutrition and conductivity and thus fruit quality.

6.5.7 Crop modelling

Another major advantage of the single truss system is that crop production can be precisely timed as the number of days required for each crop can be calculated. Giniger and Mc Avoy (1986) working at Rutgers University in the USA developed a model for computer simulations of single truss cropping systems. This model was further investigated and validated by Mc Avoy et al (1989a), Giniger and Mc Avoy (1986) and Santos et al (1992). This regression model uses PAR to predict responses of the tomato plant for timing as well as yield. The model allows cropping schedules to be generated which successfully produce a continuous harvest from sequential crops. Santos et al (1992) further developed this model to predict yield under a wide range of environmental conditions. Although the model developed by Santos et al (1992) proved

accurate from field experiments such models would require testing under New Zealand conditions, particularly in NFT systems which are not used in the overseas single truss studies.

6.5.8 Summary

There are a range of issues which need to be addressed before the full potential of the single truss system can be established. Although investigations into factors such as density, environmental manipulation, movable bench systems, computer modelling and labour requirements have been carried out, more detailed studies are required for the role of these factors to be fully understood. None of the single truss studies examined these factors based on an NFT type system which has the greatest potential to control and monitor plant nutrition. Single truss yields in an NFT bench system appear to be higher under New Zealand conditions than those obtained in the UK and USA. It would be advantageous to re examine factors such as density and environmental manipulation in this country. It is possible that with improved cultivars, correct densities, timing of conductivity application and full utilisation of greenhouse space, single truss yields could be increased higher then those obtained in the present study.

6.6 CONCLUSIONS

The present study was the first of its kind in New Zealand. Although the potential of the single truss system has been demonstrated, further issues need to be investigated. Yields of 46-51 Kg/m^2 per year are possible in the fixed bench system. The possibility of obtaining 59-65 Kg/m^2 per year from a movable bench system suggests that such a system needs to be adapted for NFT single truss cropping to reach its full potential.

Investigations into cultivars and plant density are also necessary if yields are to be optimised. Computer modelling under New Zealand conditions and systems would allow crop scheduling to provide continuous production and predict yields which would have an obvious marketing advantage. The effect of solution conductivity on fruit quality also requires further examination as high quality fruit production is expected to be of importance in the future.

The single truss system has the potential to produce yields and fruit quality equal to those of the top multi truss commercial tomato producers with the possibility of exceeding these top yields by up to 20 Kg/m^2 per year with the use of the moveable bench system. The potential of such a system for high quality, high yielding tomato fruit production warrants commercial evaluation.

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APPENDIX 1

SEED GERMINATION MEDIA

Media consists of 100% pine bark with the following additives (Table A1.1):

For 100 litres of bark media:

Table A1.1. Bark additives - Seed Germination Media

	Rate (Kg/m^3)	Rate (g/100 l)
Dolomite	3.0	300
Agricultural line	3.0	300
*PG Mix	2.0	200

*PG mix contains:

14+16+18 NPK

0.03% B

0.12% Cu

0.20% Mo

0.16% Mn

0.04% Zn

0.09% Fe

APPENDIX 2

STANDARD GROWING-ON MEDIA FOR TRANSPLANTED SEEDLINGS

Media consists of 100% pine bark with the following additives (Table A2.1):

For 100 litres of bark media:

Table A2.1 Bark additives - Growing on Media

	Rate (Kg/m^3)	Rate (g/100l)
Dolomite	3.0	300
Agricultural lime	3.0	300
Iron sulphate	0.5	50
Calcium ammonium nitrate	1.0	100
Osmocote Plus 15-4.8-11.3	4.5	450

APPENDIX 3

STANDARD HYDROPONIC NUTRIENT STOCK SOLUTION

Nutrient stock solution for greenhouse tomatoes (Table A3.1). Stock solutions A and B are diluted 1:100 to give an EC of 2 mS cm^{-1}. For higher EC values, macro elements are increased while micro elements remain at standard levels. Reference Tregidga et al (1986).

Table A3.1. NFT stock solution

Salt	Weight Kg per 100 litres	Concentration (ppm)
Stock solution A		
Calcium Nitrate	9.88	117 N
$Ca(NO_3)_2.4H_2O$		168 Ca
Chelated iron	0.789	12 Fe
FeNa EDTA		
Stock solution B		
Potassium nitrate	6.581	254 K
KNO_3		91 N
Magnesium sulphate	4.966	49 Mg
$MgSO_4.7H_2O$		
Potassium phosphate	2.72	62 P
KH_2PO_4		78 K
Manganese sulphate	0.06154	2 Mn
$MnSO_4.5H_2O$		

Boric acid H_3BO_3	0.01714	0.3 B
Copper sulphate $CuSO_4.5H_2O$	0.00275	0.07 Cu
Ammonium molybdate $(NH_4)_6Mo_7O_{24}.4H_2O$	0.00092	0.05 Mo
Zinc sulphate $ZnSO_4$	0.00308	0.07 Zn

APPENDIX 4

COMMERCIALLY PRODUCED PACKHOUSE FRUIT QUALITY

Introduction

In the past, tomato fruit producers directed crop management towards obtaining the highest possible yields from their crops. However, over recent years there has been an increasing demand for quality produce. At the present time there is limited information on the compositional quality and shelf life characteristics of greenhouse tomatoes produced by New Zealand tomato growers. The objective of this study was primarily to obtain data on the range of fruit quality produced in the Auckland area by a number of different growers, and to use this data as a basis for comparison with the single and multi truss crops produced during the present research programme.

Fruit Sampling

Fruit samples were provided by 9 commercial growers who supply tomato fruit to each of 3 Auckland packhouses. This represented 27 potential growers in the sample. Growers were selected from each packhouse on the basis of 3 growers from each of 3 growing systems - soil, pumice and NFT. The first sample (30 fruit per grower) supplied on 14 December 1993 was used for fruit compositional analysis, while the second sample (15 fruit per grower), was supplied by the same growers over the period January - February 1994 for shelf life determinations. A total of 810 fruit were provided for compositional analysis and 400 fruit for shelf life determinations.

Data Collection

Brix, dry matter percentage and titratable acidity were determined as detailed in 2.2.3.1 - 2.2.3.3, while shelf life and fruit firmness determined out as detailed in 2.2.3.4 - 2.2.3.5.

Data is presented in the form of frequency distributions to identify commonly occurring

levels or scores for individual fruit quality characteristics. Compositional quality for fruit dry matter percentage, brix and titratable acidity is presented in Figure A4.1 (a), (b) and (c) respectively, while shelf life and firmness data is presented in Figure A4.2 (a) and (b) respectively.

As there was no clear pattern between fruit quality and growing system, the data from the 3 growing systems was pooled.

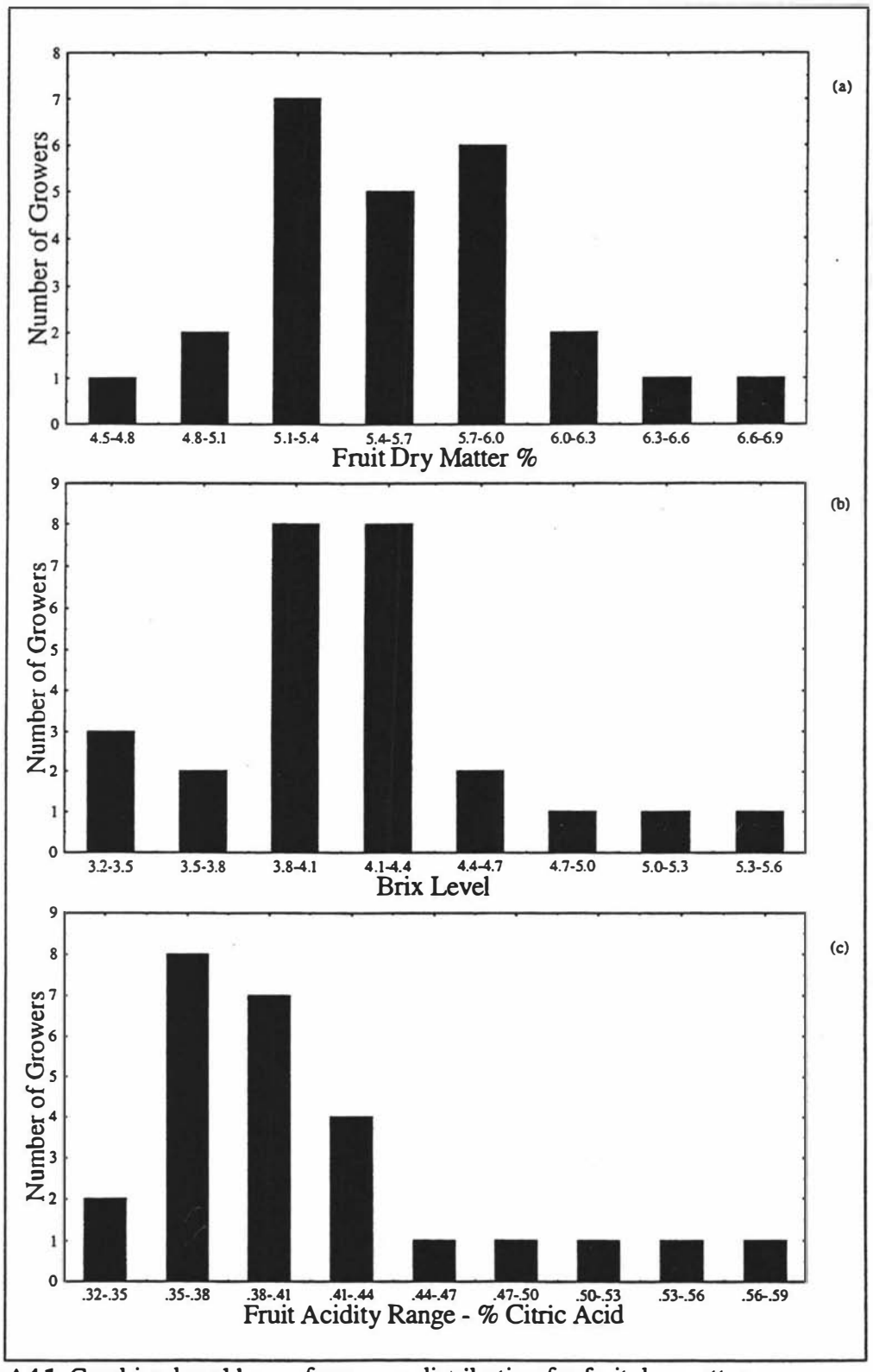

Figure A4.1 Combined packhouse frequency distribution for fruit dry matter percentage (a), brix (b) and percent citric acid (c)

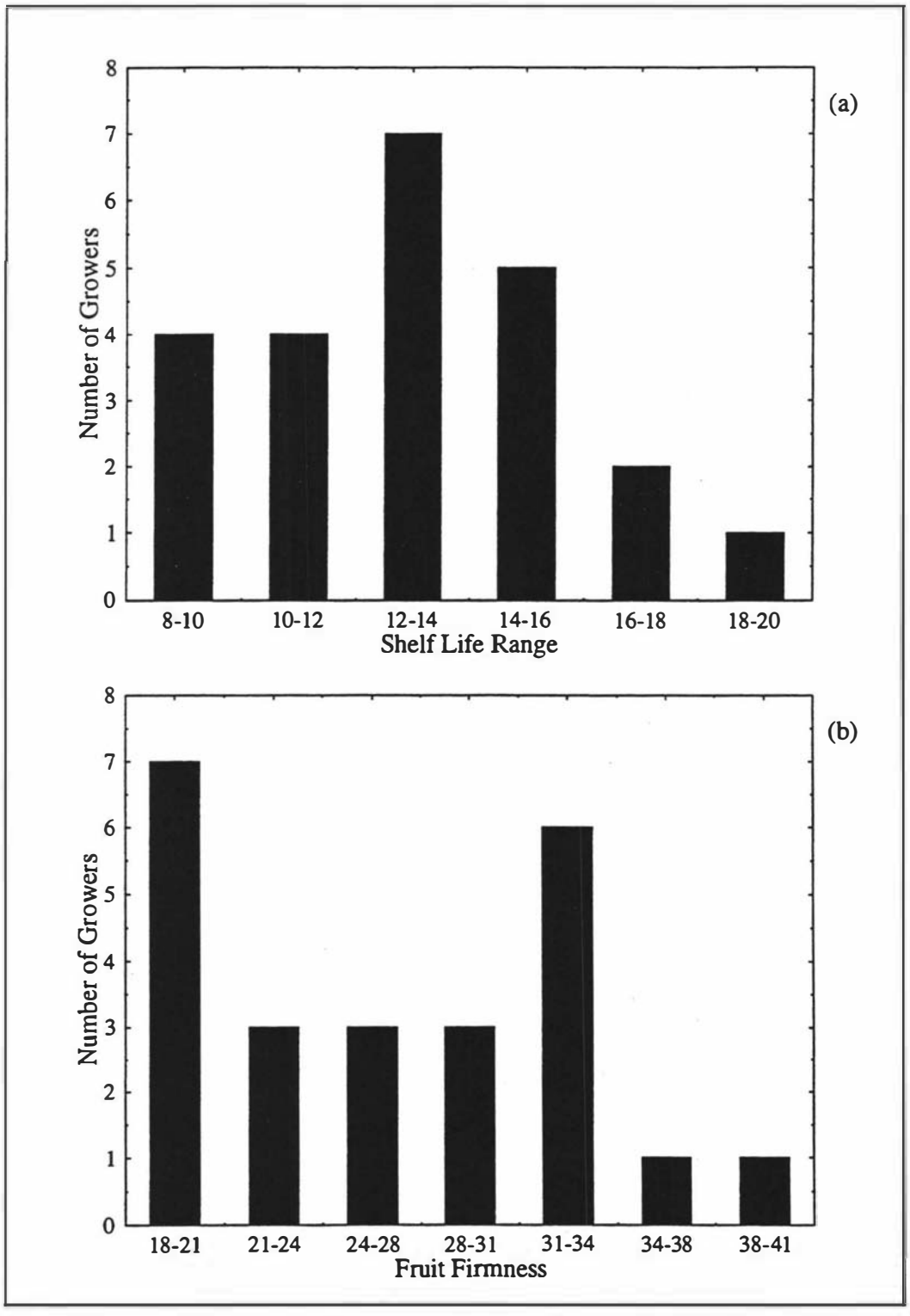

Figure A4.2 Combined packhouse frequency distribution for fruit shelf life (a) and firmness (b)

The fruit quality data presented in Figures A4.1 & 2 was determined on fruit collected from 27 commercial growers in the Auckland region. For all the fruit compositional attributes there was a wide range of values. With the exception of fruit firmness (Figure A4.2 b), there was a distinct peak for each fruit quality characteristic. That is a few samples of either excellent or inferior quality, with the majority of samples falling between these two extremes.

In Table A4.1 the common and top of the range values for the fruit samples is presented. This information will be used as a standard for comparison with the single truss and multi truss crops of the present investigation.

Table A4.1 Commercially produced packhouse fruit quality ranges.

	Fruit Quality - Average values				
Fruit origin	Dry Matter %	Brix	Citric Acid %	Shelf life (days)	Firmness
Commercial sample					
Common Range	5.1-6.0	3.8-4.4	0.35-0.41	12-16	-
Top of Range	6.6-6.9	5.3-5.6	0.56-0.59	18-20	18-21