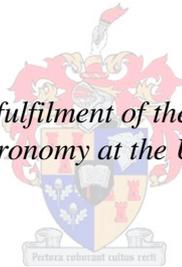# EFFECTS OF PRUNING AND NUTRITION ON GROWTH AND YIELD OF HYDROPONIC TOMATOES (*Lycopersicon esculentum* **Mill.**)

by
Craig Mark Fulton

Thesis presented in partial fulfilment of the requirements for the degree
Master of Science in Agronomy at the University of Stellenbosch

Supervisor: Mrs. Estelle Kempen
Faculty of Agronomy
Department of Agricultural Sciences

December 2011

Declaration

By submitting this thesis/dissertation electronically, I declare that the entirety of the work contained therein is my own, original work, that I am the sole author thereof (save to the extent explicitly otherwise stated), that reproduction and publication thereof by Stellenbosch University will not infringe any third party rights and that I have not previously in its entirety or in part submitted it for obtaining any qualification.

December 2011

i

Acknowledgements

Table of Contents

Abstract

The potential importance of soilless production, particularly in tomatoes, in an increasingly water scarce South Africa prompts a need for research under local conditions. In soilless production systems the application and availability of nutrients is closely linked to that of water, necessitating the research of methods to increase water and fertiliser use efficiency in soilless production systems, while diminishing environmental pollution and maintaining, or ultimately improving, tomato yield and quality. Poor management of hydroponic fertigation water results in pollution, and wastes precious water and expensive fertiliser. Pruning is an important cultural practise for ensuring high productivity of hydroponic tomatoes. Adapting pruning practises to climatic conditions could be a cheap and effective manner to improve productivity without increasing inputs. Improving water and fertiliser use efficiency is crucial to ensuring sustainable production of intensive crops, such as the tomato. Three experiments were carried out to investigate the effects of pruning and fertilisation on growth and yield and water and fertiliser use efficiency of hydroponic tomatoes.

In the first experiment the effect of EC (electrical conductivity), irrigation frequency and growing media on water use, nutrient uptake, yield and quality of greenhouse tomato was examined. A factorial design with split plots was used. Two EC treatments (1 and 2 $mS.cm^{-1}$) in factorial arrangement with 3 irrigation treatments (5x, 10x, 20x) were applied to the main plots. Plants grown in different growing media (coir, sand, sawdust) represented the split plots. Plants grown at EC 1 $mS.cm^{-1}$ were still able to uptake sufficient nutrients to achieve leaf nutrient contents associated with optimal production. Also, increasing the absolute nutrient concentration had a small effect on nutrient uptake. The organic media, coir and sawdust, reduced available N early in the tomato crop life, and tomatoes grown in coir had reduced Ca uptake compared to plants grown in sand and sawdust. Coir grown plants used more water compared to sand and sawdust grown plants. Plants grown at EC 1 $mS.cm^{-1}$ used less water compared to plants grown at EC 2 $mS.cm^{-1}$. Tomatoes grown at an EC 1 $mS.cm^{-1}$ did not differ significantly from higher EC plants in terms of marketable and green fruit yield. Plants cultivated at the lower EC had significantly lower percentage soluble solids content (Brix) compared to the higher EC treatment.

The second experiment examined the effect of leaf and fruit pruning on fruit size, total yield and marketable yield of tomatoes. Plants were grown using the high wire system and pruned to two stems. Three different leaf pruning treatments were applied: no leaf pruning, pruning every 2nd young leaf after 1m plant height, and pruning every 2nd young leaf after 2m plant height. Two fruit pruning treatments were also applied: no fruit pruning and

v

trusses pruned to 4 fruits. The experiment used a factorial design. Leaf pruning treatments had no effect and this was probably due to too late a removal of young leaves. Fruit pruning resulted in no significant difference between treatments in terms of marketable yield. Plants with unpruned trusses did have a significantly higher total yield, higher early yield, lower average marketable fruit weight, and higher yield of unmarketable fruit (particularly small fruit compared to the pruned treatment). From these results it can be concluded that fruit pruning isn't necessary on short tomato crops but this may be different over a longer cropping cycle.

The third experiment determined the combined effects of different EC and stem pruning practices on nutrition, growth and early yield of hydroponically grown tomatoes in coir. A factorial design was used, with two EC treatments (1 and 2 $mS.cm^{-1}$) in factorial arrangement with 2 stem pruning treatments (single and double). Stem pruning had little effect on plant growth but did alter plant development. Plants pruned to two stems produced significantly more trusses, but did not produce a significantly higher DM or leaf area compared to single stem plants. Stem pruning's major effect appears to be influencing fruit load; this may in the long term result in differences in plant growth and nutrition. EC 1 $mS.cm^{-1}$ plants produced significantly lower leaf area and organ dry masses but had a significantly higher marketable yield compared to EC 2 $mS.cm^{-1}$ plants. Over fertilisation in young tomatoes can negatively impact on early yield, whereas lower fertiliser application in early tomato growth improves early yield but limits canopy development which may limit plant productivity in the long term. These differences in growth are believed to be primarily related to differences in N and P nutrition.

Uittreksel

Die potensiële belang van grondlose produksietegnieke, veral by tamaties, in Suid-Afrika wat toenemend meer water skaars raak, motiveer dat navorsing onder plaaslike toestande gedoen moet word. By grondlose produksie stelsels word die toediening en die beskikbaarheid van voedingstowwe nou gekoppel aan dié van water. Navorsing rakende metodes wat water en kunsmis gebruiks doeltreffendheid sal verhoog en terselfdertyd besoedeling van die omgewing voorkom asook die opbrengste en kwaliteit van tamaties behou of verbeter is dus van uiterste belang. Swak bestuur van bemesting in hidroponiese stelsels gee aanleiding tot water besoedeling en vermorsing van kosbare water en duur kunsmis. Snoei is 'n belangrike kulturele praktyk om hoë produktiwiteit by hidroponiese tamaties te verseker. Die aanpassing van snoei praktyke by klimaatstoestande is 'n goedkoop en doeltreffende manier om produktiwiteit te verbeter sonder om insette te verhoog. Die verbetering van water en kunsmis gebruiks doeltreffendheid is dus noodsaaklik om te verseker dat intensiewe gewasse, soos tamaties, volhoubaar geproduseer word. Drie eksperimente is uitgevoer om die effek van snoei en bemesting op die groei, opbrengs en water en kunsmis gebruiks doeltreffendheid van hidroponiese tamaties te ondersoek.

In die eerste eksperiment is die effek van die EG, besproeiings frekwensie en groeimedium op die water gebruik, voedingstofopname, opbrengs en kwaliteit van tamaties ondersoek. 'n Faktoriaal ontwerp met gesplete plotte is gebruik. Twee EG behandelings (1 en 2 mS.cm^{-1}), 3 besproeiings behandelings (5x, 10x, 20x per dag) en 3 groei media (kokos, sand, saagsels) is ondersoek. Selfs by 'n EG van 1 mS.cm^{-1} was die voedingstof opname van plante vergelykbaar met waardes wat geassosieer word met blaar 'n voedingstof inhoud wat voorgeskryf vir optimale produksie. die verhoging van die absolute voedingstof konsentrasie het ook 'n klein uitwerking op voedingstofopname gehad. In die organiese media - kokos en saagsels – het die beskikbare N vroeg in die seisoen verminder, en die tamaties wat in kokos gegroei het, het ook 'n verminderde Ca opname getoon in vergelyking met die plante wat in sand en saagsels gegroei het. Die plate wat in kokos gegroei het, het meer water gebruik in vergelyking met plante wat in sand en saagsels gegroei het. Plante besproei met 'n voedingsoplossing van 1 mS.cm^{-1} EG het minder water gebruik as die plante wat besproei met 'n voedingsolossing by 'n EG van 2 mS.cm^{-1}. Tamaties wat gekweek word by 'n EG van 1 mS.cm-1 het nie beduidend verskil van hoër EG plante in terme van bemarkbare en groen vrugte nie. Plante wat gekweek is by die laer EG het 'n aansienlike laer persentasie oplosbare vastestof inhoud (Brix) in vergelyking met die hoër EG-behandeling gehad.

Die tweede eksperiment het die effek van blaar- en vrug snoei op die vruggrootte, totale opbrengs en bemarkbare opbrengs van tamaties ondersoek. Plante is vertikaal opgelei tot by die horisontale draad en na twee stamme gesnoei. Drie verskillende blaar snoei behandelings is toegepas: geen blaar snoei, snoei elke 2de jong blaar na 1m plant hoogte en snoei van elke 2de jong blaar na 2m plant hoogte. Twee vrug snoei behandelings is ook toegepas: geen vrugte gesnoei en trosse gesnoei tot 4 vrugte. 'n Faktoriale ontwerp is vir hierdie eksperiment gebruik. Blaar snoei behandelings het geen effek gehad nie, waarskynlik omdat die jong blare te laat verwyder was. Met die vrug snoei behandelings was daar geen beduidende verskil tussen die behandelings in terme van bemarkbare opbrengs nie. Plante waarvan die trosse nie gesnoei was nie het 'n aansienlik hoër totale opbrengs gelewer, asook 'n hoër vroeë opbrengs maar 'n laer gemiddelde bemarkbare vrug massa en 'n hoër persentasie onbemarkbare vrugte (baie klein vrugte in vergelyking met die gesnoeide behandeling). Vanuit hierdie resultate kan daar afgelei word dat vrug snoei nie nodig is tydens 'n kort groeiperiode vir tamaties nie, alhoewel dit wel 'n rol mag speel gedurende 'n langer groeiperiode.

Met die derde eksperiment is die gekombineerde effek van verskillende EG en stam snoei praktyke op voeding, groei en vroeë opbrengs van hidroponies verboude tamaties bepaal. 'n faktoriale ontwerp is gebruik, met twee EG behandelings (1 en 2 $mS.cm^{-1}$) en 2 stam snoei behandelings (enkel en dubbel). Stam snoei het 'n geringe uitwerking op die groei van die plant gehad, maar het wel die ontwikkeling van plante verander. Plante gesnoei na twee stamme het aansienlik meer trosse gehad, maar nie 'n hoër DM of blaar oppervlak as die enkele stam plante nie. Stam snoei se grootste effek blyk te wees op die aantal vrugte per plant en dit kan op die lang termyn lei tot verskille in die groei van plante en hul voeding. EG 1 $mS.cm^{-1}$ plante het 'n aansienlik laer blaaroppervlakte en droë massas geproduseer, maar het 'n aansienlik hoër bemarkbare opbrengs in vergelyking met EG 2 $mS.cm^{-1}$ plante gelewer. Oorbemesting kan 'n negatiewe impak op die vroeë opbrengste van tamaties hê, terwyl laer bemesting in die vroeë stadiums van groei vroeë opbrengs bevoordeel maar blaaroppervlak ontwikkeling beperk wat dan ook produktiwiteit beperk in die lang termyn. Hierdie verskille in groei word hoofsaaklik toegeskryf aan verskille in die N-en P-voeding.

viii

Chapter 1
Literature Review

1. Problem identification

Population growth and high living standards are resulting in increasing demand for good quality water (Togoni *et al.*, 1998; Bouwer, 2000). Fresh water is a scarce resource, with only 0.6% of earth's water existing as liquid fresh water (Togoni *et al.*, 1998). South Africa is facing a serious water supply crisis culminating from unreliable and sporadic rainfall, and growing demand from agriculture, industry and towns (Binns *et al.*, 2001).

Cultivation under protection first started in RSA in 1973, but the young industry was devastated in 1974 by the soil borne diseases bacterial canker and eelworm (Maree, 1994). South African producers in response converted to soilless agriculture. Soilless cultivation under protection allows crop production in areas where soil isn't normally suitable, the control of soil borne pests and diseases, increased efficiency of fertiliser use, higher planting densities and higher productivity per unit area (Jensen, 2002). Also, water use efficiency of soilless plant production is higher than soil grown plants (Raviv & Lieth, 2008), especially in closed systems which can reduce water use by 30% and fertilizer use by over 50% compared to open systems (Vernooij, 1990). This makes soilless crop production an attractive agricultural production system for South African producers.

Soilless tomato production is on the increase in South Africa due to improved economic returns (Maboko & Du Plooy, 2009). Most South African soilless producers currently make use of open irrigation systems. In these open systems plants are fed up to 130% of their theoretical requirements to compensate for irrigation inaccuracies and to enforce drainage; the excess nutrient solution runs to waste with any other agrichemicals applied to the crop (Olympios, 1999). Such excessive application of water and fertiliser is no longer considered acceptable because of increasing society awareness to environmental damage (Papadopolous et al., 1999). Over irrigation is also simply a waste of precious water and expensive fertiliser. This leaching requirement can be reduced if greater care is taken in formulating and applying nutrients (Benton-Jones, 2005).

The potential importance of soilless production, particularly in tomatoes, in an increasingly water scarce South Africa prompts a need for research under local conditions. Research needs to address the issue of increasing water and fertiliser use efficiency in soilless production systems, while diminishing environmental pollution and maintaining, or ultimately improving, tomato yield and quality. For these reasons, my studies and literature

review focus on tomato plant nutrition, irrigation related factors (media, irrigation frequency, water use) and pruning on growth and productivity of hydroponically grown tomatoes.

2. Fertigation

The theory of plant nutrition of soilless-grown plants does not differ from soil-grown plants. The fundamental factor that divides the two is that soilless cultivated plants are grown in a limited volume of substrate. This has major implications with regards to fertilizer management owing to a lower buffer capacity for solution composition and limited supply of nutrients (capacity factor) (Silber & Bar-Tal, 2008). Soilless cultivation has the benefit of precision control of plant nutrition and root environment (Olympios, 1999), but increased risk because of the smaller root system and low buffering capacity of water and nutrients (Silber & Bar-Tal, 2008). It is important in soilless agriculture to synchronise plant demands for water and nutrients otherwise deficiency or salinisation may rapidly occur (Klaring, 2001). The residuals salts accumulate in substrate solution due to variation in plant water: nutrient uptake ratio and selective uptake of ions (Sonneveld & Voogt, 2001; Klaring, 2001). Most producers counter this by over irrigating and enforcing drainage to leach the accumulated salts (Olympios, 1999; Raviv et al., 2004). This will be discussed in more detail in the following sections.

2.1 Nutrient uptake

Nutrient solution is usually applied in aggregate based hydroponic systems through a dripper irrigation system; the same system is widely used by South African soilless growers. Nutrient solution in soilless agriculture must contain all the essential elements. Essential plant elements are defined as elements required for the normal life cycle of the plant and whose nutritional role cannot be assumed by another element (Benton-Jones, 2005; Silber & Bar-Tal, 2008). These essential plant nutrients are taken up by the roots and divided into two broad categories macro and trace elements. Macro elements are needed in large quantities compared to trace elements and include the elements Nitrogen (N), Phosphorus (P), Potassium (K), Sulphur (S), Magnesium (Mg) and Calcium (Ca) (Kirby & Mengel, 1987; Benton-Jones, 2005). Plants must be supplied with adequate nutrients during the entire growth period to ensure optimal growth. Nutrient availability is a function of nutrient concentration and the ability to maintain nutrient concentration in the root zone (Kirby & Mengel, 1987; Benton-Jones, 2005). Plants draw these nutrients from three possible pools:

2

nutrients already present in substrate, nutrients applied, and nutrients accumulated in substrate (Benton-Jones, 2005).

Nutrient transport from solution to the root surface takes place via the processes of convective water flow (mass flow) and diffusion along a concentration gradient (Kirby & Mengel, 1987; Silber et al., 2003). Mobile elements such as NO_3^- are transported to the root surface mainly by convection with the water stream while less mobile elements such as P and K are transported by diffusion (Mmolawa & Or, 2000). Root activity results in considerable changes in concentration of solutes around the roots. Nutrient concentrations in the plant rhizosphere are high or even in excess immediately after irrigation (Silber et al., 2003). Nutrient depletion in the rhizosphere as a result of root sink activity has been observed for major nutrients such as N, P and K. This root induced depletion of ions creates a concentration gradient which facilitates diffusion towards the root surface (Hinsinger et al., 2006). Nutrients are not only taken up by the roots but are adsorbed onto solid phases or precipitated as insoluble compounds, thus decreasing the concentration of plant available nutrients in the root zone (Silber, 2008). These processes are time dependent and result in a progressive decline in nutrient concentration level between irrigations which may even reach deficit levels (Adams, 1994). Transport to the root surface is dominated by diffusion under conditions of low transpiration and low soil solution nutrient concentration, whereas mass flow is predominant under high soil solution nutrient concentrations and high transpiration (Kirby & Mengel, 1987).

Plant roots may take up nutrients passively or actively: passively adsorbed ions are carried into the root with the transpiration stream; alternatively ions can be adsorbed actively by the outer root cells against a concentration gradient (Benton-Jones, 2005). Plant roots are able to selectively take up ions even if the concentration and ratio of elements outside the plant differ, and thus are able to accumulate ions in roots against a concentration gradient (Epstein, 1972; Kirby & Mengel, 1987; Benton-Jones, 2005). Compelling evidence of active transport is the ability of plant cell salt concentrations to reach concentrations much higher than that of the surrounding solution (Epstein, 1972). This is illustrated by studies on tomatoes grown in nutrient flow technique (NFT). The NFT grown tomato crops established their own K:N ratio uptake regardless of the K:N ratio of the recirculating solution (Cooper, 1996), and N concentrations varying from 10-320 ppm showed little effect on plant growth, yield and N uptake (Cooper, 1996). Active uptake enables plants to absorb sufficient K, P, N and S even at low concentrations, whereas for Na, Mg and Ca, which are passively transported elements, uptake is more dependent on external concentration of substrate

3

solution (Sonneveld & Voogt, 2009). These active uptake processes are energy dependent (Kirby & Mengel, 1987).

Nutrient solutions are designed based on uptake patterns of plants. Extensive research has been done to determine the ratio of nutrient to water uptake for individual elements. These ratios are used to create balanced nutrient solutions. Plant uptake ratios are not constant, changing between crop types and growth stages of crops (Klaring, 2001). Initial tomato uptake ratio of K/N is initially 1 and increases to 2 when the plant starts fruiting; whereas fruiting cucumbers take up nutrients in a K/N ratio of 1 (Ho and Adams, 1995; Cooper, 1996).

Several studies have illustrated the benefits of high frequency irrigation scheduling on improving plant nutritional status, or maintaining plant nutritional status at low nutrient feeding concentrations. Jovicich et al. (2003), using small high frequency fertigation events, were able to grow bell peppers in a nutrient solution at half the concentration typically used by growers in Florida without reduction in yield. Silber et al. (2003) and Silber (2008) performed similar studies on lettuce and bell peppers, respectively. They found that increased irrigation frequency at low nutrient concentration levels significantly increased yield. The improvement in nutrient uptake by frequent irrigation is attributed to two mechanisms: continuous replenishment of nutrients in the depletion zone near the root surface and enhanced mass flow transport of dissolved nutrients due to a higher water content of the media (Silber et al., 2003). Frequent irrigation enhances uptake by plants of less mobile macro elements, such as P and K, and trace elements, thus enabling the concentrations of these elements to be reduced in nutrient solution (Silber et al., 2003; Silber, 2008). Frequent irrigation should be used with caution as it may result in sub optimal aeration of substrate which can negatively on impact nutrient uptake and plant growth (Silber et al., 2003).

2.1.1 Electrical conductivity

Electrical conductivity (EC mS.cm^{-1}) is a measure of the total concentration of dissolved solutes in nutrient solution (Li et al., 2001). It can therefore be used as a measure of nutrient availability. Too low concentrations of fertiliser cause mineral deficiencies and restrict plant growth, where as there is no negative effects of over supplying nutrients to a threshold point (Li et al., 2001; Sonneveld & Voogt, 2009). Therefore, producers, to avoid deficiencies and control produce quality, add large amounts of nutrients with little attention to crop uptake (Li et al., 2001). The EC required for optimal plant production depends on the crop type and growing conditions (Sonneveld & Voogt, 2009).

It is well known that saline conditions (high EC) reduce yield and plant growth in tomatoes (Li et al., 2001). An EC of 2.0 mS.cm^{-1} is sufficient to maintain optimal nutrient uptake in tomatoes; 2.5 mS.cm^{-1} is estimated as the salinity threshold for a tomato crop (Sonneveld & Welles, 1988; Sonneveld & Voogt, 2009). Sonneveld & Welles (1988) reported that for each 1 mS.cm^{-1} increase above 2.5 mS.cm^{-1} tomato yield decreased by 5-7%. Schwarz & Kuchenbuch (1998) found that plants grown at an EC of 6 mS.cm^{-1} experienced a 50% reduction in yield compared to plants grown at an EC of 1 mS.cm^{-1}. Reduced shoot and root growth is symptomatic of water and salt stress in plants (Munns, 2002). Tomatoes grown at an EC of 9 mS.cm^{-1} experienced a 20% reduction in leaf area compared to plants fed a 1 mS.cm^{-1} nutrient solution (Schwarz & Kuchenbuch 1998). These reductions in yield and plant growth are associated with reduced water uptake and shifts in water distribution within the plant (Schwarz & Kuchenbuch, 1998; Li et al., 2001). Elia et al. (2001) reported that increasing EC from 1 to 6 mS.cm^{-1} didn't reduce DM yield but reduced fresh weights of tomato shoots and fruit. Li et al. (2001) had similar findings, root zone salinity didn't affect dry matter yield, and loss in yield was the result of reduced fresh weight caused by lower tissue water content and an increased discarded fraction of small unmarketable fruit.

Tomatoes grown at higher EC tend to have a reduced yield, but increased total soluble solids (TSS), titratable acids (TA), ascorbic acid, vitamin C, and sugar content of their fruit (Sonneveld & Welles, 1988; Cornish, 1992; Elia et al., 2001). This is caused by the reduced uptake of water into the fruit and the subsequent concentration of fruit content, as well as accumulation of compatible solutes in fruit due to plant osmotic adjustment (Plaut & Grava, 2005).

The negative effects of high EC on tomato crop growth and yield are exacerbated by high light intensities and low relative humidity, but are less detrimental under low light conditions (Li et al., 2001). However, high humidity can also increase the negative effects of high EC on plant growth by impairing Ca transport to leaves (Sonneveld & Welles, 1988). Increasing EC reduces Ca content of tomato fruit and may increase the incidence of the physiological disorder blossom end rot (BER) and yield loss (Ho & Adams, 1995; Sonneveld & Welles, 2005). Sonneveld & Welles (2005) found for each 1 mS.cm^{-1} increase above 1.5 mS.cm^{-1} that Ca content decreased by 4 mmol Ca per kg of fruit dry matter and rapidly brought Ca below critical levels in tomato fruit.

EC can be used to manipulate plant growth and fruit quality, and for this reason producers don't always maintain EC levels that would be considered optimal for plant production (Sonneveld & Voogt, 2009). An example being, low light and humid conditions

5

induce lush vegetative growth in tomatoes, producers in response make use of elevated EC values in their nutrient solutions (4-8 ms.cm-1) to reduce vegetative growth, shifting the crop into a more generative state, thus improving early plant production (Sonneveld & Welles, 1988; Sonneveld & Voogt, 2009). Even under normal light conditions, producers make use of elevated ECs in nutrient solutions to improve quality parameters, such as shelf life, flavour and colouring, to receive higher produce prices (Sonneveld & Welles, 1988; Sonneveld & Voogt, 2009).

2.1.2 Relative ion ratios of feeding solution

The absolute concentration is not the only factor determining plant nutrient uptake; in fact the mutual ratios of nutrients in the root environment are more important than the absolute concentrations in the feeding solution (Sonneveld & Voogt, 2009). Sonneveld & Welles (2005) found that increasing the nutrient concentration, while maintaining the same mutual cation ratio, had a small effect on plant cation uptake in tomatoes, peppers and cucumbers in comparison to shifts in mutual ratios of fertiliser cations; a slight increase in K uptake, practically no difference in Mg uptake and a decrease in Ca uptake was observed with increasing EC. However this is not the case for all plants, and increased plant K content at increasing EC is likely linked to osmotic regulation by the plant and not necessarily a change in nutrient uptake (Sonneveld & Voogt, 2009).

The mutual ratios of the cations K-Ca-Mg-Na influence yield and quality of tomatoes, with increasing proportions of K and Ca cations having the strongest positive impact on yield (Fanasca et al., 2005; Fanasca et al., 2006; Sonneveld & Welles, 2005). Nutrient solutions containing high proportions of Na, K and Mg cause increased incidence of BER, attributed to reduced Ca uptake through antagonism (Adams, 1994; Fanasca et al., 2005; Fanasca et al., 2006). The K/Ca is important because of its influence on quality of produce and the uptake antagonism between these cations can exacerbate BER (Papadopoulos et al., 1999; Sonneveld & Voogt, 2009). High proportions of K and Na in nutrient solution have been found to increase fruit TSS, EC and TA (Fanasca et al., 2005; Fanasca et al., 2006). The recommended K: Ca: Mg meq ratio for many crops is 1:2:1 (Sonneveld & Welles, 2005). However, a nutritional study by Fanasca et al. (2006) determined that cation proportions of K 0.48, Ca 0.38 and Mg 0.14 ratio would achieve maximum fruit yield in tomatoes. A possible reason for the differences could be owing to the strength of the nutrient solution, because in a higher EC nutrient solution the proportion Ca would be increased to compensate for reduced uptake under saline conditions.

6

The balance of Ca, N and P in nutrient solution can influence the incidence of BER. Low P, high NO_3^- and SO_4^{2-} levels in nutrient solution reduce Ca uptake in tomatoes while relatively high P and Cl levels stimulate Ca uptake (Sonneveld & Voogt, 2009). Ho et al., (1999) found that BER was less at lower NO_3^- levels and more prevalent at low P levels. However, they also found Ca concentration and uptake in fruit tissue wasn't affected by these treatments, therefore, BER is not necessarily a Ca uptake related problem. The form of Ca in the fruit tissue is more important than the total tissue concentration. Ca pectate and Ca phosphate are essential for cell wall strength and membrane permeability, thus low P levels could reduce the amount of functional Ca below critical levels resulting in cell leakage and tissue rotting (Ho et al., 1999). High levels of N promote rapid fruit growth and increased Ca demand. Since Ca supply rate is limited by water uptake, the demands of rapidly growing fruit may be too high to meet resulting in BER (Ho et al., 1999). Therefore the balance between Ca, N and P acting on cell wall permeability is an important factor that may cause BER (Ho et al., 1999). High levels of Nitrogen supplied as NH_4 also increase the incidence of BER, therefore it is suggested that NH_4 supply does not exceed 10% of total N supply (Ho et al., 1999; Sonneveld & Voogt, 2009). In summary it is very important to examine the mutual ratios of major fertiliser ions in the nutrient solution and not just the absolute concentration of nutrients.

2.1.3 pH

The pH (potential Hydrogen) is the logarithm of the reciprocal of hydrogen ion concentration of the solution, and indicates the acidity or alkalinity of the solution. If the pH is less than 7, the solution is acidic; when the pH is greater than 7, the solution is alkaline (Cooper, 1996). The pH of the nutrient solution has significant effects on the availability of elements, particularly micronutrients (Benton-Jones, 2005). Microelements such as Iron, Zn and Mn have limited solubility at high pH, forming insoluble hydroxide precipitates; phosphorus precipitates out of solution as Ca-Phosphate minerals at elevated pH and may block irrigation emitters (Benton-Jones, 2005; Bar-Yosef, 2008).

The pH of nutrient solutions should be maintained between 5.0-6.0 to ensure easy availability of all nutrients for the plant, at pH < 4.5 root damage may occur and root disease risk increases (Bar-Yosef, 2008; Sonneveld & Voogt, 2009). The pH of nutrient solutions can be corrected using acids, such as HNO_3 and H_2PO_4, or bases, such as KOH, depending on the pH of the feeding water. However, the pH of substrate solutions can vary greatly during cultivation. This is facilitated by the small volumes of substrate, especially if the substrate has

7

a low buffer capacity (Sonneveld & Voogt, 2009). Plants roots are capable of altering the rhizosphere pH by releasing Hydrogen (H^+) or Hydroxyl (OH^-) ions to compensate for unbalanced cation-anion uptake at the root surface (Hinsinger et al., 2003; Ikeda, 2007). When more cations than anions are taken up, H^+ will be released into the apoplasm to balance the excess positive charges entering the cell (pH decreases); when more anions are taken up than cations, OH^-, HCO_3^- or organic anions are released into the apoplasm to balance the excess negative charges (pH decreases) (Hinsinger et al., 2003). This will result in changes of the substrate solution pH which can negatively or positively influence nutrient uptake.

2.2 Essential macroelements

2.2.1 Nitrogen (N)

Nitrogen contributes primarily towards development of vegetative components of the plant (leaves and stems) (Papadopoulos, 1998). N is a major constituent of amino acids and proteins, with 80-85 percent of plant N present as proteins and only 5 percent as nucleic acids (Benton-Jones, 2005; Barker & Bryson, 2007). Visual symptoms of N deficiency are first expressed as lightening of normal green colour, which progresses into chlorosis, and finally necrosis (Benton-Jones, 2005). Low N in tomatoes delays time to fruit set, reduces number of fruit set, reduces vegetative growth (stunting), fruit growth, fruit dry matter content, total soluble solids and fruit firmness (Huett & Dettman, 1988; Barker & Bryson, 2007). High rates of N induce vigorous growth to the detriment of fruit production (Papadopoulos, 1998). Excess N application results in overly vegetative plants which increases susceptibility to disease and insect attack, and impairs blossom and fruit development (Benton-Jones, 2005). Experiments by Huett and Dettman (1988) found contradictory results, with vegetative and root dry weights not increasing beyond 11 mmol. L^{-1} N, whereas fresh and dry weights of fruit increased with increasing N levels up to 32 mmol.L^{-1}. A leaf DM (dry matter) N content of 2.5-4.0 % N corresponds to optimal productivity in tomatoes (Peet, 2005).

Nitrogen can be supplied in the form of NH_4^+ or NO_3^- (Hinsinger et al., 2003). The major form of N supply is NO_3^- based fertilizers. NO_3^- is non toxic and readily translocated from the root apoplast through the xylem to plant roots and shoots, where it is sequestered at high concentrations in plant cell vacuoles (Rice, 2007). High concentrations of NH_4^+ are toxic to plants. Plants tolerance to NH_4^+ toxicity varies, depending on crop type, cultivar and growing conditions (Sonneveld & Voogt, 2009). Ammonium (NH_4^+) competes with Ca, Mg

8

and K for uptake, and should therefore be used carefully on crops sensitive to Ca deficiency (Hohjo et al., 1995; Sonneveld & Voogt, 2009). Special care should be taken under hot, dry and high light intensity conditions that limit Ca transport to fruit otherwise BER will occur (Adams, 1994).

High NH_4^+ concentrations are detrimental to tomato vegetative growth, reduce inflorescence size, reduce yield and can increase the number of soft fruit (Feigin et al., 1980). However the addition of NH_4^+ has been found to be beneficial to plant growth and yield of tomatoes (Claussen, 2002; Tabatabaei et al., 2008). Claussen (2002) found tomatoes yielded best with NO_3^- : NH_4^+ ratio of 75:25. NH_4^+ fertilizer application has also been associated with increased incidence of BER in tomatoes; however, studies seem to indicate that effect is not solely linked to reduced uptake of Ca (Saure, 2001).

Ammonium application improves the uptake of NO_3^- in plants, thus increasing the total N and NH_4^+ leaf concentration as NH_4^+ concentration increases (Tabatabaei et al., 2008). If plant roots absorb more NH_4^+ the pH of the substrate solution will decrease and if more NO_3^- is absorbed the pH will increase. Ikeda and Osawa (1981) found that crops will preferentially take up the desired source of N irrespective of the ratio of NH_4^+: NO_3^-, indicating that crops differ in ability to acidify the root environment. NH_4^+ is preferentially absorbed by crops at low concentrations and its addition to a nutrient solution can be used to buffer the root zone pH. Between 5-10% of N supplied as NH_4^+ is sufficient to maintain root zone pH at the required level. Improvement in yields associated with the inclusion of NH_4^+ has been primarily attributed to increased availability of elements due to a lower pH (Sonneveld & Voogt, 2009).

There has been much research, but little agreement, to determine optimum application rate of N in hydroponics to maximise yield and minimise N use. Huett and Dettman 1988 reported a tomato plant's maximal N uptake rate was 520 mg per day, whereas Morgan (2006) stated that N uptake for optimal production was only 80-110 mg per day. Güler and Güzel (1999) suggest application rates of 250 mg. L^{-1} to optimise yield and Ho et al. (1999) suggests 180mg.L^{-1}. Coltman (1988) as cited by Gent (2004) found that tomatoes supplied N at a concentration of 28 mg/L were still able to accumulate sufficient levels of N in petiole sap associated with maximum yield. Similarly, Jovicich et al. (2003) grew peppers at half the nutrient solution concentration normally used by commercial producers (73 mg. L^{-1} N versus 156 mg. L^{-1} N) in Florida without yield penalty. Plant N uptake seems fairly insensitive to N concentration in the root zone and plants are able to accumulate sufficient N even at low concentrations (Sonneveld & Voogt, 2009).

9

2.2.2 Phosphorus (P)

Phosphorus plays a key role in plant biochemical energy storage and transfer as a linkage binding site in ADP/ ATP (Sanchez, 2007). It also forms an important linkage group in membrane phospholipids, nucleotides and nucleic acids (Sanchez, 2007). P is taken up as HPO_4^{2-} and $H_2PO_4^{-}$ depending on pH (Rice, 2007; Sanchez, 2007). These ions are actively absorbed by plants through an H^+ cotransporter and HCO_3^{-} antiporter proteins allowing plants to absorb sufficient P even at very low concentrations (Rice, 2007). P is only required in small quantities for normal plant growth and high feed levels can cause P toxicity, if tissue DM content of P is > 1% toxicity will arise and plant growth will suffer (Benton-Jones, 2005; Sonneveld & Voogt, 2009).

Phosphorus is important for root growth, vegetative growth and fruit set throughout a tomato crops life span (Papadopoulos, 1998). Tomatoes only need 22-35mg of P a day according to Morgan (2006). P supplied as phosphate can form insoluble precipitates with metals such as Fe and Ca, or be absorbed onto solid phases, reducing the amount of available P in the root zone (Amiri & Sattary, 2004; Silber, 2008). However, plant root acidification activity over time can dissolve precipitated elements. High fertigation frequency has been identified as a method to increase availability of immobile elements, such as P, without the addition of high fertiliser concentrations (Silber, 2008). Nutrient solution levels of 30-50 mg.L^{-1} are often recommended, but there is increasing evidence that P concentrations of 10-20 mg. L^{-1} are sufficient for optimal plant growth (Benton-Jones, 2005).

2.2.3 Calcium (Ca)

Calcium is absorbed as the divalent cation Ca^{2+}. Calcium is largely located in the apoplastic cell wall region, and cytoplasmic Ca levels are low with most being sequestered in cell organelles (Rice, 2007). Calcium is a key element in the primary cell wall of plant cells, improving load bearing strength and cell to cell adhesion (Pilbeam & Morley, 2007). A third of all Ca exists in the plant as the compound Ca pectate, which stabilises the cellulitic matrix and cements adjacent cells together (Rice, 2007). Calcium is also an important factor in membrane integrity, ion transport regulation and also functions as a secondary messenger controlling enzyme activity (Prasad, 1997a; Cramer et al., 1985).

Bulk entry of Ca initially occurs in cell wall intercellular spaces (apoplast) where it moves passively with the transpiration stream through the pericycle after which it is forced into the symplast of endodermal cells and then finally loaded in to the xylem (Pilbeam &

10

Morley, 2007). However, Ca is only able to move past the endodermis and into the root stele just behind the tips of actively growing roots (Pilbeam & Morley, 2007).

Vegetative tomato growth needs very little Ca; Del Amor and Marcelis (2005) found no negative impacts on vegetative growth of tomato plants grown at low Ca concentration (0.5 meq.L^{-1}). Calcium nutrition is associated with the physiological disorder blossom end rot (BER) in tomatoes. This disorder is aggravated by conditions which reduce Ca uptake or functional Ca as has been mentioned earlier in the review. BER is still poorly understood and is a complex plant stress response mediated by nutrition, genetics and environmental conditions (Saure, 2001).

Excessive Ca uptake into the fruit can cause the physiological disorder 'Gold Spot', which is gold flecking on tomato fruit calyx and shoulders, particularly during summer (Peet, 2009). These specks have been identified as granular masses of Ca oxalate crystals (Ho et al., 1999). This disorder is more prevalent under high relative air humidity (>80 %) and high Ca/K ratios, conditions which favour calcium transport into tomato fruit (Peet, 2009). High temperatures also increase incidence of Gold spot and it is thought that high temperature increases the amount of calcium deposited in fruit as Ca oxalate (Ho et al., 1999). To prevent disorders linked to Ca deficiency or Ca excess, Ho et al. (1999) recommends a Ca feeding rate of 120mg.L^{-1} Ca while applying low but sufficient N (180mg/L), not excessive K (<400 mg.L^{-1}) and to avoid P depletion (>5 mg.L^{-1}) in feeding solution. A leaf DM content of between 1.0-2.0% in tomatoes is recommended for sustained growth and production (Peet, 2005).

2.2.4 Potassium (K)

Potassium is taken up as the K^+ cation, and is taken up by plants via a low and high affinity transport mechanism. Low affinity transport relies on an H^+ plasmalemma pump maintaining an electrochemical difference across the plant cell membrane, which facilitates diffusion of K into the plant cell (Mengel, 2007). This allows for rapid transport of K between and within plant tissue, and only functions at K concentrations >0.1 mM. K high affinity transport relies on a membrane bound H+/K+ symport protein, which only functions at low concentration <0.1 mM (Mengel, 2007; Rice, 2007). Potassium is involved in numerous metabolic processes including osmotic control, enzyme activation, carbohydrate production and partitioning, and anion/cation balance (Balliu & Ibro, 2002). Plants deficient in K^+ exhibit retarded growth, leaf edges become flaccid, and chlorotic stripes, starting at leaf tips, develop on the margins of older leaves (Mengel, 2007).

11

A high K supply is crucial for ensuring normal plant growth and high quality fruit in tomatoes (Papadopoulos, 1998). Potassium deficient fruit are prone to blotchy ripening, grey wall, poor colouration and are not fleshy (Balliu & Ibro, 2002; Peet, 2009). Conversely, high levels of K reduce fruit size, improve fruit shape, promote uniform colouring, increase fruit acidity and reduce the number of hollow fruit (Ho & Adams, 1995; Papadopoulos, 1998). The ratio of K:N is important to regulate growth and high levels of P and N can accentuate K deficiency (Papadopoulos, 1998).

Tomato fruit accumulate a large amount of K (Ho & Adams, 1995). Balliu & Ibro (2002) reported that 70% of plant K was found in the fruit compared to only 16% in the leaves. For this reason, a high K:N ratio of 2 in nutrient solution is recommended for fruiting tomato plants (Ho & Adams, 1995). High K levels can reduce yield either as a result of a high K:N ratio, which suppresses vegetative growth, or a high K with high N concentration that indirectly reduces yield through salinity effects (Papadopoulos, 1998). Nutritional studies by Güler and Güzel (1999) concluded that $300 mg.L^{-1}$ K was sufficient for optimal yield in tomatoes. DM leaf levels of K needed for optimal growth in tomatoes range between 2.8-4% according to Peet (2005).

2.2.5 Magnesium (Mg)

Magnesium is a major constituent of the porphyrin ring of chlorophyll, and also serves as an enzyme activator and cofactor (Merhaut, 2007). Approximately 70-85% of plant Mg is utilised in enzymatice processes and 15-30% is used in chlorophyll synthesis (Merhaut, 2007). Deficiencies result in a distinct interveinal chlorosis of older leaves giving a herringbone appearance (Benton-Jones, 2005; Rice, 2007). Severe deficiencies are difficult to rectify and are caused by high application rates of other cations and low pH (Papadopoulos, 1998).

Magnesium deficiency is common in older tomato leaves, but rarely causes losses in tomato yield (Papadopoulos, 1998). Even though sub optimal application rates of Mg have been found not to reduce overall growth in tomatoes, Mg can still influence tomato yield and quality; increasing Mg concentrations from 0.5 mM to 10 mM has been found to reduce tomato fruit weight (Merhaut, 2007). Relatively low DM leaf contents of Mg are associated with maximum yield in tomatoes compared to other elements, with 0.3-0.5% being deemed sufficient for high productivity (Peet, 2005). Suggested Mg feeding rates in nutrient solution for most hydroponic crops is $50 mg.L^{-1}$(Benton-Jones, 2005).

2.2.6 Sulphur (S)

Sulphur is crucial for the normal physiological growth of plants. It is taken up as the divalent anion sulphate (SO_4^{2-}). S is required for the formation of the S containing amino acids cysteine and thiamine (Benton-Jones, 2005; Haneklaus et al., 2007). These amino acids are important for structural conformation and function of enzymes and proteins (Haneklaus et al., 2007). Sulphate is actively taken up by energy dependent transporter proteins (Rice, 2007). These proteins are divided into two classes: high affinity and low affinity protein transporters. High affinity transporters function at low SO_4^{2-} concentrations (<0.1 mM) and low affinity transporters at relatively higher concentrations (>0.1 mM) (Haneklaus et al., 2007). In plants, S DM content ranges of 0.15-0.5% are considered sufficient for normal growth (Benton-Jones, 2005).

3. Pruning

Only light intercepted by a crop can be used for photosynthesis and assimilate production, and this is influenced by leaf area index or LAI (Papadopolous & Pararajasingham, 1997). LAI is a function of stem density, number of leaves per stem and individual leaf size (Heuvelink et al., 2005). At LAI between 2-3 $m^2.m^{-2}$ tomato crop nears light saturation (90%) and optimal DM production rate (De Koning, 1996; Heuvelink et al., 2005). The ratio between fruit growth and vegetative growth is largely determined by fruit load. Assimilate production is a determining factor of optimum fruit load and is governed by photosynthetic rate (De Koning, 1996; Heuvelink et al., 2005). Producers can maintain optimal fruit load based upon seasonal assimilate supply through fruit pruning and changing stem density, and there is also the possibility of using leaf pruning to increase dry matter (DM) partitioning to fruit (De Koning, 1996; Xiao et al., 2004). Other important factors to consider in pruning are reducing disease pressure and leaf shading of fruit to protect them from sunburn (De Koning, 1996; Heuvelink et al., 2005).

3.1 Stem density

Stem density can be altered through increased planting density or allowing side shoots to develop on plants. It is well documented that increasing plant density decreases total fruit yield per plant but increases yield per unit area (Papadopolous & Pararajasingham, 1997; Saĝlam & Yazgam, 1995).

13

Despite increasing total yield per unit area, increased planting density and stem density leads to the development of smaller fruit which may be unmarketable (Heuvelink, 1997). Maboko and Du Plooy (2009) reported that double stem plants grown at 2.5 plants m^{-2} improved yield and decreased the number of large fruit produced per plant compared to single stem plants. Xiao et al. (2004) found that increasing plant density from 2.5 to 3.8 plants m^{-2} decreased DM production and fruit yield per plant by 15% and 23% respectively. Heuvelink (1995a) found that increasing plant density had no influence on the fraction dry matter distributed to the fruit, remaining between 57-59%, thus a reduction in fruit size at higher planting densities is caused by reduced plant growth stemming from reduced light interception per plant as a result of mutual shading (Heuvelink, 1997; Papadopolous & Pararajasingham, 1997).

Stem densities must be adjusted according to prevailing light conditions, which will vary regionally and seasonally, to ensure optimal marketable yield (De Koning, 1996). Plants grown in low light winter conditions have a higher specific leaf area (SLA; SLA = leaf area/ leaf mass) compared to summer grown plants; Heuvelink (1995b) reported an average SLA of 300-400 cm^2.g^{-1} in autumn/winter and 175-250 cm^2.g^{-1} in summer. Therefore to achieve an optimal LAI in summer stem densities need to be increased (De Koning, 1996; Papadopolous & Pararajasingham, 1997). However, a higher stem density than related to optimum LAI is required under conditions of high assimilate availability to create sufficient fruit load to maintain the source:sink balance of plants (De Koning, 1996). Stem pruning achieves this through a higher relative increase in generative sink strength compared to the relative increase in source strength from increased LAI, this not only increases overall partitioning to fruits but also reduces available assimilates per fruit (Nederhoff & Houter, 2009). It is for these reasons that commercial growers in Holland increase stem density from 2.3 stems.m^{-2} in winter to 3.4 stems.m^{-2} at the onset of spring by allowing side shoots to develop (Heuvelink et al., 2005).

Increasing stem density through shoot pruning versus increased planting density has important economic implications for growers; the former reduces initial yields through assimilate competition between fruit and new shoots and requires increased labour, while the latter will require more growing media and seed (De Koning, 1996). The alteration of stem density is a simple practice that could be used to increase productivity of tomatoes.

3.2 Fruit pruning

Fruit pruning is used to control fruit load; fruit load influences partition between vegetative and generative plant growth and fruit size through mutual competition for assimilates between fruit (De Koning, 1996). Too high a fruit load can exhaust the plant, resulting in fruit and flower abortion and cyclic productivity (Papadopoulos, 1991; Heuvelink, 1997). Heuvelink (1997) found that the total fraction of DM allocated to fruit increased with increasing number of fruit per truss in a saturation type function and generative sink strength was proportional to the number of fruit per truss from 2 to 7 fruit per truss. Saĝlam and Yazgan (1999) found that decreasing fruit number per truss increased average fruit mass and improved fruit quality with the highest marketable yields achieved by pruning tomatoes to 4 or 6 fruit per truss. Therefore, maintaining as many fruit as possible per truss may result in maximum total yield, but marketable yield is likely to suffer because of reduced available assimilates per fruit resulting in small fruit which may be of lower grade or unmarketable (Heuvelink, 1997; Saĝlam & Yazgan, 1999). Truss pruning serves an important role in maximising DM partitioning to the fruit, while maximising marketable yield. Truss pruning practices should be adjusted between cultivars and will depend primarily on the desired fruit size, Beefsteak versus Cherry for example.

3.3 Leaf pruning

It is common practice in greenhouse production to remove fully grown tomato leaves from below and above the harvest ripe fruit (Heuvelink et al., 2005). The main reasons for leaf pruning are to reduce disease pressure, accelerate fruit ripening and make harvesting easier (Heuvelink et al., 2005). Heuvelink et al. (2005) found that by delaying pruning of old leaves and increasing the LAI from 3 to 4 yield was increased by 4%. But beyond a LAI of 4 there was little change in gross photosynthesis and maintenance respiration, suggesting that growers should prune their plants to ensure a LAI of no more than 4.

Generative and vegetative sinks compete for assimilates. A vegetative unit (3 leaves and stem) has 3 times the sink strength of a single tomato (Heuvelink, 1997). Leaf pruning could be used to reduce vegetative sink strength and increase biomass partitioning to the fruit (Xiao et al., 2004). Heuvelink et al. (2005) found that leaf pruning of every 2nd new leaf increased biomass allocation to fruit from 69 to 77%. Similarly, Xiao et al. (2004) found early leaf pruning increased DM partitioning to the fruit from 57 to 61%. However in both cases pruning treatments reduced total yield compared to the non-pruned control because of a reduced LAI which reduced net biomass production. The same studies indicate that leaf

15

pruning can improve yield if reduction in LAI is compensated for by increased stem density and delayed leaf pruning; when leaf pruning was delayed till a LAI of 3 was established; Heuvelink et al. (2005) observed an 10 % increase in tomato plant yield when every second young leaf was removed.

4. Growing media

Substrates can be divided into two broad categories, organic and inorganic. Inorganic compounds may be natural unmodified materials, such as sand; processed natural materials, such as perlite and rockwool, and synthetic materials like Polyurethane (Olympios, 1992). Organic substrates are more chemically reactive than inorganic substrates, and decompose over time which results in changes in physical characteristics (Costa & Heuvelink, 2003). Organic substrates tend to be cheaper than inorganic media but are usually more variable in terms of chemical and physical properties than inorganic substrates (Costa & Heuvelink, 2003; Olympios, 1999).

Differences between media can be described in more detail, beyond simply being organic or inorganic, based upon specific physical and chemical properties. The major physical criteria describing media are total porosity, air capacity and easily available water; however there is currently a paradigm shift towards the importance of relative gas diffusivity and unsaturated hydraulic conductivity (Michel, 2009). Substrates are not only characterized by specific physical properties, but also chemical properties. Growing medium chemical properties include: nutrient composition, pH, cation exchange capacity (CEC), C:N ratio and salinity (Papadopoulos et al., 2008). The importance of pH and salinity have already been discussed in preceding sections and will not be repeated, also the C:N ratio chemical property is only applicable to organic media and will be discussed later.

Among the most popular commercial growing media are rock wool and perlite. Rock wool is one of the primary substrates used in the top commercial greenhouse producing nations (The Netherlands, Canada, US, Germany, Belgium to name a few) where greenhouse vegetables are produced (Papadopolous et al., 2008). It is inert, sterile, consistent in performance, and growers can manipulate the water: air ratio and ratios betweens nutrients in the root zone with relative ease (Olympios, 1992; Papadopolous et al., 1999). However, rock wool's lack of buffering capacity for nutrients, pH and water, because of low growing slab volumes, makes it intolerant of management errors (Papadopolous et al., 2008). Rock wool's high cost is one of the main factors limiting its adoption in many countries; there are also issues with the waste management of old substrate after use (Olympios, 1999).

16

Perlite is well referenced in literature as a superior growing medium (Olympios, 1999). It has good physical characteristics – sterile, inert, porous, neutral pH, light weight, wets easily, free draining and free of heavy metals and toxic materials (Wilson, 1983). One of perlite's greatest properties is the ability of its capillarity to lift water, thus perlite is able to maintain a near constant moisture profile as long as a shallow depth of free nutrient solution is maintained in the basal substrate layer (Wilson, 1983; Olympios, 1992).

South African soilless producers initially made use of locally mined vermiculite, but the media was expensive and sterilisation was difficult (Maree, 1994). Vermiculite cannot be steam sterilised as it disintegrates during heating, and its expanded structure collapses easily (Papadopoulos et al., 2008). Producers were in search of alternative substrates that were cheap and easily available (Maree, 1994). Pinus spp. was abundant in South Africa and studies by Maree in 1994 found that locally produced pine shavings or sawdust could successfully be used for soilless culture. Most South African soilless producers currently make use of sawdust or imported coir.

4.1 Physical properties

4.1.1 Water content and hydraulic conductivity

Transpiration is a key factor to life in plants. Only about 1% of applied water is retained by the plant, but the rest serves an important role in the translocation of ions and evaporative cooling of plants (Raviv et al., 2004). Greenhouse crops are grown at higher temperatures than field grown crops, and therefore transpirational cooling is generally considered more important in these crops (Raviv et al., 2001). In order to ensure optimal productivity and maximal yields it must be ensured that plant available water isn't limiting (Raviv et al., 2001).

Moisture content of a substrate is affected by particle size, distribution and particle surface properties (Leith & Oki, 2008). The relationship between moisture tension and moisture content is unique to a particular substrate, and can be plotted as a 'moisture retention curve' (Leith & Oki, 2008). Available water is an important concept in crop irrigation and refers to the water available between field capacity and permanent wilting point. Soil matric pressure of -1500 kPa is usually used for wilting point and -10 to -33 kPa for field capacity in soil (Wallach, 2008). However, irrigation practices aiming to avoid water stress in soilless production are restricted to the range of 0 to -8 kPa of tension (Leith & Oki,

2008). Water which is easily taken up by plants is referred to as 'Easily Available water', and refers to water available at moisture tensions from -1 kPa to -5 kPa (Wallach, 2008). Water content at these moisture tensions will vary between media depending on media physical properties.

Soilless substrates normally have superior physical characteristics compared to soil (Raviv et al., 2001). Moisture tension, unlike in soil, is quite low in porous media because of more luxurious water conditions. But despite this the substrate/ root interface is often unable to cope with the atmospheric demand for water, even under ideal environmental conditions (Raviv et al., 2001). A small decrease in substrate water content can cause a sharp decline in hydraulic conductivity (Raviv et al., 2004). Substrates hydraulic conductivity decreases more rapidly than in soil at decreasing water content. Low unsaturated hydraulic conductivity diminishes water flow to the root zone, creating zones of high water tension at the root/media interface (Michel, 2009). This can be particularly problematic in media which develop hydrophobic characteristics when dry (Michel, 2009). Therefore substrate hydraulic conductivity can be considered the main factor restricting water bioavailability to plants, not the substrate matric potential (Raviv et al., 2001).

4.1.2 Porosity, pore space and particle size

The volumetric amount of water that saturates a given substrate volume is defined as the effective pore space. The difference between total porosity and effective pore space is the volume of closed pores not accessible to water (Michel, 2009) Substrates are composed of different pores: inter-aggregate pores and intra-aggregate pores. Inter aggregate pores are large pores that drain at relatively high water potentials and are the primary pathways for substrate aeration (Lopez et al., 2008). Smaller intra-aggregate pores form storage compartments of plant water supply (Lopez et al., 2008). Substrates with a high number of inter and intra aggregate pores have bimodal water retention curves (Lopez et al., 2008).

Air-filled porosity (AFP) is defined as the volumetric percentage of the medium filled with air after gravitational drainage (Wallach, 2008). Aeration is important for optimal plant growth. Poor aeration reduces nutrient and water uptake; tomatoes grown in deep water culture without aeration produced 34% less dry matter compared to aerated plants (Adams, 1994). Water holding capacity of media increases with a decrease in particle size, while air filled porosity decreases (Verdonck and Demeyer, 2004). For this reason large particles are often added to media to increase the air filled porosity based upon the assumption that it will improve media aeration (Caron et al., 2001). Air filled porosity of a media is not only

18

influenced by particle size but also pot size and geometry (Caron & Nkongolo, 1999). Aeration is also linked to the connectivity of the media air spaces. Caron et al. (2001) found that root growth parameters were significantly and positively correlated with gas relative diffusivity, but there was no correlation with air filled porosity. Therefore continuity of pore spaces in a media could be considered more important than porosity.

4.2 Chemical properties

4.2.1 C/N ratio

C/N influences the decomposition of growing media, a low C:N ratio accelerates decomposition of media (Costa and Heuvelink, 2003). Immobilisation is a well known phenomenon in organic media with high C:N ratios (Maher et al., 2008). Immobilisation is caused by microorganisms converting inorganic N compounds into plant unavailable organic N compounds (Lemaire, 1995; Langenhoven, 2004). Therefore media with high C:N ratios result in N deficiency due to N depletion (Costa and Heuvelink, 2003). In high C:N media it is recommended to increase initial N application rates to prevent nutritional imbalances in young seedlings (Langenhoven, 2004; Maher et al., 2008).

4.2.2 Cation exchange capacity

Cation exchange capacity (CEC) is the amount of exchangeable cations a substrate is able to adsorb and is expressed in terms of cmol per kg of dry material ($cmol.kg^{-1}$) (Maher et al., 2008). In short CEC indicates the ability of the substrate to retain the major and minor mineral elements supplied by fertilisation (Lemaire, 1995). This property of growing media is given by mineral clay and organic humus colloids with negatively charged surfaces, and is dependent on pH (Lemaire, 1995; Maher et al., 2008).

Only the mineral cations ($K^+, Na^+, Ca^{++}, Mg^{++}, NH4^+$) are adsorbed onto the colloidal anions, and these adsorbed cations can exchange with free ions in solution to achieve balance between fixed and free ions (Lemaire, 1995). CEC can therefore adsorb ions in excess, improving nutritional balance, or alternatively adsorb ions potentially causing deficiency, as was observed by Savvas et al. (2004) trials with tomatoes grown in zeolite. Savvas et al. (2004) found that early yields in zeolite were reduced because of a decrease in available K due to adsorption by the zeolite. But, the irrigation water in the experiment was Mg rich

19

borehole water, thus the zeolite grown plants had improved later yields attributed to the adsorption of excess Mg, which improved the nutritional status of the zeolite grown plants.

4.3 Coir

Coir is fibrous material composing the thick mesocarp of the coconut fruit. The long fibers are used by industries in Sri Lanka, Vietnam, India, Philippines, Mexico and Ivory Coast; the remaining coir dust and short fibers are used as media (Maher et al., 2008:). The chemical properties and physical properties of coir vary due to different processing techniques (Maher et al., 2008). Coir has an ideal easily available water content of 20-35 percent, and the bulk density of coir can range from 40-116 g.L^{-1} (Prasad, 1997b; Maher et al., 2008). pH in coir ranges from 4.8-6.9. Coir has a high CEC, which can vary from 35-95 cmol.kg^{-1} (Maher et al., 2008). It contains varying levels of water soluble and exchangeable sodium (Na$^+$), chloride (Cl$^-$) and potassium (K). This is reflected by the E.C. of the coir, which can vary from high to low (Maher et al., 2008). These elements should be leached before the substrate is used as a growing medium. This is done using water containing cations such as Ca, to ensure the exchangeable deleterious ions are also leached (Maher et al., 2008).

Coir has a high carbon content and a low N content resulting in high C:N ratios of 105-143 (Noguera et al., 1997; Yau & Murphy, 2000). This gives coir a moderate to high ability to fix N (80-120mg N.L^{-1}) (Prasad, 1997b). Therefore it is necessary to compensate for N retention with an appropriate fertilizer program when coir is used as substrate (Prasad, 1997a). Alternatively the coir dust can be composted to decrease the C:N ratio to a more acceptable ratio of 30, composting can further increase CEC to between 190-250 cmol.kg^{-1} (Yau and Murphy, 2000). Coir also contains significant amounts of micronutrients, but there is great deal of variation between samples (Maher et al., 2008).

4.4 Sand

Sand is composed from quartz particles (SiO2) (Papadopoulos et al., 2008). These small rock particles vary in size from 0.05 to 2 mm (Costa & Heuvelink, 2003). Sand has a large bulk density (1480 – 1800 g.L^{-1}) and a low water holding capacity (Olympios, 1999). In sand with low granulometries poor aeration can cause oxygen deficiencies (Costa & Heuvelink, 2003). Porosity ranges from 45% to 30% from fine to coarse sand, and water content at saturation is low, ranging from 39% to 27% (Papadopoulos et al., 2008). Saturated hydraulic conductivity

of coarse sand media is relatively high, however, unsaturated conductivity reduces sharply with an increase in substrate water tension (Papadopoulos et al., 2008).

Quartz is a stable mineral with low solubility, independent of pH at pH between 2.5 – 9 (Papadopoulos et al., 2008). Therefore sand is largely inert and can be steam sterilised and used for a long time (Costa & Heuvelink, 2003; Papadopoulos et al., 2008). It is often used to increase bulk density of substrate mixes, and to improve flowing of substrate in automatic potting machines (Costa & Heuvelink, 2003). Sand is cheap compared to other inorganic media, such as rockwool (Olympios, 1999).

4.5 Sawdust

Sawdust can be used alone or in mixtures. Sawdust derived from Pinus species is mainly used, but other woods may also be used as substrate. Dry sawdust has a low bulk density of 124-154g.L^{-1}, a high percentage air filled porosity (42%) and low water holding capacity (3.8%) (Prasad, 1979; Goh & Haynes, 1997; Maher et al., 2008). Frequent irrigation with small quantities can be used to meet crop water requirements despite sawdust's low available water content. Chemically, sawdust has a high C:N ratio and a very low CEC; this high C:N ratio can result in N deficiencies if not compensated for in fertilization programs (Lemaire, 1995; Prasad, 1997c). Sawdust substrates are inexpensive and can be used for up to two crops without sterilisation (Olympios, 1992).

Not all sawdust may be suitable for plant substrates as it can be phytotoxic (Olympios, 1992). It may be composted or fresh, composting of sawdust substrate prior to use can be beneficial. Composting can reduce phytotoxic compound levels, increase the water holding capacity and reduces C:N ratio of the substrate (Mbah & Odili, 1998; Maher et al., 2008).

5. Objectives

The primary objective is to examine methods for increasing the sustainability of soilless crop production through enhancing the use efficiency of inputs while at the same time maintaining or improving yield and fruit quality. This was tackled through experimental analysis of the following sections:

1. The effect of different growing media, irrigation frequency and fertiliser concentration on water use, nutrient uptake, fruit yield and fruit quality of hydroponically grown tomatoes.

2. The effects of leaf pruning and fruit pruning on fruit yield and quality of hydroponically grown tomatoes.

3. The effects of stem pruning and fertiliser concentration on nutrient uptake, growth and fruit yield of hydroponically grown tomatoes.

6. References

ADAMS, P., 1994. Nutrition of greenhouse vegetables in NFT and hydroponic   systems. *Acta Hort*. 361, 245-257.

AMIRI, M. & SATTARY, N., 2004. Mineral precipitation in solution culture. *Acta Hort*. 644, 469-471.

BALLIU, A. & IBRO, V., 2002. Influence of different levels of potassium fertiliser on growth, yield and ascorbic acid content of tomato fruit grown in non-heated greenhouse. *Acta Hort*. 579, 385-388.

BARKER, A.V. & BRYSON, G.M., 2007. Nitrogen. *In:* Barker, A.V. & Pilbeam, D.J (eds.). Handbook of Plant Nutrition. CRC Press, Boca Raton. p21-50.

BAR-YOSEF, B. 2008., Fertigation management and crops response to solution   recycling insemi-closed greenhouses. *In:* Raviv, M. & Lieth, J.H. (eds.). *Soilless Culture: Theory and Practice.* Elsevier, Amsterdam. p341-424.

BENTON-JONES, J., 2005., Hydroponics: a practical guide for the soilless grower (2nd Ed.). CRC press, Boca Raton, Florida.

BINNS, J.A., ILLIGNER, P.M. & NEL, E.L., 2001. Water shortage, deforestation and development: South Africa's working for water programme. *Land Degrad. Develop*. 12, 341-355.

BOUWER, H., 2000. Integrated water management: emerging issues and challenges. *Agr. Water Manage.* 45, 217-218.

CARON, J., MOREL, P. & RIVIÈRE, L., 2001. Aeration in growing media containing large particle size. *Acta Hort*. 548, 229-234.

CARON, J. & NKONGOLO, V.K.N., 1999., Aeration in growing media: ecent sevelopments. *Acta Hort.* 481, 545-551.

CLAUSSEN, W., 2002. Growth, water use efficiency, and proline concentration of hydroponically grown tomato plants as affected by nitrogen source and nutrient concentration. *PlantSoil* 247, 199-209.

22

COOPER, A., 1996. The ABC of NFT (2nd Ed.). Casper Publication Pty Ltd., Narrebeen.

CORNISH, P.S., 1992. Use of high electrical conductivity of nutrient solution to improve quality of salad tomatoes (*Lycopersicon esculentum*) grown in hydroponic culture. *Aust. J. Exp. Agr.* 32, 513-   520.

COSTA, J.M. & HEUVELINK, E., 2003. Substrates today. *Fruit & Veg Tech 3(4), 29-   33*.

CRAMER, G.R., LAUCHLI, A. & POLITO, V.S., 1985. Displacement of Ca^{2+} by Na^+ from the plasmalemma of root cells: a primary response to salt stress?. *Plant Physiol.* 79, 207-211.

DE KONING, N.M., 1996. Model predictions of optimum shoot density and truss size in glasshouse tomato. *Acta Hort*. 417, 99-106.

DEL AMOR, F.M. & MARCELIS, L.F.M., 2005. Response of plant growth to low calcium concentration in the nutrient solution. *Acta Hort.* 697, 529-533.

ELIA, A., SERIO, F., PARENTE, A., SANTAMARIA, P. & RODRIGUEZ, G.R., 2001. Electrical conductivity of nutrient solution, plant growth and fruit quality of soilless grown tomato. *Acta Hort*. 559, 503-508.

EPSTEIN, E. 1972., Mineral nutrition of plants: principles and perspectives. John Wiley & sons Inc., New York, USA.

FANASCA, S., ROUPHAEL, Y., CARDARELLI, M. & COLLA, G., 2005. The influence of K:Ca:Mg:Na ratio and total concentration on yield and fruit quality of soilless-grown tomatoes: a modelling approach. *Acta Hort.* 345-350.

FANASCA, S., ROUPHAEL, Y., RIVERA, C.M. & COLLA, G., 2006. Application of mitxture theory for optimising the mineral nutrition in soilless-grown tomato. *Acta Hort*. 718, 679-684.

FEIGIN, A., ZWIBEL, M., RYLSKI, I., ZAMIR, N., & LEVAV, N., 1980. The effect of ammonium/nitrate ratio in the nutrient solution on tomato yield and quality. *Acta Hort.* 98, 149-160.

GENT, M.P.N., 2004. Effect of nitrogen and potassium supply on yield and composition of greenhouse tomato. *Acta Hort.* 644, 269-375.

GOH, K.M. & HAYNES, R.J. 1977. Evaluation of potting media for commercial nursery production of container-grown plants. I. Physical and chemical characteristics of soil and soilless media and their constituents. *New Zeal. J. Agr. Res*. 20, 363-370.

GÜLER, S. & GÜZEL, N., 1999. Effect of Varying Level of Nitrogen and Potassium Concentration in the Nutrient Solution of the Yield and Leaf Composition of Drip-Fertigated Tomatoes. *Acta Hort*. 506, 81-85.

23

HANEKLAUS, S., BLOEM, E., SCHNUG, E., DE KOK, L.J. & STULEN, I., 2007. Sulphur. *In:* Barker, A.V. & Pilbeam, D.J (eds.). Handbook of Plant Nutrition. CRC Press, Boca Raton. p183-238.

HEUVELINK, E., 1995a. Effect of plant density on biomass allocation in the fruits in tomato (*Lycopersicon esculentum* Mill.). *Sci. Hortic.*64, 193-201.

HEUVELINK, E., 1995b. Growth, development and yield of a tomato crop: periodic destructive measurements in a greenhouse. *Sci. Hortic.* 61, 77-99.

HEUVELINK, E., 1997. Effect of fruit load on dry matter partitioning in tomato. *Sci. Hortic-Amsterdam* 69, 51-59.

HEUVELINK, E., BAKKER, M.J., ELINGS, A., KAARSEMAKER,R. & MARCELIS, L.F.M., 2005. Effect of leaf area on tomato yield. *Acta Hort*. 691, 43-.50.

HINSINGER, P., PLASSARD, C., TANG, C. & JAILLARD, B., 2003. Origins of root-mediated pH changes in the rhizosphere and their responses to environment constraints: a review. *Plant and Soil* 248, 43-59.

HINSINGER, P., PLASSARD, C. & JAILLARD, B., 2006. Rhizosphere: A new frontier for soil biogeochemistry. *J. Geochem. Explor.* 88, 210-213.

HO, L.C & ADAMS, P., 1995. Nutrient uptake and distribution in relation to crop quality. *Acta Hort*. 396, 33-44.

HO, L.C., HAND, D.J. & FUSSELL, M., 1999. Improvement of tomato fruit quality by Calcium nutrition. *Acta Hort*. 481, 463-468.

HOHJO, M., KUWATA, C, YOSHIKAWA, K. & ITO, T., 1995. Effects of nitrogen form, nutrient voncentration and Ca concentration on the growth, yield and fruit quality in NFT-tomato plants. *Acta Hort* 396, 145-152.

HUET, D.O. & DETTMAN, E.B., 1988. Effect of Nitrogen on growth, fruit quality and nutrient uptake of tomatoes grown in sand culture. *Aust. J. Exp. Agric.* 28, 391-399.

IKEDA, H., 2007. Environment-friendly soilless culture and fertigation technique. *Acta Hort*. 761, 363-368.

IKEDA, H. & OSAWA, T. 1981. Nitrate- and ammonium-N absorption by vegetables from nutrient solution containing ammonium nitrate and the resultant change of solution pH. *J. Japan. Hort. Sci.* 50, 225-230.

JENSEN, M.H., 2002. Controlled environment agriculture in deserts tropics and temperate regions – a world review. *Acta Hort*. 578, 19-25.

JOVICICH, E., CANTLIFFE, D.J., STOFFELLA, P.J. & VANSICKLE, J.J., 2003. Reduced Fertigation of Soilless Greenhouse Peppers Improves Fruit Yield and Quality. *Acta*

Hort. 609,193-196.

KIRBY, E.A. & MENGEL, K., 1987. Principles of Plant Nutrition (4th ed.). International Potash Institute, Bern, Switzerland.

KLARING, H., 2001. Strategies to control water and nutrient supplies to greenhouse crops. A review. *Agronomie* 21, 311-321.LANGENHOVEN, P., 2004. Yield and quality response of hydroponically grown tomatoes (*Lycopersicon esculentum* Mill.) to nitrogen source and growth medium. Ph.D. Thesis, University of Stellenbosch, Stellenbosch, South Africa.

LEMAIRE, F., 1995. Physical, chemical biological properties of growing medium. *Acta Hort*. 396, 273-384.

LIETH, J.H. & OKI, L.R., 2008. Nutrition in Substrate Grown Plants. *In:* Raviv, M. & Lieth, J.H. (eds.). *Soilless Culture: Theory and Practice*. Elsevier, Amsterdam. p117-156.

LI, Y.L., STANGHELLINI, C. & CHALLA, H., 2001. Effect of electrical conductivity and transpiration on production of greenhouse tomato. *Sci. Hortic.* 88, 11-29.

LOPEZ, J.C.C., WALLER, P. & TULLER, M., 2008. Physical Characterization of Greenhouse Substrates for Automated Irrigation Management. *Acta Hort*. 797, 333-338.

MAREE, P.C.J., 1994. Using bio-degradable material as a growing media in hydroponics in the Republic of South Africa. *Acta Hort*. 361, 141-151.

MABOKO, M.M. & DU PLOOY, C.P., 2009. Effect of stem and fruit pruning on yield and quality of hydroponically grown tomato. *African Crop Science Conference Proceedings* 9, 27-29.

MAHER, M., PRASAD, M. & RAVIV, M., 2008. Nutrition in substrate grown plants. *In:* Raviv, M. & Lieth, J.H. (eds.). *Soilless Culture: Theory and Practice.* Elsevier, Amsterdam. p459-504.

MBAH, B.N. & ODILI, P.N., 1998. Change in moisture retention properties of five waste materials during short term mesophilic composting. *Compost Sci. Utilisation* 6, 63-73.

MENGEL, K., 2007. Potassium. *In:* Barker, A.V. & Pilbeam, D.J (eds.). Handbook of Plant Nutrition. CRC Press, Boca Raton. p91-120.

MERHAUT, D.J., Magnesium. 2007. *In:* Barker, A.V. & Pilbeam, D.J (eds.). Handbook of Plant Nutrition. CRC Press, Boca Raton. p145-182.

MICHEL, J.C., 2009. Physical properties of growing media: state of the art and future challenges. *Acta Hort*. 819, 65-72.

MMOLAWA, K. & OR, D., 2000. Root zone solute dynamics under drip irrigation: A review. *PlantSoil* 222, 163-190.

MORGAN, L., 2006. Greenhouse tomato nutrition. Columbia Publishing. http://www.columbiapublications.com/tomatomagazine/december2006/greenhousenutrition.html (Accessed 23/08/2011).

MUNNS, R., 2002. Comparative physiology of salt and water stress. *Plant Cell Environ.* 25, 239-250.

NOGUERA, P. ABAD, M., PUCHADES, R., NOGUERA, V. & MAQUIEIRA, A., 1997. Physical and chemical properties of coir waste and their relation to plant growth. *Acta Hort.* 450, 365-373.

NEDERHOFF, E. & HOUTER, B., 2009. Plant management for generative or vegetative steering. *Practical Hydroponics & Greenhouses*, 51-54, March/April.

OLYMPIOS, C.M., 1992. Soilless media under protected cultivation rockwool, peat, perlite and other substrates. *Acta Hort*. 323, 215-234.

OLYMPIOS, C.M., 1999. Overview of soilless culture: advantages, constraints and perspectives for its use in Mediterranean countries. *Options Mediterraneennes* 31, 307-324.

PAPADOPOULOS, A.P., 1991. Growing greenhouse tomatoes in soil and in soilless media. Agriculture Canada, Ottawa.

PAPADOPOULOS, A. P., 1998. Seasonal fertigation schedules for greenhouse tomatoes – concepts and delivery systems. *Acta Hort*. 458, 123-140.

PAPADOPOULOS, A.P. & PARARAJASINGHAM, S., 1997. The influence of plant spacing on light interception and use in greenhouse tomato (Lycopersicon esculentum Mill.): A review. *Sci. Hortic.* 69, 1-29.

PAPADOPOULOS, A. P., HAO, X., TU, J. C. & J. ZHENG., 1999. Tomato production in open or closed rockwool culture systems with NFT or rockwool nutrient feedings. *Acta Hort*. 481, 89-96.

PAPADOPOULOS, A.P., BAR-TAL, A., SILBER, A., SAHA, U.K. & RAVIV, M., 2008. Organic Soilless Media Components. *In*: Raviv*,* M. & Lieth, J.H. (eds.). Soilless Culture: Theory and Practice. Elsevier, Amsterdam. p505-537.

PEET, M. M., 2005. Irrigation and Fertilization. *In*: Heuvelink, E. (ed). *Tomatoes*. CABI publishing, Wallingford, UK. p171-198.

PEET, M.M., 2009. Physiological Disorders in Tomato Fruit Development. *Acta Hort*. 821, 151-160.

PILBEAM, D.J. & MORLEY, P.S., 2007. Calcium. *In:* Barker, A.V. & Pilbeam, D.J (eds.). Handbook of Plant Nutrition. CRC Press, Boca Raton. p121-144.

PLAUT, Z. & GRAVA, A., 2005. Osmotic Adjustment of Tomato Fruits and Leaves Grown in Sand and Irrigated with Saline Water. *Acta Hort*. 697, 285-291.

PRASAD, M., 1979. "Physical properties of media for container-grown crops. I. New Zealand peats and wood wastes". *Sci. Hortic.* 10, 317-323.

PRASAD, M.N.V. (Ed.)., 1997a. Plant Ecophysiology. John Wiley & Sons Inc., New York.

PRASAD, M., 1997b. Physical, biological and chemical properties of coir dust. *Acta Hort*. 450, 21-29.

PRASAD, M., 1997c. Nitrogen fixation of various materials from a number of European countries by three nitrogen fixation tests. *Acta Hort*. 450, 353-362.

RAVIV, M. & LIETH, J.H., 2008. Significance of Soilless Culture in Agriculture. *In:* Raviv, M. & Lieth, J.H. (eds.). Soilless Culture: Theory and Practice. Elsevier, Amsterdam. p1-10.

RAVIV. M., WALLACH, R. & BLOM, T.J., 2004.The effect of Physical Properties of Soilless Media on Plant Performance – A review. *Acta Hort*. 644, 251-259.

RAVIV, M., LIETH, J.H., & WALLACH, R., 2001.The Effect of Root-Zone Physical Properties of Coir and UC mix on Performance of Cut Rose (CV. Kardinal). *Acta Hort* 554, 231-238.

RICE, R.W., 2007. The physiological role of minerals in the plant. *In*: Datnoff, L.E., Elmer, W.H. & Huber, D.M. (eds.). Mineral Nutrition and Plant Disease . APS Press, Minnesota, USA. p9-31.

SAĜLAM, N AND YAZGAN, A., 1995. The effects of planting and the number of trusses per plant on earliness, yield and quality of tomato grown under unheated plastic tunnel. *Acta Hort*. 412, 258-265.

SAĜLAM, N AND YAZGAN, A., 1999. Effect of fruit number per truss on yield and quality in tomato. *Acta Hort.* 486, 261-264.

SANCHEZ, C.A., 2007. Phosphorus. *In:* Barker, A.V. & Pilbeam, D.J (eds.). Handbook of Plant Nutrition. CRC Press, Boca Raton. p 51-90.

SAURE, M.C., 2001. Review: blossom-end rot of tomato (*Lycopersicon esculentum Mill.*)- a calcium – or a stress- related disorder? *Sci. Hortic.* 90, 93-208.

SAVVAS, D., OLYMPIOS, C. AND PASSAN, H.C., 2009. Management of nutrition and irrigation in soil-grown and soilless cultivation in mild-winter climates: problems, constraints and trends in the Mediterranean region. *Acta Hort*. 807, 415-426.

27

SAVVAS, D., SAMANTOUROS, D, PARALEMOS, VLACHAKOS, G., STAMATAKIS, M., & VASSILATOS, C., 2004. Yield and nutrient status in the root environment of tomatoes (*Lycopersicon esculentum*) grown on chemically active and inactive inorganic substrates. *Acta Hort.* 644, 377-383.

SCHWARZ, D. & KUCHENBUCH, R., 1998. Water uptake by tomato plants grown in closed hydroponic systems dependent on the EC-level. *Acta Hort*. 458, 323-328.

SILBER, A., 2008. High frequency irrigations as means for enhancement of nutrient uses efficiency: soilless grown bell pepper as a model plant. *Acta Hort*. 779, 281-288.

SILBER, A. & BAR-TAL, A., 2008. Nutrition in substrate grown plants. *In:* Raviv, M. & Lieth, J.H. (eds.). Soilless Culture: Theory and Practice. Elsevier, Amsterdam. p291-328.

SILBER, A., XU, G., LEVKOVITCH, I., SORIANO, S., BILU, A. & WALLACH, R., 2003. High fertigation frequency: the effects on uptake of nutrients, water and plant growth. *Plant Soil* 253, 467-477.

SONNEVELD, C. & VOOGT, W., 2001. Chemical analysis in substrate systems and hydroponics – use and interpretation. *Acta Hort*. 548, 247-259.

SONNEVELD, C. & VOOGT, W., 2009. Plant nutrition of greenhouse crops. Springer Science, New York.

SONNEVELD, C. & WELLES, G.W.H., 1988. Yield and quality of rockwool-grown tomatoes as affected by variations in EC-value and climatic conditions. *Plant Soil* 111, 37-42.

SONNEVELD, C. & WELLES, G.W.H., 2005. Cation concentrations of plant tissues of fruit-vegetable crops as affected by the EC of the external nutrient solution and by humidity. *Acta Hort*. 697, 377-386.

TABATABAEI, S.J., YUSEFI, M. & HAJILOO, J., 2008. Effects of shading on $NO_3:NH_4$ ratio on yield, quality and N metabolism in strawberry. *Sci. Hortic.* 116, 264-272.

TOGONI, F., PARDOSSI, A. & SERRA, G., 1998. Water pollution and the greenhouse environmental costs. *Acta Hort*. 458, 385-394.

VERNOOIJ, C.J.M., 1990. Reduction of environmental pollution by recirculation of drainwater in substrate cultures. *Acta Hort* 303, 9-13.

VERDONCK, O. & DEMEYER, P., 2004. The influence of the particle sizes on the physical properties of growing media. *Acta Hort*. 644, 99-101.

28

WALLACH, R., 2008. Physical characteristics of soilless growing media.. *In:* Raviv, M. & Lieth, J.H. (eds.). *Soilless Culture: Theory and Practice*. Elsevier, Amsterdam. p41-116.

WILSON, G.C.S., 1983. The physico-chemical and physical properties of horticultural substrates. *Acta Hort*. 150, 19-32.

XIAO, S., VAN DER PLOEG, A., BAKKER, M. & HEUVELINK, E., 2004. Two Instead of three leaves between tomato trusses: measured and simulated effects on partitioning and yield. *Acta Hort. 654*, 303-308.

YAU, P.Y. & MURPHY, R.J., 2000. Biodegraded coco peat as a horticultural substrate. *Acta Hortic.* 517, 275-278.

<div align="center">

Chapter 2

The effect of EC, irrigation frequency and growing media on water use, nutrient uptake, yield and quality of greenhouse grown tomatoes.

C.M. Fulton [1] & E. Kempen [2]

</div>

[1]Department of Agronomy, University Stellenbosch, Private Bag X1, Matieland 7602, South Africa, E-mail: Craigfulton@sun.ac.za

[2]Department of Agronomy, University Stellenbosch, Private Bag X1, Matieland 7602, South Africa, E-mail: Estellek@sun.ac.za

Abstract

Poor management of hydroponic fertigation water results in pollution, and wastes precious water and expensive fertiliser. Improving water and fertiliser use efficiency is crucial to ensuring sustainable production of intensive crops, such as the tomato. The effect of EC, irrigation frequency and growing media on water use, nutrient uptake, yield and quality of greenhouse tomato was examined. A factorial design with split plots was used. Two EC treatments (1 and 2 mS.cm^{-1}) in factorial arrangement with 3 irrigation treatments (5x, 10x, 20x) to the main plots was used. Plants grown in different growing media (coir, sand, sawdust) represented the split plots. Plants grown at EC 1 mS.cm^{-1} were still able to take up sufficient nutrients to achieve leaf contents associated with optimal production. Also, increasing the absolute nutrient concentration had a small effect on nutrient uptake. The organic media, coir and sawdust, reduced available N early in the tomato crop life, and tomatoes grown in coir had reduced Ca uptake compared to plants grown in sand and sawdust. Coir grown plants used more water compared to sand and sawdust grown plants. Plants grown at EC 1 mS.cm^{-1} used less water compared to plants grown at EC 2 mS.cm^{-1}. Tomatoes grown at an EC 1 mS.cm^{-1} did not differ significantly from higher EC plants in terms of marketable and green fruit yield; this was only a short term yield due to severe disease pressure. Plants cultivated at the lower EC had significantly lower percentage soluble solids content (Brix) compared to the higher EC treatment.

Key words: Nitrogen, coir, sand, sawdust, brix, water use

1. Introduction

An EC of 2.0 mS.cm^{-1} is said to be sufficient to maintain optimal nutrient uptake in tomatoes, with 2.5 mS.cm^{-1} being estimated as the salinity threshold for this crop (Sonneveld and

Welles, 1988; Sonneveld & Voogt, 2009). Elia *et al.* (2001) reported that increasing EC from 1 to 6 mS.cm^{-1} didn't reduce DM yield but reduced fresh weights of tomato shoots and fruit. Li *et al.* (2001) had similar findings; root zone salinity didn't affect dry matter yield, and loss in yield was the result of reduced fresh weight caused by lower tissue water content and an increased discarded fraction of small unmarketable fruit.

Tomatoes grown at higher ECs tend to have a reduced yield, but increased total soluble solids (TSS), titratable acids (TA), ascorbic acid, vitamin C, and sugar content of their fruit (Sonneveld & Welles, 1988; Cornish, 1992; Elia *et al.*, 2001). This is caused by the reduced uptake of water into the fruit and the subsequent concentration of fruit content in fruit due to plant osmotic adjustment (Plaut and Grava, 2005). However, Heeb *et al.* (2006) reported that a reduction in tomato fruit growth did not necessarily result in better taste, and concluded that nutrient supply also played an important role in determining fruit quality.

Electrical conductivity (EC mS.cm^{-1}) is a measure of the total concentration of dissolved solutes in solution and is used as an indicator of nutrient availability (Li *et al.*, 2001). Low enough concentrations of fertiliser can cause mineral deficiency and restrict plant growth, where as there is no negative effects of over supplying nutrients to a threshold point (Li *et al.*, 2001; Sonneveld & Voogt, 2009). Producers, to avoid deficiencies and control produce quality, add large amounts of nutrients with little attention to crop uptake (Li *et al.*, 2001). However, several studies have shown that it is possible to cultivate greenhouse crops at lower EC levels using small frequent irrigation events without negatively impacting yield and quality (Silber *et al.*, 2003; Jovicich & Cantliffe, 2003, Silber, 2008). The improvement in nutrient uptake by frequent irrigation is attributed to two mechanisms: continuous replenishment of nutrients in the depletion zone near the root surface; and enhanced mass flow transport of dissolved nutrients due to a higher water content of the growing media (Silber *et al.*, 2003).

Substrates are characterized by specific physical and chemical properties. Physical characteristics include bulk density, water retention and hydraulic conductivity. Knowledge of these physical properties is necessary for proper irrigation management to maintain high water status, and thus facilitate mass flow nutrient transport. Growing medium chemical properties include: nutrient composition, pH, cation exchange capacity (CEC), salinity content, and organic versus inorganic matrix (Papadopoulos *et al.*, 2008; Maher *et al.*, 2008). These chemical properties may cause immobilisation, adsorption of nutrients, or reduced ion uptake through antagonism, leading to nutritional imbalances and deficiencies (Savvas *et al.*, 2004; Maher *et al.,* 2008).

31

Reduced hydroponic fertiliser rates could reduce environmental pollution, input costs, and even water use. However, such a strategy will only be viable if it can be done without sacrificing productivity and fruit quality. Irrigation frequency and growing media are factors that can affect plant nutritional status, thus changes to fertilisation needs to be viewed in parallel with these factors. This study examined the effects of EC, irrigation frequency and growing media on nutrient content, marketable yield and quality of greenhouse grown tomatoes.

2. Materials and methods

2.1 Location and cropping details

Six week old tomato seedlings (*Lycopersicon esculentum* Mill. cv. MFH9343) were transplanted into a temperature controlled (23°C/18°C day/night temperature) glasshouse at Welgevallen experimental farm, Stellenbosch, Western Cape. The seedlings were transplanted into 10L plastic bags filled with different growing media on 11th September 2010. Plants were fertigated through a drip irrigation system with a complete nutrient solution at two different concentrations (EC 1 and 2 mS.cm^{-1}) with fixed nutrient ratios. The EC 1 mS.cm^{-1} nutrient solution composition in milliequivalents was: NH_4^+: 1.5; K^+: 5.3; Ca^{2+}: 2.4; Mg^{2+}: 0.8; NO_3^-: 7.1; PO_4^{2-} 1.6; SO_4^{2-}: 1.3. Micronutrients were applied at the same rate for both macronutrient concentrations: Fe 1.68, Mn 0.4, Zn 0.2, Cu 0.03, B 0.5, Mo 0.05 mg.L^{-1}. Plants were pruned to a single stem and grown at a density of 2.5 plants/m^2. The stems were vertically trellised using twine and the crop was topped once it reached the top wire. Trusses were pruned to 7 fruits.

2.2 Treatments and experimental design

The experiment used a factorial design with split plots, and four randomised blocks (18 plants per block, 3 plants per main plot). EC 1 and 2 mS.cm^{-1} (macronutrients ratios were held constant) and irrigation frequency (5x, 10x, 20x irrigation events per day) treatments were applied in a factorial arrangement to the main plots. All plants in the experiment received the same total volume of nutrient solution each day, and irrigation was increased during the course of the experiment to ensure drainage across all treatments. On the sub plot level, plants were grown in coir, sand or sawdust media.

2.3 Measurements and analysis

EC, pH and volume of drainage water was measured every 5 days, when the plants grew larger drainage was measured every 3 days. Drainage was collected by placing a container under a grill beneath the plants. At the end of each day the collected drainage was decanted into a larger lidded container. Drainage fraction was calculated by dividing total volume of drainage collected divided by the total volume of water irrigated over the given time interval. Total irrigation volume was measured by placing a dripper spike into a beaker, EC, pH and volume was measured. This was done for each irrigation frequency treatment to ensure that all plants received the same total volume each day.

At flowering on the 1st and 5th trusses the 4th and 5th leaves were sampled, dried and then analysed for macro nutrient content (Mg, Ca, K, N, P). In addition, an analysis of the nutrient content of drainage water was performed at these stages. Yield of green fruit (indicator of potential yield), yield of ripe fruit and unmarketable yield were recorded. The quality of fruit was assessed by measuring the percentage soluble solids (Brix) of the ripe fruit. During the experiment a severe powdery mildew disease outbreak occured. For this reason the experiment had to be terminated early because it was feared further experimental measurements would be skewed by the effects of disease. Therefore only the first truss was harvested red ripe and yield data is only a short term reflection of the effect of treatments on yield. Data was analysed using ANOVA, and means compared using Fischer's LSD (P<0.05) using statistical software *Statistica 10*.

3. Results and discussion

3.1 Drainage

Anova of the fraction of irrigation water drained indicated a 3-way interaction between EC, irrigation frequency and growing media (Figure 1). Plants grown at EC 2 mS.cm^{-1} in coir substrate a 20x used much more water than those grown at 5x and 10x, but the same response was not seen at coir grown plants at EC 1 mS.cm^{-1}. More frequent irrigation events create a more stable moisture environment that promotes vegetative growth (Nederhoff & Houter, 2009). This in conjunction with higher fertilisation application and the high easily available water content of coir may have resulted in faster vegetative growth, thus creating leafier plants with larger water requirements. It can be seen that within EC treatments coir grown plants drained less water, thus used more water compared to sand and sawdust grown plants. It can also be seen that plants grown at EC 1 mS.cm^{-1} used less water compared to plants

33

grown at EC 2 mS.cm^{-1}. This correlated with the ANOVA results for main effects which are shown in figure 2.

Plants grown in coir used significantly more water compared to plants grown in sand or sawdust, and EC 2 mS.cm^{-1} treated plants used significantly more water compared to EC 1 mS.cm^{-1} treated plants. Coir has an ideal easily available water content of 20-35 percent (Prasad, 1997a; Maher *et al.*, 2008), which promotes lush growth due to a high root zone water content (Nederhoff & Houter, 2009). Substrates with low water contents, such as sand and sawdust, create harsher growing conditions. This was visibly apparent during the trial with coir grown plants appearing much leafier and vegetative compared to plants grown in the other growing media (Figure 3). This more luxurious growth could possibly explain the differences in water use between the plants grown in different growing media.

Difference in water use between the different EC treatments could also be associated with more vigorous vegetative growth owing to higher applications of N in EC 2 mS.cm^{-1} treatment compared to the EC 1 mS.cm^{-1} treatment. High rates of N induce vigorous growth and over vegetative plants to the detriment of fruit production (Papadopoulos, 1998; Benton-Jones, 2005). Again, this shift towards more vegetative growth may explain the differences in water use between EC treatments.
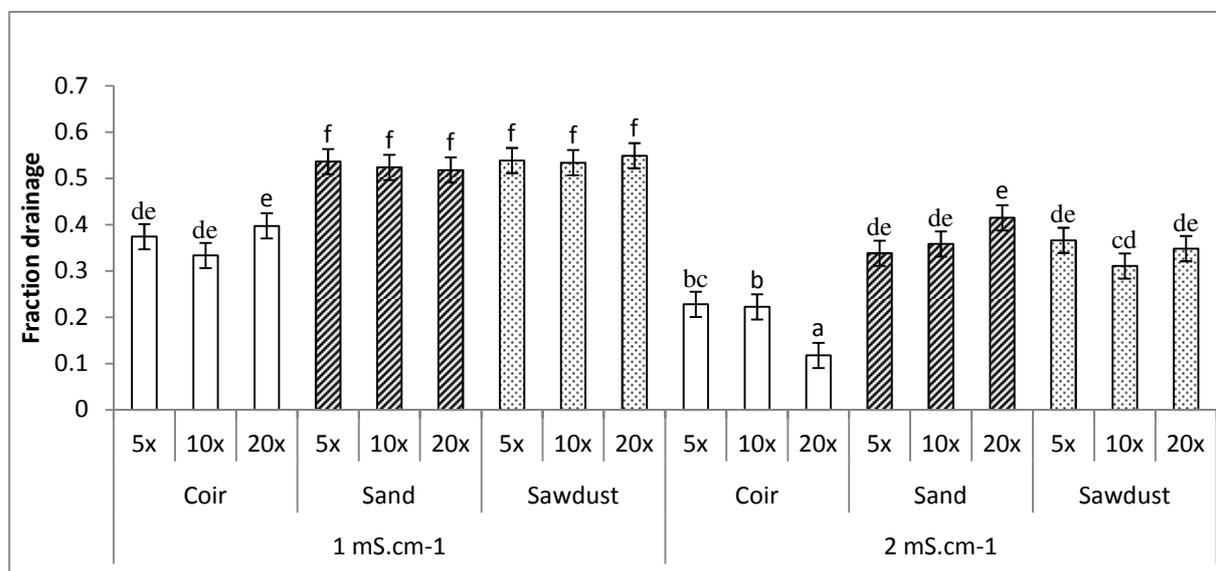
Figure 1. Fraction drainage for different treatment combinations of EC, growing media and irrigation frequency (3-way interaction) for greenhouse grown tomatoes. Treatments with different letter symbols differ significantly (P<0.05)
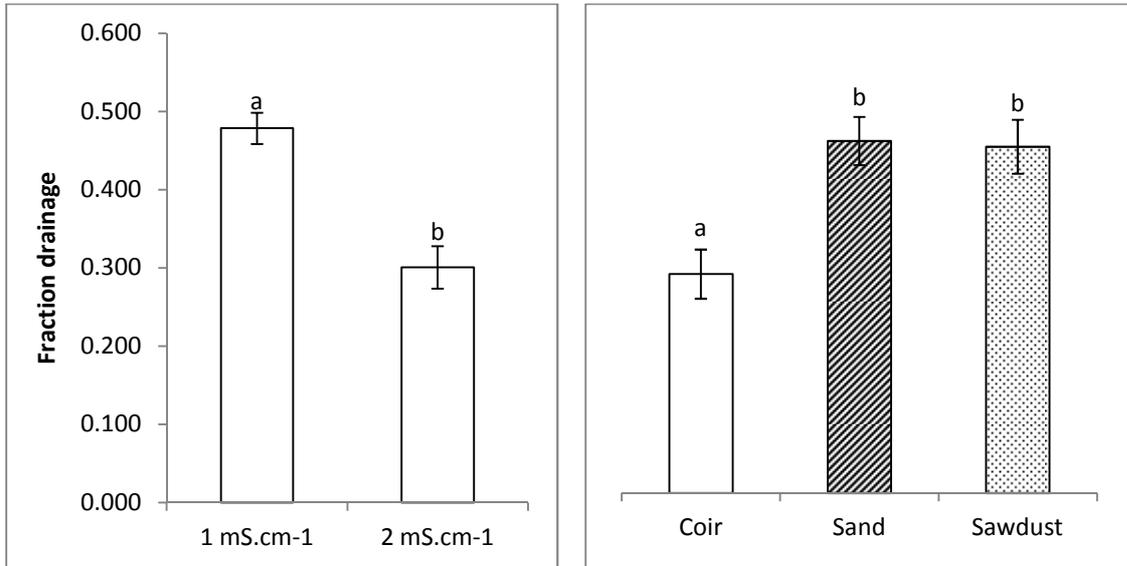
Figure 2. Fraction drainage for main effects EC and growing media for greenhouse grown tomatoes. Treatments with different letter symbols differ significantly (P<0.05)

Figure 3. Vegetative leafy growth of coir cultivated tomato plants indicated by large flimsy leaves, thick stems, and tight bunching of leaves at growing point.

3.2 Leaf macronutrient content

Growing media had a significant effect on Ca leaf content at 10 days after transplant (DAT) (Table 2). Coir grown plants had significantly lower % Ca leaf content compared to sand and sawdust grown plants (Table 2). However, by 38 DAT % Ca content of leaves were no longer significantly different between any treatments. Calcium levels at both sample times for all

treatments fell within the ranges deemed suitable for tomato production (Table 1). This was reflected in blossom end rot (BER) not being a problem in this trial, but it cannot be said whether this would extend to the long term for the treatments, since only the first truss was harvested red ripe.

Table 1. Adequate % dry mass leaf ranges for greenhouse grown tomato production of the most recently matured leaf including petiole (adapted from Peet, 2005).

Element	1st flower	Early fruit set
K	2.5-4.0	2.5-4.0
Ca	1.0-2.0	1.0-2.0
Mg	0.3-0.5	0.25-0.5
N	2.8-4.0	2.5-4.0
P	0.2-0.4	0.2-0.4
S	0.3-0.8	0.3-0.6

Ten days after transplants none of the main effects had a significant effect on % K leaf content, but by 38 DAT plants grown at EC 2 mS.cm^{-1} (10.6 meq K) had significantly higher % leaf content of K (Table 2). The reason for this development of a difference in K leaf content could be attributed to fruit development. The plants had only just started flowering 10 DAT so plant growth was devoted to the development of only vegetative organs. By 38 DAT tomato fruit were developing on the plants. Tomato fruit are heavy accumulators of K (Ho & Adams, 1995) and this could have manifested itself as a lower K leaf content in the low EC 1 mS.cm^{-1} treatment. This could be attributed to the lower fertiliser treated plants' leaf K accumulation being more sensitive to changes in K demand with fruit development than the high fertiliser treated plants. Mean % K leaf content levels in the EC 1 mS.cm^{-1} (5.3 meq K) treated plants were still above the minimum needed for optimal crop production (Table 1).

EC and irrigation frequency had no effect on Mg % leaf content, but media was found to have a significant effect (Table 2). Coir grown plants had significantly higher levels of Mg compared to sand and sawdust grown plants (Table 2). Coir has a high cation exchange capacity (CEC), which can vary from 35-95 cmol.kg^{-1}. CEC indicates the ability of a substrate to adsorb exchangeable cations (Maher *et al.*, 2008); high CEC media are therefore able to buffer the plant against changes in root zone nutrition. Coir's CEC may have absorbed a higher proportion Ca than Mg, thus resulting in a higher proportion Mg: Ca in substrate solution than in sawdust and sand. This would have been reflected in crop nutrient content

since mutual ratios of nutrients in the root environment are a major determinant in plant nutrient uptake (Sonneveld & Voogt, 2009).

Table 2. Effect of EC, irrigation frequency and growing media on % macro nutrient content of dried leaf samples taken 10 DAT and 38 DAT of greenhouse grown tomatoes. Significant F test at P<0.05 (*) and P<0.01 (**) and non significant (NS). Treatments with different letter symbols differ significantly (P<0.05)

	Ca %		K %		Mg %		N %		P %	
DAT	**10**	**38**	**10**	**38**	**10**	**38**	**10**	**38**	**10**	**38**
EC (E)										
1 mS.cm⁻¹	1.434	1.693	5.883	5.947	0.483	0.537	5.439	6.119	0.994	1.001
2 mS.cm⁻¹	1.481	1.748	6.136	6.303	0.487	0.501	6.426	6.731	1.114	1.094
	NS	NS	NS	**	NS	NS	**	**	**	**
Frequency (F)										
5x	1.429	1.786	5.979	6.027	0.479	0.518	5.888	6.320	1.028	1.039
10x	1.469	1.753	5.958	6.167	0.487	0.517	5.880	6.445	1.071	1.054
20x	1.475	1.623	6.091	6.182	0.490	0.522	6.030	6.511	1.063	1.048
	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Media (M)										
Coir	1.268a	1.595	6.003	6.072	0.565b	0.576b	5.708a	6.146	1.050	1.037
Sand	1.533b	1.822	6.162	6.348	0.435a	0.480a	6.158b	6.592	1.078	1.025
Sawdust	1.573b	1.745	5.863	5.955	0.456a	0.500a	5.932a	6.538	1.035	1.080
	*	NS	NS	NS	**	*	*	NS	NS	NS
ExF	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
ExM	NS	NS	NS	NS	NS	NS	*	NS	NS	NS
FxM	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
FxMxE	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

Percentage N leaf content indicated a 2-way interaction between EC and media at 10 DAT (Table 2). This is shown in figure 4. It can be seen that growing media had no significant effect on % N leaf content at nutrient solution feeding concentration of EC 2 mS.cm⁻¹ (3 meq NH_4^+, 14.2 meq NO_3^-), but at EC 1 mS.cm⁻¹ (1.5 meq NH_4^+, 7.1 meq NO_3^-) there were significant differences in leaf N content between growing media. These same differences are found when examining the main effects of EC and growing media 10 days after transplant, with EC 2 mS.cm⁻¹ grown plants having significantly higher N leaf levels

than EC 1 mS.cm^{-1} plants, and sand grown plants having significantly higher N leaf levels compared to sawdust and coir. However, 38 DAT the only significant differences in % leaf content are resulting from the difference in EC.
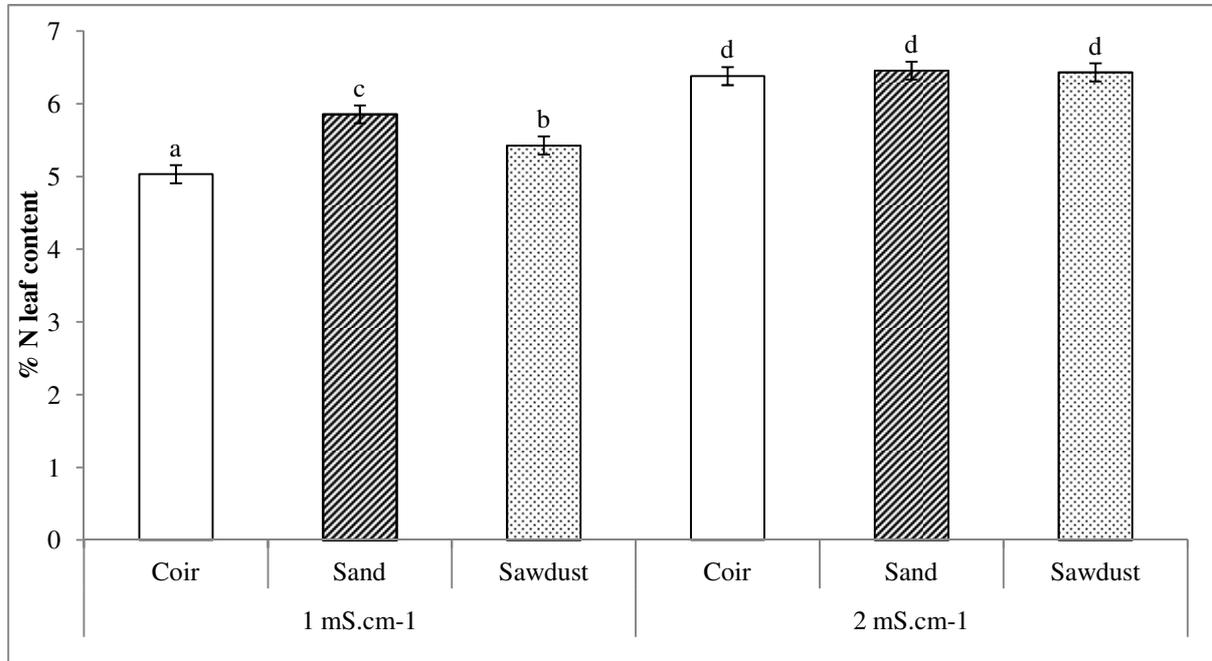
Figure 4. Percentage leaf N content for different growing media and EC treatment combinations (2-way interaction) in greenhouse grown tomatoes. Treatments with different letter symbols differ significantly (P<0.05)

Immobilisation is a well known phenomenon in organic media with high C:N ratios (Maher *et al.*, 2008).Immobilisation is caused by microorganisms converting inorganic N compounds into plant unavailable organic N compounds (Langenhoven, 2004). Therefore media with high C:N ratios result in N deficiency due to N depletion (Costa & Heuvelink, 2003). Coir has a moderate high to high ability to fix N (120mg N.L^{-1}) (Maher *et al.*, 2008). Sawdust has a high N immobilization rate which can result in N deficiencies if not compensated for in fertilization programs (Prasad, 1997b). This could account for the initially reduced N leaf content in sawdust and coir grown plants 10 DAT. But by 38 DAT, probably because the N fixing ability of the coir and sawdust media became saturated over the period between samples, the plants were then able to take up N unrestricted by immobilisation.

Even though there were significant differences in % N content, N levels across the board were still well above those deemed sufficient for optimal tomato growth (Table 1; Table 2). The high N contents could be attributed the inclusion of NH_4^+. Tabatabaei *et al.*

38

(2008) found that NH_4^+ application improves the uptake of NO_3^- in strawberries, increasing the total N and NH_4^+ leaf concentration as NH_4^+ concentration increases. Hohjo *et al.* (1995) had similar findings in tomatoes, reporting an increase in N leaf content of tomatoes with increasing ratio of NH_4^+-N for a fixed N supply.

Only EC had an effect on P % leaf content, with plants grown at EC 2 $mS.cm^{-1}$ having higher P levels compared to the EC 1 $mS.cm^{-1}$ grown plants at 10 days and 38 days after transplant (Table 2). The reason frequency had no affect on % P leaf levels can most likely be attributed to the high levels of P in the nutrient solution used (1.6 meq even at EC 1 $mS.cm^{-1}$). This can also be seen by the higher mean P leaf contents compared to suggested levels (Table 1). At low P concentrations irrigation frequency has been shown to facilitate plant uptake of less mobile elements such P, as shown by Silber *et al.* (2003) in a study on lettuce. But in this experiment Silber made use of considerable lower concentrations of P in the order of 0.8 meq and 0.4 meq.

Overall, with particular focus on the nutrient solution concentration, even at EC 1 $mS.cm^{-1}$ treatment leaf nutrient content levels of K, N and P were far in excess of the minimum required for optimal production (Table 1). Phosphorus levels were particularly high, double the recommended level, which is expected considering the high P composition of the nutrient solutions. Percentage N leaf dry matter content levels were well above the upper limit % dry matter content N for tomato production (Table 1, Table 2). Leaf Ca content levels were well within the Ca leaf content for optimal production (Table 1).

It would appear at an EC of 1 $mS.cm^{-1}$ for the particular nutrient solution used for this trial, P and N levels can be dropped without fear of deficiency. It is important to note that these leaf nutrient contents at EC 1 $mS.cm^{-1}$ are the result of environmental and plant interactions, not just the nutrient solution. But the relatively small increase in leaf content in plants grown at EC 1 $mS.cm^{-1}$ versus 2 $mS.cm^{-1}$, despite an effective doubling in the concentration of macro nutrients, is in agreement with the findings of Sonneveld & Welles (2005) that relative ratios of nutrients are more important than absolute concentration. It also hints at the non- linear saturation type function of plant nutrient uptake (Sonneveld & Voogt, 2009), therefore simply increasing overall nutrient concentrations will not always be an effective method to improve plant nutrient uptake unless nutrient levels are sub optimal. It would be interesting to make these nutrient solution adjustments and compare performance of plants grown in the adjusted trial nutrient solution, at low EC, to plants grown in the standard nutrient solutions at standard EC strengths as used by commercial growers.

3.3 Yield and fruit quality

There were no interactions between main effects (Table 3). The main effects of EC, irrigation frequency and media had no effect on marketable yield, fruit number and mass of green fruit. Green fruit were used as an indicator of potential yield. It can be seen that EC 1 mS.cm^{-1} grown plants did have a higher mean mass of marketable fruit compared to EC 2 mS.cm^{-1} grown plants, but was not significantly different; it is important to note the ANOVA P value for marketable fruit for EC main effect was borderline, P = 0.0513. It is only possible to speculate whether over time this difference may become significant as the crop matures. Also, there was no significant difference in yield of green fruit between EC treatments; green fruit yield was compared because it can be viewed as an indicator of potential yield. But, considering the leaf nutrient content data, it would be expected for there may be no differences in fruit yield. If there is no difference in productivity, or improved production, of EC 1 mS.cm^{-1} versus EC 2 mS.cm^{-1} grown plants it could be possible to achieve the same or even higher productivity with half the fertiliser input. This can only be confirmed if tested on a commercial scale over a full growing season, and effectiveness will probably be influenced by differing climatic conditions.

The EC and growing media had a significant effect on percentage soluble solids (Brix). The EC 2 mS.cm^{-1} grown plants fruit had a significantly higher percentage soluble solids compared to EC 1 mS.cm^{-1}. But this only equates to a 5.6% increase in Brix and it could be asked if this difference is even perceivable to the consumer. If not, a small reduction in soluble solids will be worth the potential financial saving of growing at a lower fertiliser concentration. A lower Brix in fruit harvested from plants grown at EC 1 mS.cm^{-1} is expected according to literature. Tomatoes grown at higher EC tend to have a reduced yield, but increased sugar content of their fruit (Sonneveld & Welles, 1988; Cornish, 1992; Elia *et al.*, 2001).This is caused by the reduced uptake of water into the fruit and the subsequent concentration of fruit content, as well as accumulation of compatible solutes in fruit due to plant osmotic adjustment (Plaut & Grava, 2005).

Ideally a full nutrient analysis of the fruit should have been performed to determine the effect of EC on fruit quality. The Ca content of fruit is particularly important as it is related to the physiological disorder BER, which can cause significant yield losses for tomato producers. Vegetative tomato growth needs very little calcium; Del Amor & Marcelis (2005) found no negative impacts on vegetative growth of tomato plants grown at low Ca concentration (0.5 meq.L^{-1}). Increasing EC, however, reduces calcium content of tomatoes and may increase the incidence of BER and yield loss (Ho & Adams, 1995; Sonneveld &

40

Welles, 2005). Sonneveld & Welles (2005) found for each 1 mS.cm^{-1} increase above 1.5 mS.cm^{-1} that Ca content decreased by 4 mmol Ca per kg of fruit dry matter and rapidly brought Ca below critical levels in tomato fruit. Therefore Ca content of fruit would have been a more suitable indicator if Ca is in fact deficient or becoming deficient in the plant than leaf Ca content.

Table 3. Effect of EC, irrigation frequency and growing media on yield and Brix of tomato fruit in greenhouse grown tomatoes. Significant F test at P<0.05 (*) and P<0.01 (**) and non significant (NS). Treatments with different letter symbols differ significantly (P<0.05)

	Marketable yield		Green fruit	Brix
	Mass (grams)	No.	Mass (grams)	
EC (E)				
1 mS.cm^{-1}	0.696	5.222	0.970	4.473
2 mS.cm^{-1}	0.609	4.806	0.950	4.725
	NS	NS	NS	**
Frequency (F)				
5x	0.682	5.333	0.963	4.647
10x	0.677	5.167	0.993	4.583
20x	0.600	4.542	0.925	4.568
	NS	NS	NS	NS
Media (M)				
Coir	0.709	5.167	0.985	4.697b
Sand	0.577	4.667	0.936	4.500a
Sawdust	0.672	5.208	0.960	4.601b
	NS	NS	NS	*
ExF	NS	NS	NS	NS
ExM	NS	NS	NS	NS
FxM	NS	NS	NS	NS
FxMxE	NS	NS	NS	NS

4. Conclusion

Plants grown at EC 1 mS.cm^{-1} were still able to take up sufficient nutrients to achieve leaf macronutrient contents associated with optimal production. Also, increasing absolute nutrient concentration had a relatively small effect on nutrient uptake. Organic media, such as coir and sawdust, reduced available N early in the tomato crop life, and tomatoes grown in coir had reduced Ca uptake compared to plants grown in sand and sawdust. This highlights the

41

importance in defining the chemical characteristics of growing media to avoid deficiencies which could limit production.

Coir grown plants used more water compared to sand and sawdust grown plants, and plants grown at EC 1 mS.cm^{-1} used less water compared to plants grown at EC 2 mS.cm^{-1}. It will be important to determine if this is the result of luxury consumption or superior plant growth. It does appear that growing tomatoes at an EC of 1 mS.cm^{-1} may not negatively impact on marketable yield, and will only marginally reduce fruit sugar content. However, whether a yield gap develops as the crop ages, one can only speculate, and the growing of tomatoes at low EC under commercial conditions (i.e unregulated temperature and full cropping cycle) under spring/ summer climatic conditions will need to be tested. The cultivation of tomatoes at low EC, with the benefits of reducing water and fertiliser use without a decline in fruit quality or yield, would be a win-win situation from an environmental and a grower perspective.

5. References

BENTON-JONES, J., 2005. Hydroponics: a practical guide for the soilless grower (2nd Ed.). CRC press, Boca Raton, Florida.

CORNISH, P.S., 1992. Use of high electrical conductivity of nutrient solution to improve quality of salad tomatoes (*Lycopersicon esculentum*) grown in hydroponic culture. *Aust. J. Exp. Agric.* 32, 513-520.

COSTA, J.M. & HEUVELINK, E., 2003. Substrates today. *Fruit & Veg Tech 3(4), 29-33.*

DEL AMOR, F.M. & MARCELIS, L.F.M., 2005. Response of plant growth to low calcium concentration in the nutrient solution. *Acta Hort.* 697, 529-533.

ELIA, A., SERIO, F., PARENTE, A., SANTAMARIA, P. & RODRIGUEZ, G.R., 2001. Electrical conductivity of nutrient solution, plant growth and fruit quality of soilless grown tomato. *Acta Hort*. 559, 503-508.

HEEB, A., LUNDEGÅRDH, SAVAGE, G. & ERICSSON, T., 2006. Impact of organic and inorganic fertilisers on yield, taste, and nutritional quality of tomatoes. *J. Plant Nutr. Soil Sci.* 169, 535-541.

HO, L.C & ADAMS, P., 1995. Nutrient uptake and distribution in relation to crop quality. *Acta Hort*. 396, 33-44.

HOHJO, M., KUWATA, C, YOSHIKAWA, K. & ITO, T., 1995. Effects of nitrogen form, nutrient concentration and Ca concentration on the growth, yield and fruit quality in NFT-tomato plants. *Acta Hort* 396, 145-152.

JOVICICH, E., CANTLIFFE, D.J., STOFFELLA, P.J. & VANSICKLE, J.J., 2003. Reduced fertigation of soilless greenhouse peppers improves fruit yield and quality. *Acta Hort*. 609,193-196.

LANGENHOVEN, P., 2004. Yield and quality response of hydroponically grown tomatoes (*Lycopersicon esculentum* Mill.) to nitrogen source and growth medium. PhD thesis, Stellenbosch University.

LI, Y.L., STANGHELLINI, C. & CHALLA, H., 2001. Effect of electrical conductivity and transpiration on production of greenhouse tomato. *Sci. Hortic*. 88, 11-29.

MAHER, M., PRASAD, M. & RAVIV, M., 2008. Nutrition in substrate grown plants. *In:* Raviv, M. & Lieth, J.H. (eds.). *Soilless Culture: Theory and Practice*. Elsevier, Amsterdam. p459-504.

NEDERHOFF, E., AND HOUTER, B., 2009. Plant balance by irrigation. *Practical Hydroponics and Greenhouses*, 45-50, March/April.

PAPADOPOULOS, A. P., 1998. Seasonal fertigation schedules for greenhouse tomatoes – concepts and delivery systems. *Acta Hort*. 458, 123-140.

PAPADOPOULOS, A. P., BAR-TAL, A., SILBER, A., SAHA, U.K. & RAVIV, M., 2008. Organic Soilless Media Components. *In*: Raviv*, M. & Lieth, J.H. (eds.). Soilless Culture: Theory and Practice. Elsevier, Amsterdam. p505-537.

PEET, M.M., 2005. Irrigation and Fertilization. *In*: Heuvelink, E. (ed). *Tomatoes*. CABI publishing, Wallingford, UK. p171-198.

PLAUT, Z. & GRAVA, A., 2005. Osmotic adjustment of tomato fruits and leaves grown in sand and irrigated with saline water. *Acta Hort*. 697, 285-291.

PRASAD, M., 1997a. Physical, biological and chemical properties of coir dust. *Acta Hort*. 450, 21-29.

PRASAD, M., 1997b. Nitrogen fixation of various materials from a number of European countries by three nitrogen fixation tests. *Acta Hort*. 450, 353-362.

SAVVAS, D., SAMANTOUROS, D, PARALEMOS, VLACHAKOS, G., STAMATAKIS, M., & VASSILATOS, C., 2004. Yield and nutrient status in the root environment of tomatoes (*Lycopersicon esculentum*) grown on chemically active and inactive inorganic Substrates. *Acta Hort*. 644, 377-383.

SILBER, A., 2008. High frequency irrigations as means for enhancement of nutrient uses efficiency: soilless grown bell pepper as a model plant. *Acta Hort*. 779, 281-288.

SILBER, A., XU, G., LEVKOVITCH, I., SORIANO, S., BILU, A. & WALLACH, R., 2003. High fertigation frequency: the effects on uptake of nutrients, water and plant growth. *Plant Soil* 253, 467-477.

SONNEVELD, C. & VOOGT, W., 2009. Plant nutrition of greenhouse crops. Springer Science, New York.

SONNEVELD, C. & WELLES, G.W.H., 1988. Yield and quality of rockwool-grown tomatoes as affected by variations in EC-value and climatic conditions. *Plant Soil* 111, 37-42.

SONNEVELD, C. & WELLES, G.W.H., 2005. Cation concentrations of plant tissues of fruit- vegetable crops as affected by the EC of the external nutrient solution and by humidity. *Acta Hort*. 697, 377-386.

TABATABAEI, S.J., YUSEFI, M. & HAJILOO, J., 2008. Effects of shading on NO3:NH4 ratio on yield, quality and N metabolism in strawberry. *Sci. Hortic.* 116, 264-272.

Chapter 3

The effect of leaf and fruit pruning on yield and fruit size of hydroponically grown tomatoes

C.M. Fulton [1] & E. Kempen [2]

[1]Department of Agronomy, University Stellenbosch, Private Bag X1, Matieland 7602, South Africa, E-mail: Craigfulton@sun.ac.za

[2]Department of Agronomy, University Stellenbosch, Private Bag X1, Matieland 7602, South Africa, E-mail: Estellek@sun.ac.za

Abstract

Pruning is an important cultural practise for ensuring high productivity of hydroponic tomatoes. Adapting pruning practises to different climatic conditions could be a cheap and effective manner to improve productivity. This study examined the effect of leaf and fruit pruning on fruit size, total yield and marketable yield of tomatoes. Plants were grown using the high wire system and pruned to two stems. Three different leaf pruning treatments were applied: no leaf pruning, pruning every 2nd young leaf after 1m plant height, and pruning every 2nd young leaf after 2m plant height. Two fruit pruning treatments were also applied: no fruit pruning and trusses pruned to 4 fruit. The experiment used a factorial design. Leaf pruning treatments had no effect and this was probably due to too late a removal of young leaves. Fruit pruning resulted in no significant difference between treatments in terms of marketable yield. Plants with unpruned trusses did have a significantly higher total yield, higher early yield, lower average marketable fruit weight, and higher yield of unmarketable fruit (particularly small fruit compared to the pruned treatment). Fruit pruning isn't necessary on a short season tomato crop but this may be different over a longer cropping cycle.

Key words: Fruit size, Sink, Source, Marketable yield

1. Introduction

The cultural practice of pruning plays an important role in ensuring high productivity in intensively grown tomatoes. The growth and yield of crop plants is limited by the size and activity of assimilate sources or sinks (Kinet & Peet, 1997; Valatin *et al.*, 1998). In tomatoes the ratio between fruit and vegetative growth is largely determined by fruit load and it is

common practise for producers to directly control fruit load through the pruning of fruit (De Koning, 1996; Heuvelink, 2005). Plant biomass allocation to fruit increases in a saturation type function with an increase in fruit number per truss (Heuvelink, 1997). However, maintaining as many fruit as possible per truss may ultimately reduce marketable yield because of more smaller unmarketable fruit (Heuvelink, 1997; Saĝlam & Yazgan, 1999). Fruit pruning prevents overbearing and improves fruit size, ensuring consistent and high quality productivity (Papadopoulos, 1991). Environmental factors such as CO_2 concentration, light intensity and temperature can directly influence sink and source activity (Valatin *et al.*, 1998). For this reason fruit pruning should be adjusted according to crop potential under the prevailing conditions (Papadopoulos, 1991).

It is common practice to remove mature tomato leaves from below and above the harvest ripe fruit. The main reasons for this leaf pruning is to reduce disease pressure, accelerate fruit ripening and make harvesting easier (Heuvelink *et al.*, 2005). Leaf excision and plant decapitation stimulates fruit growth by reducing assimilate competition between reproductive and vegetative growth (Kinet & Peet, 1997). Therefore leaf pruning can be used to reduce vegetative sink strength and increase biomass partitioning to the fruit (Xiao *et al.*, 2004; Heuvelink *et al.*, 2005). However, total yield is likely to suffer unless measures are taken to maintain optimum LAI; such measures include increasing stem density and delaying leaf pruning (Xiao *et al.*, 2004).

Pruning practices should be adjusted based upon sink/ source activity to maximise productivity under differing climatic conditions. Currently in South Africa the level of environmental control in tomatoes cultivated under protection is limited by logistical and economic constraints. Adapting pruning practises to prevailing climatic conditions could be a cheap and effective manner to improve productivity. This study examined the effects of different leaf and fruit pruning regimes on the marketable yield of hydroponically grown tomatoes under Mediterranean conditions in the Western Cape, South Africa.

2. Materials and Methods

2.1. Location and cropping details

The experiment was conducted in a plastic covered tunnel at Stellenbosch University's Welgevallen Experimental Farm, Western Cape, South Africa. Six week old seedlings of the tomato cultivar MFH9343 were transplanted into 10L plastic bags filled with three year old coir on the 11th September 2010. Coir was sterilised and rinsed with clean municipal water

before transplant. Plants were fertigated through a drip irrigation system with a standard steiner solution of EC 1.4 mS.cm^{-1}, composition in milliequivalents was: K^+: 4.9; Ca^{2+}: 6.3; Mg^{2+}: 2.8; NO_3^-: 8.4; PO_4^{2-}: 0.7; SO_4^{2-}: 4.9. Plants were planted at a density of 2.5 plants/m^2 and pruned to two stems. The stems were vertically trellised using twine and the crop was topped once it reached the top wire at 2.5 m.

2.2. Treatments and experimental design

The experiment utilised a factorial design with eight randomised blocks (90 plants per block, 15 plants per plot). Three leaf pruning treatments were applied in combination with two fruit pruning treatments. The three leaf pruning treatments were: (1) every 2nd leaf was removed from each stem starting 1 m above the bag; (2) every 2nd leaf was removed from each stem starting 2m above the bag, and (0) no leaf pruning. The two fruit pruning treatments applied were: (4P) trusses pruned to 4 fruit, and (0P) trusses received no pruning. The harvest period in this experiment was limited to just under 2 months (08/11/2010-27/01/2011) because of a heavy white fly infestation that resulted in severe outbreak of sooty mould that destroyed the plants effective canopy.

2.3. Measurements and analysis

Number of fruit, fruit size grade, total yield, marketable yield and unmarketable yield were recorded; average fruit weight was also calculated. Data was analysed using ANOVA, and means compared using Fischer's LSD (P<0.05) using the statistical software *Statistica 10*.

3. Results and discussion

No significant interactions occurred between leaf pruning and fruit pruning and therefore the two main effects will be discussed separately.

3.1. Leaf Pruning

In Table 1 and Table 2, it can be seen that leaf pruning had no significant effect on the measured parameters. The possible reason that there were no differences between treatments is that the leaf pruning took place too late. Only young developing leaves compete directly for assimilates with fruit, once mature they become net exporters of assimilates and no longer competed for assimilates. This would mean that if leaf pruning was late it would have little effect on reducing vegetative sink strength to benefit partitioning to the fruit.

The stem density was very high (5 stems. m^{-2}) in this experiment, and despite the leaf pruning the LAI across all treatments was probably still greater than 3 $m^2.m^{-2}$. At LAI between 2-3 $m^2.m^{-2}$ tomato crop nears light saturation (90%) and maximal DM production rate (De Koning, 1996; Heuvelink *et al.*, 2005). Therefore, yield would be expected to be more or less the same across leaf pruning treatments, which was the case in this study.

Table 1. Effect of leaf and fruit pruning on greenhouse grown tomato yield and average marketable fruit weight. Significant F test at P<0.05 (*) and P<0.01 (**) and non significant (NS)

	Marketable fruit		Unmarketable fruit		Total fruit		Average marketable fruit weight
	Mass	No.	Mass	No.	Mass	No.	
	$kg.m^{-2}$	$no.m^{-2}$	$kg.m^{-2}$	$no.m^{-2}$	$kg.m^{-2}$	$no.m^{-2}$	$g.fruit^{-1}$
Fruit Pruning (P)							
0P	9.10	66.59	6.79	77.53	15.88	144.13	136.57
4P	8.57	60.78	6.02	67.88	14.60	128.67	141.08
	NS	*	*	**	**	**	**
Leaf Pruning (L)							
L2	8.97	64.88	6.78	77.57	15.75	142.45	138.67
L1	8.43	61.33	6.05	68.52	14.48	129.85	137.48
L0	9.10	64.85	6.39	72.03	15.49	136.89	140.34
	NS	NS	NS	NS	NS	NS	NS
L x P	NS	NS	NS	NS	NS	NS	NS

Table 2. Effect of leaf and fruit pruning on greenhouse grown tomato fruit grade. Significant F test at P<0.05 (*) and P<0.01 (**) and non significant (NS)

	56-72 mm		30-55 mm		<30 mm		Other disorders	
	Mass	No.	Mass	No.	Mass	No.	Mass	No.
	$kg.m^{-2}$	$no.m^{-2}$	$kg.m^{-2}$	$no.m^{-2}$	$kg.m^{-2}$	$no.m^{-2}$	$kg.m^{-2}$	$no.m^{-2}$
Fruit Pruning (P)								
0P	4.25	25.04	4.84	41.55	4.04	56.02	2.75	21.51
4P	4.48	25.53	4.09	35.25	3.26	47.61	2.76	20.27
	NS	NS	**	**	**	**	NS	NS
Leaf Pruning (L)								
L2	4.28	25.30	4.69	39.57	3.82	55.63	2.95	21.95
L1	4.14	23.95	4.28	37.39	3.55	48.93	2.50	19.59
L0	4.68	26.61	4.42	38.24	3.58	50.90	2.81	21.14
	NS	NS	NS	NS	NS	NS	NS	NS
L x P	NS	NS	NS	NS	NS	NS	NS	NS

3.2. Fruit pruning

There was no significant effect of fruit pruning on overall marketable yield, but fruit pruning did result in significantly lower number of marketable fruit (Table 1). Fruit pruning significantly reduced number and mass of unmarketable fruit compared to unpruned treatments. A study by Maboko and Du Plooy (2009) also found that fruit pruning did not appear to significantly affect marketable yield of tomatoes. The unpruned plants had a significantly higher overall total yield and fruit number compared to the pruned treatments (Table 1). Also, pruned plants had a significantly higher average fruit mass compared to unpruned plants (Table 1). There was no significant difference between pruning treatments in terms of overall mass and number of fruit in the 56-72mm size class (Table 2). However, unpruned plants produced significantly higher numbers and mass of fruit in the 30-55mm and <30mm fruit classes (Table 2). The higher total yield in the unpruned treatment can be attributed to a higher number and mass of small unmarketable fruit <30mm compared to the pruned treatment.

These results correlate with the findings of Saĝlam and Yazgan (1995, 1999) and Heuvelink (1997) that reducing the number of fruit per plant results in an increase in average marketable fruit weight. High tomato fruit loads are known to cause an increased number of small fruit (De Koning, 1996; Heuvelink, 1997; Saĝlam & Yazgan, 1999). This is related to competition for assimilates between fruit (Heuvelink, 1997) and explains why in the unpruned treatment there was a higher mass and number of smaller (30-55mm) fruit, small unmarketable fruit (<30mm) and a lower average marketable fruit weight.

Figures 1-3 examine the effects of fruit pruning in more detail on a per harvest basis. Mass of marketable yield per harvest from 20-Dec to 27-Dec were significantly higher in unpruned compared to pruned treatments (Figure 1). Harvests 13-Dec to 27-Dec yielded significantly higher numbers of marketable fruit in unpruned treatments compared to pruned treatments. Unpruned treatments produce significantly higher numbers and mass of <30mm fruit compared to pruned plants for most harvests (Figure 2; Figure 3). Harvests 13-Dec to 6-Jan in unpruned plants produced significantly higher mass and number of 30-55mm fruit in comparison to the pruned plants (Figure 2; Figure 3).

Pruned treatments had significantly higher average marketable fruit masses in harvest 20-Dec to 3-June (Figure 1). However, mean marketable fruit weight decreased for both treatments as season progressed till they converged. It would have been expected that the mean fruit weight would have remained more stable, declining more slowly, and higher than the unpruned treatment.
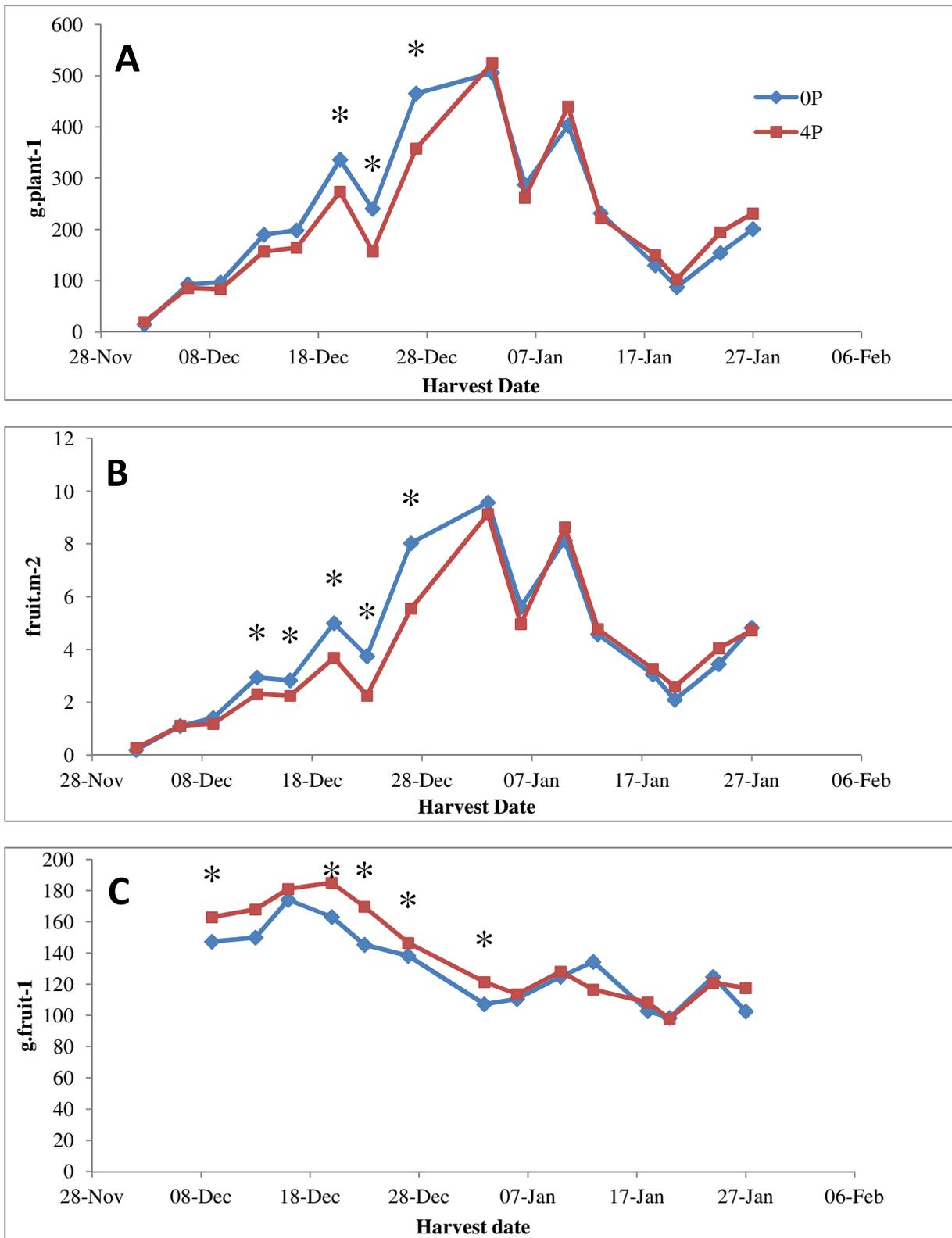
49

Figure 1. Marketable yield **(A),** number marketable fruit **(B)** and average marketable fruit weight **(C)** per harvest for truss pruning treatments in greenhouse grown tomatoes: no truss pruning (0P) and trusses pruned to 4 fruit (4P). Significant F tests within harvest dates at P<0.05 indicated by *

50

Figure 2. Yield of <30mm fruit **(A)**, 30-55mm fruit **(B)** and 56-72mm fruit **(C)** per harvest for truss pruning treatments in greenhouse grown tomato: no truss pruning (0P) and trusses pruned to 4 fruit (4P). Significant F tests within harvest dates at P<0.05 indicated by *

51

Figure 3. Number of <30mm fruit **(A)**, 30-55mm fruit **(B)** and 56-72mm fruit **(C)** per harvest for truss pruning treatments: no truss pruning (0P) and trusses pruned to 4 fruit (4P). Significant F tests within harvest dates at P<0.05 indicated by*

52

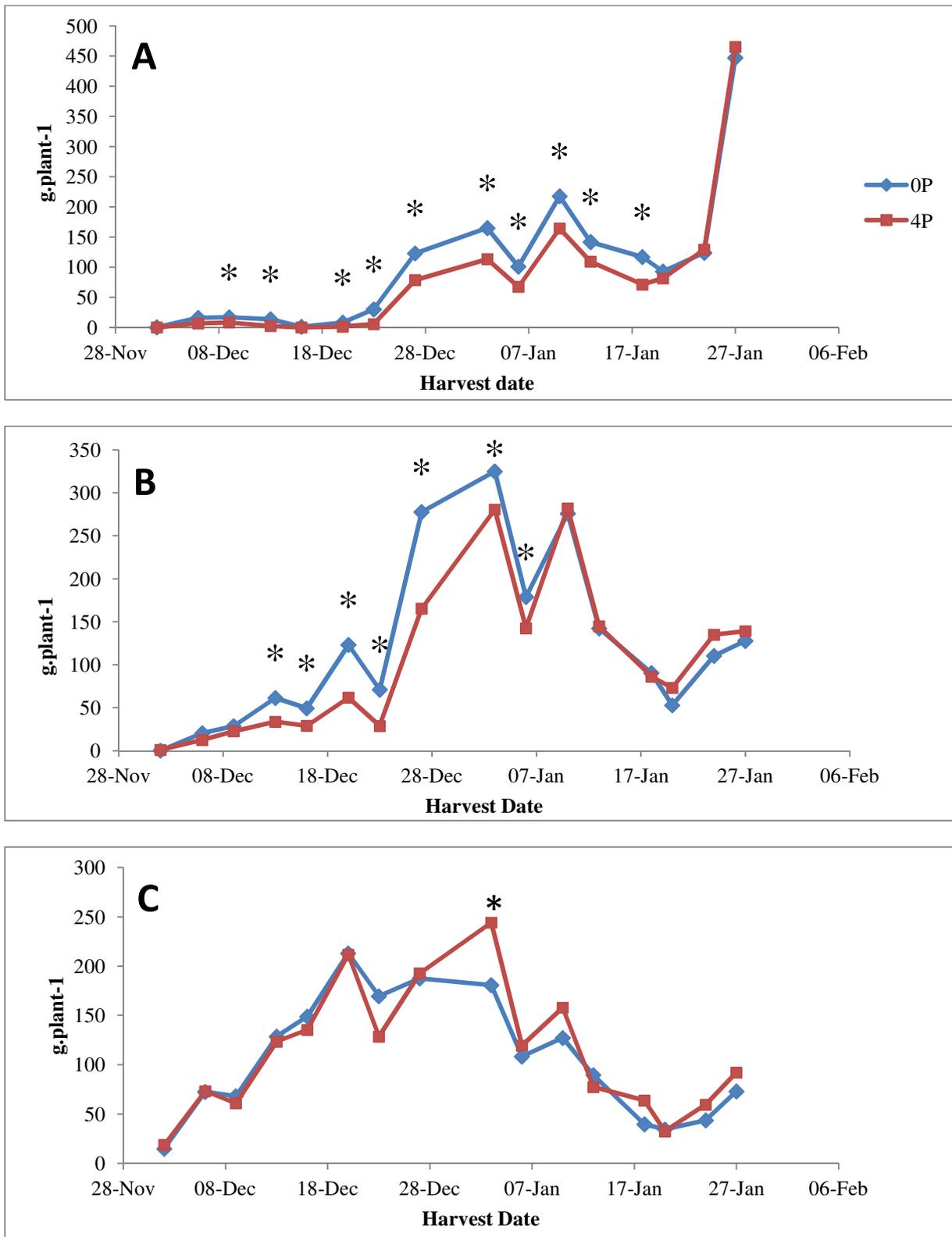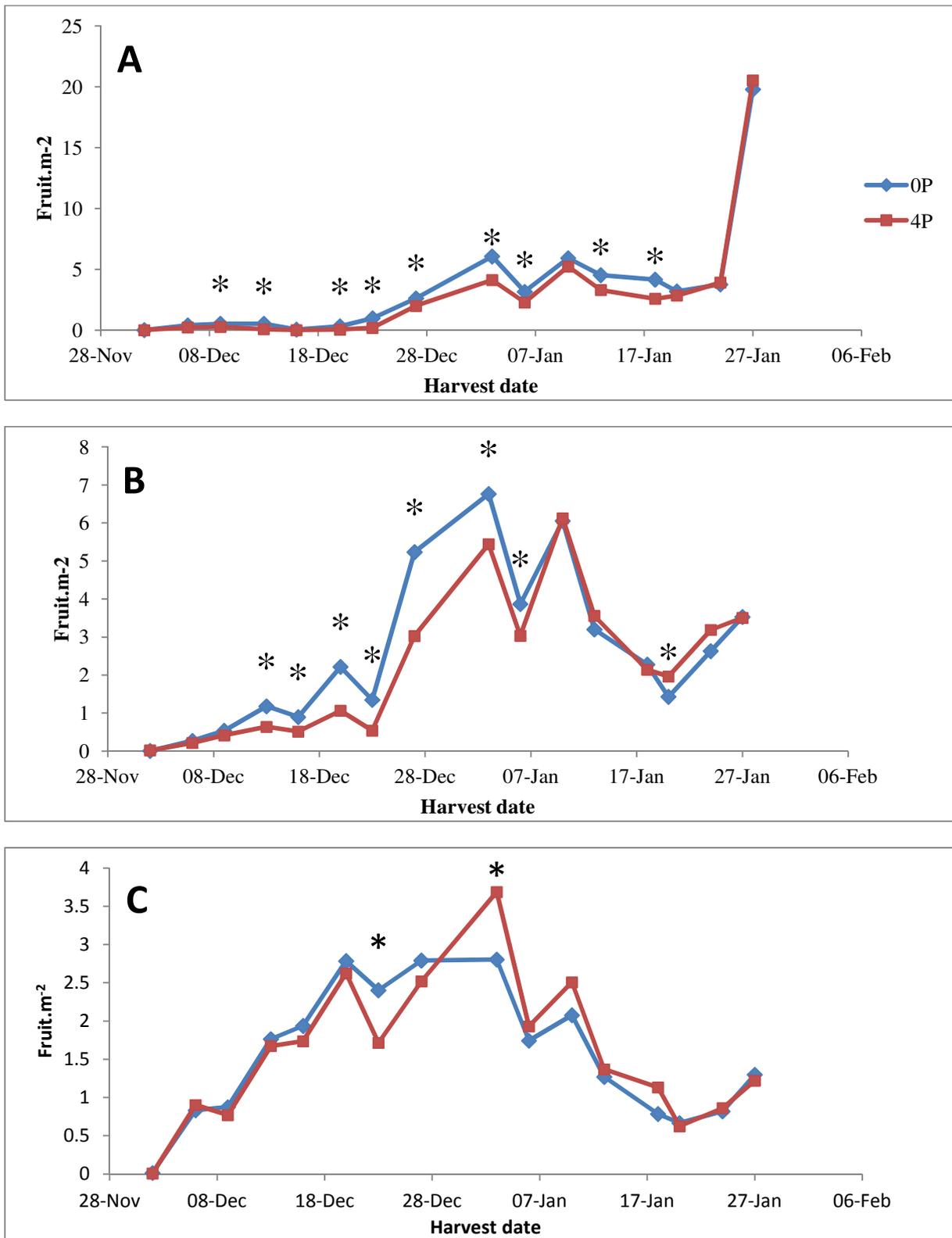Fruit within the same truss and on other trusses compete for assimilates (Kinet & Peet, 1997). Cell number of fruit is the primary factor determining fruit size in tomatoes under limited assimilate availability, with more cells resulting in larger fruit (Bertin *et al.*, 2001). In unthinned trusses, fruit position affects fruit size and this is linked to greater cell number in proximal fruit already at anthesis (Bangerath & Ho, 1984). First trusses develop under conditions of limited competition due to few growing sinks and therefore cell number was independent of fruit position (Bertin *et al.*, 2001). This could explain the higher average fruit weight of earlier harvests and lower number of <30mm fruit in the unpruned treatment, and higher average fruit weight in the pruned treatment compared to the unpruned treatment. Later trusses develop under conditions of relatively high competition due to increasing fruit load on the plant, resulting in a clear negative gradient in cell number from proximal to distal fruit (Bertin *et al.*, 2001). This also explains why many of the fruit in the unpruned treatment are unable to achieve marketable size, because of the rapid increase in competition for assimilates due to the presence of more fruit.

Therefore the decline and convergence in average fruit weight was probably related to limited availability of assimilates compared to generative sink demand. The fact that the plants are doubled stemmed could have also been a contributing factor, because pruning plants to two stems causes a higher relative increase in generative sink strength compared to the relative increase in source strength from increased LAI (Nederhoff & Houter, 2009). On top of that, at such high densities mutual shading could have contributed to reduced source strength; this effect would have become more pronounced as the season progressed and LAI increased. There was also a heavy whitefly infestation and subsequent outbreak of black mould, which would have limited effective LAI and contributed to limiting assimilate supply further; the heavy disease outbreak resulted in a short harvest period of only 2 months.

Increasing summer temperatures could therefore have been a contributing factor to the reduction in fruit size as the season progressed. The experimental plants had small leaves and thin heads from fruit set on the 3rd truss, indicating overly generative plants (Nederhoff & Houter, 2009). High temperatures favour partitioning to the fruit at the expense of vegetative growth by increasing individual fruit sink strength and accelerating plant development, thus increasing the rate of appearance of new fruit (De Koning, 1989). This could have restricted the production of new leaf area. This in combination with disease outbreak would have resulted in a rapid reduction in effective LAI. These factors could have been responsible for later trusses developing under conditions of limited assimilate, thus fewer cells in the fruit, resulting in smaller fruit.

53

4. Conclusion

Fruit pruning increases average weight of marketable fruit, but doesn't significantly influence marketable yield in a short spring tomato crop pruned to two stems. However, this may not be the case for a longer tomato crop which is able to maintain a healthy effective leaf area, or a single stemmed tomato crop. Fruit pruning also reduces the quantity of unmarketable small fruit. Leaf pruning has no effect on tomato yield, but this was probably because LAI was maintained sufficiently high, and pruning of 'young' leaves took place too late to influence vegetative:generative sink balance.

5. References

BANGERTH, F. & HO, L.C., 1983. Fruit position and fruit set sequence in a truss as factors determining final size of tomato fruits. *Ann. Bot.* 53, 315-319.

BERTIN, N., GAUTIER, HELENE, G. & ROCHE, C., 2001. Number of cells in tomato fruit depending on fruit position and source-sink balance during plant development. *Plant Growth Regul.* 00, 1-8.

DE KONING, A.N.M., 1989.The effect of temperature on fruit growth and fruit load of tomato. *Acta Hort.* 248, 329-336.

DE KONING, A.N.M., 1996. Model predictions of optimum shoot density and truss size in glasshouse tomato. *Acta Hort*. 417, 99-106.

.HEUVELINK, E., 1997. Effect of fruit load on dry matter partitioning in tomato. *Sci.Hortic.* 69, 51-59.

HEUVELINK, E., BAKKER, M.J., ELINGS, A., KAARSEMAKER,R. & MARCELIS, L.F.M., 2005. Effect of leaf area on tomato yield. *Acta Hort*. 691, 43-.50.

KINET, J.M. & PEET, M.M., 1997. Tomato. p 207-258. *In:* Wien, H.C. The physiology of vegetable crops. CAB International, Wallingford, UK

MABOKO, M.M. & DU PLOOY, C.P., 2009. Effect of stem and fruit pruning on yield and quality of hydroponically grown tomato. *African Crop Science Conference Proceedings* 9, 27-29.

NEDERHOFF, E. & HOUTER, B., 2009. Plant management for generative or vegetative steering. *Practical Hydroponics & Greenhouses*, 51-54, March/April.

PAPADOPOULOS, A.P., 1991. Growing greenhouse tomatoes in soil and in soilless media. Agriculture Canada, Ottawa.

SAĜLAM, N AND YAZGAN, A., 1995. The effects of planting density and the number of trusses per plant earliness, yield and quality of tomato grown under unheated high plastic tunnel. *Acta Hort*. 412, 258 -267.

SAĜLAM, N AND YAZGAN, A., 1999. Effect of fruit number per truss on yield and quality in tomato. *Acta Hort.* 486, 261-264.

VALANTIN, M., GARY, C., VAISSIE'RE, B.E., TCHAMITCHIAN, M. & BRUNELI, B., 1998. Changing sink demand affects the area but not the specific activity of assimilate sources in cantaloupe (*Cucumis melo L.*). *Ann. Bot-London* 82, 711-719.

XIAO, S., VAN DER PLOEG, A., BAKKER, M. & HEUVELINK, E., 2004. Two instead of three leaves between tomato trusses: measured and simulated effects on partitioning and yield. *Acta Hort.* 654, 303-308.

55

Chapter 4
The effect of EC and stem pruning on the growth and early yield of hydroponic tomatoes grown in coir

C.M. Fulton [1] & E. Kempen [2]

[1]Department of Agronomy, University Stellenbosch, Private Bag X1, Matieland 7602, South Africa, E-mail: Craigfulton@sun.ac.za

[2]Department of Agronomy, University Stellenbosch, Private Bag X1, Matieland 7602, South Africa, E-mail: Estellek@sun.ac.za

Abstract

Poor management of hydroponic fertigation water results in pollution, and wastes precious water and expensive fertiliser. Improving fertiliser use efficiency is crucial to ensuring sustainable production of intensive crops, such as the tomato. A better understanding of the effect of nutrition and pruning on plant growth could help achieve this. An experiment was conducted to determine the effects of different EC and stem pruning practices on nutrition, growth and early yield of hydroponically grown tomatoes in coir. A factorial design was used, and the experiment was conducted in an unheated plastic covered greenhouse. Two EC treatments (1 and 2 $mS.cm^{-1}$) in factorial arrangement with 2 stem pruning treatments (single and double) were applied. Stem pruning had little effect on plant growth but did alter plant development. Plants pruned to two stems produced significantly more trusses, but did not produce a significantly higher DM or leaf area compared to single stem plants. Stem pruning's major effect appears to be influencing fruit load; this may in the long term may result in differences in plant growth and nutrition. EC 1 $mS.cm^{-1}$ plants produced significantly lower leaf area and organ dry masses but had a significantly higher marketable yield compared to EC 2 $mS.cm^{-1}$ plants. Over fertilisation in young tomatoes can negatively impact on fruit set and reduce early yield, whereas lower fertiliser application in early tomato growth improves fruit set and early yield but limits canopy development which may limit plant productivity in the long term. These differences in growth are believed to be primarily related to differences in N and P nutrition.

Key words: Dry matter, leaf area, fruit load, nitrogen, phosphorus, potassium

1. Introduction

It is important in soilless agriculture to synchronise plant demands for water and nutrients otherwise deficiency or salinisation may rapidly occur (Klaring, 2001). Residual salts

accumulate in substrate solution due to a variation in plant water: nutrient uptake ratio and the selective uptake of ions (Klaring, 2001; Sonneveld & Voogt, 2001;). It is well known that saline conditions (high EC) reduce yield and plant growth in tomatoes (Li *et al.*, 2001). Electrical conductivity (EC mS.cm^{-1}) is a measure of the total concentration of dissolved solutes in solution (Li *et al.*, 2001). It can therefore be used as a measure of nutrient availability in the nutrient solution. Too low concentrations of fertiliser cause mineral deficiencies and restrict plant growth, where as there is no negative effects of over supplying nutrients to a threshold point (Li *et al.*, 2001; Sonneveld & Voogt, 2009). Therefore producers, to avoid deficiencies and control produce quality, add large amounts of nutrients with little attention to crop uptake (Li *et al.*, 2001). The EC required for optimal plant production depends on the crop type and growing conditions (Sonneveld & Voogt, 2009).

An EC of 2.0 mS.cm^{-1} is sufficient to maintain optimal nutrient uptake in tomatoes; 2.5 mS.cm^{-1} is estimated as the salinity threshold for a tomato crop (Sonneveld & Welles, 1988; Sonneveld & Voogt, 2009). Sonneveld & Welles (1988) reported that for each 1 mS.cm^{-1} increase above 2.5 mS.cm^{-1} tomato yield decreased by 5-7%. Schwarz and Kuchenbuch (1998) found that plants grown at an EC of 6 mS.cm^{-1} experienced a 50% reduction in yield compared to plants grown at an EC of 1 mS.cm^{-1}. These reductions in yield and plant growth are associated with reduced water uptake and shifts in water distribution within the plant (Schwarz and Kuchenbuch, 1998; Li *et al.*, 2001). Elia *et al.* (2001) reported that increasing the EC from 1 to 6 mS.cm^{-1} didn't reduce DM yield but reduced fresh weights of tomato shoots and fruit. Li *et al.* (2001) had similar findings; root zone salinity didn't affect dry matter yield, and loss in yield was the result of reduced fresh weight caused by lower tissue water content and an increased discarded fraction of small unmarketable fruit.

Calcium uptake is particularly sensitive to increases in EC. Increasing EC reduces calcium content of tomatoes and may increase the incidence of blossom end rot and yield loss (Ho & Adams, 1995; Sonneveld & Welles, 2005). Sonneveld & Welles (2005) found for each 1 mS.cm^{-1} increase above 1.5 mS.cm^{-1} that Ca content decreased by 4 mmol Ca per kg of fruit dry matter and rapidly brought Ca below critical levels in tomato fruit.

Most producers counter salt accumulation by over irrigating and enforcing drainage (Olympios, 1999; Raviv *et al.*, 2004). This results in plants being fed up to 130% of their theoretical requirements to compensate for irrigation inaccuracies and to enforce drainage; the excess nutrient solution runs to waste with any other agrichemicals applied to the crop (Olympios, 1999). Such excessive application of water and fertiliser is no longer considered

57

acceptable because of increasing society awareness to environmental damage (Papadopolous *et al.*, 1999).

Only light intercepted by a crop can be used for photosynthesis and assimilate production, and this is influenced by leaf area index (LAI) (Papadopolous & Pararajasingham, 1997). LAI is a function of stem density, number of leaves per stem and individual leaf size (Heuvelink, 2005). At LAI between 2-3 $m^2.m^{-2}$ a tomato crop nears light saturation (90%) and optimal DM production rate (De Koning, 1996; Heuvelink *et al.*, 2005). Assimilate production is a determining factor of optimum fruit load and is governed by photosynthetic rate (De Koning, 1996; Heuvelink, 2005).

Stem densities must be adjusted according to prevailing light conditions, which will vary regionally and seasonally to ensure optimal marketable yield (De Koning, 1996). Plants grown in low light winter conditions have higher specific leaf area (SLA) compared to summer grown plants; Heuvelink (1995) reported SLA of 300-400 $cm^2.g^{-1}$ in autumn/winter and 175-250 $cm^2.g^{-1}$ in summer. Therefore, to achieve optimal LAI per area meter, stem densities under high light conditions, such as in summer, need to be increased (De Koning, 1996; Papadopolous & Pararajasingham, 1997). Also, under high light intensities, because of increased photosynthetic rate, the source: sink ratio can become disproportionately high in tomatoes (Nederhoff & Houter, 2009). This results in plants with short curled leaves which could be much more productive if the source: sink balance was restored (Nederhoff & Houter, 2009). Allowing an extra lateral to develop can restore the source: sink balance by increasing the fruit per m^2 (Nederhoff & Houter, 2009). For these reasons, commercial growers in Holland increase stem density from 2.3 $stems.m^{-2}$ in winter to 3.4 $stems.m^{-2}$ at the onset of spring by allowing extra side shoots to develop (Heuvelink *et al.*, 2005).

South African producers are faced with increasing cost of agricultural inputs and water scarcity. Through better understanding of the influence of EC on the uptake of individual macro elements more precise nutrient solutions could be formulated which could reduce the rate of salt accumulation, fertiliser application rates and environmental pollution without impacting on marketable yield. The management of fruit load and leaf area through stem pruning is a simple practice that could be used to increase productivity of tomatoes with minimal increase in inputs.

Protected cultivation offers the advantage of a longer growing season than field grown crops, and thus are able to supply when there are shortages in the market. Early yields, though only representing a portion of total yields, fetch higher prices per kilogram compared to later production and it is therefore imperative that early yields are maximised to ensure

58

rapid return on investment For these reasons, this study examined the effect of EC and stem pruning on tomato growth, early yield and shelf life.

2. Materials and methods

2.1 Location and cropping details

The experiments were conducted at Stellenbosch University's Welgevallen Experimental Farm, Western Cape, South Africa. Four week old tomato seedlings (*Lycopersicon esculentum* Mill. cv. MFH9343) were transplanted into 10L plastic bags filled with new coir on the 18th April 2011 in a plastic covered, unheated greenhouse with a pad and fan. Plants were fertigated through a drip irrigation system with a Steiner nutrient solution at two different concentrations (EC 1 and 2 mS.cm^{-1}) with fixed nutrient ratios. EC 1 mS.cm^{-1} nutrient solution composition in milliequivalents was : K$^+$: 3.5; Ca^{2+}: 4.5; Mg^{2+}: 2; NO$_3^-$: 6; PO$_4^{2-}$: 0.5; SO$_4^{2-}$: 3.5. Micronutrients were applied at the same rate for both macronutrient concentrations: Fe 1.68, Mn 0.4, Zn 0.2, Cu 0.03, B 0.5, Mo 0.05 mg/L. All plants received the same volume of irrigation water. Irrigation volume was adjusted to ensure drainage across all treatments. Plants were grown at an initial density of 2.5 plants/m^2, vertically trellised using twine and had side shoots removed on a weekly basis. Trusses were pruned to 4 fruit per truss.

2.2 Treatments and experimental design

The experiment used a factorial design layout with four randomised blocks (40 plants per block, 10 plants per plot). Two stem pruning treatments (single stem and double stem plants) were applied in combination with two nutrient solution concentrations (1 and 2 mS.cm^{-1}). Double stem plants were created by allowing a side shoot under the first truss to develop.

2.3 Measurements and analysis

Two randomly selected plants per treatment were destructively harvested at 1st truss flowering and at 5th truss flowering. Leaf area, number of leaves, number of leaves before 1st truss and dry mass of stem, fruit and leaves were measured. Specific leaf area (SLA) was calculated by dividing leaf area by dry leaf mass. Fresh plant material was dried for 48 hours at 80°C. At the 1st destructive harvest a homogenous dry leaf sample of all leaves was taken and analysed for nutritional content. At the 2nd destructive harvest, the 4th leaf from the top of the plant and the 8th leaf from the bottom of the plant were sampled separately, dried and

59

analysed for nutritional content. A high powdery mildew disease pressure prevented a 3rd destructive harvest because of the need to rogue out heavily infected leaves.

Total number of fruit, total yield, marketable fruit number, marketable yield and unmarketable yield per plant were recorded; average fruit weight was also calculated. Harvest was conducted once a week over a 1 month period from 30th August to 19th September. The focus of the study was to examine the effect of fertilisation and stem pruning on early yield hence the short harvest period. Cultivation unde. Percentage soluble solids (Brix) were also measured. Data was analysed using ANOVA, and means compared using Fischer's LSD (P<0.05) using the statistical software *Statistica 10*.

3. Results and discussion

3.1 1st Destructive harvest

Stem pruning had no effect on any of the measured parameters 43 days after transplant (DAT). But EC 2 mS.cm^{-1} plants produced a significantly higher total plant mass compared to EC 1 mS.cm^{-1} plants (Table 1). This was attributed to both a significantly higher leaf and stem dry weight. The EC 2 mS.cm-1 plant also produced a significantly higher leaf area compared to EC 1 mS.cm^{-1}, (52% higher). According to Table 1 this difference in LA is primarily the result of higher leaf dry matter production, resulting in bigger leaves, and not the difference in SLA. This can be seen in Figure 1, with EC 2 mS.cm^{-1} plants having noticeably larger leaves, resulting in a denser canopy.

Table 1. Total dry weight (TDW), leaf dry weight(LDW), stem dry weight (SDW), leaf area (LA) and specific leaf area(SLA) from the 1st destructive harvest at 1st flowering of tomatoes grown with different EC and stem pruning treatments, 43 days after transplant. Significant F test at P<0.05 (*) and P<0.01 (**) and non significant F test (NS)

	TDW (g)	LDW (g)	SDW (g)	LA (cm^2)	SLA (cm^2.g^{-1})
EC (E)					
1 mS.cm^{-1}	33.900	23.237	10.662	5348.813	232.899
2 mS.cm^{-1}	46.268	33.218	13.050	8146.938	246.814
	**	**	**	**	NS
Stem (S)	NS	NS	NS	NS	NS
1	41.243	29.431	11.812	6808.125	230.746
2	38.925	27.025	11.900	6687.625	248.967
	NS	NS	NS	NS	NS
ExS	NS	NS	NS	NS	NS

60

The leaf analyses results indicated the only significant difference between EC treatments related to N and P contents (Table 2). The EC 2 mS.cm^{-1} plants had 31.3 % and 59.3 % higher N and P leaf content respectively compared to EC 1 plants. The differences in growth between EC 1 mS.cm^{-1} and EC 2 mS.cm^{-1} plants could be explained by these differences in plant nutrition.

Table 2. Percentage dry mass of macro nutrients of pooled tomato leaf lamina and petiole at the 1st destructive harvest at 1st flowering of tomatoes grown with different EC and stem pruning treatments, 43 days after transplant at difference EC and stem pruning treatments. Significant F test at P<0.05 (*) and P<0.01 (**) and non significant F test (NS)

	% leaf content					
Element	N	P	K	Ca	Mg	S
EC (E)						
1 mS.cm^{-1}	3.239	0.702	6.1	3.665	0.763	0.651
2 mS.cm^{-1}	4.253	1.118	6.396	3.570	0.862	0.648
	**	**	NS	NS	NS	NS
Stem (S)						
1	3.845	0.875	6.267	3.679	0.833	0.646
2	3.647	0.945	6.229	3.556	0.791	0.653
	NS	NS	NS	NS	NS	NS
ExF	NS	NS	NS	NS	NS	NS

At mild P and N limitations it has been found that morphological changes in young vegetative tomato plants are more important than changes in physiology in explaining differences in relative growth rate (RGR) (De Groot *et al.*, 2001; 2002). Similarly, Tei *et al.* (2002) and Scholberg *et al.* (2000) found that reduction in photosynthetic area and light interception were the primary cause of reductions in plant growth resulting from N limitation, and that differences in plant radiation use efficiency (RUE) were only significant at severe N limitation.

Decreases in N and P supply increase dry matter partitioning to plant roots (De Groot *et al.* 2001; 2004), therefore differences in dry matter partitioning could explain the differences in dry mass and leaf area development between EC treatments. De Groot *et al.* (2001; 2002) found that SLA of plants decreased as N and P contents of young tomato plants leaves decreased, thus a small statistically insignificant difference in SLA could cumulatively over time have contributed to the difference in dry matter and leaf area development.

There were no significant differences in leaf contents of the other macro elements. This is in accordance with the findings of Sonneveld and Welles (2005) that relative cation concentrations are more important than absolute cation concentrations in determining plant

nutrient uptake. Also, it is important to note that these plants at sampling were still young and had no developing fruit (Figure 1).

Figure 1. Photos taken 34 days after transplant of greenhouse grown tomatoes at different EC and stem pruning treatments. Left three panes: Plants grown at 1 mS.cm^{-1}; right three panes: Plants grown at EC 2 mS.cm^{-1}.

3.2 2nd Destructive harvest

3.2.1 Plant growth and development

The 2nd destructive harvest 73 DAT investigated in more detail the differences in plant development compared to the 1st destructive harvest 43 DAT. Stem pruning significantly increased the truss number and leaf number in double stemmed plants compared to single stem plants, but had no significant effect on above ground DM production and leaf area (Table 3). The EC treatments significantly affected SLA, leaf area, leaf dry weight and fruit dry weight (Table 3). By 73 DAT the relative difference in leaf area between EC 1 mS.cm^{-1} and EC 2 mS.cm^{-1} plants had increased to 97.6% from 52.3% (Figure 2). This is attributed to an increase in the relative difference in SLA from 5.9% to 32.0%, and an increase in the relative difference in leaf mass from 43.9% to 54.1%. Therefore the most important reason for the increase in the difference in leaf area was the decrease in SLA of EC 1 mS.cm^{-1} compared to EC 2 mS.cm^{-1} plants from 43 DAT to 73 DAT. The EC 1 mS.cm^{-1} plants accumulated a significantly higher mass of fruit dry matter compared to EC 2 mS.cm^{-1} plants, indicating that the treatment affected partitioning patterns of the treated plants.
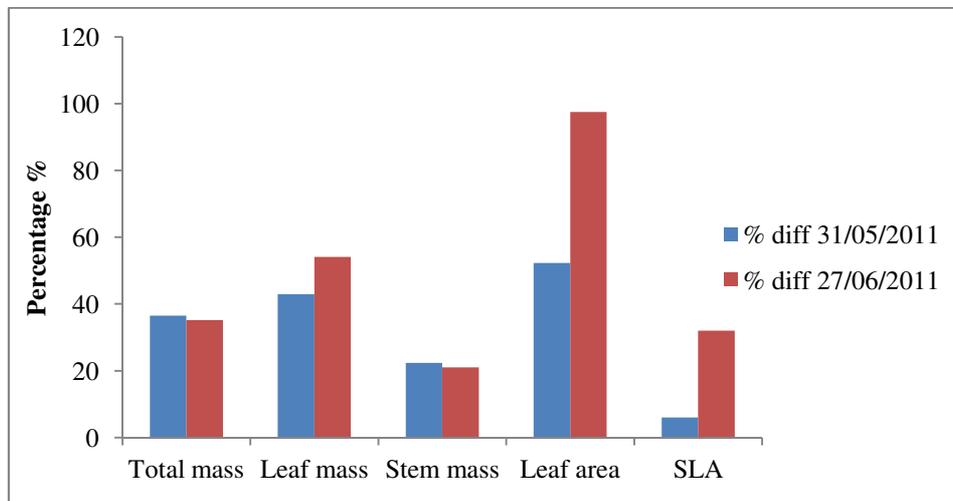
Figure 2. Relative % difference between EC 1 mS.cm^{-1} and EC 2 mS.cm^{-1} treated greenhouse grown tomato plants growth characteristics at 43 DAT and 73 DAT.

There was a 2 way interaction between EC and stem pruning for leaf number (Figure 3). There was no significant difference in leaf number between single stem plants grown at different ECs. This is expected since research has shown that temperature is the primary factor that determines leaf development in tomatoes, and not nutrition (Heuvelink, 2005).

63

Figure 3. Differences in leaf number between EC and stem pruning treatments of greenhouse grown tomatoes. Different symbols indicate a significant difference (P<0.05)

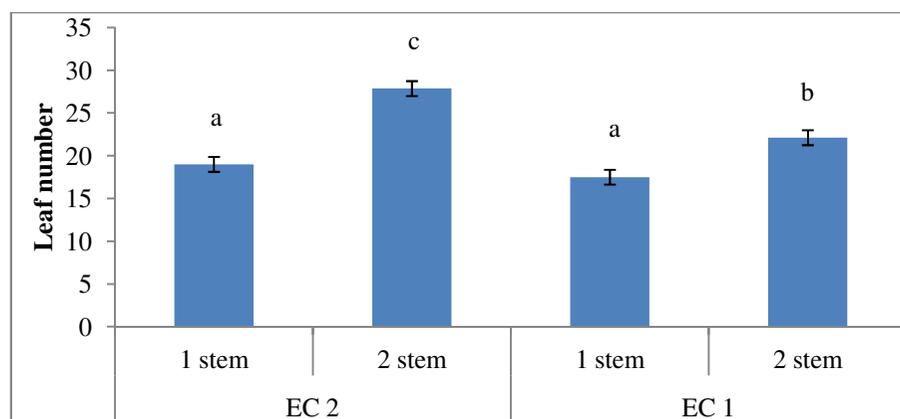**Table 3.** Total dry weight (TDW), leaf dry weight (LDW), stem dry weight (SDW), leaf area (LA) and specific leaf area (SLA) from 2nd destructive harvest at 5th flowering truss of tomatoes grown with different EC and stem pruning treatments, 73 days after transplant. Significant F test at P<0.05 (*) and P<0.01 (**) and non significant F test (NS)

	TDW(g)	LDW(g)	SDW(g)	LA(g)	FDW(g)	SLA (cm^2.g^{-1})	Number of Leaves.	Number of leaves prec. 1st truss	Number of trusses
EC (E)									
1 mS.cm^{-1}	82.181	48.760	27.856	8314.563	5.562	171.168	19.812	8.0625	4.437
2 mS.cm^{-1}	111.075	75.137	33.700	16425.440	2.237	225.973	23.437	8.125	5.500
	*	**	**	**	**	**	**		**
Stem (S)									
1	98.437	63.950	30.175	12245.5	4.312	190.786	18.250	8.1875	4.250
2	94.818	59.950	31.381	12494.5	3.487	206.355	25.000	8	5.687
	NS	NS	NS	NS	NS	NS	**		**
ExS	NS	NS	*	NS	NS	NS	*	*	NS

Double stem plants produced significantly higher leaf numbers compared to single stem plants, with double stem plants grown at EC 2 mS.cm^{-1} producing the highest number of leaves. There was no significant difference in leaf number preceding 1st truss on the side shoot (data not shown) between EC treatments, therefore the difference in leaf number between double stemmed EC treatments must have resulted from side shoot age since plants were subject to more or less the same temperatures; indeterminate tomatoes after initiating the first flower truss unfold 1 truss for every 3 leaves unfolded (Heuvelink, 2005). From this it can be deduced that differences in leaf number are related to differences in side shoot development; with EC 2 mS.cm^{-1} double stem plants developing side shoots earlier than EC 1 mS.cm^{-1} plants. This was also apparent in the trial with EC 2 mS.cm^{-1} plants requiring more frequent side shoot pruning compared to EC 1 mS.cm^{-1} plants.

Plants pruned to two stems produced more trusses than single stem plants. However, the significant difference in truss number related to EC wasn't expected, since leaf unfolding rate and truss unfolding rate are primarily controlled by temperature (Heuvelink, 2005). Therefore, differences in truss number should have mirrored differences in leaf number since truss appearance rate is roughly 1/3 of leaf appearance rate, unless there were differences in the number of leaves preceding the first truss. Even though there was significant difference in leaf number preceding the first truss on the plant stem (Table 3), these differences (<1) are not large enough to explain differences in truss number. The differences may also be a result of experimental error, for example, deciding when a truss should be counted or not counted. There was no significant effect of stem pruning on plant nutrition and plant yield in the short term; this may not be the case in the long term as fruit load will increase more rapidly on double stem plants.

Higher fertiliser applications rates appear to promote earlier side shoot formation in tomatoes. Pruning tomatoes to two stems increases truss number per plant without significantly increasing leaf area. Therefore it appears the greatest affect of stem pruning would be to increase fruit load. Stem pruning is used to increase fruit load to restore the source: sink balance in plants (De Koning, 1996). Stem pruning achieves this through a higher relative increase in generative sink strength compared to the relative increase in source strength from increased LAI; this not only increases overall partitioning to fruits but also reduces available assimilates per fruit (Nederhoff & Houter, 2009). Maintaining a high fruit load may result in maximum total yield, but marketable yield is likely to suffer because of reduced available assimilates per fruit resulting in smaller fruit which may be of lower grade or unmarketable (Heuvelink, 1997; Saĝlam & Yazgan, 1999). Also, if fruit load is too high it

65

can exhaust the plant, resulting in fruit and flower abortion and cyclic productivity (Papadopoulos, 1991; Heuvelink, 1997). Pruning salad tomatoes, such as MFH9343, to two stems could limit long term crop productivity, especially under the Western Cape's hot summer conditions, unless fruit load is carefully managed.

3.2.2 Nutrition

3.2.2.1 Nitrogen

Nitrogen levels were significantly higher in old and new leaf tissue in EC 2 compared to EC 1 plants (Table 4, Table 5). Leaf contents of N in the 4th youngest leaf and 8th oldest leaf were very similar, an indicator of N's high mobility within the plant (Table 4, Table 5). It can be seen in table 5 that N contents of plant leaves across all treatments declined from 43 DAT levels.

This decrease in leaf % N from 43 DAT to 73 DAT is probably caused by the development of fruit on the plants. Tomato fruit have been shown to be strong accumulators of N (Ward, 1964) and Voogt (1993) reported that up to 60.1% of total N taken by the plant is invested in the fruit. Tei *et al.* (2002) found that the decline in the fraction of N in field tomato leaves coincided with the increase in the fraction of N in fruits. De Groot *et al.* (2002) found a distinct curvilinear saturation type response of tomato SLA to increasing % leaf N content under low light conditions. Since this trial did take place under low light winter

Table 4. Percentage dry mass of macro nutrients of 4th tomato leaf lamina and petiole 2nd destructive harvest, 73 days after transplant of greenhouse grown tomatoes grown at different EC and stem pruning treatments. Significant F test at $P<0.05$ (*) and $P<0.01$ (**) and non significant F test (NS)

	% leaf content					
Element	**N**	**P**	**K**	**Ca**	**Mg**	**S**
EC (E)						
1 mS.cm^{-1}	2.817	0.557	2.616	2.18	0.423	0.288
2 mS.cm^{-1}	3.898	1.261	4.397	1.917	0.422	0.448
	**	**	**	*	NS	**
Stem (S)						
1	3.288	0.907	3.143	1.955	0.416	0.351
2	3.427	0.911	3.87	2.142	0.43	0.386
	NS	NS	NS	NS	NS	NS
ExS	NS	NS	NS	NS	NS	NS

66

Table 5. Percentage dry mass of macro nutrients of 8th tomato leaf lamina and petiole 2nd destructive harvest, 73 days after transplant. of greenhouse grown tomatoes grown at different EC and stem pruning treatments. Significant F test at P<0.05 (*) and P<0.01 (**) and non significant F test (NS)

Element	% content leaf content					
	N	P	K	Ca	Mg	S
EC (E)						
1 mS.cm^{-1}	2.99	0.6025	4.59625	4.31875	0.53125	0.64
2 mS.cm^{-1}	3.96375	1.8225	6.91375	5.34625	0.86	0.93375
	**	**	**	**	**	**
Stem (S)						
1	3.465	1.15	6.925	4.86	0.91	0.755
2	3.4	1.185	6.415	4.97	0.585	0.86
	NS	NS	NS	NS	NS	NS
ExF	NS	NS	NS	NS	NS	NS

conditions, this could explain why a similar reduction in N content resulted in a much greater reduction in SLA in EC 1 mS.cm^{-1} plants compared to EC 2 mS.cm^{-1} plants. Mild chlorosis of the older leaves indicated the beginning of N limitation in EC 1 plants (Figure 5); this resulted in EC 1 plants becoming generative, forming small, hard erect leaves and limiting canopy development (Figure 6).

As has been mentioned, EC 1 mS.cm^{-1} plants had invested significantly higher quantities of dry matter into fruit compared to EC 2 mS.cm^{-1} plants (Table 4). This can also be seen in Figure 6, with the visible differences in the size of developing fruits on the trusses. This difference could be explained by the differences in N nutrition between of EC 1 mS.cm^{-1} and EC 2 mS.cm^{-1} plants; high N fertilisation has been found to reduce initial partitioning of assimilates to fruits and favour the partitioning of dry matter to vegetative growth (Scholberg *et al.*, 2000).

3.2.2.2 Phosphorus

Phosphorus levels were significantly higher in old and new leaf tissue in EC 2 mS.cm^{-1} compared to EC 1 mS.cm^{-1} plants. P levels accumulated in EC 2 mS.cm^{-1} grown plants, and decreased in EC 1 mS.cm^{-1} plants leaves compared to 43 DAT. De Groot *et al.* (2001) found SLA increased in a saturation response type function in response to increasing % leaf P content. This could explain why a similar reduction in P content resulted in a much greater reduction in SLA in EC 1 mS.cm^{-1} plants compared to EC 2 mS.cm^{-1} plants, since this trial did take place under low light winter conditions. This reduction is probably attributed to competition with fruit, as tomato fruit can take up large quantities of P, with up to 60.2% of

Figure 4. A comparison of the effects of two EC treatments on the growth and fruit development of greenhouse grown tomatoes at different stages after transplanting. Left three panes are plants grown at 1 mS.cm^{-1}, from top to bottom: plants 59 days after transplant; 1st truss 59 days after transplant; 1st truss 98 days after transplant. Right three panes are plants grown at EC 2 mS.cm^{-1}, from top to bottom: plants 59 days after transplant; 1st truss 59 days after transplant; 1st truss 98 days after transplant.

Figure 5. Images of 1 mS.cm^{-1} greenhouse grown plants at different stages after transplanting, from left to right: (i) 59 DAT N deficiency, chlorosis older leaves; (ii) 131 DAT, P deficiency, purple colouration leaf veins;(iii) 131 DAT, P deficiency, purple leaf colouration.

Figure 6. Images of greenhouse grown plants grown at two different EC treatments at different stages after transplanting. Top panes: EC 1 mS.cm^{-1} grown plants; EC 1 mS.cm^{-1} grown plants. Bottom panes EC 2 mS.cm^{-1} grown plants; EC 2 mS.cm^{-1} grown plants.

the total P taken up being partitioned to the fruit (Ward, 1964; Voogt, 1993). Fujita *et al.* (2003) also found that P deficiency in tomato encouraged partitioning of C, N and P into the fruit at the cost of vegetative organs growth. The strong reduction of SLA in EC 1 mS.cm^{-1} plant may therefore be an interaction between N and P nutrition.

Nutrient solution levels of 30-50mg.L^{-1} of P are often recommended in hydroponic production, but there is increasing evidence that P concentrations of 10-20mg.L^{-1} are sufficient for optimal plant growth (Benton-Jones, 2005). Findings of this trial were in agreement. The EC 2 mS.cm^{-1} plants % leaf P in new and old leaves were higher than pooled leaf P content at 43 DAT, whereas EC 1 mS.cm^{-1} plants % P leaf content were lower than pooled leaf P content at 43 DAT. This indicated accumulation in EC 2 mS.cm^{-1} plants, and depletion in EC 1 mS.cm^{-1} plants of P. Based on this it would seem that 15mg.L^{-1} P (EC 1 mS.cm^{-1} grown plants) is insufficient to sustain vegetative and fruit growth. This became apparent later in the trial with EC 1 mS.cm^{-1} plants exhibiting symptoms of phosphorus deficiency as purple colouration of older leaves (Figure 5) and stunting of the new leaves due to reduced SLA (Figure 6). The amount of 30mg L^{-1} P (EC 2 mS.cm^{-1} plants) seemed to be in excess of plant requirements, even during winter when low root temperatures are normally limiting to P uptake; P levels were in excess of 1%, levels actually considered toxic to plant growth (Benton-Jones, 2005).

These extreme % P levels could be attributed to the low light winter conditions; De Groot *et al.* (2001) found that % leaf P levels for the same P application rates were higher in plants grown under low light conditions compared to those grown under high light conditions. De Groot *et al.* (2001) also showed the relationship between RGR and changing% P content at high and low light were parallel. Therefore under low light conditions lower P application rates than under high light conditions are necessary to achieve % P contents associated with optimal growth.

3.2.2.3 Potassium

Potassium levels in young and mature leaf tissue were significantly lower in EC 1 mS.cm^{-1} plants compared to EC 2 mS.cm^{-1} plants 73 DAT (Table 4; Table 5). Potassium leaf content had declined in both old and new leaf tissue in EC 1 mS.cm^{-1} plants compared to pooled leaf samples taken 43 DAT. In the EC 2 plants K leaf content remained similar in old leaf tissues and decreased in new leaf tissues compared to pooled levels. The reason for no significant difference in K at 43 DAT may be that growth was only vegetative and there were no fruit developing on the plant.

The greater reduction in leaf contents of K in EC 1 mS.cm^{-1} plants could be explained by the lowering feeding rates of K. Sonneveld & Welles (2005) found that K uptake did tend to increase with increasing EC in cucumbers, peppers and tomatoes. Furthermore, the EC 1 mS.cm^{-1} plants K supply rate may have been insufficient to meet the high K demands of the developing fruit. Voogt (1993) found that up to 65.6% of plant K is invested in the fruit, similarly, Balliu and Ibro (2002) found that about 70% of plant K is invested in fruits, with only 16% being invested in the tomato plants leaves. Voogt (1993) showed that K uptake increased rapidly in tomatoes from first flowering to the 10th flowering truss, reaching a maximum uptake concentration of almost 12 mol.L^{-1}. Therefore, the lower feeding rate of K in EC 1 mS.cm^{-1} plants could explain the more aggressive decline in leaf K as K is preferentially partitioned to the fruit and K is mobilised from the leaves to fruit. Potassium deficient fruit are prone to blotchy ripening, grey wall, poor colouration and are not fleshy (Balliu and Ibro, 2002; Peet, 2009). In this trial fruit disorders weren't a problem since harvest was restricted to a 1 month period, but they may manifest later in the growing the season,

3.2.2.4 Sulphur

The EC 2 mS.cm^{-1} plants had significantly higher levels of S in both old and new tissues compared to EC 1 mS.cm^{-1} plants. According Benton-Jones (2005) S levels of between 0.15-0.5% are sufficient for plant growth. There were no S deficiency symptoms throughout the trial. S leaf contents were higher in old tissue, indicating a tendency to accumulate in older tissues.

3.2.2.5 Magnesium

EC 1 mS.cm^{-1} plants and EC 2 mS.cm^{-1} plants did not differ significantly in Mg content in young leaf tissue (Table 4). But EC 2 mS.cm^{-1} plants did have significantly higher leaf Mg contents in the old leaf tissue compared to EC 1 mS.cm^{-1} plants. The EC 2 mS.cm^{-1} treated plants Mg levels of old leaves were higher than a pooled sample from 43 DAT, whereas Mg of EC 1 mS.cm^{-1} treated plants were lower (Table 5). Despite the differences between treatments there were no Mg deficiency symptoms at the time of destructive harvest. Relatively low DM leaf contents of Mg are associated with maximum yield in tomatoes compared to other elements, with levels 0.3-0.5% being deemed sufficient for high productivity (Ward and Miller, 1969; Peet, 2005).

Magnesium seemed to be accumulating in older leaf tissues of EC 2 plants, whereas in EC 1 mS.cm^{-1} plants Mg seems to be redistributed from the older leaves to other parts of the plant. Magnesium is highly mobile within the plants and as a result deficiencies occur first in the older leaves as an interveinal chlorosis giving a herringbone appearance (Benton-Jones, 2005; Rice, 2007). It would therefore be expected that Mg deficiency would eventually be seen in the EC 1 mS.cm^{-1} plants, but this was difficult to discern as the lower leaves were already chlorotic from N deficiency. Interestingly, as the trial progressed, the EC 2 mS.cm^{-1} plants started to show Mg deficiency symptoms in the middle leaves. Sonneveld & Voogt (1991) found Ca stress decreased Ca concentration in growing slabs and resulted in enhanced Mg absorption and a more even distribution of Mg throughout the plants leaves, whereas constant Ca supply resulted in reduced Mg absorption and lower Ca levels in plants middle leaves compared to older and younger leaves. The high application rates of Ca in EC 2 mS.cm^{-1} plants may have resulted in Ca accumulating in the growing media; this would have may have reduced Mg uptake since mutual ratios of nutrients in the root environment are a major determinant in plant nutrient uptake (Sonneveld & Voogt, 2009). The EC 2 mS.cm^{-1} plant may have then needed to export Mg from the lower leaves to meet the Mg demands of the new growing tissues because of the suppressed uptake, thus resulting in deficiency.

3.2.2.6 Calcium

Calcium levels were slightly but significantly lower in EC 2 mS.cm^{-1} plants compared to EC 1 mS.cm^{-1} plants in the young mature leaf sample (Table 4). In the old mature leaf sample Ca levels were significantly higher in EC 2 mS.cm^{-1} compared to EC 1 mS.cm^{-1} plants (Table 5). Ca is known to accumulate in transpiring tissue because it is phloem immobile and moves passively with transpiration stream within the plant (Pilbeam & Morley, 2007). For this reason Ca tends to accumulate in leaf tissue and a constant supply of Ca from the shoots via the xylem is necessary to meet the nutritional requirements of new growth (Barke & Menary, 1971). This accumulation effect could be seen in both EC 1 mS.cm^{-1} and EC 2 mS.cm^{-1} treatments, with leaf contents of older leaf samples being much higher than levels of the pooled leaf sample 43 DAT and the young leaf samples 73 DAT (Table 3 ; Table 4).

Plants grown at higher EC are more prone to salt accumulation in the root zone and increasing root zone EC has been shown to reduce Ca uptake (Sonneveld & Welles, 2005). The rate of salt accumulation in the root zone is affected by factors such as temperature and humidity. Because the trial was conducted over the much cooler and more humid autumn/winter period of the year in the Western Cape salt accumulation would not have been very

72

aggressive. This could explain why the difference in young mature leaf tissue was small. Calcium content levels for both treatments were still within the range (1-2%) seen as adequate for sustained plant growth, supported by the fact that the calcium deficiency related physiological disorder blossom-end rot was non-existent in the experiment (Peet, 2005).

3.3 Early yield

The EC 1 mS.cm^{-1} plants producing a significantly higher total yield per plant; this was because of significantly heavier average fruit weight since there was no significant difference in fruit number (Table 6). EC 1 mS.cm^{-1} plants also produced significantly higher marketable yield as a result of significantly more fruit and significantly heavier fruit (Table 6). EC 2 mS.cm^{-1} plants produced a significantly higher % mass unmarketable fruit compared to EC 1 mS.cm^{-1} plants, 47% versus 17%, because of high numbers of small parthenocarpic fruit (Figure 7).

The EC 2 mS.cm^{-1} plants appeared to suffer from poor pollination problems which can be seen by the small parthenocarpic fruit (Figure 7). Powdery mildew was more prevalent in the dense EC 2 mS.cm^{-1} plants canopy, due to poor ventilation and high humidity. This may have been because of excessive nitrogen application in early plant growth. Excessive N application has been found, particularly under low light conditions, to result in overly vegetative plants prone to disease, poor flower development, fruit set and size (Benton-Jones, 2005). This may have been exacerbated by the cold winter conditions.

The sparse canopy of EC 1 plants would have created a relatively warmer, drier, well ventilated micro climate that was less suitable for powdery mildew and more favourable for pollination and fertilisation, resulting in good even truss set and large fruit with many seeds (Figure 4; Figure 7). These fruit set problems may not be as severe in summer when high light intensities and high temperatures result in drier, warmer conditions. Also, harsher conditions will tend to suppress vegetative growth, decrease SLA and steer the plants to favour generative growth (Heuvelink, 1995; Nederhoff & Houter, 2009). Therefore, under summer conditions the negative effects of over application of N may not be as severe as in winter and higher application rates of N and P may be required to maintain the balance between vegetative and generative growth compared to winter.

Table 6. Total yield and marketable yield from 30/08/2011 - 19/09/2011 of greenhouse grown tomatoes grown at different EC and Stem pruning treatments. Significant F test at P<0.05 (*) and P<0.01 (**) and non significant F test (NS)

	Total yield per plant			Marketable yield per plant				
	Mass (kg)	**No.**	**Mean fruit mass (kg)**	**Mass (kg)**	**No.**	**Mean fruit mass (kg)**	**Brix**	**% Unmarketable**
EC (E)								
1 mS.cm⁻¹	0.844	8.104	0.104	0.699	5.258	0.132	5.453	17.348
2 mS.cm⁻¹	0.533	8.687	0.061	0.304	2.479	0.119	5.715	42.725
	*	NS	**	**	**	*	NS	**
Stem (S)								
1	0.778	9.375	0.084	0.569	4.333	0.130	5.587	29.086
2	0.599	7.416	0.082	0.436	3.404	0.122	5.453	30.987
	NS	NS	NS	NS	NS	NS	NS	NS
ExS	NS	NS	NS	NS	NS	NS	NS	NS

Figure 7. Fruit of greenhouse grown tomatoes grown at different EC treatments. Top left and right: Larger EC 1 mS.cm⁻¹ fruit, seeds clearly visible; Bottom: EC 2 mS.cm⁻¹ small parthenocarpic fruit with few or no visible seeds.

74

4. Conclusion

Producers aiming to increase rate of canopy establishment, whether it be to improve micro climate, shade fruit or ensure optimal dry matter production, may not find that pruning to two stems is a suitable strategy. Stem pruning should probably be viewed as a technique to manipulate fruit load. But, pruning to multiple stems will probably require more stringent management of fruit load, at least for larger fruited cultivars, otherwise plants may become overly generative and long term productivity limited.

EC affects plant development significantly, and it is believed differences in growth are primarily related to N and P nutrition. High fertiliser application rates result in overly vegetative plants that have reduced early yield and increased disease pressure, whereas lower fertilisation application rates during early tomato growth improve flower pollination, fruit set and early yields. It is important to increase N, P and K application at the onset of fruit development, otherwise leaf contents rapidly decline. As a result vegetative growth will suffer and the plant will be unable to sustain its canopy; this will likely result in reduced productivity later in the season. High application rates of fertiliser had little effect on Ca and Mg uptake in young plant tissue, and only relatively low application rates may be needed to meet tomato plant requirements for sustained growth and productivity.

5. References

BALLIU, A. & IBRO, V., 2002. Influence of different levels of potassium fertiliser on growth, yield and ascorbic acid content of tomato fruit grown in non-heated greenhouse. *Acta Hort*. 579, 385-388.

BARKE, R.E. & MENARY, R.C.,1971. Calcium nutrition of the tomato as influenced by total salts and ammonium nutrition.*Aust. J. Exp. Agric. Anim. Husb.* 11, 562-569.

BENTON-JONES, J., 2005. Hydroponics: a practical guide for the soilless grower (2nd Ed.). CRC press, Boca Raton, Florida.

DE KONING, N.M., 1996. Model predictions of optimum shoot density and truss size in glasshouse tomato. *Acta Hort*. 417, 99-106.

DE GROOT, C.C, MARCELIS, L.F.M., VAN DEN BOOGAARD, R. & LAMBERS, H., 2004. Response of growth of tomato to phosphorus and nitrogen nutrition. *Acta Hort*. 633, 357-364.

DE GROOT, C.C, MARCELIS, L.F.M., VAN DEN BOOGAARD, R. & LAMBERS, H., 2002. Interactive effects of nitrogen and irradiance on growth and partitioning of dry mass and nitrogen in young tomato plants. *Funct. Plant Biol.* 29, 1319-1328.

DE GROOT, C.C, MARCELIS, L.F.M., VAN DEN BOOGAARD, R. & LAMBERS, H. 2001. Growth and dry-mass partitioning in tomato as affected by phosphorus nutrition and light. *Plant Cell Environ.* 24, 1309-1317.

ELIA, A., SERIO, F., PARENTE, A., SANTAMARIA, P. & RODRIGUEZ, G.R., 2001. Electrical conductivity of nutrient solution, plant growth and fruit quality of soilless grown tomato. *Acta Hort*. 559, 503-508.

FUJITA, K., OKADA, M., LEI, K., ITO, J., OHKURA, K., ADU-GYAMFI, J.J. & MOHAPATRA, P.K., 2003. Effect of P-deficiency on photoassimilate partitioning and rhythmic changes in fruit and stem diameter of tomato (*Lycopersicon esculentum*) during fruit growth. *J. Exp. Bot.* 54, 2519-2528.

HEUVELINK, E., 1995. Growth, development and yield of a tomato crop: periodic destructive measurements in a greenhouse. *Sci. Hortic.* 61, 77-99.

HEUVELINK, E., 1997. Effect of fruit load on dry matter partitioning in T omato. *Sci. Hortic.* 69, 51-59.

HEUVELINK, E., 2005. Developmental processes. *In*: Heuvelink, E. (ed). *Tomatoes*. CABI publishing, Wallingford, UK. p53-84.

HEUVELINK, E., BAKKER, M.J., ELINGS, A., KAARSEMAKER,R. & MARCELIS, L.F.M., 2005. Effect of leaf area on tomato yield. *Acta Hort*. 691, 43-.50.

HO, L.C & ADAMS, P., 1995. Nutrient uptake and distribution in relation to crop quality. *Acta Hort*. 396, 33-44.

KLARING, H., 2001. Strategies to control water and nutrient supplies to greenhouse crops. a review. *Agronomie* 21, 311-321.

LI, Y.L., STANGHELLINI, C. & CHALLA, H. 2001. Effect of electrical conductivity and transpiration on production of greenhouse tomato. *Sci. Hortic.* 88, 11-29.

NEDERHOFF, E. & HOUTER, B., 2009. Plant management for generative or vegetative steering. *Practical Hydroponics & Greenhouses*, 51-54, March/April.

OLYMPIOS, C.M., 1999. Overview of Soilless Culture: Advantages, Constraints and Perspectives for its Use in Mediterranean Countries. *Options Mediterraneennes* 31, 307-324.

PAPADOPOULOS, A.P., 1991. Growing greenhouse tomatoes in soil and in soilless media. Agriculture Canada, Ottawa.

PAPADOPOULOS, A.P. & PARARAJASINGHAM, S., 1997. The influence of plant spacing on light interception and use in greenhouse tomato (Lycopersicon esculentum Mill.): A review. *Sci. Hortic.* 69, 1-29.

PAPADOPOULOS, A. P., HAO, X., TU, J. C. & J. ZHENG., 1999. Tomato production in open or closed rockwool culture systems with NFT or rockwool nutrient feedings. *Acta Hort*. 481, 89-96.

PEET, M. M., 2005. Irrigation and Fertilization. *In*: Heuvelink, E. (ed). *Tomatoes*. CABI publishing, Wallingford, UK. p171-198.

PEET, M.M., 2009. Physiological disorders in tomato fruit development. *Acta Hort*. 821, 151-160.

PILBEAM, D.J. & MORLEY, P.S., 2007. Calcium. *In:* Barker, A.V. & Pilbeam, D.J (eds.). Handbook of Plant Nutrition. CRC Press, Boca Raton. p121-144.

RAVIV. M, WALLACH, R. & BLOM, T.J., 2004.The effect of physical properties of soilless media on plant performance – a review. *Acta Hort*. 644, 251-259.

RICE, R.W., 2007. The physiological role of minerals in the plant. I*n*: Datnoff, L.E., Elmer, W.H. & Huber, D.M. (eds.). Mineral Nutrition and Plant Disease. APS Press, Minnesota, USA. p9-31.

SAĜLAM, N & YAZGAN, A., 1999. Effect of fruit number per truss on yield and quality in tomato. *Acta Hort.* 486, 261-264.

SCHOLBERG, J. MCNEAL, B.L., BOOTE, K.J., JONES, J.W., LOCASCIO, S.J. & OLSON, S.M., 2000. Nitrogen stress effects on growth and nitrogen accumulation by field-grown tomato. *Agron. J.* 92, 159-167.

SCHWARZ, D. & KUCHENBUCH, R., 1998. Water uptake by tomato plants grown in closed hydroponic systems dependent on the EC-level. *Acta Hort*. 458, 323-328.

SONNEVELD, C. & VOOGT, W., 1991. Effects of Ca-stress on blossom-end rot and Mg-deficiency in rockwool grown tomato. *Acta Hort*. 294, 81-88.

SONNEVELD, C. & VOOGT, W., 2001. Chemical analysis in substrate systems and hydroponics – use and interpretation. *Acta Hort*. 548, 247-259.

SONNEVELD, C. & VOOGT, W., 2009. Plant nutrition of greenhouse crops. Springer Science, New York.

SONNEVELD, C. & WELLES, G.W.H., 1988. Yield and quality of rockwool-grown tomatoes as affected by variations in EC-value and climatic conditions. *Plant Soil* 111, 37-42.

SONNEVELD, C. & WELLES, G.W.H., 2005. Cation concentrations of plant tissues of fruit-vegetable crops as affected by the EC of the external nutrient solution and by humidity. *Acta Hort*. 697, 377-386.

TEI, F., BENINCASA, P. & GUIDUCCI, M., 2002. Effect of N availability on growth, N uptake, light interception and photosynthetic activity in processing tomato. *Acta Hort*. 571, 209-216

VOOGT, W., 1993. Nutrient uptake of year round tomato crop. *Acta Hort*. 339, 99-112.

WARD,G.M., 1964. Greenhouse tomato nutrition – a growth analysis study. *Plant Soil* 21, 125-133.

WARD, G.M. & MILLER, M.J., 1969. Magnesium deficiency in greenhouse tomatoes. *Can. J. Plant Sci*. 49, 53-59.

Chapter 5
Summary and General Conclusions

South African producers are faced with increasing scarcity of water and rising input costs. This makes the high water use efficiency, high fertiliser use efficiency, and high yields of hydroponic production an attractive cultivation method. However, the high investment costs require that the farming operation be as efficient as possible. This has a twofold benefit, faster returns on investment and reduced environmental pollution. A series of experiments were performed at Welgevallen experimental farm at Stellenbosch University from 2010-2011 to investigate the effect of growing media, pruning and fertiliser concentration on growth, yield and nutrition of hydroponic grown tomatoes.

1.1. Growing Media

Growing media was found to affect nutritional status of young plants, particularly at low fertiliser feeding rates. Organic media, such as coir and sawdust, reduced available N early in the tomato crop life, and tomatoes grown in coir had reduced Ca uptake compared to plants grown in sand and sawdust. Also, growing media appeared to affect water uptake; this may be accredited to greater growth or differences in water holding capacity. It is important to understand the chemical and physical characteristics of growing media, and that growing media cannot be managed in the same manner. Producers' fertilisation and irrigation practices should be adjusted based upon growing media properties. This could potentially reduce fertiliser application requirements, improve productivity and reduce fertigation overdrain.

1.2. Fertilisation

During warm weather conditions, such as in summer, it seems possible to grow plants at lower fertiliser concentrations. No differences in early yield were found for the different fertiliser application during the spring/ summer trial. However, during the cool low light winter months lower fertiliser applications may limit long term productivity as nutrient uptake is limited by the cooler temperatures. Also, over fertilisation early in plant growth during the low light conditions of winter causes overly leafy plants with poor fruit set and reduced early yields compared to plants with reduced fertilisation. But low fertiliser application during fruit set cause a reduction in leaf area and the ability of the plant to

79

maintain its canopy; this could reduce long term plant productivity. Differences in plant growth and morphology seem particularly sensitive to N and P application rates. It was also found that absolute increases in nutrient solution concentration resulted in relatively small increases in plant nutritional status, particularly in the case of Mg and Ca. Relatively low feeding rates of Ca and Mg appear sufficient to meet the needs of tomatoes.

Fertiliser programs should therefore be adjusted based upon individual elements and not just absolute concentration to meet the needs of the plants as the growing season progresses. For example, relatively low applications of all macro elements are necessary during early vegetative plant growth up to the 1st truss. But thereafter, with increasing fruit load, fertilisation of N, P and K should be increased to ensure sustained canopy development and fruit growth. This would allow sustained high quality productivity of a tomato crop and better pest and disease management. Not to mention potential savings in fertiliser because only the concentration of certain elements will be increased, as opposed to an absolute increase. Also fertilisation programs composition should be adjusted based upon climatic conditions as this seems to result in quite different plant growth responses. Furthermore, lower fertiliser concentrations do appear to reduce percentage soluble solids in fruit, but whether this difference is even perceivable by consumers or can be eliminated with better production practices is unknown.

1.3. Pruning

Fruit pruning increases average weight of marketable fruit, but doesn't significantly influence marketable yield in a short spring tomato crop pruned to two stems. However, this may not be the case for a longer tomato crop which is able to maintain a healthy effective leaf area, or a single stemmed tomato crop. Fruit pruning also reduces the quantity of unmarketable small fruit. Leaf pruning has no effect on tomato yield, but this was probably because LAI was maintained sufficiently high, and pruning of 'young' leaves took place too late to influence vegetative: generative sink balance.

Stem pruning doesn't affect early growth and yield of tomatoes, but does increase development rate of trusses. Pruning to two stems may in the longer term result in higher fruit loads, which will probably require more stringent management of fruit load, at least for larger fruited cultivars, otherwise plants may become overly generative and long term productivity limited. Stem pruning should probably be viewed as a technique to increase fruit load and not a method of increasing canopy development.

80

1.4 Conclusion

Irrigation and fertilisation procedures should be adjusted for difference in growing media properties. Seasonal variation in climatic growing conditions and changes in plant growth should be accounted for in the formulation of fertilisation programs to prevent waste of fertiliser and ensure optimal productivity. Management of plant growth potential and fruit load could be an effective manner to ensure sustained productivity, but these benefits do not seem to extend to the short term. Pruning practices are not necessary for short tomato crops, but for longer crops may be invaluable in ensuring consistent high quality production.