

**YIELD AND QUALITY RESPONSE OF
HYDROPONICALLY GROWN TOMATOES
(*Lycopersicon esculentum* Mill.) TO NITROGEN SOURCE
AND GROWTH MEDIUM**

by

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DECLARATION

I, the undersigned, hereby declare that the work contained in this dissertation is my original work and has not previously in its entirety or in part been submitted at any university for a degree.

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ABSTRACT

Pine sawdust-shavings (*Pinus* spp.) is at present a very popular soilless substrate in South African greenhouses. Growers use fresh pine sawdust-shavings as a substrate, which is biologically highly unstable. The greenhouse industry is looking at alternative organic substrates such as coco peat, which already went through a decomposition process and is more stable. A biological inactive substrate such as sand was included to compare microorganism activity with organic substrates. The main objective of this study was to compare the growth, yield and quality of hydroponically grown tomatoes in response to different growth mediums in combination with nitrogen source, irrigation frequency, period of substrate use and liming. In general the drainage water pH declined with an increase in NH_4^+ -N in the nutrient solution. Low pH values in the drainage water, especially when coco peat was used, had a detrimental effect on marketable yield. The drainage water pH of pine sawdust-shavings increased during the growing season when 100 % NO_3^- -N was used. Due to the higher cation exchange capacity of coco peat, the drainage water electrical conductivity tends to increase more rapidly than with pine sawdust-shavings, during conditions with high temperatures and when insufficient irrigation volumes per irrigation cycle is applied. As expected the drainage water NO_3^- -N content decreased as the NH_4^+ -N content increased in the nutrient solution. Pine sawdust-shavings recorded a much lower NO_3^- -N and NH_4^+ -N content than sand and coco peat and thus supports the hypothesis that microbiological activity is higher in pine sawdust-shavings, especially in the second season of substrate use. Coco peat produced the highest number of marketable fruit and yield per plant, followed by pine sawdust-shavings and sand in the first season of substrate use. The number of marketable fruit and yield decreased with an increase in NH_4^+ -N content in the nutrient solution during production in warmer, summer conditions. Contrary to these findings, production in cooler, winter conditions recorded high yields when only NO_3^- -N or 80% NO_3^- -N : 20% NH_4^+ -N was applied. The unmarketable yield increased with an increase in NH_4^+ -N in the nutrient solution. Visual evaluations showed that blossom-end rot (BER) was the main contributor to unmarketable yield. Increasing levels of NO_3^- -N as nitrogen source in the nutrient solution, reduced weight loss and increased the loss of fruit firmness of tomatoes during storage. Increasing levels of NO_3^- -N also increased fruit pH and reduced total titratable acidity. Coco peat produced fruit with a higher pH than pine sawdust-shavings. An increase in irrigation frequency affected fruit firmness negatively when coco peat was used as substrate. Different irrigation and fertigation practices are needed for different growth mediums and management needs to be adapted according to the growing season (winter vs. summer).

UITTREKSEL

'n Mengsel van dennesaagsels en -skaafsels (*Pinus* spp.) word tans deur Suid-Afrikaanse kweekhuisprodusente gebruik as grondlose groeimedium. Hierdie groeimedium word nie vooraf gekomposteer nie en is dus biologies onstabiel. Die kweekhuisindustrie ondersoek tans die gebruik van alternatiewe, gekomposteerde en stabiele organiese groeimediums soos kokosveen. 'n Biologies onaktiewe groeimedium soos sand is ook ingesluit om met organiese groeimediums te kan vergelyk. Die hoof doelwit van die studie was om plantontwikkeling, opbrengs en kwaliteit van hidroponies geproduseerde tamaties te evalueer in verskillende groeimediums en in kombinasie met stikstofbron-verhouding, periode van groeimedium gebruik, besproeiingsfrekwensie en bekalking. Oor die algemeen het die pH in die dreinaat gedurende die groeiseisoen toegeneem soos die NH_4^+ -N inhoud verhoog het in die voedingsoplossing. Lae pH waardes in die dreinaat, veral waar kokosveen gebruik was, het 'n nadelige effek op bemarkbare opbrengs gehad. Die pH in die dreinaat van dennesaagsels en -skaafsels het gedurende die groeiseisoen toegeneem met die gebruik van 100% NO_3^- -N in die voedingsoplossing. Die elektriese geleiding in die dreinaat van kokosveen neem vinniger toe gedurende toestande waarin hoë temperature en onder besproeiing voorkom, as in dreinaat van dennesaagsels en -skaafsels. Die NO_3^- -N inhoud in die dreinaat het soos verwag afgeneem soos die NH_4^+ -N inhoud in die voedingsoplossing toegeneem het. 'n Baie laer NO_3^- -N en NH_4^+ -N inhoud is by dennesaagsels en -skaafsels aangeteken wat dus die hipotese ondersteun dat mikrobiologiese aktiwiteit, veral in die tweede seisoen van gebruik, hoër is in dennesaagsels en -skaafsels as in sand en kokosveen. Kokosveen het die hoogste aantal bemarkbare vrugte en massa per plant geproduseer, gevolg deur dennesaagsels en -skaafsels en sand. Die aantal bemarkbare vrugte en opbrengs het verlaag met 'n verhoging in NH_4^+ -N in die voedingsoplossing gedurende warm, somer toestande. In teenstelling met vorige resultate is gevind dat 100% NO_3^- -N of 80% NO_3^- -N : 20% NH_4^+ -N hoë opbrengste gelewer het gedurende koeler, winter toestande. Die onbemarkbare opbrengs het verhoog met hoër NH_4^+ -N vlakke. Visuele waarnemings het aangedui dat blom-end verrotting die grootste bydrae tot onbemarkbare opbrengs gelewer het. 'n Verhoging in NO_3^- -N vlakke het massaverlies beperk en die verlies in fermheid verhoog gedurende opberging. Hoër NO_3^- -N vlakke het ook die pH van vrugte verhoog en die totale titreerbare suur verlaag. Kokosveen het vrugte met 'n hoër pH as dennesaagsels en -skaafsels geproduseer. 'n Toename in besproeiingsfrekwensie het vrug fermheid negatief beïnvloed wanneer kokosveen as groeimedium gebruik was. Verskillende besproeiings- en voedingspraktyke word benodig vir verskillende groeimediums en bestuur van die groeimediums moet aangepas word by klimaatstoestande gedurende die spesifieke produksieseisoen.

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INDEX

Chapter 1

Motivation and objective

	Page
1.1 Motivation	1
1.2 Objective	2
1.3 Reference	3

Chapter 2

Literature overview

	Page
2.1 Development of hydroponics and problem areas	4
2.2 Growth media	6
2.2.1 Coco peat	6
2.2.2 Wood waste products	10
2.2.3 Sand	14
2.3 Plant nutrition in hydroponics	15
2.3.1 Nitrogen nutrition in hydroponics systems	16
2.3.1.1 Factors affecting nitrate acquisition	16
2.3.1.2 Factors affecting ammonium acquisition	19
2.3.2 Mineral nutrition of tomatoes	21
2.3.2.1 Nitrogen source and calcium	21
2.3.2.2 Chemical composition of tomato leave tissue	24
2.3.3 Pre-plant liming of growth media	25
2.4 Irrigation frequency and quantity in hydroponics systems	26
2.5 Effect of cultural practices and environmental factors on tomato fruit quality	28
2.5.1 Fruit quality	28
2.5.2 Cultural practices	30
2.5.2.1 Hydroponics and soilless substrates	30
2.5.2.2 Nutrient supply	31

2.5.2.3	Irrigation	35
2.5.3	Environmental factors	36
2.5.3.1	Light intensity	36
2.5.3.2	Temperature	36
2.5.3.3	Vapour pressure deficit	36
2.6	Conclusion	37
2.7	References	37

Chapter 3

Influence of substrate, nitrogen source and irrigation frequency on yield and quality of greenhouse grown tomatoes (*Lycopersicon esculentum* Mill.)

	Page
Abstract	60
Introduction	61
Materials and methods	62
Results and discussion	67
Conclusions	80
References	80

Chapter 4

Influence of substrate, nitrogen source, irrigation frequency and period of substrate use on yield and quality of greenhouse grown tomatoes (*Lycopersicon esculentum* Mill.)

	Page
Abstract	85
Introduction	86
Materials and methods	88
Results and discussion	93
Conclusions	119
References	120

Chapter 5

Influence of substrate, nitrogen source and pre-plant application of lime on yield and quality of greenhouse grown tomatoes (*Lycopersicon esculentum* Mill.)

	Page
Abstract	125
Introduction	126
Materials and methods	128
Results and discussion	137
Conclusions	155
References	156

Chapter 6

Influence of substrate, nitrogen source, irrigation frequency, period of substrate use and pre-plant application of lime on fruit quality of greenhouse grown tomatoes (*Lycopersicon esculentum* Mill.)

	Page
Abstract	161
Introduction	162
Materials and methods	166
Results and discussion	172
Conclusions	197
References	199

Chapter 7

Summary

	Page
7.1 Objectives of study and experiments conducted	208
7.2 Results	208
7.3 Conclusions	212

CHAPTER 1

Motivation and objective

1.1 Motivation

Commercial development of hydroponically grown crops in the Republic of South Africa started during the early seventies and in 1973 several claims of the successful use of hydroponics were made, but due to a lack of an effective advisory service and no research support, producers soon ran into many problems. Because most crops were planted in soil, bacterial cancer (*Corynebacterium michiganense*) in tomatoes and eelworms in cucumbers caused almost a cessation in growing activities (Maree, 1994).

To overcome these problems, growers changed to bag culture using vermiculite as growth medium, but it was found to be very expensive and the sterilization of the media difficult and not very successful. Due to the abundance of pine trees (*Pinus* spp.) in South Africa, wood waste products such as pine bark, pine sawdust and pine shavings were evaluated for use as a biodegradable growth medium. Fresh pine bark and pine sawdust-shavings soon became more popular due to various problems encountered, mostly nutritional, when composted pine bark were used. Experiments indicated that fresh material could be used for more than one crop. Differences in pine sawdust-shavings batches had relative little effect on yield. For these reasons pine sawdust-shavings became the most popular growth medium for hydroponically grown crops in the Republic of South Africa (Maree, 1994).

Pine sawdust-shavings mixtures are at present still the most popular soilless growth medium in South African greenhouses. However, expansion in the greenhouse industry and a decline in pine plantations may in the near future cause a shortage of pine sawdust-shavings. Other problems in regard to this growth medium are: (i) Inconsistency in particle size distribution (texture) between different consignments of pine sawdust-shavings that may influence the water holding capacity and thus the frequency of irrigation needed and (ii) the decomposition of pine sawdust-shavings

during the growing season, especially in the second season of use (6 to 10 months after planting) when nitrates are used as sole source of nitrogen. Decomposition of pine sawdust-shavings may alter the physical properties of the substrate. Alternatives such as coco peat (coir) are well known for its quality and durability as a growth medium, but is relatively expensive compared to pine sawdust-shavings. However coco peat has much better physical, chemical and biological properties than pine sawdust-shavings. Because of different biological properties, crops grown in coco peat may have different fertigation requirements.

1.2 Objective

The main objective of this study was to compare the growth, yield and quality of hydroponically grown tomatoes in response to different growth mediums in combination with nitrogen source, irrigation frequency and liming.

This objective was accomplished as follow:

- 1.2.1 A thorough literature survey on growth media, plant nutrition and irrigation in hydroponics, pre-plant liming of growth media and the effect of cultural practices and environmental factors on tomato fruit yield and quality as presented in Chapter 2;
- 1.2.2 An experiment conducted to study the effect of substrate, nitrogen source and irrigation frequency on yield and quality of greenhouse grown tomatoes as presented in Chapter 3;
- 1.2.3 An experiment conducted to study the effect of substrate, nitrogen source, irrigation frequency and period of substrate use on yield and quality of greenhouse grown tomatoes as presented in Chapter 4;
- 1.2.4 An experiment conducted to study the effect of substrate, nitrogen source and pre-plant application of lime on yield and quality of greenhouse grown tomatoes as presented in Chapter 5;
- 1.2.5 Experiments conducted to study the effect of substrate, nitrogen source, irrigation frequency and pre-plant application of lime on fruit quality of greenhouse grown tomatoes as presented in Chapter 6;

1.3 Reference

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

CHAPTER 2

Literature overview

The literature overview will provide information on the different growth media used in the experiments, plant nutrition and more specifically ammonium and nitrate nitrogen nutrition, irrigation scheduling in hydroponics, the liming of growth media and the effect of cultural practices and environmental factors on tomato fruit yield and quality.

2.1 Development of hydroponics and problem areas

Soilless culture is the cultivation of crops in media without soil. Reasons like the difficulty and cost of controlling soilborn pests and diseases, soil salinity, lack of fertile soil, water shortages etc., have lead to the development of soilless substrates. A number of growth media have been used as substrates for soilless culture, of which the most popular are: rockwool, peat, perlite, vermiculite, pine sawdust, bark chips, sand, gravel, pumic, polyurethane mats, water and mixtures of the above (Olympios, 1992). Verdonck, de Vleeschauwer & Penninck (1983) were probably the first to mention the horticultural use of coir in the scientific literature.

The origins of soilless culture goes back to the 17th century when Boyle (1666) attempted to grow plants in vials containing nothing but water. He reported that spearmint (*Raphanus aquatica*) survived for nine months in these vials. A few years later Woodward (1699) grew spearmint in water to which a small quantity of soil had been added. However, it was not until the 19th century that Liebig (1803 – 73) and Knop & Sachs (around 1859) initiated the systematic study of plant nutrition (Cooper, 1979).

The first scientist to promote the commercial potential of liquid culture was Gericke (1929). Originally Gericke (1929) defined his method as “aquaculture”. However since this term was already in use for the culture of aquatic plants and animals, other terms were quickly introduced, namely “water culture” and “solution culture”. Finally

the term “hydroponics” was proposed, based on the Greek hydro (water) and ponos (labour) (Olympios, 1992).

Main problem areas in hydroponic systems are aeration and fertilization while different crops may also respond differently. Adequate supply of oxygen to the root zone is of vital importance to the success of any cultivation, and in soilless systems this aspect is crucial. One way of overcoming the difficulties of oxygenation was the development of the nutrient film technique (NFT) and circulating nutrient solutions. Another way was the development of aggregate systems in which although all the nutrients are supplied to the plant with the water, there is nevertheless an inert rooting medium which provides both support for the plant and a means of oxygenation/aeration of the roots (Olympios, 1992). High content of available water and adequate air supply have therefore been considered as the most important physical characteristics required for container media in order to achieve optimal growth. Water availability to plant roots is strongly related to the hydraulic conductivity characteristics of the medium, which, in porous materials, drops dramatically with reduced water content (Raviv *et al.*, 2002).

The main factor that distinguishes fertilization management of hydroponically and soil-grown plants is the limited volume of medium in which the plants grow, which means a smaller buffer capacity for pH and solution composition and limited nutrient reserves. The limited volume available for root growth also results in decreased root size and increased root density, causing higher competition among roots and a larger effect of root activity on the rhizosphere. Further more, most growth media possess negative permanently and/or temporary charged surfaces, which may have a major effect on the chemical reactions taking place in the rhizosphere as well as on the availability of applied cations and their uptake efficiency (Raviv *et al.*, 2002).

Due to the low buffer capacity, nutrient ratios such as the ammonium/nitrate ratio in the nutrient solution also became very important and have been studied extensively (Mengel & Kirkby, 1978). It is now well established that nitrate nutrition stimulates organic anion synthesis and cation accumulation, while ammonium nutrition often results in a detrimental effect on crop growth, yield and quality due to impaired cation uptake and metabolism (Feigin *et al.*, 1980). High amounts of ammonium nitrogen in

the nutrient solution may for example reduce calcium uptake by the plant, thus resulting in calcium deficiency symptoms (Schnitzler & Gruda, 2002) and an increase in the development of blossom-end rot in tomatoes (Pill, Lambeth & Hinckley, 1978; Massey & Windsor, 1980).

The ultimate agronomic challenge in most hydroponic systems are to ensure maximum foliar growth, biomass production and yield with high quality, with a volume-restricted rooting system. The growth medium has several functions such as to supply oxygen, water and nutrients to the roots; to control the microflora, particularly to shelter the roots against soil-born pathogens and to have no phytotoxic affects. Any mineral, organic or artificial material can be used as growth medium on condition that those previous roles could be fulfilled (Lemaire, 1995), but their biological, physical and chemical characteristics will determine their efficiency. Different growth media may also have different watering and fertilization requirements. In this regard the nitrate/ammonium ratio may be very important, while requirements for maximum growth and quality of different crops must also be met.

2.2 Growth media

2.2.1 Coco peat

2.2.1.1 Origin and production

Coconut (*Cocos nucifera* L.) is grown commercially in Sri Lanka, The Philippines, Indonesia, Southern India and Latin America, and coco peat is the main by-product (Yau & Murphy, 2000). These countries are therefore the main source of coir for use in horticulture (Raviv *et al.*, 2002). Coir is the fibre that constitutes the mesocarp or husk of the coconut fruit and which is used in the manufacture of ropes, matting and similar products. The husk contains 60 – 70% pith tissue and the remainder is mainly fibre. Coir processing leaves a large quantity of dust and short fibres as waste product (coir dust or pith). The dust is more stable while the fibres tend to undergo secondary decomposition in the growth medium (Noguera *et al.*, 1997; Raviv *et al.*, 2002).

Production of both fractions involves a period of storage in heaps where they undergo aerobic composting. During composting the hemicellulose, cellulose and to a lesser extent lignin components are decomposed, causing the C/N ratio to decrease. These changes are accompanied by an increase in cation exchange capacity and humic acid content (Yau & Murphy, 2000). Composting also results in modified physical properties such as total porosity so that the water holding capacity increases. Usually, then the easily available water increases and air-filled porosity decreases (Mbah & Odili, 1998).

After decomposing the stable material is dehydrated and compressed into a compact form (brick) for easy transportation. With the addition of water coir expands to 5 to 9 times its compressed volume. Coir is not a uniform material. Different sources and different production procedures result in a large variability of end products (Evans, Konduru & Stamps, 1996; Prasad, 1997; Konduru, Evans & Stamps, 1999).

2.2.1.2 Main applications

Coir can serve either as a stand-alone medium or as an ingredient in a mix for the cultivation of vegetables and cut flowers, as well as for potted plants, tree saplings and young foliage plants. It is now widely accepted as a peat substitute, showing growth in sales comparable to that of peat moss (Meerow, 1994). Coir can also serve as a growth medium for cuttings under mist or in high humidity chambers. Coir dust has been claimed to enhance rooting due to the presence of root-promoting substances (Raviv *et al.*, 2002).

2.2.1.3 Physical characteristics

Coir dust is a lightweight material, having a bulk density of 0.04 – 0.08 g.cm⁻³ (Evans *et al.*, 1996). Noguera *et al.* (1997) reported more or less the same findings (0.06 – 0.08 g.cm⁻³). However, Noguera, Abad & Noguera (2000) reported that the bulk density of 13 different coir samples varied between 0.03 – 0.09 g.cm⁻³. The differences in bulk density can be attributed to differences in particle size distribution. Variations in the extraction process of coconut husk and screening of the coconut waste are responsible for these differences.

The total porosity of coir dust is in the range of 86 – 94% and the air filled porosity 9 – 14%. Coir fibre has distinctly different characteristics; with the total porosity around 98% and the air filled porosity around 70% (Lemaire *et al.*, 1998). Coir dust is according to Prasad (1997) characterized by relatively high easily available water (35%). He also suggested that predetermined levels of air filled porosity and easily available water could be obtained by mixing different proportions of coir dust and fibre. A distinct positive property of coir dust is its relatively high elasticity and resistance to compression and height loss over time, as compared to other organic media, such as white sphagnum peat and wood chips (Wever & Leeuwen, 1995; Argo & Biernbaum, 1996).

2.2.1.4 Chemical and biological characteristics

Crude coir is rich in Na and Cl, which may damage plants. Noguera *et al.* (2000) reported that the Na and Cl content of different coir waste sources varied between 25 to 389 and 28 to 2006 mg.l⁻¹ respectively. During the production stage, the coir is washed, and Ca and Mg are usually added to facilitate Na removal and to provide nutrients. Ca and Mg nutrition in coir waste-based media can be improved by adding dolomitic lime. On the other hand the content of P and K in coir is very high (44 mg.l⁻¹ P and 807 mg.l⁻¹ K), which should be taken into account in any fertilization program. The cation exchange capacity of 13 different coir wastes ranged from 320 – 950 mmol.c.kg⁻¹ and their C/N ratio averaged 117 (Evans *et al.*, 1996; Noguera *et al.*, 2000). The CEC is influenced by the source of coir waste. Noguera *et al.* (1997) reported that coir waste from Mexico and Sri Lanka had a CEC of 730 and 1170 mmol.c.kg⁻¹ respectively.

Using the Nitrogen Drawdown Index (NDI), Handreck (1993) indicated a slight N-immobilization in coir dust, but not in coir-based media, with a conventional fertilization program (Noguera *et al.*, 2000). Prasad (1997) reported that N-retention varies considerably from moderately high, to high (100 – 120 mg N.l⁻¹). These results were obtained in an experiment where coir dust was irrigated with a nutrient solution containing 140 mg N.l⁻¹ and the results indicate that coir dust, which has not aged adequately, could retain a high degree of soluble nitrogen.

Generally coir dust has a high carbon content of about 48% and is low in nitrogen (0.34%) resulting in a high C/N ratio of about 143 (Yau & Murphy, 2000). These high C/N ratios are confirmed by results from Noguera *et al.* (1997) and Noguera *et al.* (2000). C/N ratios of 105 and 117 were obtained in these studies. The high C/N ratio of coir dust is comparable to that of sawdust with a ratio of 125 and wheat straw of 120 to 150 (Yau & Murphy, 2000). These high C/N ratios could cause the immobilization of soluble nitrogen (Noguera *et al.*, 1997; Noguera *et al.*, 2000). An important part of carbon in coir waste is in the form of lignin, which are resistant to microbial decomposition. The lignin, cellulose and hemicellulose content of coir waste vary between 35 – 54, 23 – 43 and 3 – 12 % dry matter respectively (Noguera *et al.*, 2000). The C/N ratio is a very good indicator of the biostability of coir. When organic matter is composting, the C/N ratio decreases up to a value, which remains stable but variable with the kind of product. The higher the C/N ratio, the slower the decaying process will take place. Organic materials with high lignin content have higher biostability than those with hemicellulose and cellulose (Lemaire, 1997). The C/N ratio of coir dust can easily be reduced with the addition of nitrogen and a mixture of micro-fungi. This will hasten the biodegradation process and reduce the C/N ratio from 143 to about 30 after 3 months. The composted coir dust will have a higher humic acid content than raw coir dust and the CEC will also improve from about 190 to 250 mmol_c.kg⁻¹. During the process of biodegradation the hemicellulose and cellulose content decreases significantly (Yau & Murphy, 2000).

Decomposition changes the physical and chemical properties of organic substrates. Shadhidul Islam *et al.* (2002) reported that the gravimetric water-holding capacity of coconut coir increased by 25% during the growing period. As a result the bulk density also increased from 0.12 to 0.17 g.cm⁻³. Decomposition also increases the CEC of organic materials. Potassium levels decreased and Ca and Mg levels increased over time. Therefore K leaching and Ca and Mg absorption were high in new organic substrates probably due to the initial inorganic elemental composition and the CEC of coir (Shinohara *et al.*, 1999). It is to be expected that exchangeable K and Na will be desorbed due to Ca and/or Mg added by fertilization (Verhagen, 1999). These effects almost disappeared by use (Shinohara *et al.*, 1999). Verhagen (1999) indicated that

coir dust materials contain high concentrations of K, Na, Ca and Mg on the adsorption complex.

Noguera *et al.* (2000) reported that the pH of coir waste was slightly acidic (4.90 – 6.14) and close to the optimal range of pH for plant growing. Salinity readings varied between 0.4 and 6 mS.cm⁻¹ in the saturated media extract. The latter could adversely affect the growth of salt-sensitive plants.

Konduru *et al.* (1999) reported that chemical properties of 11 different coconut husk sources varied significantly. The pH and electrical conductivities were significantly different among husk sources and ranged from 5.9 to 6.9 and 1.2 to 2.8 mS.cm⁻¹, respectively. The NH₄⁺, NO₃⁻, Ca and Mg levels did not differ significantly among husk sources and ranged from 0.2 to 1.8, 0.2 to 0.9, 2.9 to 7.3, and non-detectable to 4.6 ppm, respectively. The levels of Na, K and Cl were significantly different among husk sources and ranged from 23 to 88, 126 to 236, and 304 to 704 ppm, respectively. Coir dust, produced by screening of waste grade coir through a 3, 6 or 13 mm mesh, had a significantly different fibre content compared to unscreened waste grade coir. Unscreened coir waste had more fibre, lower bulk density, lower water filled pore space and lower water-holding capacity. Unscreened coir waste also had a higher total pore space and air filled pore space, but no significant difference between the bulk densities, total pore space, air filled pore space, and water filled pore space and water-holding capacity of the 3, 6 and 13 mm screen sizes were found.

2.2.2 Wood waste products

2.2.2.1 Origin and production

Uncomposted sawdust and wood chips or wood shavings (collectively defined as wood waste) are cheap and readily available materials, resulting from the wood industry in most parts of the world. Wood fibre can also be specially produced and impregnated with nitrogen, to reduce subsequent N deficiency due to immobilization during the growth period (Gruda & Schnitzler, 1999).

Sawdust alone or in mixtures with sand, has been used successfully for cucumber production. A mixture containing 25% or more sand, or using a 2.0 cm layer of sterilized sand on top of the sawdust, or using moderately fine sawdust with a good portion of shavings, helps to ensure more even moisture distribution. Sawdust mainly from *Pinus pinaster* and *Pinus radiata*, but also from other woods are being used. Apart from being a relatively inexpensive substrate it is also effective and can be used for two crops without the need for sterilization (Olympios, 1992).

2.2.2.2 Applications

Fresh wood waste is rarely used as a stand-alone growth medium, although it may serve as a rooting medium for cuttings. Usually it forms a constituent (normally less than 50%) in mixtures (Raviv *et al.*, 2002). An unequivocal outlet for wood waste is its use as bulking agent in the composting of high moisture content organic wastes, such as sewage sludge and animal manure. Wood waste may be either added as an absorbent to the animal house and/or admixed with manure or sludge after collection and prior to composting (Flynn, Wood & Guertal, 1995). Due to the abundance of *Pinus* sp. in South Africa, fresh pine sawdust and shavings are used as stand-alone substrate for the production of tomatoes, cucumbers and sweet peppers (Maree, 1994).

2.2.2.3 Physical and chemical characteristics

Based on many years of research, Poole, Conover & Joiner (1981) recommended that the proportion of sawdust in the growing medium of foliage plants should not exceed 20%. Industrially processed, N-impregnated wood fibre is, however, acceptable and showed good results (Gruda & Schnitzler, 1997).

The use of wood waste as a constituent of growth media has led to highly variable results. In some cases a high proportion of fresh sawdust in the medium resulted in good plant performance (Haynes & Goh, 1977; Sawan, Eissa & Abou-Hadid, 1999). In other cases, rather poor results were obtained (Hicklenton, 1983). Nevertheless, in spite of the additional incurred costs, it is highly desirable to use composted wood wastes, for the following reasons: Moisture, temperature and nutrient conditions within a growth medium are favourable to the biological decomposition of wood

wastes. Unlike bark, wood wastes originate from the inner parts of the tree and are less decay resistant. Their lignin content is lower and C/N ratio is higher than bark. In fact, Goh & Haynes (1977) found extremely high C/N ratios (e.g. 6138). As a result, both nitrogen and oxygen consumption by decomposing microorganisms are higher than those of bark (although soft woods immobilize much less nitrogen than hardwoods). This consumption may lead to severe deficiencies or even anoxia in wood waste-containing media. Sharman & Whitehouse (1993), along with other researchers, have demonstrated nitrogen immobilization in media containing fresh wood wastes. Prasad (1980) found that aged sawdust generally retained less nitrogen than fresh sawdust. He also found that wood shavings retained more nitrogen than sawdust, possibly due to the higher content of younger woody material, which retains nitrogen more strongly. Indirect evidence suggested that even oxygen might be deficient when growing plants in fresh sawdust (Bowen, 1983).

Immobilization of nitrogen can cause nutritional imbalances in young seedlings grown in organic substrates, particularly with wood fibre. Usually N-supply is the main limiting factor for plant growth in unimpregnated wood fibre substrates, as it was also reported for other substrates having a wide C/N ratio. The main problem is obviously the temporary and initial fixation of inorganic N-compounds into the body substances of microorganisms during a process known as N-immobilization. Gruda & Schnitzler (1997) reported that N-immobilization in N-impregnated wood fibre was lower than in unimpregnated wood fibre. Nitrogen was applied at a rate of 40 mg per pot from which 16 and 25 mg per pot was immobilized respectively. Nitrogen immobilization can be compensated for by additional nitrogen application, but the extra cost of fertilization must be taken into account. In some cases immobilization of other nutrients, such as phosphorous should also be considered (Handreck, 1996).

The physical properties of fresh wood wastes are not ideal for a high quality growth medium: wood wastes have a very high (42%) air filled porosity and very low (3.8%) water holding capacity (Goh & Haynes, 1977; Haynes & Goh, 1978). In many cases wood wastes showed marked phytotoxicity, primarily due to the release of phenolic compounds (Politycka, Wojcik-Wojtkowiak & Pudelski, 1985). All the above drawbacks can be corrected to a large extent by proper composting. Nitrogen immobilization is greatly reduced; the ratio between air filled porosity and water

holding capacity changes towards a higher water holding capacity, while air filled porosity still remains within the optimal range (Mbah & Odili, 1998) and most phytotoxicity disappears (Worrall, 1978).

Research has shown that pine fibre substrate consist out of 15% hemicellulose, which is easily degradable by microorganisms, 46% or less readily digestible cellulose and 26% hardly decomposable lignin. Respiration and CO₂ curves prove beyond any doubt the high activity of microorganisms in pine fibre (Ghoos, 1993). In wood fibre substrates microorganisms consume nitrates and proportionally emit hydroxyl ions into the nutrient solution, thus raising the pH (Vlassak *et al.*, 1991). Microorganisms in wood fibre substrates do not only fix nitrates, but also phosphorus and calcium till the 12th week after planting. Naturally this dramatically reduces the EC. During this period a microbial biomass is built up as well, constituting on its own a decomposable substrate that will release the immobilized nutrient elements. This phenomenon is apparent from week 10 to 12 after planting (Benoit & Ceustermans, 1995a).

Lemaire, Dartigues & Rivière (1989) reported that the EC, CEC and buffer capacity of wood waste products are low. In 1995, Lemaire confirmed that the CEC of wood fibres are very low (10 eq.m⁻³) compared to other substrates. Chemical analysis indicated that during the first 6 weeks of rooting the EC, nitrates, phosphates, calcium, and the minor elements, iron, manganese, copper and boron were low in wood fibre substrates. From the 7th week onwards the chemical analysis indicated stabilization of the mineral content. The pH, potassium, chlorine, sulphate and bicarbonate levels increased during the first 7 weeks. This is due to a reaction of wood fibre. In order to adjust the pH part of the nitrogen could be administered as ammonium during the first 6 weeks of rooting. During the first week of rooting 10% ammonium can be administered. After that the ammonium can be reduced to only 5% of the total nitrogen (Benoit & Ceustermans, 1995b).

The nutrition of plants grown in wood waste-containing media has been thoroughly investigated by several researchers. The monumental contribution of Handreck (1992a; 1992b) in this respect is not to be ignored. In particular the development of the nitrogen drawdown index (NDI) is of importance in assessing the nutritional

requirements of plants grown in media with a high N-immobilization capacity, such as wood wastes.

2.2.3 Sand

2.2.3.1 Origin

Sand is the coarse fraction of soils. It is defined by the International Society of Soil Sciences as particles above 0.02 mm in diameter, and it is further separated into: (i) coarse sand, 0.2 to 2.0 mm, and (ii) fine sand, 0.02 to 0.2 mm. Coarse sand is preferred as a substrate. Pure sand is widely used in deserts and coastal plains because it is a cheap, local, natural source. As a natural deposit the particle size distribution is often not constant. The required depth of the sand layer depends on the range of particle diameter. The finer the sand, the deeper the required layer of sand to avoid water logging and poor aeration. Sand is also used as a component of various growth media mixtures, usually forming the heaviest constituent (Raviv *et al.*, 2002).

2.2.3.2 Physical characteristics

The bulk density of sand is high relative to other growth substances, 1.48 and 1.80 g.cm⁻³ for fine and coarse sand, respectively. The total porosity is relatively low, 0.45 to 0.30 for fine and coarse sand, respectively, and the water content at saturation is somewhat lower, 0.39 to 0.27, respectively. Sand has a narrow pore size distribution, so the small pore fraction retains almost a constant water volume over increasing suction from 0 to 10 cm water (coarse sand) or 0 to 20 cm water (fine sand). A further increase in water suction results in a steep decline in water content (Wever, van Leeuwen & van der Meer, 1997). Bunt (1991) reported that the mean oxygen diffusion rate in the profile of a fine sand bed was 10 to 100 times lower than that of peat, perlite, redwood bark and different mixtures. The saturated hydraulic conductivity of coarse and medium sand is relatively high, 5.1 and 7.1 cm.min⁻¹, respectively. However, the unsaturated hydraulic conductivity of coarse and medium sand reduced sharply as the water suction increase above 10 and 20 cm, respectively (Raviv *et al.*, 2002).

2.2.3.3 Chemical characteristics

Quartz (SiO_2) is the most common component of the sand fraction in soils, because, after feldspars, it is the second most common mineral in the earth's crust, and it is highly resistant to weathering. Sand has no CEC (Lemaire, 1995). Quartz density is high, 2.6 to 2.65 g.m^{-3} , with a relative low specific surface, 2 $\text{m}^2.\text{g}^{-1}$. Quartz is a stable mineral with a low solubility of 3 to 7 mg Si.l^{-1} , independent of pH in the range of 2.5 to 9.0. It is one of the purist minerals known with a very low substitution of Si by Al, Fe and other trace elements. Thus, the charge deficiency that plays a major role in the physical-chemical activity of other soil minerals is very low in Quartz (Raviv *et al.*, 2002).

2.3 Plant nutrition in hydroponics

Wood waste products (made from *Pinus* sp.) are from the inner part of the tree, contain less lignin and have a higher C/N ratio than bark and are therefore less decay resistant (Goh & Haynes, 1977). Microorganism activity in substrates with a high C/N ratio tends to immobilise the available nitrogen and therefore can create a nitrogen deficiency in the growing plant (Lemaire, 1995). Moreover, the relatively fast decomposition rate of wood fibre also leads to a reduction of pore volume (compaction); particle size alteration; a decrease in air content; change in the gaseous phase composition because of CO_2 production; an increase in water content, cation exchange capacity, salinity due to mineralization and an increase of pH-value (Lemaire, 1995; Roeber & Leinfelder, 1997). The cation exchange capacity and buffer capacity of wood fibre products are very low (Lemaire *et al.*, 1989). Compared to French brown peat (200-400 eq.m^{-3}) and fresh ground pine bark (95 eq.m^{-3}), wood fibre products only have a cation exchange capacity of 10 eq.m^{-3} . Sand has a cation exchange capacity of 0 eq.m^{-3} . Ammonium is the only nitrogen source that can settle on the colloidal anion (Lemaire, 1995).

2.3.1 Nitrogen nutrition in hydroponics systems

Mengel & Kirkby (1978) studied the effect of the ammonium/nitrate ratio in the nutrient solution on plant growth extensively. Since then it has been established that nitrate nutrition stimulates organic anion synthesis and cation accumulation. On the other hand ammonium nutrition often results in a detrimental effect on crop growth, yield and quality due to impaired cation uptake and metabolism (Feigin *et al.*, 1980). Moreover, nitrate was successfully used as a sole source of nitrogen in re-circulating nutrient solutions (Cooper, 1977). However, the combination of ammonium and nitrate as nitrogen source in re-circulating nutrient solutions is attracting much attention, since the ammonium/nitrate ratio can be used in controlling the pH of the nutrient solution, which tends to rise markedly when only nitrate is used. The tomato plant is sensitive towards nitrogen nutrition, and adverse effects of ammonium on its growth have been reported (Pill & Lambeth, 1977). However, some authors indicated that the detrimental effects of ammonium on growth were alleviated by the addition of dolomite (de Claassen & Wilcox, 1974) or calcium carbonate (Pierpont & Minotti, 1977), which buffered the pH of the nutrient solution to near neutral.

Nitrification is defined as the oxidation of ammonium to nitrate and is generally mediated by the activities of two groups of chemoautotrophic bacteria. One group, the NH_4^+ oxidizers, initiates the process with the formation of NO_2^- , while another group, the NO_2^- oxidizers, completes the process by converting NO_2^- to NO_3^- . The nitrification process is sensitive to pH, water, and temperature and has an absolute requirement for oxygen (Lang & Elliott, 1991). Under unfavourable environmental conditions for plant growth, such as an acidic growth media, or under cool, cloudy days, low rates of nitrification may lead to ammonium toxicity (Barker & Mills, 1980).

2.3.1.1 Factors affecting nitrate acquisition

The uptake mechanism for nitrate appears to be very complex and to be altered by a number of environmental factors, which affect the external supply of nitrate and the physiological and biochemical processes operating within plants.

Presence and concentration of nitrate

Nitrate uptake increases sharply with increases in the external supply of nitrate and when the supply is high, nitrates will be absorbed in excess of the needs of the plant and will accumulate internally. The external supply of nitrate is probably the most important environmental factor controlling the accumulation of nitrates in plants (Wright & Davidson, 1964; Maynard *et al.*, 1976).

Other ions

Nitrate absorption may be affected by the presence of other ions in the environment of the root. Normally, one considers that ions with similar charge and chemical properties might compete in absorption by plants; but, on the other hand, ion absorption is very selective, and little interference is encountered by similar ions at low concentrations (Elzam & Epstein, 1965; Elzam & Hodges, 1967). However, in the system of complex kinetics at higher concentrations of ions, ion absorption is generally competitive and this phenomenon may occur in nutrient solutions. Nitrate absorption, nevertheless, appears to be influenced little by similar ions such as chloride, bromide or sulphate (Rao & Rains, 1976), but cations such as calcium, potassium and ammonium affect nitrate uptake significantly (Minotti, Williams & Jackson, 1969a; 1969b; Rao & Rains, 1976). Increasing the supply of calcium or potassium generally accelerates the rate of nitrate uptake, whereas ammonium ions have an inhibitory effect. The effect of cations, like calcium, on nitrate uptake may be to counter the negative charges on the roots' cell walls so that nitrate ions may migrate more closely to the plasmalemma and its uptake sites than they could in the absence of the ions (Elzam & Epstein, 1965).

pH

The uptake of nitrates is sensitive to the external hydrogen ion concentration. Above pH 6, nitrate uptake decreases (Rao & Rains, 1976). High acidity does not affect nitrate uptake until the pH falls below 4.5 (Minotti *et al.*, 1969a). Rao & Rains (1976) observed no decline in nitrate uptake at pH values as low as 4.0.

Light

The effect of light on nitrate acquisition may be related to the supplying of photosynthates to provide energy for nitrate uptake. A continual supply of energy appears to be essential for maintenance of nitrate uptake (Barker & Mills, 1980).

Nitrate reduction and its assimilation into organic compounds are closely related to photosynthesis in green plants (Huffaker and Rains, 1978; Schrader, 1978). Nitrate reductase is activated by light (Beever & Hageman, 1972; Jordan & Huffaker, 1972). However, only short periods of illumination is needed for activation (Jones & Sheard, 1975). Nitrate reductase is postulated as having both retention and transport functions (Butz & Jackson, 1977). Therefore, activation of nitrate reductase through the mobilization of inducers or by a general stimulation of protein synthesis would enhance nitrate uptake if the absorption and reduction systems coincided (Travis & Key, 1971).

Effect of carbon dioxide

Reduction of nitrate requires the presence of carbon dioxide, as well as light and nitrate, for nitrate reductase activity is diminished in carbon dioxide-free air (Klepper, Flesher & Hageman, 1971). On the other hand, nitrate uptake has been shown to be greater in the absence of carbon dioxide than in its presence (Neyra & Hageman, 1974; Huffaker & Rains, 1978). The effect of carbon dioxide on nitrate uptake is greater at high light intensities than low light intensities (Huffaker & Rains, 1978). The inhibitory effect of carbon dioxide may be due to the competition of carbon dioxide reduction with nitrate uptake for energy or reducing power generated by light or due to stomatal closure in the presence of carbon dioxide. The latter effect results in lessening of transpiration and water flux through the roots to the shoots (Barker & Mills, 1980).

2.3.1.2 Factors affecting ammonium acquisition

Plants have evolved in soils in which nitrates are the primary form of inorganic nitrogen available for their nutrition; consequently, they have little tolerance for high levels of ammonium nitrogen in their root environment. Plant roots readily absorb ammonium ions, but they must not be absorbed more rapidly than they can be utilized in the cell; otherwise toxic reactions occur (Maynard & Barker, 1969; Ajayi, Maynard & Barker, 1970). The ammonium intake by a plant must be carefully regulated, for the tolerance range of plants to ammonium nitrogen is quite narrow and is dependent upon the presence of nitrate in the medium (Mills, Barker & Maynard, 1976a; 1976b).

Ammonium concentration

As with nitrate, the most important factor affecting the uptake of ammonium ions by plants is the ions' concentration in the environment of the roots (Munn & Jackson, 1978). Increasing the total supply of ammonium nitrogen in a medium may increase its uptake to the point of toxicity in the plant. Toxicity of ammonium ultimately decreases root and total plant growth sufficiently so that total nitrogen intake by a plant nourished with ammonium nitrogen may be far less than that of plants cultured with nitrate nitrogen or when the toxic reactions are averted (Maynard & Barker, 1969).

The proportion of ammonium nitrogen relative to nitrate in the medium is an important factor governing its acquisition and plant growth response (Mills *et al.*, 1976a; 1976b). Concentrations of ammonium in excess of that required to induce toxicity symptoms in plants can be maintained without the adverse effects when nitrate supplies part of the nitrogen (McElhannon & Mills, 1977).

Other ions

Nitrate in the presence of ammonium enhances plant growth and increases the total acquisition of nitrogen by plants (Mills *et al.*, 1976a; 1976b). Calcium and magnesium contents are lowered sharply by ammonium nutrition, with these reductions proportionately greater than those observed for potassium (Harada, Takaki

& Yamuda, 1968; Barker & Maynard, 1972), whereas phosphorus and sulphur concentrations are increased relative to those in plants grown with nitrate nutrition (Blair, Miller & Mitchell, 1970). The decreases in cation uptake have been explained in various ways, ranging from cation competition for absorption sites (Blair *et al.*, 1970) to cation-anion balances including organic and inorganic anions (Hiatt, 1978).

pH

With ammonium nutrition, plants absorb cations in excess of anions and the pH of the growth medium becomes more acidic (Raven & Smith, 1976), while nitrate absorption causes an alkaline drift (Smiley, 1974). The decline in pH increases the toxicity of ammonium nitrogen, for the most favourable pH for its utilization is near neutrality. Even when all of the nitrogen is ammoniacal, nearly normal growth can be obtained if the pH of the medium is buffered near neutrality (Barker, Volk & Jackson, 1966a; 1966b; Sander & Barker, 1978).

Light and carbohydrate status

Ammonium uptake by plants shows a wide diurnal variation. Ammonium and nitrate uptake are greater in light than in darkness and increase with increasing light intensity (Van Egmond, 1978). The decline in ammonium uptake in darkness is due to the depletion of carbohydrate reserves in the roots, for the assimilation of ammonium has high-energy requirements (Reisenauer, 1978).

Absorption and utilization of ammonium nitrogen are affected by carbohydrate supply and plant age. Plants well supplied with carbohydrates are better able to utilize ammonium nitrogen than are energy-starved plants. Young plants with active photosynthesis mechanisms may be more tolerant than older plants that are declining in photosynthetic capacity; however, older plants with adequate carbohydrate reserves may be quite tolerant of ammonium nutrition, particularly if they have large leaf areas. Seeds and seedlings are very sensitive towards ammonium toxicity (Barker & Mills, 1980)

Ketoacids are essential for the initial complexation of ammonium absorbed by the roots (Hewitt, 1970). Plants rich in carbohydrates are able to supply the necessary ketoacids for the assimilation of ammonium nitrogen into amides and other amino acids. Plants, which are grown in ammonium nutrition, accumulate larger amounts of amides than those grown on nitrate nutrition (Barker & Bradfield, 1963). Ammonium assimilation into amides within the roots appears to be a detoxification mechanism for plants to survive on high levels of ammonium nutrition. Proper pH control is essential for assimilation of ammonium nitrogen into amides in the roots (Barker *et al.*, 1966a; 1966b; Maynard & Barker, 1969).

A rapid drop in carbohydrate level in the roots occurs with the initiation of ammonium nutrition (Micheal, Martin & Owissia, 1970; Reisenauer, 1978). Nitrate nutrition does not deplete carbohydrate levels to the same extent, for nitrates can be translocated to the shoots and vacuoles to be stored and processed, which cannot occur with ammonium nutrition without toxic effects (Reisenauer, 1978).

2.3.2 Mineral nutrition of tomatoes

2.3.2.1 Nitrogen source and calcium

Nutrient uptake

In closed systems the supply of nutrients should be equal to the absorption of nutrients by the crop. Over the whole growing period of the tomato crop, the mean values of uptake concentrations of tomato to obtain optimum yield and product quality are 9.6 mM N, 6.1 mM K, 2.2 mM Ca, 1.2 mM S, 1.1 mM P, and 0.9 mM Mg. For a production period lasting 238 days, it is estimated that the mineral absorption in $\text{kg}\cdot\text{ha}^{-1}$ is 790 N, 170 P, 1415 K, 237 S, 606 Ca, 112 Mg, 70 Na, 97 Cl, 14 Fe, 4.5 Mn, 0.8 Zn, 0.5 Cu and 1.5 B (Dorais, Papadopoulos & Gosselin, 2001). The total uptake of nutrients has been used as a guide to define the nutritional program for a crop. This was then refined to take account of the different stages of plant development. Nutrient uptake of a crop varies not only with plant size, but also with changes in the environmental conditions, which can have a profound effect on the uptake of water and nutrients (Adams, 2002). The effect of environment on the absorption processes

and thus root function, as well as the effect of the aerial environment on the rate of transpiration determine the rate of nutrient uptake (Adams & Ho, 1995).

Nitrogen and quality

Nitrogen deficiencies lead to small vegetables with low Beta-carotene and Vitamin B contents, associated with a low plant protein content. On the other hand, an oversupply of nitrogen may result in low Vitamin C contents, late maturity and the development of disease sensitive plant tissue (Schnitzler & Gruda, 2002).

The nitrogen source provided to plants can influence fruit quality. Ammonium increases fruit sugar content but decreases calcium concentration of tomato fruit (Dorais *et al.*, 2001). Similarly, Pivot, Reist & Gillioz (1997) have reported that an excess of ammonium in the nutrient solution resulted in a reduction of the calcium content in fruit and increased the number of fruit affected by blossom-end rot. Ten to 20% of total nitrogen as ammonium, compared to 0% of total nitrogen as ammonium favours plant growth but decreases fruit size and total or marketable yield due to a reduction of calcium and magnesium absorption and an increase in the number of fruit affected with blossom-end rot (Hohjo *et al.*, 1995). Applications of ammonium compared to nitrate, increased glutamic acid levels in the fruit (Dorais *et al.*, 2001). In order to obtain high quality fruit the K/N ratio should be 1.2/1 for young plants (until first floescence) and 2.0 – 2.5/1 when the ninth cluster is in flower (Ho & Adams, 1995; Adams, 1999).

Calcium and quality

Calcium is a crucial element to maintain good quality in floriculture and vegetable crops (Schnitzler & Gruda, 2002). Inside the cell, calcium linked to pectic acids of the middle lamellae is responsible for maintaining cell wall tissue rigidity (Marschner, 1995). Calcium pectate is involved in cell wall plasticity and elongation (Yamauchi, Hara & Sonoda, 1986). Under high light conditions, calcium pectates increase tissue resistance to degradation by polygalacturonase and to fungal or bacterial attacks. Calcium is also essential for cellular membrane stability, and cellular compartmentation and integrity (Marschner, 1995).

To ensure optimal absorption of calcium, the temperature has to be between 18 to 22°C. An adequate supply of calcium to the fruit is essential for their firmness and for their shelf life. An insufficient supply of calcium will increase the number of fruits affected by blossom-end rot (BER) (Dorais *et al.*, 2001). In periods of rapid growth an accelerated cellular enlargement and fruit development require an additional supply of nutrients such as calcium, an important nutrient in the prevention of tomato fruit cracking (Simon, 1978) and blossom-end rot (Ho, 1999). Due to the immobility of Ca in the phloem, Ca in the leaves will not be remobilised to the fruit and Ca supply to the fruit is restricted to the xylem water, which accounts for less than 15% of total water import to the fruit (Ho, Grange & Picken, 1987). Calcium is transported primarily to the high transpiring organs such as leaves. However, the fruits, which are sinks for assimilates that is mainly transported via the phloem, receives only very little calcium. The calcium concentration in leaves are approximately 30 times higher than measured in fruit in a soilless grown crop (Schnitzler & Gruda, 2002). Therefore, calcium distribution to fruit is less than 2% of the total calcium content (Ehret & Ho, 1986b; Ho, 1999). Usually, calcium content in fruits increases with age and is strongly correlated to fruit dry or fresh weight (El-Gizawy, Adams & Adatia, 1986). However, the accumulation rate of calcium in the fruit is maximal 22 to 55 days after anthesis. The concentration in the distal fruit on the cluster tends to be lower than in the proximal ones (Petersen, Willumsen & Kaack, 1998) indicating that physiological disorders associated with calcium are more likely to develop in fruit at the end of the truss than in the fruit close to the main stem. However, Adams & Ho (1993) specified that BER is a local deficiency of calcium in tomato fruit, or in the distal end of tomato fruit, respectively.

Interactions between nutrients

Nutrient uptake and plant growth may be affected by an interaction between two or more nutrients. Where there is a mild or incipient deficiency of a nutrient, any factor, nutritional or environmental, that increases the growth rate will make the deficiency more severe. The form of nitrogen (ammonium or nitrate nitrogen) supplied to the crop can affect the uptake of nutrients profoundly. Many experiments have been concerned with the different responses to these two nitrogen sources. However, as

these responses vary with pH, a valid comparison in hydroponics can only be made if the pH is identical and held constant in both treatments (Adams, 2002). Kurvits & Kirkby (1980) who studied sunflower (*Helianthus annuus*) achieved this at pH 6.5 to 6.8. They found higher concentrations of K, Ca, Mg and Na in the dry matter of plants receiving nitrate nitrogen, but a higher P concentration in those grown with ammonium nitrogen. As the pH decreases below 6.0, K uptake is increasingly inhibited by ammonium nitrogen due to NH_4^+ and H^+ ions whereas, at pH 7.0 and above, growth may be inhibited by the presence of free NH_3 (Findenegg, 1987). Kirkby (1979) also reported earlier that Ca uptake is stimulated by nitrate and depressed by ammonium ions.

Mg deficiency, which may cause yield losses in tomatoes, became more severe with increasing levels of K, N and Ca; the greatest yield loss occurring with high levels of both N and K. High levels of N and K not only increased the severity of Mg deficiency in tomato (Adams, Graves & Winsor, 1978), but also caused considerable yield reductions in cucumber (Adams, Graves & Winsor, 1992). This effect of high nitrogen levels may even be more damaging if the nitrogen source is ammonium (Adams, 2002).

Interactions between nutrients can be a potential cause of blossom-end rot. Very high levels of NH_4^+ -N, K or Mg in the root zone can depress the uptake of Ca and therefore decrease the Ca content in the fruit (Adams & Ho, 1995).

2.3.2.2 Chemical composition of tomato leaf tissue

The form of nitrogen fertilizer has been shown to affect the chemical composition as well as growth and development of plants. Kirkby & Mengel (1967), supported by other authors, already indicated that ammonium nitrogen nutrition has resulted in lower levels of Ca and Mg.

In general growth rate of plants fertilized with ammonium nitrogen was found to decrease compared with plants fertilized with nitrate nitrogen (Wilcox, Hoff & Jones, 1973; Hartman, Mills & Jones, 1986). The results of Wilcox *et al.* (1973) indicated that leaves of ammonium treated tomato plants contained 40 – 60% less Ca than

plants that received nitrate nitrogen. This effect was even more pronounced in the roots. A treatment that included a four times higher Ca concentration in the nutrient solution, containing ammonium nitrogen, increased the Ca contents of tomato tissue to near that of the nitrate treated plants. However, this treatment did not overcome the growth retarding effect of ammonium nutrition on tomato plants. Similarly the leaves of ammonium treated tomato plants contained 40 – 60 % less Mg than plants that received nitrate nitrogen. This reduction of Mg content was prevented by a four times increase in the Mg concentration in the nutrient solution, containing ammonium nitrogen. In addition blossom-end rot occurred where ammonium nutrition was applied. Pill *et al.* (1978) and Ali *et al.* (1994) confirmed these results, and concluded that in addition to the decrease in normal fruit concentration of Ca, Mg and K, ammonium nutrition reduces fruit size.

2.3.3 Pre-plant liming of growth media

Liming materials (CaCO_3 , CaCO_3 and MgCO_3 , $\text{Ca}(\text{OH})_2$, $\text{Ca}(\text{OH})_2$ and $\text{Mg}(\text{OH})_2$) are added to a soilless growth medium to neutralize acidity, increase pH to a level acceptable for plant growth and provide a source of Ca^{2+} and Mg^{2+} . Enough lime should be incorporated to obtain an initial pH of 5.5 to 6.4. With nitrate nitrogen fertilization, the medium pH tends to increase because of OH^- and HCO_3^- secretion associated with root ion uptake. In comparison, with ammonium nitrogen fertilization, the medium pH tends to decrease because of H^+ secretion during root ion uptake. Bacterial nitrification of NH_4^+ to the NO_3^- form within the medium also releases H^+ (Argo & Biernbaum, 1997).

The detrimental effects of NH_4^+ -N nutrition have been related to root environment acidity. Maintaining pH near neutrality has resulted in nearly normal growth under NH_4^+ -N nutrition (Barker *et al.*, 1966a; 1966b; de Claassen & Wilcox, 1974). Under NH_4^+ -N nutrition, solution acidity control improved root growth and reduced plant water stress, but had no effect on either total plant weight or ion concentration of roots and shoots with the exception of increased NH_4^+ -N concentration (Pill & Lambeth, 1977). Some authors indicated that the detrimental effects of ammonium on growth could be alleviated by the addition of dolomitic lime (de Claassen & Willcox, 1974)

or calcium carbonate (Pierpont & Minotti, 1977), which buffered the pH of the nutrient solution to near neutral.

Some authors amended the pH of a substrate like coco peat with pre-plant applications of dolomitic lime that ranged from 0.8 to 4.2 kg.m⁻³ (Meerow, 1994; Noguera *et al.*, 1997; Prasad, 1997; Noguera *et al.*, 2000). Argo & Biernbaum (1997) used 0.5 kg.m⁻³ dolomitic lime or the equivalent of 0.9 kg calcium carbonate per m³ coco peat. None of the above authors applied dolomitic lime to evaluate the effect it has on pH when different NO₃⁻-N : NH₄⁺-N ratios were used.

Caraveo Lopez *et al.* (1996) evaluated the production of tomatoes in coco peat substrate, and its response to ammonium and potassium. In his experiment he also incorporated CaCO₃ in the substrate and found that the highest fruit and dry matter yields were obtained when the nutrient solution contained 16.6% NH₄⁺-N, 20 or 30% potassium (with respect to total cations) and the substrate contained 3 or 6 g CaCO₃ per kg coco peat.

2.4 Irrigation frequency and quantity in hydroponics systems

The irrigation system in hydroponics has two functions to perform. One is to replenish depleted nutrients in the root zone and the other is to provide mass flow of nutrients through the substrate. The root zone forms a conduit for materials to reach the root surface. When the concentration of certain elements becomes excessive high in the root zone, then irrigation can be used to flush or dilute these elements (Schröder & Lieth, 2002). Generally hydroponics systems yield higher than crops produced in soil (Adams & Ho, 1995). This is due to intense irrigation management and increased water use efficiency. Plant growth in hydroponics is related to water, nutrients and oxygen supply. Water and nutrients can be supplied through an efficient irrigation system and by controlling the irrigation frequency. Irrigation and the type of substrate influence the oxygen supply in the root zone (Strojny, Nelson & Willitz, 1998). Hydroponics systems can either be closed or open systems, where leachate is allowed to run off from the root zone. The leaching fraction varies between 10 and 30% depending on the quality of the water and also the sensitivity of the crop towards salts (Schröder & Lieth, 2002)

The frequency of irrigation and the quantity of nutrient solution provided to the plants affect yield and fruit quality (Mitchell *et al.*, 1991). Irrigation control can influence fruit size. Adams (1990) indicated that when tomato plants are irrigated at 60% of the normal irrigation regime, the weight of fruit declined by 16% compared to the weight of the control. The importance of proper irrigation management was evident when Ismail, Halimi & Jusoh (1993) indicated that the yield of tomatoes increased by 70% when the irrigation frequency was increased from 1 and 2 to 4 and 5 times per day.

Increasing the rate of irrigation of greenhouse tomato plants can lead to reductions in soluble solids and dry matter of fruit. Moreover, increasing the water supply increases fruit yield, but fruit quality is negatively affected. Excess water increases root pressure and, as a consequence, fruit turgor pressure which leads to fruit cracking. It has been shown that a sudden increase in media water content reduces the elasticity of the tomato cuticle and increases root pressure (Dorais *et al.*, 2001). Thus, the time between irrigations should not be so long that the water content of the growth media reaches levels so low that it is damaging the roots. A reduction in the incidence of greenhouse tomato fruit cracking was observed when the daily irrigation frequency was changed from 1 to 4 waterings per day, while total irrigation quantity remained the same (Abbott *et al.*, 1986). It is also possible to reduce fruit susceptibility to cracking by reducing the total daily supply of water (Peet & Willits, 1995).

Restriction in the water supply has been shown to improve fruit organoleptic quality. Reductions in fruit water content as well as increases in fruit soluble solids, sucrose, hexoses, citric acid and potassium have been reported in tomato plants growing under water stress conditions (Adams, 1990; Mitchell *et al.*, 1991; Pulupol, Behboudian & Fisher, 1996). However, plants grown under high water stress tend to suffer from significant growth and yield reductions (Adams, 1990; Mitchell *et al.*, 1991).

2.5 Effect of cultural practices and environmental factors on tomato fruit quality

2.5.1 Fruit quality

Several characteristics such as soluble solids, sugars, acidity and pH are important quality parameters for both fresh market and processing tomatoes (Cuartero & Fernández-Muñoz, 1999). Total soluble solids (TSS) in ripe fruits, measured by the refractometric index (°Brix), increases with salinity and hence the use of moderate saline irrigation water is recommended to improve fruit quality (Mizrahi *et al.*, 1988).

Tomato fruit flavor involves the perception of taste as influenced by aromas of many chemical constituents. Sugars, acids and their interactions are important to sweetness and sourness of the tomato (Stevens *et al.*, 1977). About 50% of tomato fruit dry matter is sugars (glucose 22%, fructose 25% and sucrose 1%) and 13% organic acids (citric acid 9% and malic acid 4%). The concentration of citric and malic acids in tomato fruit can vary with genotype, ripening stage, nutritional status of the plant (Mahakun, Leeper & Burns, 1979) and the environment (Winsor, 1979). Malic acid predominates in immature green fruit with citric acid forming 25% of the total acidity (Davies & Hobson, 1981). In ripe fruit, however, citric acid accounts for 40 to 90% of the total acidity (Stevens, 1972; Davies & Hobson, 1981). Fructose and citric acid are more important to sweetness and sourness respectively. A high sugar concentration together with a relative high acid concentration is required for best flavor, low sugars and high acids produce a tart tomato, high sugars and low acids a bland taste and both low sugars and acids results in a tasteless fruit (Grierson & Kader, 1986).

Tomato fruits grown under salt stress show higher organic acid contents and higher titratable acidity than fruits grown with fresh water (Mitchell *et al.*, 1991). Fruit shelf life (Mizrahi, 1982) and fruit firmness (Sharaf & Hobson, 1986) are lowered with high salinity levels, but salinity causes no alteration on shelf life or firmness in fruits of long-shelf life commercial cultivars (Cuartero *et al.*, 1996). High salinity causes a reduction in Ca^{2+} uptake (Adams & Ho, 1992), high temperatures causes rapid fruit growth and low humidity causes an increase in transpiration rate and hence more Ca^{2+} moving to the leaves and less to the fruit (Adams & Ho, 1993) and therefore increases the incidence of blossom-end rot (BER).

BER of tomatoes was first identified as a physiological disorder more than 100 years ago. In susceptible cultivars it may cause severe losses in some seasons and under certain environmental conditions. BER is generally attributed to an inadequacy of calcium in the fruits and it is therefore called a 'calcium-related disorder' (Saure, 2001). Adams & Ho (1993) specified that BER is a local deficiency of calcium in tomato fruit, or in the distal end of tomato fruit, respectively.

Tomatoes with BER ripen earlier and are generally smaller than healthy fruit. The incipient stages of BER have been observed only in fruit ranging from 12 to 15 days after anthesis (Saure, 2001). However, there are several reports that BER can be induced experimentally at any stage of fruit development (Barker & Ready, 1994).

Increased incidence of BER may be associated with reduced plant and fruit growth due to stress induced in the root zone such as salinity, soil water stress and ammonium toxicity (Saure, 2001). Cuartero & Fernández-Muñoz (1999) has established that there is a relation between increased nutrient salt concentration, less fruit and plant growth and a high percentage of BER. The percentage of BER may be quite low at high salinity especially where NaCl was used to increase salinity. Combrink (1998) also reported a reduction in yield, due to a reduction in fruit size and not fruit number, with increased salinity.

Adams & Ho (1992), who stated that water stress was the most common cause of BER, also noticed that BER frequently occurred when the moisture content of the substrate was fully adequate (Adams & Ho, 1993). Not only restricted absorption of water by the plant but also a greatly increased rate of transpiration of water will increase the probability that BER occurs (Saure, 2001). If there is a concurrent increase in the rate of transpiration, due to a higher air temperature, then the rate of fruit growth is increased. This increases the demand for calcium by the fruit at the very time that the calcium supply to the fruit is being limited by the greatly increased movement of water to the leaves. Thus the conditions for BER are fulfilled and if these conditions are extreme, then partly mature fruit may be affected (Adams, 2002).

Osmotic stress may occur in hydroponic culture due to uneven or infrequent watering, or additional supply of nutrients to improve fruit quality, and is more likely than calcium or water stress to induce BER. As the uptake of calcium is in proportion to the absorption of water and the import of calcium by the fruit is from the newly absorbed calcium, even a transient water/osmotic stress can cause BER in fruit during the critical stage of fruit development (Ho, Hand & Fussell, 1999).

Root absorption of calcium can be reduced by poor aeration in the root zone when the oxygen level in the feed is less than 3 mg.l⁻¹. Also the root absorption of calcium can be reduced by both low (<14°C) and high (>26°C) root temperature, but adverse root temperature as the cause of BER has not been demonstrated. Nevertheless, high root temperature has been found to aggravate the BER inducing effect of high ammonium levels in the feed (Ho *et al.*, 1999).

The supply of nitrate nitrogen will induce less blossom-end rot than nutrition with ammonium nitrogen. In the root environment, the large hydrated calcium ion competes with a number of cations, which are smaller and easier to take up and transport. The effectiveness of various cations in reducing calcium uptake thus increasing the incidence of calcium deficiency symptoms in plants is in the order NH⁴⁺ > K⁺ > Mg²⁺ > Na⁺ (Shear, 1975).

2.5.2 Cultural practices

2.5.2.1 Hydroponics and soilless substrates

Annually numerous experiments are conducted, which are aimed at comparing the effects of different substrates on plant growth and quality. Whatever substrate is used, good product quality can only be achieved if the cultural management is correctly adjusted to the properties of the substrate (Schnitzler & Gruda, 2002). Many experiments showed that there is no impact of substrate per se on product quality (Gül *et al.*, 1999; Özeker *et al.*, 1999; Tüzel *et al.*, 2001; Schnitzler & Gruda, 2002).

Mzouri, Makhoulf & Gosselin (1996) and Gül & Sevgican (1994) found no significant effect of substrate on fruit quality when different growing media were

compared. Substrate had no significant effect on fruit composition, firmness and aroma (Gormley & Egan, 1978). However, Cronin & Walsh (1983) have reported a higher fruit content in sugars, ascorbic acid and in dry matter in peat-based growing media, while fruit content in titratable acids, potassium and fruit aroma were higher under an NFT (Nutrient Film Technique) growing system. Benoit & Ceustermans (1987) found that tomatoes produced in NFT were firmer than those from soil-grown plants. They also contained more sugar, acid and sodium, resulting in a more distinct taste. Moreover, Maas & Adamson (1971) showed that good quality tomato could be successfully grown in a soilless medium composed completely of sawdust if adequately enriched with essential mineral nutrients. Alan, Zülkadir & Padem (1994) reported that the highest total soluble solids content in tomato fruit was found with peat. The highest titratable acidity and lowest pH values were found in tomato fruit when sand was used. They concluded that the pH value of the substrate might play a role in these differences.

The controversy between the different studies probably reflects the level of control of the growing regimes as a function of the substrates used. Each growing substrate has its own demands and responds more or less rapidly on accounts of its buffer effect to changes in growing conditions due to daily climatic variations (Dorais *et al.*, 2001).

2.5.2.2 Nutrient supply

Electrical conductivity

Root development, water and nutrient uptake

Tomatoes grown with saline water have a significantly lower water uptake than those grown with fresh water (Pessaraki & Tucker, 1988) and a strong linear relationship ($r=0.97$) between electrical conductivity (EC) of the nutrient solution and plant water consumption has been demonstrated (Soria & Cuartero, 1997).

In spite of the negative effect of salt on root development, root growth in tomatoes appears to be less affected by salt than shoot growth and so the root/shoot dry weight ratio is higher in plants grown under salt stress, at all stages of development (Cruz &

Cuartero, 1990). The increase in root/shoot dry weight ratio in tomato plants under salt stress must be accompanied by changes in the allocation of assimilates between root and shoot. Pérez-Alfocea *et al.* (1996) showed that in salt-treated plants there was a greater proportion of assimilates in the roots compared with assimilates in the shoots.

The flavor increase and yield decline under high salinity may be associated with a reduction in water absorption by roots (Dorais *et al.*, 2001), and hence the water content of the fruit (Adams, 2002). Ehret & Ho (1986a) have reported reduced water absorption capacity when the EC was increased from 2 to 17 $\text{mS}\cdot\text{cm}^{-1}$ and that the absorption rate of calcium was reduced by 87%. Increasing the EC from 2 to 17 $\text{mS}\cdot\text{cm}^{-1}$ reduced the fruit phosphorus concentration, increased the potassium concentration and had no effect on the nitrogen concentration. High salinity not only reduced calcium uptake into the tomato fruit, but also affected the distribution of calcium within the fruit (Adams, 1990). While fruit size decreased with increasing salinity levels, other quality attributes, including the concentration of sugars and acids, increased (Adams, 2002).

Yield characteristics

Tomatoes can tolerate a saturated soil extract EC of up to 2.5 $\text{mS}\cdot\text{cm}^{-1}$ without any yield reduction (Maas, 1986). When tomatoes are grown hydroponically, or in an inert substrate, the EC of the nutrient solution usually employed ranges between 2 to 2.5 $\text{mS}\cdot\text{cm}^{-1}$ (van Ieperen, 1996; Cuartero & Soria, 1997). Compared to the saturated soil extract EC threshold, this is very close to the EC threshold for yield reduction. Ehret & Ho (1986c) and Adams (1986) reported no significant yield reduction at EC levels above 7 $\text{mS}\cdot\text{cm}^{-1}$, perhaps due to the low light intensity and high relative humidity in their experiments. Salinity applied during the day or in spring or summer cultivation causes higher yield reductions than during the night or in autumn cultivation (van Ieperen, 1996), because higher temperature and illumination and lower humidity in summer time lower the water potential in the plant by inducing faster transpiration. Besides high transpiration, high salinity also decreases the water potential in the plant, which will reduce the water flow into the fruit and therefore the rate of fruit growth (Johnson, Dixon & Lee, 1992). A decrease in average fruit weight and/or fruit number

produced per plant can lead to a reduced tomato yield (van Ieperen, 1996; Cuartero & Soria, 1997). Fruit size is inversely related to the EC of the nutrient solution while the dry matter content of the fruit is linearly increased by the EC (Ho, 1999).

pH

Control of the pH in the nutrient solution is crucial as it affects the availability of nutrients and therefore plant nutrition. Findenegg (1987) found that when the pH decreased below 6, the potassium uptake was increasingly inhibited by NH_4^+ -N nutrition whereas, at pH 7 and above, growth may be inhibited by the presence of free NH_3 . Adams (2002) also reported that the availability of phosphorus was reduced at high pH values (7 and higher). At these high pH levels all the micronutrients, except molybdenum becomes less available. The optimum solution pH is between 5.0 and 6.0 (Sonneveld, 2002).

Plant nutrition

Calcium

Calcium is responsible for maintaining the cell wall and tissue rigidity (Marschner, 1995) and is involved in cell wall plasticity and elongation (Yamauchi *et al.*, 1986). An adequate supply of calcium to the fruit is essential for firmness and shelf life. Insufficient supply of calcium will increase the number of fruit affected by BER (Dorais *et al.*, 2001). Nevertheless, the presence of high levels of calcium in the fruit negatively affects their organoleptic quality and shelf life (De Kreij, 1995). High levels of potassium (Voogt, 1988; Nukaya *et al.*, 1995a; Bar Tal & Pressman, 1996) and ammonium nitrogen (Schnitzler & Gruda, 2002) in the root environment interfere with calcium uptake and therefore increase the risk of BER. Calcium levels in the fruit increase with an increasing calcium concentration in the nutrient solution (Bradfield & Cuttridge, 1984; Paiva, Sampaio & Martinez, 1998), but magnesium and potassium levels decrease (Paiva *et al.*, 1998).

Potassium

Potassium is involved in several metabolic processes (Dorais *et al.*, 2001) and is positively related to a good fruit shape, the reduction of ripening disorders and the increase of fruit acid concentrations (Adams, Davies & Winsor, 1978; Mahakun *et al.*, 1979). Potassium plays an important role in the maintenance of electro-neutrality of organic acids in the fruit (Davies, 1964; Mitchell *et al.*, 1991) and a positive correlation between citric and malic acid content in the fruit and potassium content in the soil has been observed (Davies, 1964; Winsor & Barker, 1982). Potassium content of fruit was negatively correlated with fruit pH (Winsor & Massey, 1958; Mahakun *et al.*, 1979; Picha, 1987). Davies & Winsor (1967) have observed a positive response of plants to potassium in terms of acidity, dry matter and organoleptic quality.

A high K:Ca ratio improved fruit firmness and acidity, while it reduced the sugar content (Janse & Gielesen, 1991), increased the number of fruit affected by BER (van der Boon, 1973), but reduced the incidence of fruit with gold specks (Voogt, 1987, Nukaya *et al.*, 1995b). A low K:Ca ratio increased the number of fruit with gold specks (Nukaya *et al.*, 1995a), thereby reducing their shelf life (Janse, 1988).

Phosphorus

Low concentrations of phosphorus adversely affect reproductive growth (Dorais *et al.*, 2001). Mahakun *et al.* (1979) have reported that phosphorus content was negatively correlated with H^+ :Total acidity ratio. Increasing the phosphorus concentration in the nutrient solution from 0.02 to 3.0 mM stimulates the absorption and distribution of Ca in the fruit (Cerda & Bingham, 1978; Cerda, Bingham & Labanauskas, 1979; De Kreij, 1996) and favors the incidence of gold specks (Voogt & Sonneveld-van Buchem, 1989; De Kreij *et al.*, 1992).

Nitrogen

Nitrogen affects the size, color and fruit cuticle characteristics of tomatoes. A very high nitrogen concentration influenced color negatively, delayed ripening, caused uneven ripening and reduced fruit soluble solids content (Locascio *et al.*, 1984). It

also increased fruit acid concentration and decreased fruit organoleptic quality (Locascio *et al.*, 1984; Thakur, Singh & Nelson, 1996). A high nitrogen concentration also interfered with Ca nutrition and, as a consequence, increased post harvest quality losses and the number of fruit affected by BER (Dorais *et al.*, 2001).

The nitrogen source provided to plants can also influence fruit quality (Dorais *et al.*, 2001). Ho (1996) has reported that $\text{NH}_4^+\text{-N}$ increases fruit sugar content, but decrease calcium concentration. Similarly, Pivot *et al.* (1997) have reported that an excess of ammonium in the nutrient solution results in a reduction of calcium content in the fruit and an increase in the number of fruit affected by BER. In order to obtain high quality fruit, the K:N ratio should be 1.2:1 for young plants (until first inflorescence) and 2.0 - 2.5:1 when the ninth cluster is in flower (Ho & Adams, 1995; Adams, 1999). Feigen *et al.* (1980) found that the application of 10 – 50% $\text{NH}_4^+\text{-N}$ to the nutrient solution markedly increased the percentage of high quality (firm) fruit after storage.

2.5.2.3 Irrigation

Increasing the rate of irrigation of greenhouse tomato plants can lead to reductions in soluble solids and dry matter content of fruit (Tüzel, Ul & Tüzel, 1994). Ismail *et al.* (1993) showed a reduction in fruit total soluble solids when plants were irrigated more than three times daily. A high irrigation regime reduces fruit quality due to high water content (reduction on soluble sugars, organic acids, vitamins, minerals and volatile compounds) and due to a tendency to crack (Abbott, Peet & Willits, 1985; Abbott *et al.*, 1986; Peet, 1992; Tüzel *et al.*, 1994; McAvoy, 1995; Peet & Willits, 1995). Restriction in the water supply has been shown to improve fruit organoleptic quality. Reductions in fruit water content as well as increases in fruit soluble solids, sucrose, hexoses, citric acid and potassium have been reported in tomato plants grown under water stress conditions (Adams, 1990; Mitchell *et al.*, 1991; Pulupol, Behboudian & Fisher, 1996)

2.5.3 Environmental Factors

2.5.3.1 Light intensity

Despite the fact that increasing light intensity also increases fruit dry matter and soluble sugars content, it has almost no effect on organic acid concentration (Janse, 1984). A high fruit dry matter content is generally associated with high firmness, while a low fruit concentration in soluble sugars is linked to a 'watery' taste of tomato (Dorais *et al.*, 2001).

2.5.3.2 Temperature

Temperature may influence the distribution of photo-assimilates between fruit and vegetative parts as well as their rate of growth (De Koning, 1992a; De Koning, 1994; Heuvelink, 1995; De Koning, 1996). High temperatures favors the distribution of assimilates to fruit, at the expense of vegetative growth (De Koning, 1989). It is generally reported that increasing the ambient temperature by 1°C increases fruit dry matter content by 0.07% (De Koning, 1992b). High temperature accelerates fruit development and reduces the time required for ripening but also decrease their size and therefore their quality (Dorais *et al.*, 2001). High temperatures will result in more juicy and aromatic fruit, with increased acidity and the fruit skin becomes thicker, hence a better keeping quality (Schnitzler & Gruda, 2002).

2.5.3.3 Vapor pressure deficit

The relative humidity in a greenhouse affects fruit quality (Dorais *et al.*, 2001). Fruit production under high vapor pressure deficit (VPD) (low relative humidity) is firmer, juicier, and less mealy and have less physiological disorders such as cracking and gold specks than fruit produced under low VPD (Janse & Schols, 1992). However under low relative humidity, 24 to 59% of fruits can be affected by BER, while the corresponding figure for conditions of high relative humidity is 19% (De Kreij, 1992; De Kreij, 1996).

2.6 Conclusion

Numerous physical and chemical characteristics of growth media, environmental factors and cultural practices affect the yield and quality of greenhouse grown tomatoes. This review points out just how complex and sensitive each growth medium is towards changes in the growing environment. The controversy between the different studies reviewed, probably reflects the level of control of the growing regimes as a function of the substrates used.

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CHAPTER 3

Influence of substrate, nitrogen source and irrigation frequency on yield and quality of greenhouse grown tomatoes (*Lycopersicon esculentum* Mill.)

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Abstract

Pine sawdust-shavings (*Pinus* spp.) is the most popular substrate for hydroponically grown crops in the Republic of South Africa. A shortage of pine sawdust-shavings is inevitable due to a decline in pine plantations and expansion in the greenhouse industry. The influence of substrate (sand, pine sawdust-shavings, coco peat), nitrogen source (NO_3^- -N : NH_4^+ -N ratios of 100% : 0%, 80% : 20%, 60% : 40%) and irrigation frequency (3x, 6x, 12x per day) on the yield and quality of greenhouse grown tomatoes were studied to determine the effect thereof on plant growth and marketable yield. Treatments were arranged in a randomised block design, using two replicates. Interactions between nitrogen source and substrate or irrigation frequency had a significant effect on marketable yield. The highest yield of tomatoes was obtained in the coco peat substrate with 100% NO_3^- -N in the nutrient solution and the optimal irrigation frequency was found to be 12 times per day. High NH_4^+ -N applications reduced the marketable yield by 16 - 48% in all the substrates as a result of a reduction in size and number of fruit and the increased incidence of blossom-end rot. The interaction between substrate and nitrogen source had a significant effect on drainage water pH. The pH of drainage water from pine sawdust-shavings and coco peat increased with time where only NO_3^- -N was applied. High NH_4^+ -N applications resulted in the lowest pH readings in coco peat.

Keywords: irrigation, nitrogen, quality, substrate, tomato, yield

Introduction

Pine sawdust-shavings mixtures are at present still the most popular soilless substrate in South African greenhouses. Currently these mixtures are used as stand-alone substrate for the production of tomatoes, cucumbers and sweet peppers (Maree, 1994). Expansion in the greenhouse industry and decline in pine plantations however may cause a shortage of sawdust. This and other problems, which will be discussed briefly, are forcing the greenhouse industry to look at other substrates such as coco peat. Coco peat is well known for its quality and durability as a substrate, but is relatively expensive compared to pine sawdust-shavings.

Inconsistency in particle size distribution between different consignments of pine sawdust-shavings may directly influence the water holding capacity and thus the optimum frequency of irrigation needed. Lemaire, Dartigues & Rivière (1989) reported a vast difference between the water holding capacity of fine and coarse wood fibre substrates. The water holding capacity and therefore the irrigation requirements of coco peat may also vary between different batches. It has also been reported that pine sawdust compared to coco peat has a very low cation exchange capacity (Lemaire, 1995; Noguera, Abad & Noguera, 2000).

However, pine sawdust has a lower lignin content compared to coco peat and as a result decomposes more rapidly during the growing season (Ghoos, 1993; Noguera *et al.*, 2000). Decomposition of pine sawdust can influence the chemical processes in the substrate, which includes a change in pH and nitrogen concentration values. Optimum plant nutrition levels, especially ammonium to nitrate N-ratios, may be different for coco peat and pine sawdust.

Generally the high C/N ratio of raw coir dust is comparable to that of fresh sawdust (Noguera *et al.*, 1997; Noguera *et al.*, 2000; Yau & Murphy 2000). These high C/N ratios could cause the immobilization of soluble nitrogen (Noguera *et al.*, 1997; Noguera *et al.*, 2000). However, composting of coir and pine sawdust can reduce the C/N ratio and therefore immobilization of inorganic N (Worrall, 1978; Yau & Murphy, 2000). Decomposition of organic substrates changes the physical and

chemical properties of the substrate and therefore may require a higher level of management.

The use of ammonium and nitrate as nitrogen source in re-circulating nutrient solutions has been attracting much attention, especially since the $\text{NH}_4^+\text{-N} : \text{NO}_3^-\text{-N}$ ratio can be used to control the pH, which tends to rise markedly when $\text{NO}_3^-\text{-N}$ is used (Pill & Lambeth, 1977). Ten to 20% compared to 0% of the total nitrogen, applied as $\text{NH}_4^+\text{-N}$, decreases fruit size and marketable yield (Hohjo *et al.*, 1995). Very high levels of $\text{NH}_4^+\text{-N}$ in the root zone can depress the uptake of calcium and therefore decreases the calcium content of the fruit, causing blossom-end rot (Adams & Ho, 1995).

As a result of the above-mentioned reasons, it was decided to conduct an experiment where yield and quality of tomatoes were evaluated in different substrates, which was subjected to different irrigation frequencies and ammonium to nitrate N-ratios. Sand was included as a substrate because it is highly resistant to weathering and not subjected to biodegradation processes.

Materials and methods

Locality and climate A greenhouse trial was conducted at Stellenbosch in the Western Cape Province of South Africa during the spring and summer of 2000/2001. The weekly average minimum and maximum temperatures outside the greenhouse are presented in Figure 1. From this figure it is clear that especially daily maximum temperatures increases gradually during the duration of the experiment.

Cultivation practices Seeds of the tomato (*Lycopersicon esculentum* Mill.) cultivar FA593 (Mayford Seeds, South Africa) were sown on 17 June 2000 in seedling trays. The seedlings were produced in a substrate that consisted of 1 part Hygrotech seedling mix (peat, polystyrene, vermiculite), 1 part vermiculite and 1 part composted pine bark. Seedlings were watered with a 50% diluted ($1.1 \text{ mS}\cdot\text{cm}^{-1}$) nutrient solution (Steiner, 1984) and transplanted into the greenhouse on 19 August 2000 (9 weeks after sowing). Only one seedling was transplanted per 18 litre black plastic bag. Drainage holes were made at 2.5 cm from the bottom of the bag to create

a reservoir from which the drainage water samples were extracted. The bags were placed in 8 double rows and the spacing between rows (from centre of bag) was 0.40 m and within the row 0.35 m. The spacing between each double row (from centre of row) was 1.60 m. A plant population of 2.5 plants per m² were maintained in the greenhouse. Standard cultural practices for the production of greenhouse tomatoes were applied. Side shoots were removed and the plants were trellised to a height of 2.40 m above the bag. An average of 8 trusses per plant were recorded. Terminal growing points were removed once the plants reached the crop support wire. A naturally ventilated greenhouse was used. No heating was applied and during hot weather, temperature control was done by means of natural ventilation and the application of lime on the polycarbonate sheeting of the greenhouse.

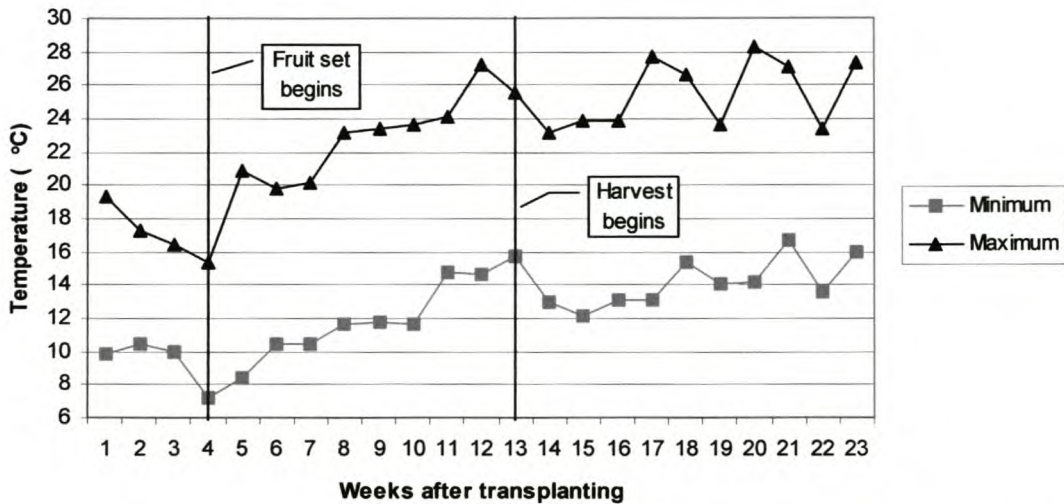


Figure 1 Weekly minimum and maximum temperatures outside the greenhouse during the growth period of 19 August 2000 to 29 January 2001

Treatments and experimental design Sand (collected from the Berg River), a pine sawdust-shavings mixture and coco peat were evaluated. The same volume of substrate (18 litre per bag) was used for all the treatments, although the characteristics of each substrate differed. All the substrates were washed with municipal water before planting. Three nitrogen source treatments (NO_3^- -N : NH_4^+ -N ratios of 100% : 0%, 80% : 20%, 60% : 40%) were evaluated (Table 1). NO_3^- -N and NH_4^+ -N was applied as $5[\text{Ca}(\text{NO}_3)_2 \cdot 2\text{H}_2\text{O}]\text{NH}_4\text{NO}_3$ and KNO_3 , and $(\text{NH}_4)_2\text{SO}_4$ respectively.

According to initial calculations made, the total nitrogen concentration for all the N-source treatments were supposed to be 14 mmol_c.l⁻¹ (196 ppm N). However, the average nitrogen content, after mixing of the different solutions, were 20.6, 19.2 and 17.3 mmol_c.l⁻¹ for the 100% NO₃⁻-N : 0% NH₄⁺-N, the 80% NO₃⁻-N : 20% NH₄⁺-N and the 60% NO₃⁻-N : 40% NH₄⁺-N treatments, respectively, but varied slightly between weeks (Table 2). The increase in total nitrogen might be due to impurities in the calcium nitrate fertilizer used. Calcium nitrate (5[Ca(NO₃)₂·2H₂O]NH₄NO₃) contains 1.3% NH₄⁺-N.

Table 1 Composition of nutrient solutions as affected by nitrogen source

Factor	NH ₄ ⁺	K ⁺	Ca ²⁺	Mg ²⁺	NO ₃ ⁻	H ₂ PO ₄ ⁻	SO ₄ ²⁻
NO ₃ ⁻ -N : NH ₄ ⁺ -N	mmol _c .l ⁻¹						
100% : 0%	0	8	8	4	14	1	5
80% : 20%	2.80	6.88	6.88	3.44	11.20	1.47	7.33
60% : 40%	5.60	5.76	5.76	2.88	8.40	1.93	9.67

Table 2 NO₃⁻-N and NH₄⁺-N content of irrigated nutrient solution during the growth period

Factor	NO ₃ ⁻ -N			NH ₄ ⁺ -N		
	(ppm)			(ppm)		
	Weeks after transplanting			Weeks after transplanting		
NO ₃ ⁻ -N : NH ₄ ⁺ -N	9	16	Average*	9	16	Average*
100% : 0%	291.5	263.7	277.6	11.2	10.6	10.9
80% : 20%	213.6	224.1	218.9	48.8	51.0	49.9
60% : 40%	162.9	150.6	157.8	82.2	85.6	83.9

*Long term average of regular measurements during growth period

Drainage water was sampled in week 2, 9 and 16 after transplanting. Measurements included electrical conductivity (EC) and pH, and NO₃⁻-N and NH₄⁺-N content (only in week 9 and 16). NO₃⁻-N was determined using the salicylic acid method (Cataldo *et al.*, 1975), while the indophenol-blue method (Keeney & Nelson, 1982) was used to determine NH₄⁺-N. The same measurements were done on the drainage water of the

substrates (Table 3) before transplanting, according to the pour-through nutrient extraction procedure (Wright, 1986), and on a regular basis on the irrigated nutrient solutions.

Table 3 EC, pH, and NO_3^- -N and NH_4^+ -N content of substrates before planting

Substrate	EC (mS.cm^{-1})	pH	NO_3^- -N (ppm)	NH_4^+ -N (ppm)
Sand	1.06	7.37	34.6	0.2
Pine sawdust	1.34	5.46	28.6	3.1
Coco peat	2.90	5.46	8.6	0

As shown in Table 4 the average EC of the three nutrient solutions varied between 2.01 to 2.03 mS.cm^{-1} during the growing season. The average pH throughout the experiment ranged between 5.67 (100% NO_3^- -N : 0% NH_4^+ -N) and 5.40 (60% NO_3^- -N:40% NH_4^+ -N) and therefore no pH correction was done. Thus the most acidic nutrient solution contained 40% NH_4^+ -N, applied as ammonium sulphate. However, the pH of the irrigated nutrient solutions slightly increased between week 2 and 9 after transplanting, but remained stable between week 9 and 16. This might be due to a change in the pH of the municipal water that was used. The EC and pH of the municipal water used in the experiment was 0.07 mS.cm^{-1} and 7.6 respectively and contributed therefore very little towards the final nutrient solution composition (Table 5).

Table 4 pH and EC measurements of irrigated nutrient solution during the growth period

Factor	pH				EC (mS.cm^{-1})			
	Weeks after transplanting				Weeks after transplanting			
	2	9	16	Average*	2	9	16	Average*
NO_3^- -N : NH_4^+ -N								
100% : 0%	5.69	6.03	6.16	5.67	1.71	2.31	2.33	2.03
80% : 20%	5.53	6.07	6.08	5.56	1.84	2.16	2.27	2.01
60% : 40%	5.48	5.91	5.92	5.40	1.99	2.16	2.26	2.03

*Long term average of regular measurements during growth period

Table 5 Composition of municipal water used during the experiment

EC	pH	Na ⁺	NH ₄ ⁺	K ⁺	Ca ²⁺	Mg ²⁺	NO ₃ ⁻	H ₂ PO ₄ ⁻	SO ₄ ²⁻	Cl ⁻	HCO ₃ ⁻
mS.cm ⁻¹		mmol.c.l ⁻¹									
0.07	7.6	0.27	0	0.01	0.25	0.14	0.01	0	0.04	0.57	0.14

The nutrient solutions were mixed and stored in 1500 litre plastic tanks. Netafim drippers (pressure compensated, non-leakage), with a capacity of 2 l.hr⁻¹, were used to irrigate each bag individually. To prevent the mixing of nutrient solutions, the system was designed so that each treatment had its own separate irrigation system. An irrigation controller and timer were used to schedule irrigation. Three irrigation frequencies (3x, 6x, 12x per day) were applied. However, the total volume of nutrient solution irrigated per treatment per day was the same for all the treatments. The first and last irrigation took place within 1 hour from sunrise and sunset respectively. The day length increased from 9 hours in August to 14 hours in December. Water application ranged from 300 ml per plant per day, just after transplanting, to 3500 ml during the peak production period (15 to 20 weeks after transplanting). The irrigation volumes per day were gradually increased during the growing season and included an over irrigation of 15 to 20%. This proved to be very difficult as a result of the different water holding capacity characteristics of the substrates.

Data collected The first fruit were harvested 13 weeks after transplanting and harvesting continued until week 23 (29 January 2001). The fruit were harvested twice a week and the yield was graded into two categories, marketable (only first class tomatoes) and unmarketable. Tomatoes were classified as unmarketable according to the following criteria: i) Fruit smaller than 40 mm in diameter; and ii) Fruit with defects like uneven colouring, shoulder cracks, fruit that is soft at harvest, fruit with blossom-end rot (BER) and abnormal growth. Marketable and unmarketable yield measurements were taken during the harvest period. At the end of the growing season the marketable and unmarketable yield per plant, the number of marketable fruit per plant, the number of fruit with BER per plant and the average fruit mass were calculated.

Statistical analysis The 27 treatment combinations were arranged in a randomized block design, using two replicates. Eight plants represented an experimental unit. The data were statistically analyzed with SAS statistical software version 8.2 (SAS, 2000). The Shapiro-Wilk test was performed to test for normality (Shapiro & Wilk, 1965). Student's t-least significant difference was calculated at the 5% level to compare treatment means. A probability level of 5% was considered significant for all significance tests.

Results and discussion

Drainage water

During week 2 and 9 after transplanting drainage samples from replicate 1 and 2 were combined and analysed as one sample due to a sampling error. As a result there was insufficient degrees of freedom for experimental error. Since there was no significant 3rd order interaction in week 16, for all parameters tested, it was decided to use the degrees of freedom of the interaction for experimental error. This did not have a significant effect on the outcome of the results, as similar trends were shown for all sampling dates (Tables 6, 7 and 8).

From these tables it became clear that substrate as a main factor had a significant effect on all parameters tested in the drainage water at all sampling times. Nitrogen source had a significant effect on pH, as well as NO_3^- -N and NH_4^+ -N content at all sampling dates, but no effect on EC 2 and 9 weeks after transplanting. Irrigation frequency had no significant effect on pH, EC and NH_4^+ -N content in drainage water, but affected the NO_3^- -N content at 9 and 16 weeks after transplanting.

Significant Substrate x Nitrogen source interactions were shown for pH, NO_3^- -N and NH_4^+ -N content in the drainage water at all sampling times, but not for EC. Substrate x Irrigation frequency and Irrigation frequency x Nitrogen source interactions were shown for NO_3^- -N at 9 weeks after transplanting and EC at 2 weeks after transplanting respectively.

Table 6 Analysis of variance (ANOVA) of drainage water pH measured at 2, 9 and 16 weeks after transplanting

Factor	pH				
	Weeks after transplanting				
	2 ^x	9 ^x	16		
	DF	<i>Pr</i> > <i>F</i>	<i>Pr</i> > <i>F</i>	DF	
Replicate				1	0.4606
Substrate	2	<.0001	<.0001	2	<.0001
Irrigation	2	0.3708	0.2706	2	0.1338
Sub x Irrig	4	0.2358	0.5753	4	0.8490
Nitrogen source	2	0.0055	<.0001	2	<.0001
Sub x Nitro	4	0.0076	0.0002	4	<.0001
Irrig x Nitro	4	0.0761	0.1458	4	0.3985
Sub x Nitro x Irrig				8	0.8459
<i>Error</i>	8			26	
<i>CV</i> (%)		2.49	2.80		7.23

^xOnly 1 replicate; DF of 3rd order interaction used for error (df=8)

Table 7 Analysis of variance (ANOVA) of drainage water EC measured at 2, 9 and 16 weeks after transplanting

Factor	EC (mS.cm ⁻¹)				
	Weeks after transplanting				
	2 ^x	9 ^x	16		
	DF	<i>Pr</i> > <i>F</i>	<i>Pr</i> > <i>F</i>	DF	
Replicate				1	0.2160
Substrate	2	<.0001	<.0001	2	0.0003
Irrigation	2	0.5276	0.0543	2	0.0956
Sub x Irrig	4	0.1567	0.1202	4	0.4301
Nitrogen source	2	0.5001	0.2597	2	0.0052
Sub x Nitro	4	0.4339	0.2981	4	0.6005
Irrig x Nitro	4	0.0353	0.2906	4	0.2085
Sub x Nitro x Irrig				8	0.9725
<i>Error</i>	8			26	
<i>CV</i> (%)		7.18	7.35		14.8

^xOnly 1 replicate; DF of 3rd order interaction used for error (df=8)

Table 8 Analysis of variance (ANOVA) of NO_3^- -N and NH_4^+ -N content in drainage water measured at 9 and 16 weeks after transplanting

Factor	NO_3^- -N (ppm)				NH_4^+ -N (ppm)			
	Weeks after transplanting							
	9 ^x		16 ^y		9 ^x		16	
DF	<i>Pr</i> > <i>F</i>	DF	<i>Pr</i> > <i>F</i>	DF	<i>Pr</i> > <i>F</i>	DF	<i>Pr</i> > <i>F</i>	
Replicate		1	0.5275			1	0.1215	
Substrate	2	<.0001	2	<.0001	2	0.0002	2	<.0001
Irrigation	2	0.0222	2	0.0342	2	0.4371	2	0.1909
Sub x Irrig	4	0.0068	4	0.5735	4	0.0735	4	0.1344
Nitrogen source	2	<.0001	2	<.0001	2	<.0001	2	<.0001
Sub x Nitro	4	0.0002	4	0.0297	4	0.0016	4	0.0023
Irrig x Nitro	4	0.0828	4	0.1254	4	0.3643	4	0.2615
Sub x Nitro x Irrig			8	0.7360			8	0.6892
<i>Error</i>	8		26		8		26	
<i>CV</i> (%)		6.60		2.32		8.30		15.69

^xOnly 1 replicate; DF of 3rd order interaction used for error (df=8)

^yData not normally distributed. Transformed with $\text{LX}=\text{Ln}(X)$

From these results it was obvious that substrate and nitrogen source and the interactions between these were by far the most important factors, which affected pH, EC, NO_3^- -N and NH_4^+ -N in the drainage water. Further discussions of the results will therefore focus on these aspects.

pH In general pH of the drainage water declined with an increase in NH_4^+ -N in the nutrient solution (Table 9). This could be expected due to the well-known acidifying effect of ammonium fertilizers. During the conversion of NH_4^+ -N to NO_3^- -N, hydrogen ions are released and in this way acidify the nutrient solution (Adams, 2002). The decline in pH increases the toxicity of NH_4^+ -N (Barker, Volk & Jackson, 1966a; 1966b).

Where sand was used as growth medium pH of the drainage water decreased with time irrespective of the nitrogen source used, but the lowest pH values were found with the highest NH_4^+ -N concentration.

Table 9 Influence of substrate and nitrogen source on drainage water pH during growth period

Factor	Drainage water pH (Weeks after transplanting)								
	Sand			Pine sawdust			Coco peat		
	2 ^x	9 ^x	16	2 ^x	9 ^x	16	2 ^x	9 ^x	16
NO ₃ ⁻ -N : NH ₄ ⁺ -N									
100% : 0%	6.8 a	6.3 b	6.3 b	6.5 b	7.1 a	7.7 a	5.1 e	5.2 c	5.5 c
80% : 20%	6.5 b	5.5 c	4.6 d	6.1 c	6.3 b	6.3 b	5.1 e	4.6 d	4.4 de
60% : 40%	6.5 b	4.7 d	4.1 de	5.7 d	4.5 d	4.5 d	5.3 e	4.1 e	4.0 e
LSD (<i>P</i> =0.05)	0.3	0.3	0.5	0.3	0.3	0.5	0.3	0.3	0.5
CV (%)	2.49	2.80	7.23	2.49	2.80	7.23	2.49	2.80	7.23

Means followed by the same letter do not differ significantly at *P* = 0.05 (LSD)

^xOnly 1 replicate; DF of 3rd order interaction used for error (df=8)

In the case of the biologically active growth substrates, pine sawdust-shavings and coco peat, pH of the drainage water increased with time where only NO₃⁻-N was applied. It is well known that microorganisms in wood fibre substrates consume nitrates and proportionally emit hydroxyl ions into the nutrient solution, thus raising the pH (Vlassak, *et al.*, 1991). Where 20% NH₄⁺-N was applied, pH of the drainage water showed either a slight increase (pine sawdust-shavings) or slight decrease (coco peat). Pill & Lambeth (1977), Adams (2002) and Sonneveld (2002) also showed that pH control could be achieved with the inclusion of ammonium (5 – 15% of the total nitrogen) in the solution formulation. Where 40% NH₄⁺-N was applied, pH declined with time for both substrates but the lowest values of 4.1 to 4.0 were found with coco peat.

Control of the pH in the nutrient solution is crucial as it affects the availability of nutrients and therefore plant nutrition. Findenegg (1987) found that when the pH decreased below 6, the potassium uptake was increasingly inhibited by NH₄⁺-N nutrition whereas, at pH 7 and above, growth may be inhibited by the presence of free NH₃. Adams (2002) also reported that the availability of phosphorus was reduced at high pH values (7 and higher). At these high pH levels all the micronutrients, except molybdenum becomes less available. The optimum solution pH is between 5.0 and 6.0 (Sonneveld, 2002). It was evident that pH of the drainage water became too low

for efficient plant nutrition, if high concentrations of NH_4^+ -N were used, especially in coco peat as growth substrate.

Electrical conductivity The nutrient solutions were made up based on a calculated EC of 2.0 mS.cm^{-1} , while measurements of the nutrient solution showed values between 2.01 and 2.03 mS.cm^{-1} (Table 4).

The EC in the drainage water was significantly affected by growth substrates with a significant increase in EC with time in all the substrates (Table 10). The largest increases were found in coco peat. This might be the result of the high cation exchange capacity (CEC) of coir (Noguera *et al.*, 1997; Noguera *et al.*, 2000). Sonneveld & van der Burg (1991) and Combrink (1998) reported that high salinity restricted plant growth and reduced the yield of tomatoes. The temperature increase (Figure 1) and insufficient water supply for good drainage might also have assisted in the EC increase. It proved very difficult to schedule irrigation as a result of the different water holding capacities of the substrates. The 15 – 20% over irrigation was not enough to leach out excess salts that might build up in the bottom of the bag.

Table 10 Influence of substrate on drainage water EC during the growth period

Factor	Drainage water EC (mS.cm^{-1})		
	Weeks after transplanting		
Substrate	2 ^x	9 ^x	16
Sand	1.84 a	3.15 b	4.14 b
Pine sawdust	1.34 c	3.23 b	3.80 b
Coco peat	1.52 b	4.71 a	4.79 a
<i>LSD (P=0.05)</i>	0.12	0.30	0.43
<i>CV (%)</i>	7.18	7.35	14.79

Means followed by the same letter do not differ significantly at $P = 0.05$ (LSD)

^xOnly 1 replicate; DF of 3rd order interaction used for error (df=8)

NO_3^- -N and NH_4^+ -N content The NO_3^- -N values measured in the drainage water was much higher, in comparison with the nutrient solution, than anticipated. However, analysis of the drainage water from substrates prior to planting (Table 3) showed that the substrates contained between 0.6 and $2.5 \text{ mmol.c.l}^{-1}$ NO_3^- -N. Although

NO_3^- -N content of the drainage water was significantly affected by irrigation frequency, Table 8 clearly showed that substrate, with nitrogen source and their interaction, were the largest contributors to differences in both NO_3^- -N and NH_4^+ -N in the drainage water. The NO_3^- -N content in the drainage water increased with time in all the substrate and nitrogen source combinations, except where 60% NO_3^- -N: 40% NH_4^+ -N was applied to coco peat (Table 11), where a slight decline in the NO_3^- -N concentration was found. The NH_4^+ -N content was constant with time (Table 12).

As expected the NO_3^- -N content of the drainage water decreased as the NH_4^+ -N content increased in the nutrient solution. In comparison the decrease in pine sawdust-shavings was much lower than in sand or coco peat. This might be due to differences in the uptake of NO_3^- -N or a higher microbial conversion of NH_4^+ -N to NO_3^- -N or immobilization of nitrogen. Vlassak *et al.* (1991) indicated that microorganisms consume NO_3^- -N nitrogen in wood fibre substrates and that the microbial biomass builds up to form its own decomposable substrate, which start to release the immobilized nutrients only 10 to 12 weeks after transplanting.

Table 11 Influence of substrate and nitrogen source on NO_3^- -N content of drainage water during the growth period

Factor	NO_3^- -N content of drainage water (ppm)					
	(Weeks after transplanting)					
	Sand		Pine sawdust		Coco peat	
NO_3^- -N : NH_4^+ -N	9 ^x	16 ^y	9 ^x	16 ^y	9 ^x	16 ^y
100% : 0%	432.6 c	514.0 b	287.1 ef	352.0 cd	637.9 a	645.8 a
80% : 20%	367.9 d	414.1 c	263.9 gf	354.0 cd	495.2 b	542.0 b
60% : 40%	244.6 fg	269.1 ef	231.2 g	242.1 f	324.8 de	306.5 de
LSD ($P=0.05$)	45.4	*	45.4	*	45.4	*
CV (%)	6.60	2.32	6.60	2.32	6.60	2.32

Means followed by the same letter do not differ significantly at $P = 0.05$ (LSD)

^xOnly 1 replicate; 3rd order interaction used for error (df=8)

^yData not normally distributed. Transformed with $LX=\ln(X)$

Table 12 Influence of substrate and nitrogen source on NH_4^+ -N content of drainage water during the growth period

Factor	NH_4^+ -N content of drainage water (ppm)					
	(Weeks after transplanting)					
	Sand		Pine sawdust		Coco peat	
NO_3^- -N : NH_4^+ -N	9 ^x	16	9 ^x	16	9 ^x	16
100% : 0%	6.4 f	5.9 f	2.8 f	1.6 f	2.2 f	1.3 f
80% : 20%	53.8 d	53.5 d	32.8 e	34.1 e	62.9 c	66.0 c
60% : 40%	103.1 b	108.4 ab	104.1 b	102.0 b	122.3 a	117.8 a
<i>LSD</i> ($P=0.05$)	8.5	10.15	8.5	10.15	8.5	10.15
<i>CV</i> (%)	8.30	15.69	8.30	15.69	8.30	15.69

Means followed by the same letter do not differ significantly at $P = 0.05$ (LSD)

^xOnly 1 replicate; 3rd order interaction used for error (df=8)

The NH_4^+ -N content increased as expected in the drainage water of each substrate as the NH_4^+ -N content increased in the nutrient solution (Table 12). Although the differences between pine sawdust-shavings and sand was not significant where 40% of the nitrogen was applied as NH_4^+ -N, the NH_4^+ -N concentration in the drainage water of the 20% NH_4^+ -N treatment, where pine sawdust-shavings was used as substrate, was significantly lower at both 9 and 16 weeks after transplanting in comparison with sand and especially coco peat. This trend supports the hypothesis that microbial activity is higher in pine sawdust-shavings, which resulted in more effective conversion of NH_4^+ -N to NO_3^- -N, compared to sand and coco peat. Nitrification is the process by which NH_4^+ -N is oxidised by chemoautotrophic bacteria to NO_3^- -N (Lang & Elliott, 1991). Coco peat and sand can therefore be characterised as substrates that is biologically stable.

The production of coco peat involves a period of storage in heaps where it undergoes aerobic composting. During composting the hemicellulose, cellulose and to a lesser extend lignin components are decomposed, causing the C/N ratio to decrease. After decomposition the coco peat is a very stable substrate (Yau & Murphy, 2000). Different sources and different production procedures result in a large variability of end products (Evans, Konduru & Stamps, 1996; Prasad, 1997; Konduru, Evans & Stamps, 1999).

Fruit yield and quality

As also found in measurements done on the drainage water, the main factors substrate and nitrogen source had a significant effect on all the yield and quality parameters (Table 13). The irrigation frequency only had a significant effect on the number of marketable fruit and the marketable yield per plant. Significant interactions between the irrigation frequency and substrate were only found for number of marketable fruit per plant, while significant irrigation frequency x nitrogen source interactions were also found for number of marketable fruit and yield per plant. Significant substrate x nitrogen source interactions were also found for all parameters with the exception of average fruit mass and percentage blossom-end rot (BER) per plant.

Table 13 Analysis of variance (ANOVA) of marketable and unmarketable yield of tomatoes

Source	DF	Marketable yield			Unmarketable yield	
		Yield (g/plant) <i>Pr > F</i>	Average fruit mass (g) <i>Pr > F</i>	Number of fruit per plant <i>Pr > F</i>	Yield (g/plant) <i>Pr > F</i>	Percentage BER per plant <i>Pr > F</i>
Replicate	1	0.0573	0.2020	0.0612	0.0002	0.0003
Substrate	2	<.0001	0.0168	<.0001	<.0001	<.0001
Irrigation	2	0.0322	0.1689	0.0020	0.3127	0.0998
Sub x Irrig	4	0.2084	0.6680	0.0176	0.0853	0.6035
Nitrogen source	2	<.0001	<.0001	<.0001	<.0001	<.0001
Sub x Nitro	4	0.0276	0.1902	0.0478	0.1322	0.0284
Irrig x Nitro	4	0.0192	0.1428	0.0300	0.6775	0.2947
Sub x Nitro x Irrig	8	0.3322	0.2362	0.1315	0.0283	0.0068
<i>Error</i>	26					
<i>CV (%)</i>		8.20	4.48	7.76	14.76	27.55

Third order interactions of significance were found for the parameters unmarketable yield and percentage BER per plant (Table 13), but because irrigation frequency, as such, did not have any significant effect on either unmarketable yield or the

percentage BER per plant, it was decided to ignore the third order interactions. Instead the effects of substrate and nitrogen source on unmarketable yield per plant and the effect of the interaction between substrate and nitrogen source on the percentage BER per plant, will be discussed.

Marketable yield The highest marketable yield per plant was obtained with coco peat as substrate, irrespective of nitrogen source used, while the lowest yields were obtained with sand as a growth substrate (Table 14). As the number of marketable fruit per plant showed the same trend, it can be assumed that marketable yield was determined by the number of fruit and not average fruit mass. Marketable yield and number of marketable fruit per plant decreased with an increase in $\text{NH}_4^+\text{-N}$ in the nutrient solution for all substrates used. This may be due to either the decrease in pH with an increase in $\text{NH}_4^+\text{-N}$ in the nutrient solution or a decrease in available $\text{NO}_3^-\text{-N}$ as shown in the drainage water.

Table 14 Influence of substrate and nitrogen source on the number of marketable fruit and yield

Factor	Marketable fruit (Number per plant)			Marketable yield per plant (g)		
	Sand	Pine sawdust	Coco peat	Sand	Pine sawdust	Coco peat
$\text{NO}_3^-\text{-N} : \text{NH}_4^+\text{-N}$						
100% : 0%	49.3 b	50.5 b	56.6 a	5948.6 bc	6129.9 b	6926.1 a
80% : 20%	36.0 d	43.9 c	47.5 bc	4109.5 e	5152.5 d	5544.4 cd
60% : 40%	28.5 f	29.9 ef	33.0 de	3110.9 g	3256.1 fg	3642.5 ef
<i>LSD</i> ($P=0.05$)	3.8			474.0		
<i>CV</i> (%)	7.76			8.20		

Means followed by the same letter do not differ significantly at $P = 0.05$ (LSD)

As already mentioned the average fruit mass was significantly affected by nitrogen source (Table 15) and substrate (Table 16). The addition of $\text{NH}_4^+\text{-N}$ decreased fruit mass from 120.7 to 94.4 g (Table 15). Pill, Lambeth & Hinckley (1978) and Ali *et al.* (1994) also found that the fruit size reduced when $\text{NH}_4^+\text{-N}$ was applied. Sand produced significantly smaller fruit than pine sawdust-shavings and coco peat (Table 16). This might be due to the low water holding capacity of sand and the intense

fluctuations in moisture content between the different irrigation schedules. However there was no significant difference in fruit mass between pine sawdust-shavings and coco peat.

Table 15 Influence of nitrogen source on fruit mass

Factor	Fruit mass (g)
NO ₃ ⁻ -N : NH ₄ ⁺ -N	
100% : 0%	120.7 a
80% : 20%	108.3 b
60% : 40%	94.4 c
<i>LSD (P=0.05)</i>	3.3
<i>CV (%)</i>	4.48

Table 16 Influence of substrate on fruit mass

Factor	Fruit mass (g)
Substrate	
Sand	105.0 b
Pine sawdust	108.5 a
Coco peat	109.8 a
<i>LSD (P=0.05)</i>	3.3
<i>CV (%)</i>	4.48

Means followed by the same letter do not differ significantly at P = 0.05 (LSD)

An optimal irrigation frequency depended on the nitrogen source used in the nutrient solution (Table 17). Where nitrate was used as the only source of nitrogen, highest yields were obtained with 12 irrigations per day. When the NO₃⁻-N content in the nutrient solution were reduced to 80% and 60%, marketable yield was also reduced but no significant differences were shown due to the frequency of irrigation. Similar trends for the number of fruit per plant again indicated that marketable yield was primarily determined by number of fruit per plant and not average fruit mass.

Table 17 Influence of nitrogen source and irrigation frequency on the number of marketable fruit and yield

Factor	Marketable fruit (Number per plant)			Marketable yield per plant (g)		
	Irrigation frequency per day			Irrigation frequency per day		
	3	6	12	3	6	12
NO ₃ ⁻ -N : NH ₄ ⁺ -N						
100% : 0%	48.8 bc	52.0 ab	55.6 a	6134.2 b	6118.4 b	6752.0 a
80% : 20%	39.3 e	45.7 cd	42.3 de	4560.0 d	5281.3 c	4965.1 cd
60% : 40%	29.7 f	32.5 f	29.3 f	3265.9 e	3541.6 e	3202.1 e
<i>LSD (P=0.05)</i>	3.8			474.0		
<i>CV (%)</i>	7.76			8.20		

Means followed by the same letter do not differ significantly at P = 0.05 (LSD)

The optimum irrigation frequency also depends on the substrate used (Table 18). The highest number of marketable fruit was produced when coco peat was irrigated 6 or 12 times per day, significantly more than with either sand and pine sawdust-shavings, but the increase in irrigation frequency did not result in a significant increase in the number of fruit when coco peat and pine sawdust-shavings was used. Sand produced significantly more fruit when irrigated 6 times per day. Trends however indicated that fewer than 12 irrigations per day might be optimal. This might be the result of a good water:oxygen ratio in the substrate when irrigated 6 times per day. Twelve irrigations per day might have been responsible for waterlogged conditions in the substrates.

Mitchell *et al.* (1991) reported that the frequency of irrigation and quantity of nutrient solution provided to the plants affected yield and fruit quality. Irrigation control can also influence fruit size (Adams, 1990). Ismail, Halimi & Jusoh (1993) indicated that proper irrigation management is of the utmost importance and that tomato yields increased significantly when the correct irrigation frequency per day is applied.

Table 18 Influence of substrate and irrigation frequency on the number of marketable fruit per plant

Factor	Marketable fruit (Number per plant)		
	Irrigation frequency per day		
	3	6	12
Substrate			
Sand	37.3 de	40.6 bcd	35.9 e
Pine sawdust	39.5 cde	41.2 bc	43.6 b
Coco peat	41.0 bcd	48.4 a	47.6 a
<i>LSD (P=0.05)</i>	3.8		
<i>CV (%)</i>	7.76		

Means followed by the same letter do not differ significantly at P = 0.05 (LSD)

Unmarketable yield The unmarketable yield increased significantly with an increase in $\text{NH}_4^+\text{-N}$ in the nutrient solution (Table 19). An increase of 96.1% and 178.8% in unmarketable yield was observed when the $\text{NH}_4^+\text{-N}$ concentration was respectively increased from 0 to 20% and 0 to 40% of the total nitrogen application. Pine sawdust-shavings produced the lowest unmarketable yield, followed by coco peat and sand (Table 20). Visual evaluations showed that BER was the main contributor to unmarketable yield (Table 21).

Table 19 Influence of nitrogen source on unmarketable yield

Factor	Yield
$\text{NO}_3^-\text{-N} : \text{NH}_4^+\text{-N}$	(g/plant)
100% : 0%	528.3 c
80% : 20%	1035.8 b
60% : 40%	1473.1 a
<i>LSD (P=0.05)</i>	102.4
<i>CV (%)</i>	14.76

Table 20 Influence of substrate on unmarketable yield

Factor	Yield
Substrate	(g/plant)
Sand	1183.9 a
Pine sawdust	817.8 c
Coco peat	1035.5 b
<i>LSD (P=0.05)</i>	102.4
<i>CV (%)</i>	14.76

Means followed by the same letter do not differ significantly at $P = 0.05$ (LSD)

The percentage BER was expressed as a percentage of the total number of fruit harvested per plant (Table 21). The lowest percentage BER fruit was produced when $\text{NO}_3^-\text{-N}$ was applied as the sole source of nitrogen. The percentage BER increased significantly in all growth substrates used as the $\text{NH}_4^+\text{-N}$ concentration in the nutrient solution increased from 0 to 40% of the total nitrogen application. The highest percentage BER fruit was produced with the 60% $\text{NO}_3^-\text{-N} : 40\% \text{NH}_4^+\text{-N}$ treatment, when sand was used as substrate. The sandy substrate also resulted in significantly more BER compared to pine sawdust-shavings and coco peat where 20% of the nitrogen was applied as $\text{NH}_4^+\text{-N}$. No significant differences in the percentage BER fruit between pine sawdust-shavings and coco peat were found at any nitrogen source treatment.

Table 21 Influence of substrate and nitrogen source on the percentage blossom-end rot of tomato fruit

Factor NO ₃ ⁻ -N : NH ₄ ⁺ -N	Percentage blossom-end rot fruit per plant		
	Sand	Pine sawdust	Coco peat
100% : 0%	5.8 de	3.0 e	2.9 e
80% : 20%	28.5 b	11.5 cd	14.2 c
60% : 40%	44.0 a	32.6 b	32.0 b
<i>LSD</i> (<i>P</i> =0.05)	6.3		
<i>CV</i> (%)	27.55		

Means followed by the same letter do not differ significantly at *P* = 0.05 (*LSD*)

The higher percentage BER found with the sandy substrate might be as a result of a higher root zone temperature, due to the fact that the plants were cultivated in black plastic bags and that sand retains more heat than pine sawdust-shavings and coco peat, and these factors might have an effect on the uptake of calcium. High root temperature has been found to aggravate the BER inducing effect of high ammonium levels in the nutrient solution (Ho, Hand & Fussell, 1999).

Kafkafi (2000) found that healthy tomato plants are grown in sand with a nutrient solution containing only NO₃⁻-N, but the addition of NH₄⁺-N caused damage to the roots. Root temperature is an important factor in determining the rates of uptake of nutrients and water (Adams, 2002). Ganmore-Neumann & Kafkafi (1983) studied the combined effect of root zone temperature and the presence of NH₄⁺-N in the nutrient solution on root function. High root zone temperatures, above 30°C, and the application of NH₄⁺-N had a detrimental effect on root growth and development. Pill *et al.* (1978) found earlier that plants receiving NH₄⁺-N experienced water stress. Adams & Ho (1993) found that not only restricted absorption of water but also an increased rate of transpiration could cause an increase in BER. Adams & Ho (1995) also proposed that restricted calcium uptake by the roots can be due to either increased salinity or interactions with other nutrients such as NH₄⁺-N in the nutrient solution, or poor aeration in the root zone. High levels of NH₄⁺-N could depress the uptake of calcium and therefore decrease the calcium content in the fruit, resulting in BER.

Conclusions

Nitrogen source and substrate have been shown to have an effect on yield and quality of tomatoes. NH_4^+ -N nutrition, between 20 and 40% of the total nitrogen in the nutrient solution, increased the incidence of blossom-end rot, and caused a reduction in fruit size and number of marketable fruit per plant. The negative effect of NH_4^+ -N on marketable yield was enhanced by the effect it had on drainage water pH within the different substrates, the lowest pH to be found in coco peat when a high NH_4^+ -N level is applied.

Unlike coco peat, pine sawdust-shavings is not composted. Therefore the microbial activity was much higher in pine sawdust-shavings, which had an effect on NO_3^- -N use and pH of the drainage water. This suggests that there might be a period of N-immobilization within the first 9 to 16 weeks after transplanting. However, coco peat was much more biologically stable than pine sawdust-shavings.

Coco peat produced the highest yield when NO_3^- -N was applied as the sole source of nitrogen and the nutrient solution was irrigated 12 times per day. Higher irrigation frequencies increase the number of marketable fruit and yield per plant.

Future research should include more frequent drainage water sampling, which will underline the effect of N-immobilization on yield and quality of tomatoes.

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CHAPTER 4

Influence of substrate, nitrogen source, irrigation frequency and period of substrate use on yield and quality of greenhouse grown tomatoes (*Lycopersicon esculentum* Mill.)

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Abstract

Pine sawdust-shavings (*Pinus* spp.) is at present a very popular soilless substrate in South African greenhouses. A shortage of this substrate is inevitable due to a decline in pine plantations and expansion in the greenhouse industry. South African producers use fresh pine sawdust-shavings as a substrate, which is biologically highly unstable. This is forcing the greenhouse industry to look at alternative substrates such as coco peat, which already went through a decomposition process and is more stable. The influence of substrate (sand, pine sawdust-shavings, coco peat), nitrogen source (NO_3^- -N : NH_4^+ -N ratios of 100% : 0%, 80% : 20%, 60% : 40%), irrigation frequency (3x, 6x, 12x per day) and period of substrate use on yield and quality of greenhouse grown tomatoes were studied to determine the effect thereof on plant growth and marketable yield. Treatments were arranged in a randomised block design, using two replicates. Interactions between nitrogen source and substrate age had a significant effect on marketable and unmarketable yield. The second season of substrate use, irrespective of nitrogen source, lead to a decrease in drainage water pH, in the number of marketable fruit and yield per plant, and an increase in unmarketable yield per plant. The highest yield of tomatoes was obtained in new coco peat. In the second season of substrate use there was no significant difference between the marketable yields of the different substrates. Drainage water NO_3^- -N values indicated that pine sawdust-shavings was the most biologically active substrate. High NH_4^+ -N applications resulted in a reduction in marketable yield and increased the incidence of blossom-end rot.

Keywords: blossom-end rot, decomposition, irrigation, nitrogen, substrate, tomato

Introduction

A mixture of pine sawdust-shavings is at present a very important soilless substrate in South African greenhouses and producers use this as a stand-alone substrate for the production of tomatoes, cucumbers and sweet peppers (Maree, 1994). However, the demand for pine sawdust-shavings increased to such an extent that a shortage is developing in some of the major greenhouse production areas. This and other problems are forcing the greenhouse industry to look at other more durable, relatively inexpensive, high quality substrates such as coco peat.

Particle size distribution has a profound effect on the water holding capacity of a substrate. Lemaire, Dartigues & Rivière (1989) reported for example a vast difference between the water holding capacity of fine and coarse wood fibre substrates. Differences in bulk density between substrates and substrate batches can also be attributed to differences in particle size distribution. Noguera, Abad & Noguera (2000) found that the bulk density of different coco peat samples varied between 0.03 and 0.09 g.cm⁻³. The extraction process of coconut husk and screening of coconut waste are responsible for these differences. Unscreened coconut waste contains more fibre, has a lower bulk density and lower water holding capacity than screened coconut waste (Konduru, Evans & Stamps, 1999). Therefore the water holding capacity and irrigation requirements of different batches of pine sawdust-shavings and coco peat may vary.

Decomposition of organic substrates changes the physical and chemical properties of a substrate and therefore may have an effect on the yield and quality of the crop being produced. The water holding capacity, bulk density and cation exchange capacity increases with degradation (Mbah & Odili, 1998; Shadhidul Islam *et al.*, 2002). Pine fibre substrates has a lower lignin content compared to coco peat and as a result decomposes more rapidly during the growing season (Ghoos, 1993; Noguera *et al.*, 2000). Decomposition of pine fibre substrates, especially when NO₃⁻-N is used as nitrogen source, results in an increase in pH (Vlassak *et al.*, 1991), which affects the availability of phosphorus and all the micronutrients except molybdenum (Adams, 2002).

Generally the high C/N ratio of raw coir dust is comparable to that of fresh sawdust (Noguera *et al.*, 1997; Noguera *et al.*, 2000; Yau & Murphy 2000). These high C/N ratios could cause the immobilization of inorganic nitrogen (Noguera *et al.*, 1997; Noguera *et al.*, 2000). However, composting of coco peat and pine sawdust may result in a reduced C/N ratio and therefore less immobilization of inorganic N (Worrall, 1978; Yau & Murphy, 2000). When organic matter decomposes, the C/N ratio decreases up to a value, which remains stable but variable with the kind of product. The higher the C/N ratio the slower the degradation process will take place. Higher biostability can be achieved with a product containing high lignin values (Lemaire, 1997).

South African producers use fresh pine sawdust-shavings as a substrate. This material is highly unstable and biodegradation will have an effect on crop production. However, the production of coco peat involves a period of storage in heaps where it undergoes aerobic composting. After decomposition coco peat is a very stable substrate (Yau & Murphy, 2000). Different sources of coco peat and different production procedures however result in a large variability of end products (Evans, Konduru & Stamps, 1996; Prasad, 1997; Konduru *et al.*, 1999).

The use of ammonium and nitrate as nitrogen source in re-circulating nutrient solutions has been attracting much attention, especially since the $\text{NH}_4^+\text{-N} : \text{NO}_3^-\text{-N}$ ratio can be used to control the pH, which tends to rise markedly when $\text{NO}_3^-\text{-N}$ is used (Pill & Lambeth, 1977). $\text{NH}_4^+\text{-N}$, applied as 10 to 20% compared to 0% of the total nitrogen, decreases fruit size and marketable yield (Hohjo *et al.*, 1995). Very high levels of $\text{NH}_4^+\text{-N}$ in the root zone can depress the uptake of calcium and therefore decreases the calcium content of the fruit, causing blossom-end rot (Adams & Ho, 1995). Optimum plant nutrition levels (N-ratio) may be different for coco peat and pine sawdust-shavings.

As a result of the lack of comparative data between substrates, it was decided to conduct an experiment where yield and quality of tomatoes were evaluated in different substrates with different usage periods, which was subjected to different irrigation frequencies and nitrate to ammonium N-ratios. Sand was included as a

substrate because it is highly resistant to weathering and not subjected to biodegradation processes.

Materials and methods

Locality and climate A greenhouse trial was conducted at Stellenbosch in the Western Cape Province of South Africa during the summer and autumn of 2001. The weekly average minimum and maximum temperatures outside the greenhouse are presented in Figure 1. From this figure it is clear that especially daily maximum temperatures decreases gradually during the duration of the experiment.

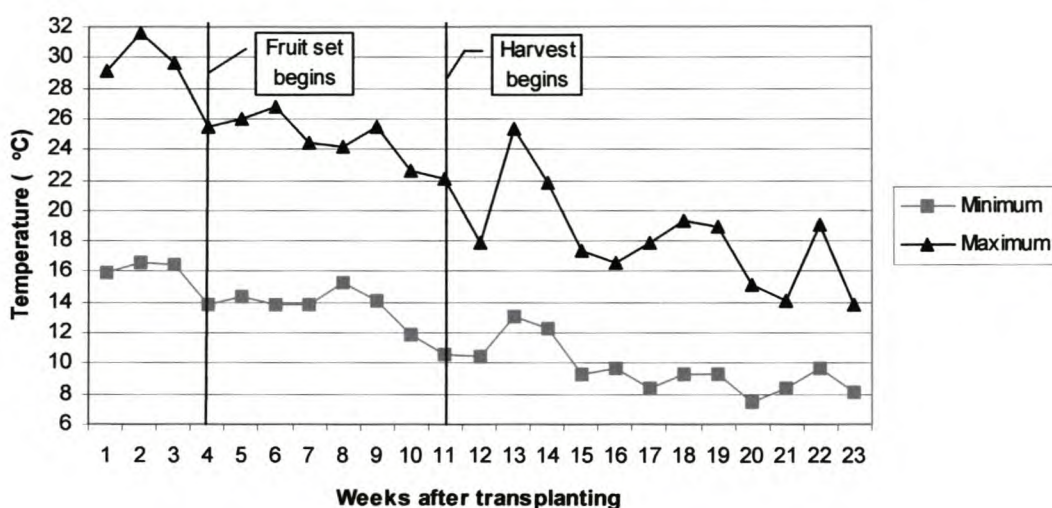


Figure 1 Weekly minimum and maximum temperatures outside the greenhouse during the growth period of 14 February 2001 to 27 July 2001

Cultivation practices Seeds of the tomato (*Lycopersicon esculentum* Mill.) cultivar FA593 (Mayford Seeds, South Africa) were sown on 3 January 2001 in seedling trays. The seedlings were produced in a substrate that consisted of 1 part Hygrotech seedling mix (peat, polystyrene, vermiculite), 1 part vermiculite and 1 part composted pine bark. Seedlings were watered with a 50% diluted ($1.1 \text{ mS}\cdot\text{cm}^{-1}$) nutrient solution (Steiner, 1984) and transplanted into the greenhouse on 14 February 2001 (6 weeks after sowing). Only one seedling was transplanted per 18 litre black plastic bag. Drainage holes were made at 2.5 cm from the bottom of the bag to create a reservoir from which the drainage water samples were extracted. The bags were placed in 8 double rows and the spacing between rows (from centre of bag) was 0.40 m and within the row 0.35 m. The spacing between each double row (from centre of

row) was 1.60 m. A plant population of 2.5 plants per m² were maintained in the greenhouse. Standard cultural practices for the production of greenhouse tomatoes were applied. Side shoots were removed and the plants were trellised to a height of 1.70 m above the bag. An average of 6 trusses per plant were recorded. Terminal growing points were removed once the plants reached the crop support wire. A naturally ventilated greenhouse was used. No heating was applied and during hot weather, temperature control was done by means of natural ventilation and the application of lime on the polycarbonate sheeting of the greenhouse.

Treatments and experimental design Sand (collected from the Berg River), a pine sawdust-shavings mixture and coco peat were evaluated. The same volume of substrate (18 litre per bag) was used for all the treatments, although the characteristics of each substrate differed. All the substrates were washed with municipal water before planting. The same substrates as the above, which have been used for 5 months (see Chapter 3), were included to determine the effect of usage period on yield and quality of tomatoes. Three nitrogen source treatments (NO₃⁻-N : NH₄⁺-N ratios of 100% : 0%, 80% : 20%, 60% : 40%) were evaluated (Table 1). NO₃⁻-N and NH₄⁺-N was applied as 5[Ca(NO₃)₂·2H₂O]NH₄NO₃ (contains 1.3% NH₄⁺-N) and KNO₃, and (NH₄)₂SO₄ respectively.

Table 1 Composition of nutrient solutions as affected by nitrogen source

Factor	NH ₄ ⁺	K ⁺	Ca ²⁺	Mg ²⁺	NO ₃ ⁻	H ₂ PO ₄ ⁻	SO ₄ ²⁻
NO ₃ ⁻ -N : NH ₄ ⁺ -N	mmol _c .l ⁻¹						
100% : 0%	0	8	8	4	14	1	5
80% : 20%	2.80	6.88	6.88	3.44	11.20	1.47	7.33
60% : 40%	5.60	5.76	5.76	2.88	8.40	1.93	9.67

According to initial calculations made, the total nitrogen concentration for all the N-source treatments were supposed to be 14 mmol_c.l⁻¹ (196 ppm N). However, the average nitrogen content, after mixing of the different solutions, were 15.3, 14.7 and 13.6 mmol_c.l⁻¹ for the 100% NO₃⁻-N : 0% NH₄⁺-N, the 80% NO₃⁻-N : 20% NH₄⁺-N and the 60% NO₃⁻-N : 40% NH₄⁺-N treatments respectively, but varied slightly between weeks (Table 2 and 3).

Table 2 NO₃⁻-N content of irrigated nutrient solution during the growth period

Factor	NO ₃ ⁻ -N (ppm)					Average
	Weeks after transplanting					
NO ₃ ⁻ -N : NH ₄ ⁺ -N	5	8	11	14	17	
100% : 0%	175.9	204.0	192.6	230.9	204.7	201.6
80% : 20%	137.7	167.9	162.5	176.2	157.8	160.4
60% : 40%	89.7	118.6	126.3	134.5	128.3	119.5

Table 3 NH₄⁺-N content of irrigated nutrient solution during the growth period

Factor	NH ₄ ⁺ -N (ppm)					Average
	Weeks after transplanting					
NO ₃ ⁻ -N : NH ₄ ⁺ -N	5	8	11	14	17	
100% : 0%	9.6	9.7	14.6	11.9	15.0	12.2
80% : 20%	44.1	41.7	47.6	44.2	50.1	45.5
60% : 40%	60.0	71.4	78.8	67.6	78.2	71.2

Drainage water was sampled during week 5, 8, 11, 14 and 17 after transplanting. Measurements included NO₃⁻-N and NH₄⁺-N content (for all sampling dates) and electrical conductivity (EC) and pH (only in week 8, 11, 14 and 17). NO₃⁻-N was determined using the salicylic acid method (Cataldo *et al.*, 1975), while the indophenol-blue method (Keeney & Nelson, 1982) was used to determine NH₄⁺-N. The same measurements were done on the drainage water of substrates before transplanting (see Chapter 3), according to the pour-through nutrient extraction procedure (Wright, 1986), and on a regular basis on the irrigated nutrient solutions.

The average EC and pH of the three nutrient solutions used for irrigation varied between 1.82 to 1.87 mS.cm⁻¹ and 5.91 to 6.16 respectively, during the growing season (Table 4 and 5). The most acidic nutrient solution contained 40% NH₄⁺-N, applied as ammonium sulphate. The pH of the irrigated nutrient solution changed very little during the growing season, except in week 17 when there was a slight increase in pH when 80% NO₃⁻-N : 20% NH₄⁺-N was applied and a slight decrease when 60% NO₃⁻-N : 40% NH₄⁺-N was applied. No pH correction was done. The EC and pH of

the municipal water used in the experiment was 0.08 mS.cm^{-1} and 7.10 respectively. Therefore the municipal water, as in the first experiment (Chapter 3) contributed very little towards the final nutrient solution composition (Table 6).

Table 4 EC measurements of irrigated nutrient solution during the growth period

Factor	EC (mS.cm^{-1})				
	Weeks after transplanting				
$\text{NO}_3^- \text{-N} : \text{NH}_4^+ \text{-N}$	8	11	14	17	Average
100% : 0%	1.85	1.93	1.81	1.71	1.83
80% : 20%	1.91	1.89	1.89	1.60	1.82
60% : 40%	1.85	2.08	1.87	1.69	1.87

Table 5 pH measurements of irrigated nutrient solution during the growth period

Factor	pH				
	Weeks after transplanting				
$\text{NO}_3^- \text{-N} : \text{NH}_4^+ \text{-N}$	8	11	14	17	Average
100% : 0%	6.17	6.13	6.15	6.17	6.16
80% : 20%	6.06	6.06	6.09	6.19	6.10
60% : 40%	5.97	5.92	5.88	5.87	5.91

Table 6 Composition of municipal water used during the experiment

EC	pH	Na^+	NH_4^+	K^+	Ca^{2+}	Mg^{2+}	NO_3^-	H_2PO_4^-	SO_4^{2-}	Cl^-	HCO_3^-
mS.cm^{-1}		$\text{mmol}_c.\text{l}^{-1}$									
0.08	7.1	0.20	0	0	0.30	0.10	0	0	0.10	0.20	0.30

The nutrient solutions were mixed and stored in 1500 litre plastic tanks. Netafim drippers (pressure compensated, non-leakage), with a capacity of 2 l.hr^{-1} , were used to irrigate each bag individually. To prevent the mixing of nutrient solutions, the system was designed so that each treatment had its own separate irrigation system. An irrigation controller and timer were used to schedule irrigation. Three irrigation frequencies (3x, 6x, 12x per day) were applied. However, the total volume of nutrient solution irrigated per treatment per day was the same for all the treatments. The first and last irrigation took place within 1 hour from sunrise and sunset respectively. The

day length decreased from 13 hours in February to 8 hours in July. Water application ranged from 500 ml per plant per day, just after transplanting, to 2300 ml during the peak production period (15 to 20 weeks after transplanting). The irrigation volumes per day were gradually increased during the growing season and included an over irrigation of 15 to 20%. This proved to be very difficult as a result of the different water holding capacity characteristics and stage of degradation of the substrates.

Data collected The stem diameter was measured 10 weeks (25 April 2001) after transplanting, just below the third tomato truss. The first fruit were harvested 11 weeks after transplanting and harvesting continued until week 23 (27 July 2001). The fruit were harvested twice a week and the yield was graded into two categories, marketable (only first class tomatoes) and unmarketable. Tomatoes were classified as unmarketable according to the following criteria: i) Fruit smaller than 40 mm in diameter; and ii) Fruit with defects like uneven colouring, shoulder cracks, fruit that is soft at harvest, fruit with blossom-end rot (BER) and abnormal growth. Marketable and unmarketable yield measurements were taken during the harvest period. At the end of the growing season the marketable and unmarketable yield per plant, the number of marketable fruit per plant, the number of fruit with BER per plant and the average fruit mass were calculated.

Statistical analysis The experimental design was a split plot with 54 treatment combinations replicated in two blocks. The main plot treatment design was a 3x3x3 factorial with three substrates (Sand, Pine sawdust-shavings, Coco peat), three irrigation levels (3x, 6x, 12x per day) and three nitrogen source treatments (NO_3^- -N : NH_4^+ -N ratios of 100% : 0%, 80% : 20%, 60% : 40%), and two subplot treatments (fresh substrate and recycled substrate). Four plants represented an experimental unit. Variables (e.g. marketable yield, unmarketable yield etc.) were assessed weekly during the trial period until the end of the season. A split-plot analysis of variance (Anova) was performed for each assessment time separately, using the GLM (General Linear Models) procedure of SAS statistical software version 8.2 (SAS, 2000). The Shapiro-Wilk test was performed to test for normality (Shapiro & Wilk, 1965). Student's t-test significant difference was calculated at the 5% level to compare treatment means. A probability level of 5% was considered significant for all significance tests.

Results and discussion

Drainage water

From Tables 7, 8, 9 and 10 it became clear that substrate as a main factor had a significant effect on all parameters tested in the drainage water at all sampling times, except when NO_3^- -N was sampled 14 weeks after transplanting. Nitrogen source had a significant effect on pH and NH_4^+ -N content at all sampling times, but had no effect on EC and NO_3^- -N content at sampling dates 11 and 14 weeks after transplanting respectively. Substrate age had a significant effect on pH at all sampling times, but had no significant effect on EC and NO_3^- -N content at 11 weeks after transplanting and NH_4^+ -N content at 14 weeks after transplanting. Irrigation frequency had no effect on any of the parameters tested in the drainage water at all sampling times.

Significant substrate x nitrogen source interactions were recorded for pH, and NO_3^- -N and NH_4^+ -N content, but not for NO_3^- -N and NH_4^+ -N content at 14 weeks after transplanting. Substrate x age interactions were significant for pH, EC, and NO_3^- -N and NH_4^+ -N content at all sampling times. Significant nitrogen source x age interactions were shown for pH at all sampling times, but not for EC at sampling dates 11 and 17 weeks after transplanting, NO_3^- -N content at sampling dates 5, 8 and 11 weeks after transplanting and NH_4^+ -N content at sampling dates 14 and 17 weeks after transplanting. Substrate x irrigation frequency interactions had no effect on pH and NH_4^+ -N content, but significant interactions were obtained for NO_3^- -N content and EC at 8 and 17 weeks after transplanting respectively. Irrigation frequency x nitrogen source interactions were significant for EC and NH_4^+ -N content at 17 weeks after transplanting, but not for pH and NO_3^- -N content at any sampling time.

Substrate x nitrogen source x irrigation frequency interactions had no significant effect on pH, EC and NO_3^- -N content at any sampling time, but affected the NH_4^+ -N content significantly at 8 weeks after transplanting. Substrate x irrigation frequency x age interactions were significant for at EC 14 and 17 weeks after transplanting, NO_3^- -N content at 5 weeks after transplanting, and NH_4^+ -N content at 8 and 11 weeks after transplanting, but not for pH at any sampling time. Significant substrate x nitrogen source x age interactions were shown for NH_4^+ -N content at all sampling times,

except 17 weeks after transplanting. Substrate x nitrogen source x age interactions were also significant for pH at 8 weeks after transplanting, EC at 14 and 17 weeks after transplanting, and NO_3^- -N content at 5 and 11 weeks after transplanting. Significant irrigation frequency x nitrogen source x age interactions were calculated for pH at 8 weeks after transplanting and for NH_4^+ -N content at 5 and 8 weeks after transplanting, but not for EC and NO_3^- -N content at any of the sampling times.

Significant substrate x irrigation frequency x nitrogen source x age interactions were obtained for NO_3^- -N content at sampling dates 8 and 11 weeks after transplanting, but not for pH, EC and NH_4^+ -N content at any of the sampling times.

From these results it is clear that substrate, nitrogen source, substrate age and their interactions were by far the most important factors which affected pH, EC, and NO_3^- -N and NH_4^+ -N content in the drainage water. Further discussions of the results will therefore focus on these aspects.

Table 7 Analysis of variance (ANOVA) of drainage water pH measured at 8, 11, 14 and 17 weeks after transplanting

Factor	DF	pH			
		Weeks after transplanting			
		8	11	14 ^y	17 ^z
	<i>Pr > F</i>	<i>Pr > F</i>	<i>Pr > F</i>	<i>Pr > F</i>	
Replicate	1	0.0618	0.4171	0.5202	0.9205
Substrate	2	<.0001	<.0001	<.0001	<.0001
Irrigation	2	0.3193	0.3713	0.1108	0.1056
Sub x Irrig	4	0.5005	0.4562	0.3157	0.7422
Nitrogen source	2	<.0001	<.0001	<.0001	<.0001
Sub x Nitro	4	<.0001	<.0001	0.0009	0.0002
Irrig x Nitro	4	0.2712	0.3720	0.0956	0.6886
Sub x Nitro x Irrig	8	0.0510	0.3410	0.6796	0.8155
<i>Error a</i>	26				
Age	1	<.0001	<.0001	<.0001	<.0001
Sub x Age	2	0.0421	0.0266	<.0001	<.0001
Irrig x Age	2	0.5786	0.8562	0.3716	0.0888
Sub x Irrig x Age	4	0.8487	0.6875	0.3615	0.4312
Nitro x Age	2	<.0001	<.0001	0.0181	0.0002
Sub x Nitro x Age	4	<.0001	0.9281	0.2841	0.8682
Irrig x Nitro x Age	4	0.1702	0.0382	0.3054	0.1890
Sub x Irrig x Nitro x Age	8	0.2483	0.0699	0.5258	0.7244
<i>Error b</i>	27				
<i>CV (%)</i>		5.41	7.50	7.24	3.68

^yData not normally distributed. Transformed with LX=1/(X)^zData not normally distributed. Transformed with LX=Log(X)

Table 8 Analysis of variance (ANOVA) of drainage water EC measured at 8, 11, 14 and 17 weeks after transplanting

Factor	DF	EC (mS.cm ⁻¹)			
		Weeks after transplanting			
		8 ^w	11 ^x	14 ^y	17 ^z
		<i>Pr</i> > <i>F</i>	<i>Pr</i> > <i>F</i>	<i>Pr</i> > <i>F</i>	<i>Pr</i> > <i>F</i>
Replicate	1	0.0111	0.0014	0.6197	0.4333
Substrate	2	<.0001	0.0004	0.0032	<.0001
Irrigation	2	0.1361	0.9995	0.7593	0.2512
Sub x Irrig	4	0.6400	0.5002	0.5622	0.0127
Nitrogen source	2	0.0274	0.0842	<.0001	0.0151
Sub x Nitro	4	0.4608	0.3687	0.0628	0.7076
Irrig x Nitro	4	0.6119	0.2528	0.1374	0.0020
Sub x Nitro x Irrig	8	0.6693	0.2794	0.9946	0.4409
<i>Error a</i>	26				
Age	1	0.0129	0.2117	<.0001	0.0416
Sub x Age	2	<.0001	0.0143	0.0110	0.0018
Irrig x Age	2	0.0902	0.0849	0.5246	0.1122
Sub x Irrig x Age	4	0.1753	0.3794	0.0395	0.0370
Nitro x Age	2	0.0144	0.6832	0.0012	0.8517
Sub x Nitro x Age	4	0.0609	0.1406	0.0140	0.0187
Irrig x Nitro x Age	4	0.5351	0.2850	0.3299	0.1341
Sub x Irrig x Nitro x Age	8	0.3423	0.3200	0.2504	0.5383
<i>Error b</i>	27				
<i>CV</i> (%)		10.09	12.75	9.20	7.88

^{wz}Data not normally distributed. Transformed with LX=1/(X)^{xy}Data not normally distributed. Transformed with LX=Log(X)

Table 9 Analysis of variance (ANOVA) of NO₃⁻-N content in drainage water measured at 5, 8, 11, 14 and 17 weeks after transplanting

Factor	NO ₃ ⁻ -N (ppm)					
	DF	Weeks after transplanting				
		5	8 ^x	11 ^y	14 ^z	17
		<i>Pr</i> > <i>F</i>	<i>Pr</i> > <i>F</i>	<i>Pr</i> > <i>F</i>	<i>Pr</i> > <i>F</i>	<i>Pr</i> > <i>F</i>
Replicate	1	0.8283	0.0007	0.0004	0.4013	0.5960
Substrate	2	<.0001	<.0001	<.0001	0.1468	<.0001
Irrigation	2	0.5447	0.6190	0.7241	0.3803	0.1368
Sub x Irrig	4	0.5563	0.0043	0.2719	0.5332	0.2466
Nitrogen source	2	0.0004	<.0001	<.0001	0.0725	<.0001
Sub x Nitro	4	<.0001	<.0001	0.0213	0.5911	0.0258
Irrig x Nitro	4	0.1723	0.5165	0.6235	0.3836	0.5154
Sub x Nitro x Irrig	8	0.2998	0.3598	0.5661	0.4239	0.4393
<i>Error a</i>	26					
Age	1	<.0001	<.0001	0.9042	0.0004	0.0459
Sub x Age	2	<.0001	<.0001	<.0001	0.0009	<.0001
Irrig x Age	2	0.0394	0.1326	0.9399	0.6220	0.0647
Sub x Irrig x Age	4	0.0145	0.8688	0.2009	0.0742	0.8391
Nitro x Age	2	0.7843	0.1509	0.3282	0.0009	0.0499
Sub x Nitro x Age	4	0.0058	0.2567	0.0037	0.2475	0.1656
Irrig x Nitro x Age	4	0.5287	0.1158	0.8874	0.6599	0.4458
Sub x Irrig x Nitro x Age	8	0.2103	0.0404	0.0325	0.1103	0.9861
<i>Error b</i>	27					
<i>CV</i> (%)		36.25	3.44	2.60	2.56	9.75

^{x y z}Data not normally distributed. Transformed with LX=Log(X)

Table 10 Analysis of variance (ANOVA) of NH_4^+ -N content in drainage water measured at 5, 8, 11, 14 and 17 weeks after transplanting

Factor	DF	NH_4^+ -N (ppm)				
		Weeks after transplanting				
		5	8	11	14	17
		<i>Pr > F</i>	<i>Pr > F</i>	<i>Pr > F</i>	<i>Pr > F</i>	<i>Pr > F</i>
Replicate	1	0.3426	0.1150	0.0090	0.7940	0.6072
Substrate	2	<.0001	<.0001	0.0002	0.0064	<.0001
Irrigation	2	0.1331	0.2431	0.5424	0.5539	0.1717
Sub x Irrig	4	0.1029	0.0855	0.4768	0.6581	0.2153
Nitrogen source	2	<.0001	<.0001	<.0001	<.0001	<.0001
Sub x Nitro	4	0.0184	<.0001	0.0425	0.1013	0.0005
Irrig x Nitro	4	0.4349	0.1315	0.7336	0.2087	0.0094
Sub x Nitro x Irrig	8	0.3443	0.0486	0.6512	0.7073	0.2209
<i>Error a</i>	26					
Age	1	<.0001	<.0001	<.0001	0.0886	0.0020
Sub x Age	2	<.0001	<.0001	<.0001	<.0001	<.0001
Irrig x Age	2	0.0010	0.0713	0.5749	0.9329	0.9142
Sub x Irrig x Age	4	0.1088	0.0298	0.0338	0.3979	0.4952
Nitro x Age	2	<.0001	<.0001	<.0001	0.1372	0.3750
Sub x Nitro x Age	4	0.0012	<.0001	0.0123	0.0398	0.5986
Irrig x Nitro x Age	4	<.0001	0.0018	0.3330	0.5740	0.6727
Sub x Irrig x Nitro x Age	8	0.1581	0.2415	0.5042	0.5194	0.1069
<i>Error b</i>	27					
<i>CV (%)</i>		36.84	16.87	11.54	14.67	12.31

pH The pH of the irrigated nutrient solution (Table 5) and drainage water (Table 11) declined with an increase in $\text{NH}_4^+\text{-N}$ in the nutrient solution. This was emphasised when the pH of drainage water from fresh and recycled (from previous experiment, Chapter 3) growth substrates were compared (Table 13). This acidifying effect of ammonium fertilizers could be expected due to the release of hydrogen ions during the conversion of $\text{NH}_4^+\text{-N}$ to $\text{NO}_3^-\text{-N}$ (Adams, 2002).

Table 11 Influence of substrate and nitrogen source on drainage water pH during the growth period

Factor	Drainage water pH			
	Weeks after transplanting			
$\text{NO}_3^-\text{-N} : \text{NH}_4^+\text{-N}$	Sand			
	8	11	14	17
100% : 0%	7.32 b	6.95 b	6.17 f	6.77 b
80% : 20%	6.16 d	5.64 d	5.12 d	5.40 cd
60% : 40%	5.81 e	5.61 d	4.78 c	5.21 d
	Pine sawdust			
	8	11	14	17
100% : 0%	7.60 a	7.54 a	7.39 g	7.37 a
80% : 20%	6.79 c	6.26 c	6.06 f	5.68 c
60% : 40%	5.03 f	4.58 ef	4.69 c	4.52 e
	Coco peat			
	8	11	14	17
100% : 0%	6.20 d	5.92 cd	5.55 e	5.11 d
80% : 20%	4.91 f	4.71 e	4.41 b	4.27 e
60% : 40%	4.41 g	4.30 f	4.16 a	3.97 f
<i>LSD (P=0.05)</i>	0.21	0.36	^y	^z
<i>CV (%)</i>	5.41	7.50	7.24	3.68

Means followed by the same letter do not differ significantly at $P = 0.05$ (LSD)

^yData not normally distributed. Transformed with $\text{LX}=1/(\text{X})$

^zData not normally distributed. Transformed with $\text{LX}=\text{Log}(\text{X})$

The pH of drainage water, irrespective of growth substrate and nitrogen source, decreased with time and the lowest pH values were found with the highest NH_4^+ -N concentration (Table 11). However, when sand was used as growth substrate, an unexpected decrease in pH occurred when drainage water was sampled 14 weeks after transplanting, irrespective of nitrogen source.

Contrary to previous findings during the spring planting (Chapter 3) the pH of the biologically active growth substrates declined with time when only NO_3^- -N was applied (Table 11). Pine sawdust-shavings maintained the highest pH values when 100% NO_3^- -N and 20% NH_4^+ -N was applied. The lowest pH values of 4.90 to 4.34 were found when coco peat was irrigated with a nutrient solution containing a N-ratio of 60% NO_3^- -N : 40% NH_4^+ -N.

In the case of biologically active growth substrates, especially wood fibre substrates, it is well known that microorganisms consume nitrates during decomposition and proportionally emit hydroxyl ions into the nutrient solution, thus raising the pH (Vlassak *et al.*, 1991). During cool weather conditions, such as experienced during the latter part of this experiment, microbiological activity might be reduced to such an extent that less hydroxyl ions are emitted and thus not raising the drainage water pH, as previously noted, with time (Chapter 3).

The uptake of NO_3^- increases with increasing seasonal temperatures and radiation levels (Kafkafi, 2000) and with an increase in root temperatures (Ali *et al.*, 1994). The temperatures declined during this experiment as the season changed from autumn to winter (Figure 1). Therefore it might be that the uptake of NO_3^- anions is less with time and therefore the emission of hydroxyl ions into the nutrient solution. Younis *et al.* (1965) and Ganmore-Neumann & Kafkafi (1980) found that low root temperatures results in NO_3^- accumulation in the roots and slowing down of NO_3^- transportation to the shoots (Power *et al.*, 1970).

The decline in drainage water pH, when NO_3^- -N was applied, could be attributed to the trace amounts of NH_4^+ -N found in the nutrient solution due to the impurity of $5[\text{Ca}(\text{NO}_3)_2 \cdot 2\text{H}_2\text{O}]\text{NH}_4\text{NO}_3$. It is well known that the uptake of NH_4^+ results in an

excretion of H^+ , which acidifies the nutrient solution (Raven & Smith, 1976; Kafkafi, 2000).

The pH of drainage water declined with increasing substrate age and during the growing period, irrespective of the type of growth substrate used (Table 12). However, the lowest pH values were found with coco peat in the 2nd season of production.

Table 12 Influence of substrate and period of substrate use on drainage water pH during the growth period

Factor	Drainage water pH			
	Weeks after transplanting			
Substrate age	Sand			
	8	11	14	17
1 st season	6.93 a	6.47 a	6.07 d	6.50 a
2 nd season	5.93 b	5.66 b	4.69 ab	5.10 d
	Pine sawdust			
	8	11	14	17
1 st season	6.90 a	6.41 a	6.08 d	6.12 b
2 nd season	6.05 b	5.84 b	5.63 c	5.38 c
	Coco peat			
	8	11	14	17
1 st season	5.40 c	5.03 c	4.74 b	4.48 e
2 nd season	4.90 d	4.88 c	4.50 a	4.34 e
<i>LSD (P=0.05)</i>	0.22	0.30	^y	^z
<i>CV (%)</i>	5.41	7.50	7.24	3.68

Means followed by the same letter do not differ significantly at $P = 0.05$ (LSD)

^yData not normally distributed. Transformed with $LX=1/(X)$

^zData not normally distributed. Transformed with $LX=\text{Log}(X)$

The period of substrate use, irrespective of nitrogen source, lead to a decrease in drainage water pH (Table 13). The drainage water pH decreased with time. However, there was a slight unexpected increase in pH when drainage water was sampled 17

weeks after transplanting, except when 20% $\text{NH}_4^+\text{-N}$ was applied during the 2nd season of substrate use. The lowest pH values were found when 40% $\text{NH}_4^+\text{-N}$ was applied, but also in the 2nd season of substrate use when 20% $\text{NH}_4^+\text{-N}$ was applied.

Table 13 Influence of nitrogen source and period of substrate use on drainage water pH during the growth period

Factor	Drainage water pH			
	Weeks after transplanting			
Substrate age	100% $\text{NO}_3^-\text{-N}$: 0% $\text{NH}_4^+\text{-N}$			
	8	11	14	17
1 st season	7.10 a	6.89 a	6.68 e	6.69 a
2 nd season	7.03 a	6.77 a	5.99 d	6.10 b
	80% $\text{NO}_3^-\text{-N}$: 20% $\text{NH}_4^+\text{-N}$			
	8	11	14	17
1 st season	6.53 b	6.13 b	5.62 c	5.65 c
2 nd season	5.36 d	4.94 cd	4.68 b	4.56 e
	60% $\text{NO}_3^-\text{-N}$: 40% $\text{NH}_4^+\text{-N}$			
	8	11	14	17
1 st season	5.69 c	4.99 c	4.78 b	4.82 d
2 nd season	4.47 e	4.67 d	4.30 a	4.28 f
<i>LSD (P=0.05)</i>	0.22	0.30	^y	^z
<i>CV (%)</i>	5.41	7.50	7.24	3.68

Means followed by the same letter do not differ significantly at $P = 0.05$ (LSD)

^yData not normally distributed. Transformed with $\text{LX}=1/(\text{X})$

^zData not normally distributed. Transformed with $\text{LX}=\text{Log}(\text{X})$

Control of pH in the nutrient solution and root zone is crucial as it affects the availability of nutrients. Adams (2002) and Sonneveld (2002) showed that pH control could be achieved with the inclusion of $\text{NH}_4^+\text{-N}$ (5 – 15% of the total nitrogen) in the nutrient solution. The optimum solution pH is between 5 and 6 (Sonneveld, 2002). It was evident that drainage water pH became too low for efficient plant nutrition, if $\text{NH}_4^+\text{-N}$ were used, especially in coco peat as growing substrate and in the 2nd period of substrate use. However, coco peat showed very low drainage water pH values in the 1st growing season as well.

Electrical conductivity The nutrient solutions were made up based on a calculated EC of 2.0 mS.cm⁻¹, while measurements of the nutrient solution showed values between 1.82 and 1.87 mS.cm⁻¹ (Table 5). However, drainage water EC was significantly affected by growth substrates and period of substrate use, with an increase in EC with time in sand and pine sawdust-shavings and between 1st and 2nd season of substrate use, especially 8, 11 and 17 weeks after transplanting when pine sawdust-shavings was used and 8 weeks after transplanting when coco peat was used (Table 14). These higher values could be ascribed to salts from fertilizer that accumulated in the growth substrate from the previous planting season. The drainage water EC of sand was much lower in the 2nd season of substrate use.

Table 14 Influence of substrate and period of substrate use on drainage water EC during the growth period

Factor	Drainage water EC (mS.cm ⁻¹)			
Substrate age	Weeks after transplanting			
	Sand			
	8	11	14	17
1 st season	3.02 de	3.05 a	3.17 a	2.16 bc
2 nd season	2.67 bc	2.70 b	2.56 c	2.03 a
	Pine sawdust			
	8	11	14	17
1 st season	2.16 a	2.31 d	2.58 c	1.98 a
2 nd season	2.61 b	2.46 cd	2.36 d	2.07 ab
	Coco peat			
	8	11	14	17
1 st season	2.83 cd	2.70 b	2.83 b	2.52 d
2 nd season	3.06 e	2.64 bc	2.63 c	2.28 c
<i>LSD (P=0.05)</i>	w	x	y	z
<i>CV (%)</i>	10.09	12.75	9.20	7.88

Means followed by the same letter do not differ significantly at P = 0.05 (LSD)

^{wz}Data not normally distributed. Transformed with LX=1/(X)

^{xy}Data not normally distributed. Transformed with LX=Log(X)

However, the EC for all treatment combinations was lower at 17 weeks after transplanting (Table 14). This might be due to cooler weather (Figure 1) and sufficient over irrigation.

The EC of the drainage water was significantly lower at 8 and 14 weeks after transplanting when 60% NO_3^- -N : 40% NH_4^+ -N was applied (Table 15). The EC at 17 weeks after transplanting was lower compared to the other sampling dates, irrespective of nitrogen source. No definite trends were however noted. The EC was in the range that is being used for the production of tomatoes (Sonneveld & van der Burg, 1991)

Table 15 Influence of nitrogen source on drainage water EC during the growth period

Factor	Drainage water EC ($\text{mS}\cdot\text{cm}^{-1}$)			
	Weeks after transplanting			
	8	11	14	17
NO_3^- -N : NH_4^+ -N				
100% : 0%	2.77 b	2.70 ab	2.89 a	2.18 b
80% : 20%	2.82 b	2.72 a	2.77 a	2.07 a
60% : 40%	2.49 a	2.50 b	2.39 b	2.23 b
<i>LSD</i> ($P=0.05$)	w	NS	y	z
<i>CV</i> (%)	10.09	12.75	9.20	7.88

Means followed by the same letter do not differ significantly at $P = 0.05$ (LSD)

^wData not normally distributed. Transformed with $\text{LX}=1/(\text{X})$

^{x,y}Data not normally distributed. Transformed with $\text{LX}=\text{Log}(\text{X})$

NO_3^- -N and NH_4^+ -N content Substrate, substrate age and nitrogen source and their interactions was the largest contributors to differences in NO_3^- -N and NH_4^+ -N content in the drainage water. The values presented in Tables 16, 17 and 18 are the difference between the drainage water value and the value of the irrigated nutrient solution at the time of sampling. Positive and negative values indicate either an increase or a decline in NO_3^- -N or NH_4^+ -N content. This will illustrate whether there was an accumulation (positive value) or withdrawal due to uptake, immobilization or conversion (negative value) of NO_3^- -N or NH_4^+ -N. The NH_4^+ -N measured in the

100% NO_3^- -N : 0% NH_4^+ -N treatment (Table 3) was probably due to the impurity of $5[\text{Ca}(\text{NO}_3)_2 \cdot 2\text{H}_2\text{O}]\text{NH}_4\text{NO}_3$.

Generally the highest values of accumulated NO_3^- -N was found in sand, irrespective of nitrogen source, followed by coco peat and pine sawdust-shavings (Table 16). Pine sawdust-shavings was the only substrate that indicated biological activity with either an uptake or immobilization of NO_3^- -N when 100% NO_3^- -N : 0% NH_4^+ -N (5 and 8 weeks after transplanting) or 80% NO_3^- -N : 20% NH_4^+ -N (5 weeks after transplanting) was applied. The uptake or immobilization of NO_3^- -N at 8 and 17 weeks after transplanting, when 60% NO_3^- -N : 40% NH_4^+ -N was applied, was insignificantly small and had no impact on the outcome of the experiment.

Table 16 Influence of substrate and nitrogen source on drainage water NO_3^- -N content, compared to NO_3^- -N content in the irrigation water, during the growth period

Factor	NO_3^- -N content (ppm)				
NO_3^- -N : NH_4^+ -N	Weeks after transplanting				
	Sand				
	5	8	11	14	17
100% : 0%	216.52	145.24	171.36	247.25	98.23
80% : 20%	364.48	151.19	153.45	222.28	64.28
60% : 40%	141.42	80.84	57.86	63.68	44.75
	Pine sawdust				
	5	8	11	14	17
100% : 0%	-111.77	-70.58	8.84	44.74	6.72
80% : 20%	-14.53	7.76	37.95	55.73	9.07
60% : 40%	24.38	-6.40	5.15	21.59	-0.94
	Coco peat				
	5	8	11	14	17
100% : 0%	133.50	142.07	120.85	102.31	132.82
80% : 20%	9.70	63.73	53.72	129.08	70.69
60% : 40%	14.40	26.52	13.27	54.64	40.16

Negative values indicate a decrease in NO_3^- -N content, compared to irrigation water

Vlassak *et al.* (1991) found that microorganisms consume NO_3^- -N in wood fibre substrates and that the microbial biomass builds up to form its own decomposable substrate, which starts to release the immobilized nutrients 10 to 12 weeks after transplanting.

The accumulation of NO_3^- -N in the sand substrate indicated that sand was biologically more stable and that it might have been over fertilized with NO_3^- -N. The same applied to coco peat when only NO_3^- -N was used, although the accumulation of NO_3^- -N in the drainage water was not as high as when sand was used.

From Table 17 it is obvious that sand accumulated more NO_3^- -N compared to pine sawdust-shavings and coco peat, irrespective of the period of substrate use, although the NO_3^- -N that accumulated in the 2nd season of substrate use was lower than in the 1st season of substrate use.

Table 17 Influence of substrate and period of substrate use on drainage water NO_3^- -N content, compared to NO_3^- -N content in the irrigation water, during the growth period

Factor	NO_3^- -N content (ppm)				
Substrate age	Weeks after transplanting				
	Sand				
	5	8	11	14	17
1 st season	257.98	165.31	164.27	226.07	83.34
2 nd season	223.64	86.20	90.85	124.13	51.40
	Pine sawdust				
	5	8	11	14	17
1 st season	-100.13	-52.39	-0.33	38.95	-6.46
2 nd season	32.18	6.24	34.95	42.09	15.62
	Coco peat				
	5	8	11	14	17
1 st season	-86.03	30.03	51.56	107.16	87.21
2 nd season	149.84	126.46	69.81	82.36	72.71

Negative values indicate a decrease in NO_3^- -N content, compared to irrigation water

The biologically active pine sawdust-shavings substrate indicated high NO_3^- -N uptake or immobilization values at 5 and 8 weeks after transplanting in the 1st season substrate. In the 2nd season of substrate use the accumulation of NO_3^- -N was insignificantly low and therefore indicated that the substrate was still more biologically active than sand and coco peat or that the uptake of NO_3^- was higher in pine sawdust-shavings. Coco peat showed an uptake or immobilization of NO_3^- -N only at 5 weeks after transplanting in the new substrate. Accumulation of NO_3^- -N was found in the 2nd season of substrate use.

Nitrification (Lang & Elliot, 1991) or the uptake of NH_4^+ might have had a significant effect on the NH_4^+ -N content of the drainage water, irrespective of substrate or nitrogen source (Table 18). However, the effect was found to be more visible in sand and pine sawdust-shavings. The drainage water NH_4^+ -N content of sand (Table 18) was lower than the irrigated nutrient solution (Table 3) when the new substrate was used, irrespective of nitrogen source or sampling date, except at 14 weeks after transplanting when 40% NH_4^+ -N was applied. In the 2nd season of substrate use NH_4^+ -N uptake or nitrification were found at 5, 8 and 11 weeks after transplanting when 0% NH_4^+ -N was applied, and at 5 and 8 weeks after transplanting when 20% NH_4^+ -N was applied.

The withdrawal of NH_4^+ -N could be ascribed to any of the following scenarios. Nitrification of NH_4^+ -N to NO_3^- -N might explain why high values of NO_3^- -N were found in the drainage water of sand. However, the uptake of NH_4^+ could be due to cooler root temperatures, although very little nitrification occurs when the root temperatures drop to 3 - 4°C (Ganmore-Neumann & Kafkafi, 1980). Ganmore-Neumann & Kafkafi (1980) also found that low root temperatures slows down the uptake of NO_3^- , but is beneficial to the uptake and translocation of NH_4^+ metabolites from the roots to the shoots of tomato plants. It is more likely that the latter scenario had the biggest effect on NH_4^+ -N withdrawal.

Table 18 Influence of substrate, nitrogen source and period of substrate use on NH_4^+ -N content of drainage water, compared to NH_4^+ -N content in the irrigation water, during the growth period

Factor NO_3^- -N : NH_4^+ -N	NH_4^+ -N content (ppm)				
	Weeks after transplanting				
	Sand				
1st season	5	8	11	14	17
100% : 0%	-7.80	-7.94	-10.74	-8.76	
80% : 20%	-42.67	-36.80	-30.25	-9.13	NS
60% : 40%	-38.55	-41.04	-7.95	4.50	
2nd season					
100% : 0%	-5.57	-8.73	-4.21	3.76	
80% : 20%	-15.60	-8.23	6.82	19.66	NS
60% : 40%	31.57	11.68	11.24	13.54	
	Pine sawdust				
1st season	5	8	11	14	17
100% : 0%	-8.54	-8.59	-10.56	-7.47	
80% : 20%	-42.43	-25.75	-15.17	6.75	NS
60% : 40%	-44.55	-11.61	13.08	20.19	
2nd season					
100% : 0%	-8.44	-7.91	-9.41	-3.16	
80% : 20%	-40.02	-20.16	-0.91	2.17	NS
60% : 40%	-14.22	4.98	7.05	17.63	
	Coco peat				
1st season	5	8	11	14	17
100% : 0%	-8.84	-7.91	-6.65	1.34	
80% : 20%	-42.62	-27.87	0.83	20.25	NS
60% : 40%	-45.99	-3.96	16.61	28.86	
2nd season					
100% : 0%	-8.46	-7.61	-8.84	-6.22	
80% : 20%	-10.12	4.78	9.78	12.67	NS
60% : 40%	27.95	19.07	11.74	18.37	

Negative values indicate a decrease in NH_4^+ -N content, compared to irrigation water

NS Data not included due to a sampling error

A similar trend as in sand occurred in the pine sawdust-shavings substrate. The only difference is that pine sawdust-shavings has shown NH_4^+ -N uptake or nitrification at 5, 11 and 14 weeks after transplanting when 40%, 20% and 0% NH_4^+ -N was applied respectively and the substrate was in its 2nd season of use. Withdrawal of NH_4^+ -N therefore continued for a longer period in pine sawdust-shavings when the substrate was in its 2nd season of use.

In the 1st season of coco peat substrate use, NH_4^+ -N uptake or nitrification was found at 5 and 8 weeks after transplanting, irrespective of nitrogen source and at 11 weeks after transplanting when only NO_3^- -N was applied. In the 2nd season of substrate use, NH_4^+ -N withdrawal was found at all sampling dates when only NO_3^- -N was applied and at 5 weeks after transplanting when 20% NH_4^+ -N was used.

These results indicated that pine sawdust-shavings was more biologically active than coco peat, especially in the 2nd season of substrate use. This might be due to the fact that the production of coco peat involves a period where the substrate undergoes aerobic composting. During composting the C/N ratio decreases and makes it less vulnerable to nitrogen immobilization (Yau & Murphy, 2000). Pine sawdust-shavings is not composted and therefore might create a situation for high biological activity.

Yield and growth parameters

Nitrogen source and substrate age as main factors had a significant effect on stem diameter of tomato plants (Table 19). Significant substrate x age and nitrogen source x age interactions were obtained. However, a significant interaction was calculated for substrate x nitrogen source x age and further discussions on the results will focus on this third order interaction.

Nitrogen source and substrate age as main factors had a significant effect on all the yield parameters (Table 19). Nitrogen source also had a significant effect on quality (blossom-end rot), but not substrate age. Substrate and irrigation frequency had no significant effect on any of the yield and quality parameters.

Table 19 Analysis of variance (ANOVA) of marketable and unmarketable yield of tomatoes

Factor	DF	Marketable yield			Unmarketable yield		
		Yield (g/plant)	Average fruit mass (g)	Number of fruit per plant	Yield (g/plant)	Percentage BER per plant ^x	Stem diameter (mm)
		<i>Pr</i> > <i>F</i>	<i>Pr</i> > <i>F</i>	<i>Pr</i> > <i>F</i>	<i>Pr</i> > <i>F</i>	<i>Pr</i> > <i>F</i>	<i>Pr</i> > <i>F</i>
Replicate	1	0.9448	0.4838	0.8183	0.0257	0.0039	0.1416
Substrate	2	0.3038	0.0866	0.7217	0.2716	0.7788	0.3896
Irrigation	2	0.5927	0.1765	0.2082	0.1190	0.6728	0.5342
Sub x Irrig	4	0.2867	0.2619	0.6100	0.2809	0.5484	0.8746
Nitrogen source	2	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001
Sub x Nitro	4	0.1917	0.7905	0.0451	0.6510	0.6787	0.0927
Irrig x Nitro	4	0.9813	0.9586	0.8215	0.7958	0.2299	0.5935
Sub x Nitro x Irrig	8	0.9691	0.9751	0.7236	0.7770	0.2176	0.8549
<i>Error a</i>	26						
Age	1	<.0001	<.0001	<.0001	0.0041	0.6100	<.0001
Sub x Age	2	<.0001	0.0004	0.0936	0.0005	0.1036	<.0001
Irrig x Age	2	0.2830	0.5391	0.2753	0.6472	0.3450	0.8663
Sub x Irrig x Age	4	0.0143	0.4190	0.2534	0.4101	0.3512	0.8522
Nitro x Age	2	0.0002	0.1937	0.0027	0.0368	0.5629	<.0001
Sub x Nitro x Age	4	0.3031	0.5061	0.7683	0.7209	0.7365	0.0221
Irrig x Nitro x Age	4	0.5114	0.2026	0.8888	0.4423	0.3264	0.2090
Sub x Irrig x Nitro x Age	8	0.3648	0.9089	0.2322	0.1845	0.7412	0.1735
<i>Error b</i>	27						
<i>CV (%)</i>		8.12	6.78	8.45	29.06	58.53	10.14

^xData not normally distributed. Transformed with $LX = \ln(X)$

Substrate x irrigation frequency, irrigation frequency x nitrogen source and irrigation frequency x age interactions had no significant effect on any of the yield and quality parameters. Significant substrate x age and nitrogen source x age interactions were shown for both marketable and unmarketable yield per plant, and the number of marketable fruit per plant. A significant substrate x nitrogen source interaction was

calculated for the number of marketable fruit per plant, but not for the other yield and quality parameters.

There was also a significant interaction for substrate x irrigation frequency x age on marketable yield per plant, but not on the other yield and quality parameters. The other third order interactions, and also the substrate x irrigation frequency x nitrogen source x age interaction, had no significant effect on any of the yield and quality parameters.

From these results it is obvious that nitrogen source and substrate age were very important factors affecting all the yield and quality parameters, but the substrate x age and nitrogen source x age interactions affected marketable and unmarketable yield profoundly. Further discussions of the results will focus on these aspects.

Stem diameter Stem diameter decreased significantly in pine sawdust-shavings and coco peat when the NH_4^+ -N content was increased from 0 – 40% in the 1st season of substrate use (Table 20). However there was no significant difference when only NO_3^- -N and 20% NH_4^+ -N was used, except in sand. Plants grown in sand had an unexpected smaller stem diameter when 20% NH_4^+ -N was applied. This might be due to experimental error.

In the 2nd season of substrate use, a significant decrease in stem diameter occurred when 20 - 40% NH_4^+ -N was used in sand and coco peat. However, plants grown in pine sawdust-shavings indicated a significant decrease in stem diameter only when 40% NH_4^+ -N was used. Sand, irrespective of nitrogen source, coco peat irrigated with nutrient solution containing 20 and 40% NH_4^+ -N and pine sawdust-shavings irrigated with 40% NH_4^+ -N produced plants with significantly thinner stems in the 2nd season. The smallest stem diameter was produced when 40% NH_4^+ -N was used with coco peat in the 2nd season of substrate use.

The low drainage water pH values (Table 12), especially in coco peat, and the increasing NH_4^+ -N content in the nutrient solution might be responsible for the decrease in stem diameter in the 2nd season of substrate use. The effect was not as severe in pine sawdust-shavings due to a higher drainage water pH.

Table 20 Influence of substrate and period of substrate use on stem diameter

Factor	Stem diameter (mm)	
	Substrate age	
	1 st season	2 nd season
NO ₃ ⁻ -N : NH ₄ ⁺ -N		
	Sand	
100% : 0%	65.7 bc	56.5 de
80% : 20%	55.3 de	42.9 f
60% : 40%	61.7 cd	41.8 f
	Pine sawdust	
100% : 0%	64.9 bc	66.2 bc
80% : 20%	61.5 cd	60.1 cde
60% : 40%	53.9 e	40.3 f
	Coco peat	
100% : 0%	75.6 a	69.0 ab
80% : 20%	69.2 ab	37.6 f
60% : 40%	66.4 bc	29.7 g
<i>LSD (P=0.05)</i>	6.79	
<i>CV (%)</i>	10.14	

Means followed by the same letter do not differ significantly at P = 0.05 (LSD)

Marketable yield The 1st season substrate, irrespective of the type of substrate, produced higher marketable yields per plant than substrate that has been used twice (Table 21). There was no significant difference between the substrates used in the 2nd season of production. The highest marketable yield per plant was found with coco peat followed by pine sawdust-shavings and sand, when new substrates were used. Sand produced the lowest yield.

As the number of marketable fruit per plant showed the same trend as marketable yield per plant, it can be assumed that marketable yield was determined by the number of fruit per plant and not average fruit mass. The highest marketable yield and number of marketable fruit per plant was obtained with the 1st season substrate and when only NO₃⁻-N or 80% NO₃⁻-N : 20% NH₄⁺-N was applied (Table 22). This is in contrast with previous findings (Chapter 3), which indicated a significant yield loss with 20%

NH_4^+ -N in the nutrient solution. It might be that 20% NH_4^+ -N is less toxic during cool weather conditions, as was found by Ganmore-Neumann & Kafkafi (1980). An NH_4^+ -N content of 40% produced a significantly lower number of marketable fruit and marketable yield per plant, irrespective of substrate age. Substrate that has been used twice produced a significantly lower number of marketable fruit and marketable yield per plant than new substrate, irrespective of nitrogen source.

Table 21 Influence of substrate and period of substrate use on marketable yield

Factor	Marketable yield per plant (g)	
	Substrate age	
	1 st season	2 nd season
Substrate		
Sand	5112.0 c	4014.2 d
Pine sawdust	5581.8 b	3925.6 d
Coco peat	5947.8 a	3808.6 d
<i>LSD (P=0.05)</i>	262.84	
<i>CV (%)</i>	8.12	

Means followed by the same letter do not differ significantly at P = 0.05 (LSD)

Table 22 Influence of nitrogen source and period of substrate use on the number of marketable fruit and yield

Factor	Marketable fruit (Number per plant)		Marketable yield per plant (g)	
	Substrate age		Substrate age	
	1 st season	2 nd season	1 st season	2 nd season
NO_3^- -N : NH_4^+ -N				
100% : 0%	42.0 a	36.8 b	6056.6 a	4901.7 b
80% : 20%	42.1 a	31.7 c	6016.7 a	3964.4 c
60% : 40%	35.1 b	25.8 d	4568.3 b	2882.3 d
<i>LSD (P=0.05)</i>	2.05		582.50	
<i>CV (%)</i>	8.45		8.12	

Means followed by the same letter do not differ significantly at P = 0.05 (LSD)

The average fruit mass was significantly affected by the substrate x substrate age interaction and also by nitrogen source (Table 23 and 24). Significantly smaller fruit were produced in the 2nd season of substrate use when coco peat and pine sawdust-shavings were used. There was no significant difference between the 1st and 2nd season when sand was used as growth substrate. Sand produced a significantly smaller fruit than coco peat and pine sawdust-shavings in the 1st season of substrate use.

Table 23 Influence of substrate and period of substrate use on fruit mass

Factor	Average fruit mass (g)	
	Substrate age	
Substrate	1 st season	2 nd season
Sand	131.2 b	125.1 bc
Pine sawdust	141.6 a	119.9 c
Coco peat	146.1 a	122.5 c
<i>LSD (P=0.05)</i>	7.73	
<i>CV (%)</i>	6.78	

Means followed by the same letter do not differ significantly at P = 0.05 (LSD)

The addition of NH_4^+ -N decreased fruit mass from 139.5 to 119.6g, although there was no significant difference between the fruit mass when only NO_3^- -N or 80% NO_3^- -N : 20% NH_4^+ -N was applied. The addition of 40% NH_4^+ -N as part of the total nitrogen content, produced the smallest fruit. Pill, Lambeth & Hinckley (1978) and Ali *et al.* (1994) also found a reduction in fruit size when NH_4^+ -N was applied.

Table 24 Influence of nitrogen source on fruit mass

Factor	Fruit mass
NO_3^- -N : NH_4^+ -N	(g)
100% : 0%	139.5 a
80% : 20%	134.2 a
60% : 40%	119.6 b
<i>LSD (P=0.05)</i>	5.48
<i>CV (%)</i>	6.78

Means followed by the same letter do not differ significantly at P = 0.05 (LSD)

The lower yield in the 2nd season of substrate use might be due to the low pH in coco peat and the advanced stage of decomposition and waterlogged conditions in pine sawdust-shavings respectively (Figure 2).

Pine sawdust-shavings visually exhibited advanced decomposition at the end of the 2nd season (10 months) when only NO₃⁻-N was used, irrespective of irrigation frequency (Figure 2). Very little decomposition was observed when 20% or 40% NH₄⁺-N was applied until the end of the 2nd season of substrate use (Figure 3a, b and c). No decomposition could be observed when coco peat was used as growth substrate.

The lower yield obtained when sand was used for a 2nd season is unexplainable, but might be due to a combination of high NH₄⁺-N applications and waterlogged conditions in sand during the crop production period.

Unmarketable yield There was no significant difference in unmarketable yield irrespective of substrate and substrate age, except when pine sawdust-shavings was used in the 1st season (Table 25). Pine sawdust-shavings produced the lowest unmarketable yield per plant when the substrate was used in the 1st season.

Table 25 Influence of substrate and period of substrate use on unmarketable yield

Factor	Unmarketable yield per plant (g)	
	Substrate age	
	1 st season	2 nd season
Sand	537.0 a	490.3 a
Pine sawdust	323.4 b	575.0 a
Coco peat	485.5 a	539.3 a
<i>LSD (P=0.05)</i>	129.03	
<i>CV (%)</i>	29.06	

Means followed by the same letter do not differ significantly at P = 0.05 (LSD)



1st season (3 x irrigation per day)



2nd season (3 x irrigation per day)



1st season (6 x irrigation per day)



2nd season (6 x irrigation per day)

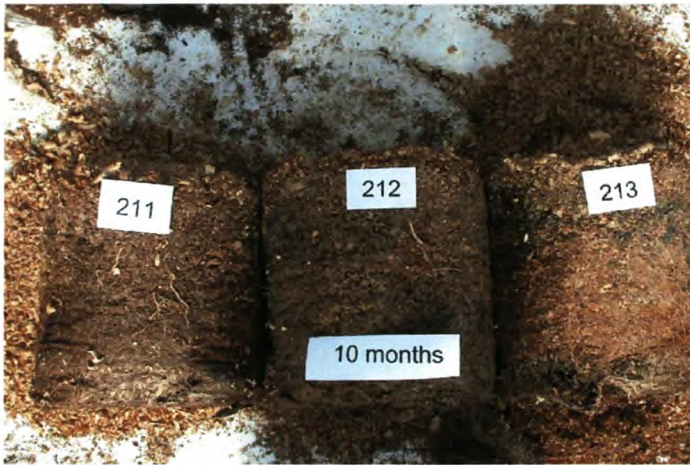


1st season (12 x irrigation per day)



2nd season (12 x irrigation per day)

Figure 2 Effect of period of substrate use on decomposition of pine sawdust-shavings when only NO_3^- -N is used with irrigation frequencies of 3, 6 and 12 times per day



3 x irrigation per day

211	100% NO ₃ ⁻ -N : 0% NH ₄ ⁺ -N
212	80% NO ₃ ⁻ -N : 20% NH ₄ ⁺ -N
213	60% NO ₃ ⁻ -N : 40% NH ₄ ⁺ -N

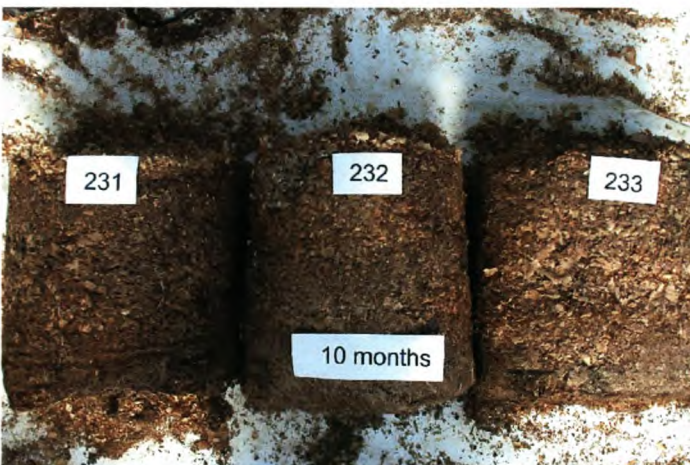
A



6 x irrigation per day

221	100% NO ₃ ⁻ -N : 0% NH ₄ ⁺ -N
222	80% NO ₃ ⁻ -N : 20% NH ₄ ⁺ -N
223	60% NO ₃ ⁻ -N : 40% NH ₄ ⁺ -N

B



12 x irrigation per day

231	100% NO ₃ ⁻ -N : 0% NH ₄ ⁺ -N
232	80% NO ₃ ⁻ -N : 20% NH ₄ ⁺ -N
233	60% NO ₃ ⁻ -N : 40% NH ₄ ⁺ -N

C

Figure 3 Effect of nitrate to ammonium N-ratio and irrigation frequency on decomposition of pine sawdust-shavings after the 2nd season of substrate use

Table 26 Influence of nitrogen source and period of substrate use on unmarketable yield

Factor	Unmarketable yield per plant (g)	
	Substrate age	
	1 st season	2 nd season
NO ₃ ⁻ -N : NH ₄ ⁺ -N		
100% : 0%	291.6 d	482.3 bc
80% : 20%	451.1 c	467.9 c
60% : 40%	603.3 ab	654.5 a
<i>LSD (P=0.05)</i>	129.03	
<i>CV (%)</i>	29.06	

Means followed by the same letter do not differ significantly at P = 0.05 (LSD)

The unmarketable yield per plant increased with an increase in NH₄⁺-N in the nutrient solution (Table 26). The lowest unmarketable yield per plant was found when only NO₃⁻-N was used in the 1st season of substrate use. Unmarketable yield increased significantly when substrates was used for a 2nd season, except when 40% NH₄⁺-N was applied. In the 2nd season of substrate use there was no significant difference in unmarketable yield when only NO₃⁻-N and 20% NH₄⁺-N was used. The highest unmarketable yield per plant, in both periods of substrate use, was found when 40% NH₄⁺-N was used.

The percentage blossom-end rot (BER) was expressed as a percentage of the total number of marketable fruit per plant (Table 27). Percentage BER increased with an increase in NH₄⁺-N in the nutrient solution with the highest percentage BER to be found when 40% NH₄⁺-N was used. Adams & Ho (1995) found that high levels of NH₄⁺-N could depress the uptake of calcium and therefore decrease the calcium content in fruit, resulting in BER. The BER values obtained are much lower than in the first experiment (Chapter 3) and might be due to cooler temperatures during the growing season. Ganmore-Neumann & Kafkafi (1980) found that NH₄⁺-N nutrition is less toxic during cool weather conditions.

Table 27 Influence of nitrogen source on the percentage blossom-end rot of tomato fruit

Factor NO ₃ ⁻ -N : NH ₄ ⁺ -N	Percentage blossom-end rot fruit per plant
100% : 0%	1.1 c
80% : 20%	2.7 b
60% : 40%	6.9 a
<i>LSD (P=0.05)</i>	x
<i>CV (%)</i>	87.22

Means followed by the same letter do not differ significantly at P = 0.05 (LSD)

*Data not normally distributed. Transformed with $LX = \ln(X)$

Conclusions

Nitrogen source and period of substrate use have been shown to have an effect on marketable and unmarketable yield, whereas quality was only affected by nitrogen source.

Variation in seasonal temperatures, radiation levels and relative humidity affected the outcome of this and an earlier experiment (Chapter 3). New coco peat produced the highest marketable yield per plant and previous findings (Chapter 3) confirmed this result. The highest number of marketable fruit and yield per plant was found when new substrate was used with only NO₃⁻-N or 20% NH₄⁺-N in the nutrient solution. This is in contrast with earlier findings (Chapter 3, summer conditions) which indicated a significant yield loss (56% higher than during cool weather conditions) with the application of 20% NH₄⁺-N. High temperatures and radiation levels (Chapter 3) and the application of 20% NH₄⁺-N resulted in an increase in blossom-end rot, 18% of total marketable fruit compared to cool weather conditions where only 2.7% blossom-end rot fruit were found.

The 2nd season of substrate use lead to a decrease in drainage water pH, in the number of marketable fruit and yield per plant and an increase in unmarketable yield. The pH decreased with an increase in NH₄⁺-N content in the nutrient solution and with time, and in some cases went below pH 5.

The organic substrate pine sawdust-shavings was biologically more active than coco peat in regards with the withdrawal or immobilization of NO_3^- -N and nitrification or uptake of NH_4^+ -N. Pine sawdust-shavings decomposed with time and therefore was vulnerable to over irrigation (waterlogged conditions). The best results with pine sawdust-shavings were found when new substrate was used with every planting. Coco peat produced the best yields when the substrate was used for the first time. However, the yield declined sharply when coco peat was used for a second planting season. This might be the result of the decline in pH with time and therefore it is recommended to adjust the pH prior to planting with liming materials such as calcium carbonate or dolomitic lime.

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CHAPTER 5

Influence of substrate, nitrogen source and pre-plant application of lime on yield and quality of greenhouse grown tomatoes (*Lycopersicon esculentum* Mill.)

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Abstract

Pine sawdust-shavings (*Pinus* spp.) is at present a very popular soilless substrate in South African greenhouses. Growers use mostly fresh pine sawdust-shavings, which is biologically highly unstable. Alternative substrates such as coco peat, which already went through a decomposition process and is more stable, are being investigated. The influence of substrate (coco peat, pine sawdust-shavings), nitrogen source (NO_3^- -N : NH_4^+ -N ratios of 100% : 0%, 80% : 20%, 60% : 40%) and the pre-plant application of lime (Experiment 1: 0, 0.75, 1.50 and 2.25 g CaCO_3 per kg substrate; Experiment 2: 0, 1.5, 3.0 and 4.5 g CaCO_3 per kg substrate) on yield and quality of greenhouse grown tomatoes were studied to determine the effect thereof on plant growth and marketable yield. Treatments were arranged in a randomised block design, using two replicates. Interactions between substrate and nitrogen source had a significant effect on marketable yield and fruit quality. No significant difference in number of marketable fruit and yield was found with coco peat, irrespective of NH_4^+ -N nutrition. Pine sawdust-shavings produced the lowest number of marketable fruit and yield with 40% NH_4^+ -N nutrition. Contrary to previous findings the drainage water pH of coco peat was generally higher and more optimal for plant growth with the application of lime in Experiment 2. In comparison with previous findings the pH of pine sawdust-shavings was generally lower, which emphasised the problem of consistency between different substrate batches. The pre-plant application of CaCO_3 resulted in no blossom-end rot fruit in coco peat and pine sawdust-shavings, irrespective of nitrogen source, except where pine sawdust-shavings received 40% NH_4^+ -N nutrition and 1.5 g CaCO_3 .

Keywords: lime, nitrogen, quality, substrate, tomato, yield

Introduction

South African producers use fresh pine sawdust-shavings as a stand-alone growth substrate for the production of tomatoes, cucumbers and sweet peppers (Maree, 1994). This material is highly unstable and biodegradation will have an effect on production. However, the production of coco peat involves a period of storage in heaps where it undergoes aerobic composting. The decomposition of coco peat, prior to use as growth substrate, reduces the C/N ratio and therefore immobilization of inorganic N (Worrall, 1978; Yau & Murphy, 2000). During composting the C/N ratio decreases up to a value, which remains stable but variable with the kind of product. Higher biostability can be achieved with a product containing high lignin values (Lemaire, 1997). Therefore coco peat, due to a higher lignin content than pine fibre substrates, decomposes slower and is very stable (Ghoos, 1993; Noguera, Abad & Noguera, 2000; Yau & Murphy, 2000). Different sources and different production procedures result in a large variability of end products (Evans, Konduru & Stamps, 1996; Prasad, 1997; Konduru, Evans & Stamps, 1999).

Decomposition of organic substrates changes the physical and chemical properties of a substrate and therefore may have an effect on the yield and quality of the crop being produced. The water holding capacity, bulk density and cation exchange capacity increases with degradation (Mbah & Odili, 1998; Shadhidul Islam *et al.*, 2002). Decomposition of pine fibre substrates, especially when NO_3^- -N is used as nitrogen source, results in an increase in pH (Vlassak *et al.*, 1991), which affects the availability of phosphorus and all the micronutrients except molybdenum (Adams, 2002).

Earlier Pill & Lambeth (1977) found an increase in pH when NO_3^- -N is used as the sole nitrogen source and reported that NH_4^+ -N can be used to control pH. Adams (2002) and Sonneveld (2002) showed that pH control could be achieved with the inclusion of NH_4^+ -N (5 – 15% of the total nitrogen) in the nutrient solution. However, the inclusion of NH_4^+ -N in the nutrient solution can lead to the production of smaller fruit and lower marketable yields (Hohjo *et al.*, 1995). It is well known that the uptake of NH_4^+ cations results in an excretion of hydrogen ions, which acidifies the nutrient solution (Raven & Smith, 1976; Kafkafi, 2000). Very high levels of NH_4^+ -N in the

root zone can depress the uptake of calcium and therefore decreases the calcium content of the fruit, causing blossom-end rot (Adams & Ho, 1995).

The uptake of NO_3^- increases with increasing seasonal temperatures and radiation levels (Kafkafi, 2000) and with an increase in root temperatures (Ali *et al.*, 1994). Younis *et al.* (1965) and Ganmore-Neumann & Kafkafi (1980) found that low root temperatures results in NO_3^- accumulation in the roots and slowing down of NO_3^- transportation to the shoots (Power *et al.*, 1970).

The process of nitrification is influenced by cooler root temperatures and very little occurs when the root temperature drops to 3 - 4°C (Ganmore-Neumann & Kafkafi, 1980). Barker & Mills (1980) found that under unfavourable conditions such as in acidic growth media, or under cool, cloudy days, low rates of nitrification might lead to ammonium toxicity. Ganmore-Neumann & Kafkafi (1980) also found that low root temperatures are beneficial to the uptake and translocation of NH_4^+ metabolites from the roots to the shoots of tomato plants. Ammonium was also shown to be an undesirable source of nitrogen for tomato plants at root zone temperatures above 30°C, as a result of its effect on root growth and development.

The detrimental effects of NH_4^+ -N nutrition have been related to root environment acidity. Maintaining pH near neutrality has resulted in nearly normal growth under NH_4^+ -N nutrition (Barker, Volk & Jackson, 1966a; 1966b; de Claassen & Wilcox, 1974). Under NH_4^+ -N nutrition, solution acidity control improved root growth and reduced plant water stress, but had no effect on either total plant weight or ion concentration of roots and shoots with the exception of increased NH_4^+ -N concentration (Pill & Lambeth, 1977). Some authors indicated that the detrimental effects of ammonium on growth could be alleviated by the addition of dolomitic lime (de Claassen & Willcox, 1974) or calcium carbonate (Pierpont & Minotti, 1977), which buffered the pH of the nutrient solution to near neutral.

Some authors amended the pH of the substrate coco peat with pre-plant applications of dolomitic lime that ranged from 0.8 to 4.2 $\text{kg}\cdot\text{m}^{-3}$ (Meerow, 1994; Noguera *et al.*, 1997; Prasad, 1997; Noguera *et al.*, 2000). Argo & Biernbaum (1997) used 0.5 $\text{kg}\cdot\text{m}^{-3}$ dolomitic lime or the equivalent of 0.9 kg CaCO_3 per m^3 coco peat. None of the above

authors applied dolomitic lime to evaluate the effect it has on pH when different NO_3^- -N : NH_4^+ -N ratios were used. Very few publications were found with exact recommendations for the application of dolomitic lime or CaCO_3 to amend the pH when NH_4^+ -N is used in the nutrient solution and applied to coco peat. However, Caraveo Lopez *et al.* (1996) evaluated the production of tomatoes in coco peat substrate, and its response to ammonium and potassium. In his experiment he also incorporated CaCO_3 in the substrate and found that the highest fruit and dry matter yields were obtained when the nutrient solution contained 16.6% NH_4^+ -N, 20 or 30% potassium (with respect to total cations) and the substrate contained 3 or 6 g CaCO_3 per kg coco peat.

As a result of the above-mentioned reasons, it was decided to conduct research where yield and quality of tomatoes were evaluated in different organic substrates, which was subjected to different lime applications and nitrate and ammonium N-ratios. In the first experiment the lime applications had no significant influence on the yield and quality of tomatoes and therefore a second experiment with higher lime applications were done.

Materials and methods

Experiment 1

Locality and climate A greenhouse trial was conducted at Stellenbosch in the Western Cape Province of South Africa during the spring and summer of 2001/2002. The weekly average minimum and maximum temperatures outside the greenhouse are presented in Figure 1. From this figure it is clear that especially daily maximum temperatures increases gradually during the duration of the experiment.

Cultivation practices Seeds of the tomato (*Lycopersicon esculentum* Mill.) cultivar FA593 (Mayford Seeds, South Africa) were sown on 27 July 2001 in seedling trays. The seedlings were produced in a substrate that consisted of 1 part Hygrotech seedling mix (peat, polystyrene, vermiculite), 1 part vermiculite and 1 part composted pine bark. Seedlings were watered with a 50% diluted ($1.1 \text{ mS}\cdot\text{cm}^{-1}$) nutrient solution

(Steiner, 1984) and transplanted into the greenhouse on 21 September 2001 (8 weeks after sowing). Only one seedling was transplanted per 18 litre black plastic bag.

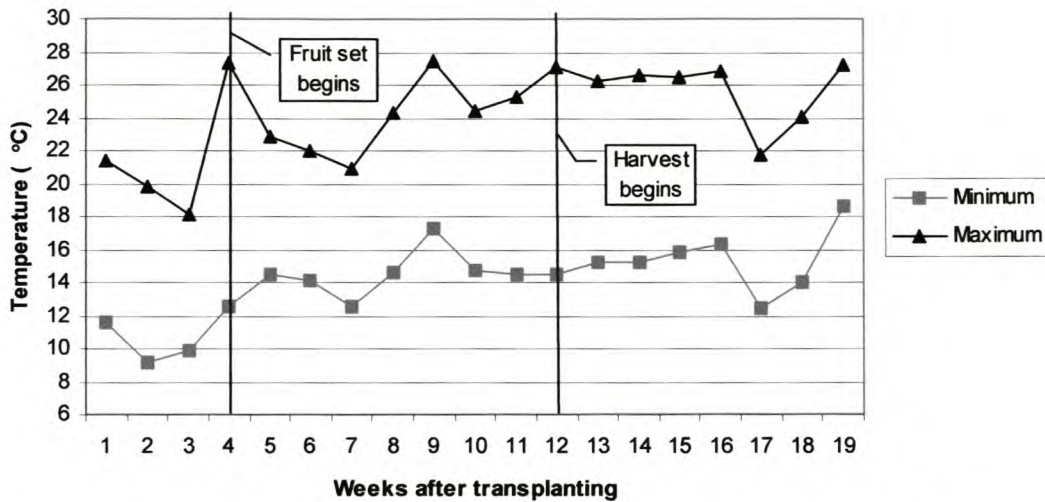


Figure 1 Weekly minimum and maximum temperatures outside the greenhouse during the growth period of 21 September 2001 to 21 January 2002

Drainage holes were made at 2.5 cm from the bottom of the bag to create a reservoir from which the drainage water samples were extracted. The bags were placed in 8 double rows and the spacing between rows (from centre of bag) was 0.40 m and within the row 0.35 m. The spacing between each double row (from centre of row) was 1.60 m. A plant population of 2.5 plants per m² were maintained in the greenhouse. Standard cultural practices for the production of greenhouse tomatoes were applied. Side shoots were removed and the plants were trellised to a height of 2.4 m above the bag. An average of 8 trusses per plant were recorded. Terminal growing points were removed once the plants reached the crop support wire. A naturally ventilated greenhouse was used. No heating was applied and during hot weather, temperature control was done by means of natural ventilation and the application of lime on the polycarbonate sheeting of the greenhouse.

Treatments and experimental design Coco peat and a pine sawdust-shavings mixture were evaluated. The same volume of substrate (18 litre per bag) was used for all the treatments, although the characteristics of each substrate differed. All the substrates were washed with municipal water before planting. Four CaCO₃ application levels (0, 0.75, 1.50 and 2.25 g CaCO₃ per kg substrate) and three nitrogen

source treatments (NO_3^- -N : NH_4^+ -N ratios of 100% : 0%, 80% : 20%, 60% : 40%) were evaluated (Table 1). NO_3^- -N and NH_4^+ -N was applied as $5[\text{Ca}(\text{NO}_3)_2 \cdot 2\text{H}_2\text{O}]\text{NH}_4\text{NO}_3$ and KNO_3 , and $(\text{NH}_4)_2\text{SO}_4$ respectively.

Table 1 Composition of nutrient solutions as affected by nitrogen source

Factor	NH_4^+	K^+	Ca^{2+}	Mg^{2+}	NO_3^-	H_2PO_4^-	SO_4^{2-}
NO_3^- -N : NH_4^+ -N	$\text{mmol}_c \cdot \text{l}^{-1}$						
100% : 0%	0	8	8	4	14	1	5
80% : 20%	2.80	6.88	6.88	3.44	11.20	1.47	7.33
60% : 40%	5.60	5.76	5.76	2.88	8.40	1.93	9.67

The following procedure was followed to determine the application rates of CaCO_3 to coco peat and pine sawdust-shavings: Eighteen liters (0.018 m^3) of coco peat and pine sawdust-shavings were dried at 60°C for 24 hours. After drying the weight of each substrate was determined. The dry coco peat and pine sawdust-shavings weighed 1.90 and 2.83 kg respectively. Since there is no clear indication on application rates and how it is calculated, the application of CaCO_3 to soil was used as reference point. The volume of 1 m^2 of soil, 0.3 m deep, is 0.3 m^3 and weighs approximately 400 kg at a bulk density of $1200 \text{ kg} \cdot \text{m}^{-3}$. When 0, 3, 6 and 9 $\text{tons} \cdot \text{ha}^{-1}$ CaCO_3 is applied to soil, it translates to 0, 0.75, 1.50 and 2.25 g CaCO_3 per kg soil. These rates were multiplied by the weight of the individual substrates to calculate the final application rate for each treatment per 18-liter bag of substrate.

One week (28 September 2001) after the tomato seedlings were transplanted the CaCO_3 was placed 8 cm below the substrate surface and directly under the arrow dripper, so that the irrigated nutrient solution will pass through the CaCO_3 with every irrigation cycle.

According to initial calculations made, the total nitrogen concentration for all the N-source treatments was $14 \text{ mmol}_c \cdot \text{l}^{-1}$ (196 ppm N). However, the average nitrogen content, after mixing of the different solutions, were 18.8, 17.2 and $15.2 \text{ mmol}_c \cdot \text{l}^{-1}$ for the 100% NO_3^- -N : 0% NH_4^+ -N, the 80% NO_3^- -N : 20% NH_4^+ -N and the 60% NO_3^- -N : 40% NH_4^+ -N treatments, respectively (Table 2 and 3). The increase in total nitrogen

might be due to impurities in the calcium nitrate fertilizer used. Calcium nitrate ($5[\text{Ca}(\text{NO}_3)_2 \cdot 2\text{H}_2\text{O}]\text{NH}_4\text{NO}_3$) contains 1.3% $\text{NH}_4^+\text{-N}$.

Table 2 $\text{NO}_3^-\text{-N}$ content of irrigated nutrient solution during growth period

Factor	$\text{NO}_3^-\text{-N}$ (ppm)							
	Weeks after transplanting							
	5	7	9	11	13	15	17	Average
$\text{NO}_3^-\text{-N} : \text{NH}_4^+\text{-N}$								
100% : 0%	250.0	291.4	182.9	257.2	250.0	264.2	245.3	248.7
80% : 20%	200.0	175.1	163.2	220.1	171.9	181.9	225.7	191.1
60% : 40%	152.6	155.8	106.7	156.7	138.8	166.2	86.6	137.6

Table 3 $\text{NH}_4^+\text{-N}$ content of irrigated nutrient solution during the growth

Factor	$\text{NH}_4^+\text{-N}$ (ppm)							
	Weeks after transplanting							
	5	7	9	11	13	15	17	Average
$\text{NO}_3^-\text{-N} : \text{NH}_4^+\text{-N}$								
100% : 0%	21.5	12.1	13.6	13.3	11.5	12.2	11.1	13.6
80% : 20%	48.7	45.3	52.1	53.2	43.1	44.7	51.4	48.4
60% : 40%	78.7	73.1	77.6	82.6	70.3	74.8	72.2	75.6

The average EC and pH of the three nutrient solutions varied between 2.04 to 2.11 mS.cm^{-1} (Table 4) and 5.29 to 5.90 (Table 5) respectively, during the growing season. The most acidic nutrient solution contained 40% $\text{NH}_4^+\text{-N}$, applied as ammonium sulphate. However, the pH of the irrigated nutrient solutions changed very little during the growing season, except in week 5 when there was a slight decrease in pH when only $\text{NO}_3^-\text{-N}$ and 60% $\text{NO}_3^-\text{-N} : 40\% \text{NH}_4^+\text{-N}$ was applied and in week 15 when a slight decrease was found when 60% $\text{NO}_3^-\text{-N} : 40\% \text{NH}_4^+\text{-N}$ was applied. No pH correction was done in the nutrient solution. The EC and pH of the municipal water used in the experiment was 0.07 mS.cm^{-1} and 7.20 respectively and therefore contributed very little towards the final nutrient solution composition (Table 6).

Table 4 EC measurements of irrigated nutrient solution during the growth period

Factor	EC (mS.cm ⁻¹)							
	Weeks after transplanting							
	5	7	9	11	13	15	17	Average
NO ₃ ⁻ -N : NH ₄ ⁺ -N								
100% : 0%	2.06	1.99	1.99	2.22	2.15	2.12	2.23	2.11
80% : 20%	2.01	1.93	1.76	2.30	1.96	2.07	2.46	2.07
60% : 40%	1.99	1.93	2.04	2.33	2.12	2.13	1.78	2.04

Table 5 pH measurements of irrigated nutrient solution during the growth period

Factor	pH							
	Weeks after transplanting							
	5	7	9	11	13	15	17	Average
NO ₃ ⁻ -N : NH ₄ ⁺ -N								
100% : 0%	4.85	6.01	6.13	6.26	5.78	6.22	6.03	5.90
80% : 20%	5.71	5.57	5.90	5.91	5.71	5.51	5.55	5.69
60% : 40%	4.70	5.40	5.84	5.95	5.59	3.88	5.64	5.29

Table 6 Composition of municipal water used during the experiment

EC	pH	Na ⁺	NH ₄ ⁺	K ⁺	Ca ²⁺	Mg ²⁺	NO ₃ ⁻	H ₂ PO ₄ ⁻	SO ₄ ²⁻	Cl ⁻	HCO ₃ ⁻
mS.cm ⁻¹		mmol.l ⁻¹									
0.07	7.2	0.26	0	0.01	0.28	0.12	0	0	0.08	0.43	0.17

Drainage water was sampled in week 5, 7, 9, 11, 13, 15 and 17 after transplanting. Measurements included pH, EC, NO₃⁻-N and NH₄⁺-N content. NO₃⁻-N was determined using the salicylic acid method (Cataldo *et al.*, 1975), while the indophenol-blue method (Keeney & Nelson, 1982) was used to determine NH₄⁺-N.

The nutrient solutions were mixed and stored in 1500 litre plastic tanks. Netafim drippers (pressure compensated, non-leakage), with a capacity of 2 l.hr⁻¹, were used to irrigate each bag individually. To prevent the mixing of nutrient solutions, the system was designed so that each treatment had its own separate irrigation system. An irrigation controller and timer were used to schedule irrigation. The total volume of nutrient solution irrigated per treatment per day was the same for all the treatments. The first and last irrigation took place within 1 hour from sunrise and sunset

respectively. The day length increased from 10 hours in September to 14 hours in December. Water application ranged from 500 ml per plant per day, just after transplanting, to 3000 ml during the peak production period (12 to 17 weeks after transplanting). The irrigation volumes per day were gradually increased during the growing season and included an over irrigation of 15 to 20%. This proved to be very difficult as a result of the different water holding capacity characteristics of the substrates.

Data collected The first fruit were harvested 12 weeks after transplanting and harvesting continued until week 19 (21 January 2002). The fruit were harvested twice a week and the yield was graded into two categories, marketable (only first class tomatoes) and unmarketable. Tomatoes were classified as unmarketable according to the following criteria: i) Fruit smaller than 40 mm in diameter; and ii) Fruit with defects like uneven colouring, shoulder cracks, fruit that is soft at harvest, fruit with blossom-end rot (BER) and abnormal growth. Marketable and unmarketable yield measurements were taken during the harvest period. At the end of the growing season the marketable and unmarketable yield per plant, the number of marketable fruit per plant, the number of fruit with BER per plant and the average fruit mass were calculated.

Statistical analysis The experiment was arranged in a randomized block design with 24 treatment combinations replicated in two blocks. The main plot treatment design was a 2x4x3 factorial with two substrates (coco peat, pine sawdust-shavings), four lime levels (0, 0.75, 1.50 and 2.25 g CaCO₃ per kg substrate) and three nitrogen source treatments (NO₃⁻-N : NH₄⁺-N ratios of 100% : 0%, 80% : 20%, 60% : 40%). Six plants represented an experimental unit. Variables (e.g. marketable yield, unmarketable yield etc.) were assessed weekly during the trial period until the end of the season. Analysis of variance (Anova) was performed for each assessment time separately, using the GLM (General Linear Models) procedure of SAS statistical software version 8.2 (SAS, 2000). Shapiro-Wilk test was performed to test for normality (Shapiro & Wilk, 1965). Student's t-least significant difference was calculated at the 5% level to compare treatment means. A probability level of 5% was considered significant for all significance tests.

Experiment 2

Locality and climate A greenhouse trial was conducted at Stellenbosch in the Western Cape Province of South Africa during the summer and autumn of 2002. The weekly average minimum and maximum temperatures outside the greenhouse are presented in Figure 1. From this figure it is clear that especially daily maximum temperatures decreases gradually during the duration of the experiment.

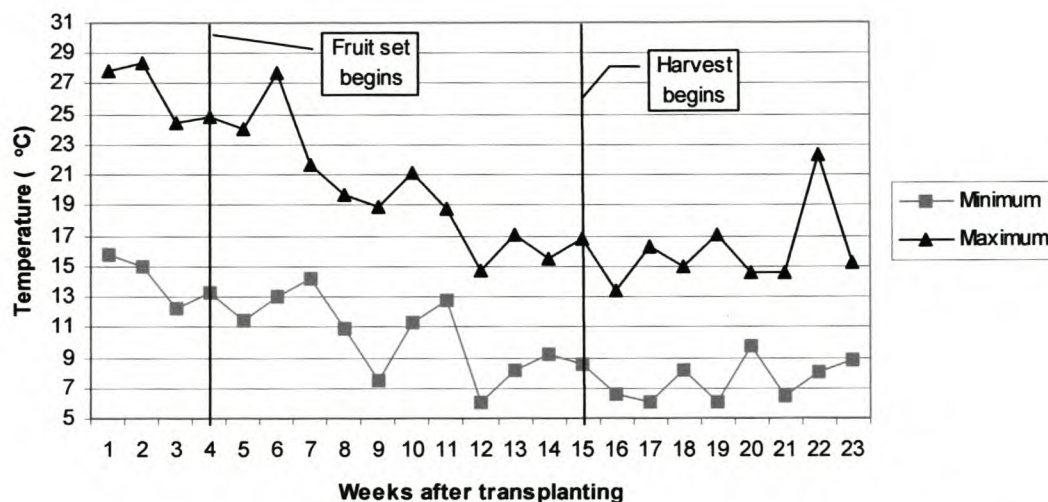


Figure 1 Weekly minimum and maximum temperatures outside the greenhouse during the growth period of 12 March to 23 August 2002

Cultivation practices Seeds of the tomato (*Lycopersicon esculentum* Mill.) cultivar FA593 (Mayford Seeds, South Africa) were sown on 5 February 2002 in seedling trays and transplanted into the greenhouse on 12 March 2002 (5 weeks after sowing). The same cultural practices as used in Experiment 1 were followed, except for the trellising height that was reduced to 1.70 m. An average of 6 trusses per plant were recorded.

Treatments and experimental design A similar experimental design and procedure to calculate the CaCO_3 application rates as for Experiment 1 were used. As mentioned earlier the CaCO_3 application levels in Experiment 1 had no significant effect on any of the parameters evaluated and the levels were therefore increased to 0, 6, 12 and 18 $\text{ton}\cdot\text{ha}^{-1}$ CaCO_3 (the equivalent of 0, 1.5, 3.0 and 4.5 g CaCO_3 per kg

substrate). The same procedure as in Experiment 1 was used for the CaCO_3 application one week after transplanting of the seedlings.

The average nitrogen content, after mixing of the different solutions, were 18.4, 15.7 and 14.4 $\text{mmol}\cdot\text{l}^{-1}$ for the 100% NO_3^- -N : 0% NH_4^+ -N, the 80% NO_3^- -N : 20% NH_4^+ -N and the 60% NO_3^- -N : 40% NH_4^+ -N treatments, respectively (Table 7 and 8). The increase in total nitrogen might be due to impurities in the calcium nitrate fertilizer used. Calcium nitrate ($5[\text{Ca}(\text{NO}_3)_2\cdot 2\text{H}_2\text{O}]\text{NH}_4\text{NO}_3$) contains 1.3% NH_4^+ -N.

Table 7 NO_3^- -N content of irrigated nutrient solution during the growth period

Factor	NO_3^- -N (ppm)								
	Weeks after transplanting								
	9	10	11	12	13	14	15	16	Average
NO_3^- -N : NH_4^+ -N									
100% : 0%	240.7	256.4	202.5	354.6	214.7	203.9	275.0	232.2	247.5
80% : 20%	199.4	195.9	157.8	213.3	169.7	173.6	205.7	138.8	181.8
60% : 40%	152.3	145.8	118.3	134.8	135.9	137.9	162.5	77.4	133.1

Table 8 NH_4^+ -N content of irrigated nutrient solution during the growth period

Factor	NH_4^+ -N (ppm)								
	Weeks after transplanting								
	9	10	11	12	13	14	15	16	Average
NO_3^- -N : NH_4^+ -N									
100% : 0%	10.4	10.7	10.4	10.6	11.5	10.1	8.2	7.6	9.9
80% : 20%	42.4	45.6	35.3	38.3	44.1	39.1	42.7	16.0	37.9
60% : 40%	69.3	76.7	62.2	62.4	75.6	79.8	65.2	59.9	68.9

Table 9 EC measurements of irrigated nutrient solution during the growth period

Factor	EC ($\text{mS}\cdot\text{cm}^{-1}$)								
	Weeks after transplanting								
	9	10	11	12	13	14	15	16	Average
NO_3^- -N : NH_4^+ -N									
100% : 0%	1.85	1.86	2.06	1.84	1.58	1.76	1.76	1.65	1.80
80% : 20%	1.86	1.78	2.00	1.81	1.63	1.48	1.83	1.58	1.76
60% : 40%	1.85	1.85	1.94	1.84	1.68	1.76	1.91	1.79	1.83

The average EC and pH of the three nutrient solutions varied between 1.76 to 1.83 $\text{mS}\cdot\text{cm}^{-1}$ (Table 9) and 5.54 to 5.96 (Table 10) respectively, during the growing season. Very little change in the pH of the irrigated nutrient solution was measured during the growing season, except in week 11 when there was a slight decrease in pH irrespective of nitrogen source. In this experiment the EC and pH of the municipal water used was $0.06 \text{ mS}\cdot\text{cm}^{-1}$ and 7.20 respectively. The water analysis was similar to that of the water used in experiment 1 and therefore also contributed very little towards the final nutrient solution composition.

Table 10 pH measurements of irrigated nutrient solution during the growth period

Factor	pH								
	Weeks after transplanting								
$\text{NO}_3^- \text{-N} : \text{NH}_4^+ \text{-N}$	9	10	11	12	13	14	15	16	Average
100% : 0%	6.14	6.09	5.84	6.03	6.27	5.75	5.82	5.76	5.96
80% : 20%	5.98	6.01	4.80	5.77	5.87	5.90	5.66	5.78	5.72
60% : 40%	5.89	5.93	4.86	5.63	5.66	5.73	5.54	5.04	5.54

Drainage water was sampled in week 9, 10, 11, 12, 13, 14, 15 and 16 after transplanting. Measurements included pH, EC, $\text{NO}_3^- \text{-N}$ and $\text{NH}_4^+ \text{-N}$ content. The $\text{NO}_3^- \text{-N}$ and $\text{NH}_4^+ \text{-N}$ content were determined with the methods referred to in Experiment 1.

The same irrigation system as in Experiment 1 was used and the water application ranged from 500 to 2200 ml per plant per day (from just after transplanting until the peak production period).

Data collected This was as described for Experiment 1, except that the first fruit were harvested 15 weeks after transplanting and harvesting continued till week 23 (23 August 2002).

Statistical analysis A similar experimental design as in Experiment 1 was used, except that the CaCO_3 application levels were increased to 0, 1.5, 3.0 and 4.5 g

CaCO₃ per kg substrate. The analysis procedure also conformed to that used in Experiment 1.

Results and discussion

Drainage water

Results on the analysis of variance (ANOVA's) done on the drainage water parameters are summarized in Table 11 to 14. From these tables it became clear that less important attributing factors could be eliminated by comparing significance levels and consistency of significance.

Substrate (Experiment 1) and nitrogen source (Experiment 1 and 2) as main factors and the interaction between substrate x nitrogen source (Experiment 2) were the most important factors affecting pH of the drainage water during the sampling period.

The main factors substrate and nitrogen source affected EC in Experiment 1 and 2.

Substrate and nitrogen source as main factors affected the NO₃⁻-N and NH₄⁺-N content in Experiment 1 and 2. The interaction substrate x nitrogen source had a significant effect on the NH₄⁺-N content in Experiment 1 and 2 during the sampling period.

From these results it is clear that substrate and nitrogen source and the interactions between these were by far the most important factors, which affected pH, EC, and NO₃⁻-N and NH₄⁺-N content in the drainage water. Where similar trends were found only data from Experiment 2 will be discussed. Further discussions on the results will therefore focus on these aspects only.

Table 11 Analysis of variance (ANOVA) of drainage water pH

Experiment 1		pH						
Factor	DF	Weeks after transplanting						
		5	7	9	11	13	15	17 ^x
		<i>Pr > F</i>	<i>Pr > F</i>	<i>Pr > F</i>	<i>Pr > F</i>	<i>Pr > F</i>	<i>Pr > F</i>	<i>Pr > F</i>
Replicate	1	0.9036	0.3927	0.3637	0.1021	0.1075	0.6578	0.7737
Substrate	1	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001
Lime	3	0.7487	0.4232	0.2308	0.9159	0.8802	0.8736	0.6337
Sub x Lime	3	0.4967	0.9330	0.3555	0.7707	0.5702	0.5367	0.2821
Nitrogen source	2	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001
Sub x Nitro	2	0.2674	0.0832	0.4030	0.0487	0.0131	<.0001	<.0001
Lime x Nitro	6	0.8184	0.7348	0.8367	0.9504	0.6500	0.1613	0.4801
Sub x Lime x Nitro	6	0.8814	0.5629	0.5903	0.6997	0.8813	0.2749	0.7062
<i>Error</i>	23							
<i>CV (%)</i>		5.10	5.91	4.68	7.24	5.59	4.11	2.38

Experiment 2		Weeks after transplanting							
Factor	DF	9	10	11	12	13	14	15	16
		<i>Pr > F</i>	<i>Pr > F</i>	<i>Pr > F</i>	<i>Pr > F</i>	<i>Pr > F</i>	<i>Pr > F</i>	<i>Pr > F</i>	<i>Pr > F</i>
Replicate	1	0.2070	0.6033	0.6595	0.9823	0.7225	0.7352	0.9876	0.3967
Substrate	1	0.7870	0.9941	0.2687	0.1236	0.1071	0.1359	0.0954	0.0196
Lime	3	0.3064	0.5426	0.4557	0.4457	0.5618	0.7241	0.4257	0.4373
Sub x Lime	3	0.3634	0.9014	0.6451	0.8419	0.6304	0.7248	0.3559	0.3028
Nitrogen source	2	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001
Sub x Nitro	2	0.0029	0.0248	0.0864	0.0110	0.0292	0.0086	0.0088	0.0014
Lime x Nitro	6	0.0255	0.2307	0.4252	0.4828	0.7021	0.6254	0.7660	0.1828
Sub x Lime x Nitro	6	0.3681	0.0469	0.2310	0.2841	0.6379	0.7914	0.2525	0.4766
<i>Error</i>	23								
<i>CV (%)</i>		10.75	10.36	11.06	10.23	11.45	10.97	8.56	9.25

^x Data not normally distributed. Transformed with $LX = \ln(X)$

Table 12 Analysis of variance (ANOVA) of drainage water EC

Experiment 1		EC (mS.cm ⁻¹)						
Factor	DF	Weeks after transplanting						
		5	7	9	11	13 ^x	15	17
		<i>Pr > F</i>	<i>Pr > F</i>	<i>Pr > F</i>	<i>Pr > F</i>	<i>Pr > F</i>	<i>Pr > F</i>	<i>Pr > F</i>
Replicate	1	0.0623	0.4464	0.9147	0.1225	0.2014	0.0243	0.5462
Substrate	1	0.0738	<.0001	0.0025	<.0001	<.0001	<.0001	0.0016
Lime	3	0.4096	0.0169	0.8827	0.5050	0.0365	0.1992	0.6787
Sub x Lime	3	0.7993	0.6310	0.0774	0.0160	0.0097	0.6838	0.8746
Nitrogen source	2	0.0004	0.0232	0.8333	0.0413	0.8910	0.1313	0.0264
Sub x Nitro	2	0.0390	0.8735	0.1067	0.7696	0.1664	0.4794	0.5724
Lime x Nitro	6	0.9121	0.4020	0.4611	0.3249	0.0253	0.4352	0.6514
Sub x Lime x Nitro	6	0.8301	0.3677	0.9481	0.1038	0.1342	0.8088	0.4352
<i>Error</i>	23							
<i>CV (%)</i>		12.87	5.77	16.58	13.57	11.83	22.08	17.31

Experiment 2		Weeks after transplanting							
Factor	DF	9	10	11	12	13	14	15	16
		<i>Pr > F</i>	<i>Pr > F</i>	<i>Pr > F</i>	<i>Pr > F</i>	<i>Pr > F</i>	<i>Pr > F</i>	<i>Pr > F</i>	<i>Pr > F</i>
Replicate	1	0.0274	0.9173	0.0003	0.0002	0.0003	0.0084	0.0108	0.2239
Substrate	1	0.0003	0.3967	<.0001	<.0001	<.0001	<.0001	<.0001	0.0017
Lime	3	0.6118	0.3432	0.5933	0.2510	0.7412	0.4898	0.7554	0.7515
Sub x Lime	3	0.2237	0.5900	0.6129	0.4716	0.4485	0.5747	0.7165	0.5523
Nitrogen source	2	<.0001	<.0001	0.0022	0.0007	<.0001	<.0001	0.4276	0.6390
Sub x Nitro	2	0.4712	0.3480	0.9770	0.9713	0.6242	0.7450	0.4320	0.4755
Lime x Nitro	6	0.1674	0.5735	0.3894	0.2395	0.2004	0.3866	0.3387	0.7818
Sub x Lime x Nitro	6	0.1521	0.7870	0.4012	0.1696	0.8068	0.9759	0.8786	0.7619
<i>Error</i>	23								
<i>CV (%)</i>		7.11	9.32	6.34	4.39	3.67	5.34	4.10	6.00

^x Data not normally distributed. Transformed with LX=Ln(X)

Table 13 Analysis of variance (ANOVA) of drainage water NO₃⁻-N content

Experiment 1		NO ₃ ⁻ -N (ppm)						
Factor	DF	Weeks after transplanting						
		5 ^x	7 ^x	9	11	13	15	17
		<i>Pr > F</i>	<i>Pr > F</i>	<i>Pr > F</i>	<i>Pr > F</i>	<i>Pr > F</i>	<i>Pr > F</i>	<i>Pr > F</i>
Replicate	1	0.4598	0.2888	0.6273	0.0056	0.5288	0.1385	0.4515
Substrate	1	0.0130	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001
Lime	3	0.2162	0.1804	0.7643	0.3000	0.1263	0.0604	0.3316
Sub x Lime	3	0.7618	0.1468	0.2132	0.0839	0.0304	0.0806	0.9417
Nitrogen source	2	0.0116	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001
Sub x Nitro	2	0.0588	0.0013	0.1467	0.0555	0.0022	<.0001	0.0383
Lime x Nitro	6	0.6026	0.3214	0.6588	0.9921	0.3389	0.1945	0.8962
Sub x Lime x Nitro	6	0.7038	0.6506	0.6203	0.3157	0.3879	0.2568	0.4598
<i>Error</i>	23							
<i>CV (%)</i>		26.60	6.26	29.51	21.79	18.03	12.47	21.25

Experiment 2		Weeks after transplanting							
Factor	DF	9	10	11	12	13	14	15	16
		<i>Pr > F</i>	<i>Pr > F</i>	<i>Pr > F</i>	<i>Pr > F</i>	<i>Pr > F</i>	<i>Pr > F</i>	<i>Pr > F</i>	<i>Pr > F</i>
Replicate	1	0.4141	0.7092	0.6757	0.0046	0.1669	0.1656	0.1798	0.1346
Substrate	1	0.0022	0.4976	<.0001	0.0003	0.0003	<.0001	<.0001	0.0010
Lime	3	0.1871	0.2480	0.7519	0.1849	0.8056	0.7515	0.0010	0.8278
Sub x Lime	3	0.9848	0.8544	0.7451	0.2734	0.7479	0.6404	0.1263	0.0810
Nitrogen source	2	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001
Sub x Nitro	2	0.1949	0.2621	0.0150	0.0983	0.0584	0.0421	0.0171	0.0012
Lime x Nitro	6	0.5990	0.4327	0.0140	0.3156	0.1033	0.5687	0.0755	0.1688
Sub x Lime x Nitro	6	0.1894	0.6767	0.2615	0.3170	0.4538	0.2914	0.8658	0.0744
<i>Error</i>	23								
<i>CV (%)</i>		15.07	20.65	9.56	10.70	9.14	7.68	8.33	9.51

^x Data not normally distributed. Transformed with LX=Ln(X)

Table 14 Analysis of variance (ANOVA) of drainage water NH_4^+ -N content

Experiment 1		NH_4^+ -N (ppm)						
Factor	DF	Weeks after transplanting						
		5 ^x	7	9	11	13	15	17
		<i>Pr > F</i>	<i>Pr > F</i>	<i>Pr > F</i>	<i>Pr > F</i>	<i>Pr > F</i>	<i>Pr > F</i>	<i>Pr > F</i>
Replicate	1	0.4584	0.2566	0.0723	0.1352	0.9307	0.1843	0.3867
Substrate	1	0.7569	0.1942	0.0020	0.0004	0.0016	<.0001	0.0005
Lime	3	0.5572	0.3234	0.3161	0.4191	0.1751	0.0036	0.2889
Sub x Lime	3	0.9271	0.4785	0.4316	0.9945	0.7344	0.0004	0.3588
Nitrogen source	2	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001
Sub x Nitro	2	0.1285	0.5318	0.0331	0.0153	0.0342	<.0001	0.0145
Lime x Nitro	6	0.9739	0.1957	0.1102	0.4483	0.2952	0.1087	0.7087
Sub x Lime x Nitro	6	0.9757	0.2672	0.8937	0.2739	0.0605	0.1744	0.9054
<i>Error</i>	23							
<i>CV (%)</i>		66.7	30.78	17.48	16.94	12.26	12.84	24.70

Experiment 2		Weeks after transplanting							
Factor	DF	9	10	11	12	13	14	15	16
		<i>Pr > F</i>	<i>Pr > F</i>	<i>Pr > F</i>	<i>Pr > F</i>	<i>Pr > F</i>	<i>Pr > F</i>	<i>Pr > F</i>	<i>Pr > F</i>
Replicate	1	0.2357	0.8106	0.0027	0.1594	0.5636	0.5009	0.0284	0.1151
Substrate	1	0.1143	0.4356	0.2123	0.0014	0.9789	<.0001	0.0042	0.0193
Lime	3	0.1425	0.4857	0.2829	0.1098	0.3942	0.4835	0.0231	<.0001
Sub x Lime	3	0.6362	0.6455	0.4404	0.6923	0.0157	0.1781	0.0789	0.0865
Nitrogen source	2	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001
Sub x Nitro	2	0.4983	0.0474	0.6493	0.3769	0.0223	<.0001	0.0046	0.0482
Lime x Nitro	6	0.7291	0.2796	0.0084	0.8494	0.2479	0.0661	0.5313	0.0044
Sub x Lime x Nitro	6	0.5678	0.2085	0.7649	0.7332	0.0120	0.2852	0.0266	0.4398
<i>Error</i>	23								
<i>CV (%)</i>		31.12	24.90	12.76	9.40	9.85	9.31	8.64	12.55

^x Data not normally distributed. Transformed with $\text{SX}=\text{SQRT}(X)$

pH The pH of the irrigated nutrient solution (Tables 5 and 10) and drainage water (Tables 16 and 17) declined with an increase in $\text{NH}_4^+\text{-N}$ content in the nutrient solution, although the average irrigated nutrient solution pH in Experiment 1 (Table 5) was marginally lower than in Experiment 2 (Table 10). The acidifying effect of ammonium fertilizers could be expected due to the release of hydrogen ions during the conversion of $\text{NH}_4^+\text{-N}$ to $\text{NO}_3^-\text{-N}$ (Adams, 2002) or the uptake of $\text{NH}_4^+\text{-N}$ (Raven & Smith, 1976; Kafkafi, 2000).

Table 15 Influence of substrate on drainage water pH during the growth period of Experiment 1

Factor	Experiment 1: Drainage water pH						
	Weeks after transplanting						
Substrate	5	7	9	11	13	15	17 ^x
Coco peat	6.11 b	5.58 b	5.25 b	4.75 b	4.72 b	4.46 b	4.37 b
Pine sawdust	7.16 a	7.20 a	7.23 a	7.05 a	6.86 a	6.65 a	6.61 a
<i>LSD (P=0.05)</i>	0.21	0.23	0.19	0.26	0.19	0.14	^x
<i>CV (%)</i>	5.10	5.91	4.68	7.24	5.59	4.11	2.38

Means followed by the same letter do not differ significantly at $P = 0.05$ (LSD)

^x Data not normally distributed. Transformed with $LX = \ln(X)$

In Experiment 1 (warmer, summer conditions) the pH of coco peat decreased with time from pH 6.11 to 4.37 (Table 15). The pH of pine sawdust-shavings slightly increased from 7.16 to 7.23 between 5 and 9 weeks after transplanting and then decreased to pH 6.61 at 17 weeks after transplanting. In this experiment the pH of the drainage water, irrespective of nitrogen source, declined with time (Table 16). When 0%, 20% and 40% $\text{NH}_4^+\text{-N}$ was used the pH decreased respectively from 7.07 to 6.11, 6.58 to 5.01 and 6.14 to 5.07, between 5 to 17 weeks after transplanting.

Table 16 Influence of nitrogen source on drainage water pH during the growth period of Experiment 1

Factor	Experiment 1: Drainage water pH						
	Weeks after transplanting						
	5	7	9	11	13	15	17 ^x
NO ₃ ⁻ -N : NH ₄ ⁺ -N							
100% : 0%	7.07 a	7.00 a	6.84 a	6.56 a	6.36 a	6.10 a	6.11 a
80% : 20%	6.58 b	6.31 b	6.15 b	5.70 b	5.63 b	5.29 b	5.01 b
60% : 40%	6.14 c	5.86 c	5.75 c	5.21 c	5.39 c	5.27 b	5.07 b
<i>LSD (P=0.05)</i>	0.25	0.28	0.23	0.32	0.24	0.17	^x
<i>CV (%)</i>	5.10	5.91	4.68	7.24	5.59	4.11	2.38

Means followed by the same letter do not differ significantly at P = 0.05 (LSD)

^x Data not normally distributed. Transformed with LX=Ln(X)

In Experiment 2 (cooler, winter conditions) the drainage water pH of coco peat slightly increased between 9 and 10 weeks after transplanting and the pH of the drainage water was slightly higher or almost the same from 10 to 12 weeks after transplanting, compared to 9 weeks after transplanting when 0% and 20% NH₄⁺-N was used (Table 17). Generally the pH declined with 0% NH₄⁺-N from 6.11 to 5.76 and with 20% NH₄⁺-N from 5.44 to 5.00 between 11 to 16 weeks after transplanting, with the largest decrease occurring at 13 weeks after transplanting. However there was, irrespective of nitrogen source, a marginal increase in pH at 14 weeks after transplanting. The drainage water pH varied during the growing season, but ranged between 5.14 and 4.85 when 40% NH₄⁺-N was used in the nutrient solution. No definite trend was shown. This is in contrast with previous findings for cooler, winter conditions where the drainage water pH of coco peat declined with time and the pH was generally lower when 20 and 40% NH₄⁺-N was used (See Chapter 4).

The highest drainage water pH for pine sawdust-shavings in Experiment 2 was measured 12 weeks after transplanting when 100% NO₃⁻-N was applied. This indicated a slight increase in pH from 9 weeks after transplanting. However, there was no definite trend as a result of lower pH values that was measured at 13 and 15 weeks after transplanting. The pH at 16 weeks after transplanting was 6.79. When the nutrient solution contained 80% NO₃⁻-N : 20% NH₄⁺-N the pH of the drainage water increased between 9 and 12 weeks after transplanting. Although a slight decline in pH

was observed between 12 and 14 weeks after transplanting, the pH still remained higher than the pH measured at 9 weeks after transplanting. The pH decreased from 5.69 to 5.43 between 14 and 15 weeks after transplanting, but at 16 weeks after transplanting it was 5.49. When 40% $\text{NH}_4^+\text{-N}$ was used in the nutrient solution the pH of the drainage water increased slightly from 4.19 to 4.62 between 9 and 15 weeks after transplanting. The pH reading at 16 weeks after transplanting was 4.42. These findings are in contrast with previous findings for cooler, winter conditions where only a decrease in pH was recorded and the drainage water pH values were higher (See Chapter 4). This emphasises the problem of consistency of substrate characteristics when pine sawdust-shavings are used as substrate.

Table 17 Influence of substrate and nitrogen source on drainage water pH during the growth period of Experiment 2

Factor	Experiment 2: Drainage water pH							
	Weeks after transplanting							
	Coco Peat							
	9	10	11	12	13	14	15	16
$\text{NO}_3^- \text{-N} : \text{NH}_4^+ \text{-N}$								
100% : 0%	6.00 b	6.15 ab	6.11 b	6.10 b	5.70 b	5.79 b	5.66 b	5.76 b
80% : 20%	5.45 bc	5.54 c	5.44 cd	5.40 cd	5.19 bc	5.26 bc	5.09 cd	5.00 cd
60% : 40%	4.99 c	5.06 c	4.89 de	5.08 de	4.97 cd	5.14 cd	4.99 cd	4.85 de
	Pine Sawdust							
	9	10	11	12	13	14	15	16
100% : 0%	6.82 a	6.71 a	6.78 a	6.94 a	6.42 a	6.70 a	6.38 a	6.79 a
80% : 20%	5.57 bc	5.60 bc	5.72 bc	5.85 bc	5.80 ab	5.69 bc	5.43 bc	5.49 bc
60% : 40%	4.19 d	4.43 d	4.55 e	4.59 e	4.54 d	4.61 d	4.62 d	4.42 e
LSD ($P=0.05$)	0.61	0.60	NS	0.60	0.64	0.63	0.47	0.52
CV (%)	10.75	10.36	11.06	10.23	11.45	10.97	8.56	9.25

Means followed by the same letter do not differ significantly at $P = 0.05$ (LSD)

From the results it is clear that lime had no influence on the drainage water pH of Experiment 1, but might have influenced the drainage water pH in Experiment 2. The average pH of coco peat was generally higher in Experiment 2 (cooler, winter conditions; higher lime application rates) compared to Experiment 1 (warmer, summer conditions; lower lime application rates) and to a previous experiment (Chapter 4: cooler, winter conditions; no lime applied). Differences between the upper

and lower drainage water pH values in Experiment 2 were much smaller compared to Experiment 1. This might also be as a result of the higher lime application rates and therefore improved buffer capacity. Previous research indicated that the detrimental effects of ammonium on growth could be alleviated by the addition of calcium carbonate (Pierpont & Minotti, 1977), which buffered the pH of the nutrient solution to near neutral.

However, the average pH of pine sawdust-shavings was generally lower in Experiment 2 compared to Experiment 1 and an earlier experiment (Chapter 4). The decline in drainage water pH in Experiment 1, when only NO_3^- -N was applied, could be attributed to the trace amounts of NH_4^+ -N found in the nutrient solution due to impurities in the fertilizer used. The slight increase in pH in Experiment 2 when pine sawdust-shavings was used with 100% NO_3^- -N in the nutrient solution and the general higher pH values compared to coco peat, could be ascribed to the well known fact that microorganisms consume nitrates, especially in wood fibre substrates, during decomposition and proportionally emit hydroxyl ions into the nutrient solution, thus raising the pH (Vlassak *et al.*, 1991). Although the drainage water pH of pine sawdust-shavings in Experiment 2 declined, irrespective of nitrogen source, the pH with time remained very stable. This might also be the result of the pre-plant application of calcium carbonate.

Control of pH in the nutrient solution and root zone is crucial as it affects the availability of nutrients. The optimum solution pH is between 5 and 6 (Sonneveld, 2002). It was evident that drainage water pH became too low for efficient plant nutrition, if NH_4^+ -N were used, especially in coco peat as growing substrate (Experiment 1) and when 40% NH_4^+ -N was applied to coco peat and pine sawdust-shavings (Experiment 2).

Electrical conductivity The nutrient solutions were made up based on a calculated EC of 2.0 mS.cm^{-1} , while measurements of the nutrient solutions resulted in average EC values of 2.04 and 2.11 mS.cm^{-1} in Experiment 1 (Table 4), and 1.76 and 1.83 mS.cm^{-1} in Experiment 2 (Table 9) respectively. The drainage water EC of Experiment 1 (warmer, summer conditions) was significantly affected by growth substrates and nitrogen source, with an increase in EC with time in coco peat and pine

sawdust-shavings (Table 18). However, the drainage water EC of coco peat was significantly higher than that of pine sawdust-shavings between 7 and 17 weeks after transplanting, probably due to the fact that coco peat had a much higher cation exchange capacity than pine sawdust-shavings (Lemaire, 1995; Noguera *et al.*, 2000) or due to the difference in composting activity (Benoit & Ceustermans, 1995). The higher EC values of Experiment 1 can be ascribed to fertilizer salts that accumulated in the growth substrates as a result of high temperatures and insufficient water volumes applied per irrigation cycle or it might be as a result of a lower microbial activity in coco peat compared to pine sawdust-shavings and therefore a lower consumption of nitrate, phosphorus and calcium. Although the data are not presented, no definite trends were observed in Experiment 2 (cooler, winter conditions). In this experiment the drainage water EC values varied for coco peat between 1.85 and 2.26 mS.cm⁻¹ and for pine sawdust-shavings between 1.74 and 2.08 mS.cm⁻¹. These EC values were much more stable during the growing season than those of Experiment 1.

Table 18 Influence of substrate on drainage water EC during the growth period of Experiment 1

Factor	Experiment 1: EC (mS.cm ⁻¹)						
	Weeks after transplanting						
Substrate	5	7	9	11	13 ^x	15	17
Coco peat	1.86 a	2.11 a	3.41 a	4.05 a	3.88 a	5.57 a	3.92 a
Pine sawdust	1.73 a	1.91 b	2.89 b	3.25 b	3.11 b	3.75 b	3.28 b
<i>LSD (P=0.05)</i>	NS	0.07	0.31	0.30	x	0.61	0.37
<i>CV (%)</i>	12.87	5.77	16.58	13.57	11.83	22.08	17.31

Means followed by the same letter do not differ significantly at P = 0.05 (LSD)

^x Data not normally distributed. Transformed with LX=Ln(X)

The drainage water EC of Experiment 1 (Table 19) increased, irrespective of nitrogen source, with time and was significantly lower with 100% NO₃⁻-N in the nutrient solution, except at 17 weeks after transplanting. Contrary to Experiment 1, the drainage water EC in Experiment 2 declined, irrespective of nitrogen source, between 11 and 16 weeks after transplanting. This can be ascribed to the cooler, winter conditions during Experiment 2 and that the excess salts were washed out by over

irrigation. Generally the EC values in Experiment 2 were much lower than in Experiment 1.

Table 19 Influence of nitrogen source on drainage water EC during the growth period of Experiment 1

Factor	Experiment 1: EC (mS.cm ⁻¹)						
	Weeks after transplanting						
	5	7	9	11	13 ^x	15	17
NO ₃ ⁻ -N : NH ₄ ⁺ -N							
100% : 0%	1.58 b	1.94 b	3.19 a	3.62 ab	3.51 a	5.04 a	3.46 b
80% : 20%	1.84 a	2.06 a	3.09 a	3.43 b	3.49 a	4.67 ab	3.97 a
60% : 40%	1.96 a	2.01 ab	3.18 a	3.90 a	3.43 a	4.27 b	3.37 b
<i>LSD (P=0.05)</i>	0.17	0.08	NS	0.36	NS ^x	NS	0.46
<i>CV (%)</i>	12.87	5.77	16.58	13.57	11.83	22.08	17.31

Means followed by the same letter do not differ significantly at P = 0.05 (LSD)

^x Data not normally distributed. Transformed with LX=Ln(X)

NO₃⁻-N and NH₄⁺-N content Substrate and nitrogen source and their interactions were the largest contributors to differences in the NO₃⁻-N and NH₄⁺-N content of the drainage water.

Table 20 Influence of substrate on drainage water NO₃⁻-N content during the growth period of Experiment 2

Factor	Experiment 2: NO ₃ ⁻ -N (ppm)							
	Weeks after transplanting							
	9	10	11	12	13	14	15	16
Substrate								
Coco peat	184.3 a	177.0 a	194.9 a	229.0 a	202.4 a	197.0 a	211.4 a	210.0 a
Pine sawdust	158.5 b	169.9 a	166.4 b	201.1 b	180.9 b	167.5 b	188.5 b	189.3 b
<i>LSD (P=0.05)</i>	15.43	NS	10.31	13.74	10.46	8.36	10.20	11.34
<i>CV (%)</i>	15.07	20.65	9.56	10.70	9.14	7.68	8.33	9.51

Means followed by the same letter do not differ significantly at P = 0.05 (LSD)

The drainage water NO₃⁻-N content in Experiment 2 (cooler, winter conditions) from coco peat was significantly higher than that from pine sawdust-shavings at all sampling dates (Table 20), except at 10 weeks after transplanting. No definite trend was observed for NO₃⁻-N content with time, although the NO₃⁻-N content was slightly

higher between 12 and 16 weeks after transplanting. The same trends were observed for drainage water NO_3^- -N content in Experiment 1 under warmer, summer conditions (data not presented), except that the values were much higher than in Experiment 2. The NO_3^- -N content values ranged in Experiment 1 between 262.3 to 477.2 ppm for coco peat and between 138.5 to 306.4 ppm for pine sawdust-shavings. In earlier experiments higher NO_3^- -N values were also found in warmer, summer conditions (Chapter 3) than in cooler, winter conditions (Chapter 4). This might be due to larger volumes of nutrient solution being irrigated during summer than winter.

As expected the NO_3^- -N content of the drainage water of Experiment 2 decreased as the NH_4^+ -N content increased in the nutrient solution (Table 21). The same trend was also recorded in Experiment 1 (data not presented), but in comparison the NO_3^- -N content values were much higher than in Experiment 2. No definite trends, irrespective of nitrogen source were observed with time in Experiment 2. Contrary to Experiment 2, an accumulation of NO_3^- -N was found from 9 to 17 weeks after transplanting. The NO_3^- -N content values in Experiment 1 ranged between 257.9 to 513.3, 213.7 to 401.8 and 129.4 to 260.2 ppm for the 0%, 20% and 40% NH_4^+ -N treatments respectively.

Table 21 Influence of nitrogen source on drainage water NO_3^- -N content during the growth period of Experiment 2

Factor	Experiment 2: NO_3^- -N (ppm)							
	Weeks after transplanting							
	9	10	11	12	13	14	15	16
NO_3^- -N : NH_4^+ -N								
100% : 0%	213.2 a	229.0 a	230.2 a	267.9 a	241.4 a	241.2 a	246.2 a	248.5 a
80% : 20%	163.9 b	150.0 b	178.1 b	208.1 b	184.6 b	167.7 b	210.4 b	200.2 b
60% : 40%	137.2 c	141.2 b	133.7 c	169.1 c	149.1 c	137.9 c	147.5 c	150.2 c
LSD ($P=0.05$)	18.90	26.19	12.63	16.83	12.81	10.24	12.51	13.89
CV (%)	15.07	20.65	9.56	10.70	9.14	7.68	8.33	9.51

Means followed by the same letter do not differ significantly at $P = 0.05$ (LSD)

In Experiment 2 the NH_4^+ -N content increased as expected in the drainage water of coco peat and pine sawdust-shavings as the NH_4^+ -N content increased in the nutrient solution (Table 22). The same trend was observed for Experiment 1 (data not presented), but in comparison the drainage water NH_4^+ -N content values were much

lower in Experiment 2. In previous experiments the drainage water NH_4^+ -N content values during cooler, winter conditions (Chapter 4) were also much lower compared to NH_4^+ -N content values during warmer, summer conditions (Chapter 3). The drainage water NH_4^+ -N content of coco peat and pine sawdust-shavings in Experiment 1 ranged between 0.6 to 9.4, 55.0 to 92.4 and 102.1 to 143.2 ppm, and 1.7 to 12.5, 40.3 to 55.4 and 90.4 to 110.9 ppm for the 0%, 20% and 40% NH_4^+ -N treatments respectively. The NH_4^+ -N content recorded in the 100% NO_3^- -N treatment (Tables 3, 8 and 22) was probably due to impurities in the fertilizers that was used.

Table 22 Influence of substrate and nitrogen source on drainage water NH_4^+ -N content during the growth period of Experiment 2

Factor	Experiment 2: NH_4^+ -N (ppm)							
	Weeks after transplanting							
	Coco peat							
	9	10	11	12	13	14	15	16
NO_3^- -N : NH_4^+ -N								
100% : 0%	0.3 c	0.4 d	2.0c	4.7 e	4.6 d	3.9 e	5.8 e	4.1 d
80% : 20%	17.7 b	16.2 c	33.8 b	36.8 c	35.2 c	33.1 c	38.5 c	32.5 c
60% : 40%	54.9 a	64.0 a	72.5 a	70.5 a	66.1 b	67.2 a	72.9 a	67.8 a
	Pine sawdust							
	9	10	11	12	13	14	15	16
100% : 0%	0.6 c	0.8 d	2.0 c	3.1 e	2.9 d	3.1 e	4.4 e	3.4 d
80% : 20%	21.7 b	24.7 b	31.8 b	32.7 d	32.7 c	25.2 d	31.5 d	31.6 c
60% : 40%	62.1 a	59.8 a	69.5 a	65.7 b	70.4 a	63.7 b	57.3 b	60.3 b
LSD ($P=0.05$)	NS	7.12	NS	NS	3.60	2.90	3.38	4.32
CV (%)	31.12	24.90	12.76	9.40	9.85	9.31	8.64	12.55

Means followed by the same letter do not differ significantly at $P = 0.05$ (LSD)

The lower drainage water NH_4^+ -N content during cooler, winter conditions (Experiment 2) could be explained by *inter alia*: nitrification (Lang & Elliot, 1991) or the uptake of NH_4^+ . However, the improved uptake of NH_4^+ could be due to cooler root temperatures, although very little nitrification occurs when the root temperatures drop to 3 - 4°C (Ganmore-Neumann & Kafkafi, 1980). Ganmore-Neumann & Kafkafi (1980) found that low root temperatures slows down the uptake of NO_3^- , but is beneficial to the uptake and translocation of NH_4^+ metabolites from the roots to the

shoots of tomato plants. It is more likely that the latter scenario had the biggest effect on the lower NH_4^+ -N values in the drainage water.

Fruit yield and quality

Nitrogen source as main factor had a significant effect on all the yield parameters in Experiment 1, but not in Experiment 2 (Table 23). Substrate had a significant effect on the number of marketable fruit and yield per plant in Experiment 2, and on average fruit mass in both experiments. The tomato quality, as indicated by blossom-end rot, was influenced significantly by substrate and nitrogen source in both experiments. In Experiment 2 lime also significantly effected tomato quality.

Substrate x nitrogen source interactions significantly affected the number of marketable fruit and yield per plant in Experiment 2. However, significant substrate x nitrogen source interactions were recorded for tomato quality in both experiments. Significant substrate x lime, lime x nitrogen source and substrate x lime x nitrogen source interactions were shown for quality in Experiment 2.

From these results it is obvious that nitrogen source in Experiment 1 and substrate in Experiment 2 were very important factors affecting the yield and quality parameters. Moreover, in Experiment 2, substrate x nitrogen source interactions affected yield and quality significantly. Lime also affected tomato quality profoundly in Experiment 2. Further discussions of the results will therefore focus on the yield and quality data obtained in Experiment 2.

Table 23 Analysis of variance (ANOVA) of marketable and unmarketable yield of tomatoes

Factor		Marketable yield			Unmarketable yield	
		Yield (g/plant)	Average fruit mass (g)	Number of fruit per plant	Yield (g/plant) ^x	Percentage BER per plant
Experiment 1	DF	<i>Pr > F</i>	<i>Pr > F</i>	<i>Pr > F</i>	<i>Pr > F</i>	<i>Pr > F</i>
Replicate	1	0.0195	0.3744	0.0456	0.7590	0.0125
Substrate	1	0.1591	0.0026	0.5528	0.6757	<.0001
Lime	3	0.4795	0.4081	0.4618	0.9078	0.1861
Sub x Lime	3	0.3783	0.4899	0.2703	0.4060	0.3305
Nitrogen source	2	<.0001	0.0016	<.0001	<.0001	<.0001
Sub x Nitro	2	0.0927	0.7339	0.0519	0.2624	0.0118
Lime x Nitro	6	0.9863	0.3577	0.9843	0.8835	0.0949
Sub x Lime x Nitro	6	0.8665	0.8699	0.8486	0.8353	0.0692
<i>Error</i>	23					
<i>CV (%)</i>		13.17	3.69	13.65	21.69	22.02
Experiment 2						
Replicate	1	0.0359	0.2271	0.0829	0.6519	0.0239
Substrate	1	0.0060	0.0108	0.0133	0.5252	0.0003
Lime	3	0.5911	0.2442	0.7166	0.5887	0.0115
Sub x Lime	3	0.4966	0.5118	0.5577	0.5577	0.0128
Nitrogen source	2	0.0797	0.1453	0.1162	0.6217	<.0001
Sub x Nitro	2	0.0205	0.2450	0.0350	0.7349	<.0001
Lime x Nitro	6	0.2607	0.9292	0.3739	0.1555	0.0025
Sub x Lime x Nitro	6	0.7151	0.7944	0.8316	0.1201	0.0030
<i>Error</i>	23					
<i>CV (%)</i>		21.34	6.89	19.76	21.74	109.42

^xData of Experiment 1 not normally distributed. Transformed with $LX=1/(X)$

Marketable yield As the number of marketable fruit per plant showed the same trend as marketable yield per plant in Experiment 2 (cooler, winter conditions), it can be assumed that marketable yield was determined by the number of fruit per plant and not average fruit mass (Table 24). No significant difference in the number of marketable fruit and yield per plant was recorded between coco peat and pine sawdust-shavings, irrespective of nitrogen source, except when pine sawdust-shavings was irrigated with 40% $\text{NH}_4^+\text{-N}$ in the nutrient solution, which resulted in the lowest number of marketable fruit and yield per plant. This verifies findings from a previous experiment conducted under cooler, winter conditions (Chapter 4), which also indicated a significant yield loss with 40% $\text{NH}_4^+\text{-N}$ in the nutrient solution. It might be that 20% $\text{NH}_4^+\text{-N}$ is less toxic under such conditions, as was found by Ganmore-Neumann & Kafkafi (1980). Another reason may be that the drainage water pH, which was near optimum and more stable due to lime application, contributed to optimum nutrient availability and therefore plant growth. The detrimental effects of $\text{NH}_4^+\text{-N}$ nutrition have been related to root environment acidity and this might have contributed to the low yield since the pH was between 4 and 5 when 40% $\text{NH}_4^+\text{-N}$ and pine sawdust-shavings was used. Barker *et al.* (1966a; 1996b) and de Claassen & Wilcox (1974) found that by maintaining the pH near neutrality has resulted in almost normal growth under $\text{NH}_4^+\text{-N}$ nutrition.

Table 24 Influence of substrate and nitrogen source on the number of marketable fruit and yield of Experiment 2

Factor	Experiment 2: Marketable yield			
	Number of fruit per plant		Yield per plant (g)	
	Substrate			
$\text{NO}_3^-\text{-N} : \text{NH}_4^+\text{-N}$	Coco peat	Pine sawdust	Coco peat	Pine sawdust
100% : 0%	24.6 a	25.6 a	3346.1 a	3492.9 a
80% : 20%	26.3 a	22.6 a	3593.0 a	2980.5 a
60% : 40%	25.8 a	17.6 b	3529.5 a	2211.3 b
<i>LSD (P=0.05)</i>	4.85		704.65	
<i>CV (%)</i>	19.76		21.34	

Means followed by the same letter do not differ significantly at $P = 0.05$ (LSD)

The average fruit mass was significantly affected by substrate (Table 25). Significantly smaller fruit were produced when pine sawdust-shavings was used.

Table 25 Influence of substrate on mean fruit mass of Experiment 2

Factor	Experiment 2
Substrate	Mean fruit mass (g)
Coco peat	144.1 a
Pine sawdust	136.4 b
<i>LSD (P=0.05)</i>	5.77
<i>CV (%)</i>	6.89

Means followed by the same letter do not differ significantly at P = 0.05 (LSD)

In Experiment 1 under the warmer, summer conditions the same trends for number of marketable fruit and yield per plant and average fruit mass were observed (data not presented) as those reported for a previous experiment, which was conducted under similar conditions (See Chapter 3).

Unmarketable yield Substrate, nitrogen source and the pre-plant application of lime had no significant effect on unmarketable yield per plant. However, the substrate and nitrogen source interaction in Experiment 2 (cooler, winter conditions) affected the percentage blossom-end rot (BER) fruit per plant significantly (Table 26). Percentage BER increased in Experiment 2, irrespective of the type of substrate used, with an increase in $\text{NH}_4^+\text{-N}$ in the nutrient solution when no CaCO_3 was applied. No fruit with BER was found, irrespective of the type of substrate, when 0%, 20% or 40% $\text{NH}_4^+\text{-N}$ was used and 1.5, 3.0 and 4.5 g CaCO_3 was applied. The only exception was with 40% $\text{NH}_4^+\text{-N}$ in the nutrient solution and when 1.5 g CaCO_3 was applied to pine sawdust-shavings, which resulted in the highest BER of 2.4%.

This 2.4% BER recorded in Experiment 2 may be attributed to the high level of $\text{NH}_4^+\text{-N}$ which could depress the uptake of calcium and therefore decrease the calcium content in the fruit (Adams & Ho, 1995). The low drainage water pH values of pine sawdust-shavings, when 40% $\text{NH}_4^+\text{-N}$ was used or the insufficient application of CaCO_3 , might also be responsible for this high percentage BER. In general the BER

values obtained under cooler, winter conditions (Experiment 2 and previous experiment reported on in Chapter 4) was much lower than the BER values obtained under warmer, summer conditions (Experiment 1 and previous experiment reported on in Chapter 3). Ganmore-Neumann & Kafkafi (1980) found that NH_4^+ -N nutrition is less toxic during cool weather conditions. In Experiment 1 the percentage BER increased with an increase in NH_4^+ -N from 1.5 to 39.1% and 2.3 to 50.1% when coco peat and pine sawdust-shavings was used as substrates respectively. The high drainage water EC from 11 to 17 weeks after transplanting might also have contributed to the higher incidence of BER. Adams & Ho (1995) proposed that restricted calcium uptake by the roots, and therefore increased incidence of BER, could be due to either increased salinity or interactions with other nutrients such as NH_4^+ -N in the nutrient solution.

Table 26 Influence of substrate, pre-plant application of CaCO_3 and nitrogen source on the percentage blossom-end rot of tomato fruit of Experiment 2

Factor	Experiment 2: Percentage blossom-end rot fruit per plant			
	CaCO_3 application (g.kg^{-1} substrate)			
	Coco peat			
NO_3^- -N : NH_4^+ -N	0	1.5	3.0	4.5
100% : 0%	0 c	0 c	0 c	0 c
80% : 20%	0.4 c	0 c	0 c	0 c
60% : 40%	0.7 bc	0 c	0 c	0 c
	Pine sawdust-shavings			
100% : 0%	0 c	0 c	0 c	0 c
80% : 20%	0.4 c	0 c	0 c	0 c
60% : 40%	1.3 b	2.4 a	0 c	0 c
<i>LSD</i> ($P=0.05$)	0.84			
<i>CV</i> (%)	109.42			

Conclusions

Contrary to previous findings during cooler, winter conditions (See Chapter 4; no lime applied), higher application levels of CaCO_3 in Experiment 2 generally increased the pH of coco peat during the growing period when 20 and 40% NH_4^+ -N was used. The results indicated that the addition of CaCO_3 with NH_4^+ -N nutrition stabilized the drainage water pH and therefore is essential in ensuring optimum pH values for maximum plant growth. The CaCO_3 levels applied during these experiments are still too low to sustain optimum pH levels during the growing season. The application method might also not be very effective.

The drainage water pH of pine sawdust-shavings, with the addition of CaCO_3 , was generally lower in comparison to previous experiments (See Chapter 4), which emphasised the problem of consistency in substrate characteristics. This highlights again that the substrate source must be consistent in quality to ensure uniformity in growth of plants and to enable high substrate management standards.

The marketable yield produced from coco peat was not significantly affected by increasing NH_4^+ -N levels in the nutrient solution. This can only be ascribed to the fact that the pre-plant application of higher CaCO_3 levels generally increased the drainage water pH to near optimum levels. Pine sawdust-shavings produced a significantly smaller yield with the application of high NH_4^+ -N levels. This indicates that in both substrates, NH_4^+ -N nutrition levels of up to 20% of the total nitrogen supply in the nutrient solution might therefore be less toxic to plants in cooler, winter conditions.

No BER fruit was found with the pre-plant application of CaCO_3 to coco peat, irrespective of NH_4^+ -N nutrition. However, pine sawdust-shavings still produced BER fruit when 1.5 g CaCO_3 per kg substrate with 40% NH_4^+ -N was applied. The application of CaCO_3 during warmer, summer conditions had no effect on BER and therefore higher CaCO_3 or reduced NH_4^+ -N application rates are required for summer production of tomatoes. In general much higher BER values was recorded in summer conditions and that indicates that climatic conditions as well as cultural practices has a profound effect on the uptake of calcium and therefore BER.

Although the pre-plant application of CaCO_3 had an effect on BER during cooler conditions, the application rates seemed to be too low to have a significant effect on drainage water pH. This may be due to the very high cation exchange capacity of organic substrates compared to most agricultural soils. Further research needs to be conducted on the method and level of pre-plant application of CaCO_3 and the effect climatic conditions have on the effectiveness of these application levels when NH_4^+ -N nutrition is applied. Further research also needs to be conducted on the use of reduced NH_4^+ -N application levels in the nutrient solution.

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CHAPTER 6

Influence of substrate, nitrogen source, irrigation frequency, period of substrate use and pre-plant application of lime on fruit quality of greenhouse grown tomatoes (*Lycopersicon esculentum* Mill.)

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Abstract

Pine sawdust-shavings (*Pinus* spp.) is at present a very popular soilless substrate in South African greenhouses. South African producers use fresh pine sawdust-shavings as a substrate, which is biologically highly unstable. This is forcing the greenhouse industry to look at alternative substrates such as coco peat, which already went through a decomposition process and is more stable. Tomato fruit quality is influenced by cultivation practices and environmental factors. The influence of substrate, nitrogen source, irrigation frequency, period of substrate use and the pre-plant application of lime on fruit quality of greenhouse grown tomatoes were studied to determine the effect thereof on weight loss, firmness, total soluble solids, pH, citric and malic acid, and total titratable acidity. Four trials were conducted from 2000 – 2002. Substrate and nitrogen source have been shown to have an effect on all parameters tested. NO_3^- -N as the sole source of nitrogen had a positive effect on weight loss and fruit pH, but influenced firmness and total titratable acidity negatively. Fruit pH values were higher in coco peat compared to pine sawdust-shavings and when 100 % NO_3^- -N was used. The total titratable acidity increased with increasing NH_4^+ -N nutrition, more so in pine sawdust-shavings, but also when coco peat was used. Fruit firmness was the lowest in sand after storage when 3 irrigations were applied per day, but increased with 6 and 12 irrigations per day. However, increased irrigation frequency affected fruit firmness negatively when coco peat was used. This study again emphasizes that different irrigation and fertigation practices are needed for different growth mediums and management needs to be adapted according to the growing season.

Keywords: irrigation, lime, nitrogen, quality, substrate, tomato

Introduction

Pine sawdust-shavings mixtures are at present still the most popular substrate in South African greenhouses. However, expansion in the greenhouse industry and decline in pine plantations in some of the major greenhouse production areas may cause shortages in the near future. This and other problems are forcing the greenhouse industry to look at other more durable, relatively inexpensive, high quality substrates such as coco peat.

Pine sawdust-shavings is highly unstable and biodegradation will have an effect on production. Decomposition of organic substrates changes the physical and chemical properties of a substrate and therefore may have an effect on the yield and quality of the crop being produced. The water holding capacity, bulk density and cation exchange capacity increases with degradation (Mbah & Odili, 1998; Shadhidul Islam *et al.*, 2002). Decomposition of pine fibre substrates, especially when NO_3^- -N is used as nitrogen source, results in an increase in pH (Vlassak *et al.*, 1991), which affects the availability of phosphorus and all the micronutrients except molybdenum (Adams, 2002). However, the production of coco peat involves a period of storage in heaps where it undergoes aerobic composting (Worrall, 1978; Yau & Murphy, 2000). Due to the higher lignin content of coco peat compared to pine fibre substrates, coco peat decomposes slower and is very stable (Ghoos, 1993; Noguera, Abad & Noguera, 2000; Yau & Murphy, 2000).

Tomato fruit quality is determined by appearance, firmness, texture, dry matter, flavor and health benefit properties. The organoleptic quality of tomato is mainly attributed to its aroma volatiles, sugar and acid content. Fruit quality as well as postharvest durability is greatly influenced by genetic characteristics of the tomato cultivar, but production of high quality fruit is also controlled by climatic factors and cultural practices (Dorais, Papadopoulos & Gosselin, 2001).

Several characteristics such as soluble solids, sugars, acidity and pH are important quality parameters for both fresh market and processing tomatoes (Cuartero & Fernández-Muñoz, 1999). Tomato fruit flavor involves the perception of taste as influenced by aromas of many chemical constituents. Sugars, acids and their

interactions are important to sweetness and sourness of the tomato (Stevens *et al.*, 1977). About 50% of tomato fruit dry matter is sugars and 13% organic acids. The concentration of citric and malic acids in tomato fruit can vary with genotype, ripening stage, nutritional status of the plant (Mahakun, Leeper & Burns, 1979) and the environment (Winsor, 1979). Malic acid predominates in immature green fruit with citric acid forming 25% of the total acidity (Davies & Hobson, 1981). In ripe fruit, however, citric acid accounts for 40 to 90% of the total acidity (Stevens, 1972; Davies & Hobson, 1981).

Tomato fruit grown under salt stress show higher organic acid contents and higher titratable acidity than fruit grown with fresh water (Mitchell *et al.*, 1991). Total soluble solids (TSS) in ripe fruits, measured by the refractometric index ($^{\circ}$ Brix), increases with salinity (Mizrahi *et al.*, 1988). The flavor increase and yield decline under high salinity may be associated with a reduction in water absorption by roots (Soria & Cuartero, 1997; Dorais *et al.*, 2001), and hence the water content of the fruit (Adams, 2002). Fruit shelf life (Mizrahi, 1982) and fruit firmness (Sharaf & Hobson, 1986) are lowered with high salinity levels, but salinity causes no alteration on shelf life or firmness in fruits of long-shelf life commercial cultivars (Cuartero *et al.*, 1996). Increasing the EC from 2 to 17 $\text{mS}\cdot\text{cm}^{-1}$ reduce the fruit phosphorus concentration, increase the potassium concentration and has no effect on the nitrogen concentration (Ehret & Ho, 1986).

High salinity causes a reduction in Ca^{2+} uptake (Ehret & Ho, 1986; Adams & Ho, 1992), high temperatures causes rapid fruit growth and low humidity causes an increase in transpiration rate and hence more Ca^{2+} moving to the leaves and less to the fruit (Adams & Ho, 1993; Saure, 2001; Adams, 2002) and therefore increases the incidence of blossom-end rot (BER). An adequate supply of calcium to the fruit is essential for firmness and shelf life. Nevertheless, the presence of high levels of calcium in the fruit negatively affects their organoleptic quality and shelf life (De Kreij, 1995). High levels of potassium (Voogt, 1988; Nukaya *et al.*, 1995; Bar Tal & Pressman, 1996) and ammonium nitrogen (Schnitzler & Gruda, 2002) in the root environment interfere with calcium uptake and therefore increase the risk of BER. Calcium levels in the fruit increase with an increasing calcium concentration in the

nutrient solution (Bradfield & Cuttridge, 1984; Paiva, Sampaio & Martinez, 1998), but magnesium and potassium levels decrease (Paiva *et al.*, 1998).

Potassium is positively related to the reduction of ripening disorders and the increase of fruit acid concentrations (Adams, Davies & Winsor, 1978; Mahakun *et al.*, 1979). Potassium plays an important role in the maintenance of organic acids in the fruit (Davies, 1964; Mitchell *et al.*, 1991) and a positive correlation between citric and malic acid content in the fruit and potassium content in the soil has been observed (Davies, 1964; Winsor & Barker, 1982). Potassium content of fruit is negatively correlated with fruit pH (Winsor & Massey, 1958; Mahakun *et al.*, 1979; Picha, 1987). Davies & Winsor (1967) have observed a positive response of plants to potassium in terms of acidity, dry matter and organoleptic quality. A high K:Ca ratio improves fruit firmness and acidity, while it reduces the sugar content (Janse & Gielesen, 1991) and increase the number of fruit affected by BER (van der Boon, 1973).

Mahakun *et al.* (1979) have reported that pH of tomato fruit can best be reduced by a reduction in phosphorus content. Increasing the phosphorus concentration in the nutrient solution from 0.02 to 3.0 mM stimulates the absorption and distribution of Ca in the fruit (Cerdea & Bingham, 1978; Cerde, Bingham & Labanauskas, 1979; De Kreij, 1996)

A very high nitrogen concentration influence color negatively, delays ripening, causes uneven ripening and reduce fruit soluble solids content (Locascio *et al.*, 1984). It also increases fruit acid concentration and decrease fruit organoleptic quality (Locascio *et al.*, 1984; Thakur, Singh & Nelson, 1996). A high nitrogen concentration also interfered with Ca nutrition and, as a consequence, increased postharvest quality losses and the number of fruit affected by BER. The nitrogen source provided to plants can also influence fruit quality (Dorais *et al.*, 2001). Ho (1996) has reported that $\text{NH}_4^+\text{-N}$ increases fruit sugar content, but decrease calcium concentration. Similarly, Pivot, Reist & Gillioz (1997) have reported that an excess of ammonium in the nutrient solution results in a reduction of calcium content in the fruit and an increase in the number of fruit affected by BER. Feigen *et al.* (1980) found that the

application of 10 – 50% $\text{NH}_4^+\text{-N}$ to the nutrient solution markedly increased the percentage of firm fruit after storage.

Whatever substrate is used, good product quality can only be achieved if the cultural management is correctly adjusted to the properties of the substrate (Schnitzler & Gruda, 2002). Many experiments showed that there is no impact of substrate per se on product quality (Gül *et al.*, 1999; Özeker *et al.*, 1999; Tüzel *et al.*, 2001; Schnitzler & Gruda, 2002). Gül & Sevgican (1994) and Mzouri, Makhlouf & Gosselin (1996) found no significant effect of substrate on fruit quality when different growing media were compared. Substrate had no significant effect on fruit composition, firmness and aroma (Gormley & Egan, 1978). However, Cronin & Walsh (1983) have reported a higher fruit content in sugars, ascorbic acid and in dry matter in peat-based growing media. Alan, Zülkadir & Padem (1994) reported that the highest total soluble solids content in tomato fruit was found with peat and that the highest titratable acidity and lowest pH values were found in tomato fruit when sand was used. They concluded that the pH value of the substrate might play a role in these differences. Moreover, Maas & Adamson (1971) showed that a good quality tomato could be successfully grown in a soilless medium composed completely of sawdust if adequately enriched with essential mineral nutrients. The controversy between the different studies probably reflects the level of control of the growing regimes as a function of the substrates used. Each growing substrate has its own demands and responds more or less rapidly on account of its buffer effect, to changes in growing conditions due to daily climatic variations (Dorais *et al.*, 2001).

Increasing the rate of irrigation of greenhouse tomato plants can lead to reductions in soluble solids and dry matter content of fruit (Tüzel, Ul & Tüzel, 1994). Ismail, Halimi & Josoh (1993) showed a reduction in fruit total soluble solids when plants were irrigated more than three times daily. A high irrigation regime reduces fruit quality due to high water content (reduction on soluble sugars, organic acids, vitamins, minerals and volatile compounds) and due to a tendency to crack (Abbott, Peet & Willits, 1985; Abbott *et al.*, 1986; Peet, 1992; Tüzel *et al.*, 1994; McAvoy, 1995; Peet & Willits, 1995).

Climatic factors such as light intensity, temperature and relative humidity plays a very important role in fruit quality. Despite the fact that increasing light intensity also increases fruit dry matter and soluble sugars content, it has almost no effect on organic acid concentration (Janse, 1984). A high fruit dry matter content is generally associated with high firmness, while a low fruit concentration in soluble sugars is linked to a 'watery' taste of tomato (Dorais *et al.*, 2001). High temperatures favors the distribution of assimilates to fruit, at the expense of vegetative growth (De Koning, 1989). It is generally reported that increasing the ambient temperature by 1°C increases fruit dry matter content by 0.07% (De Koning, 1992). High temperature accelerates fruit development and reduces the time required for ripening but also decrease their size and therefore their quality (Dorais *et al.*, 2001). High temperatures will result in more juicy and aromatic fruit, with increased acidity and the fruit skin becomes thicker, hence a better keeping quality (Schnitzler & Gruda, 2002). Fruit production under high VPD (low relative humidity) is firmer, juicier, and less mealy and have less physiological disorders such as cracking and gold specks than fruit produced under low VPD (Janse & Schols, 1992). However under low relative humidity, 24 to 59% of fruit can be affected by BER (De Kreij, 1992; De Kreij, 1996).

As a result of the above-mentioned reasons, it was decided to conduct experiments where tomato fruit quality were evaluated in different organic substrates, which was subjected to different irrigation frequencies, periods of use, lime applications and nitrate to ammonium N-ratios.

Materials and methods

Locality and climate Greenhouse trials were conducted at Stellenbosch in the Western Cape Province of South Africa during the spring and summer of 2000/2001 (Trial 1) and 2001/2002 (Trial 3, Experiment 1), and during the summer and autumn of 2001 (Trial 2) and 2002 (Trial 3, Experiment 2). See Chapter 3, 4 and 5 for weekly average minimum and maximum temperatures recorded outside the greenhouse during these trials.

Cultivation practices

Trial 1 - Influence of substrate, nitrogen source and irrigation frequency on yield and quality of greenhouse grown tomatoes (Chapter 3)

Seeds of the tomato (*Lycopersicon esculentum* Mill.) cultivar FA593 (Mayford Seeds, South Africa) were sown on 17 June 2000 in seedling trays. The seedlings were produced in a substrate that consisted of 1 part Hygrotech seedling mix (peat, polystyrene, vermiculite), 1 part vermiculite and 1 part composted pine bark. Seedlings were watered with a 50% diluted ($1.1 \text{ mS}\cdot\text{cm}^{-1}$) nutrient solution (Steiner, 1984) and transplanted into the greenhouse on 19 August 2000 (9 weeks after sowing). Only one seedling was transplanted per 18 litre black plastic bag. Drainage holes were made at 2.5 cm from the bottom of the bag to create a reservoir from which the drainage water samples were extracted. The bags were placed in 8 double rows and the spacing between rows (from centre of bag) was 0.40 m and within the row 0.35 m. The spacing between each double row (from centre of row) was 1.60 m. A plant population of 2.5 plants per m^2 were maintained in the greenhouse. Standard cultural practices for the production of greenhouse tomatoes were applied. Side shoots were removed and the plants were trellised to a height of 2.40 m above the bag. An average of 8 trusses per plant were recorded. Terminal growing points were removed once the plants reached the crop support wire. A naturally ventilated greenhouse was used. No heating was applied and during hot weather, temperature control was done by means of natural ventilation and the application of lime on the polycarbonate sheeting of the greenhouse.

Trial 2 - Influence of substrate, nitrogen source, irrigation frequency and period of substrate use on yield and quality of greenhouse grown tomatoes (Chapter 4)

Seeds of the tomato (*Lycopersicon esculentum* Mill.) cultivar FA593 (Mayford Seeds, South Africa) were sown on 3 January 2001 in seedling trays and transplanted into the greenhouse on 14 February 2001 (6 weeks after sowing). The same cultivation practices as in Trial 1 were followed, except for the trellising height that was reduced to 1.70 m. An average of 6 trusses per plant were recorded.

Trial 3 - Influence of substrate, nitrogen source and pre-plant application of lime (CaCO_3) on yield and quality of greenhouse grown tomatoes (Chapter 5)

In **Experiment 1** seeds of the tomato (*Lycopersicon esculentum* Mill.) cultivar FA593 (Mayford Seeds, South Africa) were sown on 27 July 2001 in seedling trays and transplanted into the greenhouse on 21 September 2001 (8 weeks after sowing). In **Experiment 2** the seeds were sown on 5 February 2002 in seedling trays and transplanted into the greenhouse on 12 March 2002 (5 weeks after sowing). In Experiment 1 and 2 the same cultivation practices as in Trials 1 and 2 were followed respectively.

Treatments and experimental design

Trial 1 Sand (collected from the Berg River), a pine sawdust-shavings mixture and coco peat were evaluated. The same volume of substrate (18 litre per bag) was used for all the treatments, although the characteristics of each substrate differed. All the substrates were washed with municipal water before planting. Three nitrogen source treatments (NO_3^- -N : NH_4^+ -N ratios of 100% : 0%, 80% : 20%, 60% : 40%) were evaluated (Table 1). NO_3^- -N and NH_4^+ -N was applied as $5[\text{Ca}(\text{NO}_3)_2 \cdot 2\text{H}_2\text{O}]\text{NH}_4\text{NO}_3$ (contains 1.3% NH_4^+ -N) and KNO_3 , and $(\text{NH}_4)_2\text{SO}_4$ respectively.

Table 1 Composition of nutrient solutions as affected by nitrogen source

Factor	NH_4^+	K^+	Ca^{2+}	Mg^{2+}	NO_3^-	H_2PO_4^-	SO_4^{2-}
NO_3^- -N : NH_4^+ -N	mmol _c .l ⁻¹						
100% : 0%	0	8	8	4	14	1	5
80% : 20%	2.80	6.88	6.88	3.44	11.20	1.47	7.33
60% : 40%	5.60	5.76	5.76	2.88	8.40	1.93	9.67

The nutrient solutions were mixed and stored in 1500 litre plastic tanks. Netafim drippers (pressure compensated, non-leakage), with a capacity of 2 l.hr⁻¹, were used to irrigate each bag individually. To prevent the mixing of nutrient solutions, the system was designed so that each treatment had its own separate irrigation system. An irrigation controller and timer were used to schedule irrigation. Three irrigation frequencies (3x, 6x, 12x per day) were applied. However, the total volume of nutrient

solution irrigated per treatment per day was the same for all the treatments. The first and last irrigation took place within 1 hour from sunrise and sunset respectively. The day length increased from 9 hours in August to 14 hours in December. Water application ranged from 300 ml per plant per day, just after transplanting, to 3500 ml during the peak production period (15 to 20 weeks after transplanting). The irrigation volumes per day were gradually increased during the growing season and included an over irrigation of 15 to 20%. This proved to be very difficult as a result of the different water holding capacity characteristics of the substrates. Refer to Chapter 3 for detailed information on this trial regarding the pH and EC of the nutrient solution and drainage water during the growing period.

Trial 2 Sand (collected from the Berg River), a pine sawdust-shavings mixture and coco peat were evaluated. The same volume of substrate (18 litre per bag) was used for all the treatments. All the substrates were washed with municipal water before planting. The same substrates as the above, which have been used for 5 months (see Chapter 3), were included to determine the effect of usage period on yield and quality of tomatoes. Three nitrogen source treatments (NO_3^- -N : NH_4^+ -N ratios of 100% : 0%, 80% : 20%, 60% : 40%) were evaluated (Table 1). NO_3^- -N and NH_4^+ -N was applied as $5[\text{Ca}(\text{NO}_3)_2 \cdot 2\text{H}_2\text{O}]\text{NH}_4\text{NO}_3$ (contains 1.3% NH_4^+ -N) and KNO_3 , and $(\text{NH}_4)_2\text{SO}_4$ respectively. The same mixing and irrigation practices were used as in Trial 1. The day length decreased from 13 hours in February to 8 hours in July. Water application ranged from 500 ml per plant per day, just after transplanting, to 2300 ml during the peak production period (15 to 20 weeks after transplanting). The irrigation volumes per day were gradually increased during the growing season and included an over irrigation of 15 to 20%. This proved to be very difficult as a result of the different water holding capacity characteristics and stage of degradation of the substrates. Refer to Chapter 4 for detailed information on this trial regarding the pH and EC of the nutrient solution and drainage water during the growing period.

Trial 3 Coco peat and a pine sawdust-shavings mixture were evaluated in Experiment 1 and 2. The same volume of substrate (18 litre per bag) was used for all the treatments. All the substrates were washed with municipal water before planting. In **Experiment 1** four lime application levels (0, 0.75, 1.50 and 2.25 g CaCO_3 per kg

substrate) and three nitrogen source treatments (NO_3^- -N : NH_4^+ -N ratios of 100% : 0%, 80% : 20%, 60% : 40%) were evaluated (Table 1). NO_3^- -N and NH_4^+ -N was applied as $5[\text{Ca}(\text{NO}_3)_2 \cdot 2\text{H}_2\text{O}]\text{NH}_4\text{NO}_3$ (contains 1.3% NH_4^+ -N) and KNO_3 , and $(\text{NH}_4)_2\text{SO}_4$ respectively. In Experiment 2 the same nitrogen source treatments were used, but the lime application levels were increased to 0, 1.5, 3.0 and 4.5 g CaCO_3 per kg substrate. In both experiments the same mixing and irrigation practices were used as in Trial 1. In Experiment 1 the water application ranged from 500 ml per plant per day, just after transplanting, to 3000 ml during the peak production period (12 to 17 weeks after transplanting). In **Experiment 2** the water application ranged from 500 to 2200 ml per plant per day. Refer to Chapter 5 for detailed information on these experiments regarding the pH and EC of the nutrient solution and drainage water during the growing period.

Data collected Tomato fruit were collected from the third and fourth cluster. Five fruits at the breaking stage, uniform in colour and size, were randomly selected from each experimental unit. From these five fruits, three were selected for the 14-day keeping quality evaluation and two were used for quality measurements. The fruit was weighed before and after storage and the percentage weight loss used as an indication of shelf life. Firmness was determined with a hand-held densimeter (a non-destructive procedure) with a plunger diameter of 5 mm. Firmness tests were done on the shoulder of the fruit and the average of three measurements per treatment were taken before and after storage. Samples were analysed by HORTEC Laboratories and quality measurements included total soluble solids content (TSS %), measured by a refractometer, total titratable acids (TTA %), pH, and citric and malic acid content. Titratable acids were determined by titrating 10 g tomato juice to a pH of 8.2 with 0.1M NaOH on a 7195 Titrino. The acid content was calculated as gram citric acid equivalent per 100 g juice and expressed as a percentage. After storage the fruit quality parameters were again determined. The samples were stored at room temperature, which varied between 15 and 20 °C in winter, and 20 to 25 °C in summer.

Statistical analysis

Trial 1 The 27 treatment combinations were arranged in a randomized block design, using two replicates. The main plot treatment design was a 3x3x3 factorial with three substrates (sand, pine sawdust-shavings, coco peat), three irrigation levels (3x, 6x, 12x per day) and three nitrogen source treatments (NO_3^- -N : NH_4^+ -N ratios of 100% : 0%, 80% : 20%, 60% : 40%). Eight plants represented an experimental unit. The data was statistically analyzed with the SAS program (SAS, 2000). The Shapiro-Wilk test was performed to test for normality (Shapiro & Wilk, 1965). Student's t-least significant difference was calculated at the 5% level to compare treatment means. A probability level of 5% was considered significant for all significance tests.

Trial 2 The experimental design was a split plot with 54 treatment combinations replicated in two blocks. The main plot treatment design was a 3x3x3 factorial with three substrates (sand, pine sawdust-shavings, coco peat), three irrigation levels (3x, 6x, 12x per day) and three nitrogen source treatments (NO_3^- -N : NH_4^+ -N ratios of 100% : 0%, 80% : 20%, 60% : 40%), and two subplot treatments (fresh substrate and recycled substrate). Four plants represented an experimental unit. Split-plot analysis of variance (Anova) was performed for each assessment time separately, using the GLM (General Linear Models) procedure of SAS statistical software version 8.2 (SAS, 2000). Shapiro-Wilk test was performed to test for normality (Shapiro & Wilk, 1965). Student's t-least significant difference was calculated at the 5% level to compare treatment means. A probability level of 5% was considered significant for all significance tests.

Trial 3 In **Experiment 1** the treatments were arranged in a randomized block design with 24 treatment combinations replicated in two blocks. The main plot treatment design was a 2x4x3 factorial with two substrates (coco peat, pine sawdust-shavings), four lime levels (0, 0.75, 1.50 and 2.25 g CaCO_3 per kg substrate) and three nitrogen source treatments (NO_3^- -N : NH_4^+ -N ratios of 100% : 0%, 80% : 20%, 60% : 40%). Six plants represented an experimental unit. Analysis of variance (Anova) was performed for each assessment time separately, using the GLM (General Linear Models) procedure of SAS statistical software version 8.2 (SAS, 2000). Shapiro-Wilk test was performed to test for normality (Shapiro & Wilk, 1965). Student's t-least

significant difference was calculated at the 5% level to compare treatment means. A probability level of 5% was considered significant for all significance tests. In **Experiment 2** the same experimental design and parameters as in Experiment 1 was used, except that the lime application levels were increased to 0, 1.5, 3.0 and 4.5 g CaCO₃ per kg substrate.

Results and discussion

Results on the analysis of variance (ANOVA's) done on the quality parameters of the different trials are summarized in Table 2 to 7. From these tables it became clear that as found with growth and yield parameters, less important attributing factors can be eliminated by comparing significance levels and consistency of significance.

Substrate and nitrogen source as main factors (Trial 3, Experiment 1) and the interactions irrigation frequency x nitrogen source (Trial 1) and substrate x irrigation frequency x age (Trial 2) were the most important factors affecting weight loss after the 14-day storage period. The main factors substrate and nitrogen source in Trial 3 (Experiment 1) and the main factor substrate and interaction substrate x irrigation frequency in Trial 1 were by far the most important factors, which affected fruit firmness. No definite trends were observed with regard to the parameter total soluble solids (TSS) before, after and during storage and will for this reason not be discussed. Fruit pH was significantly affected by the main factors substrate (Trial 1 and 3, Experiment 2), nitrogen source (Trial 1, 2 and 3, Experiment 1) and age (Trial 2), and the interaction substrate x nitrogen source (Trial 3, Experiment 1). The effect that the main factor substrate had on the change in pH level during storage in Trial 3 (Experiment 2) will however not be discussed due to the very high coefficient of variance shown. Similar trends were observed for citric and malic acid content, and total titratable acid (TTA) and for this reason only TTA will be discussed. TTA was significantly affected by the main factors substrate (Trial 1 and 3, Experiment 1 and 2) and age (Trial 2) and the interactions substrate x nitrogen source (Trial 1 and 3, Experiment 2) and substrate x age (Trial 2).

Further discussions of the results will therefore focus on these aspects only.

Table 2 Analysis of variance (ANOVA) of fruit weight loss and firmness

Factor	DF	Weight loss (%) <i>Pr > F</i>	Fruit firmness		
			Before storage <i>Pr > F</i>	After storage <i>Pr > F</i>	% Difference <i>Pr > F</i>
Trial 1					
Replicate	1	0.5235	0.5225	0.2753	0.1297
Substrate	2	0.6432	0.0013	0.0034	0.0255
Irrigation	2	0.1446	0.6081	0.4282	0.1551
Sub x Irrig	4	0.3462	0.1463	0.0003	0.0002
Nitrogen source	2	0.8573	0.4364	0.0333	0.2067
Sub x Nitro	4	0.2384	0.3156	0.3050	0.2648
Irrig x Nitro	4	0.0399	0.0679	0.7396	0.0920
Sub x Nitro x Irrig	8	0.4248	0.1952	0.2079	0.2287
<i>Error</i>	26				
<i>CV (%)</i>		7.49	3.83	4.72	10.58
Trial 2				x	
Replicate	1	0.1381	<.0001	0.7875	0.0642
Substrate	2	0.0966	0.0985	0.0296	0.2056
Irrigation	2	0.3497	0.6175	0.0543	0.0899
Sub x Irrig	4	0.3718	0.6317	0.4828	0.5690
Nitrogen source	2	0.1606	0.0135	0.0352	0.3191
Sub x Nitro	4	0.9501	0.0351	0.6875	0.3920
Irrig x Nitro	4	0.6794	0.0421	0.9286	0.7643
Sub x Nitro x Irrig	8	0.3986	0.0251	0.3704	0.8500
<i>Error a</i>	26				
Age	1	0.5941	0.6502	0.2751	0.3079
Sub x Age	2	0.1419	0.1798	0.7118	0.0639
Irrig x Age	2	0.7320	0.7514	0.8893	0.7472
Sub x Irrig x Age	4	0.0397	0.3702	0.5160	0.2005
Nitro x Age	2	0.3066	0.4611	0.3761	0.0400
Sub x Nitro x Age	4	0.2945	0.8398	0.3743	0.3779
Irrig x Nitro x Age	4	0.5515	0.9161	0.3363	0.3116
Sub x Irrig x Nitro x Age	8	0.5128	0.8384	0.3187	0.3500
<i>Error b</i>	27				
<i>CV (%)</i>		19.95	2.90	4.71	11.15

^xData not normally distributed. Transformed with $IX=1/(X+1)$

Table 2 (continued)

Factor	Weight loss (%)	Fruit firmness			
		Before storage	After storage	% Difference	
Trial 3					
Experiment 1	DF	<i>Pr > F</i>	<i>Pr > F</i>	<i>Pr > F</i>	<i>Pr > F</i>
Replicate	1	0.2408	0.2477	<.0001	0.0012
Substrate	1	0.0012	0.4120	0.0401	0.0151
Lime	3	0.4847	0.9722	0.7413	0.8041
Sub x Lime	3	0.9364	0.8158	0.7483	0.8350
Nitrogen source	2	0.0234	0.2491	0.0057	0.0006
Sub x Nitro	2	0.2922	0.4530	0.4951	0.1787
Lime x Nitro	6	0.0814	0.9791	0.7839	0.9156
Sub x Lime x Nitro	6	0.1410	0.4182	0.6431	0.1530
<i>Error</i>	23				
<i>CV (%)</i>		9.32	5.44	7.05	10.84
Trial 3					
Experiment 2					
Replicate	1	0.4565	0.8209	0.3335	0.4863
Substrate	1	0.1452	0.8006	0.8714	0.7941
Lime	3	0.5993	0.9909	0.4369	0.4313
Sub x Lime	3	0.5413	0.0948	0.8977	0.6872
Nitrogen source	2	0.7682	0.9464	0.6267	0.7095
Sub x Nitro	2	0.3631	0.7466	0.2852	0.5545
Lime x Nitro	6	0.4723	0.4388	0.4735	0.1608
Sub x Lime x Nitro	6	0.6334	0.6006	0.6788	0.5142
<i>Error</i>	23				
<i>CV (%)</i>		18.05	5.71	8.96	18.73

Table 3 Analysis of variance (ANOVA) of total soluble solids

Factor	DF	Total soluble solids (%)		
		Before storage	After storage	% Difference
Trial 1				
Replicate	1	0.2261	0.1075	0.9318
Substrate	2	0.2456	0.4557	0.2684
Irrigation	2	0.2910	0.3104	0.5752
Sub x Irrig	4	0.0578	0.1711	0.6655
Nitrogen source	2	0.1360	0.0144	0.9094
Sub x Nitro	4	0.7454	0.9658	0.8784
Irrig x Nitro	4	0.5676	0.9164	0.3744
Sub x Nitro x Irrig	8	0.3412	0.3600	0.2836
<i>Error</i>	26			
<i>CV (%)</i>		8.24	6.13	172.22
Trial 2				
Replicate	1	<.0001	0.1607	0.0017
Substrate	2	0.7314	0.4346	0.7734
Irrigation	2	0.5413	0.2837	0.0233
Sub x Irrig	4	0.2919	0.5804	0.5731
Nitrogen source	2	0.1807	0.0583	0.4745
Sub x Nitro	4	0.1246	0.1630	0.6141
Irrig x Nitro	4	0.3644	0.5184	0.4892
Sub x Nitro x Irrig	8	0.4057	0.3026	0.6907
<i>Error a</i>	26			
Age	1	0.6030	0.0717	0.1961
Sub x Age	2	0.0591	0.0206	0.5184
Irrig x Age	2	0.8960	0.8213	0.8848
Sub x Irrig x Age	4	0.8557	0.9385	0.8919
Nitro x Age	2	0.1217	0.0310	0.8174
Sub x Nitro x Age	4	0.1976	0.5192	0.9886
Irrig x Nitro x Age	4	0.7596	0.8590	0.6404
Sub x Irrig x Nitro x Age	8	0.2212	0.0820	0.9363
<i>Error b</i>	27			
<i>CV (%)</i>		8.55	8.79	175.17

Table 3 (continued)

Factor		Total soluble solids (%)		
		Before storage	After storage	% Difference
Trial 3	DF	<i>Pr > F</i>	<i>Pr > F</i>	<i>Pr > F</i>
Experiment 1				
Replicate	1	0.1827	0.0088	0.9589
Substrate	1	0.0258	0.3996	0.0211
Lime	3	0.1365	<.0001	0.3858
Sub x Lime	3	0.1982	0.0037	0.6410
Nitrogen source	2	0.0560	<.0001	0.2686
Sub x Nitro	2	0.7520	0.5580	0.6522
Lime x Nitro	6	0.3041	0.0127	0.5064
Sub x Lime x Nitro	6	0.6143	0.0126	0.3932
<i>Error</i>	23			
<i>CV (%)</i>		10.57	4.11	-564.0
Trial 3				
Experiment 2				
Replicate	1	0.0074	0.2430	0.3047
Substrate	1	0.0163	0.0068	0.7969
Lime	3	0.7164	0.5307	0.9091
Sub x Lime	3	0.7531	0.1004	0.5475
Nitrogen source	2	0.0382	0.4329	0.5343
Sub x Nitro	2	0.9901	0.0232	0.2580
Lime x Nitro	6	0.0456	0.7347	0.2765
Sub x Lime x Nitro	6	0.8913	0.1757	0.9114
<i>Error</i>	23			
<i>CV (%)</i>		6.87	6.10	701.29

Table 4 Analysis of variance (ANOVA) of fruit pH

Factor	DF	Fruit pH		
		Before storage	After storage	% Difference
Trial 1		<i>Pr > F</i>	<i>Pr > F</i>	<i>Pr > F</i>
Replicate	1	0.3986	0.1953	0.5445
Substrate	2	0.0028	0.0019	0.0386
Irrigation	2	0.6223	0.3385	0.6315
Sub x Irrig	4	0.7892	0.7323	0.5875
Nitrogen source	2	0.0007	<.0001	0.2595
Sub x Nitro	4	0.6462	0.1655	0.4459
Irrig x Nitro	4	0.3712	0.3194	0.7669
Sub x Nitro x Irrig	8	0.7686	0.2746	0.2418
<i>Error</i>	26			
<i>CV (%)</i>		0.87	1.04	-24.67
Trial 2				
Replicate	1	0.0035	0.0165	0.4246
Substrate	2	0.8377	0.2574	0.3244
Irrigation	2	0.0595	0.0519	0.6871
Sub x Irrig	4	0.0733	0.7625	0.0896
Nitrogen source	2	<.0001	<.0001	0.0363
Sub x Nitro	4	0.2998	0.0582	0.4021
Irrig x Nitro	4	0.3658	0.1157	0.6345
Sub x Nitro x Irrig	8	0.6147	0.2541	0.9274
<i>Error a</i>	26			
Age	1	<.0001	<.0001	0.2188
Sub x Age	2	0.2892	0.6435	0.6115
Irrig x Age	2	0.0588	0.3987	0.0040
Sub x Irrig x Age	4	0.9141	0.6150	0.3408
Nitro x Age	2	0.3887	0.0966	0.4387
Sub x Nitro x Age	4	0.8422	0.8654	0.5554
Irrig x Nitro x Age	4	0.6053	0.2817	0.1838
Sub x Irrig x Nitro x Age	8	0.5682	0.8429	0.0792
<i>Error b</i>	27			
<i>CV (%)</i>		1.56	1.15	-54.06

Table 4 (continued)

Factor		Fruit pH		
		Before storage	After storage	% Difference
Trial 3				
Experiment 1				
	DF	<i>Pr > F</i>	<i>Pr > F</i>	<i>Pr > F</i>
Replicate	1	0.8718	0.0048	0.0183
Substrate	1	0.0342	0.8536	0.1150
Lime	3	0.7632	0.7379	0.5328
Sub x Lime	3	0.3126	0.0676	0.5153
Nitrogen source	2	0.0006	0.0031	0.0180
Sub x Nitro	2	0.8191	0.0318	0.0331
Lime x Nitro	6	0.3919	0.5286	0.1398
Sub x Lime x Nitro	6	0.6792	0.1061	0.1374
<i>Error</i>	23			
<i>CV (%)</i>		0.99	1.31	-25.59
Trial 3				
Experiment 2				
Replicate	1	0.1234	0.0020	0.5803
Substrate	1	0.1053	0.0149	0.0145
Lime	3	0.1773	0.1437	0.5860
Sub x Lime	3	0.9599	0.8848	0.8929
Nitrogen source	2	0.6038	0.0043	0.2721
Sub x Nitro	2	0.2631	0.0612	0.9787
Lime x Nitro	6	0.8041	0.0567	0.5115
Sub x Lime x Nitro	6	0.9100	0.7586	0.8013
<i>Error</i>	23			
<i>CV (%)</i>		3.99	2.38	-280.72

Table 5 Analysis of variance (ANOVA) of citric acid

Factor	DF	Citric acid (%)		
		Before storage	After storage	% Difference
Trial 1		<i>Pr > F</i>	<i>Pr > F</i>	<i>Pr > F</i>
Replicate	1	0.3561	0.0879	0.8835
Substrate	2	0.0258	0.0110	0.0411
Irrigation	2	0.0345	0.3367	0.1313
Sub x Irrig	4	0.1119	0.8149	0.1027
Nitrogen source	2	0.2235	0.3782	0.3209
Sub x Nitro	4	0.6597	0.0518	0.4550
Irrig x Nitro	4	0.3985	0.8628	0.3089
Sub x Nitro x Irrig	8	0.9389	0.4343	0.7576
<i>Error</i>	26			
<i>CV (%)</i>		8.98	7.25	40.04
Trial 2				
Replicate	1	0.0092	0.0334	0.1587
Substrate	2	0.9076	0.0545	0.4475
Irrigation	2	0.4408	0.0033	0.3841
Sub x Irrig	4	0.7239	0.6852	0.5025
Nitrogen source	2	0.5308	0.0170	0.6545
Sub x Nitro	4	0.1734	0.0055	0.6020
Irrig x Nitro	4	0.5613	0.0054	0.8433
Sub x Nitro x Irrig	8	0.7706	0.3763	0.9948
<i>Error a</i>	26			
Age	1	<.0001	<.0001	0.0770
Sub x Age	2	0.1990	0.0082	0.8747
Irrig x Age	2	0.4079	0.6134	0.3269
Sub x Irrig x Age	4	0.3007	0.2600	0.4064
Nitro x Age	2	0.4848	0.3559	0.3475
Sub x Nitro x Age	4	0.0525	0.7138	0.0767
Irrig x Nitro x Age	4	0.1036	0.1534	0.4459
Sub x Irrig x Nitro x Age	8	0.7367	0.1092	0.6415
<i>Error b</i>	27			
<i>CV (%)</i>		8.44	5.88	49.66

Table 5 (continued)

Factor		Citric acid (%)		
		Before storage	After storage	% Difference
Trial 3				
Experiment 1				
	DF	<i>Pr > F</i>	<i>Pr > F</i>	<i>Pr > F</i>
Replicate	1	0.7604	0.0028	0.0055
Substrate	1	0.0107	0.9057	0.0388
Lime	3	0.2218	0.4434	0.9779
Sub x Lime	3	0.3395	0.2680	0.7462
Nitrogen source	2	0.2419	0.3577	0.0303
Sub x Nitro	2	0.3884	0.5485	0.1289
Lime x Nitro	6	0.0495	0.4004	0.0021
Sub x Lime x Nitro	6	0.5678	0.2001	0.1004
<i>Error</i>	23			
<i>CV (%)</i>		8.52	8.46	26.43
Trial 3				
Experiment 2				
Replicate	1	0.1355	0.0015	0.8452
Substrate	1	0.0168	0.1353	0.0086
Lime	3	0.4161	0.0243	0.9834
Sub x Lime	3	0.9532	0.6161	0.8088
Nitrogen source	2	0.4532	0.0564	0.5668
Sub x Nitro	2	0.3260	0.0232	0.9756
Lime x Nitro	6	0.6686	0.5281	0.8444
Sub x Lime x Nitro	6	0.9537	0.2318	0.8256
<i>Error</i>	23			
<i>CV (%)</i>		9.46	4.72	72.94

Table 6 Analysis of variance (ANOVA) of malic acid

Factor	DF	Malic acid (%)		
		Before storage	After storage	% Difference
Trial 1		<i>Pr</i> > <i>F</i>	<i>Pr</i> > <i>F</i>	<i>Pr</i> > <i>F</i>
Replicate	1	0.3742	0.0459	0.5556
Substrate	2	0.0174	0.0119	0.0366
Irrigation	2	0.0243	0.3249	0.1904
Sub x Irrig	4	0.1143	0.8533	0.1706
Nitrogen source	2	0.2127	0.3143	0.3313
Sub x Nitro	4	0.7515	0.0519	0.3085
Irrig x Nitro	4	0.3622	0.7901	0.2629
Sub x Nitro x Irrig	8	0.9653	0.5524	0.7866
<i>Error</i>	26			
<i>CV</i> (%)		8.91	7.43	35.27
Trial 2				
Replicate	1	0.0076	0.0383	0.1784
Substrate	2	0.8802	0.0458	0.4474
Irrigation	2	0.3782	0.0028	0.4186
Sub x Irrig	4	0.7595	0.9159	0.7616
Nitrogen source	2	0.5785	0.0188	0.5984
Sub x Nitro	4	0.1626	0.0061	0.6331
Irrig x Nitro	4	0.6106	0.0139	0.9096
Sub x Nitro x Irrig	8	0.7472	0.3211	0.9862
<i>Error a</i>	26			
Age	1	<.0001	<.0001	0.0588
Sub x Age	2	0.1453	0.0139	0.9671
Irrig x Age	2	0.3188	0.4147	0.2509
Sub x Irrig x Age	4	0.3047	0.1472	0.5730
Nitro x Age	2	0.4697	0.2195	0.4391
Sub x Nitro x Age	4	0.0466	0.8303	0.0362
Irrig x Nitro x Age	4	0.0933	0.1005	0.5090
Sub x Irrig x Nitro x Age	8	0.6905	0.1106	0.5265
<i>Error b</i>	27			
<i>CV</i> (%)		8.49	5.63	50.61

Table 6 (continued)

Factor		Malic acid (%)		
		Before storage	After storage	% Difference
Trial 3				
Experiment 1				
	DF	<i>Pr > F</i>	<i>Pr > F</i>	<i>Pr > F</i>
Replicate	1	0.6474	0.0057	0.0604
Substrate	1	0.0142	0.6943	0.0246
Lime	3	0.1676	0.5234	0.6084
Sub x Lime	3	0.2798	0.1073	0.7752
Nitrogen source	2	0.1976	0.1031	0.0173
Sub x Nitro	2	0.3199	0.3686	0.1034
Lime x Nitro	6	0.0615	0.3396	0.0156
Sub x Lime x Nitro	6	0.5196	0.1296	0.2341
<i>Error</i>	23			
<i>CV (%)</i>		8.53	7.24	29.40
Trial 3				
Experiment 2				
Replicate	1	0.0085	0.0018	0.8858
Substrate	1	0.0120	0.0659	0.0064
Lime	3	0.3019	0.0196	0.9458
Sub x Lime	3	0.2936	0.8690	0.8716
Nitrogen source	2	0.7195	0.0823	0.6502
Sub x Nitro	2	0.1820	0.0193	0.9509
Lime x Nitro	6	0.9587	0.6096	0.8769
Sub x Lime x Nitro	6	0.6000	0.2589	0.8677
<i>Error</i>	23			
<i>CV (%)</i>		7.02	4.80	74.46

Table 7 Analysis of variance (ANOVA) of total titratable acid

Factor	DF	Total titratable acid		
		Before storage	After storage	% Difference
Trial 1		<i>Pr</i> > <i>F</i>	<i>Pr</i> > <i>F</i>	<i>Pr</i> > <i>F</i>
Replicate	1	0.3337	0.0809	0.7911
Substrate	2	0.0176	0.0112	0.0370
Irrigation	2	0.0327	0.2919	0.2054
Sub x Irrig	4	0.1236	0.8539	0.1491
Nitrogen source	2	0.1875	0.3694	0.4012
Sub x Nitro	4	0.7202	0.0704	0.3836
Irrig x Nitro	4	0.3781	0.7842	0.2779
Sub x Nitro x Irrig	8	0.9584	0.5096	0.7352
<i>Error</i>	26			
<i>CV</i> (%)		8.98	7.34	33.19
Trial 2				
Replicate	1	0.0082	0.0227	0.1896
Substrate	2	0.8948	0.0393	0.4621
Irrigation	2	0.4209	0.0011	0.3296
Sub x Irrig	4	0.7517	0.8620	0.6899
Nitrogen source	2	0.5463	0.0054	0.5329
Sub x Nitro	4	0.1651	0.0059	0.6637
Irrig x Nitro	4	0.5352	0.0050	0.9017
Sub x Nitro x Irrig	8	0.7801	0.1866	0.9918
<i>Error a</i>	26			
Age	1	<.0001	<.0001	0.0559
Sub x Age	2	0.1644	0.0128	0.9714
Irrig x Age	2	0.3496	0.6662	0.2633
Sub x Irrig x Age	4	0.3127	0.1744	0.5478
Nitro x Age	2	0.3971	0.3625	0.4811
Sub x Nitro x Age	4	0.0639	0.7511	0.0484
Irrig x Nitro x Age	4	0.0978	0.0791	0.5246
Sub x Irrig x Nitro x Age	8	0.7090	0.0441	0.4755
<i>Error b</i>	27			
<i>CV</i> (%)		8.55	4.67	49.49

Table 7 (continued)

Factor		Total titratable acid		
		Before storage	After storage	% Difference
Trial 3				
Experiment 1				
	DF	<i>Pr > F</i>	<i>Pr > F</i>	<i>Pr > F</i>
Replicate	1	0.6568	0.0049	0.0547
Substrate	1	0.0129	0.6371	0.0187
Lime	3	0.2194	0.5826	0.7976
Sub x Lime	3	0.3019	0.0829	0.6288
Nitrogen source	2	0.2498	0.1348	0.0291
Sub x Nitro	2	0.3445	0.4094	0.1251
Lime x Nitro	6	0.0581	0.3062	0.0101
Sub x Lime x Nitro	6	0.6330	0.1186	0.2617
<i>Error</i>	23			
<i>CV (%)</i>		8.56	7.25	28.10
Trial 3				
Experiment 2				
Replicate	1	0.1258	0.0020	0.8757
Substrate	1	0.0209	0.1132	0.0093
Lime	3	0.3735	0.0257	0.9625
Sub x Lime	3	0.9360	0.7734	0.7945
Nitrogen source	2	0.4157	0.0604	0.6277
Sub x Nitro	2	0.3117	0.0199	0.9721
Lime x Nitro	6	0.7227	0.6402	0.8747
Sub x Lime x Nitro	6	0.9672	0.2436	0.8320
<i>Error</i>	23			
<i>CV (%)</i>		9.51	4.87	73.39

Weight loss In Trial 1 optimal nitrogen source ratio in the nutrient solution depended on the irrigation frequency used per day (Table 8). Where 3 irrigations were used per day, the lowest weight loss was obtained when nitrate was used as the only source of nitrogen. Weight loss increased significantly when the irrigation frequency was increased to 6 irrigations per day and when NO_3^- -N was used as the only source of nitrogen. When the NO_3^- -N content in the nutrient solution was reduced to 80% and 60%, weight loss was also increased with 3 irrigations per day, but no significant differences were shown due to the frequency of irrigation.

The application of NH_4^+ -N and the influence it has on nutrient uptake and the effect of moisture status of the substrate between irrigations might have contributed to weight loss during storage. An adequate supply of calcium to the fruit is essential for firmness and shelf life (Dorais *et al.*, 2001). Schnitzler & Gruda (2002) reported that high levels of NH_4^+ -N in the root environment interfered with the uptake of calcium. Similarly, Ho (1996) found that NH_4^+ -N decreases fruit calcium content. Increasing the rate of irrigation can lead to a reduction in soluble solids and fruit dry matter content (Tüzel *et al.*, 1994) and a high water regime can reduce fruit quality (Abbott, *et al.*, 1985; Abbott *et al.*, 1986; Peet, 1992; Tüzel *et al.*, 1994; McAvoy, 1995; Peet & Willits, 1995). However, restrictions in water supply may improve fruit quality and reduce fruit size (Adams, 1990; Mitchell *et al.*, 1991).

Table 8 Influence of nitrogen source and irrigation frequency on percentage weight loss during storage (Trial 1)

Factor	Trial 1: Weight loss (%)		
	Irrigation frequency per day		
	3	6	12
NO_3^- -N : NH_4^+ -N			
100% : 0%	4.1 b	4.7 a	4.6 a
80% : 20%	4.5 a	4.6 a	4.3 ab
60% : 40%	4.4 ab	4.3 ab	4.6 a
LSD ($P=0.05$)	0.40		
CV (%)	7.49		

Means followed by the same letter do not differ significantly at $P = 0.05$ (LSD)

Table 9 Influence of substrate, irrigation frequency and substrate age on percentage weight loss during storage (Trial 2)

Factor	Trial 2: Weight loss (%)		
	Irrigation frequency		
Substrate age	Sand		
	3	6	12
1 st season	3.55 bcd	3.35 bcd	3.35 bcd
2 nd season	3.42 bcd	3.20 bcd	4.55 a
	Pine sawdust		
	3	6	12
1 st season	3.13 bcd	3.32 bcd	3.38 bcd
2 nd season	3.03 bcd	3.0 cd	3.13 bcd
	Coco peat		
	3	6	12
1 st season	3.58 bcd	3.42 bcd	3.82 ab
2 nd season	3.80 abc	3.23 bcd	2.90 d
<i>LSD (P=0.05)</i>	0.80		
<i>CV (%)</i>	19.95		

Means followed by the same letter do not differ significantly at P = 0.05 (LSD)

Weight loss showed very little differences due to irrigation frequency or type and age of the substrate used, except when sand and coco peat was used for a second season and irrigation was applied 12 times per day (Table 9). The highest weight loss value was found when sand was used and the lowest with coco peat, both irrigated 12 times per day and in the second season of substrate use. The weight loss of fruit produced from sand increased significantly from 3.42 % with 3 irrigations to 4.55 % with 12 irrigations per day in the second season of substrate use. However, the weight loss of fruit produced from coco peat in the second season of substrate use decreased significantly from 3.80 % with 3 irrigations to 2.90 % with 12 irrigations per day.

The much lower weight loss that occurred from fruit produced in coco peat was unexpected, but might be due to a combined effect of drainage water EC and pH

(Chapter 4), increased cation exchange capacity (CEC) and nitrogen source ratio and the effect these had on plant growth (Chapter 4, Table 20), fruit number per plant (Chapter 4, Table 22) and fruit size (Chapter 4, Table 23). In the second season of substrate use the stem diameter of plants produced in sand and coco peat decreased significantly. Cronin & Walsh (1983) have reported a higher fruit content in sugars, ascorbic acid and in dry matter in peat-based growing media. Alan *et al.*, (1994) reported that the highest total soluble solids content in tomato fruit was found with peat and that the highest titratable acidity and lowest pH values were found in tomato fruit when sand was used. They concluded that the pH value of the substrate might play a role in these differences. Therefore the higher CEC of coco peat (Noguera *et al.*, 1997; Noguera *et al.*, 2000) might have resulted in a much better shelf life.

Table 10 Influence of substrate on percentage weight loss during storage (Trial 3, Experiment 1)

Factor Substrate	Trial 3, Experiment 1: Weight loss (%)
Coco peat	5.6 a
Pine sawdust	5.1 b
LSD ($P=0.05$)	0.30
CV (%)	9.32

Means followed by the same letter do not differ significantly at $P = 0.05$ (LSD)

Weight loss was also significantly affected by substrate in Trial 3 (Experiment 1) (Table 10). A significantly lower weight loss was found when pine sawdust-shavings was used compared to coco peat. This is in contrast with the results of Trial 2 (Table 9). Climatic conditions however differed significantly, Trial 2 being done in cool, winter conditions and Trial 3 (Experiment 1) in warm, summer conditions. The drainage water EC in Trial 3 (Experiment 1) was also significantly higher in coco peat than pine sawdust-shavings (Chapter 5, Table 18), which illustrated the high CEC of coir (Noguera *et al.*, 1997; Noguera *et al.*, 2000). Reduced water absorption and uptake of calcium (Ehret & Ho, 1986; Adams & Ho, 1992) is associated with increased salinity (Soria & Cuartero, 1997; Dorais *et al.*, 2001) and therefore might be responsible for the production of poor shelf life fruit. The drainage water pH of coco peat was also much lower than that of pine sawdust-shavings and might have had an

effect on the uptake of potassium (Findenegg, 1987), which is very important in fruit quality (Dorais *et al.*, 2001).

Table 11 Influence of nitrogen source on percentage weight loss during storage (Trial 3, Experiment 1)

Factor	Trial 3, Experiment 1: Weight loss (%)
NO ₃ ⁻ -N : NH ₄ ⁺ -N	
100% : 0%	5.2 b
80% : 20%	5.2 b
60% : 40%	5.6 a
<i>LSD (P=0.05)</i>	0.36
<i>CV (%)</i>	9.32

Means followed by the same letter do not differ significantly at P = 0.05 (LSD)

Weight loss was significantly affected by nitrogen source ratio in Trial 3 (Table 11). The high level of NH₄⁺-N in the nutrient solution and the acidifying effect of NH₄⁺-N (Raven & Smith, 1976; Kafkafi, 2000) might have depressed the uptake of calcium (Adams & Ho, 1995) and the low pH values (Chapter 5, Table 15) might have inhibited the uptake of potassium (Findenegg, 1987) and therefore decreased fruit quality and increased weight loss.

Fruit Firmness Fruit firmness was significantly affected by substrate before storage in Trial 1 (Table 12). Coco peat and pine sawdust-shavings produced fruit that was significantly firmer than when sand was used as substrate.

Table 12 Influence of substrate on fruit firmness before storage (Trial 1)

Factor	Trial 1: Fruit firmness
Substrate	
Sand	68.2 b
Pine sawdust	70.3 a
Coco peat	71.9 a
<i>LSD (P=0.05)</i>	1.84
<i>CV (%)</i>	3.83

Means followed by the same letter do not differ significantly at P = 0.05 (LSD)

The significantly lower firmness of fruit produced from sand might be the result of a combination of temperature and NH_4^+ -N nutrition. This trial has been conducted during warmer, summer conditions. Dorais *et al.* (2001) reported that high temperature accelerated fruit development and reduced the time required for ripening but also decreased their size and therefore their quality. Sand (Chapter 3, Table 16) produced a significantly smaller fruit than coco peat and pine sawdust-shavings. Adams & Ho (1995) also reported that a high level of NH_4^+ -N nutrition restricted the uptake of calcium and therefore increased the incidence of BER. An adequate supply of calcium to the fruit is essential for firmness and shelf life (De Kreijl, 1995). High root temperature has been found to aggravate the BER inducing effect of high ammonium levels in the nutrient solution (Ho, Hand & Fussell, 1999). The significantly lower fruit firmness before storage of fruit produced in sand may therefore be attributed to the reduced uptake of calcium since the incidence of BER in sand was significantly more than coco peat or pine sawdust-shavings (Chapter 3, Table 21).

Table 13 Influence of substrate and irrigation frequency on fruit firmness after storage (Trial 1)

Factor	Trial 1: Fruit firmness		
	Irrigation frequency per day		
	3	6	12
Substrate			
Sand	41.7 c	47.0 ab	47.7 ab
Pine sawdust	49.0 a	48.7 a	47.0 ab
Coco peat	48.3 ab	45.9 b	46.6 ab
<i>LSD (P=0.05)</i>	2.62		
<i>CV (%)</i>	4.72		

Means followed by the same letter do not differ significantly at $P = 0.05$ (LSD)

Irrigation frequency, irrespective of the substrate used, had no significant effect on fruit firmness after storage, except when sand was irrigated 3 times per day (Table 13). Fruit produced from sand, irrigated 3 times per day, had a significantly lower fruit firmness value after storage compared to fruit that was irrigated 6 and 12 times

per day and when pine sawdust-shavings and coco peat was used as substrate. Pine sawdust-shavings also obtained a significantly higher fruit firmness value than coco peat when irrigated 6 times per day.

The loss of fruit firmness during storage was affected by an interaction between substrate used and irrigation frequency (Table 14). Fruit produced from sand, irrigated 3 times per day, had a significantly higher firmness loss during storage compared to fruit that was irrigated 6 and 12 times per day. Fruit produced from pine sawdust-shavings, irrigated 3 times per day, had a significantly lower firmness loss during storage than when coco peat and sand was used as substrate. Coco peat caused a significantly higher loss in fruit firmness than pine sawdust-shavings and sand when irrigated 6 times per day.

Table 14 Influence of substrate and irrigation frequency on loss of fruit firmness during storage (Trial 1)

Factor	Trial 1: Loss in fruit firmness (%)		
	Irrigation frequency per day		
	3	6	12
Sand	39.7 a	29.8 de	30.2 cde
Pine sawdust	29.0 e	30.7 cde	34.1 bc
Coco peat	34.3 bc	35.8 ab	33.8 bcd
<i>LSD (P=0.05)</i>	4.15		
<i>CV (%)</i>	10.58		

Means followed by the same letter do not differ significantly at P = 0.05 (LSD)

The lowest fruit firmness after storage and the highest loss in firmness during storage of fruit produced from sand might be the result of a combination of substrate moisture content and temperature. High temperatures during the experiment (Trial 1) could cause an increase in transpiration and therefore more calcium to the leaves and less to the fruit (Adams & Ho, 1993; Saure, 2001; Adams, 2002). Water availability can be insufficient between irrigations if it is scheduled to far apart. Increasing the rate of irrigation can lead to reductions in soluble solids and dry matter content of fruit

(Tüzel *et al.*, 1994) and a high fruit dry matter content is generally associated with high fruit firmness (Dorais *et al.*, 2001). The drainage water EC of coco peat was significantly higher than that of sand and pine sawdust-shavings (Chapter 3, Table 10) and this might have restricted the absorption of water, thereby reducing the firmness after storage and causing an increase in loss of firmness during storage (Soria & Cuartero, 1997; Dorais *et al.*, 2001).

Table 15 Influence of substrate on fruit firmness after storage (Trial 3, Experiment 1)

Factor Substrate	Trial 3, Experiment 1: Fruit firmness
Coco peat	37.4 b
Pine sawdust	39.1 a
<i>LSD (P=0.05)</i>	1.61
<i>CV (%)</i>	7.05

Means followed by the same letter do not differ significantly at P = 0.05 (LSD)

Fruit firmness was significantly affected by substrate after and during storage (Tables 15 and 16). Pine sawdust-shavings produced fruit that was significantly firmer and also did not have a high loss in firmness after storage. The drainage water EC of coco peat was significantly higher and as explained earlier could have caused a reduction in the absorption of water and therefore reduce firmness and increase the loss in firmness.

Table 16 Influence of substrate on loss of fruit firmness during storage (Trial 3, Experiment 1)

Factor Substrate	Trial 3, Experiment 1: Loss in fruit firmness (%)
Coco peat	42.8 a
Pine sawdust	39.4 b
<i>LSD (P=0.05)</i>	2.66
<i>CV (%)</i>	10.84

Means followed by the same letter do not differ significantly at P = 0.05 (LSD)

Table 17 Influence of nitrogen source on fruit firmness after storage (Trial 3, Experiment 1)

Factor NO ₃ ⁻ -N : NH ₄ ⁺ -N	Trial 3, Experiment 1: Fruit firmness
100% : 0%	36.6 b
80% : 20%	38.2 ab
60% : 40%	40.1 a
<i>LSD (P=0.05)</i>	1.97
<i>CV (%)</i>	7.05

Means followed by the same letter do not differ significantly at P = 0.05 (LSD)

Fruit firmness was significantly affected by nitrogen source after and during storage (Tables 17 and 18). The addition of NH₄⁺-N increased fruit firmness after storage and reduced the loss in firmness during storage. The addition of 40% NH₄⁺-N as part of the total nitrogen content, produced fruit with the highest firmness values and also had the lowest loss in firmness during storage. Feigen *et al.* (1980) reported that the application of 10 – 50% NH₄⁺-N to the nutrient solution markedly increased the percentage of firm fruit after storage.

Table 18 Influence of nitrogen source on loss of fruit firmness during storage (Trial 3, Experiment 1)

Factor NO ₃ ⁻ -N : NH ₄ ⁺ -N	Trial 3, Experiment 1: Loss in fruit firmness (%)
100% : 0%	44.5 a
80% : 20%	41.5 a
60% : 40%	37.3 b
<i>LSD (P=0.05)</i>	3.26
<i>CV (%)</i>	10.84

Means followed by the same letter do not differ significantly at P = 0.05 (LSD)

Fruit pH Fruit pH was significantly affected by substrate before, after and during storage in the first trial (Table 19). Fruit produced from coco peat had a

significantly higher pH before storage, while there was no difference between fruit pH of sand and pine sawdust-shavings. Fruit produced from pine sawdust-shavings had a significantly higher pH after storage and had the highest increase in pH during storage, compared to sand and coco peat.

Alan *et al.* (1994) found that the highest titratable acidity and lowest pH values were found in tomato fruit when sand was used. They concluded that the pH value of the substrate might play a role in these differences, but according to the drainage water pH values recorded during this trial (Chapter 3, Table 9) coco peat should have produced the lowest fruit pH.

Table 19 Influence of substrate on fruit pH before, after and the difference during storage (Trial 1)

Factor Substrate	Trial 1: Fruit pH		
	Before storage	After storage	Difference (%)
Sand	4.23 b	4.55 b	-7.73 ab
Pine sawdust	4.25 b	4.62 a	-8.28 b
Coco peat	4.28 a	4.58 b	-6.62 a
<i>LSD (P=0.05)</i>	0.03	0.03	1.28
<i>CV (%)</i>	0.87	1.04	-24.67

Means followed by the same letter do not differ significantly at $P = 0.05$ (LSD)

Negative value indicates an increase in pH during storage

Fruit pH was also significantly affected by nitrogen source before, after and during storage in the second trial (Table 20). The addition of NH_4^+ -N reduced fruit pH before and after storage significantly. Significantly higher fruit pH values were found when NO_3^- -N was used as the sole source of nitrogen in the nutrient solution before and after storage. The highest increase in fruit pH during the growing season was found when 100% NO_3^- -N was used as nitrogen source. A similar trend was observed in Trial 1 and 3. In Trial 3 (Experiment 1) no significant difference was found between the fruit pH values of coco peat and pine sawdust-shavings, irrespective of nitrogen source ratio used, but a reduction in fruit pH was found with increased NH_4^+ -N levels.

The increase in acidity in the fruit might be the result of increased glutamic acid levels. Dorais *et al.* (2001) reported that the application of NH_4^+ -N compared to NO_3^- -N, increased glutamic acid levels in the fruit. Glutamic acid is one of three main amino acids in tomato fruit, which represent 65% of amino acids found in tomato fruit, and concentrations vary between 50 and 300 mg per 100 g of fresh tissue (Davies & Hobson, 1981). Although citric and malic acids are the main organic acids found in tomato fruit, no supporting literature could be found to support the effect of increasing NH_4^+ -N levels on organic acid content and fruit pH.

Table 20 Influence of nitrogen source on fruit pH before, after and difference during storage (Trial 2)

Factor	Trial 2: Fruit pH		
	Before storage	After storage	Difference (%)
NO_3^- -N : NH_4^+ -N			
100% : 0%	4.40 a	4.54 a	-3.17 b
80% : 20%	4.32 b	4.43 b	-2.48 ab
60% : 40%	4.27 c	4.35 c	-1.99 a
<i>LSD</i> ($P=0.05$)	0.03	0.03	0.89
<i>CV</i> (%)	1.56	1.15	-54.06

Means followed by the same letter do not differ significantly at $P = 0.05$ (LSD)

Negative value indicates an increase in pH during storage

Fruit pH was also significantly affected by the period of substrate use before and after storage in the third trial (Table 21). The second season of substrate use produced fruit with a significantly lower pH value. The reduction in fruit pH in the second season of substrate use is difficult to explain, but might be the result of smaller fruit that was produced (Chapter 4, Table 23) due to water logged conditions and a low pH during the growing season (Chapter 4, Tables 12 and 13).

Table 21 Influence of substrate age on fruit pH before and after storage (Trial 2)

Factor Substrate Age	Trial 2: Fruit pH	
	Before storage	After storage
1 st season	4.36 a	4.47 a
2 nd season	4.30 b	4.41 b
<i>LSD (P=0.05)</i>	0.03	0.02
<i>CV (%)</i>	1.56	1.15

Means followed by the same letter do not differ significantly at P = 0.05 (LSD)

In the third trial fruit pH after storage was found to be significantly higher when grown in coco peat compared to pine sawdust-shavings (Table 22). This is in contrast with previous findings (Trial 3, Experiment 1, Table 19). The higher pH of fruit produced in coco peat might be due to the higher and more stable drainage water pH of coco peat in Experiment 2 compared to Experiment 1 (Chapter 5, Table 17).

Table 22 Influence of substrate in on fruit pH after storage (Trial 3, Experiment 2)

Factor Substrate	Trial 3, Experiment 2: Fruit pH
	Coco peat
Pine sawdust	5.88 b
<i>LSD (P=0.05)</i>	0.09
<i>CV (%)</i>	2.38

Means followed by the same letter do not differ significantly at P = 0.05 (LSD)

Total titratable acid Fruit TTA was significantly affected by substrate before, after and during storage (Table 23) in the first trial. Fruit produced from coco peat had a significantly lower TTA before storage, while there was no difference between the TTA of fruit produced from sand and pine sawdust-shavings. Fruit produced from sand had a significantly higher TTA after storage and fruit produced from pine sawdust-shavings showed the highest reduction in TTA during storage.

Alan *et al.* (1994) found that the highest titratable acidity and lowest pH values were found in tomato fruit when sand was used. In this experiment fruit produced from

sand and pine sawdust-shavings produced the highest TTA before storage. After storage fruit produced from sand again recorded the highest TTA. Fruit from pine sawdust-shavings indicated the highest loss in TTA during storage. The reduction in TTA during storage is due to chemical composition changes during ripening. (Dorais *et al.*, 2001). A similar trend was observed in the third trial (Experiment 1 and 2).

Table 23 Influence of substrate on TTA before, after and difference during storage (Trial 1)

Factor Substrate	Trial 1: Total titratable acid (%)		
	Before storage	After storage	Difference (%)
Sand	5.86 a	4.61 a	21.06 b
Pine sawdust	5.96 a	4.31 b	27.01 a
Coco peat	5.46 b	4.29 b	20.89 b
<i>LSD (P=0.05)</i>	0.35	0.22	5.23
<i>CV (%)</i>	8.98	7.34	33.19

Means followed by the same letter do not differ significantly at P = 0.05 (LSD)

Table 24 Influence of substrate and nitrogen source on TTA after storage (Trial 2)

Factor NO ₃ ⁻ -N : NH ₄ ⁺ -N	Trial 2: Total titratable acid (%)		
	Substrate		
	Sand	Pine sawdust	Coco peat
100% : 0%	6.39 b	6.19 ab	5.97 a
80% : 20%	6.50 b	6.48 b	6.31 ab
60% : 40%	6.17 ab	7.01 c	6.52 b
<i>LSD (P=0.05)</i>	x		
<i>CV (%)</i>	4.67		

Means followed by the same letter do not differ significantly at P = 0.05 (LSD)

^xData not normally distributed. Transformed with $IX=1/(X+1)$

In the second trial, TTA increased significantly with increasing NH₄⁺-N levels in the nutrient solution after storage, when pine sawdust-shavings and coco peat was used as substrate (Table 24). Pine sawdust-shavings produced fruit with significantly higher TTA values compared to sand and coco peat when 40% NH₄⁺-N was used. Nitrogen

source ratio had no significant effect on fruit TTA when sand was used as substrate. The same trend was observed in the third trial (Experiment 1). A highly significant negative correlation, which has been reported between pH and titratable acidity (Lower & Thompson, 1967), may be the reason for this trend.

The substrate type and period of substrate use also had a significant effect on fruit TTA after storage in the second trial (Table 25). Pine sawdust-shavings and coco peat produced fruit with significantly higher TTA values in the second season of substrate use compared to sand, while fruit with a significantly higher TTA value was produced in pine sawdust-shavings compared to coco peat when new substrate was used.

Table 25 Influence of substrate and nitrogen source on TTA after storage (Trial 2)

Factor	Trial 2: Total titratable acid (%)		
	Substrate		
Substrate age	Sand	Pine sawdust	Coco peat
1 st season	6.31 b	6.36 bc	5.98 a
2 nd season	6.40 bc	6.74 d	6.57 cd
<i>LSD</i> ($P=0.05$)	x		
<i>CV</i> (%)	4.67		

Means followed by the same letter do not differ significantly at $P = 0.05$ (LSD)

^xData not normally distributed. Transformed with $IX=1/(X+1)$

Conclusions

Substrate and nitrogen source have been shown to have an effect on all fruit quality parameters tested, whereas weight loss and firmness was also affected by irrigation frequency.

Increasing levels of NO_3^- -N as nitrogen source in the nutrient solution, reduced weight loss and increased the loss of fruit firmness of tomatoes during storage. NH_4^+ -N nutrition could be toxic if applied at very high levels and therefore might reduce the uptake of water and calcium to the fruit, hence reducing shelf life. The application of NO_3^- -N does not restrict growth and therefore allows fast development of the fruit

with a fruit cuticle that is thinner and more elastic. Increasing levels of NO_3^- -N also increased fruit pH and reduced total titratable acidity (TTA) as a result of the negative correlation that exists between these parameters. However, 100% NO_3^- -N was responsible for the highest increase in fruit pH during storage. Coco peat produced fruit with a higher pH than pine sawdust-shavings. The TTA of sand was the highest before and after storage, but in general the TTA increased with increasing NH_4^+ -N nutrition, more so in pine sawdust-shavings but also when coco peat was used. The data from Trial 1 and 2 supports the conclusion that was made by Alan *et al.* (1994), in that the pH value of the substrate might play a role in the TTA contents and pH of the fruit. In the first and second trial the highest TTA values were recorded in pine sawdust-shavings, followed by sand and coco peat. In these trials the TTA and pH values followed the same trend.

Fruit firmness was the lowest in sand before storage, and after storage when 3 irrigations were applied per day, but increased with 6 and 12 irrigations per day. However, the increase in irrigation frequency affected fruit firmness negatively when coco peat was used as substrate. The loss in firmness was the highest in sand, but was reduced with increasing irrigation frequencies. The loss in fruit firmness and weight was higher in coco peat than pine sawdust-shavings. The high loss in firmness in sand could be ascribed to insufficient water availability between irrigations, especially when irrigations are scheduled to far apart. In Trial 2 weight loss in the second season of substrate use increased in sand and decreased when coco peat was used with an increasing irrigation frequency. This is in contrast with data from Trial 1, where fruit was produced in cooler, winter conditions.

Nitrate as nitrogen source in the nutrient solution has a positive effect on weight loss and fruit pH, but influenced firmness and TTA negatively. The irrigation frequency needs to be adjusted seasonally. It needs to be adapted to the type of substrate that is used and the period of substrate use. The results again emphasized that the level of management of the growing regime is influenced by a combination of factors, including the type of substrate that is used, irrigation and fertigation practices and the growing season (winter vs. summer).

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CHAPTER 7

Summary

7.1 Objectives of the study and experiments conducted

Pine sawdust-shavings is at present a very popular soilless growth medium in South African greenhouses. A shortage of this substrate is inevitable due to a decline in pine plantations and expansion in the greenhouse industry. Growers use mostly fresh pine sawdust-shavings, which is biologically highly unstable. This is forcing the greenhouse industry to look at alternative growth media such as coco peat, which already went through a decomposition process and is more stable as well as biological inactive mediums such as sand and/or perlite. Coco peat is well known for its quality and durability as a growth medium, but is relatively expensive compared to pine sawdust-shavings. However coco peat has much better physical, chemical and biological properties than pine sawdust-shavings. Because of different substrate characteristics, crops grown in coco peat may have different cultivation requirements. The main objective of this study was to compare the growth, yield and quality of hydroponically grown tomatoes in response to different growth mediums in combination with nitrogen source ratio, irrigation frequency, period of substrate use and pre-plant liming of growth media. This was achieved by a series of experiments conducted in a greenhouse during the spring and summer of 2000/2001 and 2001/2002, and during the summer and autumn of 2001 and 2002 in which the effect of three growth mediums, three irrigation frequencies, three nitrogen source ratios, two periods of substrate use and four lime application levels were evaluated. From the results it became clear that these factors influenced the root environment (drainage water) and subsequent growth and quality of tomatoes.

7.2 Results

Drainage water

pH In general pH of the drainage water declined with an increase in $\text{NH}_4^+\text{-N}$ in the nutrient solution due to the well-known acidifying effect of ammonium fertilizers.

The drainage water pH of coco peat and sand decreased with time when $\text{NH}_4^+\text{-N}$ was used, but an increase in pH was observed when 20% $\text{NH}_4^+\text{-N}$ was used with pine sawdust-shavings or when 100% $\text{NO}_3^-\text{-N}$ was used with coco peat and pine sawdust-shavings. The lowest pH was found when coco peat was used and 40% $\text{NH}_4^+\text{-N}$ was applied. Contrary to these findings during warmer, summer conditions, the pH of biologically active growth substrates declined with time when only $\text{NO}_3^-\text{-N}$ was applied during cooler, winter conditions. This may be due to the uptake of $\text{NO}_3^-\text{-N}$ and the activity of microorganisms, which increases with increasing seasonal temperatures. Therefore during cooler, winter conditions microbiological activity and the uptake of $\text{NO}_3^-\text{-N}$ might be reduced to such an extent that less OH^- are emitted and thus not raising the drainage water pH. The decline in pH increased the toxicity of $\text{NH}_4^+\text{-N}$ and had a detrimental effect on plant growth and quality parameters. The phytotoxic effect, however, was more profound in summer than winter. The addition of lime with $\text{NH}_4^+\text{-N}$ nutrition stabilized the drainage water pH.

Electrical conductivity The drainage water electrical conductivity (EC) increased during production in warmer, summer growing conditions due to the build-up of fertilizer salts as a result of high temperatures and insufficient water volumes applied per irrigation cycle. However, the increase in EC was significantly higher in coco peat than pine sawdust-shavings or sand. During cooler, winter conditions the EC was generally lower and more acceptable for production in all the substrates, but coco peat and sand still recorded a higher EC than pine sawdust-shavings. This might be the result of the high cation exchange capacity of coco peat or due to the difference in composting activity. Since coco peat can be used for up to 3 years it is advisable to flush the substrate with fresh water between plantings.

$\text{NO}_3^-\text{-N}$ and $\text{NH}_4^+\text{-N}$ content As expected the $\text{NO}_3^-\text{-N}$ content of the drainage water decreased as the $\text{NH}_4^+\text{-N}$ content increased in the nutrient solution. However, the decrease in pine sawdust-shavings was much lower than in sand or coco peat and might be due to differences in uptake of $\text{NO}_3^-\text{-N}$ or a higher microbiological conversion of $\text{NH}_4^+\text{-N}$ to $\text{NO}_3^-\text{-N}$ or immobilization of nitrogen. Pine sawdust-shavings recorded a much lower $\text{NO}_3^-\text{-N}$ and $\text{NH}_4^+\text{-N}$ content than sand and coco peat. This trend supports the hypothesis that microbiological activity is higher in pine sawdust-shavings, especially in the second season of substrate use, which resulted in

more effective conversion of $\text{NH}_4^+\text{-N}$ to $\text{NO}_3^-\text{-N}$, or high $\text{NO}_3^-\text{-N}$ uptake or immobilization, compared to sand and coco peat. The accumulation of $\text{NO}_3^-\text{-N}$ in sand indicated that it was biologically more stable and that it might have been over fertilized with $\text{NO}_3^-\text{-N}$ during production in cooler, winter conditions. The same applied to coco peat when only $\text{NO}_3^-\text{-N}$ was used, although the accumulation of $\text{NO}_3^-\text{-N}$ in the drainage water was higher than when sand was used during warmer, summer growing conditions. Nitrification or the uptake of NH_4^+ might have had a significant effect on the $\text{NH}_4^+\text{-N}$ content of the drainage water, especially during cooler, winter conditions. Low root temperatures slow down the uptake of NO_3^- , but are beneficial to the uptake and translocation of NH_4^+ metabolites from the roots to the shoots of tomato plants. However, the effect was found to be more visible in sand and pine sawdust-shavings.

Growth and fruit yield

Stem diameter of tomato plants decreased in pine sawdust-shavings and coco peat when the $\text{NH}_4^+\text{-N}$ content of the nutrient solution was increased from 0% to 40% in the first season of substrate use. However, no difference was recorded when only $\text{NO}_3^-\text{-N}$ and 20% $\text{NH}_4^+\text{-N}$ was used. In the second season of substrate use, stem diameter decreased significantly when 20 - 40% $\text{NH}_4^+\text{-N}$ was used in sand and coco peat, but plants grown in pine sawdust-shavings only indicated a decrease in stem diameter when 40% $\text{NH}_4^+\text{-N}$ was used. A similar trend was observed between the first and second season of substrate use. Low drainage water pH values in coco peat and ammonium toxicity might be responsible for the decrease in stem diameter. From these results it is clear that plant growth in pine sawdust-shavings was not as severely affected by the addition of $\text{NH}_4^+\text{-N}$ as coco peat and sand.

Coco peat produced the highest number of marketable fruit and yield per plant, followed by pine sawdust-shavings and sand in the first season of substrate use. In all the experiments the number of marketable fruit per plant showed the same trend as marketable yield and therefore can be assumed that marketable yield was determined by the number of fruit per plant and not average fruit mass. The number of marketable fruit and yield decreased with an increase in $\text{NH}_4^+\text{-N}$ content in the nutrient solution during production in warmer, summer conditions. This could be ascribed to either a

decrease in drainage water pH or a decrease in the NO_3^- -N content during the growing season. Contrary to these findings, production in cooler, winter conditions recorded high yields when only NO_3^- -N or 80% NO_3^- -N : 20% NH_4^+ -N was applied. It might be that 20% NH_4^+ -N is less toxic during cooler, winter conditions. However, marketable yield was significantly reduced with increasing NH_4^+ -N levels in the second season of substrate use. No difference in marketable fruit and yield per plant was recorded between coco peat and pine sawdust-shavings when lime was applied, irrespective of the nitrogen source that was used, except when pine sawdust-shavings was irrigated with 40% NH_4^+ -N in the nutrient solution. This might be due to the drainage water pH, which was near optimum and more stable due to the lime application and that NH_4^+ -N is less toxic under cooler, winter conditions. The addition of NH_4^+ -N decreased fruit mass. However, coco peat produced the largest fruit followed by pine sawdust-shavings and sand.

Irrigation frequency depends on the type of substrate used and the nitrogen source ratio that was applied. NO_3^- -N applied 12x per day and coco peat irrigated with 100% NO_3^- -N produced the highest marketable yield per plant. Trends, however, indicates that less than 12 irrigations per day might be optimal.

The unmarketable yield increased with an increase in NH_4^+ -N in the nutrient solution. Visual evaluations showed that blossom-end rot (BER) was the main contributor to unmarketable yield in all the experiments. However, the percentage BER fruit per plant was significantly lower in cooler, winter conditions compared to warmer, summer conditions. It might be that NH_4^+ -N is less toxic during cooler, winter conditions. The application of lime prevented the incidence of BER, irrespective of NH_4^+ -N content, when coco peat was used and only affected pine sawdust-shavings when 40% NH_4^+ -N was applied.

Fruit quality

Increasing levels of NO_3^- -N as nitrogen source in the nutrient solution, reduced weight loss and increased the loss of fruit firmness of tomatoes during storage. Increasing levels of NO_3^- -N also increased fruit pH and reduced total titratable acidity as a result of the negative correlation that exists between these parameters. However,

100% NO_3^- -N was responsible for the highest increase in fruit pH during storage. NH_4^+ -N nutrition could be toxic if applied at very high levels and therefore might reduce the uptake of water and calcium to the fruit, hence reducing shelf life. The application of NO_3^- -N does not restrict growth and therefore allows fast development of the fruit with a fruit cuticle that is thinner and more elastic.

Coco peat produced fruit with a higher pH than pine sawdust-shavings. Fruit firmness was the lowest in sand before storage, and after storage when 3 irrigations were applied per day, but increased with 6 and 12 irrigations per day. However, the increase in irrigation frequency affected fruit firmness negatively when coco peat was used as substrate. The loss in firmness was the highest in sand, but was reduced with increasing irrigation frequencies. The loss in fruit firmness and weight was higher in coco peat than pine sawdust-shavings. The high loss in firmness in sand could be ascribed to insufficient water availability between irrigations, especially when irrigations are scheduled to far apart.

7.3 Conclusions

Coco peat produced the highest number of marketable fruit and yield per plant, but it is of the utmost importance to treat the substrate with lime prior to planting to prevent the development of BER and a low drainage water pH during the growing season. Coco peat needs to be irrigated at least 12x per day to ensure high yields. Irrigation scheduling is very important when coco peat is used. The high cation exchange capacity of coco peat creates an opportunity for the build up of fertilizer salts during conditions with high temperatures and when insufficient water volumes are applied per irrigation cycle. Growers also needs to be very careful with the use of NH_4^+ -N in coco peat as the phytotoxic effect seems to be more severe, especially in the second season of substrate use, compared to pine sawdust-shavings. Pine sawdust-shavings does not produce the same yield as coco peat, but can be highly productive when used for a six month growing season. Decomposition, nitrogen immobilization and waterlogged conditions seem to be some of the biggest problems in the second season use of pine sawdust-shavings. Sand produced the lowest marketable yield and the highest percentage of fruit affected by BER. High root zone temperatures and NH_4^+ -N levels, and a low drainage water pH might be responsible for low production figures

and therefore root temperature, NH_4^+ -N content and pH needs to be carefully controlled, especially during warmer summer conditions. A range of cultural practices and environmental factors affects fruit quality. From the results it is clear that the application of low levels of NH_4^+ -N nutrition and the application of 6 to 12 irrigations per day could increase fruit quality. However, the results again emphasized that the level of management of the growing regime is influenced by a combination of factors, including the type of substrate that is used, irrigation and fertigation practices and the growing season (winter vs. summer). The complexity of the effect of cultural practices and climatic conditions on the productivity of a crop complicates the daily management of a growth medium.