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Nitrogen nutrition of tomato (*Lycopersicon esculentum* Mill.) transplants and the influence of electrical conductivity on crop growth, yield and quality

By

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Submitted in partial fulfillment of the requirements for the degree
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DECLARATION

I hereby declare that this dissertation, for the degree MSc (Agric) Agronomy at the University of Pretoria is my own work, except where duly acknowledged and that it has never been submitted before by myself for any degree at any university.

_____ _____

Sifiso Thuthukani Msibi Date

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ABSTRACT

Nitrogen is required by plants in large quantities and its deficiency is mostly related to reduction in crop production. A study was conducted to assess the importance of nitrogen in tomato (*Lycopersicon esculentum* Mill.) transplant production. Transplants were propagated at 0, 30, 60, 90, and 120 $mg \cdot L^{-1}$ N applied as NH_4NO_3 while 30 $mg \cdot L^{-1}$ P applied as NaH_2PO_4 and 30 $mg \cdot L^{-1}$ K as KCl were used. Fergitation was done by floating cavity trays in nutrient solution until the medium reached field capacity. The experiment was arranged in a randomized complete block design (RCBD) with four replications. Sampling was initiated at 21 days after sowing and was done weekly until the transplants were ready for transplanting (when transplants could be pulled out of the cavity easily without breaking) at 42 days after sowing.

Nitrogen supply had a pronounce influence on the transplant root and shoot growth. Observations throughout the experiment indicated that increased nitrogen application favoured shoot growth which is an indication that most of the assimilates were partitioned to shoots rather than to roots. Nitrogen application of 120 $mg \cdot L^{-1}$increased fresh shoot mass and subsequently enhanced dry shoot mass. As nitrogen was increased from 0 to 120 $mg \cdot L^{-1}$, it

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further promoted relative growth rate, specific leaf area, leaf mass ratio, leaf area ratio, plant chlorophyll content, leaf tissue nitrogen and improved the pulling success. At 42 days after sowing, a quality transplant that was produced with 90 $mg \cdot L^{-1}$ N, had a root to shoot ratio of 0.16, leaf mass ratio of 0.86, root mass ratio of 0.13, leaf area of 594 cm^2, plant chlorophyll content of 33, leaf tissue nitrogen of 32 $g \cdot kg^{-1}$, specific leaf area of 194 $cm^2 \cdot mg^{-1}$, leaf area ratio of 167.7 $cm^2 \cdot mg^{-1}$, relative growth ratio of 0.31 $cm \cdot mg^{-1} \cdot wk^{-1}$ and 100% pulling success. This transplant proved to be ideal for the production of tomato as compared to other treatment combinations that were employed.

Another glasshouse experiment was conducted to determine the influence of electrical conductivity (EC) and or nutrient solution composition on growth, yield and quality parameters in tomato. The pots were arranged in a randomized complete block design (RCBD). One plant per pot represented an experimental unit. Four EC treatments were used that consisted of 1.12, 2.24, 4.48 and 6.72 $mS \cdot cm^{-1}$. Each treatment was replicated six times. Distilled water was used for irrigation water to maintain the required pH, which was 5.5 to 6.2 throughout the duration of the study, and cocopeat was used as substrate.

Salinity inhibited growth (shoot length) and yield (average fruit mass, fruit diameter and fruit circumference) at the highest concentration of 6.72 $mS \cdot cm^{-1}$. However, it did not significantly affect number of trusses, number of fruits and stem diameter, rather tomato quality was improved in terms of total soluble solids. Although tomato fruits grown at 6.72 $mS \cdot cm^{-1}$ were relatively smaller than fruits grown at 1.12, 2.24 and 4.48 $mS \cdot cm^{-1}$ treatments respectively, they had higher acidity, increased soluble solids and higher sugar content which are all qualities required by the tomato processing industry. Increasing the concentration of the solution from 1.12 to 6.72 $mS \cdot cm^{-1}$ increased the %Brix from 3.9 to 6.1% while titratable acidity was also increased from 3.3 to 5.7%, respectively. The incidents of blossom end rot were higher (6.3%) at concentration of 6.72 $mS \cdot cm^{-1}$ as compared to 1.12 $mS \cdot cm^{-1}$ concentration, which was 0.5%.

Keywords: *Lycopersicon esculentum* Mill., transplants, nitrogen, electrical conductivity, growth, yield, quality, nutrient solution

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GENERAL INTRODUCTION

Tomato (*Lycopersicon esculentum* Mill.) is one of the most important horticultural crops throughout the whole world under field and greenhouse conditions (Dorais *et al*., 2001). It is considered as a small genus within the large diverse family of Solanaceae (Taylor, 1986). It is originated in the coastal strip of western South America from the equator to about 30^0C latitude South (Taylor, 1986; Papadopoulus, 2001). Initially, tomato was being placed in the genus Solanum along with potato, where it was identified as *Solanum esculentum*. However, it was changed to Lycopersicon *esculentum* (Jones, 1999). It falls under the division of Anthophyta (Papadopoulus, 2001).

Tomato is a major component of daily meals in many countries and serves as an important source of minerals, vitamins and antioxidant compounds (flavonoids and carotenoids, mainly lycopene) (Jones, 1999; Dorais *et al*., 2001). For the past decades, greenhouse produced tomato consumption has grown at an explosive rate. The catalyst fuelling this dramatic growth was on consumers' perception and awareness that greenhouse tomatoes are far superior in their consistent quality and taste as compared to the standard field grown tomato (De Giglio, 2003).

Tomato is an important commercial crop and it is an ideal research material for physiological, cellular, biochemical and molecular genetic investigations. Most tomato growers use greenhouses due to the sensitivity of the crop to unfavourable environmental conditions, such as temperatures. However, some of the growth limiting factors such as balanced nutrition and proper irrigation practices and management are still an area of concern or a challenge to most of the producers. This is due to the fact that most of the fruit physiological disorders, abnormal growth, yield and quality of fruit vegetables are greatly influenced by nutrient solution composition (Lara *et al*., 1999).

Through greenhouse production, the producer can create an environment that is optimal for plant growth in an area that is sub-optimal for plant growth and can manipulate some of the characteristics of plants to satisfy the consumers demand. However, the solution

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concentration and nutrient ratios play a key role (Lara *et al.*, 1999). The conventional nutrient management of soilless culture is based on the maintenance of relatively high concentrations. The result is reduced efficacy of nutrient use, which has serious environmental impact. It can also lead to excess ion uptake and imbalance between vegetative and reproductive growth resulting in reduced yield and quality (Maruo, 1999).

The only practical way to determine the correct concentration of nutrients in irrigation water is to measure the electrical conductivity (EC). EC is a measure of the total ion concentration of a solution or electrical resistance of water, a nutrient solution, or a soil or medium solution used to determine the level of ions in solution and as a means to determine potential effect on the plant growth (Jones, 1999). Basically, EC measures the conductance of the total dissolved solutes in the solution. It does not indicate the level of any individual ion (Resh, 1993). The composition and concentration of nutrient solutions are based on published recommendations, which are based on experience, plant species and cultivar and growth stage. Recently, the recommended total ion concentration of the nutrient solution expressed as EC has increased, especially in the production of high quality fruit vegetables, such as tomatoes and cucumbers (Schwarz & Klaring, 2002.).

Effective fertigation requires an understanding of plant growth behaviour as influenced by nutrient requirements, rooting patterns, solution composition, fertilizer chemistry (mixing compatibility, precipitation, clogging and corrosion) and water quality factors (salt, sodium hazards and toxic ions). Although the body of knowledge on the effects of N fertilization on tomato transplants for a special production system is appreciable, relatively little effort has been made to synthesize that information into a more general knowledge base.

Nitrogen (N) is the essential element most frequently deficient in soils around the world. N is a major essential nutrient element required by plants in substantial quantities. Most N on plants is in proteins, genetic material, and chlorophyll. It is the constituent of proteins and many metabolic intermediates involved in synthesis and energy transfer of nucleic acids (Mengel & Kirkby, 2001). The amount of N accumulated by plants varies

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with species, cultivar, plant part and age of the part, as well as with the nutritional status. Typical ranges of concentration are from 1,5 to 5% total nitrogen on a dry weight basis. Although the threshold for N deficiency varies with position and age of tissues, youngest matured leaves that have less than 1,5% total N probably are N deficient. A proper total supply and balance of N with other elements is very important in plant nutrition. N fertilizer normally delays rate of maturation of plants and promote shoot growth rather than root growth. N is the only plant nutrient which can be added to the soil by biological nitrogen fixation (BNF) but for many cropping system in the tropics addition of N through BFN is insufficient to cover the loss of N with crop removal, leaching and denitrification (Baloyi, 2004).

Vegetable transplants have been used for decades and advantages for their use are well documented (Dufault, 1993). Methods used to produce transplants have changed tremendously since the early 1930s (Dufault, 1998). Soils were used and compost was produced to produce more fertile soil for transplant growing (Work, 1945). By then, regulation of nutrition was not a major consideration during the production phase since soils are naturally able to provide the small quantities of nutrient required. Now the use of transplants and the transplant industry have grown dramatically necessitating more efficient greenhouse utilization. Today's transplants are grown in standardised trays in soilless medium using fertilizer programs that are completely different from the past practices. It is, therefore, necessary to control all the phases of transplant production, especially the growth rate, and the most effective way of controlling transplant growth is to manage the nutritional regimes used to grow them.

Thirthy eight papers were found in the literature on transplant nutrition that date back as early as 1940 (Dufault, 1998). The most popular crop studied was tomato with 33% of all work devoted to fresh and processing tomatoes. The major nutrient studied in all these transplant nutrition reports was N with sources of N a very popular topic. However, the diversity of plant responses to N treatment in reviewed literature makes the extraction of the essential meaning, recommendation and adaptation purposes difficult. A literature study leaves one confused about what is specifically required to produce an acceptable

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transplant. A dilemma exists because of the great diversity of conditions that the research was conducted under. To date, few specific recommendations concerning tomato nutrition can be made. Dufault (1998) summarised these confounding items that included differences due to:

- Crops
- Cultivars within the same crop
- Microclimatic diversity of greenhouse environments used in research
- Fertilizer N sources and concentrations i.e. nitrate, ammonium, urea and other nutrients used such as trace elements
- Interaction of other factors studied, for example carbon dioxide (CO_2) enrichment, nutrient ratios, timing of application, container type and size, supplemental lighting etc
- Interaction between nutrients and growth media, affecting cation exchange capacity (CEC), pH, salinity, etc
- Geographical research location and micro climatic diversity of the field environment in which transplant performance is evaluated
- Application frequency resulting in differences in total application of an element

The process of deciding the value and application of published transplant nutrition research is confounded further by the fact that transplants are hand planted with lots of care versus the real practice that commercial transplants are exposed to. Therefore, it is indeed difficult to judge the merits of recommended regimes/rates from published research and adapt them commercially without more testing of high N transplants and controlled mechanical transplanting stresses. A study was conducted with the aim of producing an ideal transplant that has a well-developed root system, good root to shoot ratio and could easily pull out of cavity trays without breaking. In order to achieve this, experiments were conducted to a) to determine appropriate N fertilization for tomato transplant production. b) To determine the amounts of nitrogen that can optimise tomato transplant shoot and root development. c) To determine the influence of EC or nutrient solution composition on growth, yield and quality parameters in tomato.

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CHAPTER 1

LITERATURE REVIEW

1.1 INTRODUCTION

Tomato (*Lycopersicon esculentum* Mill.) is considered as a small genus within the large diverse family of Solanaceae (Taylor, 1986). It is a herbaceous perennial plant that can also be grown annually in temperate regions since it is not frost tolerant. Growth varies between indeterminate and determinate habits (Picken *et al*., 1986; Jones, J.B. 1999). Seeds are flattened ovoid, up to 5 mm long, 4 mm wide and 2 mm thick consisting of the embryo, endosperm and testa or seed coat. The fruit is a berry consisting of seeds within fleshy pericarp developed from an ovary (Picken *et al*., 1986; Dorais *et al*., 2004).

The stem is typically about 4 cm in diameter at the base and is covered with glandular hairs. The compound leaf size is variable. Leaves of popular greenhouse types are 0.5 m long, a little less in width, with a large terminal leaflet and up to 8 large lateral leaflets, which may be compounded (Picken *et al*., 1986). The root zone extent to a diameter of more than 1.5 m with the tap root system that grows deeper than 0.5 m. The optimum air temperature for growth is 18 - 29ºC during the day and 18 - 21ºC at night while rooting temperature is 18 - 23ºC. It takes 6-8 days for the tomato seed to germinate (Jones, 1999). Tomato plant takes 45-95 days to maturity under warm growing conditions depending on the stage of maturity when harvested.

Although some work has been done on tomatoes, the exact nutritional needs for different cultivars grown in South Africa remain undefined. Tomato seedlings are used to establish tomato fields in many areas. Seedling nutrition research is readily available on many vegetable crops. Generally higher N regimes were associated with more vigorous seedling growth (Melton & Dufault, 1991).

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Making accurate N fertilizer recommendations for high N demanding crops is becoming more important because of concern about NO_3^- pollution of surface and ground waters in agricultural areas. Tomato is the most important vegetable transplant grown and has been the transplant crop most targeted for mineral nutrition research (Vavrina *et al.*, 1998). Work on transplant fertilization began almost as early as transplant utilization itself. With the variety of commercially available synthetic fertilizers, more scientifically based and precise transplant nutrition studies were undertaken (Henderson, 1883; Tracy, 1908).

Several factors influence transplant production and performance. It is, therefore, important to note that few of these factors will act independently to influence transplant quality and performance. In fact, the transplant production process involves optimizing many factors that govern seedling production and establishment (Cantliffe, 1993). Review of other transplant production topics will be minimized, as this paper will be discussing mainly the nitrogen nutrition and its effect on transplant growth or performance and establishment up to the stage of transplanting.

There are several characteristics of water quality that can affect the quality of transplants through changes in the nutrient status and pH of the growing medium. Biernbaum & Bos Versluys (1998) used four major quality characteristics of irrigation water which are:

(i) Concentration of soluble salts,

(ii) Relative proportion of sodium to other cations (Sodium Adsorption Ratio = SAR),

(iii) Concentration of boron and other toxic elements, and

(iv) Bicarbonate (HCO_3^-) concentration that influences the SAR value.

1.2 TRANSPLANT NUTRITION

Dufault (1986) reported that application of N from 10 to 250 mg$\cdot L^{-1}$ increased shoot and root growth of muskmelon transplants. Increasing N resulted in increased shoot: root ratio showing that dry matter was allocated more to shoots than roots. P levels of 5 to 25 mg$\cdot L^{-1}$ increased root and shoot growth while 25 to 125 mg$\cdot L^{-1}$ reduced shoot variables

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and K increase from 10 to 250 mg· L^{-1} increased seedling height, leaf area and stem diameter. Nitrogen accounted for more differences in shoot fresh and dry weight, leaf area and root dry weight than P but seedling height and leaf number were more affected by P than N. When N interacted with P, positive growth was achieved although the interaction influence was not for all seedling growth variables. At 75 mg·L^{-1} and 225 mg·L^{-1} N, shoot fresh and dry weights, seedling height, leaf area and number increased linearly with increasing P.

Melton & Dufault (1991) tested the interaction of N, P and K on tomato transplant growth over two years and reported that N played a major role in seedling growth in both years. N contributed a large portion to variation in plant height, stem diameter, leaf area, leaf number, total chlorophyll, fresh shoot weight and dry shoot and root weight during the two years. The optimum amount of N was 225 ppm for tomato transplants.

On the other hand, Tremblay *et al.* (1987) reported that application of nitrogen at 350 mg· L^{-1} enhanced broccoli, lettuce, pepper and celery seedling growth but decreased root growth. However, increasing P from 5 to 250 mg·L^{-1} enhanced shoot growth without significantly changing root growth and K rates of 200 mg·L^{-1} produced higher broccoli and pepper shoot dry weights than 50 or 300 mg·L^{-1}. Production of quality tomato seedlings requires nutrient solutions containing a minimum of 225 mg·L^{-1} N and 45 mg·L^{-1} P, while K should be applied at minimal amounts of 25 mg·L^{-1} to sustain the crop as it had no significant significance on any seedling growth parameters.

1.3 Nitrogen

1.3.1 Nitrogen nutrition

Adequate moisture and plant nutrients are important for early plant growth. However, excess nitrogen will favour shoot growth at the expense of root growth (Tremblay *et al.*, 1987; Peirce, 1987; Masson *et al.*, 1991a). During seedling production it is important to supply enough N, P and K although the nutrient requirements differ among crops.

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According to Weston & Zandra (1989), tomato seedling growth increased with an application rate of up to 400 mg· L^{-1} N and 30 mg·L^{-1} P.

According to Masson *et al*. (1991a), high rates of N fertilization increased shoot growth more than root growth in tomato and lettuce, while supplementary light promoted a balance between shoot and root growth development and hence increased the percentage dry matter of the shoot. Masson et *al*. (1991b) further reported that the use of supplementary lighting (HPS) of 100 µmols^{-1}m^{-2} (PAR) on seedlings during transplant production promoted balanced growth. It also improved shoot and root weights of all species and could be used with high N fertilization for most of the species tested to obtain vigorous plants with acceptable levels of dry matter. N of 300 to 400 mg·L^{-1} gave optimum transplant growth under natural light, while 400 mg·L^{-1} was optimal when combined with supplementary light.

Adler et *al.* (1984) reported that asparagus seedling shoot and root weights increased as N increased from 100 to 200 mg·L^{-1} and P at 20 mg·L^{-1}. At low N levels no substantial amounts of starch accumulated in the shoots since sucrose exported to the roots was rapidly hydrolysed to support growth. N deficient seedlings were slower to recover even when sufficient N was applied after transplanting (Aloni *et al*., 1991).

Vavrina *et al*. (1998) found that 30-60 mg·L^{-1} N was sufficient for tomato transplant production in Florida while Masson *et al.* (1991) recommended 300-400 mg·L^{-1} N in tomato transplant production in Canada. These diverse nutrient N requirements of tomato seedlings can be attributed to differences in climatic conditions, which affect nutrient management practices in the greenhouse. Liptay *et al*. (1992) recommended that tomato seedlings be given between 100 to 200 mg·L^{-1} N while P levels as low as less than 2 mg·L^{-1} can affect growth and survival but higher levels do not appear to have negative impact on transplant performance, thus excess P is wasteful. Potassium can be varied with little effect on transplant performance.

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Vavrina *et al*. (1998) reported that lower N fertilizer rates of 20-30 $mg \cdot L^{-1}$ should be used for growing transplants for autumn production while for spring transplant fertlisation of 45-60 $mg \cdot L^{-1}$ N in Florida may affect yield of tomato in the North because air temperature and light conditions in Florida are more like those of autumn.

1.3.2 Nitrogen role in plants

Nitrogen is the essential element most frequently deficient in soils around the world. Most of the N in plants is in proteins, genetic material and chlorophyll. Nitrogen is a major essential nutrient element required by plants in substantial quantities and therefore its deficiency symptoms are common in crops (Tisdale *et al*., 1993, Mengel & Kirby; 2001). Plants take up nitrogen as NH_4^+ and NO_3^- from organic and inorganic sources (Pierce, 1987). It is the constituent of proteins and many metabolic intermediates involved in synthesis and energy transfer of nucleic acids.

Foliage plant producers often use different N sources such as urea ($CO(NH_2)_2$), ammonium sulphate (NH_4SO_4) or ammonium nitrate (NH_4NO_3), alone or in various combinations to supply crop nitrogen (N) requirements. Determination of best N form for foliage plant production should be made after considering several factors including cost, availability, plant response under various environmental conditions and ground water pollution potential. A number of experiments have been conducted to provide growers with information useful in making these fertilizer decisions. Another factor influencing choice of N form should be amount of nitrogen leached from containers. NH_4^+ carries a positive charge that helps make it more resistant to leaching than the negatively charged NO_3^-. However, nitrification converts NH_4^+ fairly rapidly to NO_3^- (Conover & Poole 1986). Santamaria *et al.* (1999), studied the swiss chard growth with three different levels of NH_4-N:NO_3-N, which is a very critical element in the composition of nutrient solutions to be used in soilless culture. In this study, swiss chard growth was inhibited by NH_4 nutrition and reached the highest values with the NH_4:NH_3 ratio 0:100 (Santamaria *et al.*, 1999)

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1.3.3 Nitrogen with light interaction

Nitrogen applied at 100 mg·L^{-1} reduced growth of all crop species. Nitrogen at 300 to 400 mg·L^{-1} gave optimum transplant growth under natural light. Four hundred mg·L^{-1} was optimal combined with supplementary light however, higher N application can have a negative effect on crop establishment in the field. In a study in which an interaction between 4, 8, 15, 30, 60 mM/l N and natural, natural + 4 hours and natural + 8 hours supplementary light was tested, Basoccu & Nicola (1995) reported that the root to shoot ratio peaked at lower N rates. Transplants grown under natural light with 8 to 15 mM/l N yielded highest and early yield but total yields were not affected by transplant nutrition with maximum obtained at 15 mM/l N. Also, there was no interaction between N and light on early yield.

1.3.4 Nitrogen and greenhouse seasonal variations

Environmental conditions differ across seasons and this could affect the response of transplants to nitrogen. Vavrina *et al*. (1998) found that there was an increase in shoot dry weight in fall as compared to spring at the same levels of N (Figure 1.1). In a study that was conducted to determine the impact of N fertilization on tomato transplant production and response to seasonal variation, Vavrina *et al*. (1998) reported that transplant fertilization should be based on production season (Table 1.1). For autumn, transplant fertilization of 20-30 mg·L^{-1} N should be used and for spring transplant fertilization of 45-60 mg·L^{-1} N could affect yield of tomato. Masson *et al*. (1991a), on the other hand recommended 300-400 mg·L^{-1} N and these diverse nutrient N requirements of tomato seedlings can be attributed to differences in climatic conditions which affect nutrient management practices in the greenhouse and ability to plant on time.

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Table 1.1 Effects of nitrogen application on tomato transplant characteristics for fall (F) and spring(S) seasons (Adapted from Vavrina *et al*., 1998)

Nitrogen ($mg \cdot L^{-1}$)		Tissue N ($mg \cdot g^{-1}$)	Stem length (cm)	Number of leaves	Leaf area (cm^2)	Dry mass		Root: Shoot ratio	Shoot dry mass/ Leaf area
						Shoot	Root		
0	F	14.3	3.8	2.0	2.8	0.03	0.01	0.46	0.0091
	S	9.0	4.1	2.0	3.9	0.03	0.02	0.49	0.0078
15	F	14.0	6.7	3.2	9.5	0.10	0.03	0.35	0.0100
	S	10.0	5.8	2.0	9.2	0.08	0.03	0.36	0.0082
30	F	14.1	10.2	3.9	18.1	0.17	0.05	0.30	0.0091
	S	11.0	7.9	2.5	14.9	0.11	0.04	0.33	0.0075
45	F	14.9	15.3	4.1	28.4	0.22	0.06	0.28	0.0077
	S	12.0	11.7	3.0	23.8	0.16	0.05	0.30	0.0067
60	F	17.1	21.6	4.5	38.2	0.27	0.07	0.24	0.0071
	S	14.0	14.4	3.2	31.3	0.20	0.06	0.29	0.0063
75	F	17.9	21.6	4.6	49.1	0.32	0.08	0.24	0.0066
	S	14.5	16.4	3.7	39.7	0.25	0.07	0.28	0.0062
sig.	F	NS	$L^{**}Q^{**}$	L^{**}	L^{**} $L^{**}Q^{**}$	L^{**}	L^{**}	L^{**} Q^{**}	L^{*} Q^{*}
	S	L^{**}	L^{**}		L^{**}	L^{**}	L^{**}	L^{**}	L^{*}

^{NS}, *, ** non-significant, linear (L), quadratic (Q) response at $p<0.05$ (*) or $p<0.01$(**) respectively

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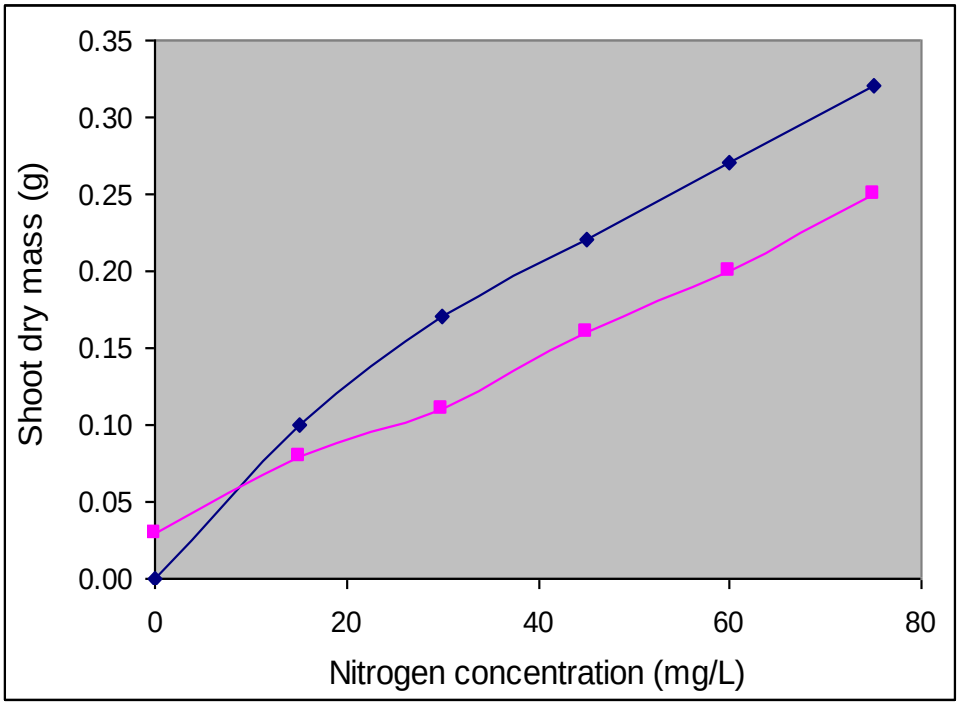

•, • autumn and spring respectively

Figure 1.1 Shoot dry mass (g) as affected by varying nitrogen concentrations applied during autumn and spring (Adapted from Vavrina *et al*., 1998).

Figure 1.1 clearly indicates the differences experienced due to seasonal variation in terms of shoot dry mass which were caused by temperature variations (Vavrina *et al*., 1998). Shoot dry mass recorded in spring was lower as than autumn values.

1.4 Interaction/complementary effect between nutrients

Adequate K concentration in the cytoplasm is needed to maintain metabolism of N in plants (Marschner, 1995). Potassium enhances utilization of NH_4^+ and reduces effects of NH_4^+ toxicities, such as stem lesions in tomato and leaf lesions in corn (Dibb & Thompson, 1985). The high absorption of NH_4^+ and K^+ with application of high rates of K shows a complimentary effect between K^+ and NH_4^+ uptake (Marschner, 1995). The effect of NH_4^+ - N in the nutrient medium on the utilization of K by sweet pepper plants depends on the concentration of both NH_4^+ - N and K. During fruit set and development, the rate of K uptake reduces with an increase in NH_4^+ - N concentration ($NH4^+$ - N > 0.9

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mM (15% of total N) but replacing 0.9 – 1.8 mM N of nitrate with NH_4^+ - N at constant total N of 6 mM stimulated the uptake of N, K and P and increased the total fruit yield in both spring – summer and autumn – winter seasons. The beneficial effect of NH_4^+ - N on sweet pepper was more significant at low K concentration (Xu *et al*., 2002).

Adler and Wicox (1995) reported that NH_4^+ – N appeared to decrease the tolerance of muskmelon to NaCl by both increasing rate of net Na influx and transport of Na to the leaf. Na influx and partitioning is controlled by mechanisms of K/Na selectivity and exchange across membranes. Therefore, NH_{4+} – N inhibiting K absorption may impair K/Na selectivity/exchange mechanisms.

1.5 Growing medium

Nutrient levels can be more accurately monitored in media characterised by minimal inherent nutrient value than in purchased and pre-packaged media containing pre-incorporated fertilizer materials (Dorais *et al.*, 2001). Low initial media fertility affords the grower the opportunity to develop a fertilization program targeted towards fulfilment of the nutrient requirements associated with the developmental stage of the species in production. Buffering capacity is the ability of the media to withstand rapid pH fluctuations. Selection of a container medium with as high buffering capacity as possible is, therefore, important to alleviate unexpected pH fluctuations.

Cation exchange capacity (CEC) quantifies the ability of media to provide a cationic nutrient reserve for plant uptake. It is the sum of exchangeable cations, or positively charged ions a media can adsorb per unit weight or volume (meq/100g) or (cmolc/kg). Media characterised by a high CEC retains nutrients from leaching during irrigation. In addition, it also provides a buffer against abrupt fluctuations in media salinity and pH (Mengel & Kirby, 2001).

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1.6 Electrical conductivity (EC) and growth

1.6.1 Dry matter partitioning

The economic value of tomato is determined by the product fresh weight and price, which may be strongly influenced by product quality. Product fresh weight is usually closely related to product dry weight. The fruit dry weight is determined by the total dry matter production and the fraction of dry matter distributed to the fruits (Bertin & Heuvelink, 1993).

It has been reported that increasing the total concentration of the nutrient solution decreased fresh yield of tomato, mainly by reducing fruit size (Li & Stanghellini, 2001). Many authors have confirmed that increased nutrient solution EC may reduce the growth rate of the whole plant and individual plant parts and can enhance ion accumulation. Increased EC may inhibit photosynthesis; thereby reducing growth (Picken *et al*., 1986; Li & Stanghellini, 2001; Schwarz & Klaring, 2002).

In contrast, some authors have reported a higher leaf net photosynthesis for tomato in response to elevated nutrient solution EC up to 18 $mS \cdot cm^{-1}$, particularly with $C0_2$ enrichment (Xu *et al*., 1995). Interactions with other experimental factors, such as carbon dioxide concentrations and nutrient solution composition makes it difficult to compare the results of different studies.

Water uptake and transpiration are distinct plant physiological processes. The balance between these processes controls and is controlled by plant water potentials, which in turn strongly affect the accumulation of water in growing tissue. At high salinity (low osmotic potential of the nutrient solution), the water potential of the plant will decrease and likewise, high transpiration will cause a decrease in water potential of the whole plant (Li & Stanghellini, 2001).

Tomato is considered to be a plant that is relatively resistant to salinity, although increase in the EC of the irrigation water has a negative effect on the vegetative growth and causes

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reduction in plant height. Plant biomass (fresh and dry weight of shoot and leaves) is the most widely used index in studies of salt tolerance in tomato (Olympios *et al*., 2003). Generally, 5 to 7.5% of the tomato content is dry matter with approximately 1% in the cuticle and seeds and 4 to 6% in soluble solids. Dry matter content in tomato fruit is inversely proportional to fruit size but positively related to total sugar content and soluble solids. It has also been reported that fruit size is inversely related to the EC of the nutrient solution while dry matter content of the fruit is linearly increased by the EC (Ho, 1999; Dorais *et al*., 2001).

There is general agreement that EC levels in the irrigation water applied at different stages of plant growth have a significant effect on fresh and dry weight of leaves and main shoot of greenhouse tomato plants (Shinohara *et al*., 1995; Olympios *et al*., 2003; Ho, 2004).

1.6.2 Root environment

Volume of the root system plays an important role in the uptake of nutrients and water in the root environment. The development of the root system can influence ion uptake and fruit quality (Dorais *et al*., 2001). For example, the absorption of potassium (K) takes place through the entire root system and its accumulation by a tomato fruit is mainly from the phloem sap, whereas calcium absorption occurs mainly in newly formed zones and moves almost exclusively through the xylem (Ho & Adams, 1995). Most plants respond to salinity with reduced growth whenever the concentration in the root environment exceeds a certain threshold value (Li *et al*., 2002).

A number of attempts have been made to adjust the EC in the root zone in order to overcome yield loss. Ho (2004) and Tabatabaie *et al*. (2004 b) recently suggested that the application of split-root system in glasshouse tomato production appeared to be promising in giving better fruit yield without the loss in yields. Split-root system means the application of high EC feed on one portion of the root while the other root portion is fed with low EC feed. In contrast, Bar Tal & Pressman (1996) reported that a restricted

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root system reduces plant growth, total yield, fruit size and potassium concentration in plant organs.

The findings of recent publications suggest that root environment condition determines water uptake rather than the root zone volume. The supply of nutrient solution with constant EC results in changes in solution EC in the root environment, because plant nutrients and water uptake is not in a constant ratio. These plant mediated changes in solution EC may lead to nutrient deficiency or salt accumulation in the root environment (Tabatabaie *et al*., 2004 a).

1.6.3 Shoot growth

Recent experiments have indicated that an increase in the EC of the irrigation water has a negative effect on the vegetative growth of tomato plants (Olympios, 2003). Number of leaves, leaf area index and plant height are some of the parameters that can be measured to determine plant growth. Most studies have confirmed that height and leaf area index is negatively affected by high EC, while the number of leaves slightly increased (Li & Stanghellini, 2001; Schwarz & Klaring, 2002; Olympios *et al.*, 2003; Tabatabaie *et al.*, 2004 a). The decrease in leaf area can be associated with leaf water status since the reduction in the leaf growth rate in high EC conditions is likely to be caused by reduced cell tugor (Tabatabaie *et al.*, 2004 a).

1.7 Influence of electrical conductivity on fruit quality

There is a growing public interest in bringing into the diet foods that can have a significant effect on body health. Therefore, the nutritional characteristics of tomato have also gained interest because consumers are becoming more health conscious. Tomato fruit enjoys a considerable attention since the red pigment (lycopene) is found in the fruit. The fruit also contains substantial quantities of vitamin A, ascorbic acid (vitamin C) and potassium (Jones, 1999; Dorais *et al*., 2001). The composition of tomato as reported from different sources is given in (Table 1.2).

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1.7.1 What is considered as good quality tomatoes?

Tomato fruit quality for fresh consumption as defined by Dorais *et al.* (2001) is determined by appearance (colour, size, shape, bruises, injuries, sunburn, foreign matter, dust, free from physiological disorders and decay), firmness, texture, dry matter, organoleptic (flavour) and nutraceutic (health benefit) properties. Organoleptic quality is mainly defined by its sugar and acid content, while nutraceutical quality is defined by mineral, vitamin, carotenoid and flavonoid contents.

Table 1.2 Composition of ripe tomato fruit per 100 g (Jones, 1999)

Constituents	**Amount**
Water	94 %
Fats	0.2 %
Protein	0.09 %
Carbohydrates	0.043 %
Fibre	0.08 %
Iron	0.05 %
Calcium	7 $mg \cdot kg^{-1}$
Phosphorus	23 $mg \cdot kg^{-1}$
Sodium	8 $mg \cdot kg^{-1}$
Potassium	207 $mg \cdot kg^{-1}$
Thiamine	0.6 $mg \cdot kg^{-1}$
Riboflavin	0.5 $mg \cdot kg^{-1}$
Niacin	0.6 $mg \cdot kg^{-1}$
Ascorbic acid (Vitamin C)	17.6 $mg \cdot kg^{-1}$
Vitamin B_6	0.5 $mg \cdot kg^{-1}$
Energy	19 KCal
Vitamin A	7600 (IU)

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1.7.2 Fruit quality attributes

The term quality implies the degree of excellence of a product or its suitability for a particular use. It is a term that is frequently used in post-harvest studies and it has different meanings for the different role players in the distribution network. Quality from a product perspective may differ from that of a consumer perspective (Abbott, 1999). The primary dividing line between differing concepts of quality is orientation. Most post-harvest researchers, producers and handlers are product-oriented in that quality is described by specific attributes of the fruit or vegetable. Consumers, marketers and economists are more likely to be consumer-oriented in that quality is described by consumer wants and needs (Abbott *et al*., 1999).

Most postharvest research (physiological as well as technological) assumes a product orientation to quality. Quality is defined as a series of attributes selected on the basis of accuracy and precision of measurement. Product-oriented quality is usually measured with analytical instruments and the data can be readily analysed with validity to any scientific study (Abbott *et al*., 1997). People use their senses (sight, smell, taste, touch and even hearing) to evaluate quality but instrumental measurements are preferred over sensory evaluations for research and commercial applications, because instruments reduce variations among individuals and can provide standardersed measures understood by researchers, industry and consumers.

1.7.3 Appearance

The appearance of fruits and vegetables is an important quality criterion because of its primary role in the evaluation of a product (Abbott, 1999). Visual assessment can be made on the basis of size, shape, colour, wilting and shriveling, absence of defects, cultivar properties, residues, damage by chemicals or gases, microbial infections and physiological abnormalities (Saure, 2001). Appearance is utilized throughout the distribution chain as the primary means of judging the quality of individual units of product.

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1.7.4 Size

Size is a criterion of quality that can be determined by circumference, diameter, length, width, volume or mass. Many fruits are graded according to size and there are certain size standards that are adhered to for certain products and may depend on the destination market and type of packaging. Largest fruit size generally indicates commercial over maturity and may not always be the best in terms of storage quality and edibility (Peet, 1992). Large fruits are much more susceptible to post-harvest physiological disorders, such as internal breakdown than small fruits. Size of individual units of a product can significantly affect consumer appeal, handling practices, storage potential, market selection and final use.

1.7.5 Shape

Shape is the general outline of the product and can be determined precisely using specific measurements. More often than not, shape is determined subjectively. It may be used in some instances to decide maturity. Shape is a criterion that distinguishes different fruits and individual cultivars (Tuzel *et al*., 2001). Little deviations in the characteristic shape (e.g. in the shape of 'Delicious' apple fruit grown under different climatic conditions) do not affect consumer choice, but large deviations are associated with poor quality and may influence purchasing decisions (Resh, 1993).

1.7.6 Titratable acidity

Titratable acidity (TA) can be determined by titrating a known volume of fruit juice with 0.1 N NaOH (sodium hydroxide) to an end point of pH = 8.2 as indicated by phenolphthalein indicator or by using a pH meter. Expressed as percent malic, citric or tartaric acid can be calculated as follows:

$$Z = \frac{V \times N \times mMol}{Y} \quad X100$$

Where:

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Z = % of Citric acid in sample

V =Volume in ml of NaOH titrated

m Mol wt = m mol of acid, which is 0.064 for citric acid

Y = Volume (ml) of samples titrated

N = normality of NaOH (0.1 N) in mMol c

The acid milliequivalent factor should be used for the predominant organic acid in the commodity. Firmness measurements may be useful for some fruit vegetables (melons, peppers) and even root vegetables (carrots, potato), but other measurements of texture are needed for stem and leafy tissues, such as asparagus or celery (force required for a blade to cut or shear). For lettuce, because of the variability of the structure of the leaves, it has been difficult to develop a standard assessment of crispness (Goud, 1983).

1.7.7 Soluble solids content (SSC) or %brix

The effect and sensitivity of using high levels of EC on greenhouse tomato varies according to the genotype, climate and the developmental stage of the plant. Several studies have shown that increasing the EC of the nutrient solution in tomato plants increases the internal and external fruit quality (Adams, 1991; Resh, 1993; Nichols *et al*., 1994; Dorais *et al.*, 2001*;* Tuzel *et al.*, 2001*;* Mpelasoka & Nichols, 2003; Olympios *et al*., 2003; Chretien *et al.*, 2004).

It has been noted that high values of EC in the root medium improve fruit quality such as total soluble solids (%), titratable acidity and dry matter content of the tomato fruit (Auerswald *et al*., 1999; Dorais *et al.*, 2001; Tuzel *et al.* 2001; Magan *et al*., 2004). However, pH shows a significant decreasing trend with increasing EC levels of nutrient solution. Sugars are the major soluble solid in fruit juice and therefore soluble solids can be used as an estimate of sugar content. Organic acids, phenolic compounds, and soluble pectins also contribute to soluble solids. Soluble solids content can be determined in a small sample of fruit juice using a refractometer.

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Total soluble solids increases with salinity and hence the use of moderately saline irrigation water is recommended to improve fruit quality. However, special care must be taken when using saline water in a commercial crop as from EC equal or greater than 2.0±2.5 dS/m, a 10% yield reduction per additional dS/m unit is expected (Saranga *et al*., 1991) as cited by Cuartero and Fernandez-Murioz (1999). Mizrahi *et al*. (1988) did not find a correlation between taste and TSS or sugars but tomatoes grown under saline conditions tasted better than tomatoes grown with fresh water and he concluded that flavour is not always a function of total sugars but could well be due to fruit constituents developed under salinity treatments (Figure 1.2).

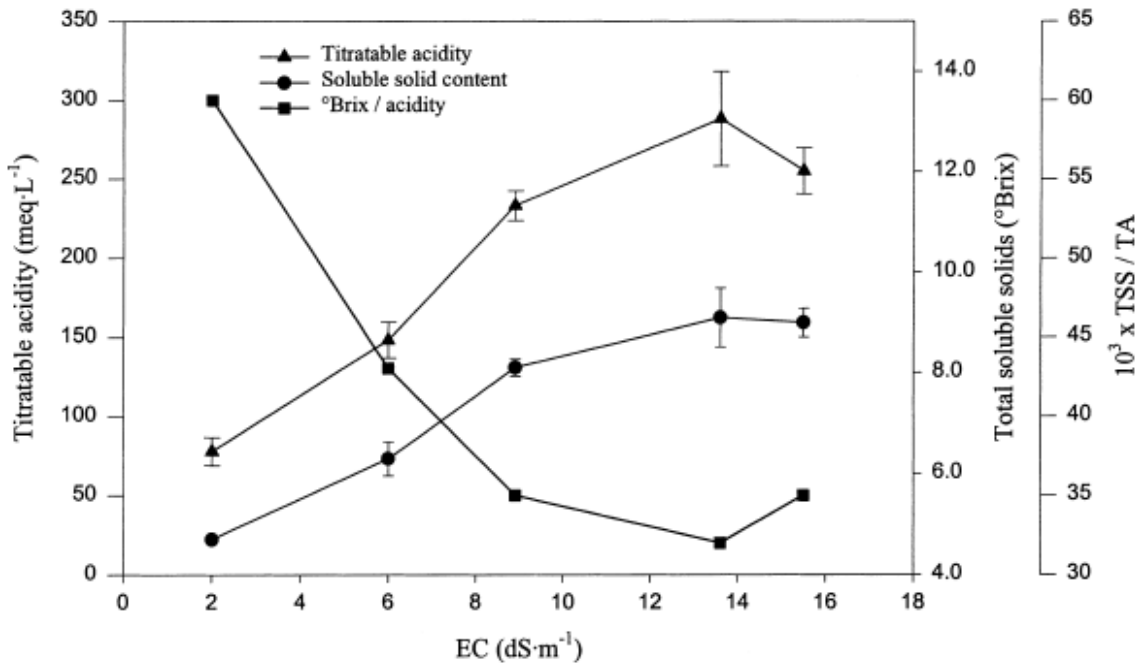

Figure 1.2 TSS, titratable acidity (TA) and relation between both parameters of vine riped fruits of `Daniela' cultivar grown at different salt concentrations in the substrate. (Adapted from Cuartero & Fernandez-Murioz, 1999)

1.7.8 Fruit flavour

The taste of tomato fruit is determined largely by the amount of solids, particularly sugars and organic acids and the volatile compounds composition (Furter, 2000). Some 95% of

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a typical ripe tomato fruit is water, so the fruit quality is therefore determined by a very small amount of solid matter. Sugars and acids do not only contribute to the sweetness and sourness of tomatoes, but are major factors influencing flavour intensity (Jones, 1999; Furter, 2000). For example, four classes are identified according to flavour intensity:

a. Good - high acidity and high sugar
b. Tart - high acidity and low sugar
c. Bland - low acidity and high sugar
d. Tasteless - low acidity and low sugar

It has been well documented that high EC levels have a positive effect on tomato fruit flavour since total soluble solids (TSS) and titratable acidity (TA) increase with increases in EC level (Petersen *et al*., 1998; Tuzel *et al*., 2001). Similar results were found by Adams (1991), Nichols *et al*. (1994) and Tuzel *et al*. (2001), though Dorais *et al*. (2001) found out that high EC result in too much stronger intensity of negative flavour attributes such as "mouldy", "bitter" and the after taste attributes such as mouldy and burning, which contribute to off-flavour. Therefore, increasing plant moisture stress does not only reduce yield by decreasing fruit size, but also has a positive effect in improving flavour mainly by increasing Brix (Nichols *et al*., 1994).

During the normal growth process of tomato fruit, a continuous increase in fructose and glucose concentrations occurs; sucrose concentration is kept low and even; starch accumulates to reach a maximum by 30-40 days after anthesis and is then dramatically reduced to almost zero in the ripe fruit (50-60 days after anthesis). The most striking difference between saline and non-saline conditions is the increased starch accumulation (Nichols *et al*., 1994) which the significance is still unclear.

1.7.9 Nutraceutical quality

Recently the nutritional and health aspects of tomato fruit and its products has been given a special attention since most of the epidemiological studies done had one of the highest

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increase correlations with cancer risk and cardiovascular disease including stroke (Jones, 1999 ; Dorais *et al*. 2001). Many protective compounds, such as antioxidants, potassium, organosulphides and folate have been identified. Most studies conducted in tomato have shown that there is positive correlation between vitamins and carotenoid and EC level (Lin & Glass, 1999).

1.8 EC influence on fruit physiological disorders

1.8.1 What is a fruit physiological disorder?

A fruit physiological disorder can be an external or internal blemish resulting from improper environmental or cultural conditions before and after harvest or a blemish without an obvious causal fungal, bacterial, viral or insect agent. Fruit physiological disorders can be in many forms depending on the causes (i.e. some are temperature-related disorders, freezing, chilling and high temperature injury); nutrition-related disorders (i.e. excess or deficiency of a specific nutrient elements), toxic chemicals and ethylene disorders are often caused by the lack of or excess of something that supports life or by the presence of something that interferes with life, and can affect plants in all stages of growth and development (Saure, 2001). It can be better explained as biological and or physiological factors causing defects, and mechanical damage (perturbment and physical wounding).

1.8.2 Disorders resembling nutrient deficiencies

Poor growth and a variety of symptoms, such as leaf discoloration and or deformities can be caused by lack of plant nutrients. This may be due to shortages of necessary nutrients, or because the nutrients are present but not available to the plant. Many factors including incorrect pH, shortages of water or an excess of another nutrient can cause this. There are a lot of disorders found in literature that are primarily caused by nutrient deficiencies. These include blossom-end rot (caused by calcium deficiency), puffiness and blotchy ripening (caused by excess nitrogen and little potassium) and fruit cracking.

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1.8.3 Blossom-end rot (BER)

Blossom-end rot is a common physiological disorder that occurs in the tomato fruit and may occur in all the tomato producing areas of the world. BER of tomato was first identified as a physiological disorder more than 100 years ago. BER has been shown to create up to 50% losses (Taylor & Locascio, 2004). Many researchers have noted the occurrence of BER in tomato as a function of calcium deficiency in the fruit or parts of the fruit in connection with the uptake of nutrients by the roots and the composition of the nutrient solution. However, a critical concentration of calcium in the fruit has not yet been found and the influence of favourable or unfavourable growing conditions on the development of BER is still poorly understood (Saure; 2001, Taylor & Locascio, 2004).

Calcium deficiency can be a consequence of water supply disturbances, excess salinity, or factors that inhibit transpiration. Due to substantially retarded xylem tissue development in the pedicel and within the fruit at high salinity, calcium transport is restricted and this causes BER in the fruit (Saure, 2001; Tuzel *et al.*, 2003). However, increase in calcium level in the nutrient solution promotes iron, copper and potassium uptake which in turn reduces levels of these nutrients due to competition, and that decrease carotene synthesis and lycopene (Paiva *et al*., 1998).

Increased incidence of BER at high salinity has frequently been confirmed and may be associated with reduced plant and fruit growth due to stress induced in the root zone such as water stress and antagonistic effect of some of the nutrient elements found in the feed solution like K and NH_4 ions (Saure, 2001). Most recent studies confirm that BER is usually not affected by one factor but high EC and nutrient activity ratios in the root zone plays a major role (Willumsen *et al*., 1996).

According to Adams and Ho (1992) and Tabatabaie *et al.* (2004 a), the number of fruit per plant affected by BER in relation to high EC of the nutrient solution increased. In recent years growers have used nutrient solutions with high EC to improve fruit quality. It has also been well documented that manipulation of nutrient solution is one of most

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important means of controlling fruit quality and yield. However, this practice can reduce fruit size and induce BER in tomato (Tabatabaie *et al*., 2004).

1.8.4 Description of BER

At the anatomical level, the earliest symptoms of BER are areas of white or brown locular tissue. Symptoms start to appear in the fruit placenta in the case of internal BER or in the pericarp in the case of external BER (Adams & Ho, 1992). Externally, the disorder begins as a small, water-soaked spot at or near the blossom scar of green tomatoes. As the spot enlarges, the affected tissue dries out and turns to be dark brown, gradually developing into well-defined, sunken, leafy spot (Willumsen *et al.*, 1996; Taylor & Locascio, 2004).

1.8.5 Causes of BER

It has long been known and confirmed by many researchers that BER occurrence in tomato fruits is a function of calcium (Ca) deficiency and or low water levels in the root zone (Saure, 2001). According to Adams & Ho (1993), the basic cause of BER is a lack of co-ordination between the transports of assimilates by the phloem and of Ca by xylem during rapid cell enlargement in the distal placenta tissue, i.e. an interaction between the rates of fruit growth and of Ca acquisition at the distal end of the fruit. Whilst changes in the environment have marked influence on the incidence of BER, genetic susceptibility is also a major cause of the disorder.

At the anatomical level, lack of Ca is the immediate cause of tissue breakdown or lack of tissue formation that leads to the development of the disorder. This lack of Ca can occur even when Ca is relatively abundant in the root zone, because it represents a localised deficiency in the distal blossom end and locular tissue of the fruit (Pill & Lambeth, 1980; Ehret & Ho, 1986; Minamide & Ho, 1993). According to Saure (2001) there are several reasons for low Ca concentration in the plant. Ca deficiency can be a consequence of water supply disturbances, oxidative stress, excess salinity; or factors that inhibit

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transpiration due to retarded xylem tissue development in the pedicel and within the fruit at high salinity Ca transport are restricted and this causes BER in the fruit. However, a critical concentration of Ca in the fruit has not yet been determined; conditions on the develpment of BER are still poorly understood (Taylor & Locascio, 2004).

1.8.6 Control

BER is not well understood and therefore control is still not always achievable in practice. However, the following general guidelines should be considered as per the recommendations by Adams (1999). Ensuring adequate supply of Ca in the root zone and guarding that concentrations of the competing cations like K^+, NH_4^+ and Mg^{2+} are not excessive in the nutrient solution since they replace Ca^{2+}. Secondly, water supply must be conducive to uptake, i.e. not too saline, flooded or otherwise restricted. Thirdly, water must go to the fruit, as opposed to the leaves, which means avoiding high daytime temperatures and low humidity. Therefore, misting and fogging inside the greenhouse should reduce BER incidence. Finally, cultivars always differ in their susceptibility. Once a fruit develops BER, it should be removed; otherwise these damage areas could serve as an entry point for disease-causing bacteria, fungi and insects.

1.8.7 Fruit cracking

Fruit cracking is a physiological disorder that causes considerable economic losses of up to 35% in both greenhouse and field-grown tomato (Peet & Willitis, 1995; Dorais *et al*., 2001). Data show that greenhouse fruit is more susceptible to fruit cracking losses. This is due to lack of resistance of most cultivars used at a later stage of harvesting when 30-60% of the fruit surface shows pink or red colour (Peet & Willitis, 1995).

There are different types of fruit cracking injury i.e. radial cracking (star shaped originating from the peduncle), concentric cracking (circular cracks originating from the peduncle and cuticle cracking, also known as russeting and the most commonly observed

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greenhouse fruit cracking (Dorais *et al*., 2001). Depending on the extent of this physiological disorder, fruit cracking can also reduce fruit appeal and shelf life, increase fruit susceptibility to pathogens and reduces fruit marketability (Peet, 1992).

According to Dorais *et al*. (2004) and Chretien *et al.* (2004) relatively high EC results in a smaller tomato size, thicker and more resistant cuticle and susceptibility to fruit cracking. Other factors such as an increase in fruit size and a high number of fruit per plant can exacerbate the problem of fruit cracking (Ehret *et al*., 1993). Increase in fruit size applies more physical stress against the epidermis and this leads to increasing susceptibility to fruit cracking. Peet & Willitis (1995) confirmed that a high number of fruit per plant increases the competition between fruit for carbohydrates, thus reducing the supply of sugars and water to each fruit and as a result fruit becomes susceptible to radial and cuticle cracking.

1.9 Effect of EC on tomato fruit yield

High number of fruits per plant increases the competition between fruits for carbohydrates, thus reducing the supply of sugars and water to each fruit. Tuzel *et al*. (2003) found that the differences in total yield is due to the reduction of fruit size caused by an increase of the EC levels in nutrient solutions. Huge losses can occur at a very high level of EC and Table 1.3 gives the relationship between EC and percentage yield that is lost (Jones, 1999).

Table 1.3 Relationship between electrical conductivity and percentage of yield loss (Jones, 1999)

Electrical conductivity (dS/m)	Yield (%)
1.7	0
2.3	10
3.4	25
5.0	50

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Total tomato production depends on the number of trusses per plant, number of flowers per truss, fruit set index and fruit weight. With respect to fruit set, Adams & Ho (1992) did not obtain a reduction with increasing salinity although reduction occurred on the upper trusses. In most of the studies conducted, the total number of fruits per plant is normally not affected because the fruit set index increases with salinity as confirmed by Tuzel *et al*. (2003) in Table 1.4.

Table 1.4 Total yield, fruit number and average fruit weight (Tuzel *et al*., 2003)

EC Treatments	Total yield	Fruit number	Av. fruit weight	BER
T2	13.63 a	154.60	85.16 a	3.93 c
T2+ T6	11.20 b	161.27	71.36 b	9.96 b
T6	9.81 c	161.62	60.62 c	13.56 a
LSD (0.05)	1.454	ns	5.023	2.854

In each column means followed by the same letter do not differ significantly. EC treatments: T2 = 2.0 dS/m (control), T6 = 6.0 dS/m and T2 + T6 = half day 2.0 and half day 6.0 dS/m

Salinity treatments affected total yield values significantly as the highest yield was obtained from the control treatment (T2). The difference in total yields was due to the reduction in fruit size with increasing EC levels in the nutrient solutions. Thus, the effect of EC levels was found to be significant on fruit size. BER incidence also increased with increasing EC levels.

The data in Table 1.4 confirm that salinity does affect tomato yield but tomato quality was improved in terms of total soluble solids. Although salinized tomato fruits were smaller than non-salinized control fruits, they had higher acidity, increased soluble solids and higher sugar content, which all are highly requested qualities by the processing tomato industry. Overall, the reduced yield of moderately salinized plants was compensated by enhanced quality of tomato fruits (Table 1.5).

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Table 1.5 Tomato yield and fruit characteristics in response to saline irrigation (Maggio *et al.*, 2004)

Salinity	Total yield			Marketable yield						
	Yield (t ha $^{-1}$)	Yield (fruit per plant)	Fruit mean weight (g)	Yield (t ha^{-1})	Yield (fruit per plant)	Fruit mean weight (g)	TSS (Brix)	EC (dSm^{-1})	Titrable acidity (% citric acid)	Fruit dry weight (% of fruit weight)
S0	51.3 a	18.9a	81.0a	43.7a	15.5a	84.3a	5.10c	4.37c	0.31c	5.0d
S1	49.0ab	19.2a	76.0a	41.7a	15.9a	78.3a	5.96c	5.24b	0.44b	5.9c
S2	46.7b	20.7a	67.3b	39.8ab	16.7a	71.0b	6.47b	5.57b	0.42b	6.5b
S3	24.7c	15.4b	47.7c	21.0b	11.2b	55.7c	8.39a	6.02a	0.49a	7.7a

S0: non-salinized control; S1: 0.25% salt; S2: 0.5% salt; S3:1,0% salt and TSS: total soluble solids. Different letters indicate significant differences at P = 0.05.

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CHAPTER 2
NITROGEN NUTRITION OF TOMATO TRANSPLANTS

2.1 Introduction

Vegetables can be either propagated by direct seeding or by transplants. Most of the vegetables produced in South Africa are propagated by means of transplanted seedlings, as climatic conditions are unpredictable. This makes the transplant production industry important in the country (Strydom, 1997). Direct seeded plants normally have a more balanced root, stem, leaf and fruit dry matter partitioning than transplants but overall, transplants give higher and earlier yield than direct seeded plants (Leskovar & Cantliffe, 1993). Nutritional practices play a major role in influencing vegetable transplant size and quality. Transplants grown in plug cells therefore require careful management of fertilizers since the cell volume is limited and seedling densities are high (Garton & Widders, 1990; Soundy *et al.*, 2001a). It is not usually feasible to supply sufficient concentrations of essential plant nutrient elements within media to sustain plant growth for a long period (Garton & Widders, 1990). Therefore, careful consideration must be given in supplying sufficient essential nutrients to support transplant growth.

To produce optimum yields of good quality tomatoes, often high amounts of nitrogen fertilizer are applied. In reality, the amount of fertilizer used is probably too high as farmers may apply more fertilizer than recommended to secure yields (Claassens, personal communication, 2004). The effect of nitrogen on transplant growth has been investigated in a number of vegetable crops. The production of transplants in plug trays has improved crop production but also brought a challenge to transplant producers. Transplants are grown in a small cell volume of for example 20 cm^3, which means reduced root zone. Therefore one needs precise nutrient and water management techniques (Biernbaum & Bos Versluys, 1998). Nitrogen is important in the formation of chlorophyll and is also a component of proteins. Deficiency of nitrogen causes slow, spindly growth and pale foliage resulting in low yields (Hadfield, 1995).

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Making accurate nitrogen fertilizer recommendations for high nitrogen demanding crops is becoming more important, because of a growing concern about NO_3 pollution of surface and ground waters in agricultural areas. Tomato is the most important vegetable transplant grown and has been the transplant crop most targeted for mineral nutrition research (Vavrina *et al.*, 1998). Transplant fertilization began almost as early as transplant utilization itself. With a variety of commercially available synthetic fertilizers, more scientifically based and precise transplant nutrition studies were undertaken. (Henderson, 1883; Tracy, 1908). To date, however, few specific recommendations concerning tomato transplant nutrition can be made due to the huge variation in recommendations and scientific approaches undertaken.

Customers want transplants that are appealing and of acceptable quality, but the contribution of these to yield, earliness and quality, uniform maturity, stand establishment remains the critical production factor (Dufault, 1998). This study aims at reviewing and characterizing information obtained from refereed journals in relation to nutritional and water management practices used in production of vegetable transplants. Based on this background, an experiment was conducted to determine the influence of nitrogen nutrition on tomato transplants and to determine the optimum level of nitrogen application required for the production of good quality tomato transplants. Ideal transplant are those that has a well-developed root system, good root to shoot ratio and could easily pull out of cavity trays without breaking.

2.2 Materials and methods

An experiment on tomato (*Lycopersicon esculentum* Mill.) transplants production was carried out in a glasshouse located at the University of Pretoria's Experimental Farm (25° 12'S, 28° 10'E). The study was set to run from mid-March 2005 to first week of May 2005. The plots were laid out in a complete randomized block design with four replications. Seedling trays were treated with chlorine solution and two to three tomato seeds of cultivar Roma VF (from Hygrotech) were sown in 200 inverted pyramid cavity trays that are commonly used in South Africa for seedling production. The trays were

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filled with Cultera growing medium and were covered with a thin layer of vermiculite (to cover the seeds after sowing). The growth medium had no added fertilizer.

The treatments used were 0, 30, 60, 90, 120 $mg \cdot L^{-1}$ N applied as ammonium nitrate (NH_4NO_3) while 30 $mg \cdot L^{-1}$ P applied as NaH_2PO_4 and 30 $mg \cdot L^{-1}$ K as KCl were used. Other nutrients like Ca, Mg, S, B, Mn, Mo, Cu and Zn were applied at half Hoagland solutions. Nutrient solutions were prepared in 150 L containers and were replaced weekly. Each treatment was replicated four times and each replication had 50 plants. Planting was done on 15 March 2005 and germination or plant emergence took exactly 5 days while overhead irrigation was applied until treatment application was initiated 5 to 6 days after emergence. Seedlings were thinned out to leave one plant per cell before the treatment application. Floatation irrigation was used where trays were floated in the nutrient solution intermittently until the field capacity was reached.

2.3 Sampling

Growth analysis was done by carefully sampling the representative seedlings. Five seedlings were pulled out from each treatment per replication at each sampling date. Plants were washed with tap water to remove soil and then divided into shoot and roots before measurements could be taken. Measurements taken were plant height, leaf area measured using a leaf area meter (model LI-3100, LI-COR, Lincolin, Nebraska), leaf count (number of expanded true leaves with clearly visible petiole), stem diameter, total chlorophyll measured using chlorophyll meter (SPAD 502, Minolta, Ramsey, N.J.), fresh and dry root mass and fresh and dry shoot mass was done weekly until the plants could pull out of the trays without breaking (ready for transplanting). Dry biomass of the separated samples was determined where all samples were oven-dried at 65^{o}C for at least 48 hours.

The experiment was terminated when at least one treatment across all replications could pull out of tray cells easily. At termination, five plants were sampled from each replicate and their pulling success recorded. Pulling success (%) was determined as the number of

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plants that could be pulled out from the cells/trays with ease and without breaking. Plant tissue analysis for N was also done using the Kjeldahl method.

Growth variables calculated were: (Dubik *et al*., 1992; Gardner *et al*., 1990; Nicola & Cantliffe, 1996):

Root to shoot ratio (RSR) = dry root mass ÷ dry shoot mass

Relative growth rate (RGR) = [ln final total dry mass – ln (initial total dry mass) ÷ (final time – initial time)]

Net assimilation rate (NAR) = (final total dry mass – initial total dry mass) ÷ (final time – initial time) × [(ln (final leaf area) – ln (initial leaf area)]

Specific leaf area (SLA) = leaf area ÷ dry shoot mass

Leaf area ratio (LAR) = leaf area ÷ total dry mass

Root mass ratio (RMR) = dry root mass ÷ total dry mass)

Pulling Success (PLS) = Number of transplants that can easily pull out of trays without breaking)

Statistical analysis

Collected data was subjected to analysis of variance using the Statistical Analysis System (SAS Institute Inc., 2003). Treatment sums of squares were partitioned into linear and quadratic polynomial contrasts. Significant differences were taken at $P \leq 0.05$ and 0.01.

2.4 Results and discussion

2.4.1Fresh and dry shoot mass

Increasing nitrogen application from 0 to 120 $mg \cdot L^{-1}$ increased fresh shoot mass in a quadratic fashion regardless of the sampling date (Table 2.1). At 21, 28, 35 and 42 days after sowing, fresh shoot mass increased from 31 to 705 mg, 74 to 1370 mg, 92 to 2200 mg and 136 to 3025 mg for transplants that were propagated with 0 to 120 $mg \cdot L^{-1}$ N, respectively. The greatest average fresh shoot mass was achieved at a nitrogen application rate of 120 $mg \cdot L^{-1}$, regardless of the sampling date while the least average fresh shoot mass was observed at 0 $mg \cdot L^{-1}$. Vavrina *et al.* (1998) discovered that at low N

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levels (0 and 30 mg·L^{-1}), no substantial amounts of starch accumulated in the shoots since sucrose exported to the roots was rapidly hydrolysed to support growth. Adler *et al.* (1984) also reported an increased shoot and root mass as N increased from 100 to 200 mg·L^{-1} on asparagus seedlings.

Dry shoot mass increased in a quadratic fashion in response to increased nitrogen application regardless of the sampling date. At 21 days after sowing, dry shoot mass were 6, 39, 57, 64 and 65 mg for transplants that were propagated at 0, 30, 60, 90 and 120 mg·L^{-1} N respectively (Table 2.1). Increasing nitrogen application from 0 to 120 mg·L^{-1} also increased dry shoot mass from 8 to 122 mg, 11 to 239 mg and 14 to 302 mg for transplants grown to 28, 35 and 42 days after sowing respectively. This response pattern is not in agreement with the results that were found by Semuli (2005) on cabbage transplants where increased nitrogen reported to have increased dry shoot mass in a linear fashion. Studies conducted by Soundy (1996) on lettuce confirmed the relative increase in shoot mass as the nitrogen application was increased from 0 to 120 mg·L^{-1}.

Transplants that did not receive nitrogen at propagation were stunted, with few leaves that were purplish to pale reddish in colour and small (Figure 2.1). The number of leaves as observed by Melton & Dufault (1991) increased in tomato as nitrogen was increased from 25 to 225 mg·L^{-1} during both years of the study. Leaf count has a direct positive correlation with fresh and dry shoot mass development since the level of nitrogen supplied affects carbohydrates utilization.

A (Unwashed) **B (Washed)**

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Figure 2.1 Shoots and roots development of tomato transplants at 35 days after sowing

2.4.2 Fresh and dry root mass

Fresh root mass increased in a quadratic fashion in response to increased nitrogen application regardless of the sampling date. At 21 days after sowing, fresh root mass was 30, 163, 322, 458 and 428 mg for transplants that were propagated at 0, 30, 60, 90 and 120 mg·L^{-1} N respectively (Table 2.1). Increasing nitrogen application from 0 to 120 mg·L^{-1} also increased fresh root mass from 52 to 229 mg, 76 to 320 mg and 164 to 592 mg for transplants grown to 28, 35 and 42 days after sowing respectively. The optimum fresh root mass was recorded from transplants that were propagated with 90 mg·L^{-1} and decreased as nitrogen increased to 120 mg·L^{-1} irrespective of the sampling date.

These results indicates that a good quality transplant was recorded at 90 mg·L^{-1} N since a well-developed root system was found there and conforms to the requirements of quality transplant as cited on literature. However, a detailed conclusive evidence is summarized on root to shoot ratio as one of the important parameter. Root development is an important factor when it comes to transplant development in field condition. More (2006) reported a relative increase in fresh root mass when nitrogen increased from 0 to 120 mg·L^{-1} on cabbage transplants. Masson *et al*. (1991 a) confirmed that high rates of N fertilization increased shoot growth more than root growth in tomato and lettuce.

Dry root mass increased quadratically to increased nitrogen application regardless of sampling date (Table 2.1). Increasing nitrogen rates from 0 to 120 mg·L^{-1} increased dry root mass from 3 to 14 mg, 4 to 33 mg, 5 to 39 mg and 6 to 48 mg for transplants grown to 21, 28, 35 and 42 days after sowing. At 35 and 42 days after sowing, dry root mass started to drop with an increase in nitrogen application to 120 mg·L^{-1}. Tremblay *et al.* (1987) reported that application of nitrogen at 350 mg·L^{-1} enhanced broccoli, lettuce, pepper and celery seedling growth but decreased root growth.

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Table 2.1 Root and shoot characteristics of tomato transplants as affected by N nutrition

Nitrogen applied ($mg \cdot L^{-1}$)	Fresh shoot mass (mg)	Dry shoot mass (mg)	Fresh root mass (mg)	Dry root mass (mg)
21 days after sowing (1st sampling)				
0	31	6.0	30	2.5
30	242	38.8	163	5.0
60	428	57.0	322	8.3
90	613	63.5	458	10.8
120	705	64.8	428	13.5
Response	Q**	Q**	Q**	Q**
28 days after sowing (2nd sampling)				
0	74	8.0	52	4.3
30	478	49.2	137	16.8
60	892	88.0	224	25.2
90	1256	114.3	252	32.5
120	1370	122.0	229	33.0
Response	Q**	Q**	Q**	Q**
35 days after sowing (3rd sampling)				
0	92	11.4	76	5.3
30	845	106.1	208	23.9
60	1637	179.4	349	37.3
90	2067	217.5	360	42.1
120	2200	238.5	320	38.7
Response	Q**	Q**	Q**	Q**
42 days after sowing (4th sampling)				
0	136	14.1	164	6.1
30	1056	121.6	365	27.9
60	2278	263.3	526	45.5
90	2882	305.5	605	47.4
120	3025	301.9	592	48.0
Response	Q*	Q**	Q**	Q**

Linear (L) or quadratic (Q) effects significant at P = 0.05 (*) or 0.01 (**) or nonsignificant (NS)

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2.4.3 Plant height

Transplant height increased in a linear fashion with increasing nitrogen application at 21 days after sowing. At 28, 35 and 42 days after sowing, plant height increased quadratically as nitrogen application increased (Table 2.2). For samples taken at 21 days after sowing, plant height was 5, 11, 15, 17 and 18 mm for transplants that were propagated with 0, 30, 60, 90 and 120 $mg \cdot L^{-1}$ N, respectively. When nitrogen increased from 0 to 120 $mg \cdot L^{-1}$, plant height also increased from 6 to 24 mm, 7 to 29 mm and 8 to 32 mm for transplants sampled at 28, 35 and 42 days after sowing, respectively. Similar results were also found by Melton & Dufault (1991) where they reported a positive correlation between the increase in transplant height and an increase in nitrogen rate from 25 to 225 $mg \cdot L^{-1}$.

2.4.4 Root: shoot ratio

Root: shoot ratio decreased in a linear fashion in response to increasing nitrogen rate applied regardless of the sampling date (Table 2.2). Transplants that did not receive nitrogen (0 $mg \cdot L^{-1}$) had the highest root: shoot ratio across the sampling dates. Increasing nitrogen from 0 to 120 $mg \cdot L^{-1}$ decreased root: shoot ratio from 0.41 to 0.21, 0.65 to 0.27, 0.49 to 0.16 and 0.46 to 0.16 for transplants grown to 21, 28, 35 and 42 days after sowing, respectively.

The decrease pattern in response to nitrogen application in root: shoot ratio suggests that more growth occurred in shoots than in the roots. Leskovar (1997) suggested that large root: shoot ratios are desirable to avoid transplant shock since large root systems are resistant to shock. The results in Table 2.2 concur with the study that was conducted by Soundy (1996) where root: shoot ratios of lettuce transplants were reported to have decreased as nitrogen was increased from 0 to 60 $mg \cdot L^{-1}$. When drought stress and root pruning methods were used to harden and prevent stem elongation in fresh market tomato transplants grown with floatation irrigation, there was an increase in lateral root

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elongation and a decrease in shoot: root ratio, but dry matter partitioning, leaf enlargement and total plant size were severely affected (Leskovar *et al.*, 1994). The results on the current experiment showed that the optimum root: shoot ratio was recorded at 60 $mg \cdot L^{-1}$ N and the trend started to be constant with the increasing nitrogen levels. This can be recommended based on the conditions and application frequency used in this experiment. Further studies would still need to be conducted to qualify these results in a field condition and to see if any developments on transplant establishment and shock would still concur with the prescribed nitrogen rates.

2.4.5 Leaf mass ratio

Leaf mass ratio increased in a quadratic fashion to applied nitrogen from 0 to 120 $mg \cdot L^{-1}$ regardless of the sampling date (Table 2.2). Increasing nitrogen from 0 to 120 $mg \cdot L^{-1}$ increased leaf mass ratio from 0.71 to 0.83, 0.61 to 0.79, 0.67 to 0.86 and 0.69 to 0.86 for transplants sampled at 21, 28, 35 and 42 days after sowing, respectively. This confirms the results from other studies that enough water and fertilizer are important for early growth. However excess nitrogen favour shoot growth at the expense of root growth (Tremblay *et al.*, 1987; Peirce, 1987; Masson *et al.*, 1991 b).

Leaf mass ratio expresses how leafy a plant is based on the dry mass; therefore the productive investment of the plant can be measured (Picken *et al.*, 1986; Li *et al.*, 2001; Tabatabaie *et al.*, 2004). The observation from this experiment suggests that the productive investment was low at 0 $mg \cdot L^{-1}$ N and higher in transplants grown with 120 $mg \cdot L^{-1}$ N.

2.4.6 Root mass ratio

Root mass ratio decreased in a quadratic fashion to applied nitrogen regardless of the sampling date (Table 2.2). Increasing nitrogen application from 0 to 120 $mg \cdot L^{-1}$ decreased root mass ratio from 0.29 to 0.17, 0.39 to 0.21, 0.33 to 0.14 and 0.31 to 0.13 for transplants sampled at 21, 28, 35 and 42 days after sowing, respectively. Similar

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results were reported by Tremblay *et al.* (1987), they found that application of N at 350 $mg \cdot L^{-1}$ enhanced broccoli, lettuce, pepper and celery seedling growth but decreased root growth. Root development is a dynamic process responding to several stress stimuli, probably as an adaptive mechanism.

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Table 2.2 Root and shoot characteristics of tomato transplants as affected by N nutrition

Nitrogen applied ($mg \cdot L^{-1}$)	Plant height (mm)	Root : shoot ratio	Leaf mass Ratio	Root mass ratio	Plant chlorophyll content	Pulling success (%)
21 Days after sowing						
0	5.04	0.41	0.71	0.29	16.39	
30	11.07	0.13	0.89	0.11	26.16	
60	14.93	0.15	0.87	0.13	28.12	
90	17.30	0.17	0.86	0.14	29.68	
120	17.87	0.21	0.83	0.17	31.58	
Response	Q**	Q**	Q**	Q**	Q**	
28 Days after sowing						
0	6.38	0.65	0.61	0.39	22.36	
30	15.02	0.34	0.74	0.26	28.91	
60	21.02	2.29	0.78	0.22	29.37	
90	24.21	0.28	0.79	0.22	30.97	
120	23.85	0.27	0.79	0.21	32.61	
Response	Q**	Q**	Q**	Q**	L**	
35 Days after sowing						
0	7.14	0.49	0.67	0.33	24.34	
30	21.00	0.22	0.82	0.18	31.52	
60	27.56	0.21	0.83	0.17	31.13	
90	29.09	0.19	0.84	0.16	32.03	
120	29.12	0.16	0.86	0.14	32.59	
Response	Q**	Q**	Q**	Q**	Q**	
42 Days after sowing						
0	7.96	0.46	0.69	0.31	23.54	10
30	23.8	0.23	0.81	0.19	30.63	60
60	29.82	0.17	0.85	0.15	32.41	90
90	33.93	0.16	0.86	0.13	33.30	100
120	32.11	0.16	0.86	0.13	30.06	95
Response	Q*	Q**	Q**	Q**	Q**	Q**

Linear (L) or quadratic (Q) effects significant at P = 0.05 (*) or 0.01 (**)

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2.4.7 Plant chlorophyll content

Plant chlorophyll content increased in a quadratic fashion to applied nitrogen regardless of the sampling dates. It must be noted that chlorophyll content is a nitrogen function and therefore the chlorophyll content will increase in response to increased nitrogen. Most of the N in plants is in proteins, genetic material and chlorophyll (Mengel & Kirby, 2001; Tisdale *et al*., 1993). In Table 2.2, changing nitrogen fertilization from 0 to 120 $mg \cdot L^{-1}$ increased the plant chlorophyll content from 16.4 to 31.6, 22.4 to 32.6, 24.3 to 32.6 and 23.5 to 30.1 for transplants sampled at 21, 28, 35 and 42 days after sowing respectively.

2.4.8 Pulling success

Raising nitrogen application rates increased the pulling success in a quadratic fashion as compared to treatments that received lower application rates (Table 2.2)**.** Increasing nitrogen application from 0 to 90 $mg \cdot L^{-1}$ improved the pulling success from 10% to 100% while at 120 $mg \cdot L^{-1}$, pulling success was reduced to 95%. The results of this experiment further indicates that as nitrogen rate increases, more assimilates are partitioned to shoot development compromising root development, which makes pulling success difficult. However, studies conducted by Soundy (1996) on lettuce transplants indicated that transplants could not be pulled easily from the transplant trays regardless of the nitrogen treatment level used. This was probably because N to only a maximum of 60 $mg \cdot L^{-1}$ was used. In this case one can conclude that if transplants cannot be pulled out of the cavity trays easily, root injuries occur during transplanting and plants establishment in the field may take longer. However, if one compares the advantages of optimum fresh root mass and good root: shoot ratio that was recorded at 60 $mg \cdot L^{-1}$ N versus the 100% pulling success recorded at 90 $mg \cdot L^{-1}$ N in the field conditions, it would be cost effective for a farmer to focus on transplants that would establish quicker than those that cannot be damaged easily but with poor root development. Unfortunately for the purpose of this experiment, there were no further analysis done in field conditions.

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2.4.9 Relative growth rate

Relative growth rate as defined by Gardner *et al.* (1990) is an increase in size of a plant per unit interval of time which can be expressed as dry mass gain over a given time interval in relation to the initial mass. The results of this experiment show that there was more dry mass accumulation in transplants grown to 28 days after sowing as compared to transplants grown to 35 and 42 days after sowing. The relative growth rate of transplants grown to 28 days after sowing increased in a linear fashion in response to increasing nitrogen and increased in a quadratic fashion for transplants grown to 35 and 42 days after sowing.

For transplants grown to 28 days after sowing, relative growth rate was 0.4, 0.47, 0.55, 0.68 and 0.68 $mg \cdot mg^{-1} \cdot wk^{-1}$ for transplants that were propagated at 0, 30, 60, 90 and 120 $mg \cdot L^{-1}$ N, respectively (Table 2.3). With transplants grown to 35 and 42 days after sowing, relative growth rate increased from 0.17 to 0.63 $mg \cdot mg^{-1} \cdot wk^{-1}$ and 0.19 to 0.36 $\cdot mg \cdot mg^{-1} \cdot wk^{-1}$ respectively as nitrogen was increased from 0 to 60 $mg \cdot L^{-1}$ and beyond which it decreased. Soundy (1996) reported an increase in relative growth rate as a function of increasing nitrogen application in lettuce whereas the results from this experiment indicates the optimum nitrogen application level to be at 60 $mg \cdot L^{-1}$ for transplants grown to 35 and 42 days after sowing.

2.4.10 Net assimilation rate

Gardner *et al.* (1990) and Mengel & Kirby (2001) defined net assimilation rate as the net gain of assimilates in mass per unit leaf area and time, which is also a measure of the amount of photosynthetic product going into plant material. The results of the experiment in Table 2.3 indicates that the greatest net assimilation rate was achieved in transplants grown to 28 days after sowing and as the transplants grew older to 42 days after sowing, the production efficiency declined, which is an indicator that the rate of leaf expansion was not directly proportional to dry matter accumulated.

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Net assimilation rate increased in a quadratic fashion in response to applied nitrogen for transplants grown to 28 days after sowing. With transplants grown to 28 and 35 days after sowing, net assimilation rate increased from 0.036 to 0.078 $mg \cdot cm^{-2} \cdot wk^{-1}$ and 0.015 to 0.046 $mg \cdot cm^{-2} \cdot wk^{-1}$ respectively as nitrogen was increased from 0 to 30 $mg \cdot L^{-1}$ and beyond which it decreased. All transplants that received 120 $mg \cdot L^{-1}$ N showed a reduced net assimilation rate as compared to other treatment levels with the exception of transplants that were sampled at 28 days after sowing, which is an indication that production efficiency declined as transplants grew older. Soundy *et al.* (2001b) reported greater net assimilation rate values in lettuce transplants grown with 60 $mg \cdot L^{-1}$ N as compared to transplants that received 100 $mg \cdot L^{-1}$ N.

2.4.11 Specific leaf area

There was a linear increase in specific leaf area to applied nitrogen at 28, 35 and 42 days after sowing whereas it increased in quadratic fashion on transplants sampled at 21 days after sowing (Table 2.3). Increasing nitrogen from 0 to 120 $mg \cdot L^{-1}$ increased specific leaf area from 180 to 283 $cm^2 \cdot mg^{-1}$, 105 to 230 $cm^2 \cdot mg^{-1}$ and 80 to 218 $cm^2 \cdot mg^{-1}$ for transplants sampled at 28, 35 and 42 days after sowing, respectively. The highest specific leaf area was recorded from transplants that received 120 $mg \cdot L^{-1}$ N with the lowest specific leaf area recorded from transplants that were sown at 0 $mg \cdot L^{-1}$ N, regardless of the sampling date.

Temblay & Senécal (1988) reported an increase in specific leaf area in broccoli and pepper transplants at 350 $mg \cdot L^{-1}$ N rates as compared to 150 $mg \cdot L^{-1}$ N application. Similar studies conducted by Vavrina *et al.* (1998) indicated a linear increase in specific leaf area of tomato transplants planted during the spring season when 45-60 $mg \cdot L^{-1}$ N was applied.

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Table 2.3 Influence of N nutrition on growth characteristics of tomato transplants.

Nitrogen applied ($mg \cdot L^{-1}$)	Relative growth Rate ($mg \cdot mg^{-1} \cdot wk^{-1}$)	Net assimilation rate ($mg \cdot cm^{-2} \cdot wk^{-1}$)	Specific leaf area ($cm^2 \cdot mg^{-1}$)	Leaf area ratio ($cm^2 \cdot mg^{-1}$)	Leaf area (cm^2)	Leaf tissue N %
21 Days after sowing						
0			88.08	62.39	5.14	
30			61.17	54.27	23.26	
60			97.78	84.99	54.89	
90			109.00	93.34	69.21	
120			121.78	100.71	78.90	
Response			Q**	L**	L**	
28 Days after sowing						
0	0.4	0.036	180.36	168.62	18.71	
30	0.47	0.078	220.90	164.36	108.6	
60	0.55	0.049	230.31	179.02	201.93	
90	0.68	0.043	270.32	210.19	307.96	
120	0.68	0.038	282.88	222.38	344.14	
Response	L**	Q**	L**	L**	L**	
35 Days after sowing						
0	0.17	0.015	105.06	136.05	21.54	
30	0.71	0.046	147.08	119.93	155.16	
60	0.73	0.024	201.96	167.37	361.39	
90	0.59	0.015	218.84	183.29	474.59	
120	0.6	0.013	229.58	197.67	545.29	
Response	Q**	Q**	L**	L**	L**	
42 Days after sowing						
0	0.19	0.0085	80.30	123.79	23.85	0.14
30	0.16	0.0011	144.60	117.88	174.81	0.21
60	0.36	0.0012	163.36	139.3	429.73	0.25
90	0.31	0.0006	193.73	167.72	593.72	0.32
120	0.29	0.0004	218.31	188.33	658.30	0.38
Response	Q*	Q**	L**	L**	L**	L**

Linear (L) or quadratic (Q) or nonsignificant (NS) effects significant at $P \leq 0.05$ (*) or 0.01 (**)

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2.4.12 Leaf area ratio

Leaf area ratio increased in a linear fashion to applied nitrogen regardless of sampling date (Table 2.3). As described by Gardner *et al.* (1990), leaf area ratio is a measure of the proportion of the plant that is engaged in photosynthesis which expresses the ratio between the photosynthesizing tissue and the total respiring plant tissues. Increasing nitrogen application from 0 to 120 $mg \cdot L^{-1}$ increased leaf area ratio from 62 to 101 $cm^2 \cdot mg^{-1}$, 169 to 222 $cm^2 \cdot mg^{-1}$, 136 to 198 $cm^2 \cdot mg^{-1}$ and 124 to 188 $cm^2 \cdot mg^{-1}$ for transplants sampled at 21, 28, 35 and 42 days after sowing respectively. A lower value of leaf area ratio reflects the reduction of leafiness in a plant and assimilates production thereof. The result of this experiment reflects that transplants grown with 0 $mg \cdot L^{-1}$ N had reduced leafiness as a result of nitrogen deficiency which in turn influenced assimilate production.

2.4.13 Leaf area

There was a linear increase in leaf area to applied nitrogen irrespective of the sampling date. Increasing nitrogen rates from 0 to 120 $mg \cdot L^{-1}$increased leaf area from 5 to 79 cm^2, 19 to 344 cm^2, 22 to 545 cm^2 and 24 to 658 cm^2 for transplants grown to 21, 28, 35 and 42 days after sowing, respectively. The lowest value for leaf area was obtained from 0 $mg \cdot L^{-1}$ N application while the greatest value was recorded at the 120 $mg \cdot L^{-1}$ N applications across sampling dates. Soundy (1996) reported a similar trend in the experiment with lettuce transplants where leaf area increased with an increase in nitrogen rate from 0 to 60 $mg \cdot L^{-1}$.

2.4.14 Leaf tissue nitrogen

Nitrogen is important in the formation of chlorophyll and is also a component of proteins. Deficiency of nitrogen causes slow, spindly growth and pale foliage resulting in limited production (Hadfield, 1995). The nitrogen content in the transplant tissues increased with an increase in the concentration of nitrogen in the nutrient solution. Leaf tissue nitrogen

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was 0.14, 0.21, 0.25, 0.32 and 0.38 % for transplants that were propagated with 0, 30, 60, 90 and 120 mg·L^{-1} N respectively (Table 3.3). The amount of nitrogen levels applied during transplant production significantly affected the leaf tissue nitrogen. These results corresponds to that found by Soundy *et al.* (2001a) where higher leaf tissue nitrogen values were recorded in lettuce transplants grown with 100 mg·L^{-1} N as compared to those grown with 60 mg·L^{-1} N. Other studies by Semuli (2005) on cabbage transplants reported a similar trend where increasing nitrogen from 0 to 120 mg·L^{-1} increased the leaf tissue nitrogen from 1.18 to 3.75%.

2.5 CONCLUSIONS

Nitrogen fertilization had a pronounced effect on transplant root and shoot growth. Throughout the experiment, increased nitrogen application favoured shoot growth which is an indication that most assimilates were partitioned to shoots than roots (e.g. leaf mass ratio of 0.86 and root mass ratio of 0.13). Root: shoot ratio, net assimilation ratio and root mass ratio decreased in a quadratic fashion when the nitrogen application was increased from 0 to 120 mg·L^{-1}. Considering all the sampling dates, the root: shoot ratio indicated an optimum of 60 mg·L^{-1} N, which afterward was gradually decreasing with increased nitrogen levels. This nitrogen rate can be recommended based on the conditions and application frequency used in this experiment. On the other hand, the pulling success was recorded at 90 mg·L^{-} N, similar to fresh root mass which is also an important parameter in determining a good quality transplant. It should be noted that these conclusions are specifically based on the conditions and application frequencies used in this experiment. Therefore it would be interesting to find out how will these transplants respond to a field condition since that would be an important aspect for consideration for a grower. More studies would need to be conducted to evaluate the transplants establishment focusing on 60 mg·L^{-1} N and 90 mg·L^{-} N as means to determine the optimum levels.

Results from this experiment indicates that greatest net assimilation rate was achieved in transplants grown to 28 days after sowing and as the transplants grew older to 42 days after sowing, the production efficiency declined, which is an indicator that the rate of leaf

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expansion was not directly proportional to dry matter accumulated. There was a quadratic increase in leaf area to applied nitrogen irrespective of the sampling date. Leaf area also showed an increase as transplants grew older across the treatments. The nitrogen content in the transplant tissues increased with increased nitrogen concentration.

2.6 SUMMARY

A greenhouse experiment was conducted in autumn to characterize and optimise the N nutrition used to grow tomato transplants. Tomato transplants were propagated with 0, 30, 60, 90 and 120 $mg \cdot L^{-1}$ N. Fertigation was done by floating cavity trays in nutrient solutions until the medium reached field capacity and that was done on daily basis. The experiment was arranged in a randomized complete block design (RCBD) with four replication. Sampling was initiated at 21 days after sowing and was done weekly until the transplants were ready for transplanting (when transplants could pull out of the cavity trays easily without breaking) at 42 days after sowing.

Nitrogen application had pronounced effect on transplant growth in relation to root and shoot growth. Results throughout the experiment indicated that increased nitrogen application favoured shoot growth which was an indication that most assimilates were partitioned to shoots than roots. Transplants that did not receive nitrogen (0 $mg \cdot L^{-1}$ N) had lower or reduced plant height, plant chlorophyll content, pulling success, relative growth rate, net assimilation rate, specific leaf area and leaf area. The overall vegetative growth was reduced. Root: shoot ratio and root mass ratio response showed a decreasing trend when nitrogen concentration applied was increased.

Nitrogen application of 120 $mg \cdot L^{-1}$ increased fresh shoot mass and subsequently enhanced dry shoot mass. As nitrogen was increased from 0 to 120 $mg \cdot L^{-1}$, it promoted relative growth rate, specific leaf area, leaf mass ratio, leaf area ratio, plant chlorophyll content, leaf tissue nitrogen and improved pulling success. At 42 days after sowing, a quality transplant with a good root development, fresh root mass, root: ratio and pulling

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success was produced at 90 $mg \cdot L^{-1}$ N, which had a root to shoot ratio of 0.16, leaf mass ratio of 0.86, root mass ratio of 0.13, leaf area of 594 cm^2, plant chlorophyll content of 33, leaf tissue nitrogen of 32 $g \cdot kg^{-1}$, specific leaf area of 194 of $cm^2 \cdot mg^{-1}$, leaf area ratio of 167.7 $cm^2 \cdot mg^{-1}$ relative growth ratio of 0.31 $mg \cdot mg^{-1} \cdot wk^{-1}$ and a 100% pulling success.

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CHAPTER 3

INFLUENCE OF ELECTRICAL CONDUCTIVTY ON TOMATO GROWTH, YIELD AND QUALITY

3.1 Introduction

Tomato is an important commercial crop and it is an ideal research material for physiological, cellular, biochemical and molecular genetic investigations. Most tomato growers use greenhouses due to the sensitivity of the crop to unfavourable environmental conditions, such as temperature. However, some of the growth limiting factors such as balanced nutrition and proper irrigation practices and management are still an area of concern or a challenge to producers. This is due to the fact that most of the fruit physiological disorders, abnormal growth, yield and quality of fruit vegetables being influenced by nutrient solution composition (Lara *et al*., 1999).

Through greenhouse production, the producer can create an environment that is optimal for plant growth in an area that is sub-optimal and can optimise some of the characteristics of plants to satisfy consumer demand. However, the solution concentration and nutrient ratios play a key role (Lara *et al*., 1999). The conventional nutrient management of soilless culture is based on the maintenance of relatively high solution concentrations. The result is reduced efficacy of nutrient use and has serious environmental impact. High solution concentrations can also lead to excess ion uptake and imbalance between vegetative and reproductive growth resulting in reduced yield and quality (Maruo, 1999).

The only practical way to determine the correct concentration of nutrients in irrigation water is to measure the electrical conductivity (EC). EC is a measurement of the ease of electrical conductance or current in water, a nutrient solution, or a soil or medium solution and is used to determine the level of ions in solution and as a means to determine potential effect on plant growth (Jones, 1999). Basically, EC measures the conductance of the total dissolved solutes in the solution. It does not indicate the level of any

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individual ion (Resh, 1993). The composition and concentrations of a nutrient solution are based on published recommendations, which are based on research experience, plant species and cultivar, growth stage and growing stem. However, the recommended concentration of the nutrient solution expressed as EC been on the use lately, especially in the production of high quality fruit vegetables, such as tomatoes and cucumbers (Schwarz & Klaring, 2002.).

The functional biology of salt stress adaptation in plants is a matter of debate. Trans-gene and mutation analyses have both contributed substantially to identify major salt tolerance determinants and to dissect the complexity of multiple mechanisms leading to stress adaptation (Chinnusamy *et al.*, 2004). Nevertheless, most results have demonstrated that overexpression of single salt tolerance components, via genetic engineering, may only confer a partially improved salinity tolerance (Maggio et al. 2002). Therefore, it is pivotal in salinity research to identify unusual salt tolerance determinants (Zhu, 2001), and to functionally analyse cause-effect relationships between physiological responses and their potential benefits in stress adaptation (Munns, 2002). The complexity of salt stress responses in actively transpiring plants throughout their growth cycle depends on several interacting variables, including the cultural environment, the plant developmental stage and the magnitude (salt concentration and time of exposure) of the stress experienced over time (Munns, 2002).

Relatively high levels of nutrients are necessary to ensure high production. In soilless culture, nutrients are usually added to the soil pre-plant, as in field production and water is supplied daily by a drip irrigation system. Additional fertilizers are injected into the watering lines as needed. This results in relatively high salinity of the nutrient solution. High salinity in the root environment decreases the availability of water in the root zone of the plant and therefore decreases water uptake and overall growth rate. Regulating the osmotic potential near the root, which depends on the nutrient concentration in the irrigation water, is used to improve plant growth, development and fruit quality.

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3.2 Material and methods

The study was carried out in a glasshouse at the University of Pretoria Research Farm located in Hatfield (Phytotron A). The pots were randomly allocated in blocks (randomized complete block design), to maintain homogeneity and in a controlled environmental conditions. The glasshouse was equipped with fans and wet walls to keep it cool. The rotating tables were used to reduce the environmental influence on the treatments. Distilled water was used for irrigation pH, which was maintained 5.5 to 6.2 throughout the duration of the study. Cocopeat was used as a substrate, EC and pH were measured. Hoagland's 1 solution was used as control (Hoagland & Arnon, 1950).

Tomato plants were germinated in seedling trays and transferred to 10L pots at transplanting. One plant per pot represented an experimental unit or plot. Four EC treatments were used that consisted of 1.12, 2.24, 4.48 and 6.72 $mS \cdot cm^{-1}$. Each treatment was replicated six times. Fertigation was done once a week. Stem diameter and shoot length were recorded using a digital calipre and measuring tape, respectively. Number of leaves was also recorded. The incidences of some physiological disorders like blossom end rot were monitored throughout the duration of the experiment. All fruits that showed signs of blossom end rot were recorded once a week for all the treatment levels to monitor the total number of fruits affected.

3.2.1 Fruit sampling

Fruits were hand harvested at the fully ripe stage and the yield components including fruit mass, size and numbers of fruits were determined. The size of the fruit was measured by measuring the fruit diameter with the use of a vernier caliper. Fruit quality parameters were also evaluated by randomly picking firm fruits at the ripe stage from the second truss, i.e. four fruits from one plant per block (one plant per pot representing an experimental unit) were sampled. Harvested fruits were immediately taken to the laboratory for chemical analysis. At the termination of the experiment, all the unripe fruits were harvested and their overall mass was recorded.

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3.2.2 Cultural practices

Twisting the trellis rope around the main stem and fixing it into a horizontal turning table bars supported the plants. Lateral branches, suckers and auxillary branches were cut off in order to maintain a single growing stem (the central leader). Prunning was done regularly as required. Rotating tables were turned on and off during the day to minimise the environmental impact and plants were shaken using a trellis rope in order to achieve proper pollination. Insect pest and diseases were controlled using chemicals and physiological disorders were also carefully monitored.

3.2.3 Chemical analysis

Quality parameters including fruit juice pH, titratable acidity and total soluble solids (% brix) were analyzed at the Physiological Laboratory in the Department of Plant Production and Soil Science, Pretoria University. All samples were cleaned with tap water and left to dry on a table before they were ground with a blender to produce a puree. The puree was then filtered through a Whatman filter paper (No. 4) in order to obtain a serum. The serum was used to determine the pH. The % brix was also measured from the same serum using a digital refractometer (PAL-1 Pocket Refractometer, ATAGO N1, Japan). The prism of the refractometer was kept clean during different samplings using distilled water. Each sample was repeated three times for accuracy of the readings and an average was taken as a final reading.

Titratable acidity was also determined by titrating 20 ml of a serum to a pH = 8.1 with 0.1N NaOH using an automated potentio meter: D 150 graphix (Italic) instrument (Mettler Toledo DL25, Switzerland). The acidity was then expressed as a percentage in terms of the predominant acid found in tomatoes, citric acid. This was determined by using the equation given by Goud (1983).

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$$Z = \frac{V \times N \times mMol}{Y} \times 100$$

Where:

Z = % of Citric acid in sample

V =Volume in ml of NaOH titrated

mMol = mMol c of acid, which is 0.064 for citric acid

Y = Volume (ml) of samples titrated

N = normality of NaOH (0.1 N) in mMol c

3.2.4 Statistical analysis

Data were analyzed using the General Linear Model procedure of the Statistical Analysis System (SAS) (SAS Institute, 2003). The Least Significant Difference (LSD) t test was used to compare treatment means at the 0.01 and 0.05% probability levels. Regression and correlation analysis, as well as the homogeneity test were conducted to determine statistical differences between the different EC levels on the observed or collected data.

3.3 Results and discussions

3.3.1 Blossom end rot incident

The incidence of blossom end rot was significantly higher by 6.3 % in the EC treatment level of 6.72 $mS \cdot cm^{-1}$ as compared to 0.5, 1.4 and 3% recorded at1.12, 2.24 and 4.48 $mS \cdot cm^{-1}$, respectively (Table 3.1). There were no significant differences observed between treatments at EC level 1.12; 2.24 and 4.48 $mS \cdot cm^{-1}$ which might be an indication that Ca mobility was still active even at EC treatment level of 4.48 $mS \cdot cm^{-1}$, which is higher than the ideal norm of 2.0 to 2.5 $mS \cdot cm^{-1}$ recommended by Adams & Ho (1992). Many researchers have noted the occurrence of BER in tomato as a function of calcium deficiency in the fruit or parts of the fruit which was linked to the uptake of nutrients by the roots and the composition of the nutrient solution (Saure, 2001; Taylor & Locascio, 2004).

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The indirect but practical cause of blossom end rot is plant stress which apparently reduces the mobility of Ca within the plant, particularly to fruit, resulting in tissue break down and typical blossom end rot symptoms (Tabatabaie *et al.*, 2004 a). The results from this experiment confirm the results of Tuzel *et al*. (2003) where the BER incidence increased with increasing EC levels. Adams and Ho (1992) also reported that number of fruit affected by blossom end rot increased with salinity in the root zone, which directly affect calcium availability. However, a critical concentration of Ca in the fruit has not yet been determined and conditions responsible for the development of BER are still poorly understood (Taylor & Locascio, 2004). Caro *et al.* (1991) reported that the average non-commercial fruit (fruit with blossom end rot) for the four cultivars increased with salinity from 2% in control (0 mM Na) conditions to 6, 12 and 16% in 25, 50 and 75 mM, respectively.

3.3.2 Shoot length

There was no significant difference between the EC treatment level of 1.12 & 6.72 $mS \cdot cm^{-1}$ with regards to shoot length, which was 187.9 and 181.4 cm, respectively. However, the shoot length recorded at an EC treatment level of 6.72 $mS \cdot cm^{-1}$ was relatively lower and significantly reduced growth from the plants sampled at an EC treatment level of 2.24 & 4.48 $mS \cdot cm^{-1}$, respectively, Table 3.1. Many researchers have confirmed that increased nutrient solution EC may reduce the growth rate of the whole plant and individual plant parts, can enhance ion accumulation and may inhibit photosynthesis; thereby reducing growth (Picken *et al.*, 1986; Li & Stanghellini, 2001; Schwarz & Klaring, 2002). At 1.12 $mS \cdot cm^{-1}$ treatment level, a reduced growth rate was observed which might be an indication that the EC level was below the optimum recommendation as prescribed by Adams & Ho (1992). However, the exact optimal range of EC level acceptable for tomato is still confounded by the fact that different environmental conditions can still play a role Tuzel *et al.* (2001). Olympios *et al.* (2003) also reported lower growth as the salinity levels or concentrations increased from 1.7 $mS \cdot cm^{-1}$ to 8.7 $mS \cdot cm^{-1}$. The nutrient ratios and nutrient activity in the solution

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concentration plays a major role in plant growth since it can result in reduced efficacy of nutrient use. This can further illustrate the role of the interaction between plant nutrients which can lead to excessive ion uptake and imbalance between vegetative and reproductive growth as reported by Maruo (1999).

3.3.3 Stem diameter

The stem diameter was not affected by any of the EC treatment levels. Salinity is often defined as the presence of an excess concentration of soluble salts in the root zone which is a threat to plant production since it depresses the external water potential, making it less readily available to the plant, Locascio *et al.* (1984) and Kang & van Larsel (2004). Tuzel *et al.* (2001) found that accumulation of salts and other ions occur, which may results in imbalances that may disturb nutrient uptake or cause toxicities. However more of the effects of using higher concentration are observed in plant yield and fruit quality parameters than on the stem itself as indicated in the current study. The result of this experiment showed no effect on stem diameter across all the EC treatment levels and that may be due to the fact that most of assimilates are partitioned to sinks like fruits which is depicted on the results from Table 3.2.

Table 3.1 Tomato growth and fruit characteristics as influenced by electrical conductivity

EC treatments ($mS \cdot cm^{-1}$)	BER (%)	Shoot length (cm)	Stem diameter (mm)	No. of trusses	No. of fruits	Av. Fr. mass (g)
1.12	0.5 b	187.9 ab	12.2	5	22.3	92.53 ab
2.24	1.4 b	198.3 a	11.34	5	21.9	98.11 a
4.48	3 b	198.9 a	10.61	5.1	23	82.76 b
6.72	6.3 a	181.4 b	11.63	5.3	20.1	62.79 c
Means	3.107	192.15	11.34	5.02	21.8	82.83
LSD $_{(0.05)}$	2.96**	12.996*	1.46^{ns}	0.36^{ns}	6.12^{ns}	11.94**

Means in each column followed by different letters are significantly different at $P \leq 0.05$

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3.3.4 Average fruit weight

Increasing the nutrient concentration from 2.24 to 6.72 $mS \cdot cm^{-1}$ reduced the average fruit mass from 98.1 to 62.8 g. No signicant differences were observed in fruit mass between EC level of 1.12 and 2.24 $mS \cdot cm^{-1}$. These results are in agreement with the body of evidence which suggests that average fruit mass is decreased when electrical conductivity of irrigation water exceeds a certain crop specific threshold (Mass & Hoffman, 1977). Average fruit mass, in turn, had an impact on the total plant yield as the EC concentration increased, which is shown in Table 3.2. Maggio *et al.* (2004) found a similar trend where salinized tomato fruits were smaller than non-salinized fruits.

3.3.5 Number of trusses

Increasing the EC levels of the nutrient solution from 1.12 to 6.72 $mS \cdot cm^{-1}$ did not have any impact on the number of trusses across the treatment levels, as no significant differences were observed. Number of trusses had little or no impact on the actual total yield of the plant as the fruit size determined the actual yield. Total tomato production depends on the number of trusses per plant, number of flowers per truss, fruit set index and fruit weight. The results on this study show that increasing nutrient solution EC can reduce the growth rate of the whole plant and individual plant parts. Some authors have suggested that increased EC may inhibit photosynthesis thereby reducing growth but results of photosynthesis measurements reported in literature are inconsistent. Other cultural practices employed during the experiment like tree training (i.e. pruning) should have been considered since they can influence in the actual vegetative growth pattern, which may contribute to the number of trusses.

3.3.6 Number of fruits

Number of fruits was not significantly affected by EC level although the treatment with the highest EC of 6.72 $mS \cdot cm^{-1}$ had numerically less fruits as compared to the EC of 4.48 $mS \cdot cm^{-1}$. A lot of studies conducted have been concentrating in increasing plant yield and

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compromising fruit quality which consumers are interested in. With respect to fruit set, Adams & Ho (1992) did not obtain a reduction with increasing salinity although reduction occurred on the upper trusses. In most of the studies conducted, the total number of fruits per plant is normally not affected, because the fruit set index increases with salinity as confirmed by Tuzel *et al*. (2003). High number of fruits per plant increases the competition between fruits for carbohydrates, thus reducing the supply of sugars and water to each fruit.

3.3.7 Fruit acidity/titratable acidity (TA) and %brix

Titratable acidity and %brix were greatly affected by nutrient solution concentration. Increasing the electrical conductivity from 1.12 to 6.72 $mS \cdot cm^{-1}$ increased the total soluble solids from 3.9 to 6.1%. Titrable acidity increased from 3.3 to 5.7% when the solution concentration was increased from 1.12 to 6.72 $mS \cdot cm^{-1}$. Van Ieperen (1996) also found that fruit acidity and %brix (TSS) increased significantly with increasing salinity. Similar studies conducted on tomato indicated that fruit soluble solids and fruit dry mass did not decrease proportionally to fresh mass because under saline conditions tomato fruit have higher soluble solid contents than in non-saline conditions (Li *et al*. 2001).

It has been well documented that high EC levels have a positive effect on tomato fruit flavour since total soluble solids (TSS) and titratable acidity (TA) increase with increases in EC levels (Petersen *et al*., 1998; Tuzel *et al*., 2001). Similar results were reported by Adams (1991), Nichols *et al*. (1994) and Tuzel *et al*. (2001). However, Dorais *et al*. (2001) found that high EC resulted in stronger intensity of negative flavour attributes such as “mouldy”, “bitter” and the after taste attributes such as mouldy and burning, which contribute to the off-flavour. Increasing plant water stress does not only reduce yield by decreasing fruit size, but also has a positive effect in improving flavour mainly by increasing brix (Nichols *et al*., 1994).

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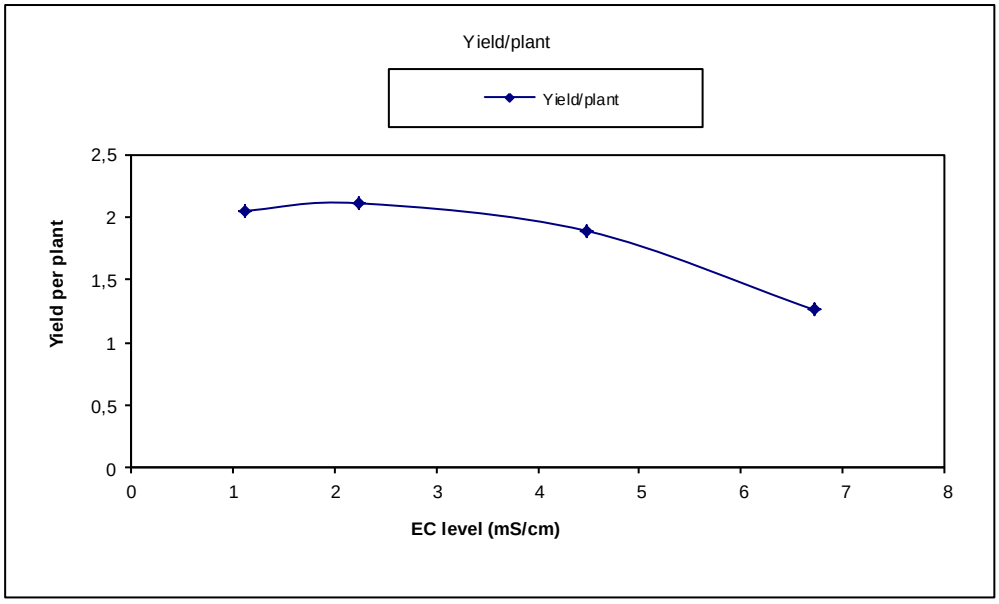
3.3.8 Fruit yield

Fruit yield per plant was significantly affected by solution concentration EC (Table 3.2). The lowest yield of 1.3 kg per plant was recorded at the highest EC concentration of 6.72 $mS \cdot cm^{-1}$ which was 25% lower than the yield obtained at an EC concentration of 2.24 $mS \cdot cm^{-1}$ (2.11 kg per plant), (Table 3.2). Although, there was no significant effect on yield per plant when the EC concentration was increased from 1.12 to 4.48 $mS \cdot cm^{-1}$, there was however a clear decreasing trend in yield with increased EC. Some research studies indicate that yield and biomass are correlated with plant water uptake in several crops and under several stress conditions, including salinity (Shani & Dudley, 2001). The graph in Figure 3.1 shows a reduction in yield per plant as the concentration EC increased. Plant response to salinity is generally described in terms of relative yield as a continuous function of root zone salinity, expressed as electrical conductivity of the solution in contact with the roots (ECe) (Maas & Hoffman, 1977).

Figure 3.1 Influence of EC on % yield per plant



Reduction in yield in the current study obtained might be due to the reduction in fruit size (average fruit mass) which includes fruit diameter and average fruit circumference since significant differences were obtained, (Table 3.2). Yield reduction with moderately saline

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water is mainly due to reduction in average fruit mass which in turn is directly proportional to fruit size, Li *et al.* (2001). These results are in agreement with studies conducted by Tuzel *et al.* (2003) in which they reported that salinity treatments affected total yield values negatively as the highest yield was obtained from the control treatment. Difference in total yield were due to the reduction in fruit size associated with the increase in EC levels in the nutrient solutions. Based on Mass & Hoffman (1977) model, most studies have found that 2 and 2.5 $mS \cdot cm^{-1}$ represent a threshold value beyond which a decrease in yield by 9 to 10% is recorded for each increase of 1 $mS \cdot cm^{-1}$ over the threshold, values which are close to those found on the current experiment.

3.3.9 Average fruit diameter

Average fruit diameter decreased as the concentration of the solution increased, which negatively affected the total plant yield, (Table 3.2). Increasing the nutrient concentration from 1.12 to 6.72 $mS \cdot cm^{-1}$ decreased the average fruit diameter from 58 to 51 mm. The highest average fruit diameter was recorded at the concentration of 2.24 $mS \cdot cm^{-1}$. In this experiment, the concentration EC of 2.24 $mS \cdot cm^{-1}$ could be regarded as the threshold when compared to the lowest concentration level of 1.12 $mS \cdot cm^{-1}$ that also had a relatively lower average fruit diameter. Tuzel *et al.* (2003) found that differences in total yield were due to the reduction of fruit size associated with the increase of EC levels in nutrient solutions. Huge losses can be expected at a very high level EC.

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Table 3.2 Tomato yield and quality parameters as affected by electrical conductivity

EC treatments ($mS \cdot cm^{-1}$)	Yield/ plant (kg)	Av. fruit diameter (mm)	Av. fruit circumference (cm)	Brix (TSS) (%)	Titrable acidity (%)	pH
1.12	2.05 a	57.99 ab	18.36 a	3.93 c	3.29 c	4.71 a
2.24	2.11 a	59.28 a	19.01 a	4.03 c	4.78 b	4.40 b
4.48	1.89 a	55.84 b	18.97 a	5.25 b	5.61 a	4.33 b
6.72	1.26 b	50.96 c	16.28 b	6.11 a	5.73 a	4.33 b
Means	1.79	55.73	18.13	4.96	5.08	4.40
LSD $_{(0.05)}$	0.45**	2.95**	1.77*	0.43**	0.40**	0.08**

Means in each column followed by different letters are significantly different at $P \leq 0.05$

3.3.10 Fruit circumference

Average fruit circumference was negatively affected by concentration of the nutrient solution, (Table 3.2). At 6.72 $mS \cdot cm^{-1}$ treatment, lowest average fruit circumference was obtained which in turn contributed negatively to the total yield per plant which was reduced at higher salinity levels. Increasing the concentration of the nutrient solution from 1.12 to 6.72 $mS \cdot cm^{-1}$ reduced average fruit circumference from 18.4 to 16.3 cm. This might be an indication that the concentration of the solution was above the optimum threshold recommended for this experiment which was 2.24 $mS \cdot cm^{-1}$. There was no significant effect on fruit circumference when the concentration of the nutrient solution increased from 1.12 to 4.48 $mS \cdot cm^{-1}$, (Table 3.2). However, evidence from several studies reveals that our recommendations from findings cannot be generalized due to other technologies that must be factored.

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3.3.11 Fruit pH

Increased electrical conductivity had a significant negative effect on fruit pH, (Table 3.2). The highest fruit pH was recorded at the EC concentration of 1.12 $mS \cdot cm^{-1}$. There was no significant effect observed on fruit pH when concentration of the nutrient solution was increased from 2.24 to 6.72 $mS \cdot cm^{-1}$.

CONCLUSIONS

Plant response to salinity is generally described in terms of yield and quality as a continuous function of root zone salinity, expressed as electrical conductivity of the solution in contact with the roots (EC). It was noted that increased solution concentration of EC in the root medium improved fruit quality such as total soluble solids, titratable acidity and dry matter content of tomato fruit although yield reduction was inevitable. Number of fruit affected by blossom end rot increased with increasing EC concentrations in the root zone, which directly affected the calcium availability. Optimum yield (2.11 kg per plant) was obtained at a concentration of 2.24 $mS \cdot cm^{-1}$ which can be recommended for the local conditions in South Africa as compared to the yield of 1.26 kg per plant recorded at 6.72 $mS \cdot cm^{-1}$ under this specific conditions that the experiment was conducted under and the frequency of fertigation application.

High salinity in the root environment decreased the uptake of water to the roots of the plant and it therefore decreased water uptake and overall growth rate. Increasing conductivity to increase dry matter content of the fruit, also reduced the rate of water accumulation and so cell enlargement, in turn the yield loss was inevitable. There is a need of some incentives for commercial growers who are paid per kilogram of fruit to increase fruit quality in exchange of compromising yield if the tomato fruit taste and quality has become more of an issue. However that can only be a common practice in the first world countries concerned, which might not be applicable to South African conditions and considering the cost involved in bringing these quality attributes, it may not be of economic value to compromise yield. It can also be considered an important

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parameter by the tomato processing industry. More concerns for South African conditions would rather be the fruit shelf life and firmness rather than flavor. Consumers taste and preference might also be a difficult exercise to measure.

SUMMARY

A glasshouse experiment was conducted to determine the influence of electrical conductivity (EC) and or nutrient solution composition on growth, yield and quality parameters in tomato. The pots were arranged in a randomized complete block design (CRBD), under controlled environmental conditions. The glasshouse was equipped with fans and wet walls, while rotating tables were used to reduce the environmental influence on the treatments.

Cocopeat was used as a substrate and fertilisation was applied through fertigation. EC and pH meter were measured. Tomato plants were germinated in seedling trays and transferred to 10L pots. One plant per pot represented an experimental unit. Four EC treatments were used that consisted of 1.12, 2.24, 4.48, 6.72 $mS \cdot cm^{-1}$. Each treatment was replicated six times and fertigation was done once every week. Physiological disorders were monitored throughout the duration of the experiment. Growth and yield parameters were recorded and measured while quality parameters were chemically analyzed in the laboratory.

Salinity inhibited growth (shoot length) and yield (average fruit mass, fruit diameter and fruit circumference) at higher concentrations (6.72 $mS \cdot cm^{-1}$). However, it did not significantly affect number of trusses, number of fruits and stem diameter, rather tomato quality was improved in terms of total soluble solids. Although tomato fruits grown to 6.72 $mS \cdot cm^{-1}$ were relatively smaller than fruits grown at 1.12, 2.24 and 4.48 $mS \cdot cm^{-1}$ treatments respectively, they had higher acidity, increased soluble solids and higher sugar content, which are all highly regarded qualities by the processing tomato industry.

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Overall, the reduced yield of plants subjected to moderately increased concentrations in the nutrient solution of 4.48 $mS \cdot cm^{-1}$ was compensated by enhanced quality of tomato fruits. Optimumt yield (2.11 kg per plant) was obtained at a concentration of 2.24 $mS \cdot cm^{-1}$ which can be recommended for local conditions in South Africa as compared to the yield of 1.26 kg per plant recorded at 6.72 $mS \cdot cm^{-1}$. Increasing the concentration of the solution from 1.12 to 6.72 $mS \cdot cm^{-1}$ increased the %brix (TSS) from 3.9 to 6.1% while titratable acidity was increased from 3.3 to 5.7%. The incidence of blossom end rot was higher (6.3%) at concentration of 6.72 $mS \cdot cm^{-1}$ as compared to 1.12 $mS \cdot cm^{-1}$ concentration which was at 0.5%.

Tomato fruit quality for fresh consumption as defined by Dorais *et al.* (2001) is determined by appearance (colour, size, shape, bruises, injuries, sunburn, foreign matter, dust, free from physiological disorders and decay), firmness, texture, dry matter, organoleptic (flavour) and nutraceutic (health benefit) properties. Organoleptic quality is mainly defined by its sugar and acid content, while nutraceutical quality is defined by mineral, vitamin, carotenoid and flavonoid contents. Although increased EC had a positive effect on fruit quality which is preferred by the tomato processing industry, it has a negative impact on yield. For the producers to maximise profit, they would rather go for the optimum yields which was recorded at 2.24 $mS \cdot cm^{-1}$ in this experiment considering high input costs that comes with it.

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GENERAL DISCUSSION AND CONCLUSION

For the past decade, greenhouse produced tomato consumption has grown exponentially. The catalyst fuelling this dramatic growth is based on consumer perception and awareness that greenhouse tomatoes are far superior in their consistent quality and taste as compared to the standard field grown artificially ripened tomato (Treder & Nowak, 2004). However relationships between greenhouse environment, salinity and mineral nutrition of tomato plants are very complex. Growing systems that recirculate nutrient solution are attractive, because they couple the savings in water and fertilizers with decreased leaching (Tremblay & Gosselin, 1989).

This study was aimed at reviewing and characterizing information in relation to nutritional and water management practices used in production of tomato transplants. This review showed that yield reduction remains a challenge as producers focus on producing quality fruits desirable for the processing industry and consumers who are conscious about the tomato fruit shelf life and taste. Based on this outcome, two experiments were conducted to determine the influence of nitrogen nutrition on tomato transplants and to determine the influence of electrical conductivity (EC) on growth, yield and quality parameters in tomato.

Results from the experiment on different EC levels showed that salinity inhibited growth (shoot length) and yield (average fruit mass and fruit diameter) at higher concentrations (6.72 $mS \cdot cm^{-1}$). However, it did not significantly affect number of trusses, number of fruits and stem diameter, rather tomato quality was improved in terms of total soluble solids. Although tomato fruits grown at EC of 6.72 $mS \cdot cm^{-1}$ were relatively smaller than fruits grown at EC of 1.12, 2.24 and 4.48 $mS \cdot cm^{-1}$, respectively, they had higher acidity, increased soluble solids and higher sugar content, which are all highly regarded qualities by the processing tomato industry. According to Li *et al.* (2001), increasing the concentration of the nutrient solution significantly decreased fresh yield of tomato, mainly by reducing size. Tuzel *et al.* (2003) found that a difference in total yields was

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due to the reduction of fruit size which was directly proportional to the increase of EC levels in nutrient solutions.

Most plants respond to salinity with reduced growth, whenever salt concentration in the root environment exceeds a threshold value in the root (Li *et al.*, 2001; Biernbaum & Natasha, 1998). It can be noted that the negative effect of high salinity on growth and yield is mainly related to the water balance of the plant. For example, Tabatabaie *et al.* (2004 b) reported that the decrease of leaf area in high EC conditions is associated with leaf water status. The reduction in leaf growth rate in high EC conditions is likely to be caused by reduced cell turgor. Even the assimilation and dry matter accumulation depends on environment and the area of leaf surface (Picken *et al.*, 1986). The incidence of blossom end rot from these results was significantly higher by 6.3 % at the EC treatment level of 6.72 $mS \cdot cm^{-1}$ as compared to 0.5, 1.4 and 3% recorded at1.12, 2.24 and 4.48 $mS \cdot cm^{-1}$, respectively. There were no significant differences observed between treatments at EC level 1.12; 2.24 and 4.48 $mS \cdot cm^{-1}$. That might be an indication that Ca mobility was still active even at EC treatment level of 4.48 $mS \cdot cm^{-1}$, which is higher than the optimum value of 2.0 to 2.5 $mS \cdot cm^{-1}$ recommended by Adams & Ho (1992).

Therefore, appropriate salinity and ion thresholds should not be generalized, because they vary according to the quality parameters and interactions between cultivars, climatic factors (light, temperature, vapour pressure deficit and carbon dioxide), composition and concentration of the nutrient solution, crop management, as well as type of growing medium and irrigation system (open or closed). There is general agreement from Tabatabaie *et al.* (2004); Picken *et al.* (1986), Li *et al.* (2001) and Tuzel *et al.* (2003) that increasing conductivity to increase dry matter content and other quality attributes of the fruit, reduces the rate of water accumulation and thus cell enlargement so that loss in yield is inevitable. More research still needs to be done on genetics and breeding of new tomato cultivars that will have good quality without yield losses. Reviewing some techniques, like seedling conditioning, seed-priming, the application of fertilizers at levels somewhat above the optimum for freshwater irrigation and, finally, the breeding of cultivars more tolerant to salinity should be considered.

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Results from the experiment on nitrogen nutrition of tomato transplants have proved that nitrogen application had a pronounced influence on transplants growth in relation to root and shoot growth. Observations throughout the experiment indicated that increased nitrogen application favoured shoot growth, which is an indication that most of assimilates were partitioned to shoots rather than roots. Transplants that did not receive nitrogen (0 $mg \cdot L^{-1}$ N) had reduced plant height, plant chlorophyll content, poor pulling success, relative growth rate, net assimilation rate, specific leaf area and leaf area. The overall vegetative growth was reduced, however, root mass ratio and root: shoot ratio was relatively low in all other treatments that had highest nitrogen application rates.

Research on the production of transplants in plug trays has improved crop production but also brought a challenge to transplant producers. Transplants are grown in small cell volumes of example 20 cm^3, which means reduced root zone. Therefore, precise nutrient and water management techniques are needed (Biernbaum and Versluys, 1998). To produce optimum yields of good quality tomatoes, high amounts of nitrogen fertilizer are often applied. In reality, the amount of fertilizer used is probably higher as farmers may apply more fertilizer than recommended to secure yields (Claassens, personal communication, 2004).

Careful considerations should be made though in terms of making some conclusive findings in a sense that other factors like temperature variations or seasonal variation can also play a role in plant growth. In a study that was conducted to determine the impact of N fertilization on tomato transplant production and response to seasonal variation, Vavrina *et al*. (1998) reported that transplant fertilization should be based on production season. Vavrina *et al*. (1998) found out that 30-60 $mg \cdot L^{-1}$ N was sufficient for tomato transplant production in Florida while Masson et al. (1991) recommended 300-400 $mg \cdot L^{-1}$ N in tomato transplant production in Canada. This huge difference on these recommendations between Vavrina *et al.* (1998) and Masson et al. (1991) were simple because of the difference on how they interpreted transplant parameters in terms of maximum versus optimum measurements. These diverse nutrient N requirement of

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tomato seedlings can be attributed to differences in climatic conditions, which affect nutrient management practices in the greenhouse and ability to plant in time. Complementary effect between nutrients, like adequate K concentration in the cytoplasm is needed to maintain metabolism of N in plants (Marschner, 1995).

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GENERAL SUMMARY

A greenhouse experiment was conducted in autumn to determine the effect of several N levels on growth and assimilate-partitioning patterns of tomato seedlings in a greenhouse. Tomato transplants were propagated with 0, 30, 60, 90 and 120 $mg \cdot L^{-1}$ N. Fertigation was done by intermittently floating cavity trays in nutrient solutions until the medium reached field capacity on daily basis until the plants were ready for tranplanting. The experiment was arranged in a randomized complete block design (RCBD) with four replications. Sampling was initiated 21 days after sowing and was done weekly until the transplants were ready for transplanting (when transplants could pull out easily from the cavity trays without breaking) at 42 days after sowing.

Nitrogen application had a pronounced influence on transplants growth in relation to root and shoot growth. As nitrogen was increased from 0 to 120 $mg \cdot L^{-1}$, transplants shoot and root mass increased. However more dry mass was partitioned to shoots than roots, as a result root: shoot ratio and root mass ratio was reduced with increasing nitrogen applied. Transplants that did not receive nitrogen (0 $mg \cdot L^{-1}$ N) had reduced plant height, plant chlorophyll content, poor pulling success, relative growth rate, net assimilation rate, specific leaf area and leaf area. The overall vegetative growth was reduced.

As nitrogen was increased from 0 to 120 $mg \cdot L^{-1}$, it further promoted relative growth rate, specific leaf area, leaf mass ratio, leaf area ratio, plant chlorophyll content, leaf tissue nitrogen and improved pulling success. At 42 days after sowing, a quality transplant was produced at 90 $mg \cdot L^{-1}$ N and had a root to shoot ratio of 0.16, leaf mass ratio of 0.86, root mass ratio of 0.13, leaf area of 594 cm^2, plant chlorophyll content of 33, leaf tissue nitrogen of 32 $g \cdot kg^{-1}$, specific leaf area of 194 $cm^2 \cdot mg^{-1}$, leaf area ratio of 168 $cm^2 \cdot mg^{-1}$ relative growth ratio of 0.31 $mg \cdot mg^{-1} \cdot wk^{-1}$ and a 100% pulling success.

Another glasshouse experiment was conducted to determine the influence of electrical conductivity (EC) and/ nutrient solution composition on growth, yield and quality parameters in tomato. The pots were arranged in a randomized complete block design

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(RCBD). The glasshouse was equipped with fans and wet wall while rotating tables were used to reduce the environmental influence on the treatments. Distilled water was used for irrigation water to maintain the required pH, which was 5.5-6.2 throughout the duration of the study. Cocopeat was used as a substrate. One plant per pot represented an experimental unit. Four EC treatments were used that consisted of 1.12, 2.24, 4.48, 6.72 $mS \cdot cm^{-1}$. Each treatment was replicated six times. Physiological disorders were monitored throughout the duration of the experiment. Growth and yield parameters were recorded and measured while quality parameters were chemically analyzed in the laboratory.

Salinity inhibited growth (shoot length) and yield (average fruit mass, fruit diameter and fruit circumference) at higher concentrations (6.72 $mS \cdot cm^{-1}$). However it did not significantly affect number of trusses, number of fruits and stem diameter, rather tomato quality was improved in terms of total soluble solids. Although tomato fruits grown to 6.72 $mS \cdot cm^{-1}$ were relatively smaller than fruits grown to 1.12, 2.24 and 4.48 $mS \cdot cm^{-1}$ treatments respectively, they had higher acidity, increased soluble solids and higher sugar content, which all are highly requested qualities by the processing tomato industry.

Highest yield of (2.11 kg per plant) was obtained at the concentration of 2.24 $mS \cdot cm^{-1}$ which can be recommended for the local conditions in South Africa as compared to the yield of 1.26 kg per plant recorded at 6.72 $mS \cdot cm^{-1}$. The incidence of blossom end rot was higher (6.3%) at concentration of 6.72 $mS \cdot cm^{-1}$ as compared to 5% on the concentration of 1.12 $mS \cdot cm^{-1}$.

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APPENDIX A: NITROGEN NUTRITION EXPERIMENT

Table A1 Analysis of variance for nitrogen nutrition on growth characteristics of tomato transplants 16 March – 2 May 2004

Sourses of variation	DF	Mean Squares					
		Relative growth rate ($mg \cdot mg^{-1} \cdot wk^{-1}$)	Net assimilation rate ($mg \cdot cm^{-2} \cdot wk^{-1}$)	Specific leaf area ($cm^2 \cdot mg^{-1}$)	Leaf area ratio ($cm^2.mg^{-1}$)	Leaf area (cm^2)	Leaf tissue N ($g \cdot kg^{-1}$)
21 Days After Sowing							
N level	4			1266.925**	971.34**	2225.89**	
Replication	3			140.0245	132.66	11.458	
Error	12			123.763	70.24	17.098	
N level L	1			5312.634**	5355**	14973.03**	
N level Q	1			833.251 ns	21.12 ns	333.79**	
28 Days After Sowing							
N level	4	0.0383**	0.0004**	2572.465*	1646.89**	42146.04**	
Replication	3	0.0054	0.000009	1458.322	262.41	229.78	
Error	12	0.00423	0.00001	778.064	170.83	77.254	
N level L	1	0.2402**	0.0018**	1186.267ns	9405.97**	289139.4**	
N level Q	1	0.0019 ns	0.00095**	8712.97**	697.64 ns	2563.39**	
35 Days After Sowing							
N level	4	0.1007**	0.000096**	3067.271*	2713.47**	110111.32**	
Replication	3	0.0003	0.000003	1744.934	742.90	581.86	
Error	12	0.0037	0.000005	894.024	275.20	121.789	
N level L	1	0.225**	0.00002*	5837.84*	13928.47**	747377.18**	
N level Q	1	0.2833**	0.00061**	2824.45 ns	248.27 ns	13686.25**	
42 Days After Sowing							
N level	4	0.0155**	0.00003**	2227.26**	2308.03**	169587.81**	213.186**
Replication	3	0.0010	0.0000003	949.43	609.09	3074.23	2.667
Error	12	0.0017	0.0000005	423.073	208.98	1286.19	1.0417
N level L	1	0.0448**	0.00011**	6263.46**	12803.36**	1139494.5**	1476.23**
N level Q	1	0.015*	0.000053**	4990.66*	1029.83 ns	19868.67**	2.161 ns

[z]F-values significant (*), highly significant (**) or non-significant (NS) at $p \leq 0.05$ or $p \leq 0.01$.

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Table A2 Analysis of variance for shoot and root characteristics of tomato transplants as affected by nitrogen nutrition, March /May 2004

Sourses of variation	DF	Mean Squares					
		Plant height (mm)	Root : shoot ratio	Leaf mass ratio	Root mass ratio	Plant chlorophyll content	Pulling success (%)
				21 Days After Sowing			
N level	4	64.4659**	0.0312**	0.0120**	0.012**	81.991**	
Replication	3	0.2725	0.00091	0.0005	0.00045	3.639	
Error	12	0.1577	0.00061	0.0003	0.00032	1.346	
N level L	1	406.4063**	0.0541**	0.0174**	0.017**	459.548**	
N level Q	1	43.9314**	0.1225**	0.0498**	0.050**	74.382**	
				28 Days After Sowing			
N level	4	129.0216**	0.0622**	0.0133**	0.013**	37.022**	
Replication	3	0.0705	0.0089	0.00175	0.0018	5.046	
Error	12	0.3334	0.0037	0.0006	0.00056	2.387	
N level L	1	778.8063**	0.2650**	0.0599**	0.060**	203.581**	
N level Q	1	123.7898*	0.1160**	0.0228**	0.023**	21.477*	
				35 Days After Sowing			
N level	4	200.4646**	0.0409**	0.0127**	0.013**	26.675**	
Replication	3	0.2667	0.00169	0.0004	0.00038	1.0462	
Error	12	0.2431	0.00357	0.0008	0.00081	1.849	
N level L	1	1083.681**	0.1877**	0.0620**	0.062**	115.736**	
N level Q	1	305.231**	0.0625**	0.0165**	0.016**	40.664**	
				42 Days After Sowing			
N level	4	253.993**	0.0373**	0.0130**	0.013**	34.081**	3754.29**
Replication	3	0.6572	0.00048	0.0002	0.00018	1.015	26.67
Error	12	0.6338	0.00027	0.0001	0.0001	1.643	110.00
N level L	1	1365.63**	0.1773**	0.0648**	0.0648**	98.942**	16810.0**
N level Q	1	396.127**	0.0718**	0.0234**	0.0233**	132.656**	8750**

[z]F-values significant (*), highly significant (**) or non-significant (NS) at $p \leq 0.05$ or $p \leq 0.01$.

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APPENDIX B:

ELECTRICAL CONDUCTIVITY EXPERIMENT

Table B1 Analysis of variance of tomato growth and fruit characteristics as affected by electrical conductivity

Sources of variation	DF	Mean squares					
		Fruit mass (g)	No. of fruits	Shoot length (cm)	Stem diameter (mm)	No. of trusses	BER (%)
EC levels	3	1819.22**	11.583 ns	556.78*	2.634 ns	0.101ns	43.435**
Error	24	107.14	28.104	126.88	1.599	0.099	6.599

[z]F-values significant (*), highly significant (**) or non-significant (NS) at $p \leq 0.05$ or $p \leq 0.01$.

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Table B2 Analysis of variance of tomato yield and quality parameters as affected by electrical conductivity

Sources of variation	DF	Mean squares					
		Yield/ plant (kg)	Fruit diameter (mm)	Fruit circumference (mm)	Brix (%)	Titratable acidity (%)	pH
EC levels	3	1.13**	101.20**	13.12**	7.53**	6.39**	0.15**
Error	24	0.149	6.53	2.35	0.14	0.122	0.005

[z]F-values significant (*), highly significant (**) or non-significant (NS) at $p \leq 0.05$ or $p \leq 0.01$.

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