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EFFECT OF NUTRIENT CONCENTRATION AND GROWING SEASONS ON GROWTH, YIELD AND QUALITY OF LEAFY LETTUCE (*LACTUCA SATIVA* L.) IN A HYDROPONIC SYSTEM

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Effect of nutrient concentration and growing seasons on growth, yield and quality of leafy lettuce (*Lactuca sativa* L.) in a hydroponic system

By

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Submitted in partial fulfillment of the requirements for the degree M. Inst. Agrar: Plant Production
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DECLARATION

I hereby declare that the dissertation submitted herein for the M. Inst. Agrar: Plant Production degree is the result of my own work, except where duly acknowledged. I further declare that no plagiarism was committed in writing.

MR T S CHILOANE

DATE

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Abstract

Lettuce is becoming an increasingly important vegetable, both as a fresh market product and a ready-to use vegetable, especially in urban areas of South Africa. Nutrient solution concentration is one of the most practical and effective ways of controlling and improving the yield and nutritional quality of crops for human consumption. However, optimal fertilizer concentration for leafy vegetables also depends on the prevailing environmental conditions. This study was carried out to determine the effects of different nutrient solution concentrations and growing seasons on growth, yield and quality of leafy lettuce.

The trial was conducted in a black and white shade net structure and the nutrient concentration treatments were 1.0, 2.0, 3.0, and 4.0 $mS.cm^{-1}$. Measurements taken included: leaf number, leaf area, fresh leaf mass, dry leaf mass, dry root mass, as well as chlorophyll content. The sensory evaluation procedure was only done on plant samples grown during summer and winter seasons.

The results showed that growth was less affected by nutrient concentration than by growing season. Regardless of the nutrient concentration, plants grown in summer

reached maturity quicker as compared to plants grown in winter. Generally, leaf number, leaf area, leaf area index, fresh leaf mass, dry leaf mass and dry root mass did not significantly increase with increasing nutrient concentrations and therefore, yield was not influenced by nutrient concentrations. Quality was influenced by nutrient concentrations during the summer-autumn seasons where increasing nutrient concentration induced increased chlorophyll content of the leaves. During the winter-spring seasons this phenomenon was not significant.

The study demonstrated that growth, yield and quality of lettuce were not significantly influenced by nutrient solution concentrations of 1.0, 2.0, 3.0 and 4.0 $mS.cm^{-1}$. The sensory evaluation also showed no significant differences on the colour (quality) and flavor of the lettuce samples grown during summer and winter seasons and unfortunately it was not done during autumn and spring seasons. Irrespective of the nutrient solution concentration, growth was influenced by growing season because plants grown during summer reached maturity quicker as compared to plants grown during the other seasons.

GENERAL INTRODUCTION

Most vegetable growers are adopting soilless production due to its potential in terms of high yield, good quality crops, and in the case of leafy lettuce rapid growth which ultimately lead to faster turnover. Soilless cultivation of vegetables provides better control of plant growth and development as compared to traditional greenhouse production in soil (Dasgan *et al.,* 2008).

Lettuce (*Lactuca sativa* L.) is the most important hydroponically grown leafy vegetable crop in Europe using the nutrient film technique (NFT) system (Resh, 2006). In South Africa, lettuce is generally grown using the gravel film technique (GFT) system (Maboko & Du Plooy, 2009). Lettuce is an important vegetable commodity and in demand by the local markets throughout the year. This popularity has led to an increase in lettuce production and consumption in urban areas, since it has become popular as a vegetable salad (Maboko & Du Plooy, 2008). Lettuce is normally consumed raw and has a high nutrient value, being rich in calcium, iron and vitamin A. It is a good source of vitamins and a popular food for weight conscious consumers because of its low kilo joule content (Niederwieser, 2001; Maboko, 2007).

Gravel film technique hydroponic system (GFT) is also called a closed/recycling system whereby the nutrient solution is collected at the bottom of the hydrolines and pumped to the top again. Besides the fact that the GFT system requires good management of plant nutrition, it offers the benefits of saving water and nutrients. (Niederwieser, 2001) It further provides an added advantage to the environment by ensuring prevention of under-ground water contamination through nutrient recycling. However, hygiene is the most critical part in the everyday management of a recycling system. If the system is not sterilized properly by using chemicals (disinfectants or sterilants) combined with the planting of disease-free seedlings, root rot diseases like *Pythium* and *Phytophtora* can spread through this system very rapidly (Niederwieser, 2001).

The nutritional quality of vegetables can be affected by many pre-and post-harvest factors. Nutrient solution concentration is one of the most practical and effective pre-harvest ways to control and improve yield and nutritional quality of crops for human consumption. Fallovo *et al.* (2009) reported that an optimal nutrient solution composition for vegetable crops in closed hydroponic systems also depends on the environmental conditions. For example, low temperatures may inhibit water and nutrient uptake as a result of reduced transpiration while higher temperatures increase transpiration which is associated with the uptake of both water and nutrients by the plants. Higher temperature is also known to cause faster crop growth which enhance tipburn incidence (Saure, 1998), and when this happens it normally affect quality. The absorption of N ions (NH_4^+& NO_3^-) was increased at high root and air temperatures (Frota & Tucker, 1972), while Gosselin and Trudel (1983) reported that an increase in root temperature from 12 to 24^{o}C increased P. K, Ca and Mg content of tomato leaves.

The total nutrient concentration of the nutrient solution used in soilless culture is one of the most important aspects for successful vegetable production. Too high levels of nutrients induce osmotic stress, ion toxicity and nutrient imbalance, while too low levels generally lead to nutrient deficiencies (Fallovo *et al.*, 2009). As mentioned by Cornish (1992), an increase in electrical conductivity (EC) of the nutrient solution resulted in increased total soluble solids (TSS), titratable acidity and reduced fruit size, but with little or no effect on fruit firmness and yield of tomatoes.

Literature showed conflicting results concerning the optimum EC levels for leafy lettuce in a closed hydroponic system. For instance, Economakis (1990) recommended an EC level of between 2.0-3.0 mS.cm^{-1} in order to obtain more satisfactory results. Serio *et al.* (2001) stated that lettuce is considered to be moderately sensitive to salinity and therefore require an EC of 1.3 mS.cm^{-1}. As a result, farmers tend to either over fertilize or under fertilize which affect the performance of lettuce in terms of growth, yield and quality. This has serious economic implications for the farmer, especially when considering the souring prices of hydroponic fertilizers. It is crucial to understand the crop’s response to nutrient solution concentration (EC) levels and temperature in order to obtain maximum yield. Although there is a lot of research being done on nutrient concentration levels of lettuce, there is very little information on research done on the nutrient solution concentrations at different growing seasons in the gravel culture system used in South Africa. Therefore, the objective of this study was to determine the effect of different concentration of nutrient solution (EC) levels in a gravel culture hydroponic system during different growing seasons on growth, yield and quality of leafy lettuce.

CHAPTER 1

LITERATURE REVIEW

1.1 LETTUCE

Lettuce (*Lactuca sativa* L.) is becoming an increasingly important vegetable in salads, especially in urban areas of South Africa. Leafy lettuce in particular is gaining popularity in the market and among consumers, and it is also a good source of vitamins (Niederwieser, 2001; Maboko, 2007). However, the growth, yield and quality of lettuce can be affected by temperature either positively or negatively. For example, Rayder (1999) and Jenni (2005) as cited by Maboko and du Plooy (2008) reported that summer production of lettuce where temperatures are above 24^{o}C, results in the development of physiological disorders such as ribbiness, rib discoloration and bolting. On a positive note, Kanaan and Economakis (1992) reported that under high light and temperature conditions, there is a remarkable increase in lettuce growth suggesting a shorter growing period. Therefore, this is of benefit to the grower being able to have more crops per year.

1.2 FACTORS AFFECTING LETTUCE PLANT GROWTH, YIELD AND QUALITY

1.2.1 Temperature

Temperature is one of the critical factors determining the rate of growth of lettuce plants, and solution and air temperatures impact a variety of physiological processes. According to Salisbury and Ross (1992), the deleterious effects of high air temperatures on plants occur primarily in photosynthetic functions and most enzymes are also influenced by temperature. Marsch (1987) reported that higher temperatures promoted rapid growth rate and larger leaf area while Wolfe (1991) observed a significant reduction of leaf area ratio for many crop species when grown at cooler temperatures and this resulted in thicker leaves. Kanaan and Economakis (1992) further mentioned that high temperature often produces spindly and light-weight plants and temperatures higher than 21^{o}C promote seed stalk elongation, puffy heads, bitterness and an increased tendency toward internal disorder. Plant leaves grown at 15^{o}C appeared greener, thicker and more leathery in texture than compatible leaves grown at 25 ^{o}C (Dale, 1965).

High solution/root temperature may yield positive effects on crop production, for instance, Hicklenton and Wolynetz (1987) reported increased root temperature in a hydroponic system resulted in increased values for specific leaf area, leaf area ratio, and leaf weight ratio at final harvest. Low solution temperature may inhibit water uptake which will ultimately affect leaf growth. However, Jensen and Malter (1995) found that cooling the nutrient solution in nutrient film systems dramatically reduced bolting and decreased the incidence of the fungus *Pythium aphanidermatum*.

1.2.2 Rib discoloration and bolting

Lorenzo & Maynard (1988), as cited by Jenni *et al.* (2008) reported that growing lettuce at high temperatures causes rib discoloration and bolting which result in a reduction in product quality. Cox (1955) and Marlatt *et al.* (1957), as cited by Jenni *et al.* (2008), mentioned that rib discoloration happens when the plants mature and the heads become firmer, and small, brown streaks appear along the midribs of leaves located below the cap leaves. These lesions darken with time and are often followed in storage by soft rots caused by *Pseudomonas* Mig. species and other bacteria.

Also known as “running to seed”, bolting is where a plant suddenly starts to grow flower stems, simultaneously stopping all useful growth of the vegetable plant. Once the flower shoots form not only is growth slowed as the plants put all their energy into reproducing, but they can rapidly become unmarketable. Lettuce, for example, becomes bitter tasting and the leaves are less tender once the plant has bolted (Done, 2009).

1.2.3 Nutrient solution concentration and electrical conductivity (EC) levels

Electrical conductivity of nutrient solution is one of the most important factors which affect the success of the hydroponic systems. Frequently, quality is improved by nutrient application up to an optimum level, while applications well in excess of this may lead to lower quality, either because of a straightforward nutrient excess or because of imbalance between nutrients. Therefore, optimum use of EC level of nutrient solution and use of the ideal variety results in higher yield and better crop quality. The quality of crop products depends on inherited genetic make-up and on environmental (external) factors. The inherited factors determine the basic quality specific to the crop and variety, while the environmental factors affect the realization of the inherited potential (Abou-Hadid *et al*., 1996).

Higher EC solutions have a risk of increasing concentrations to toxic levels during the crop growth in stationary culture systems where solution is not renewed frequently. Further toxicities could occur in nutrient solutions over time, as solution gets concentrated due to rapid water absorption. Therefore, estimation of individual nutrient requirements in different growth stages is needed for the replacement of the nutrient solutions during the growth period (Samarakoon *et al*., 2006).

1.2.4 Salinity levels

Salinity is a measure of the total amount of soluble salts. As salinity levels increase, plants absorb water less easily, aggravating water stress conditions. High salinity can also cause nutrient imbalances, result in the accumulation of elements toxic to plants, and reduce water infiltration if the level of one salt element, for example, sodium, is high. Salt-affected plants are stunted with dark green leaves which, in some cases, are thicker and more succulent than normal. Salinity tolerance is influenced by many plant, soil, and environmental factors and their interrelationships. Generally, fruits, vegetables, and ornamental are more salt sensitive than forage or field crops. Climate and irrigation also influence salinity tolerance. As soil dries, salts become concentrated in the soil solution, increasing salt stress. Therefore, salt problems are more severe under hot, dry conditions than under cool, humid conditions. Increasing irrigation frequency and applying water in excess of plant demand may be required during hot, dry periods to minimize salinity stress (Kotuby-Amacher *et al*., 2000).

In hydroponics, the possibility to use a water source to prepare the nutrient solution is limited by water quality. When electrical conductivity (EC) is high, the increase in osmotic potential causes a reduction of water and mineral uptake by plant roots.

Furthermore, the use of water containing non-essential ions (mostly sodium & chloride) may cause nutritional imbalances and toxicity effects. Osmotic stress contribute to reduced growth rate and to changes in leaf colour and growth characteristics such as root/shoot ratio. On the other hand, salinity may have favourable effects on yield, quality and disease resistance (Shannon & Grieve, 1999). For example, sugar contents increase in carrot (Bernstein, 1959); and mild saline irrigation water may improve the quality of horticultural products by increasing dry matter content and sugar concentration in tomato fruit (Li *et al.,* 2001).

1.3 LETTUCE TIPBURN

1.3.1 Introduction

Tipburn is a breakdown of the leaf margins which is of particular concern on the internal heart leaves which are not obvious at harvest. External tipburn can also occur on the outer wrapper leaves but these can be trimmed at harvest. Tipburn is a critical defect which limits the appearance and shelf life of the lettuce (fresh market lettuce and minimally processed salad mixes). Internal tipburn is a problem for summer lettuce growers because its incidence is variable, some plantings are affected more than others and it may not be apparent at harvest. Tipburn can lead to internal bacterial breakdown or slime within the head and if the lettuce is to be used for salad dramatically reduce shelf life (Murdoch *et al*., 2003).

Tipburn in lettuce has been generally recognized as a calcium deficiency disorder, caused by localized calcium deficiency of leaves or leaf margins (Saure, 1998; Cubeta *et al*., 2000). Tipburn is a serious problem when both temperatures and radiation levels are high, as can be experienced both in glasshouses and field production conditions (Collier & Tibbitts, 1982). Tipburn is a feature of rapidly growing summer lettuce (but it can also occur in spring and autumn) and reflects the inability of plants to move sufficient water and nutrients to the rapidly growing leaf tissues enclosed in the heart of the lettuce plant.

Tipburn is induced by a number of factors including growth rate, which are a function of climate, water and nutrient availability, supply of calcium and any stress imposed on the plant which results in uneven growth rate (Murdoch *et al*., 2003). Wissemeier and Zuhlke (2002) mention that in studies under controlled conditions, it could be shown that in conditions with higher growth rates due to higher temperature, high light intensity and a longer lighting period or a higher CO_2 supply the incidence and severity of tipburn were increased.

1.3.2 Symptoms of tipburn

Tipburn is the marginal collapse and necrosis, at or near the leaf margins, of rapidly expanding inner leaves (Fig 1.2 & Fig 1.3). The disorder usually occurs near harvest, when it can result in complete crop loss. Early symptoms include vein discoloration and/or the development of dark brown to black spots near or at the leaf margins. These may be accompanied by browning of small veins in the affected area. As the disorder progresses, the necrotic areas coalesce, forming a lesion up to several centimeters in length (Fig. 1.1). Necrosis is frequently delineated by venation and further leaf development and expansion is abnormal, and rots caused by secondary organisms are possible (Murdoch *et al*., 2003).

Fig. 1.1 Dark brown spots near the leaf margin followed by marginal necrosis of leaves/ external tipburn symptoms (Anonymous, 2003)

Tipburn injury is restricted to the leaf apex and distal margin, which is characterized by water-soaked, laminal and veinal chlorosis, and lacticifer rupture. Moreover, darkening of the leaf margins results from lacticifer enlargement and rupture, which release latex into surrounding tissue and causes collapse of parenchyma and occlusions of xylem elements (Collier & Tibbitts, 1982).

Fig. 1.2 Dark brown spots at the leaf margin

Creswell (1991) summarized three symptoms in lettuce as glassiness, purple spotting and cupping, and all appeared to be aspects of tipburn injury. In summary, the following developmental sequence was noted (Creswell, 1991):

- Glassiness is the first recognizable stage of tipburn and likely occurs in the mornings under high relative humidity conditions.
- The purple spots present in tissues affected by glassiness soon become desiccated producing the characteristic scorch symptoms of tipburn.
- Cupping is the final stage in the development of tipburn, which occurs because of the margins of young leaves damaged by tipburn fail to expand fully.

It was found that inner leaves with tipburn contain less calcium than inner leaves without tipburn (Collier & Tibbitts, 1982).

Fig. 1.3 Dark brown spots near the leaf margin followed by marginal necrosis of inner leaves/ internal tipburn symptoms (Anonymous, 2000)

Leaves with tipburn are unsightly and damaged leaf margins are weaker and susceptible to decay. In fact, tipburn causes the leaves to deteriorate and can result in diseases, such as soft rot, contaminating both whole and bulk shredded lettuce produce (Anonymous, 2000). Lettuce with tipburn is susceptible to secondary fungal and bacterial infections (Creswell, 1991).

1.3.3 Causes of tipburn

1.3.3.1 Calcium deficiency disorder

Calcium deficiency is considered a major cause of the tipburn disorder. Tipburn is known to be related to localized Ca deficiency in rapidly growing tissues, and Ca deficiency is considered as the cause of tipburn (Saure, 1998). Murdoch *et al.* (2003) mentioned that calcium strengthens plant cell walls and membrane integrity, and tipburn is more accurately related to the inability of plants to supply enough calcium to developing leaves during periods of rapid growth. Calcium moves from the roots to the leaves of the plant along with water drawn by the transpiration process. Rapidly transpiring outer leaves draw most of the water and accumulate most of the calcium. Enclosed heart leaves, which are growing rapidly, have a much lower transpiration rate and draw less water and consequently less calcium. With less calcium available, the rapidly growing heart leaves from weaker cell walls which may collapse and die as the leaves expand close to harvest. These breakdown sites allow entry of bacteria which results in further breakdown and unmarketable product (Murdoch *et al*., 2003).

While tipburn is generally considered a calcium deficiency problem, symptoms can occur despite plentiful supplies of calcium in most vegetable growing soils. The problem is moving sufficient calcium to the rapidly growing inner leaves. External tipburn can occur for similar reasons but can also be caused by windburn, sand blasting or other physical damage to the delicate growing leaf tips (Murdoch *et al*., 2003).

Warm temperature, excessive fertilization, an increase in light intensity, and other factors that contribute to rapid growth of lettuce can enhance the development of tipburn as a result of low mobility of calcium ions within the plant. Other factors reduce the uptake of calcium such as high salt concentrations and high humidity can intensify the problem (http://agrisupportonline.com/Articles/disorders_in_lettuce.htm).

1.3.3.2 Crop growth rate

High summer growth rates are clearly one of the major factors leading to tipburn in lettuce because high growth rates place a greater demand on the individual plants ability to provide adequate water and nutrients to rapidly growing leaf tissues. In summer, a lettuce crop grows at more than twice the rate in winter. Periodic stress will also have an impact because fluctuations in supply of fertilizer or water may cause surges in growth rate and result in tipburn (Murdoch *et al*., 2003).

The higher the growth rate of lettuce, the earlier appeared the first symptoms of tipburn, both in terms of time from emergence and of number of developed leaves. However, tipburn may still increase when there is no further increase in head weight at the end of the growing season, especially if nitrogen supply is in excess of demand (Saure, 1998).

1.3.3.3 Temperature

Temperature in the root zone also affects the uptake of Ca. The uptake of Ca increases between 14 and 26^{o}C, but at higher root temperature it will be reduced (Adams & Ho, 1993). Higher temperature enhanced tipburn incidence by promoting growth and, thus, reducing stress tolerance (Saure, 1998). Therefore, the severity of tipburn may be caused by extremes of root temperatures.

Tipburn may be a big problem for the production of Chinese cabbage and lettuce in subtropical and tropical regions during the hot season. Therefore, in these regions place and time of commercial plantings usually are chosen to avoid hot weather around harvest time. Apparently, there is a greater risk of tipburn if there is a change in temperature, with a sudden period of warm weather after an extended period at lower temperature, or several days of high temperature together with low humidity (Saure, 1998).

1.3.3.4 Humidity

Transpiration is the main driving force for Ca transport in plants, since Ca moves along with water in the xylem (Islam *et al.*, 2004). High relative humidity depresses the rate of transpiration and distribution of Ca to the leaves, particularly to the terminal leaflets of rapidly growing leaves (Adam & Ho, 1995). A study by Gislerød *et al.* (1987) found a reduced amount of Ca in tomato plants grown at high relative humidity (90-95%) compared to low relative humidity (70-75%). Creswell (1991) reported that glassiness occurred mostly on mornings with high relative humidity. Therefore, lower relative humidity improves Ca distribution in plants, which may be helpful in reducing tipburn.

1.3.3.5 Fertilizer

Most authors agree that tipburn is related to localized Ca^{2+} deficiency in the rapidly growing tissues, and many of them consider Ca^{2+} deficiency as the cause of tipburn. Consequently, the influence of external tipburn factors on tipburn incidence has been often an increased growth rate on the Ca^{2+} content of the leaves (Saure, 1998).

In addition to its effect on growth rate, high relative humidity may also interfere directly with the distribution of Ca^{2+}. Thus, the role of relative humidity in Ca^{2+} transport remains in dispute. Ca^{2+} movement in plants takes place not only by mass flow but also by a series of exchange reactions along negatively charged sites of xylem vessels.

1.3.3.6 Light

Light is regarded as a primary factor regulating plant growth and development (Gaudreau *et al.*, 1994). Sudden changes to very sunny and dry weather after an extended darker and more humid period promote the occurrence of tipburn. Tipburn does not occur under conditions of low light intensity or extended periods of darkness. Tipburn, which appears during head formation, is a disorder associated with low calcium levels and causes young leaves to become brown and to have necrosis beginning at the leaf margins (Collier and Tibbitts, 1982). Head formation is a major standard of lettuce quality and is stimulated by suitable light and temperature conditions (Gaudreau *et al.*, 1994).

1.3.4 Control of tipburn

Good cultural and management practices that do not promote rapid and excessive plant growth limit the incidence of tipburn. For example, the use of drip irrigation instead of massive, intermittent types of water application may help to avoid sudden changes in growth rates (Davis *et al*., 1997). Therefore, good irrigation practices are critical to maintaining a good even crop growth rate and facilitating effective uptake of nutrients. Lettuce has a shallow root system and, to achieve a marketable yield, requires a constant supply of moisture during the growing season. To maintain an even moisture level in the soil and any other medium, the moisture levels should be monitored and irrigation requirements scheduled according to need (Murdoch *et al*., 2003).

Foliar sprays of calcium salts can reduce tipburn in particularly or fully opened butterhead, leaf, and romaine types of lettuces but are ineffective on crisphead cultivars (Davis *et al*., 1997). Cultivars can have the most significant effect on any individual factor on the incidence of tipburn. In field trials, cultivars differed significantly in their susceptibility to tipburn throughout the season. It is important when choosing cultivars for times of the year when tipburn may be a problem to consider using some cultivars with tipburn resistance. Relatively resistant cultivars are available, although the genetic basis is not known. Check with your seed suppliers for appropriate cultivars (Murdoch *et al*., 2003).

Growth rate is critical to lettuce and it is important to maintain a consistent crop growth rate by maintaining an even supply of nutrients and water throughout the growth of the crop, but particularly towards (maturity stage) harvesting. There is potential to control growth rate by reducing excessive application of nutrients such as nitrogen and providing consistent, even moisture levels (Murdoch *et al*., 2003).

Ocamb (2007) summarized the control of lettuce tipburn as follows:

- Use the more resistant cultivars.
- It is important to maintain adequate calcium levels in soil and to manage fertilizer and irrigation programs to provide even growth throughout the plant's life. Soil samples should show adequate base saturation and adequate levels of calcium.
- Nitrogen forms may be important; nitrate forms are preferred to ammonium forms.
- Harvest lettuce at optimum maturity because tipburn tends to be more serious on overmature lettuce.

1.4 DISCUSSION AND CONCLUSIONS

Lettuce is traditionally grown as a cool weather crop but, by optimizing temperature and nutrition lettuce production can be grown throughout the year (Thompson & Langhans, 1998). Higher temperatures may result in the development of physiological disorders such as tipburn and bolting. However, cooler temperatures may retard plant growth although it will not affect yield and quality. Therefore, plants grown during cooler season takes longer period to mature as opposed to plants grown during the warmer months.

Cultivar choice is vital as it may determine the success or failure of lettuce production. Although lettuce is considered as a cool season crop, nowadays there are cultivars that can tolerate heat. It is very important that when planting during the warmer months, heat-tolerant cultivars should preferably be considered. Heat tolerant cultivars have low incidences of physiological disorder. As mentioned by Maboko and du Plooy (2008), improvement in yield and quality can be obtained by selecting the correct cultivars for winter production of lettuce in a soilless condition.

Nutrition of lettuce is another important factor that may influence the growth, yield and quality of lettuce plants. There is very little information in the literature on the standard nutrient solution concentration (EC) levels for hydroponic production of lettuce. As a result, too high or too low nutrient solution concentrations are used which negatively affect crop growth and yield.

Too high levels of nutrients stimulate faster plant growth which will induce tipburn and nutrient imbalance while too low nutrient levels will lead to nutrient deficiencies (Fallovo *et al.*, 2009).

Further studies are needed to investigate proper nutrient solution concentrations and temperature manipulation (out-of-season production) for lettuce production in a soilless medium. These studies should focus on standard nutrition (fertilization) levels, correct cultivar choice, optimum temperature or an interaction between these parameters.

CHAPTER 2

MATERIALS AND METHODS

2.1 INTRODUCTION

Lettuce (*Lactuca sativa* L.) is the most popular amongst the salad vegetable crops and it belongs to the family Asteraceae. It is closely related to common wild lettuce or prickly lettuce (*Lactuca seriola* L.) and less closely related to two other wild lettuces (*Lactuca saligna* L. and *Lactuca virosa* L.) (Valenzuela *et al*., 1993).

Recirculating gravel film technique (GFT) system is becoming increasingly popular in the production of leafy vegetables in South Africa. The GFT system can produce excellent quality plants and improve uniformity because of more even watering and fertilization (Kang & Van Iersel, 2001). Lettuce is regarded as a winter crop, however, with the use of optimum nutrient concentrations for the right temperatures, lettuce can be profitably produced throughout the year. The water use efficiency of plants depend greatly on environmental conditions, therefore, plant response to fertilizer/nutrient concentrations can be affected by environmental conditions. For example, Vavrina (1996) has shown that the optimal nutrient concentration for the production of vegetable transplants differs in spring and autumn (Kang & Van Iersel, 2001).

Unfortunately, most recommendations for the fertilization of vegetable plants has been done for European conditions and does not take into account the South African climatic conditions. The transpiration rate of plants generally increases with increasing temperature, decreasing the water use efficiency. Therefore, different temperatures may be a good treatment variable to look at possible interactive effects of environmental conditions and nutrient solution concentration on plant growth (Kang & Van Iersel, 2001).

2.2 MATERIALS AND METHODS

2.2.1 Locality

The trial was conducted in a 40% black and white shade net structure, at the Experimental farm of the Agricultural Research Council's Vegetable and Ornamental Plant Institute (ARC-VOPI) at Roodeplaat (25º 35' S and 28º 31' E, at an altitude of 1 164 m above sea level) situated approximately 17 km north of Pretoria, South Africa, from May 2008 to March 2009.

2.2.2 Treatments and experimental design

The trial was laid out as a Latin Square Design (LSD). The treatments were four electrical conductivity levels and four replicates. The electrical conductivity (EC) levels of the nutrient solutions utilized in the trials were 1.0 $mS.cm^{-1}$ (30 g Hygroponic + 30 g Calcium Nitrate); 2.0 $mS.cm^{-1}$ (85 g Hygroponic + 85 g Calcium Nitrate); 3.0 $mS.cm^{-1}$ (130 g Hygroponic + 130 g Calcium Nitrate) and 4.0 $mS.cm^{-1}$ (190 g Hygroponic + 190 g Calcium Nitrate), prepared in 100L of water. These fertilizers are products of Hygrotech, South Africa. The composition and chemical concentration of the two fertilizers are presented in Table 2.1.

Leafy lettuce seedlings of green-oakleaf cultivar 'NIZ 44-675' (Nickerson-Zwaan, South Africa) were raised according to the normal procedure for seedling production as described by Niederwieser (2001). This cultivar is fast growing with bright, lime green and long wavy leaves. It copes well with summer heat as it holds flavour and texture well and is slow to bolt. It is also a good choice in cooler areas for its ability to grow rapidly even in early spring. Seedlings for the different seasons were raised for four weeks and transplanted into mini-hydroponic tables using gravel as the growing medium. The seedlings that were transplanted were free from diseases and pests, of the same size in terms of height and age as pointed out earlier. The particle size of the gravel was between 9-13 mm in diameter and a plant spacing of 15 x 20 cm was used. A total of 30 plants were planted in each of the 16 tables and 12 data plants per treatment were used for analysis. The gravel was contained in BR100Z black troughs of 139 x 76 x 11 cm, and the slope of the table was 3%.

Table 2.1 Composition and chemical concentration of the two fertilizers (Hygroponic and Calcium Nitrate) used are as follows

Types of fertilizer	Composition	Concentration ($g.kg^{-1}$)
Hygroponic	Nitrogen (N)	68
	Phosphate (P)	42
	Potassium (K)	208
	Magnesium (Mg)	30
	Sulfur (S)	64
	Iron (Fe)	1,254
	Copper (Cu)	0.022
	Zinc (Zn)	0.149
	Manganese (Mn)	0.299
	Boron (B)	0.373
	Molybdenum (Mo)	0.037
Calcium Nitrate	Nitrogen (N)	117
	Calcium (Ca)	166

The pH of the irrigation water was maintained to vary between 5.5-6.8 using nitric acid and this was corrected only once a week just before adding fertilizers into the water.

Black plastic drums used as reservoirs were placed at the bottom of the tables with a constant recirculation of the nutrient solution. A small submersible pump in each drum supplied the nutrient solution through five spaghetti tubes connected on a 15 mm black polyethylene pipe at the top end of every table. The flow rate of the nutrient solution was adjusted using a ball-valve to release 300 ml per minute per spaghetti tube. The pump was ran 24 hours a day. The pH and EC of the nutrient solution were measured and recorded on a daily basis using pH & EC combo meter (Hanna Instruments, Mauritius).

Minimum and maximum ambient temperatures inside the shade net structure was recorded daily (Maxima-Minima Thermometer, Germany) and nutrient solution temperature was measured on a daily basis at 12 o'clock midday (Digi-Sense Thermocouple Thermometer, Singapore).

2.2.3 Plant growth measurements

The plant samples were sent to University of Pretoria's Soil Science Laboratory to analyze and determine the nutrient content. The plant growth parameters that were measured at the end of the growing season included leaf number, leaf area, fresh leaf mass, dry leaf mass and dry root mass. Leaf area was measured with a LI-3100 leaf area meter (Licor, Nebraska, USA). Any other possible observations including physiological disorders were recorded. The chlorophyll content was taken from the young leaf of one plant per treatment per replicate. Chlorophyll content was measured weekly using Minolta SPAD meter (Japan).

The number of days to maturity was determined by counting the total number of days from transplanting to harvesting.

2.2.4 Statistical analysis

Plant growth data were analysed using the statistical software GenStat (2003). Analysis of variance (ANOVA) was used to test for differences between the four nutrient concentrations and treatment means were separated using Fisher's protected t-test least significant difference (LSD) at the 5% level of significance (Snedecor & Cochran, 1980).

CHAPTER 3

EFFECT OF NUTRIENT CONCENTRATION AND SUMMER GROWING SEASON ON GROWTH, YIELD AND QUALITY OF LEAFY LETTUCE IN A HYDROPONIC SYSTEM

3.1 INTRODUCTION

Temperature affects the productivity and growth of a plant, depending upon whether the plant is classified as a warm- or cool-season crop. For instance, if temperatures are high and day length's long, cool-season crops such as spinach will flower, while temperatures too low for a warm-season crop such as tomato will prevent fruit set. Adverse temperatures also cause stunted growth and poor quality vegetable production; for example bitterness in lettuce is caused by high temperatures (http://www.d.umn.edu/biology/courses/bio1010/documents/5lFactorslecture_000.doc).

As reported by Jenni (2005), Maboko and Du Plooy (2009) and Rayder (1999) summer production of lettuce with associated high temperatures, results in the development of physiological disorders like tipburn, ribbiness, rib discoloration and bolting (Figure 3.1). Although lettuce is considered as a cool weather crop, the use of proper nutrient solution concentration (electrical conductivity level), choosing the right cultivar for any particular season and manipulation of temperature can result in the out-of-season production of good quality lettuce. It is well known that most plant roots function best at a temperature between high teens and the mid twenties, outside this range, roots will function poorly (Chil *et al.*, 2001). For example, solution temperature directly affects the nutrient status of a plant by affecting nutrient absorption and translocation and indirectly by its effects on the production rate of hormones in the roots (Papadopoulos & Tiessen, 1987). Solution temperature affects water uptake and therefore, nutritional problems can result from high root temperatures as well as low root temperatures (Barry, 1996), because nutrients are transported from the root system to different parts of the plant through the transpiration stream. As reported by Gent and Ma (2000), Cannell *et al.* (1963) and Cornillon (1974) root-zone temperature cooler than 15ºC dramatically slows the uptake of mineral elements in the shoots of tomato, even if the shoots are at an optimum temperature. Heating the root-zone to 24ºC increases phosphorus and potassium concentrations in the shoots of tomato plants grown under a 12 or 15ºC night temperature, but the effect of heating roots is much less at air temperatures of 21ºC or above (Gosselin & Trudel, 1983b).

The objective of this study was to determine whether growth, yield and quality of leafy lettuce can be influenced by nutrient concentration during the summer growing season.

3.2 MATERIALS AND METHODS

3.2.1 Locality

The trial was conducted from January 2009 to February 2009. Please refer to Chapter 2 for more materials and methods.

3.2.2 Sensory analysis

Quality (taste) tests were also done at the end of the growing season (after harvesting) by conducting the sensory evaluation procedure. The lettuce samples were harvested and immediately delivered to the Sensory Research Division, University of Pretoria on Wednesday, 4 February 2009. Within each of the four sample treatments, four replicates were included (± 3 heads per replicate). The lettuces were stored at 5°C for use the following day. The lettuce leaves were removed by hand from the heads and placed in basins filled with tap water and washed. Very large leaves (the outer leaves) were cut in half so that there was no big difference in the size of the leaves served to consumers. The samples were served in the order of a completely balanced block design. Each consumer received a tray with four lettuce samples. Leaves for each sample were placed on a white foam tray (260 mm X 120 mm). Each sample included four leaves, one leaf from each replicate. The four foam trays were served simultaneously on a larger plastic tray (390 mm X 280 mm). Filtered tap water in a 175 ml foam glass was provided to consumers to serve as a palate cleanser. The lettuce leaves within a sample that were served to consumers did vary in size. An effort was made to sort and serve leaves over the group of samples in such a way that the variation in leaf sizes did not play a significant role in the evaluation. Consumers indicated their acceptance (how much they liked or disliked) the colour and taste (“flavour”) of the lettuce leaves using a 5 point scale: 1=very poor, 2=poor, 3=moderate, 4=good and 5=very good. The results of the sensory evaluation tests were captured and analysed using Compusense ® *five* data collection software (Compusense ® *five*, release 4.6, Compusense Inc., Guelph, ON, Canada) and Microsoft Excel. The effect of the sample and consumer on the preference for colour and taste were analysed using two-way analysis of variance (ANOVA). To determine significant differences between the treatments, a 5% significance value (p-value) was used and where applicable, the Fisher Least Significant Difference (LSD) test was used to investigate the nature of the differences in the preference ratings for different samples. For the preference ranking, Friedman analysis test at 10% significance value (p-value) for rank sum totals was used.

3.2.3 Statistical analysis

Plant growth data were analysed using the statistical software GenStat (2003). Analysis of variance (ANOVA) was used to test for differences between the four nutrient concentrations and treatment means were separated using Fisher’s protected t-test least significant difference (LSD) at the 5% level of significance (Snedecor & Cochran, 1980).

3.3 RESULTS AND DISCUSSION

Temperature recorded during the summer season was higher (17-34ºC) (Fig. 3.1) than the recommended optimum temperature (17-27ºC) for lettuce growth (Niederwieser, 2001). Because of this temperature effect, plants grew faster during this season reaching maturity within 30 days and physiological disorders like tipburn (Fig. 3.5) and bolting (Fig. 3.2) were also observed (data not presented). In other words, the summer season had the most tipburn prevalence. This which was not related to EC levels since it affected all the crops across the different treatments.

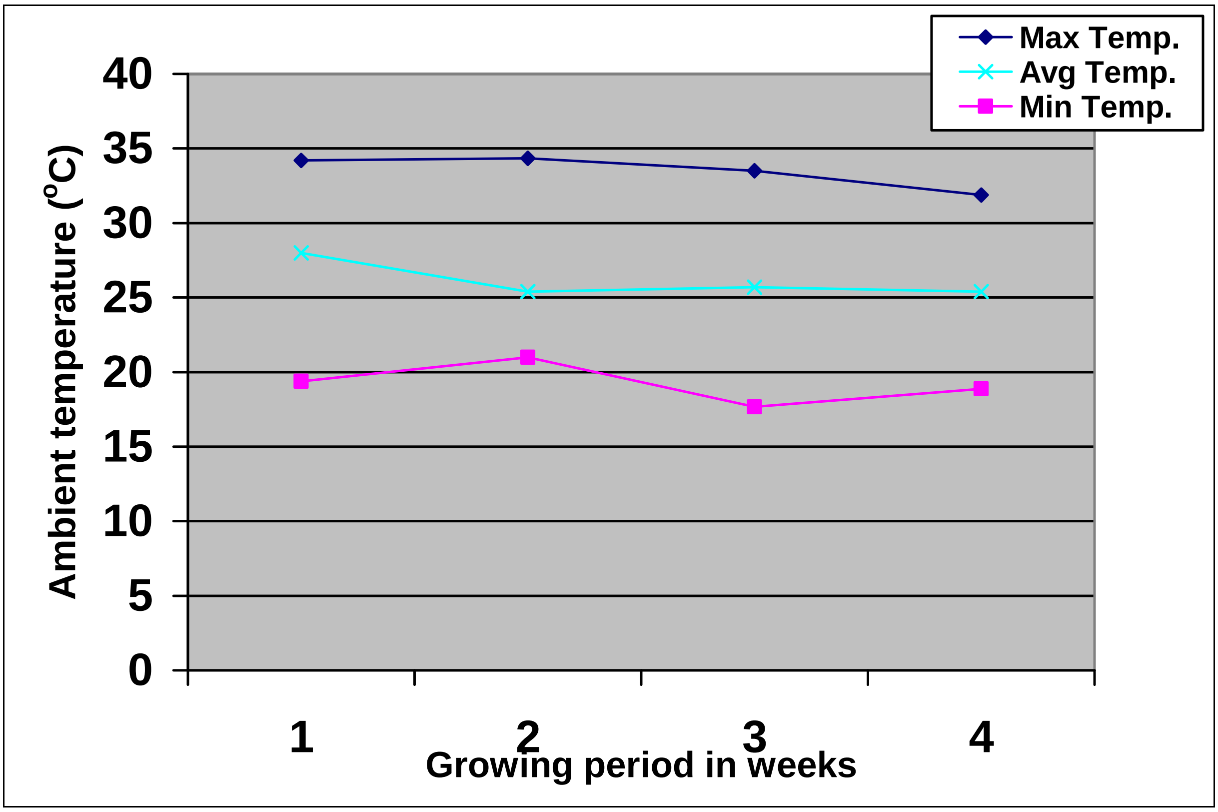

Fig. 3.1 Ambient temperature readings recorded during the summer growing season

Fig. 3.2 Lettuce plant showing elongated stem indicating bolting

3.3.1 Effect of nutrient concentration on growth, yield and quality

An increase in nutrient concentration did not contribute to an increase in the number of leaves (Table 3.1). Although there was also no significant difference in leaf area among the different treatments there was a tendency to increased leaf area with increasing nutrient solution concentration (Table 3.1). The highest leaf area was obtained from plants grown at EC levels (nutrient concentrations) of 2 and 3 $mS.cm^{-1}$. It is well known that crop growth and yield are negatively affected by too high or too low nutrient solution concentrations. This is consistent with a trial conducted by Fallovo *et al.* (2009) who found that the marketable fresh yield, dry shoot biomass and leaf area index were significantly reduced at low (2 and 18 mequiv L^{-1}) and high (66 mequiv L^{-1}) fertilizer concentrations as a result of nutrient deficiencies and osmotic stress respectively.

Fresh mass increased with increasing the nutrient concentration reaching maximum at EC level of 3 $mS.cm^{-1}$ (Table 3.1). Although EC of 1 $mS.cm^{-1}$ resulted in the lowest fresh mass, it was not significantly different from the fresh mass at other EC levels. In lettuce, leaf area and fresh mass are directly related to yield and the higher EC levels (3 and 4 $mS.cm^{-1}$) resulted in the highest yield.

Table 3.1 Effect of nutrient concentration on leaf number, leaf area, leaf area index and fresh mass of lettuce plants

Treatment ($mS.cm^{-1}$)	Leaf number ($number.plant^{-1}$)	Leaf area ($cm^2.plant^{-1}$)	Leaf area index (cm^2)	Fresh mass ($g.plant^{-1}$)
EC 1	27.5 ± 6.9a	1668 ± 576.8a	4.7a	163.4 ± 42.7a
EC 2	26.4 ± 4.6a	2417 ± 1196.0a	6.9a	217.1 ± 61.4a
EC 3	27.0 ± 4.4a	2838 ± 1007.0a	8.1a	235.2 ± 61.6a
EC 4	24.8 ± 6.2a	2169 ± 792.5a	6.2a	220.7 ± 67.7a
LSD	ns	ns	ns	ns

Means followed by the same letter within the column are not significantly different at 5% level of probability

There were no significant differences between the leaf dry mass in all the treatments. As from EC of 1 $mS.cm^{-1}$ to EC of 2 $mS.cm^{-1}$ the leaf dry mass tended to increase with increasing nutrient solution concentration and thereafter it remained almost constant (i.e. EC 2, 3 and 4 $mS.cm^{-1}$) (Table 3.2).

Although there was a trend of decreasing root dry mass with an increase in the nutrient concentration, the root dry mass was not significantly different among all the treatments (Table 3.2). Therefore, an increase in nutrient concentration did not contribute to root development and growth. All the treatment parameters during the summer season were not significantly different and this could be due to a high degree of normal variation.

Table 3.2 Effect of nutrient concentration on leaf dry mass and root dry mass of lettuce plants

Treatment ($mS.cm^{-1}$)	Leaf dry mass ($g.plant^{-1}$)	Root dry mass ($g.plant^{-1}$)
EC 1	6.2 ± 1.7a	7.7 ± 2.3a
EC 2	8.4 ± 2.5a	7.0 ± 2.9a
EC 3	8.2 ± 2.8a	6.7 ± 2.1a
EC 4	8.0 ± 2.4a	7.6 ± 2.1a
LSD	ns	ns

Means followed by the same letter within the column are not significantly different at 5% level of probability

There was significant increase of the chlorophyll content with increasing EC levels of the nutrient solution concentrations (Fig. 3.3). These results are consistent with the findings of Fallovo *et al.* (2009). There were significant differences between treatments 1 and 3 (1 $mS.cm^{-1}$ and 3 $mS.cm^{-1}$), with the highest chlorophyll concentration observed at 3 $mS.cm^{-1}$. The chlorophyll content of plants grown using treatments 2 and 4 (2 $mS.cm^{-1}$ and 4 $mS.cm^{-1}$) were not significantly different. This colour differences indicate a positive effect with increased nutrient concentration on the quality (colour) of lettuce plants whereby EC of 1 $mS.cm^{-1}$ resulted in light green/yellowish plants (Fig. 3.4).

However, it must be stressed that it is easy to see colour differences on lettuce plants in the field (Fig. 3.4) but rather a bit difficult during the sensory evaluation. Plants grown with an EC of 3 $mS.cm^{-1}$ showed to have dark green colour while plants grown with an EC of 2 and 4 $mS.cm^{-1}$ produce lettuce with normal green colour.

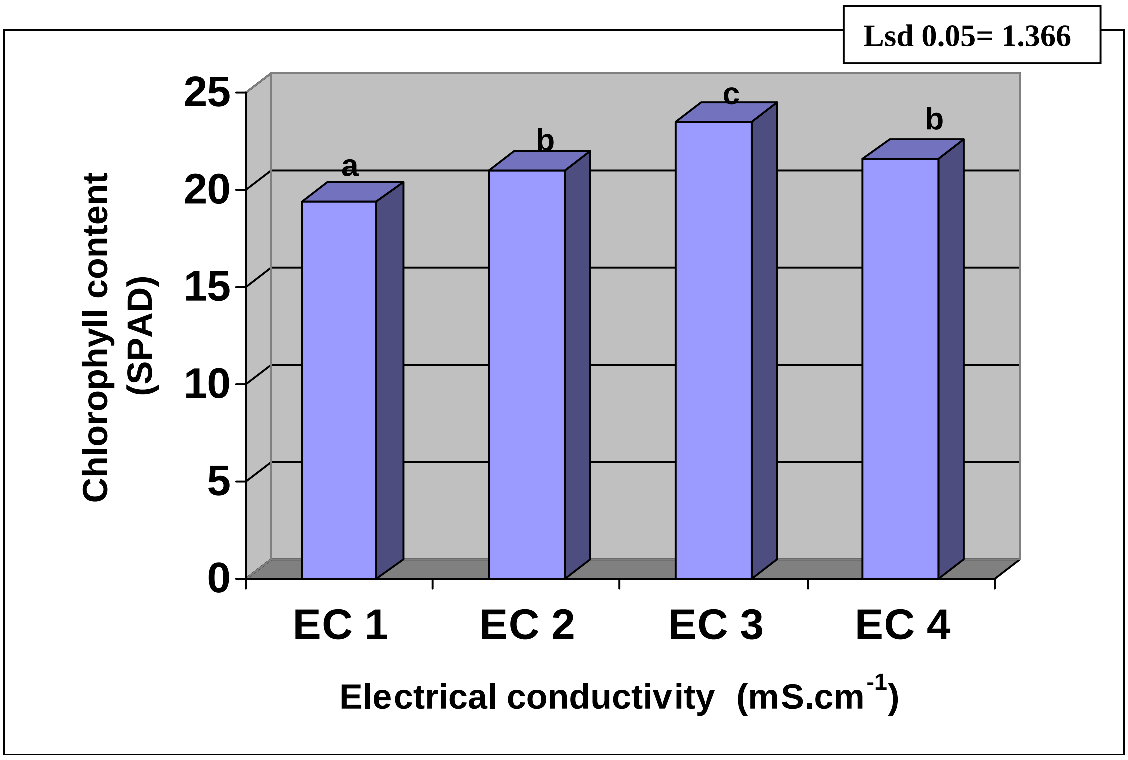

Fig. 3.3 Chlorophyll content of lettuce measured using SPAD meter during the summer growing season. Bars with the same letters are not significantly different at 5% level of probability

3.3.2 Sensory evaluation test

No significant differences were found regarding the preference for any of the four lettuce samples in terms of colour and flavour/taste. The colour of the lettuce samples was described as ranging from normal lettuce colour, pale green to dark green. The colour differences are related to higher chlorophyll content due to increased nutrient solution concentration treatments (Fig. 3.4). In terms of lettuce flavour, consumers' comments ranged from bland, sweet to bitter taste.

Fig. 3.4 Colour difference on the lettuce plants as influenced by nutrient concentrations (EC levels)

Table 3.3 Mean ratings (± std dev) for the consumer acceptance (n=50) of the lettuce samples (1=Very poor, 5=Very good)

Attribute	EC level 1	EC level 2	EC level 3	EC level 4	p-value
Colour	3.6 ± 0.9	3.8 ± 1.0	3.7 ± 0.9	4.0 ± 0.8	0.08
Taste	3.0 ± 1.2	3.5 ± 1.2	3.0 ± 1.2	3.4 ± 1.2	0.09

The different treatments that the lettuce samples were exposed to, did not have an effect on consumer preferences. In other words, consumers equally liked the lettuce samples from the four treatments with regard to the colour and flavour (Table 3.3).

3.3.3 Effect of EC levels on nutrient content in leaf tissues

The nitrogen (N) content from the plants grown using treatment 4 (4 $mS.cm^{-1}$) were significantly higher than the N content from plants grown using 1 $mS.cm^{-1}$, 2 $mS.cm^{-1}$ and 3 $mS.cm^{-1}$ probably due to high N concentrations in the fertilizer solution. The N content from plants grown using treatments 1-3 $mS.cm^{-1}$ were not significantly different. The phosphorus (P), potassium (K), calcium (Ca) and magnesium (Mg) contents in leaf tissues of lettuce plants were not significantly different, but they showed a quadratic increase with increasing nutrient concentrations. These results are consistent with the findings of Fallovo *et al.* (2009) and Samarakoon *et al.* (2006) who observed quadratic and linear increases respectively in response to increasing nutrient concentrations. However, plants grown using 2 $mS.cm^{-1}$ tended to have higher P, Ca and Mg contents than the other treatments except for treatment 3 (3 $mS.cm^{-1}$) which had a slightly higher K content (Table 3.4). As reported by Fallovo *et al.* (2009) vegetables contribute about 24% to the total K and Mg dietary intake of humans, therefore an increase in the K and Mg concentrations with increasing nutrient solution concentration is very interesting from a nutritional point of view.

Table 3.4 Effect of nutrient concentration (EC) levels on nutritional element concentrations in leaf tissues of lettuce plants

Treatment ($mS.cm^{-1}$)	N (%)	P (%)	K (%)	Ca (%)	Mg (%)
Acceptable ranges	**3.0-6.0**	**0.8-1.3**	**5.0-10.8**	**1.1-2.1**	**0.3-0.9**
EC 1	2.9 a	1.3 a	1.7 a	1.3 a	0.3 a
EC 2	2.9 a	1.5 a	2.9 a	1.5 a	0.4 a
EC 3	3.0 a	1.5 a	2.9 a	1.4 a	0.4 a
EC 4	3.5 b	1.3 a	2.4 a	1.2 a	0.3 a
LSD	0.355	ns	ns	ns	ns

Means followed by the same letter within the column are not significantly different at 5% level of probability

The microelements were also analysed and were not significantly different in all the treatments which means that they were not affected by the treatments or an increase in nutrient concentrations.

3.4 CONCLUSIONS

Growing of lettuce during the summer months without proper understanding of the correct fertilization (amount of fertilizer to apply) would result in economic loss due to poor growth, yield and quality. As shown in the results obtained during this trial, increasing the nutrient solution concentration above 2 $mS.cm^{-1}$ during the summer season had no positive effect on lettuce crop in terms of growth, yield and quality. All the lettuce plants grown using the different treatments reached maturity simultaneously. Growing lettuce at 2 $mS.cm^{-1}$ resulted in good quality crop in terms of colour and flavour/taste which were not different from the crops produced at higher EC levels (3 and 4 $mS.cm^{-1}$). In fact, lettuce samples grown using treatment 2 were more preferred by the consumers than the samples grown with other treatments (Table 3.5). Summer production of lettuce has an added advantage of faster growth whereby plants reached maturity quicker due to high temperatures.

Table 3.5 Preference ranking results of the four lettuce samples (1 = sample most preferred, 4 = sample least preferred) (n=51)

	Sample	Rank totals	p-value (0.093)
1	EC level 2	109	
2	EC level 4	126	
3	EC level 1	137	
4	EC level 3	138	

Tipburn in lettuce has been generally recognized as a calcium deficiency disorder, caused by localized calcium deficiency of leaves or leaf margins (Saure, 1998; Cubeta *et al.*, 2000). Tipburn is a serious problem when both temperatures and radiation levels are high (Collier & Tibbitts, 1982). The results of the nutrient analysis in the leaves indicate that Ca was enough or within the recommended ranges (Table 3.4), however, there was a problem of tipburn across all the different treatments.

Fig. 3.5 Lettuce plant showing tipburn symptoms

The fact that tipburn during this season (Fig. 3.5) was more prevalent although there was enough Ca, shows that this problem was possibly triggered by high temperatures recorded during the growth of the crop as mentioned by Collier and Tibbitts (1982). Producing lettuce using EC level of 2 $mS.cm^{-1}$ will be of benefit to the grower in terms of saving on fertilizers without compromising on quality.

CHAPTER 4

EFFECT OF NUTRIENT CONCENTRATION AND AUTUMN GROWING SEASON ON GROWTH, YIELD AND QUALITY OF LEAFY LETTUCE IN A HYDROPONIC SYSTEM

4.1 INTRODUCTION

Leafy lettuce grown in soilless condition require careful management of fertilizer concentrations, therefore, optimization of the nutrient solution concentration is critical for the farmer in order to maximize yield and quality. Fallovo *et al.* (2009b) mentioned that the total nutrient concentration of the solution used in soilless culture is one of the most important aspects for successful vegetable production. It is also an important tool to determine the nutrient requirements of crops in order to avoid probable toxicities due to over fertilization and also to monitor the growth and the productivity under different climatic conditions (Samarakoon *et al.,* 2006).

For example, when electrical conductivity (EC) is high, the increase in osmotic potential cause a reduction of water and mineral uptake by plant roots. Osmotic stress contribute to reduced growth rate and to changes in leaf colour and growth characteristics such as root/shoot ratio and nutritional disorders (Tesi *et al.,* 2003).

However, an optimal nutrient solution composition for vegetable crops in closed systems also depends on environmental conditions (Fallovo *et al.*, 2009a). Therefore, the objective of this trial was to determine whether growth, yield and quality of leafy lettuce can be influenced by nutrient solution concentrations and autumn growing season.

4.2 MATERIALS AND METHODS

The trial was conducted from March 2009 to April 2009 and please refer to Chapter 2 for more information on materials and methods.

4.3 RESULTS AND DISCUSSION

The maximum temperatures during the autumn season were high above the optimum temperature range for lettuce growth. Throughout the growing season the maximum temperatures ranged between 31-33ºC (Fig. 4.1). This resulted in the plants growing faster, reaching maturity within 4 weeks after transplanting. However, the average temperature was well within the recommended temperatures for optimum growth with the minimum temperature slightly below the required minimum temperature.

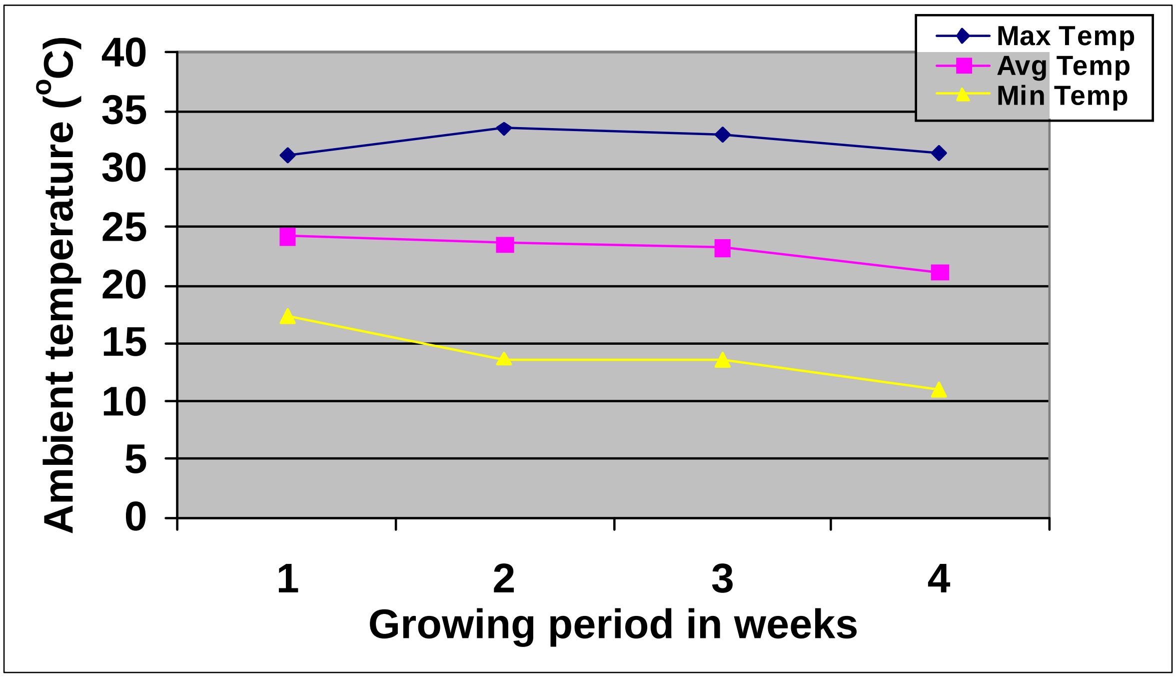

Fig. 4.1 Ambient temperature readings recorded during the autumn growing season

4.3.1 Effect of nutrient concentrations on growth, yield and quality

There were no significant differences on the number of leaves between the different treatments (Table 4.1). In a trial on the growth and yield of lettuce under different salinity levels Andriolo *et al.* (2005) found that number of leaves were not affected by treatments.

Although there were no significant differences in the leaf area and leaf area index between the treatments, there was a tendency of increasing leaf area and leaf area index with increasing EC levels. These results are in line with the findings of Fallovo *et al.*

(2009a). The maximum leaf area was obtained at treatment 3 (3 $mS.cm^{-1}$) which was followed by treatment 2 (2 $mS.cm^{-1}$), and the lowest leaf area was recorded at treatment 1 (1 $mS.cm^{-1}$) followed by treatment 4 (4 $mS.cm^{-1}$) (Table 4.1).

Fresh mass followed the same trend as leaf area and leaf area index, whereby increasing nutrient concentrations resulted in increasing fresh mass, but the increases were not significantly different. Andriolo *et al.* (2005) also recorded a positive effect of EC levels on shoot fresh mass. Treatment 3 (3 $mS.cm^{-1}$) gave the highest fresh mass with treatment 1 (1 $mS.cm^{-1}$) recording the lowest (Table 4.1). Increases in nutrient concentrations has contributed to yield increases by increasing leaf area and fresh mass even though this increases were not significant. These results portrays similar trend to the results discussed in Chapter 3, and this could be linked to the close relationship/similarity of higher temperatures recorded between the two seasons (summer and autumn).

Table 4.1 Effect of nutrient concentration on leaf number, leaf area, leaf area index and fresh mass of lettuce plants

Treatment ($mS.cm^{-1}$)	Leaf number ($number.plant^{-1}$)	Leaf area ($cm^2.plant^{-1}$)	Leaf area index (cm^2)	Fresh mass ($g.plant^{-1}$)
EC 1	24.8 ± 3.2a	2112 ± 520.8a	6.0a	158.4 ± 47.7a
EC 2	24.7 ± 3.1a	2487 ± 447.6a	7.1a	219.3 ± 53.5a
EC 3	24.7 ± 2.6a	2550 ± 661.7a	7.2a	220.8 ± 50.2a
EC 4	24.9 ± 1.9a	2334 ± 276.5a	6.6a	215.2 ± 35.6a
LSD	ns	ns	ns	ns

Means followed by the same letter within the column are not significantly different at 5% level of probability

There were no significant differences on leaf dry mass in all the treatments (Table 4.2), however, the leaf dry mass just like fresh mass followed similar trend of increasing leaf dry mass with increasing nutrient concentrations. As in the case of fresh mass, maximum leaf dry mass was recorded at treatment 3 (3 $mS.cm^{-1}$) with treatment 1 (1 $mS.cm^{-1}$) giving the least amount. Recently Fallovo *et al.* (2009a) found that total dry biomass was highly influenced by nutrient concentration and these results were supported by Miceli *et al.* (2003).

The root dry mass was not significantly affected by treatments and it remained almost constant, except for treatment 4 (4 $mS.cm^{-1}$) which could possibly be associated with salt toxicity (Table 4.2). This was confirmed by Andriolo *et al.* (2005) who also found no effect of nutrient concentration on root dry mass. Salt toxicity may cause poor root development of the lettuce plants.

Table 4.2 Effect of nutrient concentration on leaf dry mass and root dry mass of lettuce

Treatment ($mS.cm^{-1}$)	Leaf dry mass ($g.plant^{-1}$)	Root dry mass ($g.plant^{-1}$)
EC 1	7.3 ± 2.8a	5.6 ± 2.2a
EC 2	9.4 ± 2.2a	5.7 ± 1.9a
EC 3	10.1 ± 3.1a	5.5 ± 1.7a
EC 4	9.1 ± 1.9a	4.7 ± 1.3a
LSD	ns	ns

Means followed by the same letter within the column are not significantly different at 5% level of probability

There was an increasing trend in the chlorophyll content with increasing nutrient solution concentrations and the maximum chlorophyll content was recorded at treatment 3 (3 $mS.cm^{-1}$) and the lowest at treatment 1 (1 $mS.cm^{-1}$). Nutrient concentrations had significantly influenced the quality of lettuce plants in terms of colour with treatments 1 (1 $mS.cm^{-1}$) and 4 (4 $mS.cm^{-1}$) being the most negatively affected probably due to nutrient deficiencies and salinity toxicity respectively (Fig. 4.2). These results are similar to the findings of Fallovo *et al.* (2009a) who mentioned that nutrient concentration had significantly affected total chlorophyll. Treatment 3 (3 $mS.cm^{-1}$) had significantly higher chlorophyll content which may translate into dark green plants than the other treatments.

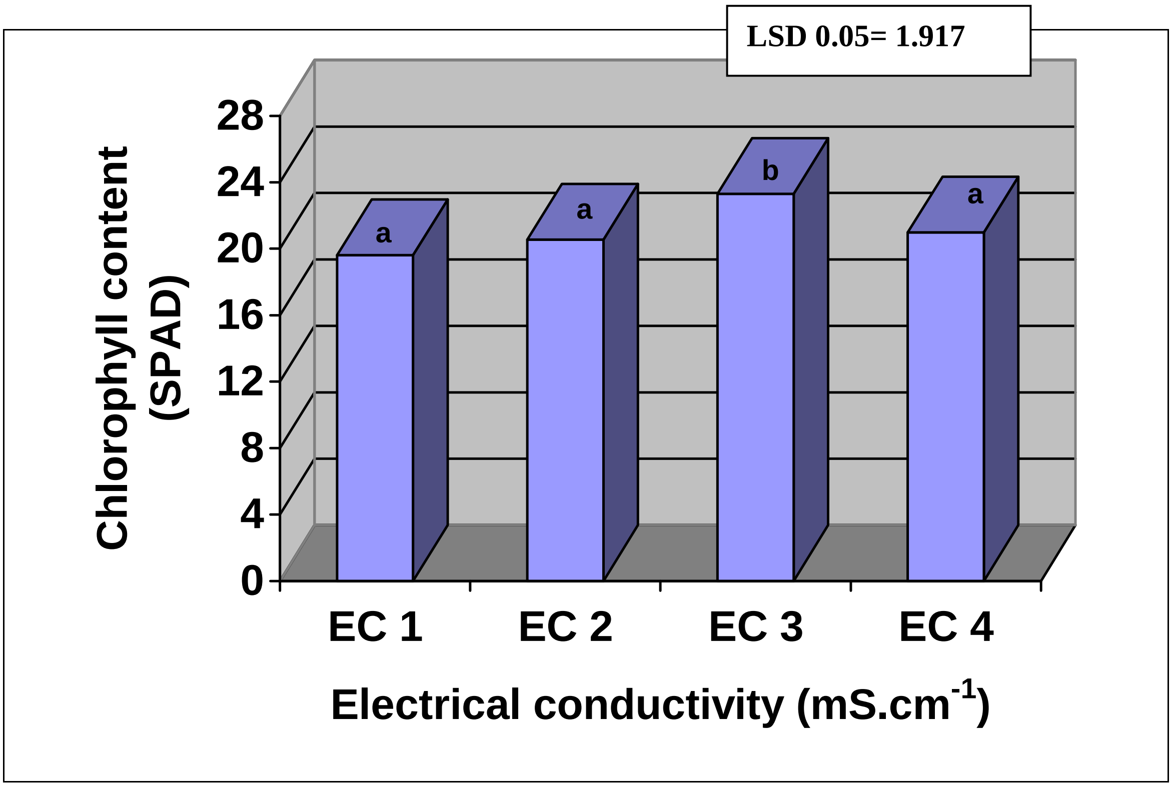

Fig. 4.2 Chlorophyll content of lettuce measured using SPAD meter during the autumn growing season. Bars with the same letters are not significantly different at 5% level of probability

4.3.2 Effect of nutrient concentrations (EC levels) on nutrient uptake in leaf tissues

The N, P, Ca and Mg elements were not significantly different in all the treatments, but N and P percentages had the tendency to increase with increasing nutrient concentrations (Table 4.3). The plants grown using treatments 1 and 4 (1 $mS.cm^{-1}$ and 4 $mS.cm^{-1}$) contain the lowest and the highest N and P percentages respectively. On the other hand, Ca and Mg did not follow a specific tendency, that is, they did not either increase or decrease with increasing nutrient solution concentrations.

There were significant differences on the K percentage between treatment 1 (1 $mS.cm^{-1}$) and the rest of the other treatments (2 $mS.cm^{-1}$, 3 $mS.cm^{-1}$ and 4 $mS.cm^{-1}$). All the treatments contain the K percentages far below the recommended ranges in the leaves of healthy plants with treatments 1 (1 mS.cm^{-1}) and 3 (3 mS.cm^{-1}) having the lowest and the highest percentages respectively.

Table 4.3 Effect of nutrient concentrations (EC levels) on macroelements (N, P, K, Ca and Mg) in leaf tissues of lettuce plants

Treatment (mS.cm^{-1})	N (%)	P (%)	K (%)	Ca (%)	Mg (%)
Acceptable ranges	**3.0-6.0**	**0.8-1.3**	**5.0-10.8**	**1.1-2.1**	**0.3-0.9**
EC 1	4.8 a	1.9 a	2.3 a	2.1 a	0.7 a
EC 2	4.9 a	2.1 a	3.0 b	1.7 a	0.6 a
EC 3	4.9 a	2.1 a	3.1 b	1.8 a	0.6 a
EC 4	5.3 a	2.1 a	2.9 b	1.8 a	0.6 a
LSD	ns	ns	0.582	ns	ns

Means followed by the same letter within the column are not significantly different at 5% level of probability

4.4 CONCLUSIONS

Too high nutrient concentrations and too low nutrient concentrations may result in nutrient toxicity and nutrient deficiencies respectively (Fallovo *et al.*, 2009a). Therefore, it is important that lettuce production be accompanied by proper understanding of agronomic traits like fertigation (fertilization), temperature, etc. The results of this trial showed that growth and quality can be improved by temperature (season), while yield can be increased by proper nutrient solution concentration. Although the results were not significantly different except for the chlorophyll content, good yield and quality were generally obtained with treatment 3 (3 mS.cm^{-1}). As mentioned by Fallovo *et al*. (2009a) treatments 1 and 4 resulted in poor yield and quality probably due to lower nutrient concentrations and higher nutrient concentrations respectively. However, treatment 3 had significantly higher chlorophyll content than all the other treatments (Fig. 4.2) and therefore, the use of EC 3 ($mS.cm^{-1}$) could be adopted during the autumn season to obtain good yield and good quality lettuce.

CHAPTER 5

EFFECT OF NUTRIENT CONCENTRATION AND WINTER GROWING SEASON ON GROWTH, YIELD AND QUALITY OF LEAFY LETTUCE IN A HYDROPONIC SYSTEM

5.1 INTRODUCTION

There is growing interest among consumers in baby leaf vegetables, mostly requested for mixed salads, both as fresh market products and ready-to-use vegetables. Lettuce is regarded as a winter crop and optimal nutrient solution concentration, water and nutrient supply in hydroponics depend on the environmental conditions (Fallovo *et al.*, 2009). Temperature plays an important role whereby if not managed or if the crop is grown out-of-season, water and nutrient uptake will be inhibited and as a result plant growth will be reduced. Every vegetable crop has its own optimum temperature and therefore temperatures too far away from the optimum ranges, either too high or too low, crop growth, yield and quality will be compromised. For example, too high temperatures will cause bitter taste, induce tipburn and bolting in lettuce and too low temperatures will retard plant growth by inhibiting nutrient uptake. These clearly stress the fact that it’s very critical to grow vegetable crops according to their temperature/seasonal requirements. Although lettuce is a winter crop, growth rate is slower in cooler seasons than during the warmer months. The objective of this trial was to determine whether growth, yield and quality of leafy lettuce can be influenced by nutrient concentration and winter season.

5.2 MATERIALS AND METHODS

The trial was conducted from May 2008 to June 2008. Please refer to Chapter 2 for more on materials and methods.

5.2.1 Sensory analysis

Quality (taste) tests were also done at the end of the growing season (after harvesting) by conducting the sensory evaluation procedure. The lettuce samples were harvested and delivered immediately to the Sensory Research Division, University of Pretoria's Department of Food Science on Monday 25 June 2008. Within each of the four sample treatments, four replicates were included. The lettuces were stored at 5°C for use the following day. The lettuce leaves were removed by hand from the heads and placed in basins filled with tap water and washed. Very large leaves (the outer leaves) were cut in half so that there was no big difference in the size of the leaves served to consumers. The samples were served in the order of a completely balanced block design. Each consumer received a tray with four lettuce samples. Leaves for each sample were placed on a white foam tray (260 mm X 120 mm). Each sample included four leaves, one leaf from each replicate. The four foam trays were served simultaneously on a larger plastic tray (390 mm X 280 mm). Filtered tap water in a 175 ml foam glass was provided to consumers to serve as a palate cleanser. The lettuce leaves within a sample that were served to consumers did vary in size. An effort was made to sort and serve leaves over the group of samples in such a way that the variation in leaf sizes did not play a significant role in the evaluation. Consumers indicated their acceptance (how much they liked or disliked) the colour and taste ("flavour") of the lettuce leaves using a 5 point scale: 1=very poor, 2=poor, 3=moderate, 4=good and 5=very good. The results of the sensory evaluation tests were captured and analysed using Compusense ® *five* data collection software (Compusense ® *five*, release 4.6, Compusense Inc., Guelph, ON, Canada) and Microsoft Excel. The effect of the sample and consumer on the preference for colour and taste were analysed using two-way analysis of variance (ANOVA). To determine significant differences between the treatments, a 5% significance value (p-value) was used and where applicable, the Fisher Least Significant Difference (LSD) test was used to investigate the nature of the differences in the preference ratings for different samples. For the preference ranking, Friedman analysis test at 10% significance value (p-value) for rank sum totals was used.

5.3 RESULTS AND DISCUSSION

The average daily temperatures for the winter season were within the recommended ranges of the optimum temperature (17-27^{o}C) for lettuce growth (Niederwieser, 2001). The temperatures did not differ a lot (maximum temperature ranged between 22 and 24^{o}C) (Fig. 5.1), and the plants took longer period to reach maturity, about 5 weeks.

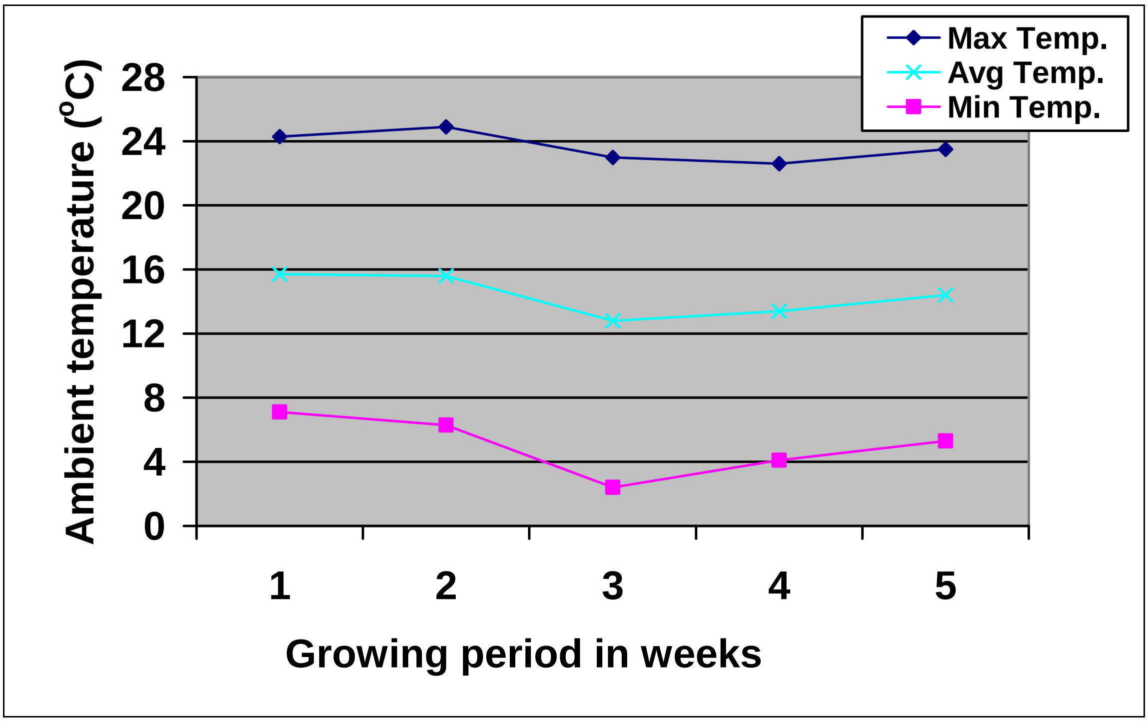

Fig. 5.1 Temperature readings recorded during the winter growing season

5.3.1 Effect of nutrient concentrations on growth, yield and quality

There were no significant differences between the treatments on the number of leaves and leaf number tended to slightly decrease with an increase in the nutrient solution concentration (Table 5.1). The highest number of leaves was obtained in EC 1.0 mS.cm^{-1} treatment which is surprising considering it had the lowest amount of nutrient concentration. Samarakoon *et al*. (2006) found similar tendencies of descending leaf number with an increase in the EC levels of the nutrient solution. These results are also confirmed by Miceli *et al*. (2003).

There was a tendency of increasing leaf area with an increase in the nutrient solution concentration (Table 5.1), but these increases were not significantly different. As mentioned by Serio *et al*. (2001) in a trial using two different lettuce cultivars, whereby one cultivar's leaf area increased with increasing nutrient solution concentration while the other cultivar decreased with increasing nutrient solution concentration.

Fresh mass had shown to increase with increasing nutrient concentration levels from EC 1.0 $mS.cm^{-1}$ to EC 3.0 $mS.cm^{-1}$ and decreased from EC 4.0 $mS.cm^{-1}$ (Table 5.1). In a trial with 2 lettuce cultivars, Serio *et al*. (2001) found that fresh mass of one of the two cultivars increased with increasing the EC of the nutrient solution concentration while the opposite was recorded for the other cultivar.
The same results were obtained by Andriolo *et al*. (2005) who also found an increase in shoot fresh mass with an increase in electrical conductivity of up to 2 $mS.cm^{-1}$ and as from EC of 3 $mS.cm^{-1}$ to 5 $mS.cm^{-1}$ a decrease in shoot fresh mass was recorded. Lettuce is considered to be moderately salt sensitive, which means that at high salinity growth may be retarded. Miceli *et al*. (2003) and Ehret & Ho (1986) mentioned that plants under salt stress condition may decrease the uptake of water and change the absorption ratio of nutrients.

Table 5.1 Effect of nutrient concentration on leaf number, leaf area, leaf area index and fresh mass of lettuce plants

Treatment ($mS.cm^{-1}$)	Leaf number ($number.plant^{-1}$)	Leaf area ($cm^2.plant^{-1}$)	Leaf area index (cm^2)	Fresh mass ($g.plant^{-1}$)
EC 1	16.2 ± 3.0a	1462 ± 372.6a	4.2a	140.3 ± 40.5a
EC 2	15.7 ± 2.3a	1516 ± 407.6a	4.3a	155.4 ± 47.3a
EC 3	15.6 ± 2.2a	1509 ± 409.9a	4.3a	156.2 ± 37.1a
EC 4	15.6 ± 1.8a	1572 ± 324.6a	4.5a	152.3 ± 39.4a
LSD	ns	ns	ns	ns

Means followed by the same letter within the column are not significantly different at 5% level of probability

There was a close correlation between the fresh mass and dry mass. An increase in the EC of the nutrient solution concentration resulted in an increase in leaf dry mass, although it remained constant at EC 3 and 4 $mS.cm^{-1}$ (Table 5.3). Miceli *et al*. (2003) in a trial with 2 lettuce cultivars' response to different EC levels found an increase in leaf dry mass with increasing conductivity levels in both cultivars.

Referring to Table 5.2, root dry mass increased with increasing the electrical conductivity of the nutrient solution. The root dry mass of EC 4.0 $mS.cm^{-1}$ were significantly higher than the root dry mass of all the other treatments. Economakis (1990) found that an increase in conductivity resulted in significant increases in root dry mass. As cited by Economakis (1990), Bruggink *et al.* (1987) also found similar results to that of Economakis (1990) but on fresh root mass. However, there was indifferent relationship between the dry root mass and all the other treatments.

Table 5.2 Effect of nutrient concentration on leaf dry mass and root dry mass of lettuce

Treatment ($mS.cm^{-1}$)	Leaf dry mass ($g.plant^{-1}$)	Root dry mass ($g.plant^{-1}$)
EC 1	6.0 ± 1.9a	4.6 ± 2.1a
EC 2	6.8 ± 2.1a	4.8 ± 1.8a
EC 3	7.1 ± 1.9a	5.3 ± 1.5a
EC 4	7.1 ± 1.9a	7.4 ± 3.1b
LSD	ns	1.695

Means followed by the same letter within the column are not significantly different at 5% level of probability

5.3.2 Sensory evaluation test

The consumers equally liked the lettuce samples from the four treatments with regard to the appearance and flavour (“taste”). There was no significant difference ($p > 0.05$) in the preference ranking of the lettuce samples (Table 5.3), suggesting that the different treatments that the lettuce samples were exposed to, did not have an effect on consumer preferences.

Table 5.3 Rank sum totals of the four lettuce samples (1 = sample most preferred, 4 = sample least preferred)

Sample	Rank totals	p-value (0.145)
1 EC 2	137	
2 EC 4	134	
3 EC 3	116	
4 EC 1	113	

In terms of lettuce flavour ("taste"), consumers' comments ranged from bland, sweet, and bitter taste, which were not influenced by nutrient concentration.

The colour of the lettuce samples was described as ranging from normal lettuce colour, pale green to dark green. The colour differences are probably due to the different nutrient solution concentrations that the lettuce plants were exposed to.

5.3.3 Effect of EC levels on nutrient content in leaf tissues

The amount of nitrogen (N) and potassium (K) in leaf tissues had the tendency to increase with increasing EC levels and began to decrease at EC 4 $mS.cm^{-1}$. This shows the positive effect of nitrogen on yield (leaf area). Phosphorus (P) was higher in EC 3 and 4 $mS.cm^{-1}$ than in EC 1 and 2 $mS.cm^{-1}$ and it's known to be good for root development. In Table 5.2, the root dry mass obtained in EC 4 $mS.cm^{-1}$ was significantly higher than that of the other treatments, which could be as a result of the amount of P contained in the plant shoots. As far as the calcium (Ca) content is concerned, EC of 1 $mS.cm^{-1}$ was significantly higher than that of EC 2, 3 & 4 $mS.cm^{-1}$. Ca deficiency is known to cause tipburn disorder and during this season no tipburn disorder was either noticed or recorded. The amount of magnesium (Mg) was constant among the treatments except for EC 4 $mS.cm^{-1}$ which had the lowest amount of Mg content (Table 5.4).

Table 5.4 Leaf tissue analysis of lettuce done at the end of the winter growing season

Treatment ($mS.cm^{-1}$)	N (%)	P (%)	K (%)	Ca (%)	Mg (%)
Acceptable ranges	**3.0-6.0**	**0.8-1.3**	**5.0-10.8**	**1.1-2.1**	**0.3-0.9**
EC 1	3.0 c	1.4 a	4.2 a	1.3 a	0.4 a
EC 2	3.3 ab	1.4 a	4.3 a	1.0 b	0.3 a
EC 3	3.4 a	1.5 a	4.7 a	1.0 b	0.3 a
EC 4	3.0 bc	1.5 a	4.2 a	1.0 b	0.2 a
LSD	0.250	ns	ns	0.197	ns

Means followed by the same letter within the column are not significantly different at 5% level of probability

5.3.4 Chlorophyll content

Plants grown with treatments 3 and 4 had almost the same amount of chlorophyll content which was higher than that of treatments 1 and 2. The plants receiving treatment 1 were yellowish in colour an indication of low nutrient concentration (Fig. 5.2). The chlorophyll content was not significantly different between the treatments although there was an increasing trend of chlorophyll content with increasing nutrient solution concentration (Fig. 5.3).

Fig. 5.2: Lettuce plants with colour differences caused by different nutrient solution concentrations/EC levels

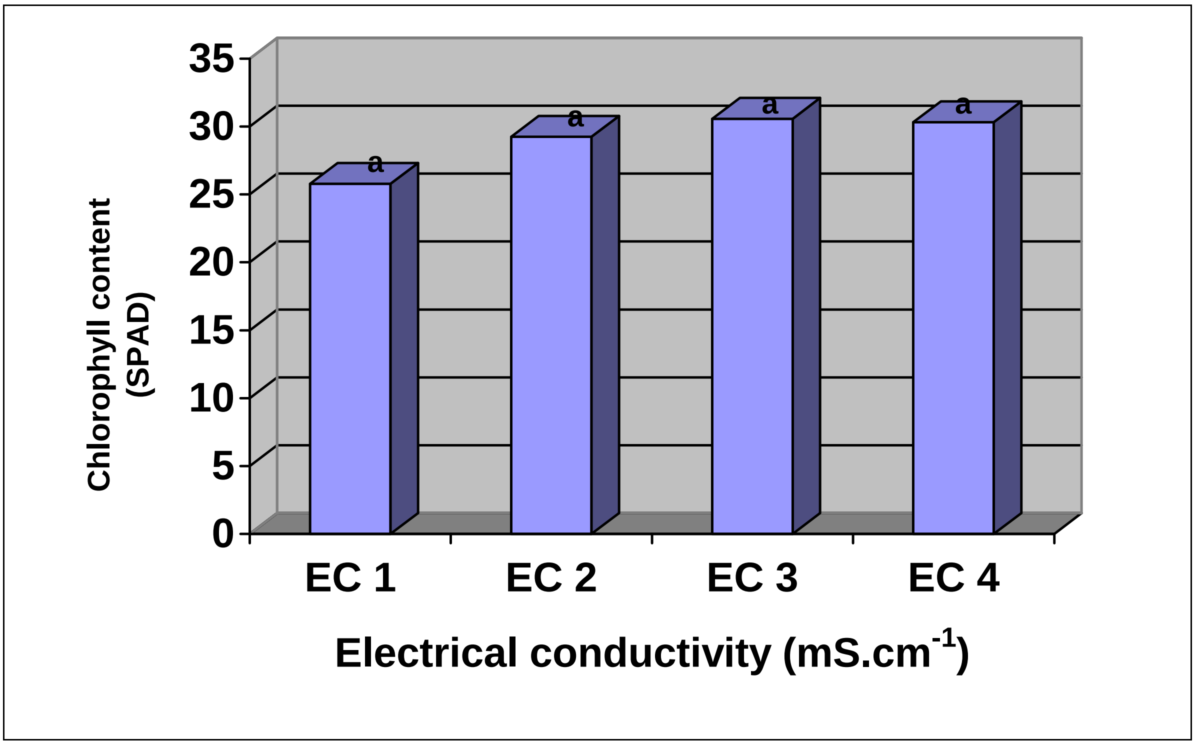

Fig. 5.3 Chlorophyll content of lettuce measured using SPAD meter during the winter growing period

5.4 DISCUSSION AND CONCLUSIONS

Temperature plays an important role in the production of vegetables and it is for this reason that vegetables are classified according to their adaptability to different temperatures (with regard to seasons). For example, there are cool season-crops, warm-season crops as well as intermediate crops. In this case, lettuce is considered a cool-season crop. Although lettuce is a winter crop, very cold temperatures might have severe effect on the crop growth by either scorching the leaves or causing slower growth rate. The maximum temperature for this trial ranged between 22-24^{o}C, which was well within the optimum temperature requirement (17-27^{o}C) for lettuce growth (Niederwieser, 2001).

Leaf number was the only parameter which was negatively affected by nutrient concentrations whereby it decreased with increasing nutrient concentrations. Leaf area, fresh mass, leaf dry mass, root fresh and dry mass all showed positive response to nutrient solution concentrations, whereby they increased with an increase in nutrient concentrations although the increases were not significant.

In terms of quality, chlorophyll content was used to determine the colour of the lettuce plants. The higher the nutrient concentration, the higher the chlorophyll content. Therefore, in order to improve the colour of the lettuce plants during winter, higher EC levels (3 and 4 $mS.cm^{-1}$) can be used. It was also very important to look into the taste/flavour of the lettuce plants and this was done using the sensory evaluation procedure. As mentioned earlier, the treatments did not affect the consumer preference on the lettuce plants with regard to taste. The sensory evaluation results showed that the colour of the lettuce ranged from normal lettuce colour, pale green to dark green which was as a result of low to high nutrient solution concentrations. As far as the nutrient content in leaf tissues is concerned, N played a bigger role in leaf growth and colour development. As witnessed in the results, an increase in the EC level which meant a significant increase in the N content resulted in an increase in the leaf area and fresh mass. Ca was significantly higher in Treatment 1 than in the other treatments, although the other 3 treatments had slightly lower Ca content than the recommended range for optimum growth, tipburn was not experienced during the entire growing season.

During the winter season, Treatment 2 compared with the other treatments has shown to be the most promising. Therefore, using Treatment 2 will result in better leaf number and leaf area. This means that by taking into consideration the amount of fertilizers applied in Treatment 2 relative to the other treatments, good yield can be obtained.

CHAPTER 6

EFFECT OF NUTRIENT CONCENTRATION AND SPRING GROWING SEASON ON GROWTH, YIELD AND QUALITY OF LEAFY LETTUCE IN A HYDROPONIC SYSTEM

6.1 INTRODUCTION

Since lettuce is consumed raw as a vegetable salad, its production throughout the year will be of benefit to both the producer and the consumer. Although lettuce is considered a cool season crop, consumption of lettuce is very high during the warmer months than in the cooler months. Production of lettuce throughout the year including spring will help close the gap of the high demand for lettuce. However, the effect of nutrient concentration during spring season is not known, therefore, the objective of this trial was to determine the effect of nutrient concentration during spring season on growth, yield and quality of leafy lettuce.

6.2 MATERIALS AND METHODS

6.2.1 Trial date

The trial was conducted from September 2008 to October 2008.

Please refer to Chapter 2 for more detailed information on materials and methods.

6.3 RESULTS AND DISCUSSION

Temperature is the most important factor to be considered in vegetable production and it determines when and where a certain crop can be grown. As mentioned by Fallovo *et al.* (2009) nutrient concentration depends on environmental conditions to effectively support plant growth and yield. Therefore, the importance of understanding crop temperature requirement cannot be overemphasized.

Temperature plays a key role in plant growth and development and it is critical that plants are always grown at the correct temperature regime. Too high temperatures will promote quick growth in lettuce plants resulting in physiological disorders like tipburn and bolting while too low temperatures will affect plant water absorption which will eventually lead to short and stunted plants (Fig. 6.1).

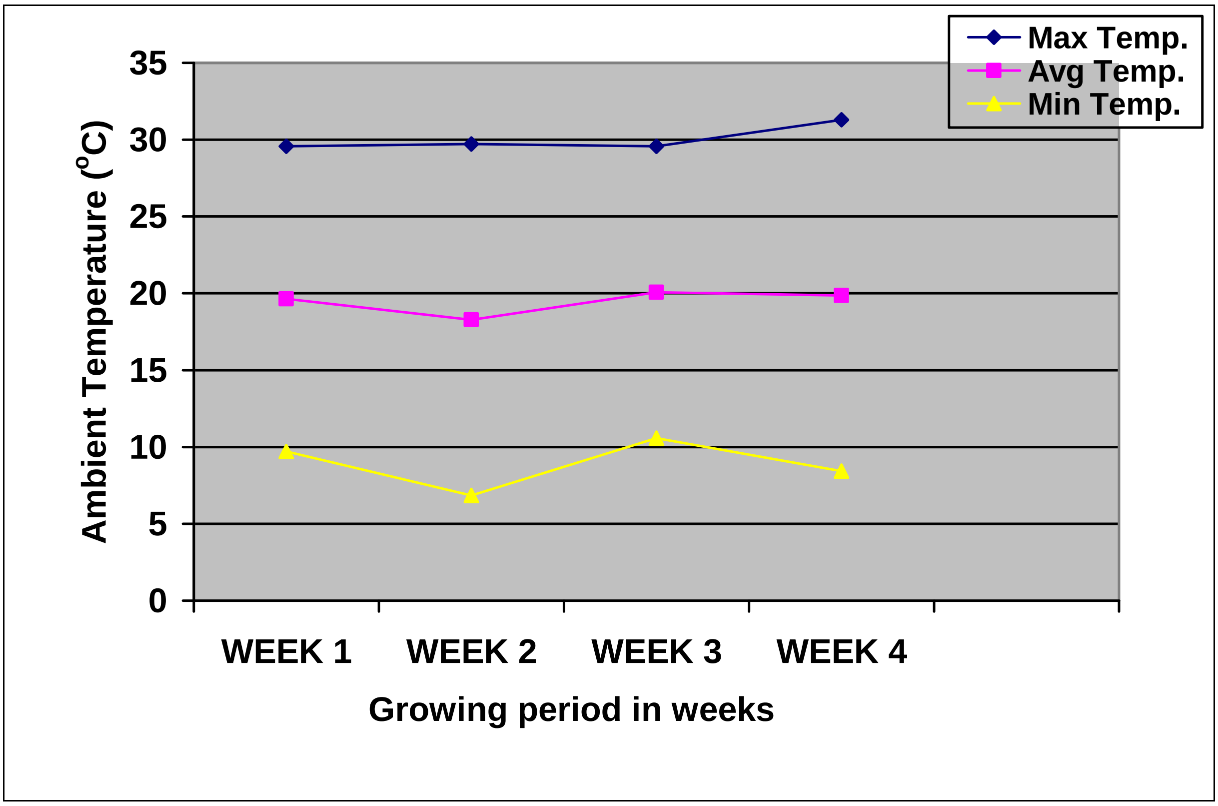

Fig. 6.1 Temperature readings recorded during the spring growing season

6.3.1 Effect of nutrient concentration on growth, yield and quality

Leaf number was not significantly affected by the treatments, since it did not either increase or decrease with increasing nutrient solution concentration. Andriolo *et al.* (2005) found similar results whereby leaf number was not affected by salinity levels.

There was no significant difference on leaf area between the treatments. However, the leaf area decreased with increasing EC levels of the nutrient concentration and this could be associated with salinity toxicity. Similar results of decreasing leaf area with increasing EC levels were found by Samarakoon *et al.* (2006). In a trial on the effect of electrical conductivity of nutrient solution on lettuce growth, yield and nitrate content using two cultivars, Serio *et al.* (2001) also found decreasing leaf area in one of the two lettuce cultivars with increasing EC levels of the nutrient concentration. Fresh mass decreased with increasing nutrient solution concentration but there was no significant difference between the treatments. This decreases meant that there was a decline in yield of lettuce during the spring season (Table 6.1). Serio *et al.* (2001) found decreasing fresh shoot mass with increasing nutrient solution concentration. These results are consistent with that found by Samarakoon *et al.* (2006).

Table 6.1 Effect of nutrient concentration on leaf number, leaf area, leaf area index and fresh mass of lettuce plants

Treatment ($mS.cm^{-1}$)	Leaf number ($number.plant^{-1}$)	Leaf area ($cm^2.plant^{-1}$)	Leaf area index (cm^2)	Fresh mass ($g.plant^{-1}$)
EC 1	24.4 ± 2.1a	2311 ± 419.5a	6.6a	194.3 ± 28.3a
EC 2	23.5 ± 3.2a	2065 ± 673.9a	5.9a	176.2 ± 66.2a
EC 3	24.3 ± 3.0a	2040 ± 425.5a	5.8a	175.2 ± 43.7a
EC 4	23.9 ± 3.3a	1856 ± 449.4a	5.3a	160.4 ± 42.9a
LSD	ns	ns	ns	ns

Means followed by the same letter within the column are not significantly different at 5% level of probability

Leaf dry mass increased with increasing EC levels although the increase was not statistically significant. There was no significant difference on root dry mass among the treatments because it did not show any specific tendency of either increasing or decreasing with increasing nutrient solution concentration (Table 6.2). This confirm the results by Andriolo *et al.* (2005) who found no effect of salinity levels on the growth and yield of lettuce plants.

However, there was contrasting results between fresh mass (Table 6.1) and leaf dry mass (Table 6.2) whereby fresh mass was decreasing with an increase in nutrient concentration while leaf dry mass was increasing with increasing nutrient concentration. This could be attributed to the fact that plants grown at 1 $mS.cm^{-1}$ had more water content where as plants grown a higher EC level (4 $mS.cm^{-1}$) had less water content but more dry matter content.

Table 6.2 Effect of nutrient concentration on leaf dry mass and root dry mass of lettuce

Treatment ($mS.cm^{-1}$)	Leaf dry mass ($g.plant^{-1}$)	Root dry mass ($g.plant^{-1}$)
EC 1	6.0 ± 1.3a	4.5 ± 1.0a
EC 2	7.0 ± 1.9a	4.8 ± 1.4a
EC 3	6.4 ± 2.2a	4.5 ± 1.7a
EC 4	7.5 ± 1.5a	4.9 ± 1.2a
LSD	ns	ns

Means followed by the same letter within the column are not significantly different at 5% level of probability

The chlorophyll content was not significantly different among the different treatments, however, the highest chlorophyll content was recorded in treatments 2 and 3 while treatments 1 and 4 had equal amount of chlorophyll (Fig. 6.2). This indicate that there was very little nutrients (nutrient deficiency) in the lower EC (1 $mS.cm^{-1}$) while high salt content resulted in low chlorophyll content in the higher EC levels (4 $mS.cm^{-1}$).

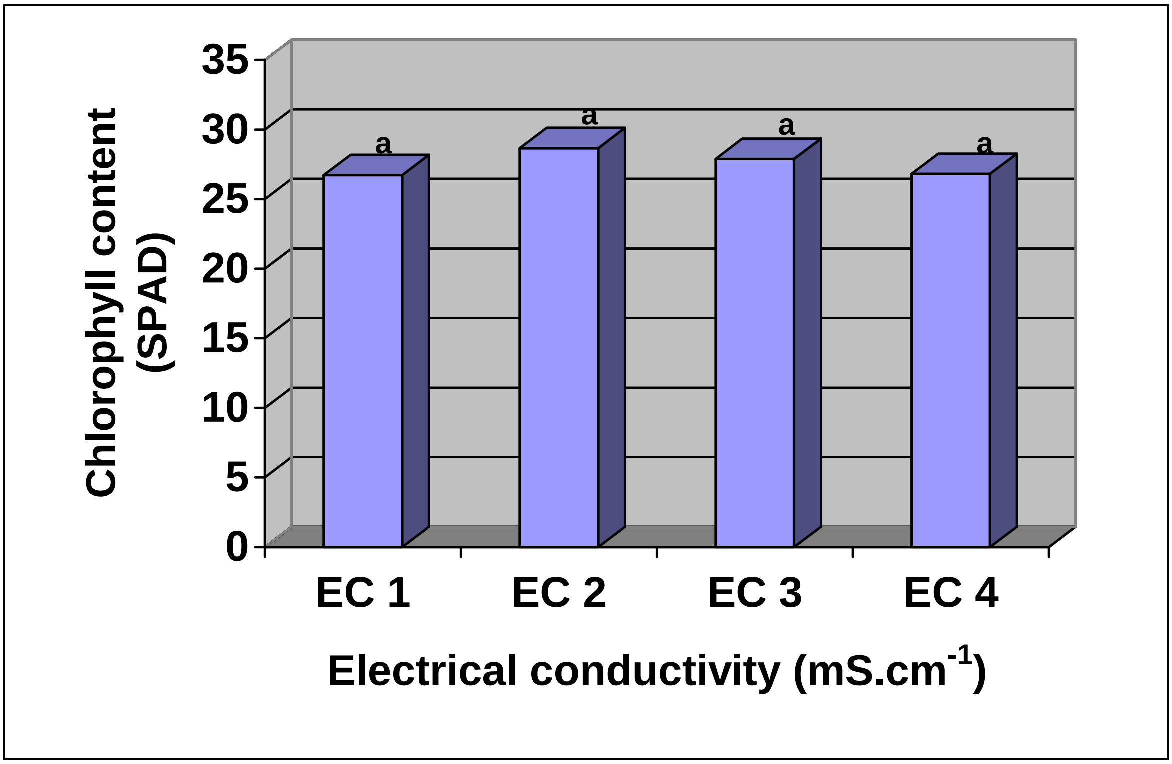

Fig. 6.2 Chlorophyll content of lettuce measured using SPAD meter during the spring

6.3.2 Effect of EC levels on nutrient content in leaf tissues

Nitrogen (N) significantly increased with increasing nutrient solution concentration. The N content in the leaf samples of EC 1 mS.cm^{-1} was below the recommended range for lettuce growth, hence the yellowing of the leaves. This increase in the N content did not contribute to yield increases either in the form of an increase in leaf number or leaf area as it (N) is known to induce leaf growth and development. There was a tendency of increasing P content with increasing EC level, and the percentage P found in the leaves was higher than the recommended ranges except for EC 1 mS.cm^{-1} which was within the range. Phosphorus is good for root development but there was conflicting relationship between the P content in the leaves and the dry root mass which could not be explained. Calcium (Ca) decreased with increasing the EC level while magnesium (Mg) remained constant, but both were slightly lower than the recommended range. However, potassium (K) was below the recommended range although it did not affect lettuce quality/taste (Table 6.3).

Table 6.3 Leaf tissue analysis of lettuce done at the end of the spring growing season

Treatment ($mS.cm^{-1}$)	N (%)	P (%)	K (%)	Ca (%)	Mg (%)
Acceptable ranges	**3.0-6.0**	**0.8-1.3**	**5.0-10.8**	**1.1-2.1**	**0.3-0.9**
EC 1	2.7 a	1.2 a	1.9 a	1.1 a	0.2 a
EC 2	3.0 ab	1.5 a	1.9 a	1.0 a	0.2 a
EC 3	3.4 b	1.5 a	2.0 a	0.9 a	0.2 a
EC 4	3.4 b	1.6 a	2.0 a	0.8 a	0.2 a
LSD	0.440	ns	ns	ns	ns

Means followed by the same letter within the column are not significantly different at 5% level of probability

6.4 CONCLUSIONS

Nutrient solution concentration is one of the most important factors and should form the basis for plant nutrition in order to achieve good yield in a hydroponic vegetable production. Lettuce growth and yield are mostly dependent on leaf growth and development which can be achieved by plant nutrition designed to promote vigorous growth. Leaf number, leaf dry mass and root dry mass were not significantly affected by nutrient concentrations. On the other hand, leaf area and fresh mass were decreasing with an increase in nutrient concentrations. Interestingly enough is the fact that treatment with the lowest nutrient concentration had the highest leaf area and fresh mass while the opposite was true for the highest nutrient concentration. As a result an increase in nutrient concentration resulted in a decrease in yield.

Quality is one of the most important parameters in lettuce production and although treatment 1 had the highest leaf area and fresh mass, the quality of the lettuce samples with regard to chlorophyll content was poor. Nitrogen is associated with colouring of the leaves and treatment 1 had the lowest amount of nitrogen. It was well below the recommended range for optimum growth and it is for this reason that the chlorophyll content (quality) of the lettuce samples in treatment 1 was low. However, treatment 2 (2 $mS.cm^{-1}$) had the second highest leaf area and fresh leaf mass which makes it the better treatment to be recommended during spring. Although there were no significant differences, treatment 2 (2 $mS.cm^{-1}$) had the highest chlorophyll content.

GENERAL DISCUSSION AND CONCLUSIONS

Lettuce is one of the most important fresh leafy vegetable grown in South Africa. It is consumed raw especially in salads. The gravel-flow technique system (GFT) is still a fairly new technology in South Africa particularly to small scale farmers. Therefore, the system is not popular and widely used for the production of leafy vegetables. As a result, growth, yield and quality of leafy lettuce are affected by lack of knowledge and information leading to poor or incorrect application of fertilizers or nutrient concentrations.

There is little information available on how nutrient concentrations under different growing seasons affect the growth, yield and quality of leafy lettuce in a hydroponic system under local conditions. Therefore, the objective of the study was to determine:

- the effect of different nutrient concentrations on growth, yield an quality of leafy lettuce.
- nutrient changes in leafy lettuce as affected by electrical conductivity (EC) levels and growing seasons.

With regard to the summer season, it was found that increasing the EC level above 2 $mS.cm^{-1}$ did not prove to bring any significant increase in yield and quality of leafy lettuce. However, higher temperatures during summer season resulted in faster growth rate which negatively induced tipburn. The prevalence of tipburn was related to higher temperatures and not to EC levels because it was observed amongst all the treatments. It can be mentioned that the colour of the crop produced with an EC level of 2 $mS.cm^{-1}$ was visually similar to that of the crop grown with an EC level of 4 $mS.cm^{-1}$. By using the SPAD meter it was found that the chlorophyll content of the leafy lettuce grown at 3 $mS.cm^{-1}$ was significantly higher than that of the other treatments. Although not significantly different, EC level of 3 $mS.cm^{-1}$ also produced higher absolute values for most of the parameters than the other treatments.

During the winter season, increasing EC levels did not significantly increase yield but EC level of 2 $mS.cm^{-1}$ proved to have the potential to produce good yield. Interestingly though, the chlorophyll content (using SPAD meter) of EC 2 $mS.cm^{-1}$ was slightly lower than that of EC 3 and 4 $mS.cm^{-1}$. Surprisingly, the absolute values of chlorophyll content for the winter season were found to be higher than of the other seasons. The higher chlorophyll contents in winter could probably be due to a concentration effect since the plants were generally smaller than during the other seasons.

Generally, leaf number, leaf area, fresh leaf mass, leaf dry mass and root dry mass were not statistically significant during the summer, autumn and spring seasons. Leaf area index was not significantly different during all the four seasons. However, during the winter season all the parameters were also not significantly different except for root dry mass. The difference between winter season and the other three seasons (summer, autumn and spring) might be linked to temperature variations. The winter season had the lowest temperatures than all the other seasons, and it is known that low temperatures reduce water and nutrient uptake by plants. Temperature played a very important part in the growth and development of lettuce plants because regardless of the EC levels, the yield results for the cooler season (winter) were lower than that of the warmer season (summer).

The chlorophyll content for the summer and autumn seasons significantly increased with increasing nutrient concentrations while for the winter and spring seasons were not significantly different. The summer and autumn temperatures were above the recommended temperatures while winter and spring temperatures were within and slightly above the recommended temperatures for lettuce growth. Lettuce grows well in relatively cooler temperatures, therefore, the reason for these differences between the summer-autumn and winter-spring could be the higher and lower temperatures, respectively. At the same time, in order to achieve good quality with regard to colour (using SPAD meter), growing season becomes very critical. However, as observed in the results of the sensory evaluation, it is quite difficult to see visual differences in terms of colour.

With regard to the sensory evaluation, there were no significant differences between the treatments during summer and winter in terms of colour and flavour. These results demonstrated that the nutrient content in plant tissues were not dependent on nutrient concentration and growing season.

It can be mentioned that EC levels showed positive tendencies on growth, yield and quality of lettuce. Further studies needs to be conducted to confirm whether quality with regard to colour is dependent on growing season or EC level. Furthermore, it is advisable to determine colour differences using a SPAD meter which can pick up differences that cannot be made visually using sensory evaluation.

GENERAL SUMMARY

A trial was established under a shade net structure on hydroponic tables to determine the effect of different nutrient solution concentrations on growth, yield and quality of leafy lettuce. The trials were planted over 4 seasons and the treatments were four electrical conductivity levels: 1.0 $mS.cm^{-1}$ (30 g Hygroponic + 30 g Calcium nitrate); 2.0 $mS.cm^{-1}$ (85 g Hygroponic + 85 g Calcium nitrate); 3.0 $mS.cm^{-1}$ (130 g Hygroponic + 130 g Calcium nitrate) and 4.0 $mS.cm^{-1}$ (190 g Hygroponic + 190 g Calcium nitrate).

Measurements that were recorded at the end of each growing season included leaf number, leaf area, fresh leaf mass, dry leaf mass and dry root mass. Chlorophyll content was measured weekly using a SPAD meter and the number of days to maturity was determined by counting the total number of days from transplanting to harvesting. Quality tests (taste) were only done at the end of the summer and winter seasons by conducting a sensory evaluation procedure.

The different EC levels did not significantly affect leaf number, leaf area, fresh leaf mass, dry leaf mass and dry root mass during summer, autumn and spring seasons. However, leaf area index for all the different seasons was also not statistically different. During the winter season dry root mass increased significantly with increasing nutrient concentration. The chlorophyll content for the warmer months (summer and autumn) had lower absolute values compared to the cooler months (winter and spring), regardless of the EC level.

In summer, plants grown using EC level of 2 $mS.cm^{-1}$ showed potential by producing better quality plants and according to the results of the sensory evaluation they were also found to taste better. In addition, the macro elements analysed in the plant tissues were within the recommended range. But due to high temperatures during the summer season, symptoms of tipburn were recorded across all the different treatments. During the autumn season EC level of 3 $mS.cm^{-1}$ showed potential by giving higher leaf area and greater fresh and dry leaf mass. It also produced significantly higher chlorophyll content than the other treatments. Plants grown with EC level of 2 $mS.cm^{-1}$ produced better yield with

regard to leaf number, leaf area and fresh mass as well as good quality during the winter and spring seasons.

This trial demonstrated that increasing the EC level above 2 $mS.cm^{-1}$ during summer, winter and spring and above 3 $mS.cm^{-1}$ during autumn will not significantly increase the yield and quality of leafy lettuce.

REFERENCES

ABOU-HADID, A.F., ABD-ELMONIEM, E.M., EL-SHINAWY, M.Z. & ABOU-ELSOUD, M. 1996. Electrical conductivity effect on growth and mineral composition of lettuce plants in hydroponic system. *Acta Horticulturae* 434: 59-66.

ADAMS, P. & HO, L.C. 1993. Effects of environment on the uptake and distribution of calcium in tomato and the incidence of blossom-end rot. *Plant and soil* 154, 127-132.

ADAMS, P. & HO, L.C. 1995. Uptake and distribution of nutrients in relation to tomato fruit quality. *Acta Horticulturae* 412, 374-385.

ANDRIOLO, J.A., LUZ, G.L., WITTER, M.H., GODOI, R.S., BARROS, G.T. & BORTOLOTTO, O.C. 2005. Growth and yield of lettuce plants under salinity. *Horticultura Brasileira* 23: 931-934.

ANONYMOUS. Environmental factors that affect growth. Website: http://www.d.umn.edu/biology/courses/bio1010/documents/5lFactorslecture_000.doc.

ANONYMOUS. Lettuce-Disorder in lettuce. Website: http://agrisupportonline.com/Articles/disorders_in_lettuce.htm.

ANONYMOUS. 2000. Lettuce best management practices-Tipburn. Website: http://www.nre.vic.gov.au/agvic/ihd/r&d/doc-133.htm.

ANONYMOUS. 2003. Tipburn of lettuce. Website: http://ag.arizona.edu/PLP/plpext/diseases/vegetables/lettucetip.htm.

BARRY, C. 1996. Nutrients - The handbook to hydroponic nutrient solutions. Casper, Australia pp 33-43.

BERNSTEIN, L. 1959. Salt tolerance of vegetable crops in the West. USDA Information Bulletin 205.

BRUGGINK, G.T., SCHOUWINK, H.E. & COLLEN, E.A.J.M. 1987. Effects of different day and night osmotic pressure of the nutrient solution on growth, water potentials and osmotic potentials of young tomato plants in soilless culture. Soilless Culture 3: 9-19.

CANNELL, G.H., BINGHAM, F.T., LINGLE, J.C. & GARBER, M.J. 1963. Yield and nutrient composition of tomatoes in relation to soil temperature, moisture and phosphorus levels. *Soil Science Society Proceedings* 27: 560-565.

CHIL, C.D., KIM, S.Y., JEONG, J.C., SHIN, K.Y. & LEE, Y.B. 2001. Solution temperature effects on potato growth and mineral uptake in hydroponic system. *Acta Horticulturae* 548: 517-522.

COLLIER, G.F. & TIBBITTS, T.W. 1982. Tipburn of lettuce. *Horticultural Reviews* 4: 49-65.

CORNILLON, P.1974. Behavior of the tomato in terms of substrate temperature. *Annals of Agronomy* 25: 753-777.

CORNISH, P.S. 1992. Use of high electrical conductivity of nutrient solution to improve the quality of salad tomatoes (*Lycopersicon esculentum*) grown in hydroponic culture. *Australian Journal of Experimental Agriculture* 32: 513-520.

COX, R.S. 1955. A preliminary report on diseases of lettuce in the Everglades and their control. *Plant Disease Reporter* 39: 421-423.

CUBETA, M.A. CODY, B.R. SUGG, R.E. & CROZIER, C.R. 2000. Influence of soil calcium, potassium, and pH on development of leaf tipburn of cabbage in Eastern North Carolina. *Communications in Soil Science and Plant Analysis* 31, 259-275.

CRESWELL, C. 1991. Effect of lowering nutrient solution concentration at night on leaf calcium levels and the incidence of tipburn in lettuce. *Journal of Plant Nutrition* 14, 913-924.

DALE, J.E. 1965. Leaf growth in *Phaseolus vulgaris* II. Temperature effects and the light factor. *Annals of Botany* 29 (114): 293-307.

DAVIS, R.M., SUBBARAO, K.V., RAID, R.N. & KURTZ, E.A. 1997. Compendium of lettuce diseases. The APS Press. St. Paul, Minnesota, USA.

DONE, J. 2009. Cool season crops and bolting. Website: http://www.growveg.com/growblogpost.aspx?id=76

ECONOMAKIS, C.D. 1990. Effect of solution conductivity on growth and yield of lettuce in nutrient film culture. *Acta Horticulturae* 287: 309-316.

EHRET, D.L. & HO, L.C. 1986. The effects of salinity on dry matter partitioning and fruit growth in tomatoes grown in nutrient film culture. *Journal of Horticultural Science* 61: 361-367.

FALLOVO, C., ROUPHAEL, Y., REA, E., BATTISTELLI, A. & COLLA, G. 2009. Nutrient solution concentration and growing season affect yield and quality of *Lactuca sativa* L. var. *acephala* in floating raft culture. *Journal of the Science of Food and Agriculture* 89: 1682-1689.

FALLOVO, C., ROUPHAEL, Y., REA, E., BATTISTELLI, A. & COLLA, G. 2009a. Nutrient solution concentration and growing season affect yield and quality of *Lactuca sativa* L. var. *acephala* in floating raft culture. *Journal of the Science of Food and Agriculture* 89: 1682-1689.

FALLOVO, C., ROUPHAEL, Y., CARDARELLI, M., REA, E., BATTISTELLI, A. & COLLA, G. 2009b. Yield and quality of leafy lettuce in response to nutrient solution composition and growing season. *Journal of Food, Agriculture and Environment* 7(2): 456-462.

FROTA, J.N.E. & TUCKER, T.C. 1972. Temperature influence on ammonium and nitrate absorption by lettuce. *Soil Science Society Annals Proceedings* 36: 97-100.

GAUDREAU, L., CHARBONNEAU, J., VEZINA, L.P. & GOSSELIN, A. 1994. Photoperiod and photosynthetic Photon Flux Influence Growth and Quality of Greenhouse-Grown Lettuce. *Horticultural Science* 29 (11) 1285-1289.

GENT, M.P.N. & MA, Y.Z. 2000. Mineral nutrition of tomato under diurnal temperature variation of root and shoot. *Crop Science* 40: 1629-1636.

GISLERØD, H.R., SELMER-OLSEN, A.R. & MORTENSEN, L.M. 1987. The effect of air humidity on nutrient uptake by some greenhouse plants. *Plant and Soil* 102: 193-196.

GOSSELIN, A. & TRUDEL, M.J. 1983. Interactions between air and root temperatures on greenhouse tomato: II. Mineral composition of plants. *Journal of American Society for Horticultural Science* 108: 905-909.

GOSSELIN, A. & TRUDEL, M.J. 1983b. Interactions between air and root temperatures on greenhouse tomato: II. Mineral composition of plants. *Journal of American Society for Horticultural Science* 108: 901-905.

HICKLENTON, P.R. & WOLYNETZ, M.S. 1987. Influence of light- and dark-period air temperatures and root temperature on growth of lettuce in nutrient flow systems. *Journal of American Society for Horticultural Science* 112: 932-935.

ISLAM, N., GRINDAL PATIL, G., TORRE, S. & GISLERØD, H.R. 2004. Effects of relative air humidity, light, and calcium fertilization on tipburn and calcium content of the leaves of *Eustoma grandiflorum* (Raf.) Shinn. *European Journal of Horticultural Science* 69 (1): 29-36.

JENNI, S. 2005. Rib discoloration: A physiological disorder induced by heat stress in crisphead lettuce. *HortScience* 40: 2031-2035.

JENNI, S., DE KOEYER, D. & EMERY, G. 2008. Rib discoloration in F_2 populations of crisphead lettuce in relation to head maturity. *Journal of American Society for Horticultural Science* 133 (2): 249-254.

JENSEN, M.H. & MALTER, A.J. 1995. Protected agriculture, A global review. World Bank Tech. Paper No. 253. The World Bank, Washington D.C.

KANAAN, S.S. & ECONOMAKIS, C.D. 1992. Effect of climatic conditions and time of harvest on growth and tissue nitrate content of lettuce in nutrient film culture. *Acta Horticulturae* 323: 75-80.

KANG, J.G. & VAN IERSEL, M.W. 2001. Interactions between temperature and fertilizer concentration affect growth of subirrigated petunias. *Journal of Plant Nutrition* 24: 753-765.

KUTOBY-AMACHER, J., KOENIG, R. & KITCHEN, B. 2000. Salinity and plant tolerance. Utah State University, Cooperative Extension.

LI, Y.L., STANGHELLINI, C. & CHALLA, H. 2001. Effect of electrical conductivity and transpiration on production of greenhouse tomato (*Lycopersicon esculentum* L.) *Scientia Horticulturae* 88: 11-29.

LORENZO, O.A. & MAYNARD, D.N. 1988. Knott's handbook for vegetable growers. Wiley, New York.

MABOKO, M.M. 2007. Leafy lettuce grown in a hydroponics system. Undercover Farming Magazine, Pretoria, South Africa, 3 (6): 8.

MABOKO, M.M. & DU PLOOY, C.P. 2008. Evaluation of crisphead lettuce cultivars (*Lactuca sativa* L.) for winter production in a soilless production system. *African Journal of Plant Science* 2 (10): 113-117.

MABOKO, M.M. & DU PLOOY, C.P. 2009. Effect of plant spacing on growth and yield of lettuce (*Lactuca sativa* L.) in a soilless production system. *South African Journal of Plant Science* 26 (3): 195-197.

MARLATT, R.B., STEWART, J.K. & BERKENKAMP, B.B. 1957. Storage of lettuce with rib discoloration. *Phytopathology* 47: 231-233.

MARSH, L.S. 1987. A model of greenhouse hydroponic lettuce production: Daily selection of optimum air temperatures and comparison of greenhouse covers. PhD diss. Cornell Univ., Ithaca, N.Y.

MICELI, A., MONCADA, A & D'ANNA, F. 2003. Effect of salt stress in lettuce cultivation. *Acta Horticulturae* 609: 371-375.

MURDOCH, C., KNOXFILED, S.V. & BAIRNSDALE, R.D. 2003. Tipburn in lettuce. State of Victoria, Department of Primary Industries.

NIEDERWIESER, J.G. 2001. Guide to hydroponic vegetable production (2nd ed.). Agricultural Research Council, Roodeplaat, Vegetable and Ornamental Plant Institute. Pretoria, South Africa.

OCAMB, C. M. 2007. Plant disease control. Oregon State University, Corvallis.

PAPADOPOULOS, A.P. & TIESSEN, H. 1987. Root and air temperature effects on the elemental composition of tomato. *Journal of American Society for Horticultural Science* 112 (6): 988-993.

RAYDER, E.J. 1999. Lettuce, endive and chicory. CAB Intl., New York.

RESH, H. 2006. Hydroponic services. Hydroponic culture of lettuce I.

SAMARAKOON, U.C., WEERASINGHE, P.A. & WEERAKKODY, W.A.P. 2006. Effect of electrical conductivity (EC) of the nutrient solution on nutrient uptake, growth and yield of leaf lettuce (*Lactuca sativa* L.) in stationary culture. Tropical Agricultural Research 18: 13-21.

SAURE, M.C. 1998. Causes of the tipburn disorder in leaves of vegetables. *Scientia Horticulturae* 76, 131-147.

SERIO, F., ELIA, A., SANTAMARIA, P., RODRIGUEZ, G.R., CONVERSA, G., BIANCO, V.V., FERNANDEZ, J.A., MARTINEZ, P.F. & CASTILLA, N. 2001. Lettuce growth, yield and nitrate content as affected by electrical conductivity of nutrient solution. *Acta Horticulturae* 559: 563-568.

SHANNON, M.C. & GRIEVE, C.M. 1999. Tolerance of vegetable crops to salinity. *Scientia Horticulturae* 78: 5-38.

SNEDECOR, G.W & COCHRAN, W.G. 1980. Statistical methods (7th ed.) Iowa State University Press, pp 507.

TESI, R., LENZI, A. & LOMBARDI, P. 2003. Effect of salinity and oxygen level on lettuce grown in a floating system. *Acta Horticulturae* 609: 383-387.

The guide to GenStat® for windows (10th ed.) - Introduction (Payne, R.W.), Published 2003 by VSN International, UK. ISBN 1-904375-08-1.

THOMPSON, H.C. & LANGHANS, R.W. 1998. Shoot and root temperature effects on lettuce growth in a floating hydroponic system. *Journal of American Society for Horticultural Science* 123 (3): 361-364.

VALENZUELA, H., KRATKY, B. & CHO, J. 1993. Lettuce production guidelines for Hawaii. University of Hawaii.

VAVRINA, C.S. 1996. Seasonal differences occur in transplants too. Florida Vegetable Transplant Growers News 7 (2): 1-2.

WISSEMEIER, A. H. & ZUHLKE, G. 2002. Relation between climatic variables, growth and the incidence of tipburn in field-grown lettuce as evaluated by simple, partial and multiple regression analysis. *Scientia Horticulturae* 93, 193-204.

WOLFE, D.W. 1991. Low temperature effects on early vegetative growth, leaf gas exchange and water potential of chilling-sensitive and chilling-tolerant crop species. *Annals of Botany* 67: 205-212.