Effects of electrical conductivity (EC) of the nutrient solution on growth, yield and quality of lettuce under vertical hydroponic systems

Nguyen Van Quy[1], Wantana Sinsiri[1*], Supharat Chitchamnong[1], Kriangsuk Boontiang[1] and Waranyoo Kaewduangta[1]

ABSTRACT: This experiment was carried out in a greenhouse at the Faculty of Agronomy, Hue University, Viet Nam. The objective of this research was to investigate the effects of the EC concentration levels on growth, yield and quality of lettuce under vertical hydroponic system. The experiment was laid out in Randomized Complete Block Design (RCBD) with four replications. Five treatments consist of the EC levels (0.5, 1.0, 1.5, 2.0 and 2.5 mS/cm). The Rapid Red lettuce cultivars was used for testing. Two weeks after germination, the seedlings were transplanted under the vertical hydroponic systems. The pH was maintained at 6.0 - 6.5 for the entire the growing period. It can be concluded that the ability to grow, yield and quality of lettuce grown in vertical hydroponic systems were significantly affected by nutrient solution concentrations (EC). Yield was significantly ($P \leq 0.01$) affected by EC levels. The EC at 2.5 mS/cm produced maximum yield (27.5 t/ha), but not significant difference with 2.0 mS/cm. For quality, the highest vitamin C and chlorophyll content were obtained at the 1.5 mS/cm of the EC level in the present study. The lettuce grown in EC at 2.5 mS/cm considered to be the best productivity under vertical hydroponic systems .

Keywords: Lettuce, vertical garden, hydroponic systems, electrical conductivity

Introduction

Lettuce is leafy vegetables, which is often grown using hydroponic methods (Anonymous, 2000). Growing lettuce with the hydroponic method will help control and supply nutrients more conveniently, thus lettuce will grow better as well as give higher yield and quality than planting on common land (Furlani et al., 1999). The most important factor in controlling nutrients for lettuce grown with hydroponic methods is electrical conductivity (EC). This indicator represents the total amount of dissolved mineral salts in hydroponic nutrient solution. In addition, the EC also affects the water absorption ability and fertilizer of lettuce, which influence the development, productivity and quality of this plant. Although the water absorption process is more favorable at low EC level, there would not enough nutrition for regulars growth and create its yield. In contrast, high EC level usually increase mineral concentration in the nutrient solution but descrease water potential , this will make it difficult for the absorption of water and nutrients through the cell membrane of the roots into the plants (Volkmar et al., 1998). At the

[1] Faculty of Technology , Mahasarakham university, Thailand
* Corresponding author: wantana.sinsiri@gmail.com

extreme EC level, plants are not able to take up any more water, but water will move backwards out of the nutrient solution, which makes plants withered. This has also been examined by many researchers on several hydroponic crops such as lettuce (Willumsen, 1984; Huett, 1994), cucumber (Ho and Adams, 1994), tomatoes (Ehert and Ho, 1986; Ismail and Abmad, 1997; Kuchenbuch and Schwarz, 1997) and pepper (Tadesse, 1997). In addition, growing lettuce with the hydroponic method at high EC levels also increases production costs and result in excess nutrient in plants, especially nitrate excess (NO_3) (Willumsen, 1984).

There have been many reports on EC for hydroponic lettuce were conducted and showed that the EC level of 0.6 - 1.1 mS/cm is the most suitable for the growth of lettuce (Morgan et al., 1980; Morgan and Tan, 1980). The lettuce grown at 0.5 - 1.0 mS/cm will give the highest yield and quality (Willumsen, 1984).

The vertical hydroponics system is one of the ways that can be used to increasing lettuce yield per unit area (Ozeker et al., 1999; Linsley et al., 2006). Ozeker et al. (1999) reported that planting density per unit area can be increased three times by using a vertical system (Morgan, 2006). However, Dijkstra et al. (1993) reported that the weight of each plant on a vertical hydroponics system was lower than that compared with conventional cultivated forms. The cause of this decrease is due to the distribution of fertilizer on the vertical system (Durner, 1999).

The revious studies on the EC of the nutrient solution for lettuce was carried out. However, all these experiments were conducted under the conventional horizontal hydroponic systems. Therefore, the present study aims to find out the most suitable EC concentration level of the nutrient solution for cultivation lettuce under the vertical hydroponic systems

Materials and Methods

This study was carried out from February to April, 2013 in a greenhouse at the Faculty of Agronomy, Hue University, Viet Nam. The 'Rapid Red' lettuce cultivar used was. Seeds were germinated in polypropylene tray of 120 cells filled with coconut fibre. Two weeks after germination, the seedlings were transplanted onto the vertical hydroponic systems. A hydroponic nutrient solution from Ministry of Agriculture and Fishery (Tregidga et al., 1986) was used as fertilizer with the EC of the solution being maintained at 0.5 to 2.5 mS/cm. The pH was maintained at 6.0 to 6.5 entire the growing period.

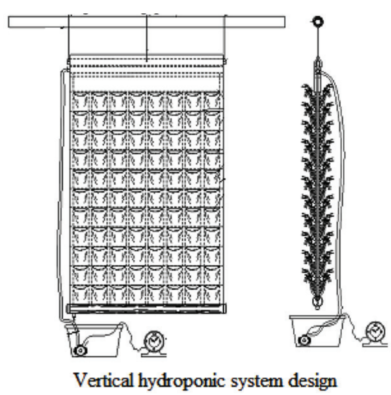

Figure 1 Verical hydroponic system design

A total of 20 vertical hydroponic systems were established for the experiment. The system was made of 1.3x2 m by Mat plastic, planting density of 10x12 cm (160 plants/m^2). (**Figure 1**) (Nguyen Van Quy et al., 2016)

The total system was suspended 0.2 m above the ground in a North-South direction to absorb optimal sunlight. The spacing between each of the vertical hydroponic systems was 1 m. A tank of water and nutrients with a capacity of 30 L and a 30 W pump with 2 liters per minute of flow rate was installed under each vertical hydroponic system to provide water and nutrients for the plants. The time of irrigation was set at 6.00 am, 12.00 am, and 6.00 pm and the period of each irrigation was 15 minutes.

The experiment was laid out in Randomized Complete Block Design (RCBD) with 4 replications. The treatments consist of 5 different EC concentration levels (0.5, 1.0, 1.5, 2.0 and 2.5 mS/cm). At 45 days after planting (DAP), ten randomly assigned plants from each experimental units were collected data. To recorded all plant growth parameters, number of leaves/plant, plant canopy diameter, total fresh and dry weight per plant.

Leaf area and leaf area index were determined by Portable area meter (Model: LI-3000C). Chlorophyll concent was analyzed by followed the methods of Arnon (1949). Ascorbic acid (vitamin C) concentration was analyzed as procedure of ISO 6557/2 (Anonymous, 1984). Nitrate concentration was determined by selective electrode method (Bedwell et al., 1995). Sensory evaluation was recorded by a 15 member panel on 5 score hedonic scale, with 1 being the lowest and 5 the highest. Yield was recorded from harvesting areas of 2x2 meter at 45 DAP, and calculating to ton per hectare.

Data was analyzed using STATISTIC version 8.0 (Statistic, 2007). Least Significant Difference (LSD) was calculated at 5% level to compare the treatment means.

Results and Discussion

Plant height: The plant height of lettuce was significantly ($P \leq 0.01$) affected by EC concentration levels at 35, 40, 45 days after planting (DAP), but not significantly ($P \leq 0.05$) difference at 30 DAP (**Table 1**). The maximum plant height was observed at the maximum E.C. of 2.5 mS/cm. In the present experiment, plant height increased with EC increased (**Table 1**). This results was similar to the initial experiments reported by Samarakoon et al. (2006), who did experiments on growing lettuce at the EC level of 1.4, 2.0 and 3.0 and reported that lettuce height increased as the EC increased from 1.4 to 2.0. But when the EC continued to increase up to 3.0, the lettuce height did not increase further. TS Chiloane (2012) also said that lettuce height seemed to increase when the EC of the nutrient solution increased from 1 to 4, but this increase stopped at EC = 3. This is also consistent with a test conducted by Myeong WhoonSeo et al. (2009).

Table 1 Plant height of lettuce as affected by Electrical Conductivity (EC) levels at different growth stage

Treatments	Plant height (cm) Days after planting				
	25	30	35	40	45
EC- 0.5 mS/cm	6.77	7.76^{b}	11.36^{c}	14.20^{c}	15.80^{c}
EC- 1.0 mS/cm	6.80	7.77^{b}	12.23^{c}	14.60^{bc}	16.63^{c}
EC- 1.5 mS/cm	7.00	8.17^{b}	13.63^{b}	15.60^{b}	18.60^{b}
EC- 2.0 mS/cm	7.10	9.26^{a}	15.03^{a}	17.23^{a}	20.43^{a}
EC- 2.5 mS/cm	7.30	9.63^{a}	15.76^{a}	17.70^{a}	21.63^{a}
F-test	ns	*	**	**	**
CV%	5.19	10.59	13.08	9.90	12.77

Means followed by the same letter at the same column were not significantly different than the LSD ($P \leq 0.05$)

* ; ** Significant at ($P \leq 0.01$), ns = Not significant

Number of leaves: The number of leaves per plant was significantly ($P \leq 0.01$) affected by the EC concentration levels at harvest (**Table 2**). The highest number of leaves per plant was obtained at the maximum E.C. of 2.5 mS/cm but did not show significant difference from one at 2.0 mS/cm. In this study, the number of leaves per plant increased with EC concentration increased (**Table 2**). This results agree with the previous research by Myeong WhoonSeo et al. (2009), who did experiments on growing lettuce at the EC level of 0.5, 1.0, 2.0 and 3.0 and reported that the highest number of leaves per plant was obtained at EC of 2.0. This is also consistent by Sangnandeekul (1999).

Plant canopy diameter: There was a significant difference ($P \leq 0.01$) in plant canopy diameter of lettuce at different EC concentration levels at harvest (**Table 2**). The maximum plant canopy diameter was observed at 2.5 mS/cm concentration, but not significant difference with 2.0 mS/cm concentration. This is also consistent with a test conducted by Fallovo et al. (2009).

Leaf area and leaf area index: The different EC levels had a significant ($P \leq 0.01$) effect on the leaf area (LA) per square meter (m^2) and leaf area index (LAI) of lettuce at harvest (**Table 2**). The highest LA/mand LAI were obtained at the maximum E.C. of 2.5 mS/cm but did not significant difference from one at 2.0 mS/cm. In the present experiment, LA and LAI increased with EC increased. This results agree with the previous research reported by Chiloane (2012), who reported that leaf area and leaf area index of lettuce peaked at EC level from 2 to 3 mS/cm. Myeong WhoonSeo et al. (2009) reported that the highest leaf area index of lettuce was obtained at EC of 2.0.

Table 2 Number of leaves, plant canopy diameter, leaf area and leaf area index of lettuce as affected by Electrical Conductivity (EC) levels at 45 days after planting

Treatments	Number of leaves per plant	Plant canopy diameter (cm)	Leaf area (cm^2)	Leaf area index
EC- 0.5 mS/cm	11.70[d]	10.40[c]	520[c]	8.32[c]
EC- 1.0 mS/cm	14.23[c]	12.40[b]	670[b]	10.72[b]
EC- 1.5 mS/cm	17.06[b]	12.80[b]	760[ab]	12.16[ab]
EC- 2.0 mS/cm	18.93[a]	14.26[a]	830[a]	13.28[a]
EC- 2.5 mS/cm	19.46[a]	14.60[a]	850[a]	13.60[a]
F-test	**	**	**	**
CV%	19.31	12.88	18.09	18.09

Means followed by the same letter at the same column were not significantly different than the LSD ($P \leq 0.05$)

** Significant at ($P \leq 0.01$)

Vitamin C: The vitamin C (Ascorbic acid) in leaves of lettuce was significantly ($P \leq 0.01$) affected by the EC concentration levels at harvest (**Table 3**). The highest vitamin C value was obtained at 1.5 mS/cm concentration. Sangnandeekul (1999) reported that vitamin C content in leaves of lettuce was the highest value when it grown at 1.5 mS/cm concentration of the EC nutrient solution. In general, EC concentration at higher (>1.5 mS/cm) or lower (<1.5 mS/cm) levels, the vitamin C content in leaves of lettuce will be decreased. Shinohara et al. (1978), Shinohara & Suzuki (1981) reported that the ascorbic acid content increased at 1/4 concentrations of the standard nutrient solution, compared with 1/2 concentrations or more. In the study of Evers (1994) reported that excess nitrogen decreased vitamin C content, while Sorensen et al. (1994) found that the vitamin C content decreased from 64.8 to 5 1 .5 mg/kg with increased nitrogen supply from 50 to 200 kg N ha- 1 in the field.

Sensory evaluation: For sensory evaluation (based on taste, leaf color and stem size), EC concentration at different levels had a significant effect on a sensory evaluation at harvest (**Table 3**). The highest senory evaluation score was observed at 2.5 mS/cm concentration, but not significant difference as compared to EC concentration at 1.5 mS/cm. This indicates that consumers prefer the lettuce grown at 1.5 and 2.0 mS/cm of EC concentration. For lettuce grown at 2.5 mS/cm concentration, the consumers stated that it taste has more bitter than those of 1.5 and 2.0 mS/cm.

Nitrate accumulation: Vegetable crops uptake nitrate and further conversion to nitrite which cause methemoglobinemia in infants (Sangnandeekul, 1999). In the present experiment, nitrate accumulation in leaves were significantly ($P \leq 0.01$) affected by the EC levels (**Table 3**). The highest nitrate accumulation value (644.6 mg/kg) was observed from plants grown at EC of 2.5 mS/cm. This is the safe nitrate level for consumers. The nitrate accumulation increased with EC level increased. This result was similar to the initial experiments reported by Sanguandeekul (1999), who argued that the increased EC levels of hydroponic nutrient solution led to a corresponding increase in the nitrate accumulation in lettuce leaves.

Chlorophyll content: There was significantly different in the leaf chlorophyll content at different EC levels at harvest (**Table 3**). The maximum chlorophyll content value was obtained from plants grown at 2.5 mS/cm, but not significant difference with concentration at 1.5 and 2.0 mS/cm. The result agrees with the findings of Fallovo et al. (2009), who said that the chlorophyll content in lettuce leaves tended to increase when EC level of nutrient solution increased. T S CHILOANE, 2012 also reported that the increased level of nutrient solution, the chlorophyll content of lettuce tend to increase and reached the highest level of EC from 2 to 3 mS/cm.

Table 3 Vitamin C (Ascorbic acid), sensory evaluation and nitrate concentration of lettuce as affected by Electrical Conductivity (EC) at 45 days after planting

Treatments	Vitamin C(mg/100g)	Sensory evaluation (score)	Nitrate (mg/kg)	Chlorophyll content (mg100/g)
EC- 0.5 mS/cm	15.33^{c}	2.5^{c}	241.3^{d}	13.40^{b}
EC- 1.0 mS/cm	17.30^{ab}	3.1^{b}	306.3^{cd}	14.20^{b}
EC- 1.5 mS/cm	17.76^{a}	3.4^{ab}	358.6^{c}	15.90^{a}
EC- 2.0 mS/cm	16.76^{b}	3.6^{a}	489.0^{b}	16.16^{a}
EC- 2.5 mS/cm	15.70^{c}	3.2^{b}	644.6^{a}	16.36^{a}
F-test	**	**	**	**
CV%	6.42	5.48	37.09	8.75

Means followed by the same letter at the same column were not significantly different than the LSD ($P \leq 0.05$)

** Significant at ($P \leq 0.01$)

Above ground fresh weight, dry weight and yield: The EC concentration levels were significantly ($P \leq 0.01$) affected on Above Ground Fresh Weight (AFW) and Above Ground Dry Weight (ADW) per plant at harvest (**Table 4**). The maximum AFW and ADW were obtained from plants grown at 2.5 mS/cm, but not significant differet from ones grown at 2.0 mS/cm C. Irrespective of yield per unit land areas, the EC concentration levels had a significant ($P \leq 0.01$) effect on yield of lettuce at harvest (45 DAP) (**Table 4**). The highest calculated yield (fresh weight) was obtained from plants grown at EC of 2.0 and 2.5 mS/cm. Many studies have shown that EC optimal concentration level for lettuce cultivation was 2 mS/cm as reported by Morgan and Tan (1980), and at 2-3 mS/cm as reported by Economakis (1990) and Chiloane (2012). The lettuce grown at high EC concentration levels reduce growth and yield. This was due to high EC level reduce the permeability of the cell and subsequent reduce the ability of plants to absorb water (Terry et al., 1983; Longnecker, 1994; Al-Herbi, 1994). This is also consistent with a test conducted by Fallovo et al. (2009) who found that fresh and dry yield of lettuce significantly reduced at extremely low (0.5 mS/cm) or high EC level (> 4 mS/cm).

Table 4 Above ground fresh weight, above ground dry weight and yield of lettuce as affected by Electrical Conductivity (EC) levels at 45 days after planting

Treatments	Above ground fresh weight (g/plant)	Above ground dry weight (g/plant)	Calculated Yield (t/ha)
EC- 0.5 mS/cm	10.40[c]	0.57[d]	16.6[c]
EC- 1.0 mS/cm	13.56[b]	0.69[c]	21.7[b]
EC- 1.5 mS/cm	14.86[b]	0.80[b]	23.8[b]
EC- 2.0 mS/cm	16.66[a]	0.89[ab]	26.7[a]
EC- 2.5 mS/cm	17.20[a]	0.91[a]	27.5[a]
F-test	**	**	**
CV%	17.88	17.97	17.88

Means followed by the same letter at the same column were not significantly different than the LSD ($P \leq 0.05$)

** Significant at ($P \leq 0.01$)

Relationship between yield and EC concentration: The coefficient of determination (R^2) was 0.934 (**Figure 2**). This demonstrates a positive correlation between yield of Rapid Red lettuce cultivars and their corresponding level, indicating that yield increases as the EC of the nutrient solution increases.

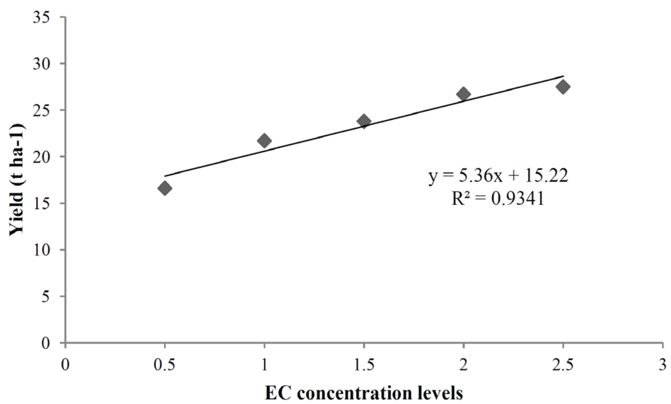

Figure 2 Linear regression between yield of lettuce and EC concentration levels

Conclusions

The different EC levels used on the vertical hydroponics system had significant effect on the parameters of lettuce. The EC concentration at 2.5 mS/cm produced maximum growth, yield and quality of Rapid Red lettuce cultivar, but not significant difference with 2.0 mS/cm concentration level in vertical hydroponic systems. Therefore, lettuce cultivated in EC concentration levels at 2.0-2.5 mS/cm is recommended as a potential use under vertical hydroponic systems for growing lettuce with high productivity.

Acknowledgements

The authors wish to thank Professor Dr. Anan Polthanee for invaluable advices and his kind assistance in reviewing .This research received facilities support from Mahasarakham University and Hue University is greatly acknowledged. We also thanks technical assistances of department of Agricultural Technology, faculty of Technology, Mahasarakham University.

References

Addiscott, T.M., A.P. Whitmore, and D.S . Powlson. 1991. Farming, fertilizers and the nitrate problem. C.A.B. International. Wallingford.

Anonymous. 1984: Fruit, vegetables and derived products- Detennination of ascorbic acid content - Part2: Routine methods. ISO 6557/2: Interational Organization for Standardization 5p.

Anonymous. 2000. ARC Training Report 2000. The 18 th Regional Training Course on Vegetable Production, Research and Extension, ARC-AVRDC, Thailand.

Al-Harbi, A.R. 1994. Eff ect of manipulating nutrient solution salinity on the growth of cucumber. Cucumis sativus L. grown in NFT. Acta horticulturae 361: 267-273.

Arnon, D.I. 1949. Copper enzymes in isolated chloroplasts. Polyphenoloxidase in Beta vul-garis. Plant Physiol. 24: 1-15

Bedwell, C.L., D.W. Hamar, M.L. Hoesterey, P. Sondennan,and K.G. Odde. 1995. Comparison of four methods for forage nitrate analysis. Jourl of veterinar diagnosis investigation. 7: 527-530.

Benoit, F., and N. Ceustennans. 1995. Horticultural aspects of ecological soilless growing methods. Acta horticulturae 396: 11-21.

Dijkstra, J., J. De Bruijn, A. Scholtens,and J.M. Wijsmuller. 1993. Effect of planting distance and peat volume on strawberry production in bag and bucket culture. Acta Horticulturae. 348: 180-187.

Durner, E.F., 1999. Winter greenhouse strawberry production using conditioned plug plants. Hortscience. 34: 615-616.

Economakis, E.D. 1990: Effect of solution conductivity on growth and yield of lettuce in nutrient film culture. Acta horticulturae. 287: 309-316

Ehert, D.L., and L.e. Ho. 1986. Effects of salinity on dry matter partitioning and fruit growth in tomatoes grown in nutrient film culture. Journal of experimenta l botany. 37: 1297-1302.

Evers, A.M. 1994. The influence of fertilizer and environment on some nutritionally important quality criteria in vegetables-a review of research in the Nordic countries. Agricultural science in Finland. 3: 177- 187.

Fallovo, C., Y.Rouphael, E.Rea, A. Battistelli, and G. Colla. 2009.Nutrient solution concentration and growing season affect yield and quality of Lactuca sativa var. acephala in floating raft culture. Journal of the Science of Food and Agriculture. 89: 1682-1689

Furlani, P.R., L.C.P. Silveira, D. Bolonhesi, and V. Faquin. 1999. Cultivo hidroponico de plantas. Campinas: IAC, 52p (Boletim Técnico 180).

Ho, L.C., and P. Adams. 1994. Regulation of the partitioning of dry matter and calcium in cucumber in relation to fruit growth and salinity. Annals of botany. 73: 539-545.

Huett, D.O. 1994. Growth, nutrient uptake and tipburn severity of hydroponic lettuce in response to electrical conductivity and K: Ca ratio in solution. Australian journal of agriculture research. 45: 252-267.

Ismail, M.R., and R. Abmad. 1997. Differential growth and yield responses of tomato plants grown in dif ferent solution concentrations using nutrient film technique and sand culture. Acta horticulturae. 450: 449-455.

Kuchenbuch, R and D. Schwarz. 1997. Growth analysis of tomato in a closed recir culating system relation to the EC-value of the nutrient solution. Acta horticulturae. 450: 169- 176.

Linsley-Noakes, G., L. Wilken, and S. De Villiers. 2006. High density, vertical hydroponics growing system for strawberries. Acta Horticulturae. 708: 365-370.

Longnecker, N. 1994. Nutrient deficiencies and vegetative growth. Pp. 137- 172 in: Mechanisms of plant growth and productivity. Basra, A.S. ed. New York: Marcel Dekker, Inc.

Morgan, JV., A.T. Moustafa, and A. Tan. 1980. Factors aff ecting the growing-on stages of lettuce and chrysanthemum in nutrient solution culture. Acta horticuLturae. 98: 253-261.

Morgan, J.V., and A.L. Tan. 1983. Greenhouse lettuce production at high densities in hydroponics. Acta horticuLturae. 133: 39-46

Morgan, L. 2006. Hydroponic strawberry production. A technical guide to the hydroponic production of strawberries. Suntec (NZ) Ltd, Tokomaru, New Zealand.

Nguyen Van Quy, W.Sinsiri, S. Chitchamnong, K. Boontiang, and W. Kaewduangta. 2016. Effect of plant densities and supporting materails of the vertical hydroponic system on growth and yields of lettuce. KHON KAEN AGR. J. 44: 723-730

Ozeker, E., R.Z. Eltez, A. Gul, K. Onal, and A. Tanrisever. 1999. Investigations on the effects of different growing media on the yield and quality of strawberries grown in vertical bags. Acta Horticulturae. 486: 409-413.

Ryall, A.L., and W.J. Lipton. 1979. Handling, tran sportation and storage of fruits and vegetables. Volume one, 2nd edition Vegetables and melons. Westport, Connecticut, AVI Publishing Company, Inc

Shinohara, Y., K.Tanaka, Y. Suzuki, and K. Yamasaki. 1978. Growing conditions and the quality of vegetables. !. Effects of nutrition and foliar spray treatment on the ascorbic acid content of leaf vegetables. Joural of the Japanese Societ for Horicultural Science. 47: 63-70.

Shinohara, Y., and Y. Suzuki. 1981. Efects of light and nutritional conditions on the ascorbic acid content of lettuce. Joural of the Japanese Societ for Horticultural Science. 50: 239-246.

Sorensen, N., A.S. Johansen, and N. Poulsen. 1994. Infuence of growth condition on the value of crisphead lettuce: 1. Marketable and nutritional quality a affected by nitrogen supply, cultivar and plant age. Plant-food for human nutrition. 46: 1-1 1.

Sunlarp Sanguandeekul, 1999. The effect of cultivar, nutrient solution concentration and season on the yield and quality of NFT produced lettuce (*Lactuca saliva* L.). A thesis presented in partial fulfilment of the requirements for the degree of Doctor of Philosophy in Plant Science at Massey University. March, 1999.

Tadesse, T. 1997. Some factors aff ecting the yield and quality of sweet pepper (*Ca psicum annuum* L.) cv. Domino. Ph.D. thesis, Massey University, New Zealand.

Terry, N., L.J. Waldron, and S.E. Taylor. 1983. Environmental influences on leaf expansion. Pp 179-205 in: The growth and functioning of leaves, Dale, J.E. ; Millthorpe, F.L. ed. Cambridge London New York New Rochelle Melbourne Sydney: Cambridge University Press.

Tregidga, G., M. Tregigda, and R. Lewthwaite. 1986. Hydroponics nutrient film technique for commercial vegetable growing. New Zealand Ministry of Agriculture and Fishery: HPP 322.

Chiloane, T.S. 2012. Effect of nutrient concentration and growing seasons on growth, yield and quality of leaf lettuce in a hydroponic system. Submitted in partial fulfillment of the requirements for the degree M. Inst. Agrar: Plant production in University of Pretoria.

Samarakoon, U.C., P.A. Weerasinghe and W.A.P. Weerakkody, 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 (2006)

Volkmar, K.M., Y. Hu, and H. Steppuhn. 1998. Physiological responses of plants to salinity: A review. Canadian journal of plant science. 78: 19-27.

Willumsen, J. 1984. Nutritional requirements of lettuce in water culture. Proceedings of the fifth International Congress on Soilless Culture: 777-792.