Effect of Electrical Conductivity [EC] of the Nutrient Solution on Nutrient Uptake, Growth and Yield of Leaf Lettuce (*Lactuca sativa* L.) in Stationary Culture

U.C. Samarakoon, P.A. Weerasinghe and W.A.P. Weerakkody[1]

Faculty of Agriculture
Rajarata University of Sri Lanka
Puliyankulama, Sri Lanka

ABSTRACT. *This study was conducted to economize the hydroponics lettuce production by optimizing the Electrical Conductivity (EC) in stationary culture under hot (38.5^{0}C) greenhouse conditions in Sri Lanka. Four plants were grown in 50 L troughs, where lower dosages (0.5 and 1 g/l) were compared with the standard dosage (2 g/l) of Albert's solution. The EC of the 0.5, 1.0 and 2.0 g/l treatments were 1.4, 2.0, 3.0 dS/m, respectively. The solutions were adjusted for pH daily and replaced with new solutions after two weeks (at the end of early vegetative growth) and plants were harvested at 4 weeks after transplanting. With increasing EC of the nutrient solution, both fresh and dry weights of plants decreased significantly. Higher leaf formation (leaf number) in 1.4 dS/m than 2.0 and 3.0 dS/m lead to increased fresh and dry weights. Other morphological features such as stem height and leaf area also appeared to be in the same trend, but were not statistically significant. In contrast, uptake of N, P, K and Ca significantly increased with increasing EC. The difference between 2.0 and 3.0 dS/m were the most dominant. Except P, uptake rates of other three ions were higher or equal in the late vegetative phase (last 2 weeks). High concentrations of all four nutrients in the remaining solutions indicated the nutrient availability even under the lowest EC at the end of both early and late vegetative stages. The inverse relationship of plant growth and yield with nutrient uptake rates could be due to negative impacts of excessive uptake of plant nutrients, on the growth physiology in the forms of toxicities, imbalances or defensive responses. Albert's solution at EC of 1.4 dS/m (0.5 g/l) with complete replacement after two weeks could be selected as the best nutrient concentration to be used for growing leaf lettuce (Lactuca sativa* L.*) under hot weather conditions in tropical green houses of dry zone in Sri Lanka.*

INTRODUCTION

Leaf lettuce (*Lactuca sativa* L.) is cultivated mainly in up country of Sri Lanka in open fields as well as under greenhouse conditions. It has been found that simple hydroponics techniques such as the stationary culture (trough culture) is successful in growing leafy vegetables. The best quality lettuce is obtained when it is grown to the harvesting maturity in a short period. This is assured by adequate fertilizing, steady supply of water and cool temperature (Anon, 1999).

[1] Department of Crop Science, Faculty of Agriculture, University of Peradeniya, Peradeniya, Sri Lanka.

At present in Sri Lanka, nutrient solutions are used in hydroponics without determining the optimal nutrient requirement or environmental conditions for individual species. Thus, it is important to determine the nutrient requirements to avoid probable toxicities due to over fertilization and also to monitor the growth and the productivity under hot climatic conditions. Lettuce has shown to be cultivated successfully under hydroponics in the *Maha* season (average day time temperature) in poly tunnel is 35^0C with standard dosage of fertilizers (Samarakoon *et al*., 2006).

The electrical conductivity (EC) measured using the EC meter is an indirect indication of the strength of nutrient solution. The ideal EC range for hydroponics is between 1.5 to 2.5 dS/m and higher EC hinders nutrient absorption due to increase in osmotic pressure whereas lower EC may severely affects plant health and yield (Anon, 2002).

The objective of this study was to investigate the effect of optimum EC as an indicator for nutrient concentration in the hydroponics solution on the growth of lettuce and to examine the feasibility of growing lettuce under greenhouse conditions in the *Yala* season (hot condition) of the dry zone in Sri Lanka.

METERIALS AND METHODS

Lettuce was cultivated under semi-shade conditions in a 10'x 15' poly tunnel located in the dry zone of Sri Lanka (Faculty of Agriculture, Rajarata University of Sri Lanka). Average daytime temperature inside the greenhouse (poly-tunnel) at noon was around 38.5^0C. Lettuce seeds of variety Grand Rapid of Thailand origin were germinated using sponge nursery technique (Anon, 2002). They were transferred 3 weeks after seeding to a stationary (trough) culture system (Plate 1) which is a non-circulating and low cost hydroponic technique. Albert's solution of the Chemical Industries Colombo Ltd. (CIC) was used as the main source of fertilizer. Three concentrations of Albert's solution; 0.5 g/l (T1), 1 g/l (T2) and 2 g/l (T3) (Table 1) with an EC of 1.4, 2.0 and 3.0 dS/m, respectively, were tested at two week replacements. The pH was adjusted to be maintained between 5.5-6.5 during the period by adding, 0.1M NH_4OH and 0.1M phosphoric acid solutions in the troughs at the end of the early vegetative phase (2^{nd} week after transferring) and late vegetative phase (4^{th} week after transferring). Analyses for NH_4-N, NO_3-N, P, K and Ca were carried out according to procedures specified by van Ranst *et al.* (1998) at the Crop Science Laboratory, Faculty of Agriculture, University of Peradeniya. Similarly, water and fresh solutions of Albert's solution of above concentrations were also analyzed for plant nutrients. Nutrient uptake rate of plants per day was calculated for early vegetative phase and late vegetative phase separately using initial and final concentrations of nutrients in the solutions and the evapotranspiration. Initial concentration of nutrients was calculated by using the CIC laboratory analysis report of individual elements present in the fertilizer samples and using the results of analysis of fresh solutions for nutrients at the laboratory. Relative adjustments were done by addition of acids and bases for pH and nutrient quantities present in water.

Each treatment comprises of 4 replicates and 4 plants per trough were considered as a plot. The treatment 3, having the recommended dosage of Albert's solution, (2 g/l) was used as the control and the experiment was conducted as a complete randomized block design (CRBD).

Plate 1. Arrangement of plants in the stationary culture system.

Fresh weight of leaves, stems and roots, the height of the entire plant, the number of leaves per plant, and leaf area of the harvested plants were determined. The average dry weight of leaves and stems of a one plant sample (per plot) were also determined. The data were statistically analyzed according to the General Linear Model (GLM) procedure and the mean separation was done using the Least Significant Difference (LSD) at P=0.05 level. SAS Statistical software (version 8.0) was used for the statistical analysis.

Table 1. Amounts of nutrients in the initial solution (mg/l).

Concentration of Albert's solution (g/l)	*Nitrogen*	*Phosphorus*	*Potassium*	*Calcium*
0.5	59	27	68	48
1.0	118	54	137	96
2.0	236	108	274	192

RESULTS

Uptake rates of all nutrients increased with increasing nutrient solution concentration although it did not contribute to yield increase. The mean fresh weights of T1, T2, and T3 were in the descending order (89.42, 69.22 and 57.25 g/plant, respectively) (Fig. 1). Dry weight of above ground parts were also significantly different among treatments (at P=0.05), showing a similar pattern to fresh weights where it decreased the dry matter production from T1 to T3 (Fig. 2). Dry matter production of T1 (4.98 g/plant) was significantly higher than that of T3 (3.09 g/plant). Leaf number of lettuce varied significantly with changing dosage of fertilizer. The highest leaf number was given by T1 (20 leaves). Leaf area (per plant) and plant height although increased with increasing solution concentration were not significantly different among treatments (Table 2).

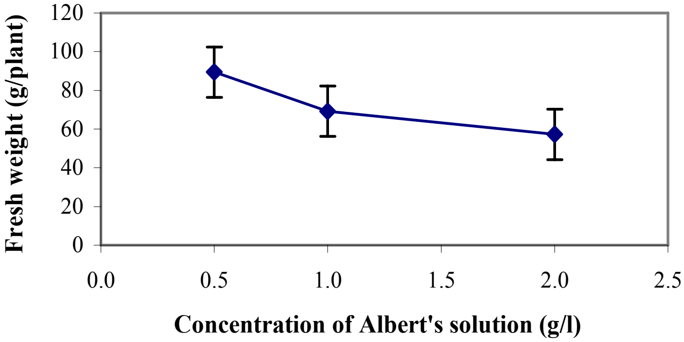

Fig. 1. **Average fresh weight of above ground parts of lettuce in hydroponics.**
Note: The vertical error bars indicate LSD at p=0.05.

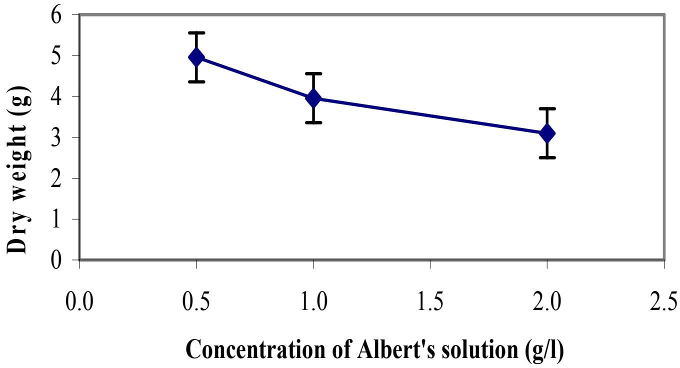

Fig. 2. **Average dry weight of above ground parts of lettuce in hydroponics.**
Note: The vertical error bars indicate LSD at p=0.05.

Table 2. **Leaf area, leaf number and plant height of lettuce in hydroponics.**

Concentration of Albert's solution (g/l)	Leaf area per plant (cm^2)	Leaf number per plant	Plant height (cm)
0.5 (T1)	2137.7[a]	20[a]	31.0[a]
1.0 (T2)	1653.0[a]	16[b]	29.1[a]
2.0 (T3)	1623.6[a]	15[b]	24.8[a]

Note: Values followed by same letter are not significantly different at p=0.05 level.

Plant uptake of nitrogen (NH_4-N and NO_3-N) increased significantly with increasing concentration of the Albert's solution (Table 3) and the difference was significant between T1, T2 and T3, both during early vegetative phase (EVP) and late vegetative phase (LVP). Comparison of N uptake rate and remaining N concentration in the solutions indicate a higher rate of N-uptake in T3 at LVP than the other treatments (Table 4).

Phosphorus levels in solution at the end of EVP and LVP significantly increased (P= 0.001) with increasing fertilizer dosage. The P uptake also relatively increased during EVP than LVP. At T1 (1.4 dS/m) P level of the solution at the end of LVP, has depleted compared to EVP. However, in all other treatments, P concentrations were higher in the solution at the end of LVP than EVP (Table 4).

Increased uptake of calcium by plants was observed along with the increase in concentration of Albert's solution (p=0.0001). Uptake observed at the LVP was greater than the EVP in T1 and T2 (Table 3), but in T3, the Calcium uptake did not vary between EVP and LVP. Calcium levels in the remaining solution was also significantly increased (p=0.0001) with increasing concentration of Albert's solution. It showed a pattern similar to P where the levels were high in the remaining solution at the end of LVP than in the EVP in T2 and T3 but levels were lower at the end of LVP in T1.

Potassium uptake rates in plants increased with increasing concentration of Albert's solution (p=0.0001). A comparatively higher rise in uptake rate of potassium could be observed in T1 between two growth phases (LVP and EVP) when compared with the same in T2 and T3 (Table 3). Potassium levels in the solution at the end of EVP and LVP also gradually increased with increasing concentration of Albert's solution (p=0.0001). But once again exceptionally, potassium concentrations in T1 were lower at the end of LVP than EVP (Table 4), testifying comparatively higher rate of uptake at LVP.

Table 3. Nutrient uptake rate in plants (mg/plant/day) during EVP and LVP at different EC Values.

EC (dS/m)	Nitrogen		Phosphorous		Potassium		Calcium	
	EVP	LVP	EVP	LVP	EVP	LVP	EVP	LVP
1.4 (T1)	0.1^c	13.6^c	4.7^c	4.1^c	7.2^c	23.6^c	0.1^c	16.1^c
2.0 (T2)	10.0^b	21.2^b	19.1^b	13.2^b	38.1^b	42.8^b	17.9^b	23.8^b
3.0 (T3)	94.0^a	139.6^a	61.1^a	48.4^a	118.5^a	126.7^a	71.5^a	68.0^a

Note: Values followed by same letter are not significantly different at p=0.05;
EVP - Early Vegetable Phase; LVP - Late Vegetable Phase.

With regard to the changes of EC over the period in all treatments, the EC levels have increased in both phases over time. EC change or shift was high with increasing concentrations where nutrients are concentrated over time with the reduction of water due to evapotranspiration. In T3, the EC increased up to a higher level as 3.4 dS/m at the end of growth period compared to T1 where an increase up to 1.43 dS/m were only observed. Hence solutions having a high EC have a risk of increasing concentrations to toxic levels during the crop growth in stationary culture systems especially where the solution is not renewed frequently.

Table 4. Remaining nutrient concentrations of the solution (mg/l) at the end of EVP and LVP at different EC values.

EC (dS/m)	Nitrogen		Phosphorous		Potassium		Calcium	
	EVP	LVP	EVP	LVP	EVP	LVP	EVP	LVP
1.4 (T1)	68.2[c]	88.7[c]	37.5[b]	32.9[c]	63.0[c]	51.8[c]	62.5[c]	50.1[c]
2.0 (T2)	111.1[b]	132.2[a]	42.9[a]	46.5[b]	98.2[b]	105.6[b]	89.9[b]	94.7[b]
3.0 (T3)	134.9[a]	110.0[b]	45.6[a]	61.4[a]	145.8[a]	150.7[a]	126.7[a]	144.5[a]

Note: Values followed by same letter are not significantly different at p=0.05;
EVP - Early Vegetable Phase; LVP - Late Vegetable Phase.

DISCUSSION

Effect of high electrical conductivity on yield

Although uptake rate of all nutrients increased with increasing nutrient solution concentration (EC), it did not contribute to yield increase. Thus, situation can be explained on the general theories of mineral absorption by plants. Some ions at high concentrations could be taken up by the plant in high quantities while uptake of certain ions, which are present in lower quantities is inhibited. High uptake of ions may have caused a nutrient imbalance in plants leading to reduction in total dry matter production (Schwarz, 1995; Bugbee, 1995).

Yield reduction due to increased concentration of solution has been observed in earlier research where marketable yield, plant fresh weight and leaf number of lettuce was reduced when EC increased from 1.6 to 4.6 dS/m in coir dust culture (Miceli *et al.*, 2003). Similar observations were made by Serio *et al*. (2001) on fresh weights of lettuce when grown in a drip-fertigated peat and pumice substrate with three solution EC levels (range from 1.5 to 3.5 dS/m). Along with increase in EC, fresh and dry weights of lettuce reduced together with other morphological parameters such as leaf number, leaf area and plant height. Thus, the yield reductions observed appeared to be due to the primary effect on leaf growth in lettuce. Stanghellini *et al*. (1996) and Serio *et al.* (2001) observed lower rate of leaf growth (LAI) under higher EC in lettuce under open soil less system. Furthermore, Huett (1994) found the greatest leaf and head fresh weight at 1.6 dS/m, which is closer to the EC of 1.4 dS/m. Therefore, this current experiment, and some of the previous experiments conducted under similar conditions (Samarakoon, 2006) confirms the phenomenon of reduction in leaf yield of lettuce with increasing solution concentration levels above 1.4 dS/m.

Effects of nutrients on yield

Due to continuous water uptake, certain nutrients in the solution get concentrated and are in a propensity to convert to unavailable forms (Schwarz, 1995). Increasing nutrient concentration of solution over the time has been observed in this study for all treatments, except for T1 (1.4 dS/m). This increase is higher in the LVP probably due to higher rate of water uptake. Similarly, Munns (2003) has also reported that excessive accumulation of nitrogen (i.e. ammonium or nitrate), phosphorus, boron, manganese, copper, and chloride in hydroponic solutions especially that are allowed to get concentrated due to plant transpiration.

The high accumulation and resultant increase in uptake of some mineral ions may have caused a nutrient imbalance in plants especially in T3 as explained by Bugbee (1995). Meanwhile, rate of removal of plant nutrients such as NO_3-N, NH_4-N, P, K, Mn from nutrient solutions through plant uptake receives precedence followed by that of Mg, S, Fe, Zn, Cu, Mo *etc*. The remaining nutrients, Ca and B are passively absorbed from solution and often get accumulated in solution (Bugbee, 1995). Therefore, the high rate of Ca uptake in T3 during the LVP in this study could be a result of accumulation based increased concentration which may have later resulted in rapid uptake by plants. Observations of Huett (1994) on high rate of Ca uptake at low EC levels (1.38 dS/m) support this result.

Further toxicities could occur in nutrient solutions over time, as solution gets concentrated due to rapid water absorption. In T2 and T3 of this study, about 10% increase in EC was observed in LVP and a significant increase in nitrogen, potassium, phosphorous and calcium was detected along with that. Although not measured with increasing EC, other macro and microelements in the nutrient solution may have reached toxic levels especially with high nutrient concentration in T3.

A study related to Butter-head lettuce using a nutrient film technique, found that NO_3-N, PO_4-P and K uptake rates by the lettuce plant were relatively stable within a comparatively wide range of nutrient concentrations above 1 meq (Maruo, 2002). As reported by Dellacecca and Miggiano (1996), the phosphorus requirement is less and nitrogen and potassium are higher for lettuce. Therefore, there is a possibility of P reaching toxic levels in the solution.

T1 (0.5 g/l) or EC of 1.4 dS/m) treatment with replacement at 2 week intervals gave much better yields under the high temperature conditions. Nutrient uptake rate vary between EVP and LVP. Therefore, estimation of individual nutrient requirements in different growth stages is needed for the replacement of the nutrient solutions during the growth period.

Furthermore, EC drift in the solution with time was higher when higher concentrations were used for hydroponics. Hence, high 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.

CONCLUSIONS

Production of leafy lettuce in stationary (trough) culture of hydroponics can be done very successfully under tropical greenhouse conditions (38.5^0C). A solution concentration of 0.5 g/l of Alberts solution (having an EC of 1.4 dS/m) with renewals at 2 week intervals could be identified as the best fertigation strategy under hot and humid conditions (*Yala* season). Increasing solution concentrations above that level up to 2 dS/m increased the plant uptake of N, P, K and Ca but, without a significant increase in leaf growth and yield.

REFERENCES

Anonymous. (2002). Hydroponics, Extension and Training Centre, Department of Agriculture, Sri Lanka.

Anonymous. (1999). CABI crop protection compendium- CD version. 1999 edition. CABI publication. UK.

Bugbee, B. (1995). Nutrient management in recirculating hydroponic culture. Proceedings from the Hydroponic Society of America. pp. 15-30.

Dellacecca, V. and Miggiano, A. (1996). A five year research on two combined doses of water and fertilizers applied to tomato and lettuce grown in greenhouse. *In:* The International Symposium on Water Quality and Quantity in Greenhouse Horticulture-WQQ96 Tenerife. Canary Islands, Spain. http://www.icia. rcanaria.es/eventos.

Huett, D.O. (1994). Growth, nutrient uptake and tip burn severity of hydroponic lettuce in response to electrical conductivity and K:Ca ratio in solution. Australian J. Agric. Res. 45(1): 251-267.

Maruo, T., Shinohara, Y., Iwata, M. and Ito, T. (2002). Effects of nutrient concentration on the absorption of N, P and K by lettuce cultured in NFT system. Japanese Soc. for Horti. Sci. 71(5): 675-682.

Miceli, A., Moncada, A. and D'Anna, F. (2003). Effect of salt stress in lettuce cultivation. Acta Horti., (ISHS). 609: 371-375.

Munns, D. N. (2003). Nutrient deficiencies and toxicities hydro farm horticulture products. www.hydrofarm.com.

Samarakoon, U.C. (2006). Management of nitrogen nutrition and electrical conductivity in hydroponics for leafy lettuce (*Lactuca sativa*) cultivation in the dry zone. Unpublished M. Phil Thesis, Postgraduate Institute of Agriculture, University of Peradeniiya, Peradeniya.

Samarakoon, U.C., Weerasinghe, P.A. and Weerakkody, W.A. P. (2005). Optimum nitrogen nutrition for stationary culture of lettuce (*Lactuca sativa*) under dry zone conditions. SLAAS proceedings of the 61st annual sessions, 2005. Pp. 17.

Schwarz, M. (1995). Soilless Culture Management: Advance Series in Agricultural Sciences, Springer, Germany.

Serio, F., Elia, A., Santamaria, P., Rodriguez, G.R., Conversa, G., Bianco, V.V., Fernandez, J.A., Martinez, P.F. and Castilla, N. (2001). Lettuce growth, yield and nitrate content as affected by electrical conductivity of nutrient solution. Acta Horti. 559(2): 563-568.

Stanghellini, C., van Meurs, W. M., Simonse, L., van Gaalen, J. (1996). Leaf development of a tomato crop under salinity stress. *In:* The International Symposium on Water Quality and Quantity in Greenhouse, Horticulture-WQQ96 Tenerife. Canary Islands, Spain. http://www.icia.rcanaria.es/eventos.

Van Ranst, E. (1998). Laboratory Manual for Soil Chemistry and Fertility Analytical Methods for Soils and Plants Equipment and Management of Consumables. University of Ghent, Belgium.