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GROWTH AND YIELD OF LETTUCE AS INFLUENCED BY SALINITY LEVELS AND ROOTING SUBSTRATES UNDER HYDROPONIC SYSTEM OF CULTIVATION

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ABSTRACT

A field experiment was conducted during *Rabi* season of 2019 at ZARS, V. C. Farm, Mandya with an objective to study the effect of salinity levels and rooting substrates on growth and yield of lettuce under hydroponic system. The experimental design was Randomized Complete Block Design which involved 4 × 4 factorial scheme with four Salinity levels of nutrient solution (0.50, 0.75, 1.10 and 1.30 dS m^{-1}) and four rooting substrate (Rockwool, sponge sphagnum moss and floral bed), that totalized 16 treatments with 2 replicates. The evaluated variables were number of leaves per plant, leaf area, leaf length, chlorophyll content, shoot length, shoot fresh and dry weight, root length, fresh and dry root weight and root to shoot ratio. Analyzed variables were significantly affected by salinity levels and rooting substrates. The results showed that nutrient solution having salinity level of 1.30 dS m^{-1} with rockwool rooting substrate recorded significantly higher growth and yield of lettuce.

***Key words*:** Hydroponics, lettuce, salinity and rooting substrates

Introduction

Hydroponics system of cultivation is gaining popularity all over the world due to efficient management of resources with quality food production. Soil based agriculture is now facing various challenges such as urbanization, natural disaster, climate change, indiscriminate use of chemicals and pesticides which are causing soil degradation. Besides, urbanization and infrastructure development causing shrinkage of arable land. Under these circumstances, hydroponics has proved to be another alternative crop production system. In recent years, due to scarcity of labour, mechanized modern agriculture and precision agriculture practices have gained much importance where, it not only conserves natural resources but also protect from environmental hazards. The term Hydroponics is derived from the Greek words '*hydro*' means water and '*ponos*' means labour and literally means work with water. The word hydroponics was coined by Professor William Gericke in the early 1930s; to describe the growing of plants with their roots suspended in water containing mineral nutrients (Sharma *et al.*, 2018).

Many soilless culture systems are based on the use of solid rooting media for growing plants. They are usually called "growing media" or "substrates" (Gruda, 2009). There are different kinds of growing media *viz.*, rockwool, oasis cubes, vermiculite, perlite, sphagnum mass, floral bed, coconut fiber (coir), peat, composted bark, pea gravel, sand, expanded clay, sawdust, pumice, foam chips, polyurethane grow slabs and rice hulls. Hence, media performs the role of soil and provide anchorage for the root system, supply water, nutrients and adequate aeration to the plant (Gruda *et al.*, 2006).

The nutrient solutions are prepared by dissolving appropriate salts in good quality water for cultivation of crops under hydroponic system. The aim is to prevent plants from saline stress during high transpiration demand or reduction in growth rate due to low availability of mineral nutrients. In general, the growth of lettuce is affected by low concentrations of the nutrients in solution and EC of the nutrient solution. The threshold EC value and nutrient requirement varies with crop and also species of the crop. The optimum pH and electrical conductivity required is 5.5 to 6.5 and 0.8-1.4 ds m^{-1}, respectively. Too high levels of nutrients induce osmotic stress, ion toxicity and nutrient imbalance while, too low levels lead to nutrient deficiencies (Fallovo *et al.*, 2009).

Lettuce (*Lactuca sativa*) is an annual herb which belongs to family Asteraceae having chromosome number 2n=18. *Lactuca* means 'milk-forming', *sativa* means 'common'. The crop is originated from the Mediterranean region and nowadays it is being cultivated commercially worldwide as a leafy vegetable. Lettuce is cole crop, usually grown during *Rabi* season and the crop duration is 45- 60 days. It is a rich source of vitamin-K, vitamin-A and moderate source of folate and iron, most often used for salads and other kinds of food, such as soups, sandwiches and wraps. Earlier, Europe and North America are the leading producers of lettuce, but by the late 20th century the production and consumption of lettuce had spread throughout the world. The major lettuce growing countries in the world are China, US, Italy, Spain, India and Japan (Dolma *et al*., 2010). China is the leading producer of lettuce followed by USA and India ranks 3rd in commercial production occupying four per cent of world's total production of lettuce. China produces almost one-half of the world's lettuce and its production (11 million metric tonnes) is double that of US. Since 1980s, worldwide lettuce production has increased approximately 2.7-fold with 22.4 million metric tonnes produced in 2005 (FAO 2006). In 2017, world production of lettuce was 27 million tonnes, with China alone producing 15.2 million tonnes or 56 per cent of the world total (UN Food and Agriculture organization).

Material and methods

Experimental site

The experiment was carried out during *Rabi* season of 2019 inside the shade net house at water technology center, ZARS, V. C. Farm, Mandya, falls under the region III and Agro Climatic Zone VI (Southern dry zone) of Karnataka. The experimental area was geographically located between 76º 49' 23" East Longitude and 12º 34' 06" North Latitude with an altitude of 659 meter above mean sea level.

Experimental design

The experiment was conducted in Factorial – Randomized Complete Block Design consisting of two factors *viz*., Factor A: Salinity (ds m^{-1}) levels of nutrient solution (S_1 – 0.50, S_2 – 0.75, S_3 – 1.10 and S_4 – 1.30) and Factor B: Rooting substrate (M_1 - Rockwool + LECA, M_2 - Sponge + LECA, M_3 - Sphagnum moss + LECA and M_4 - Floral bed + LECA) with two replications.

Hydroponic structure

The vertical circulating hydroponic system was established under the shade net in an area of 58.14 m^2 (10.2 m × 5.7 m). "A" frame type model was designed with a height of 135 cm and a width 186 cm. The structure consists of PVC pipes (Diameter-90 mm) having length of 186 cm, fixed on an angular iron frame with 8 drilled holes having four pipes accommodating 32 net cups for each replication. The end caps (90 mm) are provided on both the end of the pipes to maintain minimum water level and steady state of water flow. The elbows are used to change the direction of water flow from one end of the pipe to another end for continuous supply of water and return to water storage tank. Pipe union (0.75"), a type of fitting which unites two pipe lines ; detached without causing any deformation of the pipes during physical obstructions or movements and control valves (16 mm) are fitted on the laterals, to regulate the flow of nutrient solutions.

The drilled holes are accommodated with net cups having a dimension of 7.5 cm (L) × 23 cm (B), used for the planting seedlings and to grow for a period of 60 days. Each model consists of four different rooting substrates (media) and provided with nutrient solution concentration. The nutrient solutions and water are supplied to each model with the help of 0.500 hp motor.

Preparation of nutrient solution

The nutrient solutions were prepared using modified Hoagland solution as reference to achieve different salinity levels and to fulfill the nutrient requirement of lettuce crop.

The salts *viz*., monoammonium phosphate, potassium nitrate, calcium nitrate, magnesium sulphate, iron sulphate, copper sulphate, manganous sulphate, zinc sulphate, boric acid and ammonium molybdate at different proportions were used to prepare the solutions and to supply essential nutrients required for crop growth. The EC of respective salts were used as a base for preparing the nutrient solution to obtain the desired salinity level *viz*., 0.50, 0.75, 1.10 and 1.30 dS m^{-1}. The amount of salts used for preparing the nutrient solution of different salinity levels is depicted in Table 1. The required quantities of salts

Table 1: Standardization of nutrient solutions with different salinity levels for lettuce under hydroponic system.

Salts used ($mg\ L^{-1}$)	Salinity levels			
	S_1	S_2	S_3	S_4
Monoammonium phosphate	28.00	43.00	63.00	74.00
Potassium nitrate	150.00	225.00	330.00	390.00
Calcium nitrate	163.00	243.00	357.00	375.00
Magnesium sulphate	60.00	90.00	132.00	156.00
Ferrous sulphate.$7H_2O$	50.00	75.00	110.00	130.00
Copper sulphate. $5H_2O$	5.00	8.00	11.00	13.00
Manganous sulphate.$2H_2O$	18.00	27.00	35.50	40.500
Zinc sulphate.$7H_2O$	19.00	28.00	47.00	55.00
Boric acid	3.00	4.00	5.50	6.25
Ammonium molybdate	1.00	2.00	2.75	3.25
pH	6.89	6.94	7.03	7.08
EC ($dS\ m^{-1}$)	0.50± 0.09	0.75± 0.05	1.10± 0.07	1.30± 0.05

were dissolved in 1 L of de-ionized water, then the actual electrical conductivity of the nutrient solutions was measured to ascertain their salinity level before feeding to hydroponic system. The solution was fed to "A" frame hydroponic system as per the treatment requirement using PVC suction hose pipe attached to 0.500 hp motor in recycled manner. The fresh solution was replenished to maintain the suction level.

Growing environment

The lettuce *cv*. 'Romaine' was used in the experiment. The seeds of lettuce were sown in pro trays by using soil less media having cocopeat and compost in the proportion of 3:1 and lettuce seeds (one seed per cell) were sown and water immediately. The seedlings were allowed to grow in portrays for 15 days and irrigation was given every day inside the naturally ventilated shade net house.

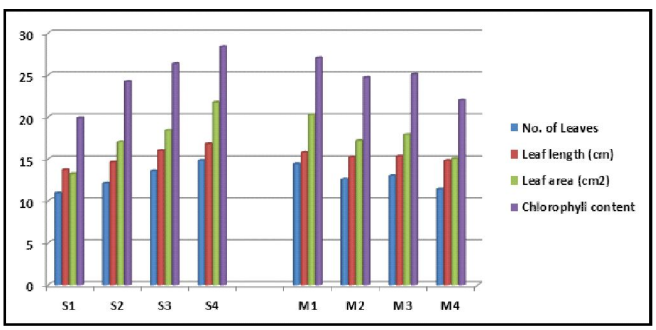

Fig. 1: Effect of salinity levels and rooting substrates on number of leaves and leaf length of lettuce under hydroponic system. (**Note:** S_1 - 0.50 dS m^{-1}, S_2- 0.75 dS m^{-1}, S_3- 1.10 dS m^{-1}, S_4- 1.30 dS m^{-1}. M_1- Rockwool + LECA, M_2- Sponge + LECA, M_3- Sphagnum moss + LECA, M_4- Floral bed + LECA).

The plants were cultured in nutrient solution treated as circulating hydroponic technique. Two weeks old seedlings were transplanted in hydroponic structure with holes having net cups, where the cups were filled with different growing medium like rockwool, sponge, sphagnum moss, floral bed and LECA which allows the nutrient solution to pass through the roots of the plants, facilitating the uptake of nutrients. The solution having different nutrient concentration were prepared and supplied to the plants regularly and the nutrient solution being recycled.

Data collection

Data was collected at harvest on number of leaves $plant^{-1}$, leaf length leaf area, chlorophyll content, shoot length, shoot fresh and dry weight, root length, fresh and dry root weight, root to shoot ratio of lettuce. The leaf area was calculated by using Biovis leaf area meter. The average length of leaf, shoot and root of five randomly selected plants were measured at harvest using meter scale and expressed in centimeter (cm). The chlorophyll content of lettuce leaf was determined by Konica monilta SPAD (Soil Plant Analytical Development) 502 chlorophyll meter before harvesting of the crop. Shoot and root of five randomly selected plants were detached by using sharp knife and fresh weights was recorded on an electric balance at harvest and then mean fresh weight (g) was recorded and expressed in g $plant^{-1}$. Dry matter content was determined by drying fresh plant samples after harvest. The samples were dried at 65 ± 5 °C for 48 hours and samples were weighed on an electrical balance and then mean dry weight was calculated and expressed in g $plant^{-1}$.

Root to shoot ratio was calculated using below formula:

$$\text{Root to shoot} = \frac{\text{Dry weight of roots}}{\text{Dry weight of shoots}}$$

Statistical analysis

The analysis and interpretation of the data was done using Fisher's method of analysis of variance (ANOVA) as given by Gomez and Gomez (1984). Significance between the treatments was tested by 'F' test. Whereas, difference between the treatments mean were tested by critical difference (CD) at 1% level of significance.

Results and Discussion

The amount of nutrients available for absorption by the crops in soil or in solution depends on uptake or supply of macro and micro nutrients. The optimum supply of nutrients in hydroponic culture can influence plant growth, appearance, nutritional value and shelf life of lettuce. The

Table 2: Effect of salinity levels and rooting substrates on number of leaves, leaf length, leaf area and chlorophyll content of lettuce at harvest under hydroponic system.

Treat-ments	No. of leaves	Leaf length (cm)	Leaf area (cm^2)	Chlorophyll content
Factor 1: Salinity levels (ds m^{-1})				
S_1	10.94	13.72	13.23	19.89
S_2	12.12	14.63	17.03	24.22
S_3	13.57	16.01	18.41	26.36
S_4	14.82	16.82	21.77	28.39
S.Em ±	0.15	0.06	0.28	0.14
CD @ 1%	0.45	0.19	0.85	0.43
Factor 2: Rooting substrate				
M_1	14.43	15.78	20.27	27.05
M_2	12.59	15.23	17.20	24.70
M_3	13.02	15.35	17.92	25.09
M_4	11.40	14.81	15.05	22.00
S.Em ±	0.15	0.06	0.28	0.14
CD @ 1%	0.45	0.19	0.85	0.43
Interactions				
T_1- S_1M_1	12.24	14.19	15.25	22.28
T_2-S_1M_2	10.79	13.64	13.01	19.73
T_3-S_1M_3	11.05	13.80	13.39	20.24
T_4-S_1M_4	9.66	13.24	11.26	17.30
T_5-S_2M_1	13.61	15.08	19.49	26.86
T_6-S_2M_2	11.96	14.59	17.00	24.39
T_7-S_2M_3	12.33	14.65	17.60	24.95
T_8-S_2M_4	10.60	14.20	14.04	20.66
T_9-S_3M_1	15.12	16.53	20.76	28.92
T_{10}-S_3M_2	13.23	15.95	18.01	26.30
T_{11}-S_3M_3	13.83	16.10	18.62	26.74
T_{12}-S_3M_4	12.10	15.47	16.25	23.49
T_{13}-S_4M_1	16.76	17.33	25.61	30.14
T_{14}-S_4M_2	14.40	16.75	20.72	28.39
T_{15}-S_4M_3	14.88	16.85	22.07	28.46
T_{16}-S_4M_4	13.25	16.36	18.68	26.56
S.Em ±	0.30	0.12	0.5007	0.29
CD @ 1%	0.90	0.37	1.71	0.86

Note: S_1 - 0.50, S_2 - 0.75, S_3 - 1.10 S_4 - 1.30
M_1- Rockwool with LECA, M_2 - Sponge with LECA,
M_3 - Sphagnum moss with LECA,
M_4 - Floral bed with LECA

increase in number of leaves, leaf length, leaf area and chlorophyll content at optimum salinity might be due to availability of macro and micro-nutrients over the period of time, which aides in better crop growth by proper and regular cell division, cell elongation and increased accumulation of photosynthates. The results are in accordance with the findings of Andriolo *et al.*, (2005) who stated that lettuce growth was affected by strength of nutrient solutions.

The substrate used in hydroponic system must support better growth due to their physical support and root anchorage (Gruda *et al*., 2006). The substrate must have high surface area, binding sites, porosity and water holding capacity and must be chemically inert. The growth parameters are enhanced when rockwool was used as a substrate. The improvement in growth parameters with rookwool might be attributed to its higher porosity, surface area, binding sites, water and nutrient holding capacity that might have been a complement fertilization regime for hydroponic system. These results were in line with findings of Tapia and Caro (2009). The least growth parameters were recorded with floral bed that could be due to less porosity, low surface area, low water and nutrient holding capacity which resulted in decreased root proliferation and penetration with lesser humidity in the rooting zone (Gul *et al*., 2007). While, sphagnum moss and sponge occupy intermediate properties of rockwool and floral bed are that might be the probable reason to achieve better growth parameters.

Number of leaves

Number of leaves per plant as influenced by different salinity levels, rooting substrates and their interactions in each treatment showed significant difference (Table 2).

The significantly higher number of leaves per plant (14.82) was recorded in nutrient solution having salinity of 1.30 dS m^{-1} followed by 1.10 dS m^{-1} (13.57), 0.75 dS m^{-1} (12.12) and less number of leaves per plant (10.94) was observed in salinity level of 0.50 dS m^{-1}.

Among the rooting substrates, number of leaves per plant was found to be significantly higher in rockwool (14.43) followed by sphagnum moss (13.02) which was on par with sponge (12.59) and lower number of leaves per plant was noticed in floral bed (11.40).

Significant difference was observed among interaction effect of salinity levels and rooting substrates. The rockwool substrate at nutrient solution having salinity level of 1.30 dS m^{-1} recorded higher number of leaves per plant (16.76).

The number of leaves of lettuce increased with increase in salinity level of the nutrient solution. Thus, higher number of leaves per plant was noticed at salinity level of 1.30 dS m^{-1}. The higher number of leaves at this salinity level might be attributed to sufficient amount of nutrients in the hydroponic solution as a result of which, the cell division, cell elongation and accumulation of photosynthates improved in the plants. The similar observations were noticed by Quy *et al.*, (2018) in lettuce crop. This fact was evidenced in the present investigation as higher SPAD reading which is an indicator of chlorophyll content was recorded with higher salinity nutrient solution.

Leaf length

Length of the lettuce leaves showed significant difference among salinity levels, rooting substrates and their interactions (Table 2).

Significantly higher leaf length (16.82 cm) was recorded in nutrient solution having salinity of 1.30 dS m^{-1} followed by 1.10 dS m^{-1} (16.01 cm), 0.75 dS m^{-1} (14.63 cm) and lower leaf length (13.72 cm) was observed in nutrient solution having salinity level of 0.50 dS m^{-1}.

Among rooting substrates, rockwool documented significantly higher leaf length (15.78 cm) followed by sphagnum moss which was on par with sponge (15.35 and 15.23 cm, respectively) and lower leaf length was observed in floral bed (14.81 cm).

Interaction effect between salinity levels and rooting substrates differed significantly in leaf length. The higher leaf length of 17.33 cm was recorded in rockwool with the nutrient solution of salinity level of 1.30 dS m^{-1} compared to other interaction (13.24 to 16.53 cm).

Leaf area

Leaf area (cm^2) showed significant difference among the salinity levels, rooting substrates and their interactions (Table 2).

Significantly higher leaf area of 21.77 cm^2 was noticed in nutrient solution having salinity of 1.30 dS m^{-1} followed by 18.41 cm^2 at 1.100 dS m^{-1}, 17.03 cm^2 at 0.75 dS m^{-1} and minimum leaf area of 13.23 cm^2 was recorded at a salinity of 0.50 dS m^{-1}.

Among different rooting substrates, significantly higher leaf area was observed in rockwool (20.27 cm^2) followed by sphagnum moss (17.92 cm^2) which was on par with sponge (17.20 cm^2) and lower leaf area was noticed in floral bed (15.05 cm^2).

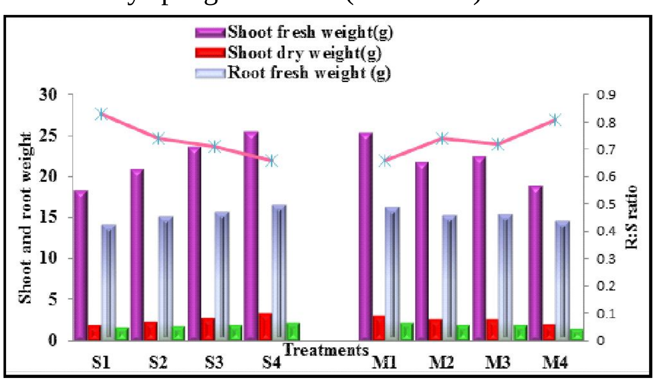

Fig. 2: Effect of salinity levels and rooting substrates on shoot and root parameters of lettuce under hydroponic system. (**Note:** S_1 - 0.50 dS m^{-1}, S_2- 0.75 dS m^{-1}, S_3- 1.10 dS m^{-1}, S_4- 1.30 dS m^{-1}. M_1- Rockwool + LECA, M_2- Sponge + LECA, M_3- Sphagnum moss + LECA, M_4- Floral bed + LECA).

Interaction effect between salinity levels and rooting substrates showed significant difference in leaf area. Rockwool recorded significantly maximum leaf area (25.61cm^2) followed by sphagnum moss (22.07 cm^2) on par with sponge (20.72 cm^2) and minimum leaf area was observed in floral bed (18.68 cm^2) with nutrient solution having salinity level of 1.30 dS m^{-1}.

The leaf area has great relevance for lettuce, since it is a growth variable indicative of leaf yield (Taiz and Zeiger, 1998). Higher leaf area was documented at nutrient solution having salinity level of 1.30 dS m^{-1}, because of sufficient amount of nutrients provided to the crop which ensured good vegetative growth, thereby ensuring increase in leaf area over rest of the treatments. The reduction in leaf area might be due to reduced turgor pressure affected leaf cell expansion. As salinity level of the nutrient solution increases, there was a positive increase in leaf area of lettuce and was obtained at 2.2 dS m^{-1} of the nutrient solution by Silva *et al.*, *(*2019). The results of Albornoz and Leith (2015) are closely related to the present research findings and they reported that leaf area in lettuce increased when the concentration of nutrients was raised from 0.6 to 1.2 dS m^{-1}.

Chlorophyll content

The chlorophyll content was measured using SPAD meter and the results were expressed as SPAD values. Salinity levels, rooting substrates and their interactions showed significant difference in Chlorophyll content (Table 2).

The significantly higher chlorophyll content was accounted in nutrient solution having salinity level of 1.30 dS m^{-1} (28.39) followed by 1.10 dS m^{-1} (26.36), 0.75 dS m^{-1} (24.22) and lower chlorophyll content was reported in salinity of 0.50 dS m^{-1} (19.89).

Rockwool recorded significantly higher chlorophyll content among the rooting substrate followed by sphagnum moss which was on par with sponge and lower chlorophyll content was observed in floral bed (27.05, 25.09, 24.70 and 22.00, respectively).

Interaction effect of salinity levels and rooting substrates showed significant difference. Rockwool documented significantly higher chlorophyll content (30.14) followed by sphagnum moss (28.46) which was on par with sponge (28.39) and lower chlorophyll content was observed in floral bed with salinity level of 1.30 dS m^{-1} (26.56) when compared with other interactions (17.30 to 28.92).

Table 3: Effect of salinity levels and rooting substrates on shoot parameters of lettuce at harvest under hydroponic system

Treat-ments	Shoot length (cm)	Shoot fresh weight (g plant^{-1})	Shoot dry weight (g plant^{-1})
Factor 1: Salinity levels (ds m^{-1})			
S_1	17.03	18.39	2.06
S_2	19.25	20.85	2.41
S_3	20.68	23.66	2.82
S_4	21.109	25.49	3.42
S.Em ±	0.22	0.26	0.03
CD @ 1%	0.66	0.78	0.06
Factor 2: Rooting substrate			
M_1	22.19	25.26	3.11
M_2	19.19	21.76	2.72
M_3	19.81	22.51	2.76
M_4	16.96	18.86	2.12
S.Em ±	0.22	0.26	0.03
CD @ 1%	0.66	0.78	0.06
Interactions			
T_1- S_1M_1	20.81	21.40	2.55
T_2-S_1M_2	16.30	18.02	2.08
T_3-S_1M_3	16.81	18.51	2.10
T_4-S_1M_4	14.22	15.66	1.49
T_5-S_2M_1	22.01	23.96	2.85
T_6-S_2M_2	19.05	20.68	2.53
T_7-S_2M_3	19.43	20.95	2.60
T_8-S_2M_4	16.52	17.84	1.68
T_9-S_3M_1	22.88	26.86	3.35
T_{10}-S_3M_2	20.45	23.66	2.86
T_{11}-S_3M_3	21.308	24.75	2.89
T_{12}-S_3M_4	18.00	19.38	2.19
T_{13}-S_4M_1	23.07	28.84	3.70
T_{14}-S_4M_2	20.96	24.70	3.41
T_{15}-S_4M_3	21.65	25.84	3.46
T_{16}-S_4M_4	19.08	22.58	3.12
S.Em ±	0.44	0.5002	0.06
CD @ 1%	1.303	1.506	0.18

Note: S_1 - 0.50, S_2 - 0.75, S_3 - 1.10 S_4 - 1.30
M_1- Rockwool with LECA, M_2 - Sponge with LECA,
M_3 - Sphagnum moss with LECA,
M_4 - Floral bed with LECA

Chlorophyll content in lettuce leaves increased with increase in salinity level of nutrient solution. It was significantly lower in low salinity levels probably due to the low availability of nutrient elements such as N, Mg and Fe which play vital role in chlorophyll pigment for photosynthetic activity. The results were in agreement with those of Mak and Yeh (2001), Fallovo *et al.*, (2009) in lettuce and Kang and Iersel (2004) in salvia.

Shoot parameters

Shoot length

- Salinity levels, rooting substrates and their interactions, showed significant difference in shoot length (Table 3).
- Significantly higher shoot length of 21.109 cm was recorded in S_4 (1.30 dS m^{-1}) followed by 20.68 cm in S_3 (1.10 dS m^{-1}), 19.25 cm in S_2 (0.75 dS m^{-1}) and 17.03 cm in S_1 (0.50 dS m^{-1}).
- Among the rooting substrates, maximum length of shoot was noticed in rockwool (22.19 cm) followed by sphagnum moss which was on par with sponge (19.81 and 19.19 cm) and lower root length was recorded in floral bed (16.96 cm).
- Interaction effect of salinity levels and rooting substrates showed significant difference. Rockwool substrate at nutrient solution having salinity of 1.30 dS m^{-1} recorded significantly higher shoot length (23.07 cm) followed by sphagnum moss (21.65 cm) which was on par with sponge (20.96 cm) and lower shoot length (19.08 cm) was observed in floral bed compared to other interactions (14.22 to 22.88 cm).

Shoot fresh weight

- Salinity levels, rooting substrates and their interactions showed significant effect on shoot fresh weight (Table 3).
- Nutrient solution having salinity level of 1.30 dS m^{-1} showed significantly higher shoot fresh weight of 25.49 g plant^{-1} followed by 23.66, 20.85 and 18.39 g plant^{-1} recorded with nutrient solution having salinity of 1.10, 0.75 and 0.50 dS m^{-1}, respectively.
- Significantly higher shoot fresh weight among the rooting substrate was observed in rockwool followed by sphagnum moss which was on par with sponge (25.26, 22.51 and 21.76 g plant^{-1}, respectively) and lower root length was observed in floral bed (18.86 g plant^{-1}).
- Among the interactions, effect of salinity levels and rooting substrates showed significant difference in shoot fresh weight. The rockwool substrate with nutrient solution having salinity level of 1.30 dS m^{-1} recorded higher shoot fresh weight (28.84 g plant^{-1}).

Shoot dry weight

- Shoot dry weight showed significant difference among salinity levels and rooting substrates and their interaction (Table 3).

- Significantly higher shoot dry weight of 3.42 g plant^{-1} was recorded in S_4 (1.30 dS m^{-1}) followed by 2.82 g plant^{-1} in S_3 (1.10 dS m^{-1}), 2.41 g plant^{-1} in S_2 (0.75 dS m^{-1}) and S_1 (0.50 dS m^{-1}) showed lower shoot dry weight of 2.06 g plant^{-1}.
- Among rooting substrates, significantly higher shoot dry weight was recorded in rockwool followed by sphagnum moss which was on par with sponge and lower shoot dry weight was observed in floral bed (3.11, 2.76, 2.72 and 2.12 g plant^{-1}, respectively).
- Interaction effect of salinity levels and rooting substrates showed significant difference. The higher shoot dry weight of 3.70 g plant^{-1} was recorded in rockwool with nutrient solution having salinity level of 1.30 dS m^{-1} compared to other interactions (1.49 to 3.35 g plant^{-1}).

The shoot length, fresh and dry shoot weights were increased with increase in salinity of nutrient solution that might be due to increased permeability of the cell, better absorption of water and nutrients as water and nutrients are in direct contact with the root rhizosphere which leads to better nutrient uptake. The production of higher number of leaves and leaf area caused enhanced absorption of solar radiation, increased the rate of photosynthesis and accumulation of more photosynthates and resulted in more dry matter production. Dry matter accumulation was reduced at low concentrations of the nutrient solution because of lower availability of nutrients for absorption as a result of which the number of leaves, length of leaves and leaf area were reduced. The results are in close promixity with the findings of Albornoz and Leith (2015), Junior *et al.*, (2008) in lettuce reported that leaf biomass was increased at salinity of 1.2 dS m^{-1}. Leafy lettuce grows best (the higher fresh and dry weights) at EC of 1.4 dS m^{-1} under greenhouse conditions (Samarakoon *et al.*, 2006).

The substrate rockwool produced higher yield and dry matter because of its favorable properties of high surface area with higher binding sites resulted in high water and nutrient holding capacity. In accordance to this, Guler *et al.*, (1995) reported that substrate rockwool showed higher yield and heaviest average fruit weight in sweet melon fruit when grown in open soilless culture systems. Sabat *et al.*, (2018) noticed that concentration of the nutrient solution had a positive effect on the average weight of marketable head of lettuce when grown in rockwool. The significantly lower fresh weight and dry matter recorded with floral bed might be due to its low water retention capacity probably influencing transpiration (Dannehl *et al.*, 2015). The low water holding capacity of the floral bed decreased the plant water level, which caused decrease in the fresh weight of the plant. Growth and yield significantly increased in lettuce when grown in sphagnum moss than floral bed and this might be attributed to their relatively greater water holding capacities and more favorable growing condition that allowed better root growth (Arancon *et al.*, 2015).

Root parameters

Root length

- Salinity levels, rooting substrates and their interaction showed significant influence on root length (Table 4).
- The significantly maximum root length of 19.13 cm was found in nutrient solution having EC of 1.30 dS m^{-1} followed by 18.46 cm in 1.10 dS m^{-1}, 16.42 cm in 0.75 dS m^{-1} and minimum root length of 14.81 cm was observed in salinity level of 0.50 dS m^{-1}.
- Rockwool recorded significantly higher root length (18.31 cm) among the rooting substrate. Sphagnum moss and sponge were on par with each other (17.40 and 17.15 cm, respectively) and lower root length was observed in floral bed (15.96 cm).
- However, significant difference was observed among interaction of salinity levels and rooting substrates. Rockwool recorded significantly higher root length (20.03 cm) followed by sphagnum moss that was on par with sponge and lower root length was observed in floral bed with salinity level of 1.30 dS m^{-1} (19.18, 18.97 and 18.35 cm, respectively).

Root fresh weight

- Fresh root weight showed significant difference among salinity levels, rooting substrates and their interaction (Table 4).
- Higher fresh root weight of 16.58, 15.69, 15.14 and 14.08 g plant^{-1} was obtained with nutrient solution having salinity level of 1.30, 1.10, 0.75 and 0.50 dS m^{-1}, respectively.
- Among rooting substrates, significantly higher fresh weight of root was recorded in rockwool followed by sphagnum moss which was on par with sponge and lower fresh weight of root was noticed when plants grown with floral bed (16.23, 15.45, 15.26 and 14.55 g plant^{-1}, respectively).
- Interaction effect of salinity levels and rooting

Table 4: Effect of salinity levels and rooting substrates on root parameters and root to shoot ratio of lettuce at harvest under hydroponic system.

Treat-ments	Root length (cm)	Root fresh weight (g plant^{-1})	Root dry weight (g plant^{-1})	Root to shoot ratio
Factor 1: Salinity levels (ds m^{-1})				
S_1	14.81	14.08	1.67	0.83
S_2	16.42	15.14	1.85	0.74
S_3	18.46	15.69	2.06	0.71
S_4	19.13	16.58	2.25	0.66
S.Em ±	0.09	0.07	0.07	0.01
CD @ 1%	0.27	0.22	0.22	0.04
Factor 2: Rooting substrate				
M_1	18.31	16.23	2.28	0.66
M_2	17.15	15.26	1.95	0.74
M_3	17.40	15.45	2.01	0.72
M_4	15.96	14.55	1.509	0.81
S.Em ±	0.09	0.07	0.07	0.01
CD @ 1%	0.27	0.22	0.22	0.04
Interactions				
T_1- S_1M_1	16.07	15.36	1.94	0.76
T_2-S_1M_2	14.69	13.81	1.69	0.83
T_3-S_1M_3	15.06	14.51	1.73	0.82
T_4-S_1M_4	13.42	12.99	1.303	0.89
T_5-S_2M_1	17.63	16.09	2.10	0.65
T_6-S_2M_2	16.45	15.06	1.83	0.75
T_7-S_2M_3	16.74	15.17	1.90	0.73
T_8-S_2M_4	14.89	14.24	1.507	0.83
T_9-S_3M_1	19.54	16.24	2.45	0.63
T_{10}-S_3M_2	18.52	15.67	2.02	0.72
T_{11}-S_3M_3	18.63	15.74	2.12	0.70
T_{12}-S_3M_4	17.18	15.09	1.65	0.79
T_{13}-S_4M_1	20.03	17.23	2.62	0.5009
T_{14}-S_4M_2	18.97	16.48	2.24	0.67
T_{15}-S_4M_3	19.18	16.73	2.31	0.65
T_{16}-S_4M_4	18.35	15.87	1.81	0.73
S.Em ±	0.18	0.14	0.04	0.02
CD @ 1%	0.5004	0.43	0.12	0.07

Note: S_1 - 0.50, S_2 - 0.75, S_3 - 1.10 S_4 - 1.30
M_1- Rockwool with LECA, M_2 - Sponge with LECA,
M_3 - Sphagnum moss with LECA,
M_4 - Floral bed with LECA

substrates showed significant difference. Fresh root weight was significantly higher (17.23 g plant^{-1}) when grown with rockwool substrate followed by sphagnum moss (16.73 g plant^{-1}) that was on par with sponge (16.48 g plant^{-1}) and lower fresh root weight (15.87 g plant^{-1}) was recorded when grown in floral bed with a salinity level of 1.30 dS m^{-1} compared to remaining interactions (12.99 to 16.24 g plant^{-1}).

Root dry weight

- Root dry weight was significantly influenced by salinity levels, rooting substrates and their interactions (Table 4).
- The significantly higher dry root of weight of 2.25 g plant^{-1} was recorded in S_4 (1.30 dS m^{-1}) followed by 2.06 g plant^{-1} in S_3 (1.10 dS m^{-1}), 1.85 g plant^{-1} in S_2 (0.75 dS m^{-1}) and lower dry root weight of 1.67 g plant^{-1} was recorded in S_1 (0.50 dS m^{-1}).
- Among rooting substrates, lettuce grown with rockwool substrate showed significantly higher root dry weight (2.28 g plant^{-1}) followed by sphagnum moss (2.01 g plant^{-1}) which was on par with sponge (1.95 g plant^{-1}) and lower root dry weight was recorded in floral bed (1.509 g plant^{-1}).
- Significant difference was found among interaction effect of salinity levels and rooting substrates. The rockwool substrate at nutrient solution having salinity level of 1.30 dS m^{-1} recorded higher root dry weight (2.62 g plant^{-1}).

The root parameters *viz.,* root length, fresh root weight and dry root weight increased with increase in salinity level of the nutrient solution in lettuce. The higher root length, fresh root weight and dry root weight were noticed at maximum salinity level of 1.30 dS m^{-1}, this was due to better uptake of water and nutrients by the roots which lead to the production of more number of lateral roots. The reduced root biomass at low concentrations of the nutrient solution because of low uptake of mineral nutrients by roots and inadequate aeration in hydroponic culture. The findings are in line with Albornoz and Leith (2015) and they opined that higher fresh and dry root weight were found at a concentration of 1.2 dS m^{-1}.

Among the substrate, rockwool and sphagnum moss are porous in nature, they did not pose any physical barriers for root entry into the moist air space. This physical nature of these two substrates allowed unrestricted root growth in the moist air space to induce maximum root aeration with increased root proliferation and penetration. The results are in agreement with Arancon *et al.,* (2015).

Root to shoot ratio

- Statistically significant root to shoot ratio was observed among salinity levels, rooting substrates and their interaction (Table 4).
- Root to shoot ratio was found maximum at nutrient solution having salinity of 0.50 dS m^{-1} followed by salinity with 0.75, 1.10 and lower

root to shoot ratio was observed at salinity of 1.30 dS m^{-1} (0.83, 0.74, 0.71 and 0.66, respectively).

- Higher root to shoot ratio was noticed with floral bed substrate (0.81) followed by sponge (0.74) which was on par with sphagnum moss (0.72) and lower ratio was recorded in rockwool substrate (0.66).
- Significant difference was observed among interaction effect of salinity levels and rooting substrates. Significantly higher root to shoot ratio was observed in floral bed (0.89) followed by sponge (0.83) which was on par with sphagnum moss (0.82) and lower root to shoot ratio was noticed in rockwool (0.76) with nutrient solution having salinity of 0.50 ds m^{-1} compared to other interactions (0.59 to 0.83).
- Root: shoot ratio decreased with increase in nutrient concentration. Since, plants at high fertilizer concentrations substitute larger fraction of carbohydrates to shoot growth than those at lower concentrations. The root to shoot ratio is proportional to nutrient supply with a greater ratio at low nutrient supply (Kang and Van Iersel, 2004). The findings are in line with Albornoz and Lieth (2015) where in they reported that plants grown with the lower solution concentration showed a higher root: shoot ratio than those grown at 1.2 dS m^{-1} and this ratio decreased with increasing nutrient availability. The osmotic potential of the solutions may have contributed to the reduction of root growth, since the area is limited in hydroponic system, salinity injury to root and low osmotic potential reduces the length of elongation of root in root apical meristem.

Conclusion

Present study revealed that nutrient solution prepared with appropriate combinations of salts to achieve salinity level of 1.30 dS m^{-1} along with rockwool as rooting substrate is ideal for obtaining higher growth and yield of lettuce as compared to nutrient solution having lower salinity levels and other rooting substrate.

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