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Nutrient content and uptake of lettuce as influenced by salinity levels and rooting substrates under hydroponic system of cultivation

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Abstract

Salinity plays a crucial role in hydroponics as it influences water uptake, nutrient availability, and overall plant health. Excessive salinity can lead to osmotic stress, reducing plant growth, while optimal levels support nutrient absorption. Similarly, the choice of rooting substrate affects root aeration, moisture retention, and nutrient accessibility, all of which are essential for plant development. A field experiment was conducted during the Rabi season of 2019 at ZARS, V.C. Farm, Mandya, to evaluate the effects of salinity levels and rooting substrates on the growth and yield of lettuce in a hydroponic system. The experiment utilized a Randomized Complete Block Design with a 4 × 4 factorial arrangement, testing four nutrient solution salinity levels (0.5, 0.75, 1.10, and 1.30 dS m^{-1}) and four rooting substrates (Rockwool, sponge, sphagnum moss, and floral bed). These factors were selected to examine their combined influence on plant growth, as salinity affects nutrient uptake and osmotic balance, while substrate properties play a crucial role in root development. The study comprised 16 treatment combinations, each replicated twice. The results revealed that salinity levels, rooting substrates and their interaction recorded non-significant in primary (N, P and K), secondary (Ca, Mg and S) and micronutrient (Fe, Cu, Mn and Zn) content. The nutrient solution with salinity level of 1.30 dS m^{-1} with Rockwool rooting substrate recorded significantly higher nutrient uptake followed by sphagnum moss on par with sponge and lower uptake was noticed in floral bed in lettuce compared to other treatment combination. These findings indicate that hydroponic lettuce can tolerate a range of salinity levels without major disruptions to nutrient balance. However, selecting the right substrate is crucial for maximizing nutrient uptake and overall plant health. The results provide valuable insights for optimizing hydroponic nutrient management strategies, supporting more efficient and productive lettuce cultivation.

Keywords: Hydroponics, lettuce, salinity, nutrient solution 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) [14]. In India, Hydroponics was introduced by W. J.Shalto Duglas in 1946 and he established a laboratory in Kalimpong area, West Bengal and wrote a book on Hydroponics, named as "Hydroponics - The Bengal System". It is the technique of growing plants in soil-less condition with their roots immersed in nutrient solution (Maharana and Koul, 2011).

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) [9].

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) [8].

Concentration of nutrients is the basics of hydroponic system, as the composition and optimization of nutrient solutions in commercial hydroponics can reduce fertilizer costs. To obtain higher yield and quality crops in hydroponic system, the nutrient solution supplied to the plants must be specific for the particular crop, climatic conditions or hydroponic system used. There is an increasing need to re-circulate and reuse the nutrient solutions in order to reduce environmental and economic costs. The total nutrient concentration of the nutrient solution used in soilless culture is one of the most important aspects for successful crop production.

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Lettuce (*Lactuca sativa*) is an annual herb belongs to family Asteraceae having chromosome number 2n=18. 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) [4]. 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* 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 frames 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 0.5 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, manganeous 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 were dissolved in 1 L of de-ionized water, then the actual electrical conductivity of the nutrient solutions were 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 0.5 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.
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**.**

Collection and preparation of plant samples
Lettuce plant without roots was collected separately after the harvest of the crop. The lettuce plant samples were washed with water and dried in hot air oven at 65±5°C until the weight remains constant. Further, dried samples were powdered using cyclone mill and were stored in butter paper bags for nutrient analysis (Jackson, 1973).

Total nitrogen (%)
Total nitrogen was estimated by Micro Kjeldahl's method as described by Piper (1966) [16]. A known quantity of powdered samples was digested with concentrated sulphuric acid in the presence of digestion mixture (K_2SO_4: $CuSO_4$: Se powder in the ratio 100:20:1). Because, of heat of dilution of H_2SO_4 the organic forms of nitrogen was converted into ammonical form. The ammonium so released was distilled under alkaline condition (NaOH) to liberate ammonia and which was trapped by boric acid mixed indicator and titrated against standard sulfuric acid.

Digestion of plant samples with Di-acid mixture (Wet oxidation): Powdered plant sample of 1.0 g were pre-digested with conc. HNO_3 overnight and then digested with di-acid mixture containing HNO_3 and $HClO_4$ in the proportion of 9:4 till a snow white residue was obtained (Piper, 1966) [16]. The volume of the digest was made to 100 ml with distilled water and used for total elemental analysis as detailed below.

Total phosphorus content
The phosphorus content in the lettuce plant digest was determined by vanadomolybdo-phosphoric acid yellow color method using spectrophotometer at 420 nm wavelength (Piper, 1966) [16].

Total potassium content
The potassium content in the lettuce plant digest was determined by flame photometer method (Piper, 1966) [16].

Total calcium and magnessium (%)
The calcium and magnesium content in di-acid digested lettuce plant sample was determined by complexometric titration method involving standard EDTA (Piper, 1966) [16].

Total sulphur content (%)
Sulphur in the di-acid digested samples was determined by developing turbidity using $BaCl_2$ crystals. The intensity of turbidity developed was measured at 420 nm using spectrophotometer and estimated by referring to S-standard curve (Piper, 1966) [16].

Micronutrients (Fe, Mn, Zn and Cu content)
Micronutrients **(**Fe, Mn, Zn and Cu) concentration in the di-acid extract was determined using Atomic Absorption Spectrophotometer (Lindsay and Norwell, 1978) [10].

Nutrient uptake
The uptake of nutrients by lettuce plant grown in hydroponics at harvest was worked out by using the formula,

$$\text{Nutrient uptake (g plant}^{-1}\text{)} = \frac{\text{Nutrient concentration (\%)}}{100} \times \text{Dry matter content (g plant}^{-1}\text{)}$$

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) [7]. 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
Nitrogen, Phosphorus and Potassium
Nutrient solution with different salinity levels and its interaction with rooting substrate had no significant effect on primary nutrient content. However, higher N (4.10%), P (0.55%) and K (2.66%) content was observed in nutrient solution having salinity level of 1.3 dS m^{-1} followed by 1.10, 0.75 and 0.5 dS m^{-1} (3.98, 3.83 and 3.68% N, 0.50, 0.41 and 0.35% P and 2.60, 2.52 and 2.46% K, respectively).
Among the rooting substrates, Rockwool recorded higher N (4.02%), P (0.53%) and K (2.66%) which was statistically on par with sphagnum moss, sponge and floral bed (3.94, 3.86 and 3.77% N, 0.48, 0.42 and 0.38% P and 2.58, 2.53 and 2.47% K, respectively).

Calcium, Magnessium and Sulphur
Nutrient solution having salinity of 1.3 dS m^{-1} recorded higher Ca, Mg and S content in lettuce leaves (2.56, 0.58 and 0.51%, respectively) which is statistically on par with salinity level of 1.10, 0.75 and 0.5 dS m^{-1} (2.49, 2.41 and 2.33% Ca, 0.50, 0.43 and 0.37% Mg, 0.43, 0.36 and 0.30% S, respectively).
Among the substrates, Rockwool recorded higher Ca (2.54%) Mg (0.56%) and S (0.47%) content which was on par with sphagnum moss, sponge and floral bed (2.48, 2.42 and 2.35% Ca, 0.49, 0.44 and 0.38% Mg and 0.42, 0.39 and 0.32% S, respectively). No significant difference was observed among salinity levels, rooting substrates and their interactions in calcium, magnesium and sulphur content.

Iron, Copper, Manganese and Zinc

Interaction between salinity levels and rooting substrates were found non-significant with respect to micronutrients content in lettuce leaves.

However, higher Fe (374.55 ppm), Cu (17.06 ppm), Mn (274.68 ppm) and Zn (78.64 ppm) content was observed in lettuce leaves when grown with nutrient solution having salinity level of 1.3 dS m^{-1} which was statistically on par followed by 1.10, 0.75 and 0.5 dS m^{-1} (367.68, 357.97 and 349.46 ppm Fe, 16.32, 15.47 and 14.98 ppm Cu, 266.34, 260.19 and 253.50 ppm Mn and 75.02, 70.12 and 66.53 ppm Zn, respectively).

Statistically on par micro nutrient content was observed among rooting substrates, Although, higher Fe (368.86 ppm), Cu (16.60 ppm), Mn (268.20 ppm) and Zn (77.86 ppm) content was observed in content was noticed in Rockwool followed by sphagnum moss, sponge and floral bed (364.81, 359.48 and 356.50 ppm Fe, 16.17, 15.71 and 15.35 ppm Cu, 265.52, 262.14 and 258.85 ppm Mn and 74.64, 70.56 and 67.25 ppm Zn, respectively).

Though the content of nutrients in lettuce leaves grown with supply of different quantities of nutrients in solution did not show significant difference, the concentration of N, P, K, Ca, Mg, S, Fe, Cu, Mn and Zn in leaves showed a linear increase with increasing salinity level of nutrient solution which might be attributed to higher nutrient absorption with increase in nutrient content of the solution. In lettuce similar linear increase in nutrient concentration with increase in nutrient solution salinity has been reported by Samarakoon *et al.* (2006) [13], while quadratic response with increase in feeding nutrient solution concentration reported by Fallovo *et al.* (2009) [5]. Thus higher content of the above nutrient element was recorded in lettuce leaves grown with nutrient solution having salinity of 1.3 dS m^{-1}. Similar observations were noticed by Unlukara *et al.* (2008) [15] in lettuce and Park and Chiang (1995) [11] in Chicory.

Among the substrates, the plant grown with Rockwool as a substrate showed higher N, P, K, Ca, Mg, S, Fe, Cu, Mn and Zn content in leaves followed by sphagnum moss as compared to other substrates studied. Similar trend was observed in the interaction effect between nutrient salinity level and rooting substrate. The higher nutrient content in leaves of lettuce grown with Rockwool as a substrate might be attributed to enhanced root proliferation, root length, root fresh and dry weight. These results are in conformity with those reported by Dannehl *et al.* (2014) [3] in tomato where they have used Rockwool as substrate. While, Arancon *et al.*, 2015 [2] observed higher nutrients in the lettuce rhizosphere providing more nutrients and accelerates the growth of lettuce grown using sphagnum moss rooting substrate.

Nutrient uptake as influenced by salinity levels and rooting substrates in lettuce

Nitrogen uptake: Nitrogen uptake was found statistically significant among salinity levels, rooting substrates and their interactions (Table 5).

The significantly higher N uptake (140.39 mg $plant^{-1}$) by the plants was recorded with nutrient solution having salinity level of 1.30 dS m^{-1} followed by 1.10 dS m^{-1} (112.76 mg $plant^{-1}$), 0.75 dS m^{-1} (92.41 mg $plant^{-1}$) and minimum (76.02 mg $plant^{-1}$) N uptake was observed in nutrient solution having salinity level of 0.5 dS m^{-1}.

Among the rooting substrates, significantly higher N uptake was observed when grown using Rockwool substrate (126.22 mg $plant^{-1}$) followed by sphagnum moss (109.47 mg $plant^{-1}$) which was on par with sponge (105.54 mg $plant^{-1}$) and lower N uptake was documented in floral bed (80.35 mg $plant^{-1}$).

However, significant difference was observed among interaction effect of salinity levels and rooting substrates. The higher N uptake (158.03 mg $plant^{-1}$) was recorded in lettuce plants grown using Rockwool substrate at a salinity level of 1.3 dS m^{-1}.

Phosphorous uptake

Phosphorous uptake showed significant among salinity levels, rooting substrates and their interactions (Table 5).

Nutrient solution having salinity of 1.30 dS m^{-1} recorded significantly highest P uptake by lettuce (18.96 mg $plant^{-1}$) followed by 1.10 dS m^{-1} (14.24 mg $plant^{-1}$), 0.75 dS m^{-1} (10.04 mg $plant^{-1}$) and minimum (6.80 mg $plant^{-1}$) was observed in nutrient solution having salinity level of 0.5 dS m^{-1}.

Among rooting substrates, significantly higher P uptake (16.89 mg $plant^{-1}$) was recorded in plants grown with Rockwool substrate followed by sphagnum moss which was on par with sponge (13.02 and 11.72 mg $plant^{-1}$, respectively) and lower P uptake was observed in floral bed (8.43 mg $plant^{-1}$).

Among the interactions, effect of salinity levels, rooting substrates showed significant difference. Rockwool recorded significantly higher P uptake followed by sphagnum moss on par with sponge and floral bed (23.42, 19.57, 18.21 and 14.65 mg $plant^{-1}$, respectively) with salinity level of 1.3 dS m^{-1} compared to rest of the interactions (4.18 to 19.69 mg $plant^{-1}$).

Potassium uptake

Salinity levels, rooting substrates and their interaction influenced significantly on potassium uptake **(**Table 5).

The higher K uptake of 91.04 mg $plant^{-1}$ was recorded in nutrient solution having salinity level of 1.30 dS m^{-1} followed by 73.49 mg $plant^{-1}$ at 1.10 dS m^{-1}, 61.03 mg $plant^{-1}$ at 0.75 dS m^{-1} and minimum K uptake of 50.79 mg $plant^{-1}$ was observed in nutrient solution having salinity of 0.5 dS m^{-1}.

Among the rooting substrate, significantly higher potassium uptake was noticed in Rockwool (83.11 mg $plant^{-1}$) followed by sphagnum moss (71.56 mg $plant^{-1}$) which was on par with sponge (69.07 mg $plant^{-1}$) and lower potassium uptake was observed in plants grown with floral bed substrate (52.60 mg $plant^{-1}$).

Significant difference was observed among interaction effect of salinity levels and rooting substrates. The Rockwool at nutrient solution EC of 1.3 dS m^{-1} showed maximum potassium uptake (102.27 mg $plant^{-1}$) by lettuce followed by sphagnum moss (92.20 mg $plant^{-1}$) on par with sponge (89.91 mg $plant^{-1}$) and minimum potassium uptake was recorded in floral bed substrate (79.77 mg $plant^{-1}$) compared to other interactions (35.11 to 90.41 mg $plant^{-1}$).

Calcium uptake: Calcium uptake showed significant difference among salinity levels, rooting substrates and their interactions (Table 6).

The significantly higher Ca uptake was recorded in nutrient solution having salinity of 1.30 dS m^{-1} (87.82 mg $plant^{-1}$)

followed by 1.10 dS m^{-1} (70.93 mg plant^{-1}), 0.75 dS m^{-1} (58.21 mg plant^{-1}) and lower Ca uptake was observed in nutrient solution having salinity of 0.5 dS m^{-1} (48.16 mg plant^{-1}).

Among the rooting substrate, Rockwool aided significantly higher Ca uptake by lettuce plants followed by sphagnum moss which was on par with sponge and lower Ca content was observed in floral bed substrate (79.82, 68.97, 66.15 and 50.19 mg plant^{-1}, respectively).

Interaction effect of salinity levels and rooting substrates showed significant difference. Rockwool facilitated significantly higher Ca uptake (97.67 mg plant^{-1}) at nutrient solution having salinity level of 1.30 dS m^{-1} compared to other interactions (33.18 to 89.00 mg plant^{-1}).

Magnesium uptake

Magnesium uptake showed significant difference among salinity levels and rooting substrates and their interactions (Table 6).

Significantly higher magnesium uptake of 19.99 mg plant^{-1} was recorded in S_4 (1.30 dS m^{-1}) followed by 14.57 mg plant^{-1} in S_3 (1.10 dS m^{-1}), 10.46 mg plant^{-1} in S_2 (0.75 dS m^{-1}) and S_1 (0.5 dS m^{-1}) showed lower magnesium uptake of 7.71 mg plant^{-1}.

Among rooting substrates, Rockwool recorded significantly higher Mg (17.93 mg plant^{-1}) uptake followed by sphagnum moss (13.87 mg plant^{-1}) which was statistically on par with sponge (12.47 mg plant^{-1}) and lower Mg uptake was seen in plants grown with floral bed substrate (8.46 mg plant^{-1}).

Significant difference was reported in interaction effect between salinity levels and rooting substrates. Significantly higher Mg uptake (25.19 mg plant^{-1}) was recorded in Rockwool substrate followed by sphagnum moss (20.92 mg plant^{-1}) which was on par with sponge (19.55 mg plant^{-1}) and lower Mg uptake was noticed in plants grown with floral bed substrate (14.32 mg plant^{-1}) with nutrient solution having salinity level of 1.3 dS m^{-1}.

Sulphur uptake

Salinity levels, rooting substrates and their interaction showed significant influence on sulphur uptake **(**Table 6).

The significantly higher S uptake of 17.59 mg plant^{-1} was recorded in nutrient solution having salinity of 1.30 dS m^{-1} followed by 12.29 mg plant^{-1} in 1.10 dS m^{-1}, 9.17 mg plant^{-1} in 0.75 dS m^{-1} and minimum S uptake of 6.34 mg plant^{-1} was observed in nutrient solution having salinity of 0.5 dS m^{-1}.

Among the rooting substrates, significantly higher sulphur uptake (14.94 mg plant^{-1}) was observed in plants grown with Rockwool substrate followed by sphagnum moss (12.02 mg plant^{-1}) which is on par with sponge (11.10 mg plant^{-1}) and lower sulphur uptake was observed in floral bed substrate (7.32 mg plant^{-1}).

Significant difference was observed among interaction effect of salinity levels and rooting substrates. The Rockwool substrate at nutrient solution having salinity level of 1.3 dS m^{-1} facilitated significantly higher sulphur uptake (22.12 mg plant^{-1}) compared to other interactions (3.51 to 16.65 mg plant^{-1}).

Iron uptake

Significant difference was observed in iron uptake among salinity levels, rooting substrates and their interactions (Table 7).

Significantly higher Fe uptake of 1282.14, 1038.30, 864.90 and 720.12 µg plant^{-1} obtained with nutrient solution having salinity of 1.30, 1.10, 0.75 and 0.5 dS m^{-1}, respectively.

Rockwool rooting substrate recorded significantly higher Fe uptake (1153.89 µg plant^{-1}) followed by sphagnum moss (1011.96 µg plant^{-1}) which was on par with sponge (980.70 µg plant^{-1}) and lower Fe uptake was noticed in floral bed (758.91 µg plant^{-1}) .

Interaction effect of salinity levels and rooting substrates showed significant difference. Plants grown with Rockwool substrate showed higher iron uptake (1419.57 µg plant^{-1}) followed by sphagnum moss (1308.26 µg plant^{-1}) which was on par with sponge (1261.72 µg plant^{-1}) and lower in floral bed with salinity level of 1.3 dS m^{-1} (1139.02 µg plant^{-1}) compared to other interactions (514.02 to 1255.40 µg plant^{-1}).

Copper uptake

Copper uptake significantly influenced by salinity levels, rooting substrates and their interactions (Table 7).

The significantly higher Cu uptake of 58.37 µg plant^{-1} was recorded in S_4 (1.30 dS m^{-1}) followed by 46.21 µg plant^{-1} in S_3 (1.10 dS m^{-1}), 37.53 µg plant^{-1} in S_2 (0.75 dS m^{-1}) and lower Cu uptake of 30.93 µg plant^{-1} was recorded in S_1 (0.5 dS m^{-1}).

Among rooting substrates, plants grown with Rockwool substrate recorded significantly higher Cu uptake (52.00 µg plant^{-1}) followed by sphagnum moss (44.99 µg plant^{-1}) on par with sponge (42.99 µg plant^{-1}) and lower Cu uptake was recorded in plants grown with floral bed substrate (33.06 µg plant^{-1}).

Significant difference was observed among interaction effect of salinity levels and rooting substrates. The higher uptake of copper (65.25 µg plant^{-1}) was recorded in plants grown with Rockwool substrate with nutrient solution having salinity level of 1.3 dS m^{-1}.

Manganese uptake

Salinity levels, rooting substrates and their interaction showed significant in manganese uptake (Table 7).

Significantly highest Mn uptake of 939.80 µg plant^{-1} was recorded in nutrient solution having salinity of 1.30 dS m^{-1} followed by 1.10 dS m^{-1} (752.86 µg plant^{-1}), 0.75 dS m^{-1} (628.55 µg plant^{-1}) and lower Mn uptake (522.54 µg plant^{-1}) was noticed in nutrient solution having salinity of 0.5 dS m^{-1}.

Among rooting substrates, lettuce plants grown with Rockwool substrate found significantly higher Mn uptake followed by sphagnum moss which was statistically on par with sponge and lower Mn uptake was recorded in floral bed (838.75, 736.63, 715.74 and 552.63 µg plant^{-1}, respectively).

Interaction effect of salinity levels and rooting substrates showed significant difference. Rockwool recorded significantly higher Mn uptake (1031.83 µg plant^{-1}) followed by sphagnum moss (954.09 µg plant^{-1}) on par with sponge (930.36 µg plant^{-1}) and lower Mn uptake (842.92 µg plant^{-1}) was noticed in floral bed with nutrient solution having salinity of 1.3 dS m^{-1} compared to other interactions (372.14 to 912.92 µg plant^{-1}).

Zinc uptake

Zinc uptake showed significant difference among salinity levels and rooting substrates and their interactions (Table 7).

Significantly higher Zn uptake of 269.70 µg plant^{-1} was recorded in nutrient solution having salinity of 1.30 dS m^{-1} followed by 1.10 dS m^{-1} (213.16 µg plant^{-1}), 0.75 dS m^{-1} (172.07 µg plant^{-1}) and lower uptake of Zn was noticed in 0.5 dS m^{-1} (140.00 µg plant^{-1}).

Among rooting substrates, plants grown with Rockwool substrate reported higher zinc uptake (244.98 µg plant^{-1}) followed by sphagnum moss (208.17 µg plant^{-1}) which was statistically on par with sponge (196.75 µg plant^{-1}) and lower zinc uptake was documented in floral bed substrate (145.04 µg plant^{-1}).

Interaction effect of salinity levels and rooting substrates showed significant difference. Plants grown with Rockwool recorded significantly higher zinc uptake (311.58 µg plant^{-1}) at nutrient solution having salinity level of 1.3 dS m^{-1} compared to other interactions (92.40 to 270.10 µg plant^{-1}).

The nutrient uptake by the crop is the product of biomass, yield and nutrient concentration. Thus significantly higher nutrient uptake of N, P, K, Ca, Mg, S, Fe, Cu, Mn and Zn was seen in lettuce. The higher uptake could be attributed to higher fresh and dry weight of lettuce and higher nutrient content in leaf tissue of lettuce. The nutrient uptake increased with increasing level of solution nutrient concentration as both fresh and dry weight and nutrient content were also increased with increasing level of solution nutrient content. The balanced increase in fertilizer additions increases the uptake of N, P, Mg and S, resulting in a more efficient photosynthetic apparatus in lettuce crop (Albornoz and Leith, 2015) [1]. The increased nutrient content and uptake in hydroponic system might be due to submergence of roots in nutrient rich solution which helps the plants to absorb nutrients constantly for the entire crop growth period.

The plants grown with Rockwool as a rooting substrate recorded significantly higher nutrient uptake as compared to other rooting substrates. The significant increase in uptake might be due to increased fresh and dry weight and also increased nutrient content in the plant grown with Rockwool as a substrate.

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	40.50
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})	0.5±0.09	0.75±0.05	1.1±0.07	1.3±0.05

Table 2: Primary nutrient content of lettuce as influenced by salinity levels and rooting substrates under hydroponic system

Treatments	Nitrogen (%)	Phosphorous (%)	Potassium (%)
Factor 1: Salinity levels (ds m^{-1})			
S_1	3.68	0.35	2.46
S_2	3.83	0.41	2.52
S_3	3.98	0.50	2.60
S_4	4.10	0.55	2.66
S.Em ±	0.17	0.08	0.07
CD @ 1%	NS	NS	NS
Factor 2: Rooting substrate			
M_1	4.02	0.53	2.66
M_2	3.86	0.42	2.53
M_3	3.94	0.48	2.58
M_4	3.77	0.38	2.47
S.Em ±	0.17	0.08	0.07
CD @ 1%	NS	NS	NS
Interactions			
T_1- S_1M_1	3.78	0.42	2.55
T_2-S_1M_2	3.64	0.33	2.44
T_3-S_1M_3	3.72	0.37	2.50
T_4-S_1M_4	3.61	0.28	2.36
T_5-S_2M_1	3.90	0.49	2.63
T_6-S_2M_2	3.81	0.38	2.49
T_7-S_2M_3	3.86	0.44	2.55
T_8-S_2M_4	3.73	0.34	2.42
T_9-S_3M_1	4.15	0.57	2.70
T_{10}-S_3M_2	3.93	0.47	2.56
T_{11}-S_3M_3	4.00	0.52	2.62
T_{12}-S_3M_4	3.85	0.42	2.53
T_{13}-S_4M_1	4.27	0.64	2.77
T_{14}-S_4M_2	4.05	0.52	2.64

T_{15}-S_4M_3	4.18	0.58	2.67
T_{16}-S_4M_4	3.89	0.47	2.56
S.Em ±	0.17	0.16	0.14
CD @ 1%	NS	NS	NS

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

Table 3: Secondary nutrient content of lettuce as influenced by salinity levels and rooting substrates under hydroponic system

Treatments	Calcium (%)	Magnessium (%)	Sulphur (%)
Factor 1: Salinity levels (ds m^{-1})			
S_1	2.33	0.37	0.30
S_2	2.41	0.43	0.36
S_3	2.49	0.50	0.43
S_4	2.56	0.58	0.51
S.Em ±	0.09	0.08	0.10
CD @ 1%	NS	NS	NS
Factor 2: Rooting substrate			
M_1	2.54	0.56	0.47
M_2	2.42	0.44	0.39
M_3	2.48	0.49	0.42
M_4	2.35	0.38	0.32
S.Em ±	0.09	0.08	0.10
CD @ 1%	NS	NS	NS
Interactions			
T_1- S_1M_1	2.43	0.45	0.36
T_2-S_1M_2	2.31	0.34	0.28
T_3-S_1M_3	2.36	0.39	0.31
T_4-S_1M_4	2.23	0.30	0.24
T_5-S_2M_1	2.50	0.52	0.42
T_6-S_2M_2	2.37	0.40	0.34
T_7-S_2M_3	2.44	0.45	0.40
T_8-S_2M_4	2.32	0.36	0.30
T_9-S_3M_1	2.59	0.59	0.50
T_{10}-S_3M_2	2.45	0.47	0.41
T_{11}-S_3M_3	2.53	0.54	0.46
T_{12}-S_3M_4	2.37	0.42	0.35
T_{13}-S_4M_1	2.65	0.68	0.60
T_{14}-S_4M_2	2.55	0.56	0.50
T_{15}-S_4M_3	2.60	0.61	0.53
T_{16}-S_4M_4	2.46	0.47	0.42
S.Em ±	0.18	0.16	0.20
CD @ 1%	NS	NS	NS

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

Table 4: Micronutrient content of lettuce as influenced by salinity levels and rooting substrates under hydroponic system

Treatments	Iron (ppm)	Copper (ppm)	Manganese (ppm)	Zinc (ppm)
Factor 1: Salinity levels (ds m^{-1})				
S_1	349.46	14.98	253.50	66.53
S_2	357.97	15.47	260.19	70.12
S_3	367.68	16.32	266.34	75.02
S_4	374.55	17.06	274.68	78.64
S.Em ±	8.66	0.72	8.16	5.07
CD @ 1%	NS	NS	NS	NS
Factor 2: Rooting substrate				
M_1	368.86	16.60	268.20	77.86
M_2	359.48	15.71	262.14	70.56
M_3	364.81	16.17	265.52	74.64
M_4	356.50	15.35	258.85	67.25
S.Em ±	8.66	0.72	8.16	5.07
CD @ 1%	NS	NS	NS	NS
Interactions				
T_1- S_1M_1	355.07	15.37	256.87	71.07
T_2-S_1M_2	346.89	14.96	252.53	64.57
T_3-S_1M_3	350.83	15.33	254.83	68.49
T_4-S_1M_4	345.04	14.28	249.78	62.00
T_5-S_2M_1	361.71	16.28	264.66	75.64

T_6-S_2M_2	356.29	15.15	258.72	68.20
T_7-S_2M_3	360.23	15.56	262.46	72.42
T_8-S_2M_4	353.66	14.91	254.91	64.23
T_9-S_3M_1	374.75	17.08	272.08	80.61
T_{10}-S_3M_2	364.20	15.99	264.07	72.87
T_{11}-S_3M_3	370.10	16.55	269.05	77.54
T_{12}-S_3M_4	361.67	15.66	260.16	69.05
T_{13}-S_4M_1	383.92	17.68	279.18	84.13
T_{14}-S_4M_2	370.56	16.74	273.24	76.59
T_{15}-S_4M_3	378.11	17.25	275.75	80.11
T_{16}-S_4M_4	365.64	16.57	270.57	73.73
S.Em ±	17.33	1.44	16.31	10.15
CD @ 1%	NS	NS	NS	NS

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

Table 5: Primary nutrient uptake of lettuce as influenced by salinity levels and rooting substrates under hydroponic system

Treatments	N (mg plant^{-1})	P (mg plant^{-1})	K (mg plant^{-1})
Factor 1: Salinity levels (ds m^{-1})			
S_1	76.02	6.80	50.79
S_2	92.41	10.04	61.03
S_3	112.76	14.24	73.49
S_4	140.39	18.96	91.04
S.Em ±	2.39	0.45	1.66
CD @ 1%	7.17	1.37	4.98
Factor 2: Rooting substrate			
M_1	126.22	16.89	83.11
M_2	105.54	11.72	69.07
M_3	109.47	13.02	71.56
M_4	80.35	8.43	52.60
S.Em ±	2.39	0.45	1.66
CD @ 1%	7.17	1.37	4.98
Interactions			
T_1- S_1M_1	96.77	10.58	65.08
T_2-S_1M_2	75.58	5.39	50.57
T_3-S_1M_3	78.01	7.07	52.42
T_4-S_1M_4	53.71	4.18	35.11
T_5-S_2M_1	111.17	13.87	74.70
T_6-S_2M_2	95.82	9.68	62.86
T_7-S_2M_3	100.17	10.92	66.18
T_8-S_2M_4	62.49	5.71	40.39
T_9-S_3M_1	138.93	19.69	90.41
T_{10}-S_3M_2	112.85	13.60	72.95
T_{11}-S_3M_3	115.26	14.51	75.44
T_{12}-S_3M_4	84.01	9.17	55.16
T_{13}-S_4M_1	158.03	23.42	102.27
T_{14}-S_4M_2	137.90	18.21	89.91
T_{15}-S_4M_3	144.46	19.57	92.20
T_{16}-S_4M_4	121.19	14.65	79.77
S.Em ±	4.78	0.91	3.32
CD @ 1%	14.34	2.73	9.96

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.

Table 6: Secondary nutrient uptake of lettuce as influenced by salinity levels and rooting substrates under hydroponic **system**

Treatments	Ca (mg plant^{-1})	Mg (mg plant^{-1})	S (mg plant^{-1})
Factor 1: Salinity levels (ds m^{-1})			
S_1	48.16	7.71	6.34
S_2	58.21	10.46	9.17
S_3	70.93	14.57	12.29
S_4	87.82	19.99	17.59
S.Em ±	1.47	0.52	0.47
CD @ 1%	4.41	1.56	1.40
Factor 2: Rooting substrate			
M_1	79.82	17.93	14.94
M_2	66.15	12.47	11.10
M_3	68.97	13.87	12.02

M_4	50.19	8.46	7.32
S.Em ±	1.47	0.52	0.47
CD @ 1%	4.41	1.56	1.40
Interactions			
T_1- S_1M_1	61.70	11.58	9.13
T_2-S_1M_2	48.17	6.94	6.23
T_3-S_1M_3	49.60	7.92	6.50
T_4-S_1M_4	33.18	4.39	3.51
T_5-S_2M_1	70.92	14.81	11.89
T_6-S_2M_2	59.83	9.97	9.46
T_7-S_2M_3	63.33	11.04	10.25
T_8-S_2M_4	38.77	6.01	5.09
T_9-S_3M_1	89.00	20.15	16.65
T_{10}-S_3M_2	69.95	13.41	11.71
T_{11}-S_3M_3	72.97	15.59	13.16
T_{12}-S_3M_4	51.82	9.14	7.65
T_{13}-S_4M_1	97.67	25.19	22.12
T_{14}-S_4M_2	86.64	19.55	17.02
T_{15}-S_4M_3	89.96	20.92	18.16
T_{16}-S_4M_4	77.00	14.32	13.05
S.Em ±	2.94	1.04	0.94
CD @ 1%	8.82	3.12	2.81

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

Table 7: Micronutrient uptake of lettuce as influenced by salinity levels and rooting substrates under hydroponic system

Treatments	Fe (mg plant^{-1})	Cu (mg plant^{-1})	Mn (mg plant^{-1})	Zn (mg plant^{-1})
Factor 1: Salinity levels (ds m^{-1})				
S_1	720.12	30.93	522.54	140.00
S_2	864.90	37.53	628.55	172.07
S_3	1038.30	46.21	752.86	213.16
S_4	1282.14	58.37	939.80	269.70
S.Em ±	13.59	0.78	10.98	3.96
CD @ 1%	40.82	2.34	32.97	11.82
Factor 2: Rooting substrate				
M_1	1153.89	52.00	838.75	244.98
M_2	980.70	42.99	715.74	196.75
M_3	1011.08	44.99	736.63	208.17
M_4	758.91	33.06	552.63	145.04
S.Em ±	13.59	0.78	10.98	3.96
CD @ 1%	40.82	2.34	32.97	11.82
Interactions				
T_1- S_1M_1	907.69	39.15	657.45	182.70
T_2-S_1M_2	721.70	31.10	525.40	140.96
T_3-S_1M_3	737.05	32.16	535.16	143.92
T_4-S_1M_4	514.02	21.31	372.14	92.40
T_5-S_2M_1	1032.91	46.47	752.81	215.53
T_6-S_2M_2	899.61	38.25	653.27	177.21
T_7-S_2M_3	934.78	40.35	681.07	187.91
T_8-S_2M_4	592.31	25.05	427.05	107.63
T_9-S_3M_1	1255.40	57.12	912.92	270.10
T_{10}-S_3M_2	1039.77	45.65	753.92	208.05
T_{11}-S_3M_3	1067.75	47.77	776.20	223.69
T_{12}-S_3M_4	790.28	34.30	568.42	150.83
T_{13}-S_4M_1	1419.57	65.25	1031.83	311.58
T_{14}-S_4M_2	1261.72	56.96	930.36	260.76
T_{15}-S_4M_3	1308.26	59.66	954.09	277.15
T_{16}-S_4M_4	1139.02	51.60	842.92	229.31
S.Em ±	27.19	1.56	21.96	7.92
CD @ 1%	81.64	4.68	65.94	23.76

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

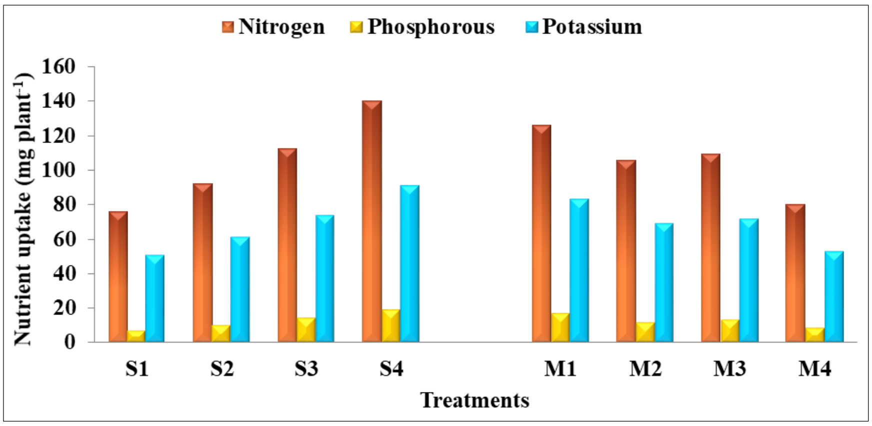

Fig 1: Primary nutrient uptake of lettuce as influenced by salinity levels and rooting substrates under hydroponic system

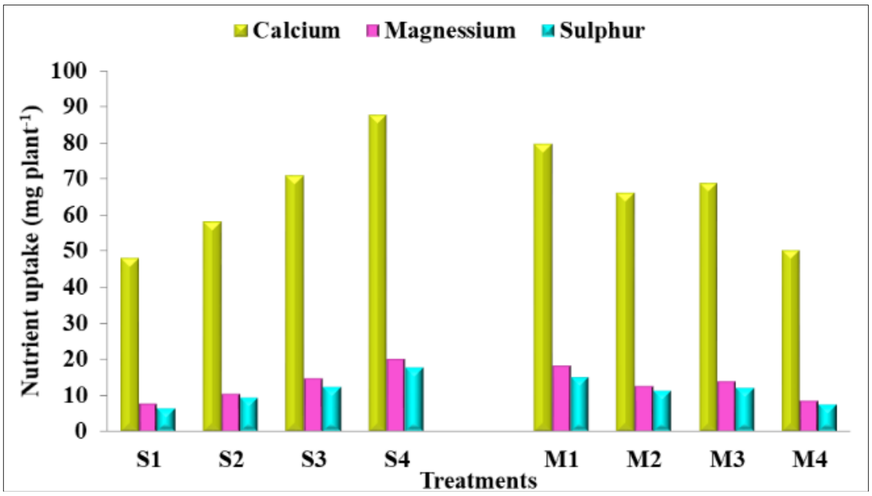

Fig 2: Secondary nutrient uptake of lettuce as influenced by salinity levels and rooting substrates under hydroponic system

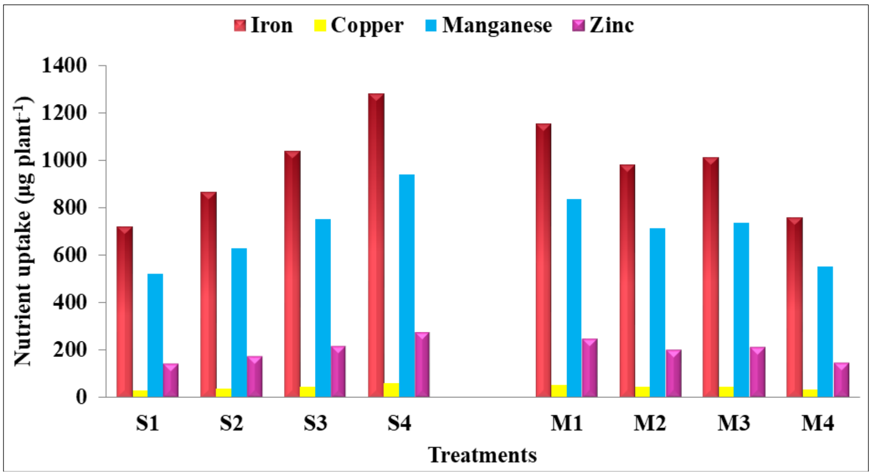

Fig 3: Micro nutrient uptake of lettuce as influenced by salinity levels and rooting substrates under hydroponic system

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