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Effects of micro-nano bubbles and electrical conductivity of nutrient solution on the growth and yield of green oak lettuce in a hydroponic production system

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ABSTRACT

The purpose of the study was to evaluate the effect of using water with micro-nano bubbles (MNBs) and different electrical conductivity (EC) on the growth and yield of green oak lettuce in hydroponic systems. The green oak lettuce plantation was studied from December 2020 to February 2021 at the Agricultural Technology Research Institute, Rajamangala University of Technology Lanna, Thailand. The experimental design was a 2x3 factorial in CRD. Factors were: 1) giving MNBs water at 0 or 5 minutes weekly and 2) giving of EC (Electrical conductivity) at 0.3, 0.6, and 1.2 mS cm^{-1} in a deep flow technique (DFT) hydroponics system. The results showed that MNB treated water for 5 minutes affected the fresh and dry weight of the leaves and the total weight of green oak lettuce, and the different levels of EC had significant effects on the growth and yield of green oak lettuce. The interaction between MNBs and EC affected plant height, canopy width, leaf greenness values (SPAD), fresh leaf yield, shoot, and the total weight of green oak lettuce had significant differences. Moreover, concentrations of N, P, K, Ca, and Mg in the leaf increased with increasing EC. Those MNBs treatment increased N, P, K, and Ca but did not affect Mg.

Keywords: electrical conductivity, micro-nano bubbles, hydroponic, green oak lettuce

INTRODUCTION

Green oak lettuce, known scientifically as *Lactuca sativa* var. crispa L., is a leafy vegetable that is very popular in Thailand due to its potential of growing well in hydroponic systems. Hydroponics is a new technique to grow plants in a nutrient solution that increases growth, yield, income, profit, and crop number per year. (Siringam et al., 2014). The average result of outdoor lettuce in hydroponic systems or the Nutrient Film Technique (NFT) with the principle of a constant flow of liquid nutrient solution produced about 1.85 times plant yield higher than that in soil culture (Wattanapreechanon and Sukprasert, 2012). Moreover, the benefits of hydroponic vegetable cultivation can also control plant growth, reduce agricultural chemicals, and prevent contamination of chemicals from the soil, resulting in better yield, sanitation, and quality than conventional methods (Quy et al., 2018). Several factors are involved in the growth of plants in hydroponic systems, including sunlight, water, temperature, plant nutrients, pH, and EC. Moreover, the concentrated nutrient solutions with regulated pH and EC also need to be kept at appropriate levels for each type of vegetable or plant. Too much or too little pH and EC will affect the quality, growth, and yield of the vegetable (Quy et al., 2018, Phaengkieo et al., 2019). Aside from nutrients in solution, oxygen content in water is one of the main factors affecting the growth of plants and vegetables. The MNBs are technology capable of making tiny air bubbles of 100 to 200-nanometer diameter. These tiny bubbles effectively increase the oxygen content in water, and with MNBs, the nutrient solution could also improve vegetative growth (Jiang et al., 2016, Sritontip et al., 2019a). Therefore, the objective of this experimental study was to evaluate the effect of MNBs water and EC on the physiological character, yield, and leaf nutrient concentration of green oak lettuce produced in a hydroponic system.

MATERIALS AND METHODS

The green oak lettuce was planted from December 2020 to February 2021 at the Agricultural Technology Research Institute, Rajamangala University of Technology Lanna, Thailand. The experiment was assigned in a factorial arrangement in a completely randomized design (CRD) with two factors, including applied MNBs for water at 0 and 5 minutes weekly for five consecutive weeks. It used EC with three levels: 0.3, 0.6, and 1.2 mS cm^{-1}, respectively. There were four replications each. The nutrient solution was modified from Hoagland and Arnon's (1952) and Huett (1993) formulas. The stock solution in 1 liter of water consisted of $Ca(No_3)_2$ $4H_2O$, KNO_3, $NH_4H_2PO_4$, KH_2PO_4, $MgSO_4$•$7H_2O$, Fe-EDTA, $MnSO_4$ H_2O, $ZnSO_4$•$7H_2O$, $CuSO_4$ $5H_2O$, H_3BO_3, and $(NH_4)_6Mo_7O_{24}$•$7H_2O$. All crops were grown in the non-circulating hydroponic growing method (Deep flow technique, DFT) (Kratky, 2009). Green oak lettuce was planted in boxes 25x29x10 centimeters in size that had the capacity of 3 liters of nutrient solution per box. The polystyrenes were kept floating on the nutrient solution to support the plants. The pH of the nutrient solution was maintained within the range of 6.5 by adding sulfuric acid. Oxygen was provided through an air pump generator. Every week air was supplied to the MNBs water for 0 and 5 minutes and the nutrient solution was added to the box after bubbling the air. The air micro-nano bubbles used model KVM-25 which were water flow rate of 25 L/min, airflow rate of 2 L/min, operation pressure 0.25-0.4 MPa, and 0.75 kW motor power; having air nanobubbles in the range of 107-108 bubbles/mL measured by Horiba-960A laser bubble analyzer that developed by the unit of excellence in the High Voltage Plasma and Micro/Nano Bubble Application to Agriculture and Aquaculture, Rajamangala University of Technology Lanna (RMUTL), Chiang Mai, Thailand. The dissolved oxygen (DO) of the nutrient solution was measured by waterproof, model DO600, Eutech Instrument, Singapore; EC was controlled with EC meter, model EC 59, Martini Instrument, Romania. The physiological character attributes of green oak lettuce in a hydroponic system were measured, including plant height, canopy width, leaf number per plant, root length, leaf greenness value (SPAD), fresh leaf, dry leaf, shoot, root, and total weight. Growth parameters of green oak lettuce were recorded weekly for five weeks from the plant-grown period until harvesting. The fresh weight of leaves, shoot, roots, and the total weight were recorded after 45 days of growth. The material was kept in an oven at 70 ºC in a paper bag for dry weight. Once dry, it was then taken out of the oven and recorded. The leaf nutrient concentration was analyzed. The samples were washed and dried at 70 ˚C for 48 hours and milled. Leaf nitrogen was determined using a micro-Kjeldahl digestion solution. The digested solution was diluted before colorimetric analysis using the indophenol reaction (Novozamsky et al., 1974). Phosphorus was determined by dry digestion followed by the vanadomolybdate method (Walinga et al., 1995), and K, Ca, and Mg by dry digestion and atomic absorption spectroscopy (AA-6401F, Atomic absorption flame emission spectrophotometer, Shimadzu, Tokyo, Japan) (Kalra, 1998; Walinga et al., 1995). The statistical data were analyzed for Analysis of Variance. Statistical differences with P-values less than 0.05 and 0.01 were considered significant, and highly significant, respectively; the means were compared by Duncan's multiple range test.

RESULTS AND DISCUSSION

Different EC levels in the nutrient solution at 0.6 and 1.2 $mS.cm^{-1}$ influenced plant height and canopy width of green oak lettuce at weeks 3, 4, and 5 (Figures 1 and 3). The 5-minutes of MNBs significantly affected plant height at week 5 (Figure 2) and canopy width at weeks 2 and 3 (Figure 4). There were interactions between the solution concentrations and MNBs water on height growth at weeks 4 and 5 (Figure 5) and canopy width at weeks 2, 3, 4, and 5 (Figure 6).

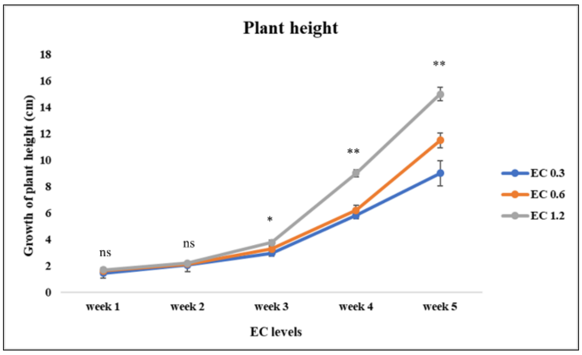

Figure 1. Effect of EC levels on plant height.

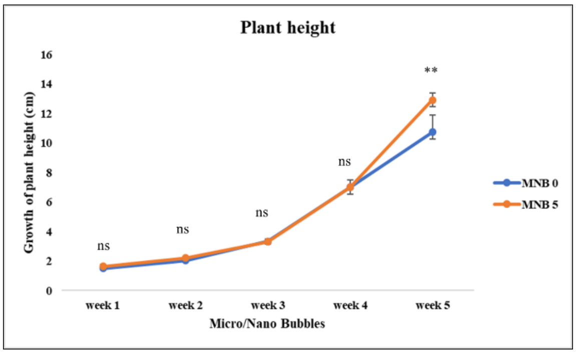

Figure 2. Effect of MNBs on plant height.

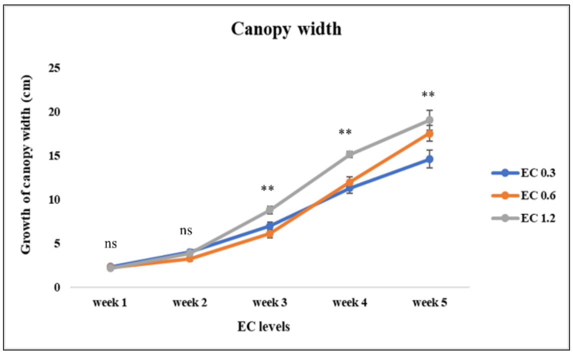

Figure 3. Effect of EC levels on canopy width.

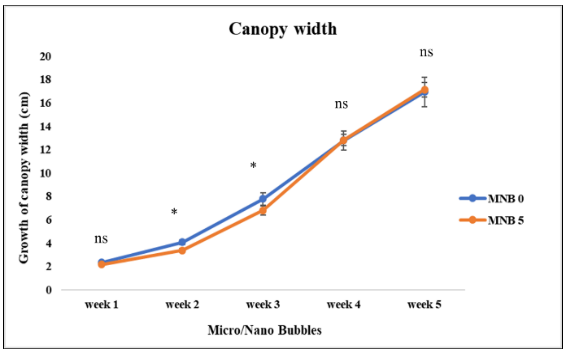

Figure 4. Effect of MNBs on canopy width.

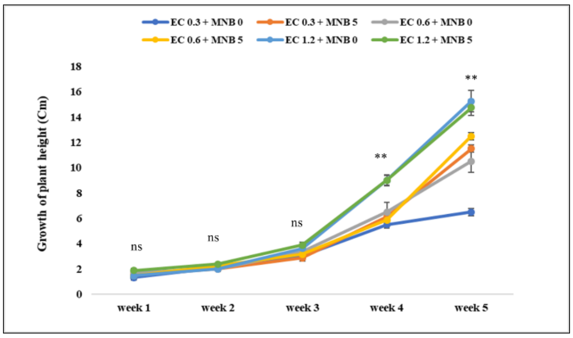

Figure 5. Combination between EC levels and MNBs on plant height.

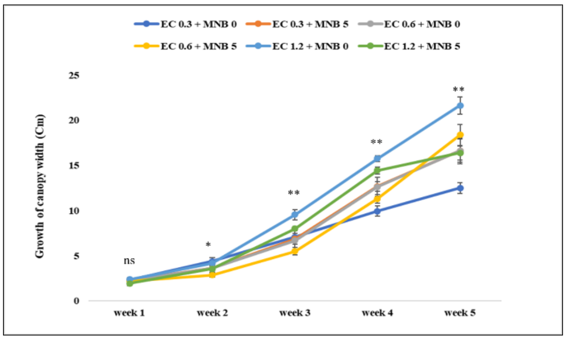

Figure 6. Combination between EC levels and MNBs on canopy width.

At 1.2 mS/cm^{-1}, the EC concentration level affected the leaf number at weeks 2, 4, and 5 (Figure 7). When using 0 and 5 minutes of MNBs water, the number of leaves did not change significantly (Figure 8) but interacted with each other. At the EC concentration of 1.2 mS.cm$^{-1,}$ the most extended root length was found at weeks 3 and 4 (Figure 9). The root length when 5 minutes of MNB water were used was significant at week 4 (Figure 10). The interaction of the solution concentrations and MNBs water affected leaf number at weeks 2 and 5 (Figure 11) and root length at weeks 3 and 4 (Figure 12).

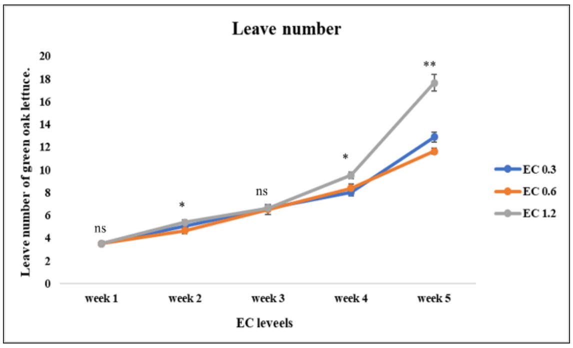

Figure 7. Effect of EC levels on leaf number.

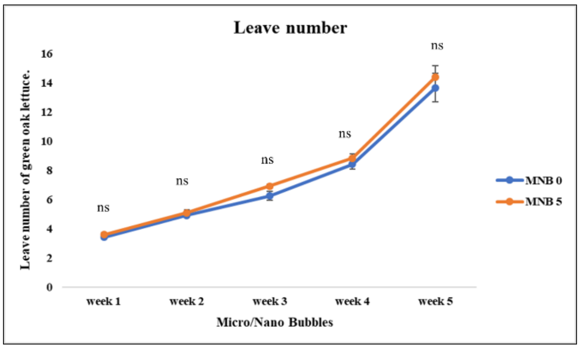

Figure 8. Effect of MNBs on leaf number.

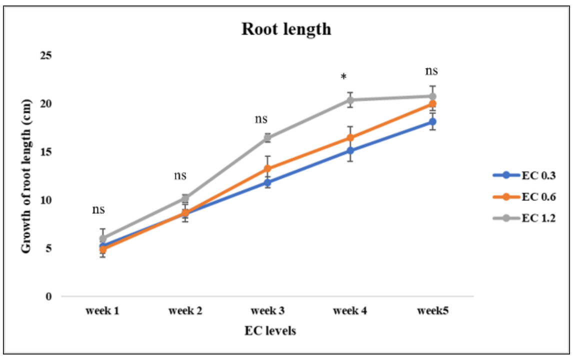

Figure 9. Effect of EC levels on root length

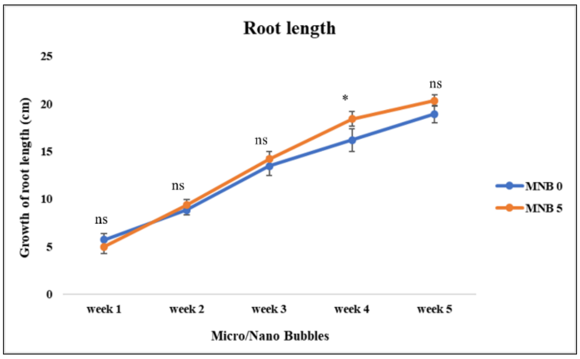

Figure 10. Effect of MNBs on root length.

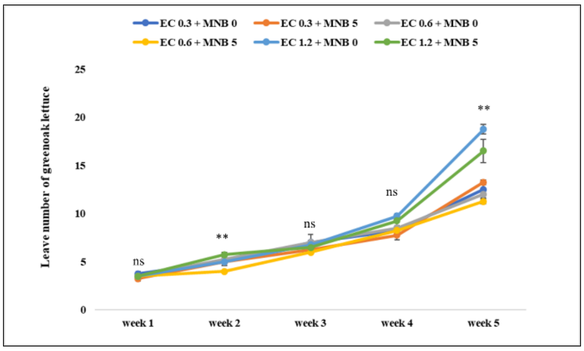

Figure 11. Combination between EC levels and MNBs on leaf number.

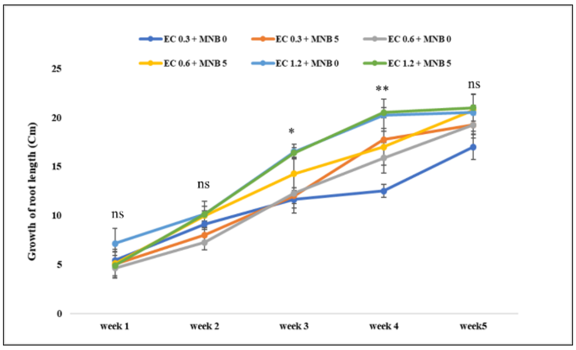

Figure 12. Combination between EC levels and MNBs on root length.

The SPAD unit of green oak lettuce was affected at EC 0.6 and EC 1.2 mS cm^{-1} at weeks 2, 3, and 4 (Figure 13), and significantly after using 5 minutes of MNBs water at week 4 (Figure 14). The solution concentrations and MNBs water interacted at weeks 3 and 4 (Figure 15).

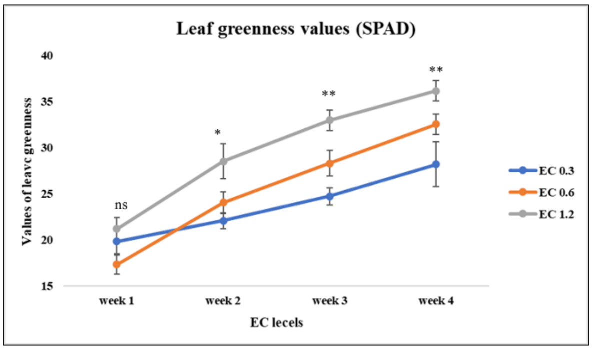

Figure 13. Effect of EC levels on SPAD.

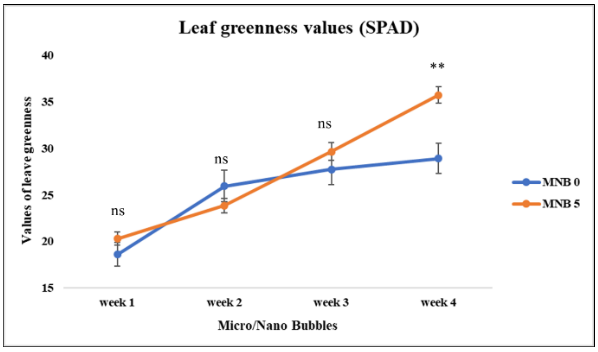

Figure 14. Effect of MNBs on SPAD.

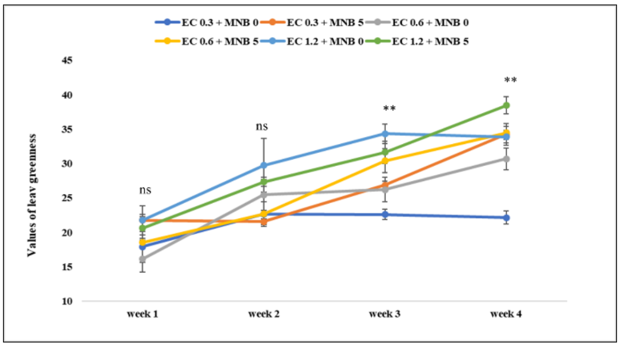

Figure 15. Combination between EC levels and MNBs on SPAD.

At an EC concentration of 1.2 mS cm^{-1}, the yield of the fresh and dry weight of leaf, shoot, root, and the total weight of green leaf oak lettuce was higher than for EC 0.3 and 0.6 mS cm^{-1}, see Figures 16 and 19. Using water with MNBs for 5 minutes produced a higher fresh and dry weight of the leaves and a higher total weight of green oak lettuce (Figures 17 and 20). The interaction of EC and MNB water gave significant differences between the fresh weight of leaves, shoots, root and the total weight (Figure 18). However, this interaction was not significant for the dry weight of the root (Figure 21).

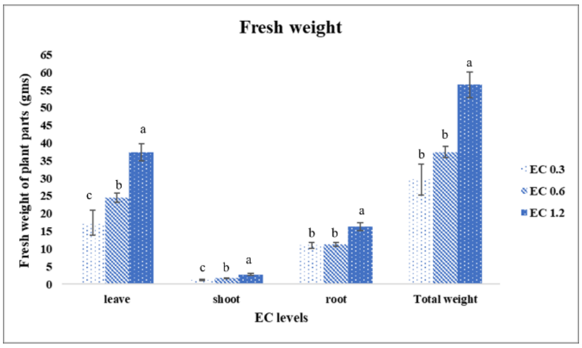

Figure 16. Effect of EC levels on fresh weight.

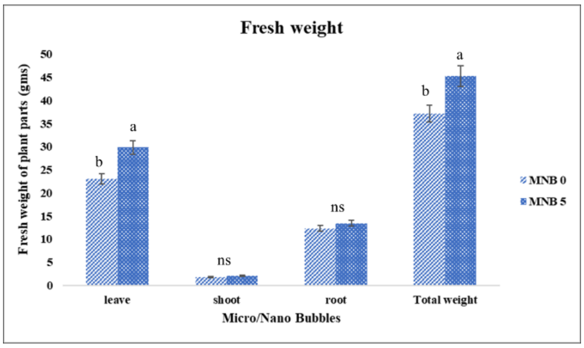

Figure 17. Effect of MNBs on fresh weight.

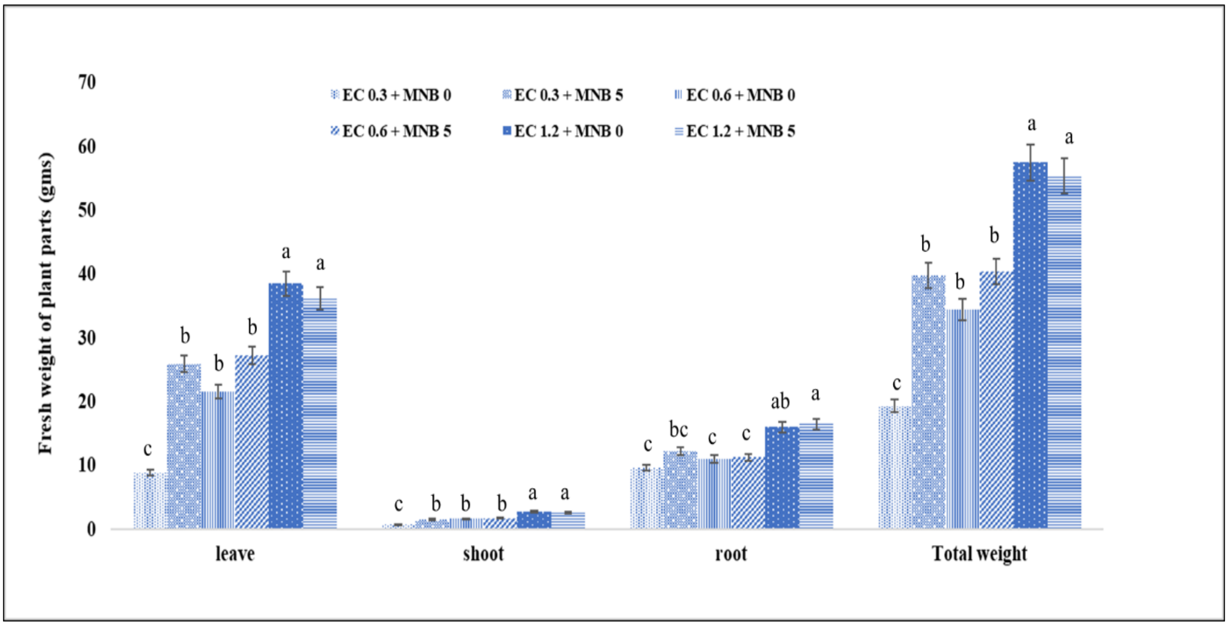

Figure 18. Combination between EC levels and MNBs on fresh weight.

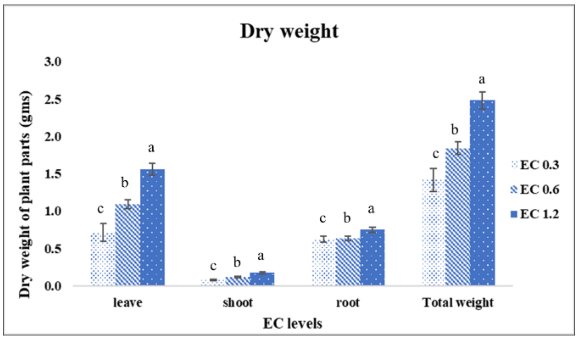

Figure 19. Effect of EC levels on dry weight.

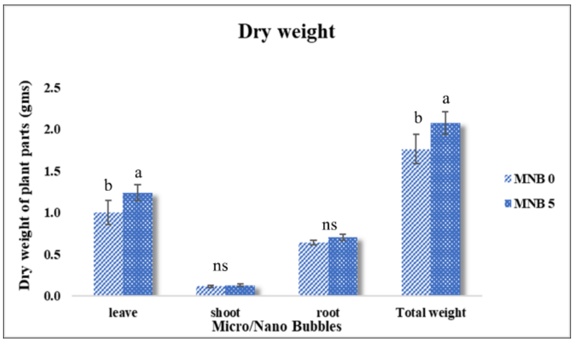

Figure 20. Effect of MNBs on dry weight.

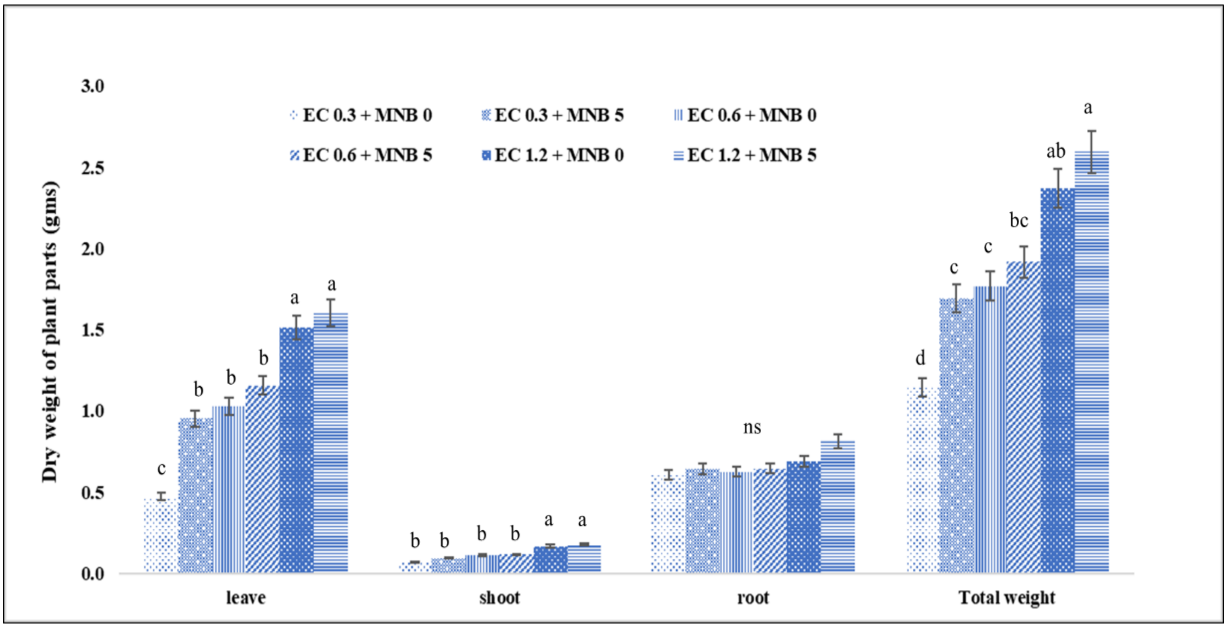

Figure 21. Combination between EC levels and MNBs on dry weight.

At electrical conductivities of 0.3 to 1.2 mS cm^{-1} the dissolved oxygen in the nutrient solution of the culture showed similar patterns (Figure 22). However, a 5-minute MNBs treatment increased the dissolved oxygen to levels not reached with MNBs-untreated water (Figure 23).

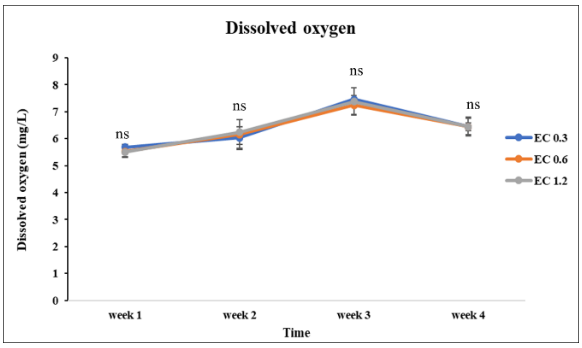

Figure 22. Effect of EC levels on dissolved oxygen

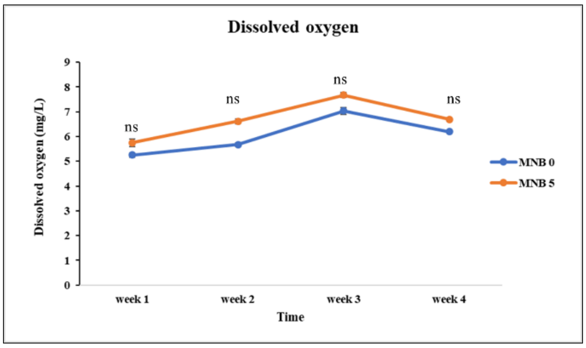

Figure 23. Effect of MNBs on dissolved oxygen.

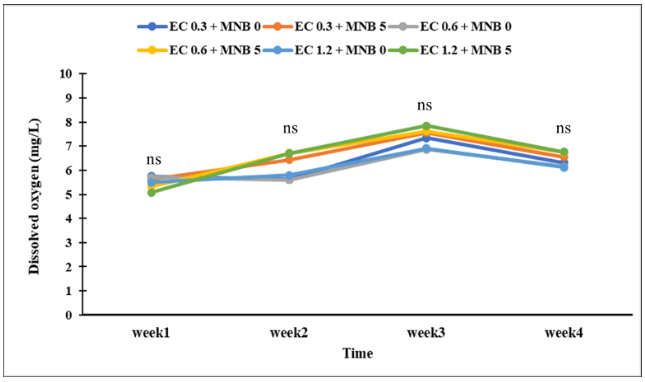

Figure 24. Combination between EC levels and MNBs on dissolved oxygen.

The concentrations of nitrogen, phosphorus, potassium, calcium, and magnesium in green oak lettuce plant tissue increased when the EC was increased from 0.3-1.2 mS cm^{-1}. Furthermore, a MNBs treatment increased the leaf nutrient concentration of nitrogen, phosphorus, potassium, and calcium to higher than a non-MNBs treatment, while magnesium and phosphorous uptake levels remained similar. There was an interaction between EC and MNBs on the nitrogen concentration. At 0.3-0.6 mS cm^{-1} were more effective of MNBs treatment that could induce leaf nitrogen concentration (Table 1).

Table 1. Effect of EC levels and period of MNBs on leaf nutrient concentration after treatments.

Factors	Nitrogen (%)	Phosphorus (%)	Potassium (%)	Calcium (%)	Magnesium (%)
EC (A)					
0.3 mS cm^{-1}	3.57^{c}	0.08^{c}	1.92^{c}	5.72^{b}	0.11^{b}
0.6 mS cm^{-1}	4.44^{b}	0.12^{b}	2.95^{b}	6.14^{ab}	0.14^{ab}
1.2 mS cm^{-1}	4.99^{a}	0.14^{a}	3.56^{a}	7.69^{a}	0.15^{a}
MNBs (B)					
0 minute	4.10^{b}	0.10^{b}	2.41^{b}	6.13^{b}	0.13
5 minutes	4.56^{a}	0.12^{a}	3.20^{a}	6.91^{a}	0.14
A*B					
0.3 mS cm^{-1}	3.05^{d}	0.06	1.37	5.57	0.10
0.3 mS cm^{-1} + MNBs	4.08^{c}	0.09	2.46	5.88	0.12
0.6 mS cm^{-1}	4.26^{bc}	0.11	2.78	5.65	0.14
0.6 mS cm^{-1} + MNB	4.62^{ab}	0.12	2.89	6.46	0.13
1.2 mS cm^{-1}	4.98^{a}	0.12	3.36	7.33	0.14
1.2 mS cm^{-1} + MNB	4.99^{a}	0.15	4.02	8.22	0.16
A	*	*	*	*	*
B	*	*	*	*	ns
A x B	*	ns	ns	ns	ns

*Means within the column followed by the different letters were significantly different (P< 0.05), ns =not significant.

The effect of water with MNBs and EC levels on the growth and yield of green oak lettuce in hydroponic systems was studied. EC levels of 0.5-2.0 mS cm^{-1} enhanced growth and yield in green oak lettuce (Department of Agriculture Extension, 2015). Maximum growth was achieved with solution concentrations between 1.2 and 4.8 mS.cm^{-1} (Albornoz and Lieth, 2015). The Air MNBs water induced plant growth in green oak lettuce because MNBs water increased DO in the medium and enhanced the oxidation effect of surface water (Oshita and Liu. 2013, Takahashi, 2005; Liu and Tang, 2019). Jiang et al. (2016) reported that the introduction of oxygenated MNB into the water significantly improved the DO content, resulting in increased plant growth, product yield, and quality of the lettuce. The lettuce grown in the nano-bubble system had a healthier appearance, plant height, canopy width and longer roots than the same plant grown in a conventional hydroponic system (Phaengkieo et al., 2019). Furthermore, the EC levels of an experiment in 'Green Butter' found that the yield was 75 g less at 1.4 mS.cm^{-1} when compared with 1.8 mS.cm^{-1} (Samarakoon et al., 2020). This experiment indicated that as the EC levels increased from 0.3-1.2 mS cm^{-1}, the N, P, K, and Ca in leaf tissue were greater in increasing EC. The lettuce plant growth and yield were higher than lower EC. The nutrient solution was total ionic concentration from 16 essential elements (Trejo-Téllez and Gómez-Merino, 2021). Furthermore, in the research on dill tissue (*Anethum graveolens* 'Fernleaf'), the concentration of N, K, S (sulfur), Fe (iron), and B (boron) climbed with increasing EC. At the same time, calcium and magnesium were negatively affected (Currey et al*.*, 2019). Moreover, EC of the nutrient solution in all three basil species showed that the SPAD increased with increasing EC, and in holy basil tissue, N and P increased when the EC rose from 0.5 to 3.0 mS cm^{-1} (Walters and Currey, 2018)

Using water treated with MNBs resulted in a positive effect when the MNBs were tiny bubbles smaller than 50 micrometers and 200 nanometers. Air MNBs can stay for long periods. (Agarwal et al., 2011; Takahashi, 2015). The lettuce can be sensitive to MNBs treatments and improve plant growth because of the small size of gas bubbles, long residence time in the water, the ability to generate hydroxyl radicles, and tremendous negative electronic changes (Agarwal et al., 2011; Zhang et al., 2020; Tsuge, 2015). Takahashi (2015) reported that the microbubbles were electrical double layers with a negative charge in above pH conditions and positive charge in strong acid conditions. The growth and development were stimulated with MNBs. That was possibly why the positive ions in the nutrient solution were transported preferentially up the root system and DO enrichment in a nutrient solution. The microbubbles in the nutrient solution could induce plant growth and enhance the development of lettuce under hydroponic conditions (Park and Kurata, 2009; Park et al., 2010). Furthermore, fine bubbles or MNBs enhanced seed germination and root length of Chinese celery and sweet corn. MNBs promoted vegetative growth in melons but did not affect fruit quality (Sritontip et al., 2019b). Moreover, ultrafine bubbles enhanced the plant growth of soybean seedlings (Iijima et al., 2020). MNBs characterize by small specific surface areas and long residence times in water (Lui and Tang, 2019; Lui et al., 2019). This research indicated 5 minutes MNBs could stimulate the growth and development of green oak lettuce. Besides, EC levels of 1.2 mS cm^{-1} appropriated nutrient solution concentration of green oak lettuce.

CONCLUSIONS

This experiment studied the effect of oxygen micro-nano bubble (MNBs) water generated through an air pump. Supplying MNB water for 5 minutes to green oak lettuce grown in a hydroponic system increased the fresh and dry weight of the leaves and the total plant weight. Three concentrations of EC, 0.3, 0.6, and 1.2 mS cm^{-1}, gave significant differences and affected the growth and yield of green oak lettuce. However, the EC concentration of 1.2 mS cm^{-1} was the greatest of all treatments. An interaction between the MNBs and EC was also observed, resulting in improved plant height, canopy width, leaf greenness values (SPAD), the yield of fresh leaves, shoot, and the total weight of green oak lettuce. Increasing the EC also increased N, P, K, Ca, and Mg in the leaves.

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