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EFFECT OF TOTAL DISSOLVED SOLIDS AND pH ON THE GROWTH AND YIELD OF SPINACH (*Spinacia oleracea* L.) IN THE AEROPONIC SYSTEM

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ABSTRACT

A study on the total dissolved solids and pH on the growth and yield of spinach (*Spinacia oleracea* L.) in an aeroponic system was carried out at the Tien Giang Center of Applied Research and Science Technology Services in 2024. The study aimed to determine the effectiveness level of total dissolved solids and pH on the promotion of plant growth and yield of spinach in an aeroponic system. The two-factor experiment was arranged in a completely randomized design with nine treatments and five repetitions. Total dissolved solids have 3 levels: 1,000 ppm; 1,200 ppm and 1,400 ppm corresponding to A1, A2 and A3. pH has 3 levels: 6.0, 6.5 and 7.0 corresponding to B1, B2 and B3. Nine treatments to incorporate total dissolved solids and pH include: A1B1 (1,000 ppm/6.0), A1B2 (1,000 ppm/6.5), A1B3 (1,000 ppm/7.0), A2B1 (1,200 ppm/6.0), A2B2 (1,200 ppm/6.5), A2B3 (1,200 ppm/7.0), A3B1 (1,400 ppm/6.0), A3B2 (1,400 ppm/6.5) and A3B3 (1,400 ppm/7.0). Results showed that spinach grew well in the aeroponic systems with total dissolved solids at 1,200–1,400 ppm and pH at 6.0–6.5. Our results show that, from 10 days to 20 days after transplanting, there is an interaction between the factors “total dissolved solids” and “pH”, affecting the growth and development of spinach in the aeroponics system, with differences between pairs of treatments. However, statistical analysis did not find the interaction between factors “total dissolved solids” and “pH” affecting the yield of spinach in aeroponic systems. In the treatments, A3B1 (1,400 ppm/6.0) results in terms of number of leaves (27.50 ± 0.14 leaves/plant), Plant height (44.82 ± 1.16 cm), leaf length (28.86 ± 1.62 cm), leaf width (14.40 ± 1.37 cm), root length (87.42 ± 4.33 cm) were higher than in other treatments.

Keywords: Aeroponic system, pH, growth, spinach, Total Dissolved Solids.

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INTRODUCTION

Spinach (*Spinacia oleracea* L.) is a green leafy vegetable, with high nutrients, containing lots of beta carotene, folate, and vitamin C, etc. (Morelock et al., 2008). Spinach usually grows well in cool, humid climates (Wahocho et al., 2016) and produces high yields in a short time (Murcia et al., 2020). When vegetables are grown on soil, they are easily effected by pests and water pollution also influences food quality and safety. Nutrient deficiencies in the soil also affect the growth and yield of vegetables (Bradley et al., 2009). Soilless crop growing techniques bring many socio-economic benefits including the ability to cope with growing global food challenges, environmental pollution, climate change, effective management and consuming natural resources (Butler et al., 2006). Growing vegetables without soil, including hydroponics and aeroponics, is one of the new agricultural methods that saves water and fertilizer (Raviv et al., 2008). In an aeroponics system, plant roots are placed in a controlled and closed chamber. Plant roots are suspended freely in the air on support and are supplied with nutrient-rich water mist ray through a nozzle, creating a fine mist intermittently or continuously the nutrient solution is reused many times (Lakhiar et al., 2018).

Therefore, it is necessary to regularly measure the TDS and pH values of nutrient solutions for plants to grow well. However, these issues are poorly documented on the growth and development of spinach in aeroponic systems. Therefore, determining “TDS” and “pH” appropriate for the growth and yield of spinach in aeroponics systems needs to be researched.

MATERIALS AND METHODS

Materials

Variety

Variety F1 Turkana spinach variety (supplied by Rang Dong Co., Ltd.).

Aeroponic system

The chamber: height 0.8 m, length 1 m, width 1 m, surrounded by composite on the outside. The top surface (support) is a square with a side of 1 m, containing 49 planting holes, the hole has a diameter of Þ40 mm, the hole center is 0.1 m from the edge and the hole center is 0.13 m from the hole center.

Spraying system: The growing solution is contained in a plastic tank located under the chamber with a volume of 20 liters. The growing solution is pumped by a pump with a flow rate of 4.5 liters/minute and a pressure of 100 PSI (6.9 Bar) through a filter and is sprayed directly onto the roots of the plant through 8 nozzles with each nozzle having a flow rate of 6 liters/hour. Part of the growing solution adheres to the root hairs of the plant, part will be circulated back to the tank to perform the next cycle.

Timer system: Automatically programmed with a pump operating time of 40 seconds and a pump rest time of 4 minutes. The process is repeated throughout the growth and development of plants on the aeroponic system.

Cultivation conditions: The box is sealed and dark.

Nutrient solution

Based on the Howard Resh formula. Solution (A) $Ca(NO_3)_2.4H_2O$, Fe(EDTA), KNO_3 and Solution (B) H_3BO_3, $CuSO_4.5H_2O$, $MgSO_4.7H_2O$, $MnSO_4.H_2O$, H_3PO_4, KH_2PO_4, $Na_2MoO_4.2H_2O$, $ZnSO_4.2H_2O$ (Gopinath et al., 2017).

Preparing the planting medium and seedlings

The F1 Turkana spinach seeds were soaked in warm water at a ratio of 2 boiling: 3 cold for 4 hours. Take seeds and put them in a tray containing rockwool (tray size: 49 cm long, 28 cm wide, 5 cm high, with 84 holes). After 5 days of germination, when the seedling had 2 cotyledons and the plant height ranged from 1.5–2.5 cm they would be transplanted.

Table 1. Nutritional composition

Nutrient	Concentration (g/L)
$N\text{-}NH_4$	0.54
$N\text{-}NO_3$	0.35
P	0.40
K	0.35
Ca	0.17
Mg	0.08
Na	0.04
Fe	0.09
Zn	0.03
B	0.03
Cu	0.04

Methods

The experiment treatment

The two-factor experiment was arranged in a completely randomized design (CRD) with nine treatments and five repetitions. TDS had 3 levels: 1,000 ppm; 1,200 ppm; 1,400 ppm corresponding to A1, A2, A3. pH has 3 levels: 6.0, 6.5, 7.0 corresponding to B1, B2, B3. Nine treatments of incorporate TDS and pH include A1B1 (1,000 ppm/6.0), A1B2 (1,000 ppm/6.5), A1B3 (1,000 ppm/7.0), A2B1 (1,200 ppm/6.0), A2B2 (1,200 ppm/6.5), A2B3 (1,200 ppm/7.0), A3B1 (1,400 ppm/6.0), A3B2 (1,400 ppm/6.5) and A3B3 (1,400 ppm/7.0) (Table 2). The planting density was 49 plants per square meter. Spraying systems were implemented to monitor and alter spraying pattern, flow rate, droplet size, time and atomizing air pressure automatically. Misting lasted 40 seconds, then paused for 4 minutes before misting again. Droplet size was 50 µm and nutrient solution was reused. The experiment was arranged in a shaded greenhouse with a light intensity of 10,000–50,000 lux.

According to the aeroponics study by Gopinath et al. (2017), TDS varies depending on the crop but is usually between 600 ppm and 1,300 ppm. Low TDS means that the crop is not getting enough nutrients. It is recommended to avoid TDS greater than 2,500 ppm. At higher TDS, the plant will die. The optimal pH for plant growth is between 5.8 and 6.5. The above study on spinach on a floating system by Oztekin et al. (2018) showed that the effective pH and TDS thresholds were 800–1,600 ppm and pH from 5.5 to 6.5 depending on different stages.

Table 2. Experimental treatments

pH (B)	TDS (A)		
	A1 (1,000 ppm)	A2 (1,200 ppm)	A3 (1,400 ppm)
B1 (6.0)	A1.B1	A2.B1	A3.B1
B2 (6.5)	A1.B2	A2.B2	A3.B2
B3 (7.0)	A1.B3	A2.B3	A3.B3

Data collection

The number of leaves (leaves/plant) is the total number of leaves on the plant counted; Plant height (cm) is measured from the base of the stem to the tip of the leave; Leaf size (cm) is determined by choosing the leaves on the tree that are well developed and large and then measuring the length and width of the leaves (record every 5 days); Measure root length (cm) at harvest from the base of the stem to the tip of the root; Plant fresh weight (g/plant): Plants were cut near the base of the stem and weighed at harvest. Yield (kg/m^2): Calculated by weighing 49 plants per square meter (recorded on day 30).

Data analysis

Data was presented in average and standard deviation in the form of images and tables. The significant difference was analyzed and tested by using analysis of variance (Two-way ANOVA). Duncan's Multiple Range Test (DMRT) is further used in order to compare mean values for significantly different treatments.

RESULTS AND DISCUSSION

The temperature and humidity

The greenhouse had a temperature range of 35.3–36.6 ^oC and a humidity of 40–48.6% because the experiment was conducted in the dry season. However, the nutrient reservoir was in the soil, so the temperature of the nutrient solution was maintained at 29–30.2 ^oC and the temperature in the aeroponics system was maintained at 29.6–30.5 ^oC (Table 3). If the temperature of the root is too high, that can inhibit root growth and cause nutrient deficiencies, reducing photosynthetic efficiency. Temperatures of root from 20 ^oC to 38 ^oC, which increased the Rubisco concentration, protected plants against photoinhibition and increased nitrate absorption (He et al., 2013; Eldridge et al., 2020). Misting lasted 40 seconds, then paused for 4 minutes before misting again, So the humidity in the aeroponic system was always maintained at 99% (Table 3). According to research by Lakhiar et al. (2018), the system needed to maintain 100% humidity in the chamber. In the aeroponic system, humidity was a necessary component for plant growth and development.

Table 3. Temperature and humidity inside and outside the chamber were recorded throughout the experiment

Parameters	Temperature (^oC) (DAT)					
	5	10	15	20	25	30
The greenhouse	35.3	35.6	36.3	35.6	36.0	36.6
The chamber	29.6	29.8	30.3	30.0	30.1	30.5
The nutrient solution	29.0	29.3	30.1	29.5	29.7	30.2
Parameters	Humidity (%) (DAT)					
The greenhouse	45.0	48.3	48.6	44.6	40.0	44.6
The chamber	99	99	99	99	99	99

Note: DAT: Day after transplanting.

Effects of TDS and pH on the growth of spinach in aeroponics system

The number of leaves increased with each stage of growth and development of spinach.

Regarding TDS, at 5 days after transplanting in the aeroponic system, there was no difference in the number of leaves between treatments ($p > 0.05$). At 10 days after transplanting, number of leaves in A2 (3.99 ± 0.05 leaves/plant) was significantly different from A1 (3.90 ± 0.13 leaves/plant) and A3 (3.89 ± 0.13 leaves/plant) ($p = 0.0081$). From 15 days to 20 days after transplanting, there was no difference in number of leaves ($p > 0.05$), ranging from 7.91–8.06 leaves/plant and 14.10–14.39 leaves/plant, respectively (Fig. 1a). From 25 days to 30 days after transplanting, the number of leaves had a significant difference (Fig. 1a). At 30 days after transplanting, it was recorded that the number of leaves in A3 (26.96 ± 0.68 leaves/plant) had statistically significant difference compared to A1 (26.39 ± 0.64 leaves/plant) ($p = 0.0085$).

Regarding pH, from 5 days to 10 days after transplanting, there was no difference in the number of leaves ($p > 0.05$), ranging from 2.00 leaves/plant and 3.91–3.94 leaves/plant, respectively. From 15 days to 30 days after transplanting, number of leaves had a significant difference (Fig. 1b). At 30 days after transplanting, number of leaves in B1 (27.15 ± 0.38 leaves/plant) and B2 (26.74 ± 0.60 leaves/plant) was significantly different from B3 (26.03 ± 0.54 leaves/plant) ($p < 0.001$).

Analysis results showed that interaction between factors "TDS" and "pH" was from 10 days to 20 days after transplanting, with differences between pairs ($p < 0.001$). However, there was no interaction between factors "TDS" and "pH" from 25 days to 30 days after transplanting ($p > 0.05$). At 30 days after transplanting, treatment A3B1 (27.50 ± 0.14 leaves/plant) had a higher number of leaves than other treatments (Fig. 1c).

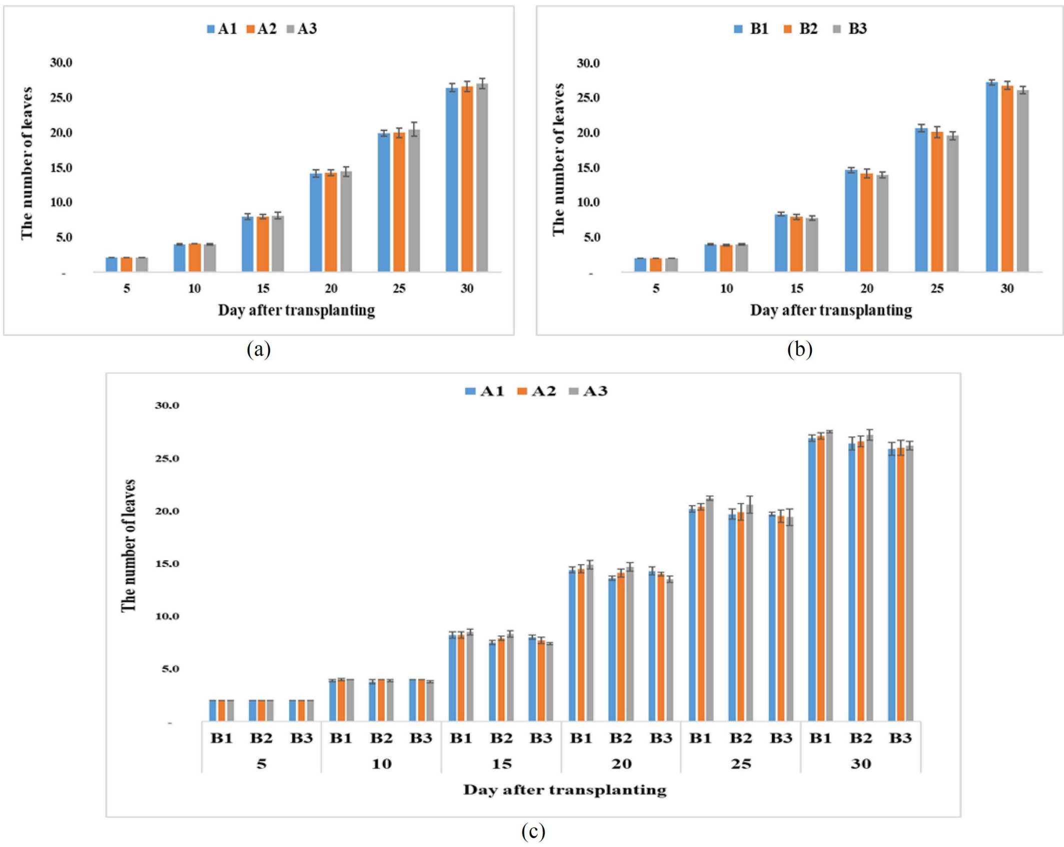


Figure 1. Average and standard deviation of leave number under effecting of TDS and pH. (a) Effect of TDS on number of leaves; (b) Effect of pH on number of leaves; (c) The interaction between factors "TDS" and "pH" affects the number of leaves

Plant height increased during the experiment.

Regarding TDS, from 5 days to 20 days after transplanting in the aeroponic system, the plant height did not have a significant difference ($p > 0.05$). Plant heights range from 4.89–5.82 cm, 8.87–8.93 cm, 16.64–16.96 cm and 25.45–26.13 cm, respectively (Fig. 2a). However, from 25 days to 30 days after transplanting, there was a significant difference in plant height (Fig. 2a). At 30 days after transplanting, A3 (43.66 ± 1.85 cm) was significantly different from A1 (41.56 ± 1.22 cm) ($p = 0.0021$).

Regarding pH, from 5 days to 25 days after transplanting in the aeroponic system, plant height in B1 had a significant difference compared to B2 and B3 ($p < 0.001$) (Fig. 2b). At 30 days after transplanting, B1 (43.35 ± 1.70 cm) had a significant difference compared to B3 (41.57 ± 1.34 cm) ($p = 0.0068$).

Analysis results showed interaction between factors "TDS" and "pH" was from 10 days to 20 days after transplanting, with differences between pairs ($p < 0.05$). However, from 25 days to 30 days after transplanting, there was no interaction between factors "TDS" and "pH" affecting the height development of spinach ($p > 0.05$). At the 30 day after transplanting, treatment A3B1 (44.82 ± 1.61 cm) had higher plant height than other treatments (Fig. 2c).

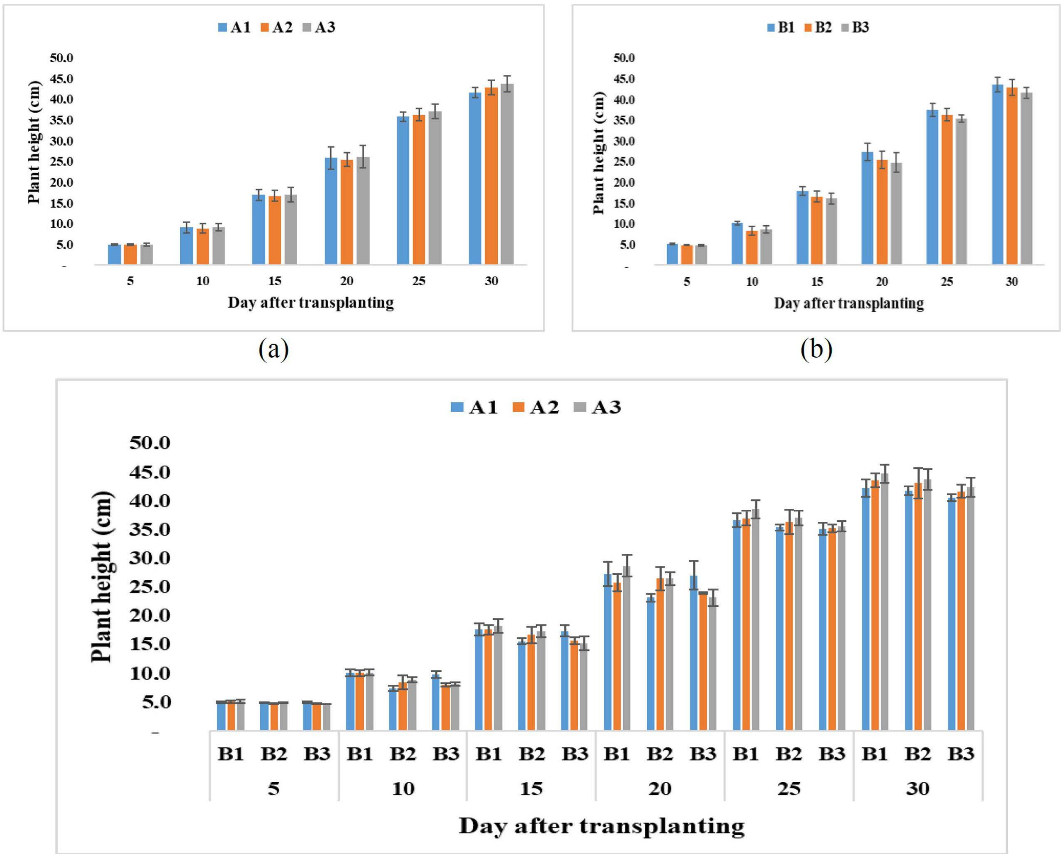


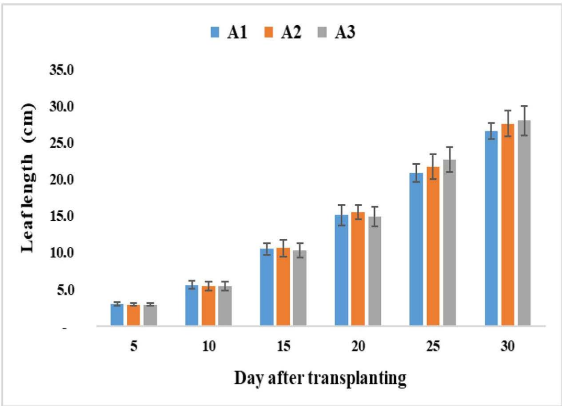
Figure 2. Average and standard deviation of height development of spinach under effecting of TDS and pH. (a) Effect of TDS on plant height; (b) Effect of pH on plant height; (c) The interaction between factors "TDS" and "pH" affects the plant height

Leaf size increased with each stage of growth and development of spinach. Leaf size included leaf length and width. Leaf length is clearly shown in Figure 3.

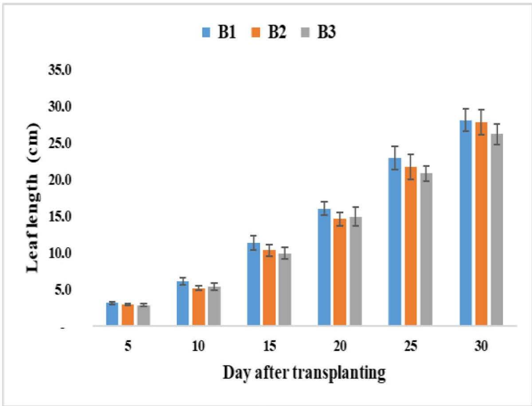
Regarding TDS, at the fifth day after transplanting in the aeroponic system, A1 (3.01 ± 0.18 cm) had a significant difference compared to A2 (2.85 ± 0.19 cm) ($p = 0.0389$). From 10 days to 20 days after transplanting, there was no significant difference, leaf length ranged from 5.41–5.62 cm, 10.29–10.63 cm and 14.89–15.49 cm, respectively ($p > 0.05$). From 25 days to 30 days after transplanting, leaf length increased rapidly and there was a significant difference ($p < 0.05$). At 30 days after transplanting, A3 (28.00 ± 2.00 cm) had a significant difference compared to A1 (26.5 ± 1.10 cm) (Fig. 3a).

Regarding pH, from 5 days to 30 days after transplanting, leaf length increased and there was a significant difference ($p < 0.01$). At the 30 day after transplanting, B1 (28.14 ± 1.50 cm) and B2 (27.85 ± 1.65 cm) had significant differences compared to B3 (26.21 ± 1.42 cm) (Fig. 3b).

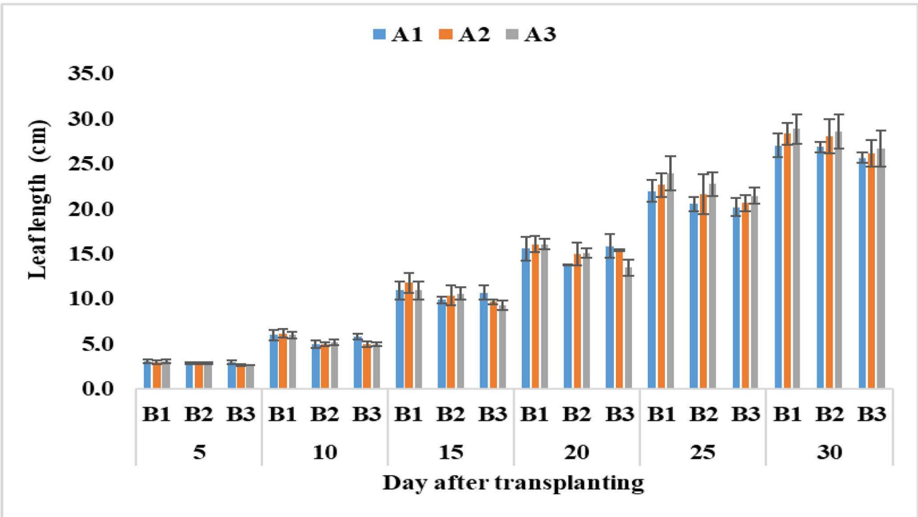
Analysis results showed that interaction between factors "TDS" and "pH" was from 10 days to 20 days after transplanting, with differences between pairs ($p < 0.05$). However, from 25 days to 30 days after transplanting, there was no interaction between the factors "TDS" and "pH" affecting the length development of spinach leaves ($p > 0.05$). At 30 days after transplanting, it was noticeable that A3B1 (28.86 ± 1.62 cm) had longer leaf length than other treatments (Fig. 3c).



(a)



(b)



(c)

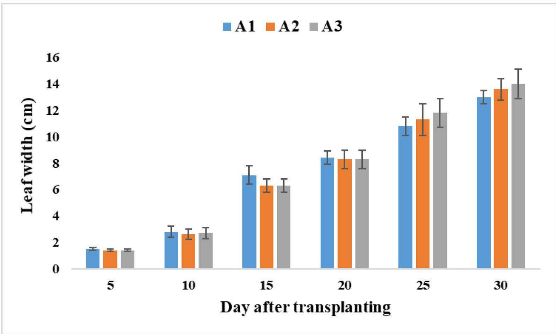
Figure 3. Average and standard deviation of the leave length development under the effecting of TDS and pH. (a) Effect of TDS on leaf length; (b) Effect of pH on leaf length; (c) The interaction between factors "TDS" and "pH" affects the length leaf

For leaf width, the results are recorded in Figure 4.

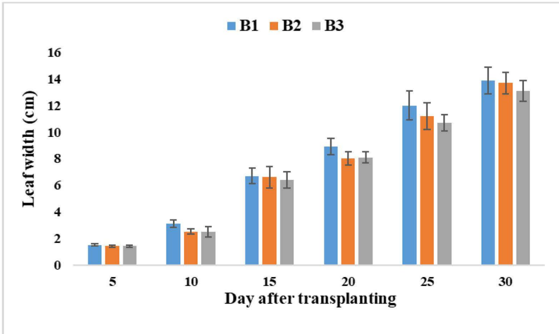
Regarding TDS, from 5 days to 20 days after transplanting, no significant difference was noted, leaf width increased and ranged from 1.45–1.49 cm, 2.65–2.81 cm, 6.37–6.69 cm, 8.25–8.35 cm, respectively ($p > 0.05$). From 25 days to 30 days after transplanting, having significant difference was recorded ($p < 0.05$). At 30 days after planting, A3 (14.03 ± 1.10 cm) had a significant difference compared to A1 (13.03 ± 0.51 cm) (Fig. 4a).

Regarding pH, from 5 days to 30 days after transplanting, leaf width increased and there was a significant difference ($p < 0.05$). At 30 days after transplanting, B1 (13.87 ± 1.04 cm) had a significant difference compared to B3 (13.09 ± 0.67 cm) (Fig. 4b).

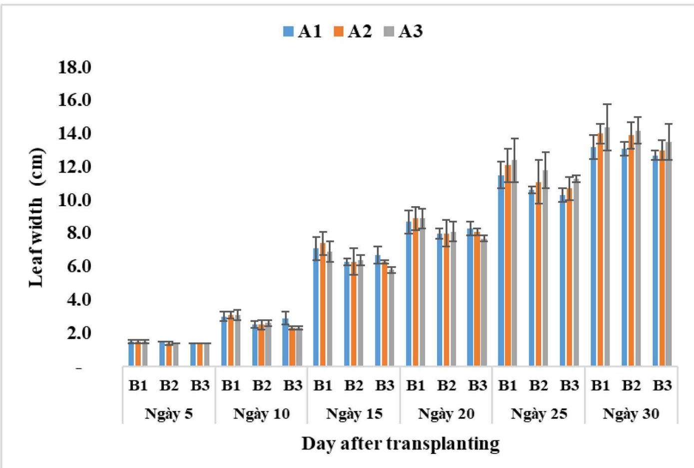
Analysis results showed that interaction between the factors "TDS" and "pH" only occurred 10 days after implantation, with differences between pairs ($p < 0.001$). In the remaining stages, no interaction was recorded between factors "TDS" and "pH" ($p > 0.05$). At 30 days after transplanting, it was noticeable that A3B1 (14.40 ± 1.37cm) had a leaf width wider than other treatments (Fig. 4c).



(a)



(b)



(c)

Figure 4. Effect of TDS and pH on width development of spinach leaf. (a) Effect of TDS on leaf width; (b) Effect of pH on leaf width; (c) The interaction between factors "TDS" and "pH" affects the leaf width

Results in Table 4 show the root length of spinach, regarding TDS in A3 was significantly different from A1 (p: 0.0146). Regarding pH, the root length in B1 and B2 had a significant difference compared to B3 ($p < 0.001$).

There is no interaction between the factors "TDS" and "pH" affecting the growth of spinach roots ($p > 0.05$). In treatment A3B1 (87.42 ± 4.33 cm), plant roots developed better than other treatments (Fig. 5).

Table 4. Effect of TDS and pH on roots development of spinach

pH (B)	TDS (A)			Average B
	A1 (1,000 ppm)	A2 (1,200 ppm)	A3 (1,400 ppm)	
B1 (6.0)	81.92	83.34	87.42	84.23^{A}
B2 (6.5)	79.20	82.50	82.78	81.49^{A}
B3 (7.0)	75.54	77.18	78.58	77.10^{B}
Average A	78.89^{B}	81.01^{AB}	82.93^{A}	
CV(%) = 5.88; $F_A = 4.75^{*}$; $F_B = 15.04^{***}$; $F_{AB} = 0.42^{ns}$; $LSD_{0.05(A)} = LSD_{0.05(B)} = 2.66$; $LSD_{0.05(A\times B)} = 4.61$				

Notes: LSD has 95% reliability, respectively, mean with the same letters is not different by the Duncan test. *,*** significant at 5, 1% level, ns: non-significant.

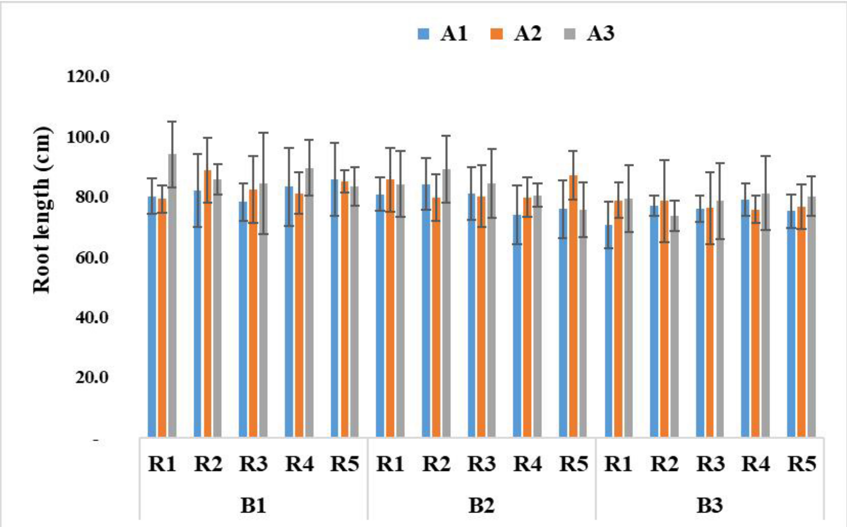


Figure 5. The interaction between factors “TDS” and “pH” affects the root length of spinach

A B

Figure 6. Effect of TDS and pH on the growth of spinach (*Spinacia oleracea* L.) in aeroponic system. A-TDS from left to right 1,000 ppm; 1,200 ppm; 1,400 ppm; B-pH from left to right 6.0, 6.5, 7.0

From the above analysis results, spinach grew well in aeroponics systems with TDS at 1,200–1,400 ppm and pH at 6–6.5 (Fig. 6). Analysis results showed that interaction between factors "TDS" and "pH" was from 10 days to 20 days after transplanting, with differences between pairs. However, there was no interaction between factors "TDS" and "pH" from 25 days to 30 days after transplanting. Treatment results at the 30 day after transplanting showed: that TDS at A3 (1,400 ppm) and pH at B1 (6.0) resulted in a total number of leaves (27.50 ± 0.14 leaves/plant), Plant height (44.82 ± 1.16 cm), leaf length (28.86 ± 1.62 cm), leaf width (14.40 ± 1.37 cm), root length (87.42 ± 4.33 cm) were higher than the other treatments.

Effect of TDS and pH on the yield of spinach in an aeroponic system

The fresh weight of the plant includes the total weight of the stem and leaves of the plant when harvested. The total number of leaves on the plant, plant height and leaf size plays an important role in determining plant productivity.

Plant fresh weight shown in Table 5, regarding TDS in A3 was significantly different from A1 (p: 0.0073). Regarding pH, there was a difference in plant fresh weight, B1 was significantly different from B3 (p: 0.0031). The analysis results did not record the interaction between factors "TDS" and "pH" on the fresh weight of spinach plants ($p > 0.05$). In treatment A3B1, plant weight was 97.42 ± 7.56 g/plant, this result is a higher weight compared to the remaining treatments in the experiment.

After harvest, results of yield analysis of spinach in Table 5, regarding TDS, there was no difference between A2 and A3, but A3 had a significant different compared to B1 (p: 0.0009). Regarding pH, there was no difference between B1 and B2, but B1 has a significant different compared to B3 (p: 0.0031). Statistical analysis results did not record the interaction between factors "TDS" and "pH" on spinach yield in aeroponics systems ($p > 0.05$). Treatment A3B1 (4.24 ± 0.29 kg/m^2) was the highest yield in the experiment.

Table 5. Effect of total dissolved solids and pH on plant fresh weight and yield of spinach

Plant fresh weight (g)				
pH (B)	TDS (A)			Average B
	A1 (1,000 ppm)	A2 (1,200 ppm)	A3 (1,400 ppm)	
B1 (6.0)	88.36	93.64	97.42	93.14^a
B2 (6.5)	84.58	89.20	93.96	89.25^{ab}
B3 (7.0)	83.90	85.70	88.70	86.10^b
Average A	85.61^b	89.51^{ab}	93.36^a	
CV(%)=7.62; F_A=6.83**; F_B =5.66**; F_{AB}=0.27^{ns}; $LSD_{0.05(A)=}$ $LSD_{0.05(B)}$= 4.25; $LSD_{0.05(A\times B)}$ = 7.36				

Yield (kg/m^2)				
pH (B)	TDS (A)			Average B
	A1 (1,000 ppm)	A2 (1,200 ppm)	A3 (1,400 ppm)	
B1 (6.0)	3.86	4.08	4.24	4.06^a
B2 (6.5)	3.68	3,92	4,14	3.91^{ab}
B3 (7.0)	3.62	3,70	3,88	3.73^b
Average A	3.72^b	3.90^{ab}	4.09^a	
CV(%) = 7.51; F_A=8.46***; F_B = 6.79**; F_{AB} = 0.32^{ns}; $LSD_{0.05(A)}$ = $LSD_{0.05(B)}$= 0.18; $LSD_{0.05(AxB)}$ = 0.31				

Notes: LSD has 95% reliability, respectively, mean with the same letters is not different by the Duncan test. **, *** significant at 1, 0.1 % level, ns: non-significant.

The concentration of dissolved substances in the growing solution directly affects the ability of the plant to absorb substances. This is the basis for adjusting and supplementing nutrients to suit the growth and development of the plant. The good pH of the nutrient solution is neutral pH (Kim et al., 2005). In aeroponic conditions, the optimal pH value was from 5.5 to 6.5 (Chadirin et al., 2007; Hang et al., 2023). Regularly measure the nutrient concentration and pH in nutrient solution so that plants grow and develop well (Lakhiar et al., 2018). Root zone aeration in hydroponics helped support plant productivity by allowing roots to be exposed to oxygen. Reduced oxygen in the root zone reduces productivity, growth rate, mineral and water absorption. Aeroponic systems helped roots access oxygen available in the root zone, hence, improving crop productivity (Soffer et al., 1991; Nichols et al., 2002; Gopinath et al., 2017; Eldridge et al., 2020).

CONCLUSION

The results showed that spinach (*S. oleracea*) grew and developed well in the aeroponic system with total dissolved solids at 1,200–1,400 ppm and pH at 6–6.5. However, analysis results showed that interaction between factors "TDS" and "pH" was from 10 days to 20 days after transplanting, with differences between pairs. The experiment of total dissolved solids at 1,400 ppm and pH at 6.0 showed a better effect than other treatments. Our result can provide the appropriate level of total dissolved solids and pH helped to better understand the growth and development process of spinach on aeroponic systems. Thereby, it was possible to improve the fresh weight of plants and the yield of spinach, bringing economic efficiency to farmers.

REFERENCES

Bradley F. M., Ellis B. W., Martin D. L. eds., 2009. The Organic gardener's handbook of natural pest and disease Control. Rodale. ISBN 978-1-60529-677-7.

Butler J. D., Oebker N. F., 2006. Hydroponics as a Hobby - Growing plants without soil. Circular 844. Information Office, College of Agriculture, University of Illinois, Urbana, IL 61801.

Chadirin Y., Matsuoka T., Suhardiyanto H., Susila A. D., 2007. Application of deep sea water (DSW) for nutrient supplement in hydroponics cultivation of tomato: effect of supplemented DSW at different EC levels on fruit properties. *Jurnal Agronomi Indonesia (Indonesian Journal of Agronomy)*, 35(2).

Eldridge B. M., Manzoni L. R., Graham C. A., Rodgers B., Farmer J. R., Dodd A. N., 2020. Getting to the roots of aeroponic indoor farming. *New Phytologist*, 228(4): 1183–1192.

Gopinath P., Vethamoni P. I., Gomathi M., 2017. Aeroponics soilless cultivation system for vegetable crops. *Chemical Science Review and Letters*, 6: 838–849.

Nguyen T. N. H., Nguyen T. P., Tran T. T., 2023. Effect of organic fish and inorganic fertilizers on the growth and yield of lettuce "Batavia" in aeroponic system. *South Asian Journal of Agricultural Sciences*, 3(1): 140–144

He J., Qin L., Lee S. K., 2013. Root-zone CO_2 and root-zone temperature effects on photosynthesis and nitrogen metabolism of aeroponically grown lettuce (*Lactuca sativa* L.) in the tropics. Photosynthetica, 51(3): 330–340.

Wahocho N. A., Memon N., Kandhro M. N., Miano T. F., Talpur K. H., Wahocho S. A., 2016. Response of nitrogen on the growth and productivity of spinach (*Spinacia oleracea* L). *Sindh University Research Journal-SURJ (Science Series)*, 48(2).

Kim H. K. H., Cho Y. S. C. Y., Kwon O. K., Cho M. W., Hwang J., Bae S. D. B. S., Jeon W. T. J W., 2005. Effect of pH and EC of hydroponic solution on the growth of greenhouse rose. *Asian Journal of Plant Sciences*, 4(4): 348–355.

Lakhiar I. A., Gao J., Syed T. N., Chandio F. A., Buttar N. A., 2018. Modern plant cultivation technologies in agriculture under controlled environment: A review on aeroponics. *Journal of Plant Interactions*, 13(1): 338–352.

Akon M. R., 2019. The influence of nutrient solution pH on growth and yield of strawberry plants grown in aeroponic system. *Journal of the Bangladesh Society for Agricultural Science and Technology*, 16(1–4): 23–8.

Morelock T. E., Correll J. C., 2008. Spinach. In Vegetables I: Asteraceae, brassicaceae, chenopodicaceae, and cucurbitaceae (pp. 189–218). New York, NY: Springer New York.

Murcia M. A., Jiménez-Monreal A. M., Gonzalez J., Martínez-Tomé M., 2020. Spinach. In Nutritional Composition and Antioxidant Properties of Fruits and Vegetables (pp. 181–195). Academic Press

Nichols M. A., Woolley D. J., Christie C. B., 2002. Effect of oxygen and carbon dioxide concentration in the root zone on the growth of vegetables. *Acta Horticulturae*, 578: 119–122.

Oztekin G. B., Uludag T., Tuzel Y., 2018. Growing spinach (Spinacia oleracea L.) in a floating system with different concentrations of nutrient solution. *Applied Ecology and Environmental Research*, 16(3): 3333–3350.

Raviv M., Lieth J. H., Bar-Tal A., 2008. Significance of soilless culture in agriculture. *Soilless Culture*, 1-11.

Soffer H., Burger D. W., Lieth H., 1991. Plant growth and development of Crysanthemum and Ficus in aero-hydroponics: response to low dissolved oxygen concentrations. *Scientia Horticulturae*, 45: 287–294.