

Research Article

Effect of pH Upper Control Limit on Nutrient Solution Component and Water Spinach Growth under Hydroponics

^{1,2}Lichun Wang, ³Xuzhang Xue, ^{2,3}Yinkun Li, ⁴Feng Li, ³Fang Zhang and ^{2,3}Wenzhong Guo

¹Beijing Research Center of Information Technology for Agriculture,

²Key Laboratory of Urban Agriculture (North) Ministry of Agriculture,

³Beijing Research Center of Intelligent Equipment for Agriculture, Beijing,

⁴Ningxia Academy of Agriculture and Forestry Sciences, Yinchuan, China

Abstract: In this study, experiment with four levels of nutrient solution pH control upper limit was conducted to explore the optimal nutrient solution pH management scheme under hydroponics by evaluating the nutrient solution characters i.e., pH, Electric Conductivity (EC), nitrate, soluble phosphorus (soluble-P), water spinach growth and quality. The results showed that the nutrient solution pH was 8.2 and unsuitable for water spinach growth under the treatment with no pH regulation during the experimental period. The pH could be maintained within a reasonable range for water spinach growth by adding nitric acid to nutrient solution. Meanwhile, the availability of cations and soluble-P were improved. The water/nutrition uptake was also promoted. Through nutrient solution pH control, the plant height, leaf number and fresh/dry shoot weight increased by 34.66-55.70%, 12.42-13.66%, 39.18-101.72% and 13.78-74.03%, respectively. It indicated that pH regulation could improve water spinach growth, promote allocation of photosynthetic product to shoot and increase the effective yield. The nitrate content of water spinach shoot increased, but which was lower than the critical value of 3000 mg/kg FW. Vitamin C content decreased under the treatment which 6.5 of pH control upper limit was set. There were no significant differences in soluble sugar and crude protein content among the four treatments. Considering the yield and quality of water spinach, the suitable nutrient solution pH control upper limit was 7.0.

Keywords: Hydroponics, nutrient solution, pH control upper limit, quality, water spinach, yield

INTRODUCTION

Hydroponics is a novel technology which has developed rapidly recent years (Zhao and Li, 2001). The nutrient solution composition can be adjusted to create a reasonable nutrient environment for crop yield and quality improving under hydroponics (Caruso *et al.*, 2011). There is no doubt that hydroponics overcomes the problems of soil acidification, salinification and soilborne diseases under protection culture (Bradley and Marulanda, 2000; Sheikh, 2006).

There are six macronutrients i.e., N, P, K, Ca, Mg and S contained in commonly used nutrient solution under hydroponics (Pardossi *et al.*, 2002). As we know, the amount of N, P and K absorbed by plant is more than that of Ca, Mg and S. Therefore, the nutrient balance of culture solution will be off under close-loop hydroponics, which the nutrient solution is reused. In most cases, the nutrient solution pH rises due to unbalanced ion uptake by plant (Spinu *et al.*, 1997).

Nutrient solution pH is one of the most important factors for crop growth under hydroponics. The

availability of soluble phosphorus (soluble-P) and cations in nutrient solution decrease with the rising of nutrient solution pH (Savvas and Adamidis, 1999; Meric *et al.*, 2011). In general, the suitable range of nutrient solution pH for plant growth is 5.5-6.5 (Webb, 1993; Ko *et al.*, 2013). Therefore, the nutrient solution pH should be adjusted by adding nitric acid to nutrient solution in closed-loop hydroponic system (Morales and Urrestarazu, 2013). Meanwhile, the nitrate is added to nutrient solution with nitric acid. One hand, nitrate is important nutrient for plant growth. On the other hand, excessive application of nitrate results quality deterioration due to nitrate accumulation. It is important to strike the balance between reasonable pH range for vegetable yield and safe quality under hydroponics. In this study, the nutrient solution pH/EC and water spinach yield/quality were investigated to explore the reasonable pH control upper limit under hydroponics. It would provide theoretical basis for making optimal nutrient solution pH management schedule under hydroponics.

Corresponding Author: Wenzhong Guo, Key Laboratory of Urban Agriculture (North) Ministry of Agriculture, Beijing, China

This work is licensed under a Creative Commons Attribution 4.0 International License (URL: <http://creativecommons.org/licenses/by/4.0/>)

MATERIALS AND METHODS

Experimental designing: The experiment was conducted from October 8 to November 15, 2013. The experimental area is located at National Experimental Station for Precision Agriculture, Changping District Beijing, China (40°11'N, 116°26'E).

Before sowing, the water spinach (*Ipomoea aquatica* Forsk cv. bamboo leaf) seeds were surface sterilized with 0.1% g/g K_2MnSO_4 solution for 0.5 h, then washed with deionized water for 3 changes and soaked in saturate $CaSO_4$ solution for 4 h. Seeds were placed on moist filter paper and germinated in darkness for 48 h at a constant temperature of 25°C. On Oct 10, 2013, the seeds were planted in sponge cubes (2.0 cm×2.0 cm×2.0 cm) and irrigated with nutrient solution, which contained (mg/cm³): NO_3^- -N, 0.042; SO_4^{2-} -S, 0.032; $H_2PO_4^{2-}$ -P, 0.031; Mg^{2+} , 0.024; K^+ , 0.078; Ca^{2+} , 0.02. Microelements contained in the nutrient solution were (mg/m³): Cu, 20; Zn, 50; Mn, 500; B, 500; Fe, 2800; Mo, 10.

On Oct 18, 2013, water spinach seedlings were transferred into NFT hydroponic systems. Each system was composed of a polyfoam channel (500 cm length×50 cm width×12 cm depth), a 2 m³/h of recycling pump and a 80 L of nutrient solution tank. Each channel was covered with five polyfoam boards (1 m in length), in which 20 holes (3 cm in diameter) had been bored symmetrically. One water spinach seedling was planted in each hole of the polyfoam boards and fixed with a sponge strip. 100 seedlings were planted in each hydroponic system. The recycling pump opened frequency was 15 min/h. The volume of nutrient solution in hydroponic system was added to 80 L, when half of that was consumed by water spinach.

In this study, four treatments were set based on the different nutrient solution pH control upper limit i.e., 6.5, 7.0, 7.5 and a control treatment with no pH regulation, which were denoted as treatments T1, T2, T3 and T4, respectively. The nutrient solution pH was modified within the range of pH control upper limit by injecting nitric acid to nutrient solution by an irrigation method (Yang *et al.*, 2012), when it rose to the upper limit of different treatments.

Measurements of nutrient solution characteristics:

In order to assess the influence of pH control upper limit on nutrient solution characteristics, 40 mL of nutrient solution was sampled from every treatment in 2 days interval. The nutrient solution pH was measured with a pH portable acidity meter (Beijing Hangtian Computer Co, China). The Electric Conductivity (EC) was determined with a DDS-307 electric conductivity meter (Shanghai Precision and Scientific Instrument Inc., Shanghai, China). The NO_3^- concentration of nutrient solution was monitored with an ion selective electrode PNO₃-1 (Shanghai Dianguang

Device Factory, Shanghai). Soluble-P concentration was determined by vanadomolybdophoric acid colorimetric method at 460 nm using a spectrophotometer 752 (Shanghai Spectrum Instruments, China).

Plant yield measurements: At harvest, 3 water spinach plants for each treatment were selected randomly to determine plant height, leaf number and shoot/root fresh weight. After that, the shoot/root dry weights were determined by drying for 48 h to a constant weight at 75°C.

Quality determination: To estimate water spinach quality under various treatments, four quality indexes were determined. At harvesting time, fresh water spinach shoots were chopped and mixed in lab for quality measurements. Contents of vitamin C, soluble sugar and crude proteins were determined in methods of 2, 6-dichloro-indophenol titration; anthrone ethyl acetate colorimetric and coomassie brilliant blue G250 dye binding, respectively. Finally, nitrate content was measured according to salicylic acid method.

Statistical analysis: The data of water spinach yield and quality was evaluated using SPSS 19.0 to determine any statistically significant differences at the 0.05 significance level by Duncan's test.

RESULTS AND DISCUSSION

The effect pH control upper limit on nutrient solution characteristics:

The change of nutrient solution pH under various treatments: As shown in Fig. 1, the pH stability reduced with the decreasing of pH control upper limit. The most stable nutrient solution pH dynamic was obtained under treatment T4. However, the nutrient solution pH was about 8.2 during the experimental period, which was higher than the suitable range for plant growth (Meric *et al.*, 2011; Savvas and Adamidis, 1999). There were smaller amplitudes of nutrient solution pH change from 4 to 12 DAP. With the growth of water spinach, significantly differences were shown among the four treatments. This could be due to more water and nutrient absorbed by water spinach during the later experimental period.

The change of nutrient solution EC under various treatments:

As shown in Fig. 2, similar trends were found in the nutrient solution EC fluctuation among four treatments. However, some difference was shown among them. The nutrient solution EC under treatment T4 was lower than the other three treatments. This may be due to no nitric acid injected into the nutrient solution and then the available of soluble-P and cations were influenced because of high pH (Meric *et al.*, 2011; Savvas and Adamidis, 1999). The highest nutrient

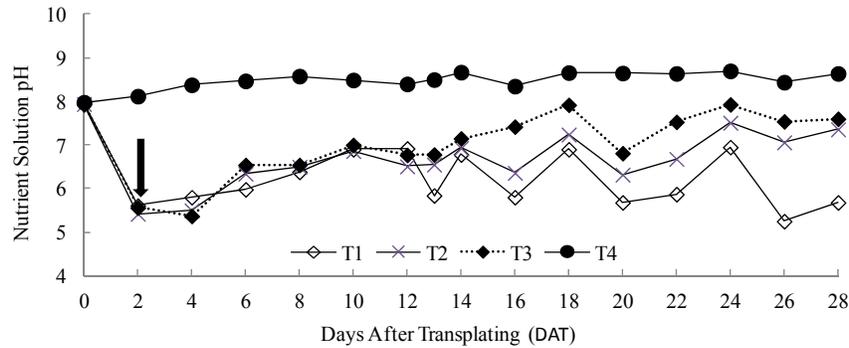


Fig. 1: The variation of nutrient solution pH for each treatment (Arrow represents first time of nutrient solution pH adjusting)

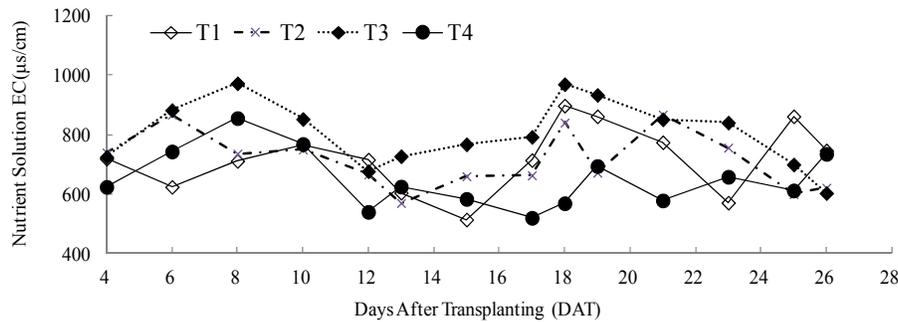


Fig. 2: The variation of nutrient solution EC for each treatment

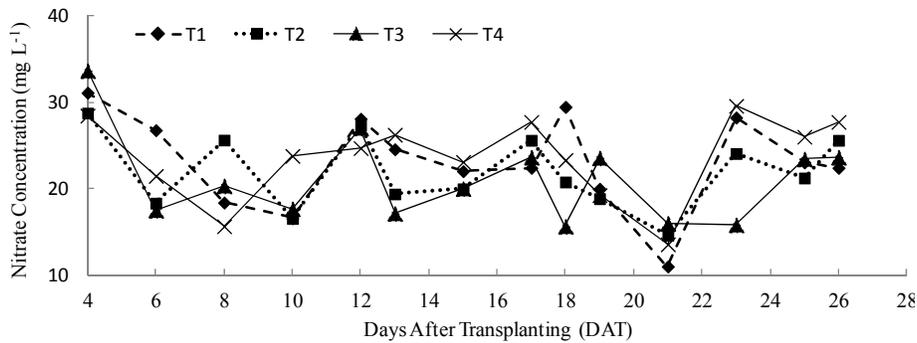


Fig. 3: The variation of nitrate concentration of nutrient solution for each treatment

solution EC was obtained under treatment T3 and followed by treatments T1 and T2, respectively. It indicated that spinach nutrient uptake was promoted by nutrient solution pH adjustment.

The change of nutrient solution NO_3^- -N concentration under various treatments: As shown in Fig. 3, the change of nutrient solution NO_3^- -N concentration had a similar trend and lower than that of original nutrient solution under four treatments during the experimental period. The fluctuation of NO_3^- -N concentration was caused by nutrient solution supplement and pH adjustment with nitric acid. Compared with treatments T1, T2 and T3, the nutrient

solution NO_3^- -N concentration was slightly higher under treatment T4, which no nitric acid was added. It indicated that nitrate uptake was inhibited under high nutrient solution pH condition.

The change of nutrient solution soluble-P concentration under various treatments: As shown in Fig. 4, the nutrient solution soluble-P concentration under treatment T4 was lower than the other three treatments, because the availability of nutrient solution soluble-P was influenced by high nutrient solution pH (Fig. 1). The soluble-P concentration of original nutrient solution was a little high and exceeded the demand of water spinach. Therefore, it increased with the growth of water spinach.

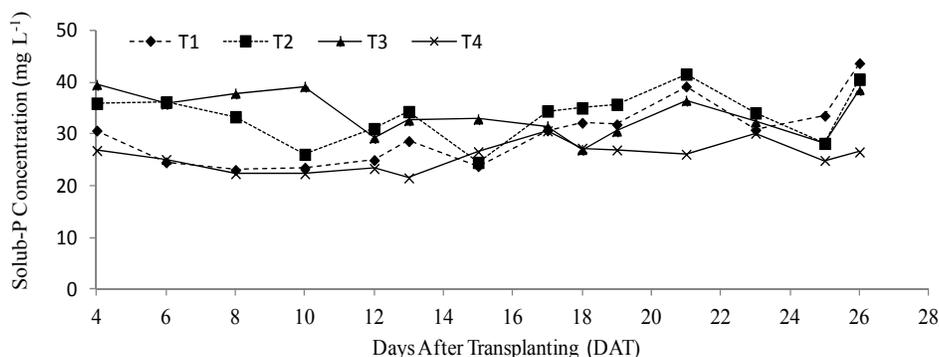


Fig. 4: The variation of soluble-P concentration of nutrient solution for each treatment

Table 1: Effect of different nutrient solution pH control upper limit on growth and yield of water spinach

Treatment	Plant height (cm)	Fresh Weight (g)		Dry Weight (g)		Leaf number	Root: Shoot Ratio
		Shoot	Root	Shoot	Root		
T1	39.44b	67.78b	26.10a	4.88b	2.39a	60.67ab	0.39a
T2	36.78b	73.95b	30.69a	5.43b	2.50a	60.33ab	0.42a
T3	34.11b	51.02a	23.99a	3.55a	2.24a	61.00b	0.47b
T4	25.33a	36.66a	24.28a	3.12a	2.20a	44.61a	0.66c

Table 2: Effect of nutrient solution pH control upper limit on quality of water spinach

Treatment	Vitamin C mg/kg FW	Nitrate mg/kg FW	Soluble sugar Mg/kg FW	Crude protein Mg/kg FW
T1	273.67ab	416.47a	7.89a	1.87a
T2	243.33a	601.62c	6.90a	2.10a
T3	284.33ab	579.88bc	7.15a	1.93a
T4	265.67c	566.59b	7.13a	2.00a

The effect of different pH control upper limit on water spinach yield and quality:

The water spinach yield under various treatments:

As shown in Table 1, the shoot growth of water spinach was significantly influenced by nutrient solution pH control upper limit. However, there was no obvious difference in the root growth of water spinach among the four treatments. The water spinach plant height, shoot fresh/dry weight and leaf number under treatment T4 were lower than those under treatments T1, T2 and T3. The water spinach shoot fresh weight under treatment T4 was 36.66 g, which was 84.89, 101.72 and 39.18%, respectively lower than that under treatments T1, T2 and T3, respectively. The water spinach leaf number under treatment T4 was 44.6, which was 13.04%, 12.42% and 13.66% lower than that under treatments T1, T2 and T3, respectively. The root: shoot ratio under treatment T4 was 0.66, significantly higher than that the other three treatments. It indicated that water spinach nitrate uptake was restrained by high nutrient solution pH (Fig. 3) and then the shoot growth of water spinach was influenced. The maximum water spinach yield was obtained under treatment T2.

The water spinach quality under various treatments:

As shown in Table 2, there was no significant difference in water spinach shoot soluble sugar and crude protein content among the four treatments. However, water spinach shoot vitamin C and nitrate content were obviously influenced by

nutrient solution pH regulation. Compared with treatment T4, the water spinach shoot nitrate content increased when nitric acid was added to nutrient solution to adjust the pH for the other three treatments. Especially under treatment T1, the nitrate content in water spinach shoot was 44.46% higher than that under treatment T4. However, it didn't exceed the limit of 3000 mg/kg (Du *et al.*, 2010). The lowest vitamin C content was obtained under treatment T2. There was no significant difference of shoot vitamin C content under the other three treatments. It indicated that low level of nutrient solution pH control upper limit was made against of quality improvement due to nitrate accumulation and vitamin C decrease in water spinach shoot.

CONCLUSION

- The nutrient solution pH increased due to the unbalanced absorption of nutrient by water spinach. The pH controlling was in favor of improving the nutrient availability and balancing pH/EC of nutrient solution. The nitrate uptake was also promoted by nutrient solution pH management.
- The water spinach shoot growth indexes i.e., leaf number, plant height and shoot fresh/dry weight were promoted by nutrient solution pH regulation. There was no obvious effect on water spinach root growth. Besides improving the water spinach

growth, nutrient solution control promoted allocation of photosynthetic product to shoot and increased the effective yield.

- The nitric acid was added to the nutrient solution with pH management, which led to an increase of nitrate content in water spinach shoot. However, it didn't exceed the upper limit of 3000 mg/kg. The vitamin C content decreased remarkably under the treatment with pH control upper limit of 6.5. There were no obvious difference on soluble sugar and crude protein content under various treatments under hydroponics.
- Under the treatment with pH upper control limit of 7.0, the change of nutrient solution pH/EC was relative stable. Highest yield of water spinach was obtained. The nitrate content could be controlled under a limit of 3000 mg/kg. There were no distinct change in vitamin C, soluble sugar and crude protein content compared with the control treatment. Therefore, the suitable nutrient solution pH control upper limit was 7.0.

ACKNOWLEDGMENT

This study was supported by the Natural Science Foundation of Beijing (6144022), Youth Foundation of Beijing Academy of Agriculture and Forestry Sciences (QNJJ201421) and the Technology Innovation Ability Construction Projects, Beijing Academy of Agriculture and Forestry Sciences (KJCX20140415).

REFERENCES

- Bradley, P. and C. Marulanda, 2000. Simplified hydroponics to reduce global hunger. *Acta Hort.*, 554: 289-295.
- Caruso, G., G. Villari, G. Melchionna and S. Conti, 2011. Effects of cultural cycles and nutrient solutions on plant growth, yield and fruit quality of alpine strawberry (*Fragaria vesca* L.) grown in hydroponics. *Sci. Hortic-Amsterdam*, 129(3): 479-485.
- Du, S., C. Jin and Y. Zhang, 2010. Current situations and research progress of nitrate pollution in vegetables and their regulating strategies. *Sci. Agric. Sin.*, 43(17): 3580-3589. (In Chinese)
- Ko, M.T., T.I. Ahn, Y.Y. Cho and J.E. Son, 2013. Uptake of nutrients and water by paprika (*Capsicum annuum* L.) as affected by renewal period of recycled nutrient solution in closed soilless culture. *Hortic. Environ. Biotechnol.*, 54(5): 412-421.
- Meric, M.K., I.H. Tuzel, Y. Tuzel and G.B. Oztekin, 2011. Effects of nutrition systems and irrigation programs on tomato in soilless culture. *Agr. Water Manage.*, 99(1): 19-25.
- Morales, I. and M. Urrestarazu, 2013. Effect of a passive mixing device on the electrical conductivity and pH values of a nutrient solution. *J. Irrig. Drain. E-ACSE*, 140(4): 1-4.
- Pardossi, A., F. Malorgio, L. Incrocci, C.A. Campiotti and F. Tognoni, 2002. A comparison between two methods to control nutrient delivery to greenhouse melons grown in recirculating nutrient solution culture. *Sci. Hortic-Amsterdam*, 92(2): 89-95.
- Savvas, D. and K. Adamidis, 1999. Automated management of nutrient solutions based on target electrical conductivity, pH and nutrient concentration ratios. *J. Plant Nutr.*, 22(9): 1415-1432.
- Sheikh, B.A., 2006. Hydroponics: Key to sustain agriculture in water stressed and urban environment. *Pak. J. Agric. Agril. Eng. Vet. Sci.*, 22(2): 53-57.
- Spinu, V.C., R.W. Langhans and L.D. Albright, 1997. Electrochemical pH control in hydroponic systems. II modelling plant growth. *Environ. Control Farm Manage. Protect. Cultivat.*, 456: 275-282.
- Webb, M.J., 1993. A multichannel pH controller for solution culture systems. *Plant Soil*, 155(1): 501-504.
- Yang, Q., L. Wei and W. Liu, 2012. *System and Practice of Plant Factory*. Chemical Industry Press, Beijing, pp: 18-38. (In Chinese)
- Zhao, S. and B. Li, 2001. Introduction to present status, development and new techniques of nutri-culture systems in Japan. *T. CSAE*, 17(4): 171-173. (In Chinese)