

## Supplemental Effects of Self-extracted Organic Nutrient Solution on the Growth and Yield of Water Spinach (*Ipomoea Aquatic F.*) in an Aquaponic System

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### Abstract

Aquaponics combines two technologies, recirculating aquaculture systems and hydroponics in a closed system. The nutrients recycled from fish tanks supply nutrients for vegetables grown in hydroponics, however in some cases, the nutrient levels may not be sufficient for the optimal growth and yield of plants. In this study, two experiments were conducted to understand the effects of supplemental organic nutrient solutions on plant growth and yield in climbing perch-water spinach aquaponics. Experiment 1 (Exp.1) was conducted to evaluate the effects of three types of leaf-based organic fertilizers on the growth and yield of water spinach, namely self-extracted organic nutrient solution (OE), and two popular commercial foliar organic fertilizers, Hydro Fulvic (OF1) and TCN HUME (OF2), with the dose of 1%. Exp.1 showed that supplementation with the self-extracted solution significantly increased the growth and yield of water spinach but did not change the quality of water spinach in terms of the Brix values and nitrate residue content compared to the control. However, the self-extracted solution showed less effectiveness than the two commercial fertilizers in this experiment. Therefore, we conducted experiment 2 (Exp.2) to determine the suitable concentration and potential use of this extract for water spinach in aquaponics. The results of Exp.2 indicated that the concentration of 2% was the most economical and effective to provide supplemental nutrients for water spinach in the climbing perch-water spinach system. The study suggests that self-extracted organic nutrient solutions can be effectively used for growing water spinach in aquaponic systems.

### Keywords

Aquaponics system, nutrient supplement, self-extracted organic nutrient solution, water spinach

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### Introduction

Aquaponics is a bio-integrated system that combines fish farming

with hydroponic vegetables by reusing wastewater, thereby improving water and nutrient use efficiency, and minimizing aquaculture waste to the surrounding environment (Nuwansi *et al.*, 2019; Yep & Zheng, 2019). The dissolved nutrients that are excreted by fish (fish manure, fish feed waste) are recovered by plants grown in hydroponics. Vegetables absorb the nutrients in the water from the fish tank, thereby purifying the water and improving the quality of the fish tank water that creates a closed system (Buzby & Lin, 2014). This system can give a higher yield (Jordan *et al.*, 2018) with 90% less water-use (Graber & Junge, 2009) than conventional soil-based farming systems and uses water more efficiently than conventional fish farming systems (Liang & Chien, 2015). In arid and semi-arid regions, the reuse of water in aquaponic units can achieve a remarkable water use efficiency of 95-99% (Dalsgaard *et al.*, 2013). Thus, this fish-vegetable farming system could be a sustainable solution to provide enough fish and vegetables as well as meet food and water shortages in many developing countries (Bosma *et al.*, 2017).

Two main questions arise from this system: how do vegetables grow in an aquaponic system and are the nutrients from fish tanks sufficient for plants? Plants need at least 16 macro-and micro-nutrients for growth and development (Somerville *et al.*, 2014). Plants grown in an aquaponic system receive nutrients through fish effluent water. It is estimated that many fish species only utilize up to 20-30% of the nitrogen in their diet (Schneider *et al.*, 2005). This means about 70-80% of the N supplied by the feed is excreted into the water, which can then be incorporated into plant tissues (Roosta & Hamidpour, 2011). Because fish and plants have different nutrient requirements, fish feed is not formulated to optimize plant growth and plants may experience deficiencies in key nutrients, especially calcium, potassium, and iron (Rakocy *et al.*, 2006; Somerville *et al.*, 2014). Studies comparing hydroponic and aquaponic plant production have indicated that many nutrients may be insufficient for plants in aquaponic systems with fish waste as the only nutrient source (Rakocy *et al.*, 2006; Roosta &

Hamidpour, 2011; Delaide, 2017). Bittsanszky *et al.* (2016) indicated that the nutrients provided by fish in the fish-vegetable system were lower than that of a conventional hydroponic system. Therefore, it is necessary to add nutrients according to the growth stages of the crops (Rakocy *et al.*, 1997). In this study, an experiment to determine the effects of nutrient supplements for vegetables (water spinach) grown in a fish-vegetable system was carried out. The use of a self-extracted organic nutrient solution from available plant and animal sources (Nguyen Thi Ngoc Dinh *et al.*, 2015; Nguyen Thi Ai Nghia, 2018) for providing additional nutrients for water spinach grown in an aquaponic system was also tested by evaluating the effects of this solution on the growth, yield, and quality of water spinach as well as economic efficiencies of the whole system.

## Materials and Methods

### Materials

To find out the effects of organic fertilizer supplements on water spinach in an aquaponic system, we compared three different leaf-based organic fertilizers (a self-extracted organic nutrient solution, and two other popular commercial organic fertilizers: Hydro Fulvic and TCN HUME fertilizers) in the first experiment (Exp.1). Then, the second experiment (Exp.2) was carried out to find out the appropriate concentration when using a self-extracted organic nutrient solution for water spinach. Both experiments were conducted in 2021 and we collected data during two harvesting times for Exp.1 and two growing seasons for Exp.2. The water spinach variety used in both experiments was the NN.105 variety originating from Thailand. This variety is easy to cultivate with small leaves and thin, hard stems, has drought and pest resistance, and can grow year-round. The water spinach seeds were sown in trays and uniform seedlings were transplanted to gravel hydroponic beds of an aquaponic system with a distance of 10cm between rows and 5cm between plants.

The organic fertilizer solutions were sprayed once a week after plant emergence. The

components of the organic fertilizers were as follows: the Hydro Fulvic fertilizer contained 30% organic matter, 15% fulvic acid, 1% humic acid, and 1.8% amino acids; and the TCN HUME fertilizer contained 18% of humic and fulvic acids, and the beneficial microorganisms including the nitrogen-fixing bacteria-*Paenibacillus polymyxa*, *Bacillus*, and *Trichoderma*. The self-extracted organic nutrient solution was extracted from different organic materials including vegetables, bananas, papaya, fish, and bones in 2021 by the methods of Cho & Koyama (1997) and contained N ( $134.4 \pm 4.50$  mg/100 mL), P<sub>2</sub>O<sub>5</sub> ( $59.21 \pm 6.50$  mg/100 mL), and K<sub>2</sub>O ( $1941.7 \pm 10.80$  mg/100 mL) (Nguyen Thi Ngoc Dinh *et al.*, 2015).

### Experimental methods

As mentioned above, to determine the supplemental effects of foliar organic fertilizer on the growth and yield of water spinach in an aquaponic system, we conducted two experiments:

Exp.1 consisted of four treatments, namely the control (no fertilizer supplement for plants) and three treatments supplemented with either the self-extracted organic nutrient solution (OE), Hydro Fulvic fertilizer (OF1), or TCN HUME fertilizer (OF2) with the doses of 1 mL/100 mL (1%).

Exp.2 was continued from the Exp.1 results that the self-extracted nutrient solution had positive effects on plant production in the aquaponic system however the effectiveness was lower than the two commercial foliar fertilizers. Therefore, Exp.2 was carried out with four treatments, namely the control (no fertilizer supplement for plant) and three treatments supplemented with the self-extracted nutrient solution (OE) at different concentrations of 1%, 2%, or 3% to confirm the potential use of this extract for aquaponic vegetable production and also determine which concentration is suitable for water spinach.

Exp.1 was conducted in the spring-summer season of 2021, and Exp.2 was conducted in the spring-summer season and summer season of 2021.

Both experiments were carried out in an aquaponic system with two parts: the tank for rearing fish with an area of 1.2m<sup>2</sup> and a water depth of 1m; and an upper tank for growing hydroponic vegetables with an area of 1.2m<sup>2</sup>. The experiments were arranged in a randomized complete block design (RCBD) with three replications. The experiments included three tanks, and each upper tank was divided into four portions, one for each treatment for growing vegetables. The system was placed outdoors at the experiment site of the Center of Organic Agriculture, Faculty of Agronomy, Vietnam National University of Agriculture, Hanoi, Vietnam. Each fish tank was stocked with 50 climbing perch fish (*Anabas testudineus*), which were obtained from the Aquaculture Faculty of Vietnam National University of Agriculture. Fish were fed at 9 am once daily with a commercial fish feed (Sakura Tropical Fish Food, SakuraGold), which contained 35% protein, at the rate of 1% of body weight for the first two months according to Yang & Kim (2020) and 3% from the third month according to the suggestion of the Aquaculture Faculty. Each fish water tank was aerated by an air pump.

### Measurements and calculations

The water quality parameters, namely pH and TDS (total dissolved solids - ppm) of the tank water, were measured every seven days using the pH HANNAHI 98107 and TDS HANNA HI 86302 machines, respectively.

The height and number of leaves were measured on five randomly selected plants in each replication every seven days. The plant height was measured from the bedding media of the container to the top of the main plant stem using a measuring tape. Each and every visible leaf on each plant was counted and recorded carefully each time.

SPAD was measured at the midpoint of the topmost fully expanded leaf using a SPAD-502 chlorophyll meter (Spectrum Technology, Inc., Aurora, IL, USA). The fresh biomass of plants was measured by cutting plants and weighing them using an electric balance.

Water spinach of all the treatments was harvested simultaneously when the height of the

plants was about 20-40cm. The plants were harvested in the early morning by cutting through the stem 2cm above the bedding media using a knife. During the harvesting time, plant weight was measured using an electric balance. The total yield of the two harvesting times was recorded in both experiments.

Five random plants were collected in each replication to measure the Brix values immediately after harvesting using a Brix Milwaukee 882 machine, and the content of  $\text{NO}_3^-$  residue by the spectrophotometer method.

### Data analysis

Analysis of variance (ANOVA) was performed using IRRISTAT version 5.0 (Pham Tien Dung, 2008) to test for significance of fertilizer types and concentrations for growth and physiological characteristics, quality and yield of water spinach. Mean comparisons were done by LSD (least significant difference) at  $P < 0.05$ .

## Results and Discussion

### Effects of different organic fertilizer supplements on the growth and yield of water spinach

#### *Water Quality Parameters (pH, TDS)*

The pH of the fish tank water ranged from 6.2 to 7.2 over the study period with a mean of 6.8 (**Figure 1**). This range of pH is suitable for both climbing perch and nitrifying bacteria. The literature revealed that the desirable pH range for pond culture is between 6.5 and 9.0 (Swingle, 1967) whereas nitrifying bacteria growth is inhibited below a pH of 6.5 (Tyson *et al.*, 2007). Water spinach affected the temperature, pH, and oxygen content of the experimental water (Pamula, 2019). Fish can grow in conditions up to 600ppm TDS (Ahmed *et al.*, 2019). **Figure 1** shows the maximum TDS was 500ppm, and the minimum value was 430ppm. Several studies have shown that an aquaponic system also inhibits the formation of poison from fish food residues (Nuwansi *et al.*, 2017).

#### *Growth Characteristics (Plant height, number of leaves)*

Nine days after planting (DAP), the plant

heights were approximately 10.0cm on average. The plant heights increased rapidly during the first growth period (days 9-27) (**Figure 2A**). At 23 DAP, the plants reached an average height of 18.9-37.4cm. The plants supplemented with organic foliar fertilizer gave higher plant heights compared to plants in the control treatment without organic foliar fertilizer application. In the first harvest, the plant heights of treated plants were much higher than the control plants, especially at 23 DAP, and the plants sprayed with TCN HUME were about two times higher than plants in the control treatment. A similar trend was observed at the second harvest at 14 DAH (days after harvesting).

The leaf numbers were significantly higher in the treated plants compared to the control. The number of leaves reached 8.0-14.5 leaves plant<sup>-1</sup> at 23 DAP in the first harvest (**Figure 2B**). The treatment with TCN HUME foliar fertilizer also gave the highest leaf numbers (14.5 leaves plant<sup>-1</sup>) among the treatments, which was nearly double that of the control treatment (8 leaves plant<sup>-1</sup>). Water spinach is a leaf vegetable in which both its green leaves and stems are consumed, therefore increasing the number of leaves will increase the yield and sensory quality of the products.

#### *Physiological characteristics (SPAD, fresh weight)*

**Figure 3A** presents that the SPAD did not show significant differences among the treatments. However, the foliar spray with organic fertilizers significantly increased the amount of fresh matter compared to the control (**Figure 3B**).

#### *Water spinach quality (Brix, $\text{NO}_3^-$ content)*

The  $\text{NO}_3^-$  content of harvested plants in the treatments was in the range of 169.4 to 321.7 mg kg<sup>-1</sup>, which shows a safe level of  $\text{NO}_3^-$  in the vegetables harvested from an aquaponic system according to the Regulations of MARD (2008). In addition, the Brix values of the vegetables did not differ significantly among treatments in the first harvest. In the second harvest, the Brix values slightly increased in all the treatments

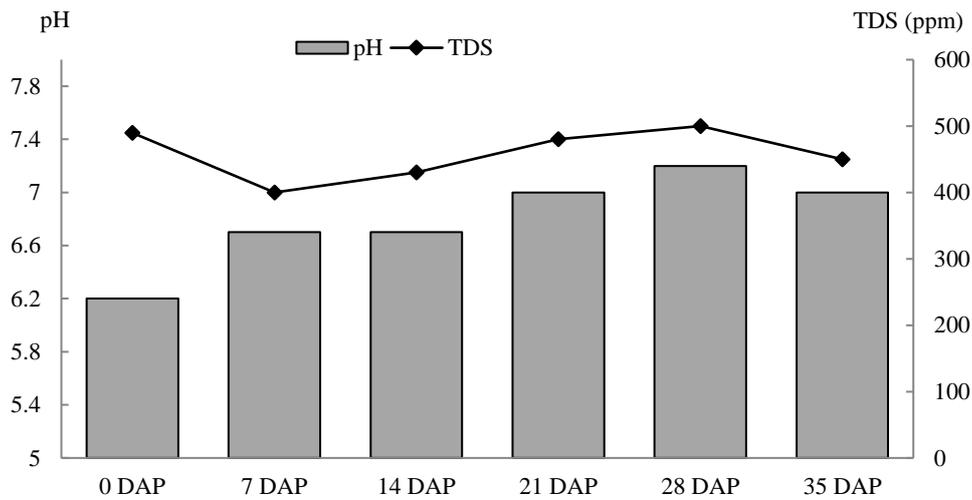
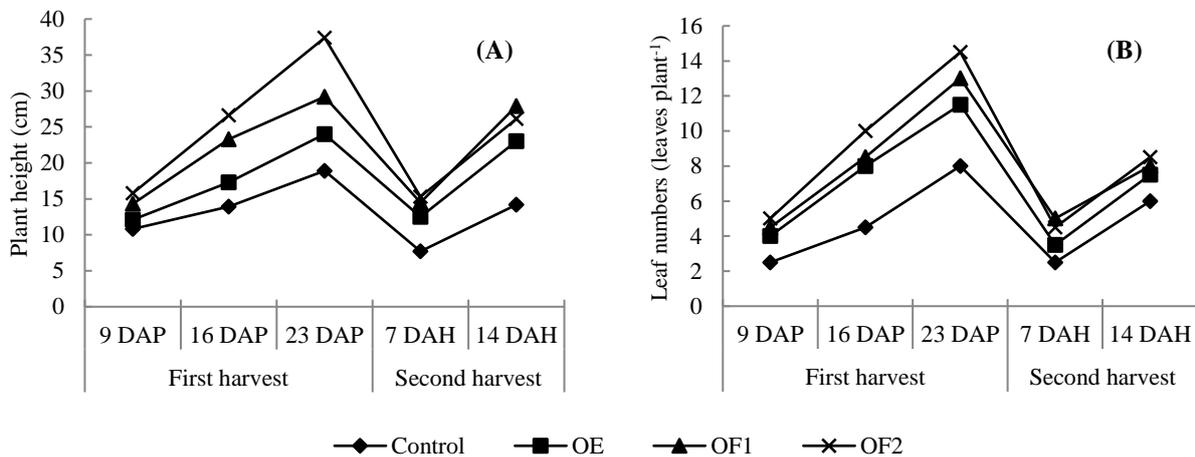


Figure 1. Water quality parameters of the fish tank water



Note: DAP (Days after planting), DAH (Days after harvesting).

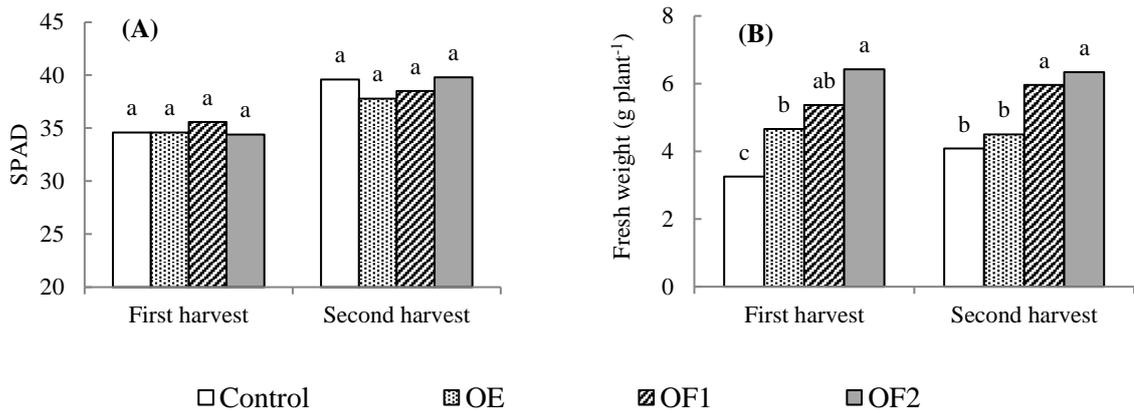
Figure 2. Effects of different organic fertilizers on plant height (A) and leaf numbers (B) of water spinach

compared to the first harvest but there were no significant differences among treatments. Therefore, supplementation with organic nutrient solutions did not affect the quality of water spinach in terms of  $\text{NO}_3^-$  content and Brix.

#### Water spinach yield ( $\text{kg m}^{-2}$ )

The addition of organic fertilizer supplements increased the yield of water spinach compared to the control (Figure 4). The yields of water spinach in the first harvest were 0.51, 0.76, 0.90, and 1.02  $\text{kg m}^{-2}$  in the control, OE, OF1, and OF2 treatments, respectively. In the second

harvest, the production of water spinach increased slightly with yields of 0.73, 0.93, 1.09, and 1.27  $\text{kg m}^{-2}$  for the control, OE, OF1, and OF2 treatments, respectively, representing the better performance of OF2 (spraying with TCN HUME). The yield in the treatment with the TCN HUME fertilizer was nearly double that of the control treatment. The higher number of leaves and higher plant height (Figure 2) in this treatment resulted in increasing the yield of the water spinach (leafy vegetable). The self-extracted nutrient solution (OE) also increased the yield significantly compared to the control but was still lower than the values of the two



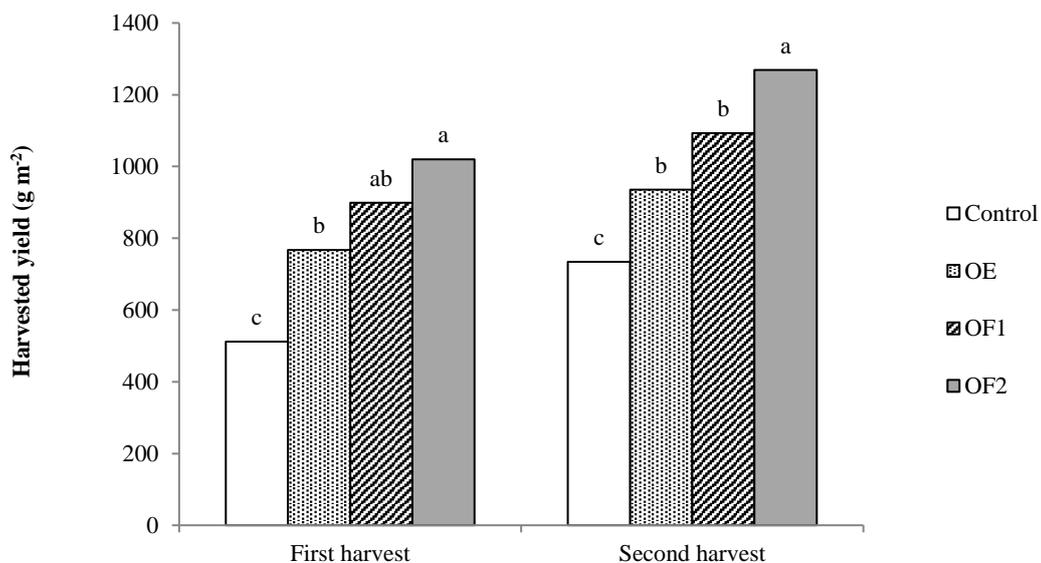
Note: Values within a column for each treatment followed by the same lowercase letter are not significantly different at the 0.05 probability level.

Figure 3. Effects of different organic fertilizers on SPAD (A) and fresh weight (B) of water spinach

Table 1. Effects of different organic fertilizers on NO<sub>3</sub><sup>-</sup> content (mg kg<sup>-1</sup>) and Brix values of water spinach

Treatment	NO <sub>3</sub> <sup>-</sup> content (mg kg <sup>-1</sup> )	Brix	
		First harvest	Second harvest
Control	169.4	2.87 <sup>a</sup>	3.49 <sup>a</sup>
OE	266.6	2.97 <sup>a</sup>	3.38 <sup>a</sup>
OF1	279.1	3.00 <sup>a</sup>	3.34 <sup>a</sup>
OF2	321.7	2.67 <sup>a</sup>	3.32 <sup>a</sup>
LSD <sub>0.05</sub>		0.40	0.36
CV (%)		8.10	8.40

Note: Values within a column for each treatment followed by the same lowercase letter are not significantly different at the 0.05 probability level.



Note: Values within a column for each treatment followed by the same lowercase letter are not significantly different at the 0.05 probability level.

Figure 4. Effects of different organic fertilizers on total yield (g m<sup>-2</sup>) of water spinach

commercial fertilizers at both harvesting times. This result is similar to the study of Bethe *et al.* (2017), who showed a higher yield of water spinach with compost tea spray than with no spray. This is because the organic matter in aquaponic systems may contain not only nutrients but also beneficial species of bacteria, fungi, protozoa, and nematodes that improve plant growth (Delaide *et al.*, 2016). It is assumed that there are two factors present in fish tank water that have plant growth-promoting effects, namely dissolved organic matter, and plant growth-promoting rhizobacteria and/or fungi. Plant growth-promoting microbes in aquaponics could release phytohormones or induce hormonal changes to promote plant growth and improve root development (Ruzzi & Aroca, 2015). Yep & Zhang (2019) also suggested that more research on the role of plant promoting microbes in aquaponics is needed in order to be able to achieve yields similar to hydroponics, despite nutrient levels being significantly lower. Besides, humic acids, such as fulvic acid, can increase shoot and root growth as well as root ATPase activity (Mylonas & McCants, 1980; Canellas *et al.*, 2009). Haghghi *et al.* (2012) pointed out that adding humic acid to a hydroponic solution improved the nitrogen metabolism, photosynthetic activity, and yield of lettuce. This can explain the high effectiveness of the two commercial organic fertilizers containing humic and fulvic acids (TCN HUME and Hydro Fulvic fertilizers) used in this experiment.

From this experiment, we can see that spraying organic fertilizer on the vegetables in an aquaponic system could increase the growth and yield of water spinach. Among the organic fertilizers used in Exp.1, the self-extracted organic nutrient solution can be produced by aquaponic growers by using available plant and animal residues, and it can serve as an option for the sustainable development of an aquaponic system. Thus, the examination of the potential use of this extract for aquaponic vegetables was carried out in Exp.2.

### **Effects of different self-extracted organic nutrient solution concentrations on the growth and yield of water spinach in an aquaponic system**

The data in **Table 2** show that the higher concentrations of self-extracted nutrient solution increased the plant height and number of leaves of water spinach in both seasons. The highest values were recorded in the treatment with the 3% concentration in both seasons. As a consequence, plant weights at harvesting time in the treatments with the self-extracted solution were significantly higher than that in the control treatment. This agreed with the results of Roosta & Hamidpour (2011) who found that foliar fertilizer application with macro-and micro-nutrients increased the vegetative growth of aquaponic tomatoes. The study of Roosta (2014) also showed that foliar spray with potassium (K) significantly increased the growth of mint, radish, parsley, and coriander in an aquaponic system.

The SPAD readings of plants in the summer season were slightly higher than in the spring-summer season but the application of organic extracted fertilizer did not increase these values compared to the control in either season. Similarly, the quality (in terms of Brix and NO<sub>3</sub><sup>-</sup> residue) of water spinach was not affected by the different nutrient concentration applications, and increasing the concentration up to 3% did not affect the nitrate residue content of the products.

The yields of water spinach were significantly higher in the treated plants as compared to the untreated control. The yields of water spinach treated with the extracted solutions increased 34.7%, 51.7%, and 77.8% in the spring-summer season 2020 and 26.6%, 35.2%, and 43.5% in the summer season for the 1%, 2%, and 3% concentration treatments compared to the control treatment, respectively. The 3% concentration treatment showed the highest yield in both seasons but the values were not significantly higher than those of the 2% concentration. The study of Nguyen Thi Ngoc Dinh *et al.* (2015) on the static hydroponic system using self-extracted nutrient solution reported that the concentration of 3% gave the highest yield and was recommended for water

**Table 2.** Effects of the self-extracted organic nutrient solution concentrations on the growth and yield of water spinach

Treatment	Spring-summer season 2021						
	Plant height (cm)	Leaf number	SPAD	Fresh weight (g plant <sup>-1</sup> )	Total yield (g m <sup>-2</sup> )	Brix	NO <sub>3</sub> <sup>-</sup> content (mg kg <sup>-1</sup> )
Control	25.4 <sup>c</sup>	6.3 <sup>c</sup>	36.7 <sup>a</sup>	3.09 <sup>d</sup>	679.1 <sup>c</sup>	3.7 <sup>a</sup>	134.3
OE 1%	26.9 <sup>b</sup>	7.1 <sup>b</sup>	37.2 <sup>a</sup>	4.94 <sup>c</sup>	915.0 <sup>b</sup>	3.8 <sup>a</sup>	151.1
OE 2%	27.6 <sup>b</sup>	9.7 <sup>a</sup>	38.8 <sup>a</sup>	5.51 <sup>b</sup>	1030.7 <sup>ab</sup>	4.1 <sup>a</sup>	163.6
OE 3%	30.4 <sup>a</sup>	9.9 <sup>a</sup>	38.9 <sup>a</sup>	6.24 <sup>a</sup>	1206.8 <sup>a</sup>	4.2 <sup>a</sup>	189.3
LSD <sub>0.05</sub>	0.8	0.26	2.6	0.25	205.2	0.56	
CV (%)	11.5	11.7	4.3	9.5	14.9	6.1	
Summer season 2021							
Control	36.0 <sup>b</sup>	8.9 <sup>d</sup>	37.8 <sup>a</sup>	6.10 <sup>d</sup>	1189.8 <sup>c</sup>	3.8 <sup>a</sup>	134.2
OE 1%	36.6 <sup>b</sup>	9.8 <sup>c</sup>	38.9 <sup>a</sup>	8.36 <sup>c</sup>	1506.2 <sup>b</sup>	3.9 <sup>a</sup>	151.0
OE 2%	39.8 <sup>a</sup>	10.8 <sup>b</sup>	39.7 <sup>a</sup>	8.83 <sup>b</sup>	1608.9 <sup>ab</sup>	4.0 <sup>a</sup>	181.8
OE 3%	40.6 <sup>a</sup>	13.0 <sup>a</sup>	39.5 <sup>a</sup>	9.59 <sup>a</sup>	1707.9 <sup>a</sup>	4.1 <sup>a</sup>	210.8
LSD <sub>0.05</sub>	0.9	0.4	2.7	0.16	190.5	0.67	
CV (%)	11.6	12.7	4.6	8.6	12.5	5.0	

Note: Values within a stage for each treatment followed by the same lowercase letter are not significantly different at the 0.05 probability level.

spinach production. However, in an aquaponic system where the nutrients for plants are available from fish water, the 2% concentration of the self-extracted solution is sufficient to provide supplemental nutrients for water spinach while resulting in high yields and cost-savings. Roosta & Hamidpour (2011) pointed out that foliar spray of macro- and micro-nutrients significantly increased tomato fruit numbers and yield in aquaponics in the order of K > Fe > Mn > Zn > Mg > B. The self-extracted nutrient solution has the advantage of having a high potassium (K) concentration which supplemented the potassium shortage in the aquaculture effluent due to the fish feed often having a low portion of potassium since this element is not required by fish, which leads to a low level of potassium available for plants (Graber & Junge, 2009; Suhl *et al.*, 2016). This may be explained by the positive effects of this solution as a foliar fertilizer for plant grown in an aquaponic system.

## Conclusions

This study indicated that it is necessary to supplement with foliar fertilizer to ensure the

productivity of water spinach grown in a climbing perch-water spinach aquaponic system. Supplementing with organic foliar fertilizer increased the growth and yield of water spinach. The use of the self-extracted organic nutrient solution also brought a positive impact on water spinach, and the best concentration for aquaponic water spinach was 2%, which provided the highest yield and cost-savings. These results suggest an option for aquaponic growers to handle their aquaponic system in an economic and environmental way by using extracted nutrient solutions from available plant and animal residues.

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