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Evaluation of the nutrient elements profiling of cucumber plants fertigated by three different nutrient solutions in soil and soilless culture systems

Mohammad Ali Golestani [a]*, Hossein Sharifi Azad [b], Seyed Hossein Mirdehghan [b]

[a] *Department of Landscape Architecture, Chalous Branch, Islamic Azad University, Chalous, Iran*
[b] *Department of Horticultural Sciences, College of Agriculture, Vali-e-Asr University of Rafsanjan, Rafsanjan, Kerman, Iran*

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ABSTRACT

In order to assess the impact of various nutrient solutions on the nutrient content of cucumber plants, a factorial experiment was conducted with two factors: cultivation system (soil cultivation and soilless cultivation) and nutrient solution (Hoagland, Papadopoulos, and Commercial). The experiment was carried out in a completely randomized design with three replications in a greenhouse setting. The results showed that the highest concentrations of N, K, Ca, Mg, and Fe in the leaves were obtained from plants grown in a hydroponic system and fertigated with the Hoagland nutrient solution. Additionally, plants grown in the hydroponic system had the highest P content, while those grown in soil-based cultivation had the lowest phosphorus levels. Moreover, plants grown in a hydroponic system with a combination of Hoagland and commercial nutrient solutions exhibited the highest levels of Zn and Cu. The highest manganese content was observed in plants grown in the hydroponic system with the Hoagland and commercial nutrient solutions. Overall, the results suggest that soilless cultivation with the Hoagland nutrient solution had a significantly positive impact on the nutrient content of cucumber plants compared to the other treatments.

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* Corresponding author: M. A. Golestani
E-mail address: golestani554@gmail.com

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1. Introduction

In recent years, the presence of some problems in soil cultivation such as salinity, improper soil structure, and limited water resources in some countries, especially Iran, has led to the development of soilless cultivation (hydroponics). Soil fertility decline, increased salinity, and the occurrence of soil-borne diseases after successive crops are observed. Therefore, the use of soilless cultivation as an alternative to soil cultivation is considered in the Iran. Research has shown that if nutrients are provided to plants through fertigation or nutrigation, the plant does not need soil for growth (Hayden, 2006; Papadopoulos, 1994). Hydroponics is a method in which plant growth and development can be well controlled, resulting in relatively high performance. A key advantage of this method is its applicability worldwide (Benton Jones, 2005). Sustainable agriculture is a type of agricultural system that aims to achieve desirable performance by using minimal inputs and external chemical factors. Additionally, sustainable agriculture minimizes harmful effects on the environment and enhances the quality of the environment and natural resources in the long term. With the increasing population and its substantial food needs, traditional and low-yielding agricultural methods are no longer sufficient to meet these demands. Furthermore, pollution of water and soil resources is another factor hindering the use of chemical fertilizers in the soil. In this context, hydroponic cultivation plays a significant role in sustainable agriculture by optimizing agricultural inputs and achieving high yields. Nutrient supply and environmental conditions such as light, temperature, and relative humidity are among the most important factors for the successful management and cultivation of greenhouse cucumbers. Continuous research on nutrient solutions is essential for identifying the best nutrient solutions for specific crops given the increasing greenhouse industry and production of greenhouse products (Graber and Junge, 2009). In hydroponics, careful attention must be paid to nutrient elements, as deficiencies of any element manifest quickly in this method (Papadopoulos, 1994). Therefore, determining the best type and combination of nutrient solutions for achieving desirable performance serves as one of the key methods for managing the nutrition of products in controlled conditions (Roosta et al., 2009). One of the key indicators of a suitable nutrient solution is to supply the necessary elements in a way that the plant receives macro- and micro-elements in optimal amounts to avoid nutritional stress, and most importantly, its economic viability to ensure its acceptance among investors. Having sufficient knowledge of important nutrient solution formulations is crucial, but more importantly, knowing how to manage them is essential for successful production (Benton Jones, 2005).

Cucumber (Cucumis sativus L.) is a strategic crop produced under controlled conditions and has allocated a large area of greenhouse production in Iran. Therefore, high quality and performance production of this crop in controlled conditions requires proper management. In recent years, the decrease in water quality due to high salt content, as well as pests and diseases, has posed challenges to the production of this crop (Naureen et al., 2018).

In soilless cultivation methods, all essential elements must be supplied to the plant in the form of soluble salts. A standard nutrient solution contains all essential nutrients at specified concentrations, and experts may modify or use different concentrations of standard solutions based on research components, cultivation conditions, and plant species. Considering that an element exists in various salt forms, the choice of salt or fertilizer type to supply that element depends on factors such as element ratios, solubility, pH, growing medium, cost, and the mechanisms by which that element is affected (Tabatabaei, 2009). Different countries around the world use different nutrient solutions based on cultivation type, environmental factors, and the cost of various fertilizers. In Iran, due to the relatively short history of hydroponic industry, the effects of different nutrient solutions on highly productive plants such as cucumbers have been less explored. Therefore, to achieve better performance and quality, it is necessary to study important nutrient solutions to select the most suitable ones economically, in terms of performance impact, and even environmental factors. It has been observed that different ratios of potassium and nitrogen in hydroponic conditions lead to changes in growth and performance indicators of cucumber plants so that growth indicators such as stem length, leaf area, stem diameter, fruit length, fruit diameter, and fruit weight are affected by the application of different nitrogen and potassium concentrations (Cardoso et al., 2017). The separate application of potassium, phosphorus, calcium, magnesium, and nitrogen in field conditions results in increased growth indicators of tomato plants through increased chlorophyll content and nutrient concentration in leaf tissue (Cole et al., 2016). In an experiment, 12 important nutrient solutions worldwide were compared, and it was observed that the nutrient composition of these widely used nutrient solutions significantly affects micronutrient concentration in plants (De Rijck and Schrevens, 1998). Proper nutrition management and selecting the best fertilizer source with a suitable combination and concentration of nutrients can be considered as a fundamental and scientific solution for cucumber production to increase yield and deliver a quality product to consumers (Cardoso et al., 2017). Considering the increasing trend of soilless cucumber production in Iran, investigating the nutrient content of cucumbers in soil and soilless cultivation, as well as identifying the best nutrient solution for them in Iranian climate conditions, seems essential. Therefore, an experiment was conducted with the objective of determining the best nutrient solution for cucumbers by adjusting the concentration of essential elements in the nutrient solution.

2. Materials and methods

2.1. Growth condition

This research was conducted in 2020 to evaluate the impact of different nutrient solutions on the nutrient element concentration of cucumber plants in soil and soilless cultivation in a greenhouse, with average minimum and maximum temperatures of 24 ± 3 ◦C during the day and 21 ± 3 ◦C at night, and an average relative humidity of 54%.

2.2. Experimental Design and Treatments

The experiment was conducted in a factorial design as a completely randomized design with three replications. The experimental treatments included cultivation systems (soil and soilless cultivation) and types of nutrient solution (Hoagland, Papadopoulos, and commercial).

2.3. Preparation of Growing Media and Nutrient Solution

In soil-based cultivation, 18 pots (10 L volume) were used, with one plant grown in each pot. In the soilless cultivation system, the cultivation bags in the experimental setup consisted of a mixture of cocopeat and perlite in a ratio of 50:50. The water required to prepare the nutrient solution was obtained from a water purification system with 5 filters and an output EC of 14 µs cm^{-1} available in the greenhouse. In the hydroponic system, manual nutrient solution application was carried out twice daily. The plants in soil-based cultivation were irrigated with the nutrient solution every 12 days based on the treatments, and to maintain moisture, the soil-based plants were also irrigated with tap water twice (every 4 days). The nutrient solution used had a pH of 5.8-6.5 and an EC of approximately 1.7 dS/m.

Table 1. Nutrient element concentration (mg L^{-1}) in Hoagland (Hoagland and Arnon, 1950), Papadopoulos (1994) and commercial nutrient solution.

Nutrient element	Hoagland	Papadopoulos	Commercial
N	242	117	120
P	31	35	30
K	232	175	175
Ca	224	95	100
Mg	49	25	20
S	113	59	38

Micronutrients were according to Hoagland and Arnon (1950).

2.4. Preparation of Seedlings (Tray Cultivation)

For this purpose, cucumber seeds of the Nagin variety were sown in cultivation trays filled with a mixture of perlite and cocopeat (in a 1:1 ratio) to produce seedlings, which were then placed in the greenhouse environment. Additionally, in soil-based cultivation, the seeds were first sown in cultivation trays and then transferred to 10-liter pots.

2.5. Planting of Seedlings

Fourteen days after sowing the cucumber seeds, when the seedlings had reached the 4-6 leaf stage and a height of 12 centimeters, the seedlings were transferred to cultivation bags (Grow bag) for hydroponic cultivation and to 10-liter pots for soil-based cultivation.

2.6. Stem Training

Twenty days after transferring the seedlings, nylon strips were used to tie the plants to stakes to train their growth upwards. As the plants grew, the stems were gently wrapped around the nylon strip holder.

2.6. Measurement of Nutrients

The nutrients measured in this experiment included N, P, K, Ca, Mg, Zn, Cu, Mn, and Fe in the leaves. For the preparation of the extract, initially 5.0 g of the dried and ground sample was weighed and then placed in an oven at 550 ◦C for 3 hours to convert the samples into ash. Subsequently, 5 ml of 2 N hydrochloric acid was added to each sample and then made up to a volume of 50 ml with distilled water. This extract was used directly for the measurement of K, Cu, Mn, Fe, and Zn. For the measurement of P using the ammonium molybdate and ammonium vanadate (yellow) method, initially 5 ml of the extract prepared in the previous stage was mixed with 10 ml of the ammonium molybdate and ammonium vanadate solution and then made up to a volume of 50 ml with distilled water (Olsen et al, 1954). Phosphorus was measured at a wavelength of 470 nanometers using a spectrophotometer. Copper, Zn, Mn, and Fe elements were measured using an atomic absorption spectrophotometer, and K was measured using a flame photometer (Jenwyay, PEP7, Germany).

For N measurement, initially, 2.0 grams of the dried plant material at 70 ◦C passed through a sieve and precisely weighed, then placed inside a tube. Subsequently, 10 ml of concentrated sulfuric acid, along with 2 ml of distilled water and 1.1 g of potassium iodate, were added to the tube. The tubes were placed on a digestion device and heated at 270 ◦C for one hour and then at 370 ◦C for half an hour. The clear extract was collected at the bottom of the tube. The tubes were allowed to cool to room temperature. At this point, the plant sample was ready for the distillation stage. In the distillation stage, 10 ml of 40% hydrochloric acid, 5 ml of 4% boric acid, and 5 ml of distilled water were added to the tubes obtained from digestion. Then, a few drops of bromocresol purple indicator were added to the beaker (usually 2 drops), turning the solution from colorless to reddish-purple (the intensity of color depending on the amount of boric acid used differs). As soon as ammonia was introduced to the boric acid, the solution started changing color, and when the solution turned green, approximately 90% of the ammonia from the samples had distilled. To ensure, the test was continued until the volume of ammonium borate reached 75, which is almost 3 times the initial amount of boric acid. The green-colored ammonium borate was titrated with 0.1 normal sulfuric acid until the appearance of the reddish-purple color (the intensity of color depending on the amount of boric acid used differs). Then, the amount of nitrogen was calculated using the formula: T.N = (HCl × NHCl × 100 × 14) / (W × 100)

T.N = Total Nitrogen (%), HCl = Borate obtained from titration (milliliters), NHCl = 1% Normal Hydrochloric Acid, W = Sample weight (g), 14 = Constant

Calcium was measured by titration. Firstly, 5 ml of the prepared extract was poured into a flask and made up to a volume of 50 ml with distilled water. Then, 5 drops of sodium hydroxide (soda, NaOH) and 5 drops of silver chromate were added. The solution was then titrated with ethylene diamine tetraacetic acid (EDTA) until a color change from brick red to blue or green occurred. The obtained number was subtracted from the previously measured amount of calcium, and the resulting number was put into the following formula, calculating the concentration of calcium (Klute et al., 1986). Ca^{2+} (meq/l) = (meq/l EDTA × N EDTA)/ (meq/l Extract) × 1000

The calcium measured by the above method was removed, and the remaining number was placed into the equation below to calculate the concentration of magnesium. Mg^{2+} (meq/l) = (meq/l EDTA × N EDTA) / (meq/l Extract) × 1000

In order to measure magnesium, the complexometric method was used. Five ml of the extracted solution were made up to a volume of 25 ml with distilled water. Then, 10 drops of ammonium chloride buffer and 4 drops of eriochrome black T were added. Following this, titration was carried out with EDTA until the solution changed from brick red to blue or green. The obtained number was placed into the formula above, calculating the concentration of magnesium (Ryan et al., 2001).

2.8. Data Analysis

Statistical analyses were performed using the SAS software, and the relevant graphs were plotted using Excel. Minitab software was used for data normalization.

3. Results and discussion

3.1. Nutrient elements

The highest nitrogen content in the leaves was obtained from plants grown in the hydroponic medium. Additionally, the Hoagland nutrient solution had a higher nitrogen content compared to the Papadopoulos and commercial nutrient solutions. Based on Figure 1, the highest nitrogen content in cucumber leaves in plants grown in the hydroponic medium with the Hoagland nutrient solution was 2.85% dry weight, and the lowest nitrogen content in leaves was observed in plants grown in soil-based cultivation with the Papadopoulos nutrient solution at 1.7% dry weight.

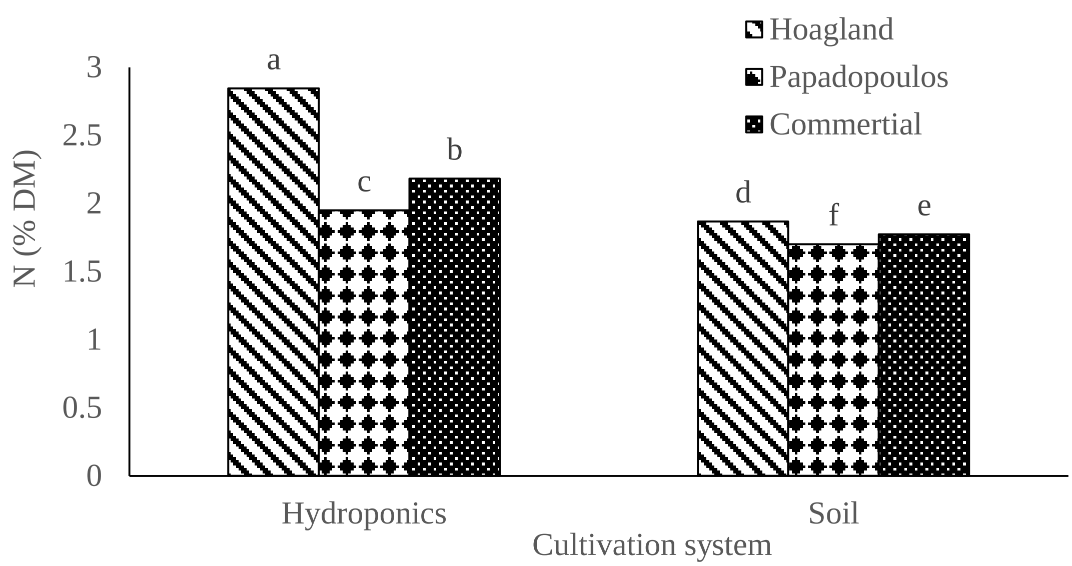

Figure 1. The impact of the growing medium and nutrient solution on the N content of greenhouse cucumber leaves. Means with similar letters did not show a significant difference statistically at the 5% level in the Duncan's multiple range test.

The highest phosphorus content in the leaves of plants grown in the hydroponic medium was 0.22% dry weight, while the lowest phosphorus content in the leaves of plants grown in soil-based cultivation was 0.19 milligrams per gram dry weight (Figure 2). Additionally, plants treated with the Hoagland nutrient solution had a higher phosphorus content (0.21% dry weight) compared to those treated with commercial nutrient solutions (0.2% dry weight) and the Papadopoulos solution (0.19% dry weight) (Figure 2).

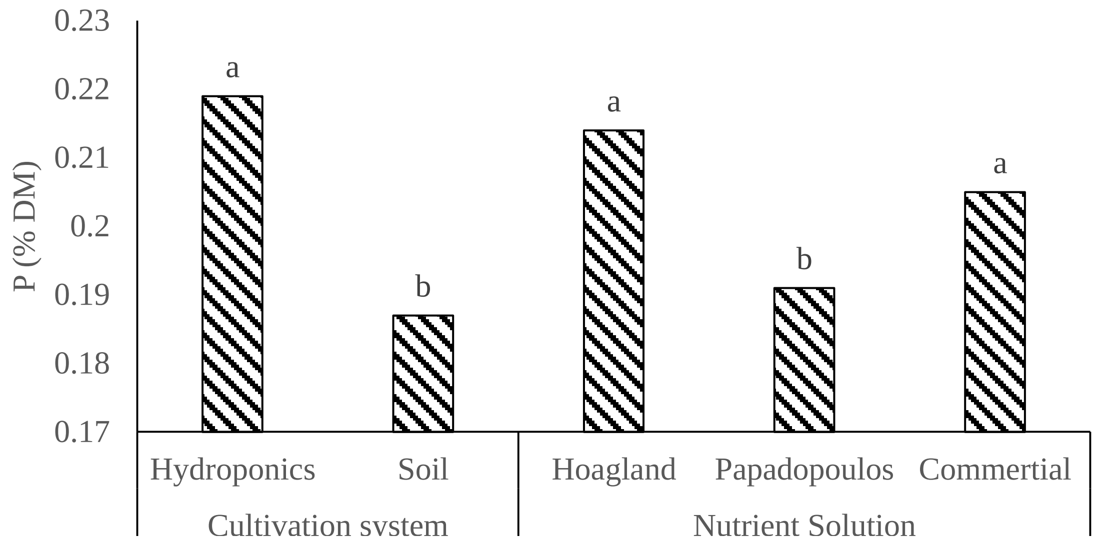

Figure 2. The effect of the growing medium and nutrient solution on the P content of greenhouse cucumber leaves. Means with similar letters did not show a significant difference statistically at the 5% level in the Duncan's multiple range test.

The results showed that the highest potassium content in the leaves of plants grown in soil-based and hydroponic cultivation with the Hoagland nutrient solution was 5.17% and 3.77% dry weight, respectively, while the lowest potassium content in the leaves of plants grown in soil-based cultivation with the Papadopoulos nutrient solution was 3.15% dry weight (Figure 3).

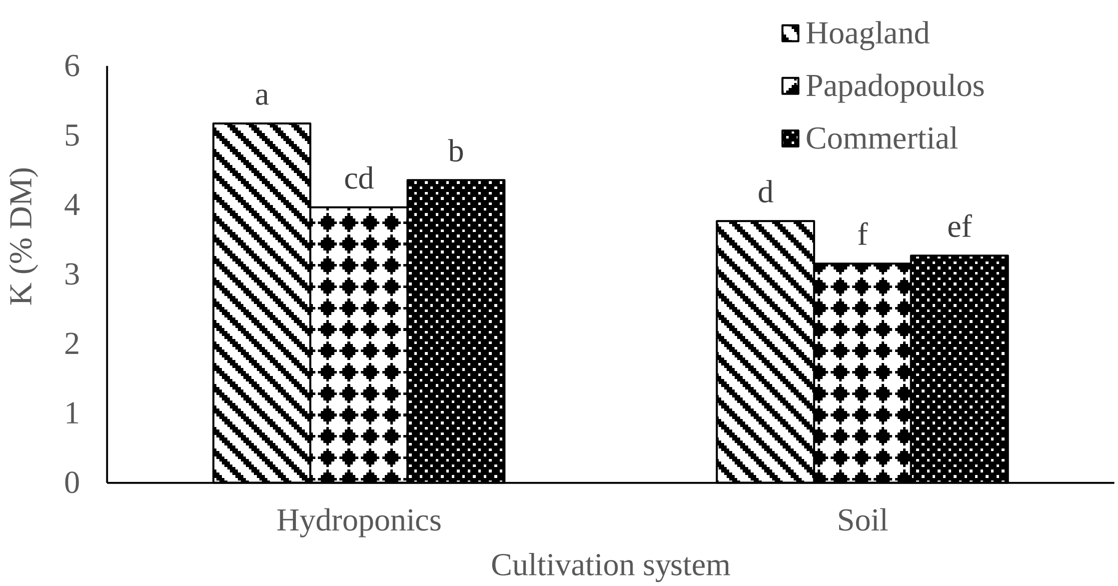

Figure 3. The impact of the growing medium and nutrient solution on the K content of greenhouse cucumber leaves. Means with similar letters did not show a significant difference statistically at the 5% level in the Duncan's multiple range test.

The calcium content in the leaves of plants grown in the hydroponic medium was higher than in plants grown in soil-based cultivation, with plants fertigated with the Hoagland nutrient solution having more calcium compared to those fertigated with the Papadopoulos and commercial nutrient solutions. The highest calcium content in the leaves of plants in the hydroponic medium with the Hoagland nutrient solution was 0.67% dry weight, and the lowest calcium content in the leaves of plants in soil-based cultivation with the Papadopoulos nutrient solution was 0.44% dry weight (Figure 4).

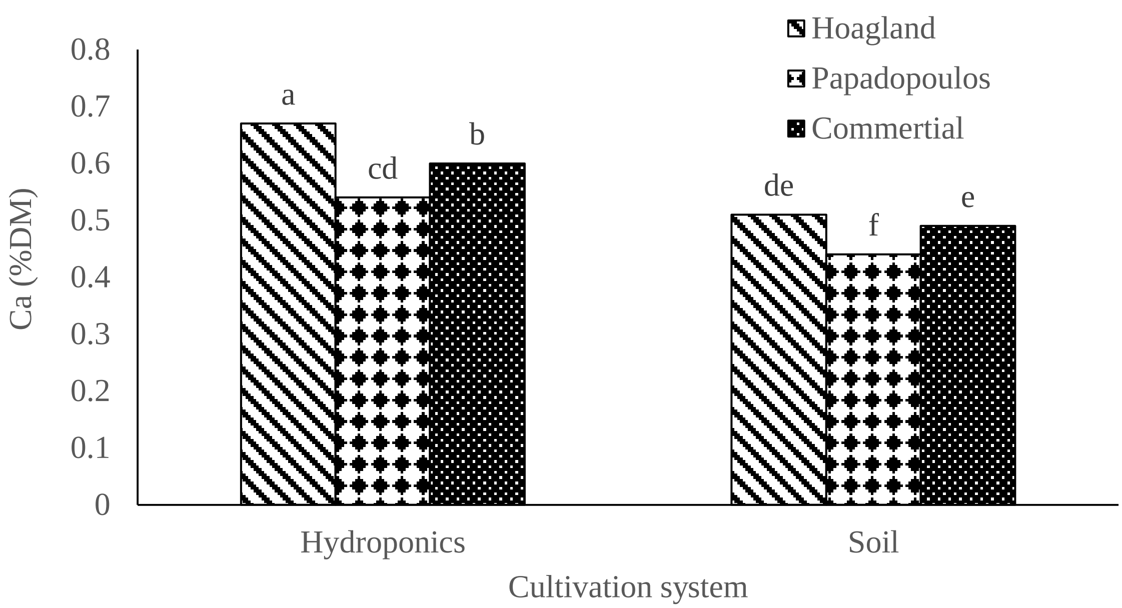

Figure 4. The effect of the growing medium and nutrient solution on the Ca content of greenhouse cucumber leaves. Means with similar letters did not show a significant difference statistically at the 5% level in the Duncan's multiple range test.

Based on the data, the highest magnesium content in the leaves was obtained from plants grown in the hydroponic medium with the Hoagland nutrient solution at 0.31% dry weight, while the lowest magnesium content was in plants grown in soil-based cultivation with the Papadopoulos nutrient solution at 0.19% dry weight. There was no significant difference between the Papadopoulos and commercial nutrient solutions, with only a significant difference observed with the Hoagland nutrient solution.

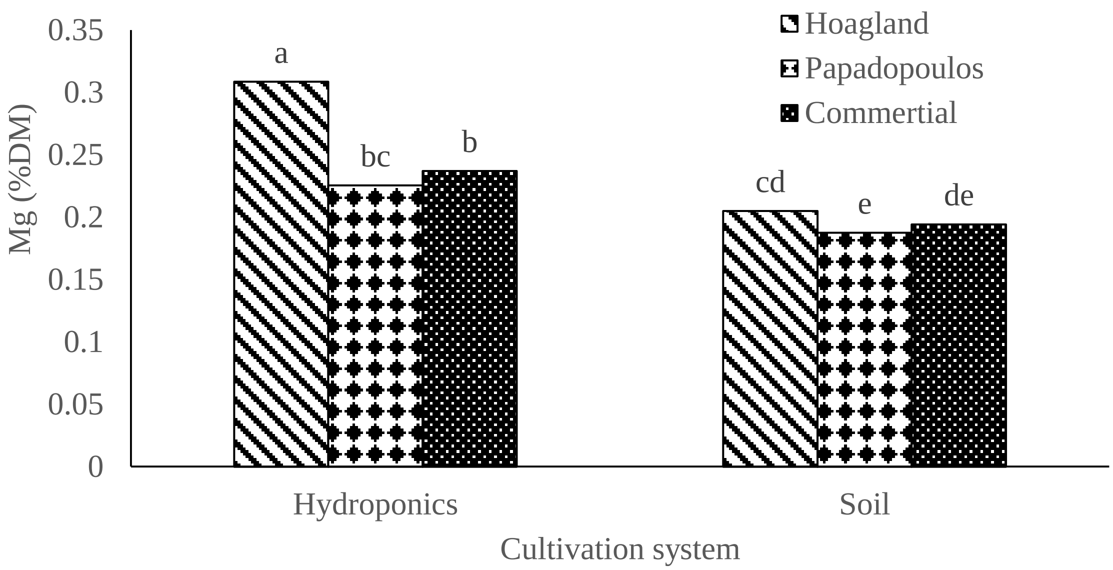

Figure 5. The effect of the growing medium and nutrient solution on the Mg content of greenhouse cucumber leaves. Means with similar letters did not show a significant difference statistically at the 5% level in the Duncan's multiple range test.

Regarding the manganese content, the highest manganese content in the leaves was obtained from plants grown in the hydroponic medium. Manganese concentration was higher in the Hoagland and commercial nutrient solutions at 127.5 and 125.5 mg kg^{-1} dry weight, respectively (Figure 6). The lowest manganese content in the leaves was from plants grown in soil-based cultivation.

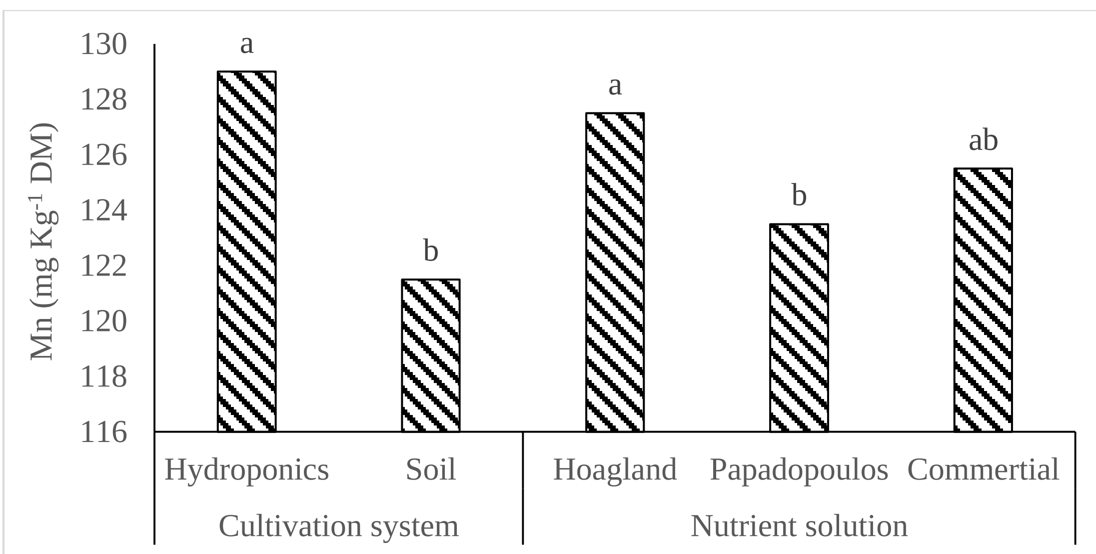

Figure 6. The impact of the growing medium and nutrient solution on the Mn content of greenhouse cucumber leaves. Means with similar letters did not show a significant difference statistically at the 5% level in the Duncan's multiple range test.

According to Figure 7, the highest level of zinc in plants from hydroponic cultivation with a combination of Hoagland and commercial nutrient solution was 50 and 44.4 mg Kg-1 of dry leaf weight, respectively. The lowest level was found in plants from soil cultivation with a combination of Papadopoulos nutrient solution (27.20 mg Kg-1 of dry leaf weight).

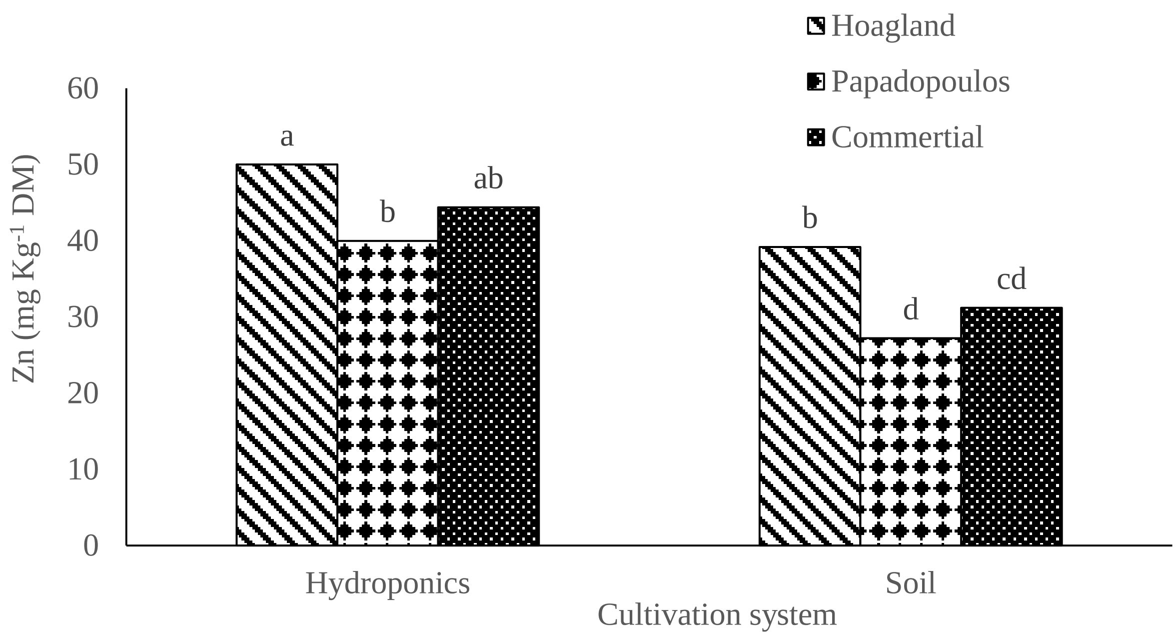

Figure 7. The impact of the growing medium and nutrient solution on the Zn content of greenhouse cucumber leaves. Means with similar letters did not show a significant difference statistically at the 5% level in the Duncan's multiple range test.

Plants grown in hydroponic cultivation had higher levels of copper compared to plants grown in soil cultivation. Additionally, plants that were fertigated with Hoagland nutrient solution had the highest level of copper, which was significantly different from those fertigated with Papadopoulos nutrient solution. The results showed that the highest level of copper in plants was observed in those grown in soilless cultivation with Hoagland nutrient solution at 9.80% dry weight of leaves, while the lowest level of copper was seen in plants grown in soil cultivation with Papadopoulos nutrient solution at 5% dry weight of leaves (Figure 8).

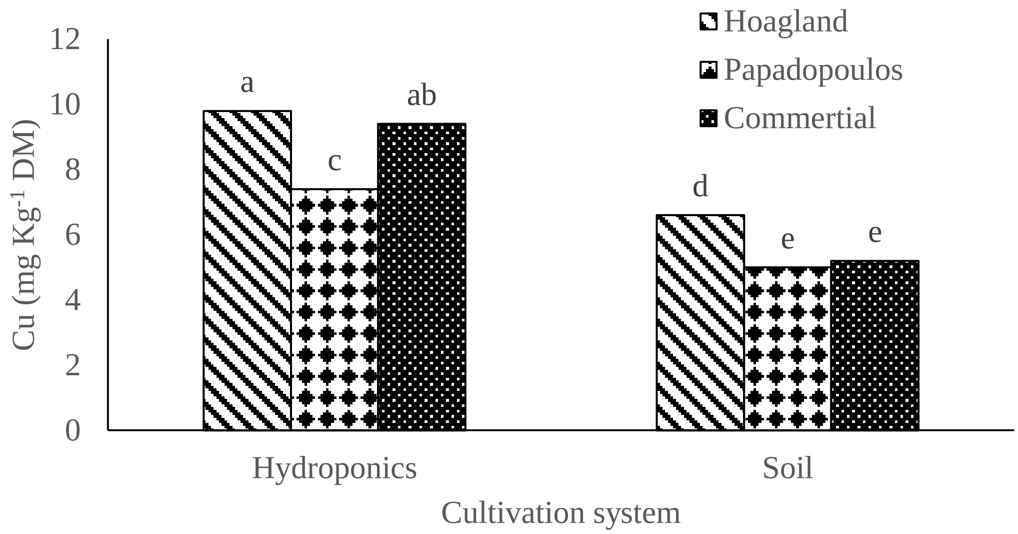

Figure 8. The impact of the growing medium and nutrient solution on the Cu content of greenhouse cucumber leaves. Means with similar letters did not show a significant difference statistically at the 5% level in the Duncan's multiple range test.

The highest iron content in the leaves was seen in plants grown in the hydroponic medium compared to soil-based cultivation. Additionally, plants fertigated with the Hoagland nutrient solution had a higher iron content compared to those fertigated with the Papadopoulos nutrient solution. The highest iron content in the leaves of plants in soilless cultivation with the Hoagland nutrient solution was 223 mg Kg^{-1} dry weight, and the lowest iron content in the leaves of plants in the soil medium with the Papadopoulos nutrient solution was 146 mg Kg^{-1} dry weight.

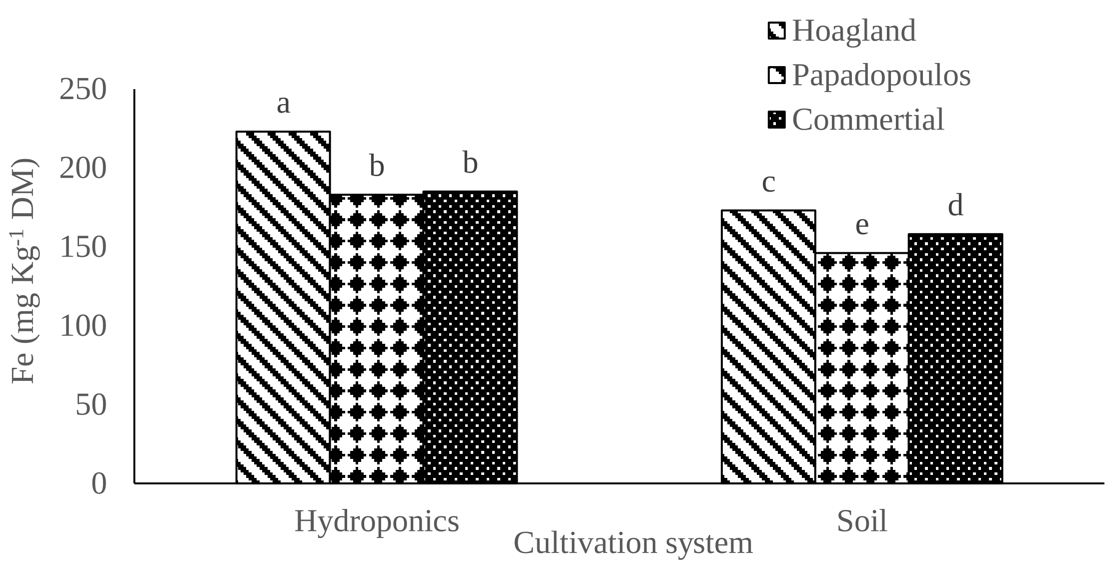

Figure 9. The impact of the growing medium and nutrient solution on the iron content of greenhouse cucumber leaves. Means with similar letters did not show a significant difference statistically at the 5% level in the Duncan's multiple range test.

4. Discussion

The nutritional quality of plant is influenced by pre- and post-harvest factors (Blake and Hartge, 1986). Fertilization is one of the most practical and effective pre-harvest methods for controlling and improving the performance and nutritional quality of agricultural products for human consumption. From this perspective, soilless cultivation has an important role because it allows precise control of plant nutrition (Domingues et al., 2012; Qiu et al., 2014). Nitrogen is considered one of the most essential and effective nutrients throughout the plant growth stages, playing a crucial role in plant nutrition and metabolism processes (Saxena, 2004). The main role of nitrogen is in rapid shoot development, allowing the plant to quickly cover its surface completely and maximize its growth during the growth period (Honeycutt et al., 1996). An increase in nitrogen levels also affects the absorption of other elements such as potassium, magnesium, calcium, and phosphorus, intensifying the absorption of some elements in some cases (Rajiv and Misra, 2011).

Most of the soil nitrogen is organic and not readily available to plants. The use of compost and vermicompost led to an increase in nitrogen concentration and plant yield in broccoli. Fallovo et al. (2009) reported that the nitrogen concentration in the leafy part of cabbage was positively affected by the application of nutrient solutions with high nitrogen content. An increase in ammonium in the growing medium leads to an increase in organic forms such as amides and, consequently, an increase in nitrogen concentration. Studies have also shown that the application of ammonium in nutrient solutions has increased the concentration of cationic trace elements in spinach (Assimakopoulou, 2006). With the application of ammonium, anions are absorbed more than cations, and thus H^+ is released from the roots to balance the free charge, leading to root acidification and increased availability of cationic micronutrients such as Fe, Mn, Zn, and Cu (Marschner, 2012). Potassium is an element that is actively absorbed by plants. It seems that the higher the concentration of potassium in the nutrient solution, the higher the absorption by the plant (Marschner, 2012). Potassium plays a crucial role in accelerating the photosynthetic process in chloroplasts of plant leaves, leading to a faster transfer of photosynthetic processes through water-conducting vessels to reserve organs, thereby enhancing the yield and quality of the product. By examining the potassium concentration in the nutrient solutions, it can be seen that the highest K concentration and yield is associated with nutrient solutions with the highest potassium concentrations, which aligns with the results of this study. The decrease in potassium absorption in soil treatments is due to the salinity of the soil and sodium competition with potassium in absorption. The highest growth performance in fig cuttings treated with Hoagland nutrient solutions with 234 mg L^{-1} of potassium was reported (Kilinc et al., 2007). Calcium is also an essential element for plant growth, but its mobility in plants is very low, and its quantity and movement within the plant are greatly influenced by the calcium level in the root environment and the plant's water relations and transpiration rate (Marschner, 2012). In a study that evaluated the effect of growing media on the absorption of some essential elements by greenhouse cucumbers in soilless cultivation, it was found that the highest nitrogen, potassium, and magnesium leaf content was related to the cocopeat growing medium, possibly due to the higher nitrogen and potassium levels seen in plants in the cocopeat growing medium, which suggests that cocopeat, due to its high absorbable potassium content, gradually released potassium and made it available to the plant. Experimental results showed that the potassium concentration in fruits grown in organic media such as peat moss was higher compared to media such as perlite and rockwool. In contrast, the uptake of calcium and phosphorus by fruits increased in organic media. It has been reported that increasing the amount of vermicompost in the cultivation environment significantly increases the aerial part content of phosphorus, calcium, and magnesium in cucumber and spinach (Sainz et al., 1998). According to these researchers, the different physical and chemical properties of growing media and their interactions with the nutritional composition and absorption of nutrients by the plant lead to this situation (Colla and Saccardo, 2003). To evaluate soilless growing media with four treatments: peat, perlite, a mixture of perlite and rice husk, and rice husk alone on the yield and quality of cucumber, demonstrated that the mineral element concentration in fruits increased in different growing media with the peat cultivation medium having the highest potassium concentration in the fruit, while the perlite and perlite-rice husk media had the highest calcium and phosphorus concentrations, respectively. Aalifar et al. (2017) studied the impact of four types of nutrient solutions (Hoagland 1, Hoagland 2, Noop, and UK) on the leaf nutrient content of pepper plants in hydroponic cultivation and found that the highest nitrogen and potassium leaf content was observed in the Hoagland 1 and 2 nutrient solutions, respectively, and the highest phosphorus leaf content was observed in the Hoagland 1 and Noop/UK solutions, which aligns with the results of this study. The effect of Hoagland, Steiner, Noop, England, Holland, and Tabriz University nutrient solutions on the nutrient content in the leaves of two cucumber varieties (Negin and Catherine) grown in hydroponic cultivation was investigated, with the highest nitrogen and potassium leaf content observed in the Steiner and England nutrient solutions, respectively (Khezri and Tabatabaei, 2010). According to the research by Soundy et al. (2001), providing a minimum of 15 mg L^{-1} of phosphorus in the hydroponic culture medium with peat and vermiculite is necessary to produce cabbage seedlings with the highest fresh and dry weight aerial part. In a study, the application of nutrient solutions with high potassium, calcium, and magnesium ratios positively affected leafy cabbage under hydroponic cultivation (Fallovo et al., 2009), which is consistent with the results of this study. A significant increase in iron concentration in the aerial parts of plants fed with nutrient solutions in hydroponic may be attributed to the effect of media pH.

4. Conclusions

The results of this study indicate that the use of hydroponic systems and cocopeat-perlite as growing media in greenhouse cultivation of cucumbers leads to an increase in nutrient element concentration. Therefore, based on the results of this study, the use of soilless cultivation and Hoagland nutrient solution is recommended for increasing nutrient uptake of greenhouse cucumbers compared to soil cultivation.

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