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Irrigation of Celery (Apium Graveolens) Plants with Aquaculture Effluent AQE Using Hydroponic System and Surface Drip Irrigation

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KEYWORDS
aquaculture, economic impacts, Celery, hydroponics, drip irrigation

ABSTRACT:
Aquaculture is fish farming that consist as one of the major fish productions, its basic farming in water. The discharge of aquaculture effluent is a main disadvantage of aquaculture farming. The aim of this work to investigated the effect of using AQE in irrigation of Celery (Apium graveolens) plants using hydroponic or aquaponic and surface drip irrigation system. The benefit of aquaculture effluent will help in protecting the environment and useful in irrigation a new product. Aquaculture bowel pool installed at Al-Quds University campus, its integrated with two system hydroponic and surface drip irrigation to investigation the effect of AQE irrigation in Celery (Apium graveolens) plants. The plant growth parameters (plant height, fresh and dry weight and both dry leaves and stems) for both surface drip irrigation and hydroponic systems demonstrated there are no significant difference between irrigation with FW and AQE. Further, the plant tissue analysis of Celery leaves and stems revealed no influence in irrigation with AQE as compared to FW. In addition, no accumulation of sodium or chloride ions in the plant tissues was detected showing no effect of both ions in plants. The results show that the growth parameters, the chemical and physical characteristics of the plant in the aquaponics water effluent AQE pipes are similar to those grown in FW. Furthermore, water characteristics of AQE and FW with commercial fertilizers (13 N:13 P:13 K) during the growing the season and at the end of season shows approximately the same characteristics. Thus, the irrigation with AQE will be same effect of using commercial fertilizer system in both surface drip irrigation of hydroponic system or aquaponic for Celery plants. The combination of surface drip irrigation process and hydroponic system with aquaculture system is useful technique to benefits from the application of AQE in irrigation. This irrigation method is considered to be cheap in construction, easy operation, a long lifespan and needs low maintenance requirements.

Introduction

The scarcity of freshwater in many countries around the world is an increasingly critical problem, particularly as world population continues to grow rapidly and places higher demands on water resources. The agriculture sector is known to be the largest consumer of water supplies. Agriculture consumes about 87% of the total water consumption in the Middle East and North Africa region (MENA) [1]. In the Palestinian territories, the total estimated water used for agriculture does not exceed 150 million cubic meters annually. This amount represents 45% of the total water consumption, which is reflected directly on the limited prospects for the development of irrigated agriculture that can have an important economic, social and political role in rebuilding the Palestinian economy [2].

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Aquaculture is identified as the breeding and harvesting of fish and aquatic animals in water or the farming of aquatic organisms, also referred to as fish farming [3]. Aquaculture is one of the major food production sectors in the world with 3.2% average annual growth. It is estimated that the share of fish for human consumption originating from aquaculture is projected to increase from 52% (average in the period 2016– 2018) to 58% in 2028 [4-5]. its aquaculture production was found to exceed 50 million tons, accounting for more than 60% of the world's aquaculture production in 2018 [6]. The advantages of aquaculture are that it continuously supplies us with fish and helps protect endangered species, as it is a source of food for the growing population in all countries. It is also a source of income for many people. In spite of this, the disadvantages of aquaculture cannot be ignored. High density and intensive farming methods can cause negative impacts on the environment, resulting in the eutrophication of the water body and a waste of water resources. It is possible for aquaculture to polluted water systems with excess nutrients and excrement due to the large numbers of fish, as this water is usually discharged without any treatment into waterways and rivers, which harms the environment [7-9].

Aquaculture specialists have known for a long time that some fish species (specifically Tilapia) gain weight more rapidly when grown at high population densities. Tilapia (Oreochromis spp. and Sarotherodon spp.; Cichlidaceae) are grown for human consumption in over 100 nations worldwide [10]. Tilapia have a high market value potential in Egypt as well as many other parts of the world. But a main problem with growing fish has been the removal of their waste products in a cost -efficient manner. Numerous researchers have tried to decrease water consumption by developing relatively complex recirculatory systems. Even in filtered recirculatory fish culture systems, nitrates and phosphates accumulate to unacceptable levels [10]. The Hydroponic system is a simple technology that enables the growth of plants in water directly without soil [11]. Hydroponic systems have been used as one of the standard methods for plant biology research and are also used in commercial production for several crops, including lettuce, tomato and more. Plentiful hydroponic systems have been designed to study plant responses to biotic and abiotic stresses. The use of a hydroponic growth system is most beneficial in situations where the nutrient media needs to be well controlled and when intact roots need to be harvested for downstream applications [12]. Hydroponic systems can be utilized to both produce food and treat wastewater [13]. The plants can play a major role in treating the water by absorbing nutrients, toxics elements or any pollutant before discharging the treated water to the environment [14]. The production of high -quality foods of large quantity on a consistent basis are essential to the individual, cultural and national survival. As a requirement to development, human populations require high-quality proteins, vitamins and minerals for proper nutrition. Fish and vegetables are excellent sources of these food groups. Therefore, there is a strong need for establishing a technology which allows for the efficient cultivation of these food groups while conserving freshwater and land resources.

Aquaponic system a technology joining both of aquaculture and hydroponic system in one unified system, it is a developing agricultural technique that offers several environmental solutions to problems such as water pollution. Aquaponics is a viable substitute to traditional production methods, especially in regions where water scarcity is a problem [15].

Aquaponics is a system that has fish tanks which contain fish waste, as fish defecates ammonia in aquaculture system. The ammonia product accumulates in the water. Which will be used later on by beneficial bacteria that transforms ammonia into nitrates NO-3 to be used as valuable nutrients by plants. [16].

The aquaponic system makes it possible to grow fish and produce plant crops while consuming fewer resources in the process. The aquaponic system has different advantages such as increasing crop yields, which can be helpful to reduce the amount of land used for agriculture as it is also safe, low cost and allows better water management in the long run. [17].

The aim of this study is to compare between irrigation of a Celery (Apium graveolens) plants using two water types (aquaculture effluent AQE and fresh water FW) by aquaponic systems and soil pots surface drip irrigation system. The AQE was used as plant fertilizer whereas the plants treated by the AQE function as a physical filtration system by nutrients' uptake.

Experimental Part:

The major challenges of aquaponic technology are the water preservation, food safety in addition to environmental protection from pollution especially the eutrophication.

The experiment was conducted at Al-Quds university campus in Abu-Dies, 5 km east of Jerusalem in a green house. It consists of three parts the first aquaculture system, second is hydroponic system (aquaponic system) and the third is pots soil experiment. The water system is composed of two equivalent sections; one is FW and the other is AQE used for irrigation the Celery (Apium graveolens) plants in soil pots experiment and AQE for hydroponic system. The FW was used as a control in soil pots experiment.

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Aquaculture system

The aquaculture system installed in a green house, it consists of concrete bowl-shaped pool with 3 m diameter and 1.5 m depth filled with 5 cubic meters of fresh water (FW) from Abu Dies municipality, a controlling hydraulic pump system installed inside the pool to pumping the AQE to hydroponic system through a net of pipes. The pool contains 500 Tilapia fish's species that feeding (2-3) times daily as the first experiment for Tilapia fish farming.

The AQE which contains nutrients, dissolved solids, and waste by products from fishes was pumped to used as plant fertilizer to hydroponic system. About 25% of water from aquaculture pool which classified as AQE must daily discharged. The AQE pumped to hydroponic system from aquaculture pool was flows back into an aquaculture pool after treated from plants inside the hydroponic system. The same AQE was pumped also to pots experiment.

Hydroponic system:

The cultivation of plants in a nutrient solution rather than soil. The Celery plants (Apium graveolens L.) were selected to planted in hydroponic system. The hydroponic system that consisted of 24 polyvinyl chloride (PVC) open channels lines installed 1 m over ground for slope monitoring, each line about 8m in length with 10 cm diameter, each 8 meters of line had 80 small holes, with a 7cm diameter for the plants to fit in each hole. The system contains continuous water - flow and continuous aeration in a total of approximately 200 m of lines for the cycle before flow back to aquaculture pool as closed loop. The system included a hydraulic- pump as part of aquaculture system, However, water would always return by gravity through the 24 PVC pipes before flow back to aquaculture pool.

Surface drip irrigation system

Pots experiment consisted of 14 pots filled with same soil divided into two groups connected with different irrigation system programmed to irrigate the plants for 15 minutes equally. Each system consists of 0.5 m^3 storage tanks installed upper the irrigation line for both irrigation media AQE and FW. The first group (7 pots) connected to an AQE; the second group of pots were connected with fresh water FW. The same soil types were filed for all pots.

Plant selection:

Many species of plants can adapt in hydroponic system as herbs plant and medicinal plants that characterized with hairy roots, low to medium nutritional dosages like basil, coriander, chives, parsley, purslane and mint, lettuce and spinach, chard, watercress, calendula and zinnia. Several ornamental plants, vegetables and grasses were found to be suitable for aquaponic due to their adaptation capacity of each plant species to hydroponic growth and their tolerance to salt in addition to their hairy roots that helping in nutrient uptake as Geranium, Basil, Rosemary [18-22].

Celery plants (Apium graveolens L.) were selected for this experiment. Celery (Apium graveolens L) is a plant from the apiaceae family, and is one of the annual or perennial plants that grow throughout Europe and the tropical and subtropical regions of Africa and Asia [23]. Also depending on the adaptation and survival of the plant in water media, rooting composed of fine rootlets "hairy roots" that increase the absorption area of nutrients. However, celery is very sensitive to nutritional disorders and growers frequently experience a wide variety of quality problems that can often be traced to nutrient deficiencies, excesses or imbalances [24]. Young Celery plants were planted in hydroponic line holes as well as planted in the pots at same time.

Biological growth parameters of plants:

Young Celery plants were grown in PVC pipes of AQE and in soil pots experiment for both FW AQE. The experiment started in September 29th and ended November 20 about 50 days. The following biological growth parameters were monitoring during and after harvesting the Celery plants, heights and branching were monitored bi-weekly during the experiment, the branching number was measured at the beginning, during and the end of the experiment. Dry and fresh biomass were measured at the end of the experiment after harvesting.

The chemical plants tissue analysis after harvesting. The plants were harvested, dried in an open air at room temperature. The dried samples were separated into stems and leaves. Each part was weighed after drying before used for chemical tissue analysis.

Water analysis

The water quality included chemical, physical and biological analysis were performed for aquaculture water effluent (AQE) and fresh water (FW) according to standard methods [25].

The analysis was included electrical conductivity EC, pH, total dissolved solids (TDS), and most important ions (Cl^-, NO_3^-, Na^+, Ca^{+2}, total N, total K, total P) in addition total coliform TC and total plate count TPC tests.

Soil analysis

Soil samples were taken from all the pots at 0-5 cm depth that irrigated with both AQE and FW. The soil is a loam brown soil having water permeability of 7.1 × 10-6 cm/s. Soil samples were collected before plantation and after harvest, the physical, chemical and

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biological analysis performed according to standard procedures [26]. Soil was sieved, extract and diluted for analysis. The analysis included pH, electrical conductivity, TDS, total P, NO_3^-, Na^+, K^+, and Total coliform TC test.

A commercial fertilizer (13N: 13 P as P_2O_5: 13 K as K_2O) was added for FW pots experiment. 1 gm of powder fertilizer was added per 1 L of FW in the main tanks (250 g\250 L)

Statistics and Yield Component Analysis:
Results were expressed as means and standard deviations for three replicates. All statistical analyses were carried out using Statistical Analysis System (SAS) (SAS Institute Inc., Cary, NC, USA, Release 8.02, 2001). Comparison among data was carried out using the GLM procedure. The Bonferroni procedure was employed with multiple-tests in order to maintain an experiment wise of 5%.

Results and Discussion
Water analysis:
The same AQE was used for irrigation both the hydroponic system and the pots soil experiment. The AQE was used as plant fertilizer because it included the plant nutrient from fishes feed and waste. Table (2) summarizes the chemical, physical and biological analysis of both AQE and FW initially when starting the experiment (I), during the experiment (D) and in the final stage before harvesting (F).

Table (2): **Chemical, physical and biological analysis of the two type of water AQE and FW initial, during and final.**

	AQE			**FW**		
	I	**D**	**F**	**I**	**D**	**F**
pH	7.40±1.10	7.98±1.09	7.09±0.98	7.84±0.66	7.82±1.06	7.44±.0.90
EC(µS/cm)	568±2.00	545±1.90	506±2.11	612±4.04	518±2.1	470±2.30
TDS(mg/L)	284±1.04	272.5±0.8	253±1.50	306±2.02	259±1.05	235±1.15
TP(ppm)	27.18±3.03	30.27±4.2	32.12±2.09	25.27±2.01	29.27±3.78	30.10±2.65
TK(ppm)	4.1±0.68	19.81±2.33	13.63±1.74	2.60±0.85	7.63±1.65	6.14±1.11
Na^+(ppm)	41.5±6.82	61.16±10.02	61.96±9.25	34.70±4.12	69.85±11.24	61.02±10.58
Ca^{2+}(ppm)	27.18±6.43	27.6±2.11	24.1±4.57	25.27±2.98	25.11±1.02	23.80±2.57
Cl^-(ppm)	71.5±12.57	63.9±9.82	192.80±5.60	55.61±7.35	73.48±10.59	168.03±4.23
NO_3^-(ppm)	0.11±0.09	0.67±0.05	1.24±0.98	0.49±0.08	4.53±1.05	3.75±0.93
FC(cfu/100ml)	null	null	Null	null	null	null
TC(cfu/100ml)	null	null	Null	null	null	null

The results show the same characteristics of AQE and FW, both shown accumulation of micronutrients K, P and N giving enough nutrients to Celery plants. The biological analysis indicated there are no accumulation for microbes in both aquaculture pool which included variation weights of Tilapia fishes and soil this due to that this experiment is the first one for both hydroponic and pot experiment after installation the aquaponic system, in addition to that there are no sources of environmental contamination such animal fesses or rainfall that causing a contaminated to the aquaculture pool in our experiment [27]. The overall of microbe analysis shown no bad effect of bacteria in both irrigation media for hydroponic system and pot soil experiment.

Soil Pots Experiment:
The experiment consists of 14 soil pots divided into two types, the first 7 pots irrigated with AQE and the second 7 pots irrigated with FW with same soil. The soil characterized including physical, chemical and biological analysis before plantation and after harvesting were analysis. Biological growth parameters (Height, number of branches, Biomasses fresh and dry and weight of steam and leaves) were measured during the experiment and after harvesting. The chemical plant tissue analysis included (NPK) were measured for dry leaves and stems.

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Biological plant growth parameters:

Figures (1-4) shows the variation biological plant growth parameters of Celery plant in soil pots irrigated with both media AQE and FW during the experiment time and after harvesting. Figure 1 and Figure 2 shows the variation of height and branch numbers as function of time. The results of plant height and branch numbers indicated that the both parameters increasing normally with time. This finding adaptation of Celery plant in both media. There was no significant difference between the branch number for both media whereas slightly difference in plant height in the case of AQE and FW this due to availability of more nutrient concentration in AQE more than FW.

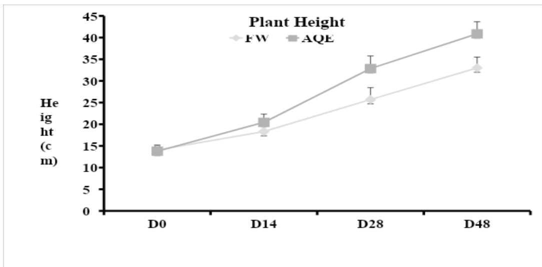

Fig 1: Variation of celery height (cm) during the pots soil experiment which irrigated with AQE and FW.

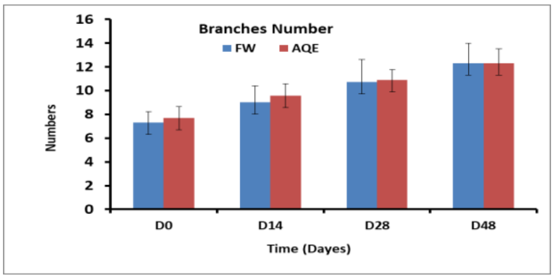

Fig (2): Variation of celery branch number during the pots soil experiment irrigated with AQE and FW.

The Celery plants were harvesting at the end of season, the plants were weighted fresh and after dried at room temperatures for few days. The dried Celery plants were separated to leaves and stems, each part were weighted before chemical plant tissue analysis. Figure 3 shows the biomasses of fresh and dried Celery plants irrigated with AQE and FW while Figure 4 shows the weight of steam and leaves of Celery plants after dried and separated.

The results of Figure 3 and 4 shows that the same trend was observed for the celery fresh and dry weights at the end of the experiment and the weight of leaves and stem. These results shown no significant difference between the Celery biomasses in both fresh or dried in AQE or FW also the same for the dried steam and leaves weight. This enhancing the adaptation of Celery plants in similarity effect of AQE and FW

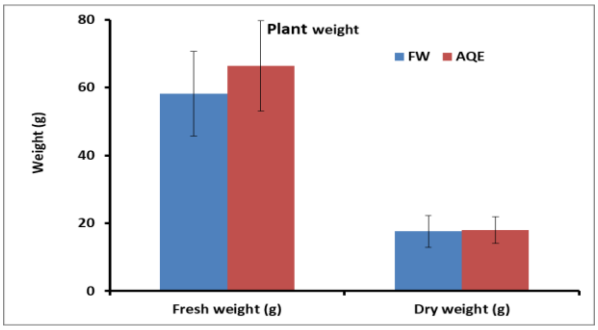

Fig (3): Variation of Celery plant weight in fresh and dry condition in grams (g) after harvesting, the Celery plants irrigation using AQE and FW.

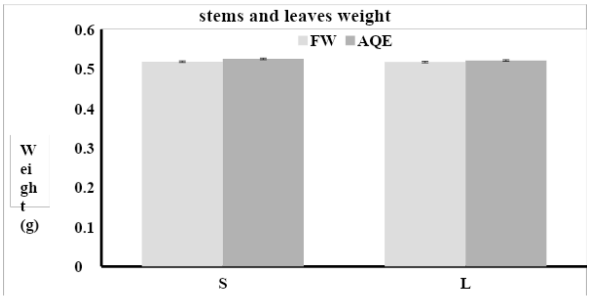

Fig (4): Variation of celery stems and leaves weight in dry condition in grams (g) after the end of plantation period using AQE and FW.

Chemical composition of plant tissues:

The dried steam and leaves Celery plant samples were analysis for chemical analysis (TN, TP and TK). Figures 5 and 6 summarizes the chemical tissues analysis of leaves and steam Celery planted in soil pots experiments irrigated with AQE and FW.

Figures 5 and 6, they show that Total k content appears in high concentration in stems and leaves compared to the total nitrogen and phosphorus. In addition, Slight difference in chemical tissue analysis for nitrogen and phosphorus in stems and leaves for Both media

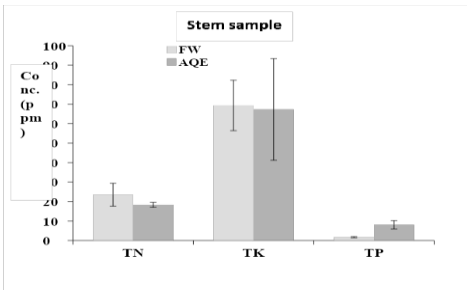

Fig. (5): Variation of nutrients content (TN, TK, TP)

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in ppm of celery stems at the end of the soil experiment using AQE as compared to FW.

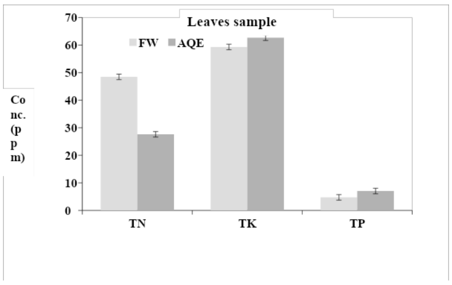

Fig. (6): Variation of nutrients content (TN, TK, TP) in ppm of celery leaves at the end of the soil experiment using AQE as compared to FW.

Soil analysis

The soil samples were analyzed before plantation and after harvesting to compare between soil characteristics before and after using AQE in physical, chemical and biological characteristics of soil. Table summarizes the characteristics of soil before and after irrigation with AQE and FW.

Table 1 shows no significant difference between the characteristics initially and finally. The results show no significant difference between the uptake in FW and AQE. Fecal coliform showed no units. The result in the soil after harvesting shows no accumulation in the salts and no difference in major nutrients as compared to fresh water.

Table (1): Chemical, physical and biological analysis of soil initially before plantation and after harvesting. The soil was irrigated with the two type of water FW and AQE.

	I Before plantation	**F after harvesting**	
		FW	**AQE**
pH	7.56±0.05	7.78±0.21	7.26±0.1
EC (µS/cm)	510±0.01	662.50±32.17	677.41±76.67
TDS (mg/L)	255±0.01	331.25±16.08	338.71±38.34
TK (mg/g)	35.90±2.00	34.78±2.00	32.25±1.50
Na^+ (mg/g)	0.15±0.02	0.15±0.03	0.16± 0.02
NO_3^-(mg/g)	0.14±0.03	0.13±0.01	0.13± 0.02
Cl^- (mg/g)	0.76±0.01	0.75±0.01	0.78±0.01
TP (mg/g)	0.13±0.01	0.11±0.01	0.12 ±0.01
FC (cfu/100ml)	null	Null	null
TC(cfu/100ml)	null	Null	null

Hydroponic experiment:

Biological plant growth parameters:

Figure 7 summarizes the variation of average Celery plants height and branch number irrigated with AQE using hydroponic system as function of time whereas Figure 8 summarizes the Variation of Celery plant weight as fresh and dry condition in grams (g) after the harvesting.

Figures 7 shows a significant increase in plant height and increasing the number of branches in AQE media showing an adaptation of Celery plants in hydroponic system and normally grown of the plants with time. Figure 8 shows the biomasses of fresh and dried masses of Celery plants after harvesting.

Plant growth parameters (plant height, branch numbers, fresh weight and dry weight) of Celery cultivated in AQE in hydroponic system is shown that he plants grew very well in the hydroponic system increasing both the height and branch number.

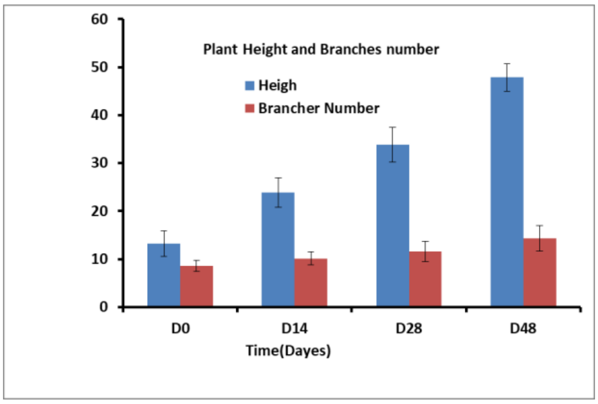

Fig 7: Variation of Celery plants height (cm) and branches Number during the Hydroponic experiment irrigated with AQE.

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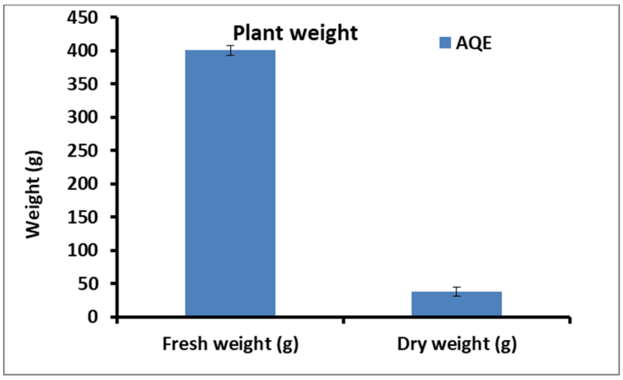

Fig 8: Variation of celery plant weight in fresh and dry condition in grams (g) after the end of the hydroponic experiment using AQE.

Chemical analysis of plant tissue:

Chemical Composition of Plant Tissues was analysis for dried steam and leaves, it included the concentration TN, TP, TK and Na^+. Figure 9 summarizes the chemical composition of plant tissue. The results indicated that all chemical composition have the same concentration in both steam and leaves. The K^+ was the highest concentration and accumulation in both steam and leaves compare to other macronutrient. The increasing the concentration of K^+ is advantage properties in both soil and water to increasing the productivity of crops [28-29]. K^+ rates from 10 to 250 ppm affected the growth and didn't interact with both phosphorus or nitrogen [30]. The result also shows no significant difference in chemical tissue analysis for phosphorus in stem and leaves, with phosphorous concentration below 10 ppm. Phosphorous is considered to be a major growth-limiting nutrient in aquatic systems [31]. P is an essential element in plants, and deficiency can significantly limit plant growth. P is important at increasing total above-ground mass, marketable trimmed yield of Celery and yield of the larger grade sizes [24].

Many studies have indicated that excessive phosphorus application can result in plant toxicity leading to inhibition of growth, leaf chlorosis, and micronutrient deficiency [32-33]. Phosphorus concentration from 5 to 125 ppm had no effect on growth [34]. The Na concentration below 15 ppm in both stem and leaves plants shown no symptoms inhibition growth or toxicity effect in the plants. Celery (Apium graveolens L.) is a salt-tolerant vegetable species which could be used for cropping with saline water [35-36]. Celery plant resistant for saline water. No symptoms of Na toxicity were observed even at the highest Na level. increasing salinity had little or no influence on plant growth, water relations, and the tissue concentration of macronutrients, but it enhanced the uptake of Na and Cl [35- 37].

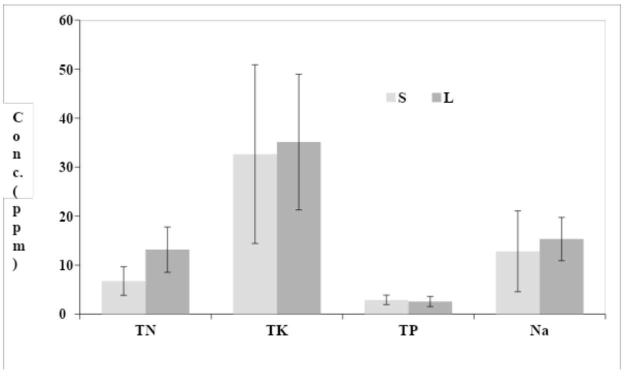

Fig (9): Variation of nutrients content of celery stems and leaves at the end of the hydroponic experiment.

Conclusion

This study has showed that combining Aquaponics and surface drip irrigation system in the plantation of Celery plants fulfilled the goal of maintaining sustainable environment with low- cost technology and social benefits. This research demonstrated that Celery's biological growth parameters and the chemical plant tissue analysis of stems and leaves revealed that irrigation with both AQE and FW is comparable and there are is no salinity accumulation in both parts. Therefore, it can be safe to state that Celery plants can be planted with great efficiency utilizing the AQE the same as fertilized FW. This study has proved no negative impact on the aqua-effluent water treatment on plants or on the environment. The cultivation in hydroponic system with AQE prefer for soil experiment due to the disadvantages of cultivation that need large surface compare to hydroponic that need les area

References:

[1] Abu-Madi, M., Braadbaart, O., Al-Sa'ed, R., Alaerts, G. (**2003**). Willingness of farmers to pay for reclaimed wastewater in Jordan and Tunisia. Water Science & Technology Water Supply, VHL Search Portal Information and Knowledge for Health. 3, 115–122.

[2] Alsharif, K., Feroz, E., Klemer, A., Raab, R. **)2008(.** Governance of water supply systems in the Palestinian Territories: A data envelopment analysis approach to the management of water resources. J. Environ. Manage. 87, 80–94.

[3] Baganz, G.F.M., Junge, R., Portella, MC. et al. **(2021).** The aquaponic principle — It is all about coupling. Rev Aquac. 14, 252–264. https://doi.org/10.1111/raq.12596.

[4] Tom, A. P., Jayakumar, J. S., Biju, M., Somarajan, J., & Ibrahim, M. A. **(2022).** Aquaculture

wastewater treatment technologies and their sustainability: A Review. Energy Nexus, 4, 100022.

[5] OECD/FAO. **(2018).** OECD-FAO agricultural outlook, OECD agriculture statistics (database). 10.1787/agr-outl-data-en.

[6] Wei, Y., Li, W., An, D., Li, D., Jiao, Y., & Wei, Q. **(2019).** Equipment and Intelligent Control System in Aquaponics: A Review. IEEE Access, 7, 169306-169326. doi: 10.1109/ACCESS.2019.2953491.

[7] Wang, Y., Fu, L., Fu, Y., Li, B., & Jiao, B. **(2011).** Aquaculture Industry in China: Current State, Challenges, and Outlook. Reviews in Fisheries Science, 19(3), 187-200. doi: 10.1080/10641262.2011.573597.

[8] Wahyuningsih, S., Effendi, H., & Wardiatno, Y. **(2015).** Nitrogen removal of aquaculture wastewater in aquaponic recirculation system. Aquaculture, Aquarium, Conservation & Legislation, 8(4), 491-499.

[9] Endut, A., Jusoh, A., & Ali, N. A. **(2014).** Nitrogen budget and effluent nitrogen components in aquaponic recirculation system. Desalination and Water Treatment, 52(4-6), 744-752.

[10] Balarin, J. D., & Haller, R. D. **(1982).** The intensive culture of tilapia in tanks, raceways, and cages. In J. F. Muir & R. J. Roberts (Eds.), Recent Advances in Aquaculture (pp. 267-355). Westview Press.

[11] Jayachandran, A., Jain, S., Saini, S., & Maurya, P. **(2022).** Hydroponics: An art of soilless farming. The Pharma Innovation Journal, SP-11(9), 1049-1053.

[12] Nguyen, N. T., McInturf, S. A., & Mendoza-Cózatl, D. G. **(2016).** Hydroponics: A Versatile System to Study Nutrient Allocation and Plant Responses to Nutrient Availability and Exposure to Toxic Elements. Journal of Visualized Experiments, 113.

[13] Sundar, P., Jyothi, K., & Sundar, C. **(2021).** Indoor Hydroponics: A Potential Solution to Reuse Domestic Rinse Water. Biosciences Biotechnology Research Asia, 18(2), 373–383. https://doi.org/ 10.13005/bbra/2924.

[14] Cifuentes-Torres, L., Mendoza-Espinosa, L. G., Correa-Reyes, G., & Daesslé, L. W. **(2020).** Hydroponics with wastewater: A review of trends and opportunities. Water and Environment Journal, 12617. https://doi.org/10.1111/wej.12617.

[15] Krastanova, M., Sirakov, I., Ivanova-Kirilova, S., Yarkov, D., & Orozova, P. **(2022).** Aquaponic systems: biological and technological parameters. Biotechnology & Biotechnological Equipment, 36(1), 305-316. doi: 10.1080/13102818.2022.2074892.

[16] Puteri Edaroyati, M. W., Siti Aishah, H., & Al-Tawaha, A. M. **(2017).** Requirements for inserting intercropping in aquaponics system for sustainability in agricultural production system. Agronomy Research, 15(5), 2048–2067. https://doi.org/10.15159/AR.17.070.

[17] Rajalakshmi, M., Manoj, V. R., & Manoj, H. **(2022).** Comprehensive Review of Aquaponic, Hydroponic, and Recirculating Aquaculture Systems. Journal of Experimental Biology and Agricultural Sciences, 10(6), 1266-1289.

[18] Licamele, J. **(2009).** Biomass production and nutrient dynamics in an aquaponics system [Ph.D. thesis]. University of Arizona, Tucson, AZ, USA.

[19] Xanthoulis, D., Dumont, P., & Wauthelet, M. **(2003).** Epuvalisation: A Developing Technique. Experiences, results in different countries. In Proceedings of the 2nd International Symposium on Ecological Sanitation, Lübeck, Germany, 7–11 April 2003 (pp. 527-530).

[20] Qurie, M., Abbadi, J., Scrano, L., Mecca, G., Bufo, S. A., Khamis, M., & Karaman, R**. (2013).** Inland Treatment of the Brine Generated from Reverse Osmosis Advanced Membrane Wastewater Treatment Plant Using Epuvalisation System. International Journal of Molecular Sciences, 14(7), 13808-13825. https://doi.org/10.3390/ijms140713808.

[21] Qurie, M., Daghra, S., Khamis, M., Kanan, A., Barghouthi, Z., & Karaman, R. **(2019).** Rosemary (Rosmarinus officinalis) plants irrigation with secondary treated effluents using epuvalisation technology. Net Journal of Agricultural Science, 7, 69-77.

[22] Qurie, M., Daghra, S., Khamis, M., Kanan, A., Barghouthi, Z., Alimari, A., & Karaman, R. **(2019).** Application of the epuvalisation technology for the tertiary treatment of secondary treated effluents using geranium plants. Annals of Agricultural Sciences, 64(2), 237-243. doi:10.1016/j.aoas.2019.12.007.

[23] Gauri, M., Javed Ali, S., & Shahid Khan, M. **(2015).** A review of Apium graveolens (Karafs) with special reference to Unani medicine. International Archives of Integrated Medicine, 2, 131-136.

[24] Li, Y., Wang, T., Li, J., & Ao, Y. **(2010).** Effect of phosphorus on celery growth and nutrient uptake under different calcium and magnesium levels in substrate culture. Horticultural Science, 37(3), 99–108.

[25] American Public Health Association (APHA). **(2005).** Standard Methods for Examination of

Journal of Chemical Health Risks
www.jchr.org
JCHR (2024) 14(1), 3046-3054 | ISSN:2251-6727

Water and Wastewater Analysis, 21st edition. Washington DC, USA: APHA.

[26] Ryan, J., Harmsen, K., & Rashid, A. A. **(1996).** Soil and Plant Analysis: Manual Adapted for the West Asia and North Africa Region. ICARDA, Aleppo, Syria.

[27] Valenzuela-Armenta, J. A., Díaz-Camacho, S. P., Cabanillas-Ramos, J. A., de Jesus Uribe-Beltrán, M., de la Cruz, M. D. C., Osuna-Ramírez, I., & Báez-Flores, M. E. **(2018).** Microbiological analysis of Tilapia and water in aquaculture farms from sinaloa. Biotecnia, 20(1), 20-26.

[28] Khalid, K. A. (2006). Influence of water stress on growth, essential oil, and chemical composition of herb (Ocimum basilicum L.). International Agrophysics, 20, 289-296.

[29] Westgate, M. E., & Grant, L. T. **(1989).** Water deficits and reproduction in maize. Plant Physiology, 91, 862-867.

[30] Dufault, T. J. **(1985).** Relationships among nitrogen, phosphorus, and potassium fertility regimes on celery transplant growth. HortScience, 20, 1104-1106.

[31] Seitzinger, S., Mayorga, E., Bouwman, A., Kroeze, C., Beusen, A., Billen, G., Van Drecht, G., Dumont, E., Fekete, B., Garnier, J., & Harrison, J. A. **(2010).** Global river nutrient export: A scenario analysis of past and future trends. Global Biogeochemical Cycles, 24, GB0A08. https://doi.org/10.1029/2009GB003587.

[32] Hawkin, H. J., Hettasch, H., Mesjasz-Przybylowicz, J., Przybylowicz, W., & Craner, M. D. **(2008).** Phosphorus toxicity in the Proteaceae: A problem in post-agricultural lands. Scientia Horticulturae, 117, 354-365.

[33] Burnett, S.E., & Zhang, D. **(2008).** Effects of phosphorus on morphology and foliar nutrient concentrations of hydroponically grown Scaevola aemula R. Br. 'Whirlwind Blue'. HortScience, 43, 902–905.

[34] Dufault, T.J. **(1985).** Relationships among nitrogen, phosphorus, and potassium fertility regimes on celery transplant growth. HortScience, 20, 1104–1106.

[35] Pardossi, A., Bagnoli, G., Malorgio, F., Campiotti, C. A., & Tognoni, F. **(1999).** NaCl effects on celery (Apium graveolens L.) grown in NFT. Scientia Horticulturae, 81(3), 229-242. doi:10.1016/S0304-4238(99)00020-5.

[36] Francois, L.E., & Maas, E.V. **(1994).** Crop response and management on salt-affected soils. In Pessarakli, M. (Ed.), Handbook of Plant and Crop Stress (pp. 149–181). Marcel Dekker.

[37] Pardossi, A., Malorgio, F., & Tognoni, F. **(1999).** Salt tolerance and mineral nutrition for celery. Journal of Plant Nutrition, 22(1), 151-162.