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Research Article

Growth and yield of cucumber and tilapia fish in aquaponics under UAE climatic condition

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ABSTRACT

The healthiest and most effective method of producing food is aquaponics, particularly in arid regions. In comparison to conventional crop production, aquaponics uses less than 90% of the water, produces crops that grow more quickly, and does not employ pesticides. With an average weight of 17g, fish Oreochromis niloticus tanks were stocked with 120 fish per m^2. Three times per day, Nile tilapia were fed a floating commercial tilapia diet until they were full. Three cucumber plants were planted per square meter in plant culture raceways. Water, feed, and electricity usage are all tracked in aquaponics systems. The growth characteristics and monthly production of the fish and cucumber were noted. Environmental aspects of the system, including light intensity, temperature, and water quality parameters, were assessed. Six months were spent conducting the experiment in a two-time cultivation. Three months were needed from one seedling to harvest; the first month was spent growing and flowering the plant, and the second and third months were used to harvest the cucumbers. With an input of 992.67 tons of feed, 12110.13 K.Wh of electricity, and 59.20 m^3 of water consumption, each aquaponics system produced on average 3.2 tons of cucumber in a 120 m2 area and 0.5 tons of fish in a 15 m^3 area.

INTRODUCTION

Aquaponics is a technology that combines intensive aquaculture with hydroponic vegetable production. Dr. James Rakocy and his team at the University of the Virgin Islands created modern aquaponics as a way to produce a lot of fish at a high density [1]. In an aquaponic system, the plants in vegetable production raceways are grown using nutrient-rich fish feces and metabolic wastes. The fish production facility benefits from the fact that plant roots and root bacteria separate fish-harming ammonia and fecal wastes from water. Fish waste, leftover feed, and environmental algae growth are the sources of these wastes. Under normal circumstances, these toxic waste materials ought to be eliminated from the aquatic environment either by continuously regenerating the environment with fresh water input into the systems with water flow or by mechanically and biologically filtering the water; in aquaponics systems, filtration is directly carried out by plant roots through natural means [2,3]. The vegetables most frequently used for this purpose in aquaponic systems are lettuce, spinach, kale, basil, chard, cucumber, onion, and tomato [4,5]. It is crucial to select plants that are readily adaptable to the culture medium. However, the use of aquaculture on a large scale is constrained by a lack of available land and water as well as environmental issues brought on by emissions and waste [6]. Aquaculture's future growth thus depends on the creation and implementation of new technologies that intensify fish farming while maximizing nutrient and water reuse and reducing environmental impacts [7].

Global aquaculture production increased at an average annual rate of 6.2% over the past few decades, making up 44.1% of all production (including that used for food uses) in 2014. [8]. Aquaponics, an inventive fusion of aquaculture and hydroponics, may offer a remedy for these issues. Fish excrement supplies nutrients for plant growth, and the system can repurpose the treated water. The number of publications on various aquaponics systems (different setups, different plants, and different fish species) has been growing exponentially over the past decade as aquaponics has gained popularity [9]. Its role in ensuring food security would be especially important given that the world's population has surpassed 7.2 billion people and is expanding quickly. Around 2050, it is predicted to reach 9.6 billion, with more than 75% of people living in cities. As a result of the population growth, there will be a rise in the demand for animal protein [10,11]. However, rising but unstable energy and oil prices, climate change, and pollution pose a threat to conventional farming's ability to meet this demand in the future, including through intensive animal protein production. These problems are made more difficult by resource constraints such as declining arable land, limited freshwater resources, degrading soil, and soil nutrient depletion [12,13].

A promising sustainable food production technique, the intertwining of aquacultural and hydroponic procedures enables some of the shortcomings of the individual systems to be addressed. According to [14], who define sustainable agriculture as a process that does not exhaust any non-renewable resources that are necessary to agriculture in order to sustain the agricultural practices, aquaponics can be regarded as a sustainable agricultural production system and add that one of the key features of aquaponics is "designing systems that close nutrient cycles," which can be used to create sustainable agricultural production [15].

Numerous fish and vegetable species may be suitable for aquaponic farming. However, the most widespread fish species are the African catfish (*Clarias gariepinus*), rainbow trout (*Onchorynchus mykiss*), common carp (*Cyprinus carpio*), and Nile tilapia (*Oreochromis niloticus*). These fish can be combined with leafy vegetables like lettuce (*Lactuca sativa*), basil (*Ocimum basilicum*), and spinach (*Spinacia oleracea*). The choice of plant species currently largely depends on experience, considering the fish tank stocking density and subsequent nutrient concentrations of aquaculture effluent [16]. According to [17], cucumber (*Cucumis sativus*) is a significant hydroponic greenhouse crop with the potential to be produced in aquaponic systems [18]. In 2002, more than 2.2 million metric tons of tilapia (*Oreochromis* sp.) were produced globally, with farmed aquaculture accounting for 68% of that total [19]. Alternatives to wild fisheries and field-grown vegetable production that are responsibly designed and managed include aquaculture and hydroponic systems [20, 18].

Therefore, the purpose of this study was to investigate the production traits of an aquaponic cucumber and Nile tilapia unit in arid greenhouse environments. The study aimed to explore the potential of aquaponic systems as a sustainable alternative to traditional agricultural practices. By combining aquaculture and hydroponics, these systems can produce both fish and vegetables in a closed-loop system that minimizes waste and maximizes efficiency. The focus of this particular study was on the production traits of an aquaponic unit that paired Nile tilapia with cucumber plants in arid greenhouse environments. The results of the study could have important implications for the future of agriculture, particularly in regions where water is scarce or where traditional farming methods are not feasible. Overall, the findings suggest that aquaponics systems have great potential as a sustainable and efficient means of food production, and further research in this area is warranted.

MATERIALS AND METHODS

System description

Eight primitive tetraploid wheat genotypes and two local cultivated Three aquaponics units, each one inside a 400 m2 greenhouse with a 120 m^2 plantation area in four turfs (each 24.4* 1.23* 0.42m^3 L W H covered with 2-inch-thick perforated Styrofoam sheets), two circular (3m diameter and 1.2 m height) fish tanks each with 7.7m^2. Water consumption from evaporation and evapotranspiration and cooling system were measured using two water meters (KENT PSM 15mm water meter PN 16, GRUNDFOS, England. Electricity consumption was measured using one electrical meter (Elster A1100 polyphase meter by: Elster metering Ltd. Stafford). Two air cooler fan: Euroemme® EM50n, Exhaust fan with 1.5 HP motor. (fan) Propeller diameter 1,270 mm. 6 Kista, blade, Sweden. One WATER PUMP for cooling pad: GRUNDFOS DK-8850, 1 HP single phase motor Capacity of water pulling 5 m^3/h.

Culture condition

Fish tanks were stocked with 120 fish m^3 of *Oreochromis niloticus* fingerlings with an average weight of 14 g. Nile tilapia were fed floating 36% protein commercial tilapia floating feed from Arabian Agricultural Services Company ARASCO, Saudi Arabia. Tilapia growth and growth parameters such as; fish weight gain (WG), feed intake (FI), and feed conversion ratio (FCR), Additionally, protein and fat deposition values were calculated as followed; where WG is the weight gain, W2 is the mean final weight (g) per fish and W1 is the mean initial weight (g) per fish.

The cucumber seeds were directly seeded on the culture raceways floated Styrofoam sheets with the help of rock wool contained plastic cups at the rate of 3 Cucumber plants per square meter. The experimental period is prolonged to six months for two harvesting; each harvest period is 3 months.

Analyses

Light intensity was measured by the LUX meter (Make: Tekemura; Model: DM – 28) weekly. Water quality from tanks were analyzed once every week; pH, Temperature and Electrical conductivity was measured using HACH HQd portable meter (Make: HACH; Model: HQ 40d), TDS (HACH TDS meter Pocket pro™ (HACH; Model: DR 900), TAN (Total Ammonia Nitrogen) (Salicylate method) Nitrite (USEPA Diazotization Method), Nitrate (Cadmium Reduction Method) and Fe (FerroVer® Method) using HACH portable calorimeter (HACH; Model: DR 900). DO, Orion star™ and Star plus meter (Make Thermo Scientific; Model: Orion 4 star), Total Alkalinity and acidity to be measured by the Titration method of APHA [21], Minerals Analysis was done using ICP-OES. (Inductively Coupled Plasma Optic Emission Spectroscopy (ICP_OES) Model 710- ES, Varian, United States). Experimental diet and fish, lettuce and sludge samples were analyzed in triplicate for moisture using a forced air oven, crude protein by macro-Kjeldahl, crude fat by ether extraction method total ash by muffle furnace (550°C) for 24 h, and CF (for feed samples only) using Lab. Conco (Lab. Conco Corporation, Kansas City, MO, USA). The methods of analysis were performed as prescribed method [22]. Growth energy was calculated based on standard energetic values for protein (23.67 MJ kg)1), carbohydrate (17.17 MJ kg-)1) and lipids (39.79 MJ kg)1) [23].

Statistical analysis

All data were subjected to one-way ANOVA to determine significant ($P < 0.05$) differences among the treatment means. Student–Neuman–Keuls multiple range test was used to distinguish significant differences among treatment means. All statistical analyses were conducted using a system for Windows (version 8.0, SAS Institute, Cary, NC, USA, 1995).

Calculated parameters

Several parameters were calculated as followed;

1. Amount of Cucumber produced using kg of fish feed = amount of Cucumber produces/ amount of feed fed
2. Productivity of unit of water in terms of Cucumber and fish
    - Amount of Cucumber produced kg/vol. of water used m^3
    - Amount of fish produced kg/volume of water used m^3
3. Electrical consumption per unit Cucumber and fish production
    - Amount of Cucumber produced kg/electrical consumption kW
    - Amount of fish produced kg/electrical consumption kW.

RESULTS

Water quality parameters

No signs of disease or pests affected cucumber plants or cucumbers during the six-month experiment. The three aquaponic systems didn't differ significantly from one another. From the beginning of spring until the middle of summer is the experimental period. As a result, the water's temperature significantly rose from the first to the last month. Other water quality parameters include the following: total ammonia nitrogen (TAN), dissolved oxygen (DO), and nitrate NO_3 levels, as shown in Table 1. pH was unaffected but slightly decreased from the first to the last month. Between the first and last months, there was no discernible difference in the nitrite level.

Total dissolved solids significantly increased over time, but relative increases in electric conductivity occurred in the final months (Fig. 1). In addition, a noticeable increase in light intensity was observed from the beginning to the end of the experiment (Fig. 2). However, there were no appreciable differences in any of the parameters between the two aquaponics systems.

Fish production

The growth and feed efficiency performance of *O. niloticus* growth parameters such as weight gain, feed intake and feed conversion ratio, are shown in Table 3. There were no significant differences between the three aquaponics units among the following parameters initial and final weight of fish, weight gain, feed intake, and feed conversion rate ($P > 0.05$).

Table 1. Water quality parameters of the six months experimental period.

Month	Temperature (°C)	DO (mg/l)	pH	Ammonia (mg/l)	Nitrate (mg/l)	Nitrite (mg/l)
1	21.76d	5.03a	6.68a	0.16d	5.62d	0.47ª
2	21.97d	5.00ab	6.49b	0.25cd	12.62c	0.29ª
3	21.12bc	4.99ab	6.41b	0.31cd	20.14bc	0.15ª
4	23.73b	5.18b	6.40b	0.56bc	17.70b	0.18ª
5	27.58a	4.67c	6.42b	1.08a	23.93a	0.24ª
6	28.44a	4.53c	6.47b	0.73b	21.63bc	0.18ª

Each columns showed superscripts means significant difference ($P < 0.05$).

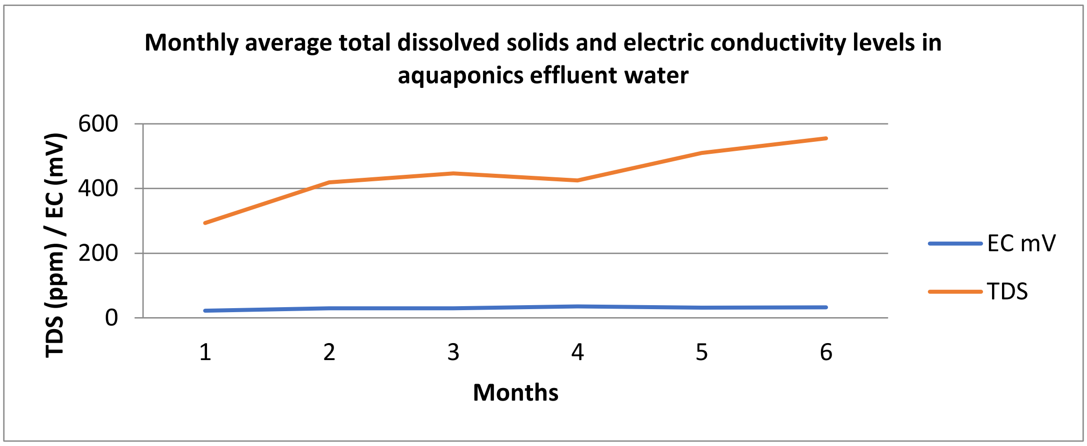

Fig. 1. TDS and EC of water from aquaponic tank.

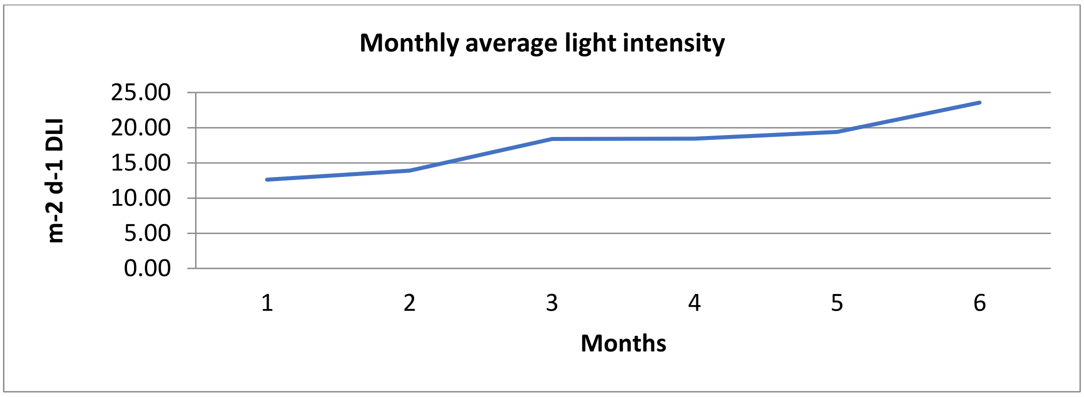

Fig. 2. Monthly average light intensity.

Table 2. Fish *Oreochromis niloticus* production characteristics growth and feed conversion values during the six months' experiment duration.

System	W11(g fish^{-1})	W22 (g fish^{-1})	WG3	FCR 4	FI5 (g fish-1)	Survival rate
1	16.47a	306.94 a	293.47 a	1.54 a	471.5 a	97.94 a
2	18.50 a	366.85 a	348.35 a	1.40 a	515 a	95.94 a
3	17.97 a	359.62 a	341.65 a	1.40 a	502. a 5	97.69 a
Average	18	344	328	1.44	496	97

Each columns showed superscripts means significant difference ($P < 0.05$), w1 = Mean initial weight, w2 = Mean final weight, WG = Weight gain, FCR = Feed conversion ratio (feed (dry) intake (g)/wet weight gain (g) per fish for the eight-months period), FI = Feed intake.

Table 3. Average total production and physiological characteristics of cucumber at each aquaponics system.

Aquaponics System	No of plant	Cucumber yield (Kg)	Weight / cucumber (gm)	Length /Cucumber (cm)	Width /Cucumber (mm)	Yield / plant (kg)	Yield /m^2
1	347	1014.23 a	65.87 a	11.78 a	27.50 a	2.92 a	8.45a
2	347	1051.11 a	64.58 a	11.82 a	27.89 a	3.02 a	8.75a
3	347	1150.54 a	66.38 a	12.11 a	27.59 a	3.31 a	9.58a
Average	347	1071.96	65.61	11.9	27.66	3.08	8.92
Total	1041	3215.88	65.61	11.9	27.66	3.08	8.93

Each columns showed superscripts means significant difference ($P < 0.05$).

Cucumber production and physical quality

During the period of experiment, a total of four months is harvesting period. The harvesting periods cucumber production characteristics namely; monthly average production, no, of Cucumber in a plant, physical character of cucumber (weight, height and width), total yield in a plant and production in one m^2 are indicated in Table 4. The monthly average cucumber production show no significant different from in between aquaponics system. As well as the physical character, like cucumber weight, length and width also show no significant different in throughout of the period of experiment (Table 3). In each month average cucumber production were significantly similar between the three aquaponic units while they gradually increased with time (Each month harvest) within each unit (Fig. 3).

Proximate composition of input and output materials

The cultivated fish, cucumber, fish feed and fish produced sludge total proximate composition like Crude protein, fat, fiber carbohydrate, moisture, ash and energy level are provided in Table 4. In the present study, the cultivated cucumber plants parts are subjected to analyzed the total content of macro and micro nutrients level. The results are provided in Table 6. In this result in between the samples had no significant different. But the different part of samples shows significant increment. Maximum minerals are significantly higher in root sample followed by the stem, leaves and cucumber respectively.

Total input and output yield

In the current study, Table 5 shows the average total system input and output, which includes feed, water, and electricity consumption along with productions of cucumber, fish, and slugs. The aquaponic units did not differ in any of the aforementioned factors. Table 7's water productivity calculation revealed that each unit utilized an average of 992.67 kg of fish feed, 12887 kwh of electricity, and 59.20 m^3 of additional water per unit. Within a six-month period, the 992.67 kg of fish feed resulted in a yield of 535.33 kg of fish, 3215.88 kg of cucumbers, and 41.41 kg of sludge. Table 7 lists the yield of fish and cucumber for each kilogram of fish feed produced. 310 g of cucumber and 597.38 g of fish were produced per kg of feed. 1 m^3 of water yielded 9.23 kg of fish, 26.8 kg of cucumbers, and 55.45 kg of cucumbers per m^3. The data presented in Table 7 highlights the significant impact that the use of fish feed, electricity, and water has on the yield of fish and cucumbers. In a six-month period, an average of 992.67 kg of fish feed was used, resulting in a yield of 535.33 kg of fish, 3215.88 kg of cucumbers, and 41.41 kg of sludge. This translates to a production rate of 310 g of cucumber and 597.38 g of fish per kilogram of feed produced. Additionally, the use of 59.20 m^3 of water yielded 9.23 kg of fish, 26.8 kg of cucumbers, and 55.45 kg of cucumbers per m^3 used. It is clear that optimizing the use of these resources can have a significant impact on overall production rates and efficiency in aquaponics systems.

Water quality parameter

Water quality parameters, namely temperature, DO, pH, and total ammonia, nitrite, and nitrates (Table 1), of the water within the adequate range for raising the experimental Tilapia Oreochromis niloticus. The present water quality parameters are similarly agreed with the statements of previous researchers [24-29]. The present water quality results for cucumber cultivation in aquaponics systems are similarly agreed with by [30,31] in the study of cucumber cultivation in aquaponics systems. The number of the nitrifying bacteria (Nitrosomonas and Nitrobacter) increased with time to keep the increasing levels of ammonia production from growing fish within safe levels, which indicates a successfully active biological filter. So, the nitrate level is significantly improving in the initial and final months.

The levels of total dissolved solids were significantly improved throughout the period of experimentation in the system as the fish grew. Consequently, fish waste increased while cucumber plants utilized some of the dissolved solids throughout the six-month duration. The levels of electrical conductivity and the total amount of dissolved ions in the water also gradually increased with time for the same reason (Fig. 2). The level of TDS and electrical conductivity improvements similarly agree with the earlier reports [1, 29]. Each aquaponics system is well capable for cultivation the fish and cucumber cultivation. Light intensity is one of the important factors for plant growth and energy production of plants, the higher plants required light intensity was higher than the minimum for plant growth (15-24 m^{-2} d^{-1}) [32].

Fish production

The growth and feed efficiency performance of *O. niloticus* namely; fish weight gain (WG), feed intake (FI), and feed conversion ratio (FCR), are shown in Table 2 and the fish proximate composition is provided in Table 4. There were no significant ($P > 0.05$) differences between the three aquaponics units with regard to fish initial, final weights, weight gain, feed intake, and feed conversion rate. Feed conversion ratio of the present study agreed with the FAO statements which indicated that tilapias have an FCR of 1.4–1.6 [33]. Also, the fish growth parameters like, weight gain, feed intake, feed conversion ratio and body proximate composition are similarly agreed with the findings of some previous studies [34-38].

Cucumber production and physical and proximate nutrient quality

In the present study, the cucumber production quality, physical quality is provided in Table 2 and Fig.3. The produced cucumber proximate composition provided in Table 4. The produced cucumber average weight, length and width is 65.61 gm, 11.90 cm 27.66 mm respectively. The total yield in an aquaponics system is 3.2 tons and the total no of cucumber is 211060.9. The cultivated cucumber contain total proximate composition like Moisture, ash, crude protein, fiber, fat carbohydrate and energy as follows 95.25%, 16.97%, 8.43%, 16.56%, 0.36%, 57.68% and 1.20 k.cal.J. the present results are similarly agreed with the findings of [39-42].

In the present study, the cultivated cucumber plants different parts are subjected to analysed the total content of macro and micro nutrients level. The different part of samples shows significantly different. Maximum minerals are significantly higher in root sample followed by the stem, leaves and cucumber respectively. This result revealed that the mineral absorption and accumulation is well in the all part of aquaponics cucumber plants. So, the roots contain high content of minerals comparatively other parts. The present result are similarly reported by the previous aquaponics integrated crop cultivation researches (43,44).

Aquaponics units input output

In the present study, the total system average input and output means feed, water and electric consumption produced cucumber, fish and slugdge productions are provided in Table 5. All the above parameters did not vary between the aquaponic units. Water productivity was calculated from Table 7 and showed that each unit averagely used 59.20 m^3 of addition water and 12887 k.wh of electricity and 992.67 kg of fish feed. The 992.67 kg of fish feed produced the yield is 535.33 kg of fish, 3215.88 kg of cucumber and 41.41 kg of sludge within the six-month duration period. Each kg of fish feed produced cucumber and fish yield are tabulated in Table 7. Each kg of feed produced 310 gm of cucumber and 597.38 gm of fish. The each m^3 of water produced 55.45 kg of cucumber and 26.8 kg per m2 and 9.23 kg of fish from 1m^3 of water.

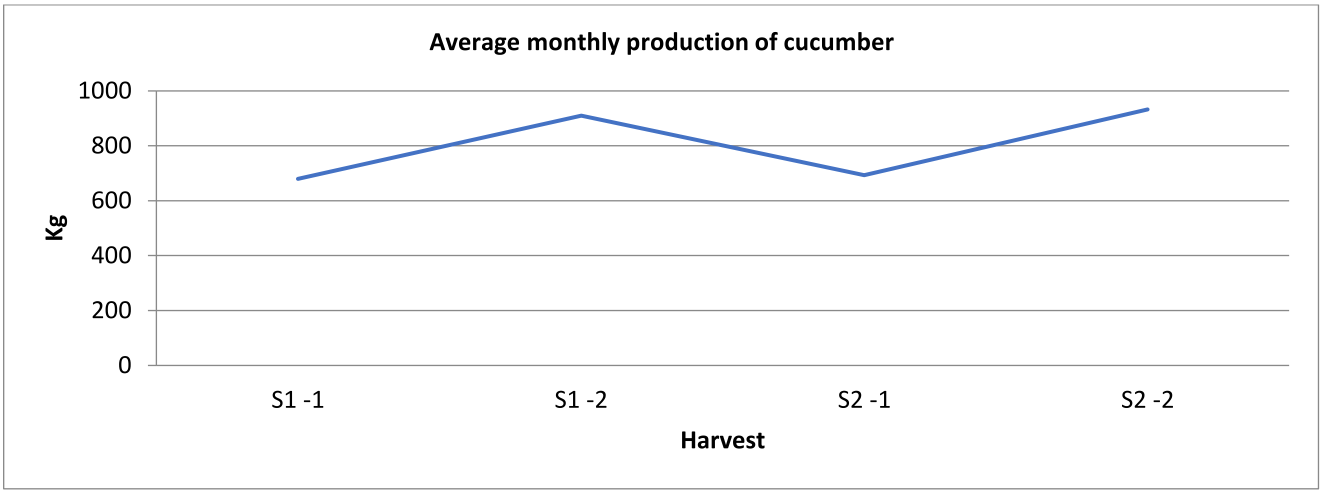

Fig. 3. Average monthly production of cucumber. *S1 – seedling 1 (2 month harvest), S2 – seedling 2 (2 month harvest)*

Table 4. Proximate composition (%) of fish feed, fish, Cucumber, and sludge on dry matter bases.

Factors	Moisture	Ash	Crude Protein	Crude Fiber	Crude Fat	CHO	Energy
Fish feed	10.5	11	38.9	3.17	9.3	37.62	1.26
Fish	74.66	12.11	52.52	1.65	29.55	4.16	2.49
Sludge	12.33	28.76	26.64	6.51	6.25	31.82	1.06
Cucumber	95.25	16.97	8.43	16.56	0.36	57.68	1.20

Table 5. Average input and output of each of the three units of (400 m^2 of aquaponic unit) inside a greenhouse each in eight months' duration in three replicates under the Arid land condition Input and output in Aquaponics system.

Input		Out put	
Water (m3)	59.20	Fish (kg)	535.33
Electricity (k.wh)	12110.13	Cucumber (kg)	3215.88
Feed (kg)	992.67	Sludge (kg)	41.41

Table 6. Micro and macro minerals contents (ppm) in cucumber, stem, leaves and root.

Samples	Ca	Co	Cu	Fe	K	Mg	Mn	Mo	Na	P	S	Zn
Cucumber	7198.41b	0.18c	11.76b	103.68b	20676.60b	3023.63b	9.46b	5.25a	1291.77c	7718.83b	3245.09c	42.69c
Stem	26595.27a	0.19c	9.43c	59.55b	19546.63b	6160.20a	6.89b	2.39a	4333.51b	3489.16c	2268.66d	48.41c
Leaves	37777.97a	0.40b	19.23b	496.22b	26467.14a	6198.35a	74.81b	2.24a	1456.50c	16809.41a	5372.20a	119.95b
Root	15264.16b	4.02a	37.46a	1720.65a	13742.12c	6093.92a	467.42a	1.42a	11885.18a	5266.92c	4603.06b	153.05a

Each columns showed superscripts means significant difference ($P < 0.05$).

Table 7. Total yield of cucumber and fish with the consumption of water and electricity.

System	Fish total (kg)	consumed feed (kg)	1kg feed produced fish (gm)	1 m^3 of water produced fish	Cucumber yield (kg)	Cucumber yield / m^3	1kg feed produced Cucumber (gm)	Electric usage (K.Wh)	Cucumber yield / m^2	Sludge
1	481	943	466.09	8.29	3191.70	55.03	0.295	12460.00	26.60	28.12
2	563	1030	571.43	9.71	3195.60	55.10	0.322	11935.20	26.63	46.81
3	562	1005	754.63	9.69	3260.33	56.21	0.308	11935.20	27.17	49.28
Average	535.33	992.67	597.38	9.23	3215.88	55.45	0.310	12110.13	26.80	41.41

In this study tilapia recovered sludge from the aquaponics system was 5% and these same results reported in the percentage of tilapia sludge ranges from 5-10% of consumed feed [45]. It is known that percentages of sludge of feed intake depends on many factors like feed formulation feed intake, feeding duration and fish size and species. Calculated fish feeding to cucumber ratio in the present study was 46 g of feed/m^2/day of plant growing are per day and a m^2 area planted 3 cucumber plants. As per FAO [33] recommendation higher plants plantation in aquaponics system 4-8 plants/ m^2 and the plants required 50-80g feed/m^2/day. So, the feeding ratio is similarly agreed with the previous findings [33. 45]. At this ratio (3 plants/ m2 required 46 g of feed/m^2 of plant growing area/day) the nutrient accumulation rate decreased and the hydroponic tanks were capable of providing sufficient nitrification. Finally, in this study results revealed that the aquaponics system one m^2 is capable to produce 26.80 kg of cucumber and one m3 of water produced 9.23 kg of fish within the six-month periods and these findings were similarly reported by the previous aquaponics and economic feasibility projects [46].

CONCLUSION

With the aid of input materials like 992.67 kg of feed, 12880 kWh of electricity, and 58.20 m^3 of additional water, it was determined that the aquaponics system was effective in producing 3.2 tons of cucumber, 535 kg of fish, and 41.41 kg of sludge over the course of the six-month aquaponics experiment. It means that in a period of six months under UAE climatic conditions, 1 m^3 of water produced 9.23 kg of fish and 55.45 kg of cucumber, and per kg of feed produced 597.39 g of fish and 310 g of cucumber. The results of the current study showed that in an aquaponics system, fish are effectively used as fish food and cucumber plants effectively use fish waste to grow and produce cucumbers. The nitrification process is effectively carried out in this system, aside from the biological system. The integration of fish and plant production in an aquaponics system offers a sustainable and efficient method of food production. The results of the study suggest that the system can produce significant yields of both fish and cucumbers with minimal waste. This method of farming also has the potential to reduce water usage and minimize the environmental impact of agriculture. The nitrification process, which converts ammonia into nitrate, is an essential component of this system, as it provides the necessary nutrients for plant growth. Overall, aquaponics presents a promising solution for sustainable food production in areas with limited resources or challenging environmental conditions.

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