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RESEARCH ARTICLE

EFFECT OF TOMATO PLANT DENSITY ON AQUAPONIC SYSTEM PRODUCTION

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ABSTRACT

The need to increase food production and match the food security demands under climate change impacts generate the force for developing aquaponic system. An aquaponic system was established at the Central Laboratory for Agricultural Climate (CLAC), Egypt, to investigate the effect of tomato plant density (2, 4 and 6 plants / m^2) on tomato and fish production as well as the quality of rare water. Nutrient film technique (3 m length) used to produce tomato integrated with aquaculture of tilapia fish. Vegetative growth characteristics and yield parameters of Tomato as well as tilapia yield parameters plus the nutrient contents of rare water were recorded.

The revealed results indicated that increasing the tomato plant density from 2 up to 6 plants / m^2 led to a decrease in the No. of leaves, total leaves area and plant height of tomato. The early and total yield of tomato per plant significantly increased by decreasing the plant density from 6 to 4 and 2 plants /m^2. On the contrary, the highest total yield per m^2 was given by tomato density 6 plants. Tilapia average weight of (g), tilapia total yield (Kg/m^3), average daily gain (ADG) and specific growth rate % (SGR) results increased significantly by increasing the plant density of tomato from 2 and 4 up to 6 plants / m^2. Increasing the tomato plant density led to decrease significantly NO_3, P, K, Ca and Mg (ppm) values of fish rare water content during the season period due to increasing the removal of nutrients for tomato sake. The accumulation of nutrients in rare fish water increased by increasing the growth of fish tilapia. The highest results of NO_3, P, K, Ca and Mg were recorded by tomato plant density 2 plants /m^2 while 6 plants /m^2 had the lowest nutrient contents.

For sustainable food production, the study recommended the plant density of tomato 6 plants /m^2. 18 tomato plants in 3 m NFT system length (6 plants/m^2) integrated with 150 tilapia fish in 1 m^3.

KEYWORDS

Soilless culture, Nutrient film technique (NFT), aquaculture, tilapia, tomato, food production and sustainable.

1. INTRODUCTION

One of agriculture's major issues in the twenty-first century is the necessity to find more effective and sustainable food production techniques to feed the expanding population that suits both the current climatic conditions and the anticipated climate change (FAO, 2009). The efficient utilization of water resources is necessary due to the growing population and the ensuing need for food. As a result, it is crucial to use alternate food production techniques in agriculture (Saha et al., 2016). To overcome the problems of food shortages due to water scarcity, soil degradation, climate change and overpopulation, aquaponics systems could be one of the alternative ways to address these global problems.

Aquaponic is an integrated technique that includes two different techniques (soilless culture and aquaculture) for producing crops and fish in a single unique system for raising fish (Yıldız and Bekcan, 2017). It's an economically and environmentally sound approach to maximize natural resources use efficiencies for growing food sustainability (Tyson et al., 2011; Salam et al., 2013).

The aquaponic system has become one of the methods of sustainable agriculture, as it depends on the symbiotic coexistence between fish and plants in water recycling systems, where the plants grown in a hydroponic system absorb the soluble nutrients from microbial decomposition of unconsumed fish feed and organic waste excreted by fish (Rakocy et al., 2006). Based on the theory of the nitrogen cycle, nitrifying bacteria play an important role in converting dissolved waste in the aquaponics system into plant nutrients where plants can benefit from these nutrients for their growth (Ghaly et al., 2005; Nelson, 2008).

In aquaponic systems, biofiltration by nitrifying bacteria maintains water quality for the fish, converting waste ammonia to nitrate nitrogen for plants (Timmons et al., 2002). The potential of plants and fish for production in aquaponic has been investigated (Adler et al., 1996, McMurtry et al., 1997, Rakocy, 1992; Watten and Busch, 1984). Recirculating aquaculture-hydroponic systems are designed to provide an artificial, controlled environment that optimizes the growth of fish (or other aquatic species) and soil-less plants while conserving water resources (Rakocy and Hargreaves, 1993). One of the most complex and important subsystems of re-circulating aquaculture is the bio-filtration and removal of fish waste. Recirculating systems must incorporate both solid removal and biological filtration and the water reconditioning process to achieve proper water quality for fish and plants (Harmon, 2001). As a stated that the hydroponic component in the Aquaponic system serves as a biofilter, and therefore a separate biofilter is not needed as in other recirculating systems (Rakocy et al., 2000). Aquaponic systems have the only biofilter that generates income, which is obtained from the sale of hydroponic produce such as vegetables, herbs and flowers (Rakocy et al., 2004). In the integrated aquaponic system, nutrients, which are excreted directly by the fish or generated by the microbial breakdown of organic wastes, are absorbed by plants cultured hydroponically (without soil). The fish feed provides most of the nutrients required for plant

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growth. As the aquaculture effluent flows through the hydroponic component of the recirculating system, fish waste metabolites are removed by nitrification and direct uptake by the plants, thereby treating the water, which flows back to the fish-rearing component for reuse (Rakocy et al. 2000).

Fish produce ammonia-nitrogen as an intermediate by-product of protein metabolism by fish. High levels of this nitrogen can cause death to fish. Growing plants in the hydroponic system play an important role in getting rid of ammonia nitrogen by absorbing it as a fertilizer. Thus, the harmful by-product of fish production becomes a useful input for plant production (Sumeth et al., 2017). Tilapia species is the most popular fish grown in aquaponics systems (Love et al., 2015). Tilapia fish are known for their quick growth rates, high-quality flesh, and resilience to disease, ability to adapt to various environmental circumstances, and capacity to grow and reproduce in aquariums (Lim and Webster, 2006).

Plants, such as tomatoes, are an ideal complementary crop in an integrated system because they grow rapidly in response to the high levels of dissolved nutrients that are generated from the microbial breakdown of fish wastes (Rakocy, 1992).

The proper management of various variables such as water quality, nutrient levels, plant and fish densities as well as growing conditions of crops and fish. This can affect the overall efficiency of the aquaponics system. Tomato plant density is one such element that has a large impact on the production and quality of aquaponic tomatoes.

This paper aimed to explain the effects of tomato plant density on aquaponic system production and the optimal tomato plant density for producing tomatoes as well as telipea fish.

2. Materials and Methods

The experiment was carried on at Central Laboratory for Agricultural Climate (CLAC), Agriculture Research Center, Egypt during two successful winter seasons of 2021 and 2022. The investigation focuses on the aquaponic production of tomato and tilapia fish by studying the effect of tomato plant density per m^2 under greenhouse conditions.

2.1 Aquaponic System Material

The aquaponic system included two integrated systems, a soilless culture system for producing tomato plants via using the nutrient film technique (NFT) and an aquaculture system for producing tilapia fish via rearing tanks.

2.1.1 Nutrient Film Technique (NFT)

Plastic gullies (0.15 m width, 0.15 m height and 3 m length) were used to create NFT plastic gullies. The length of NFT gully according to (Khater and Ali, 2015). Tow gullies were performed on a rising bed (0.9 m width, 3.0 m length and 0.2 m height). Each bed had a slope of 1 % in the direction of the rear water tank for collecting the circulated water (drainage) by gravity back to the separated tank (rearing tank 1 m^3) to perform a close NFT system with submersible pump (110-watt) for pumping the rearing water via polyethylene pipe 16 mm for both NFT gullies on the rising bed. The water.

The pumping of the rearing water tank schedule was programmed to work 18 - 24 times per day depending upon the season and growth stage via a digital timer (each time 10 min./hour).

2.1.1.1 Plant Material

Tomato (*Solanum lycopersicum*) cv. Agyad F$_1$ hybrid seeds were sown on The first week of September for both seasons in polystyrene trays (209 holes). Tomato seedlings were transplanted after 6 weeks from sowing the seeds (4 – 5th true leaf stage), into net cups (11cm) filled with peat moss: perlite (1: 1 v/v) substrate (200 ml) and arranged in the NFT plastic gullies regarding the different tomato plant densities.

2.1.2 Aquaculture System

A plastic tank (volume 1 m^3) was presented as a rear water tank for growing 150 tilapia fish. Each tank served one bed of the NFT system.

An air pump (35 watts) was used to supply air for each plastic tank through a polyethylene pipe 8 mm to avoid O_2 depletion and to offer sufficient dissolved oxygen (8 – 9 ppm). A plastic tube by air stone is connected to the air pump to ensure consistent air delivery.

Mechanical Filtering units consist of two plastic buckets (18 litter volume) containing a basal layer (10 cm) of gravel (2-7 ml) and the rest filled by perlite. The main objective of the mechanical filtration unit is to eliminate solid waste from tilapia and unfiltered feeders. The mechanical filter worked partly as a biological filter to improve the nitrification cycle and plant nutrition. No need to direct biological filters regarding the NFT gullies length and tomato plants that work as biological filters as well as the rearing water volume.

2.1.2.1 Fish Material

Nile Tilapia (*Oreochromis niloticus*), Mono sex finger (average weight 15-20 grams) was transplanted. The fish density (150 tilapias/ m^3 of water) was constant for all treatments. Also, the feeding rate and dosage of tilapia fish were constant in all rearing tanks, feeding three times per day with a full sinking pellet (30 % protein). The feed rate varied based on the average weight of tilapia regarding the progress of growth. Samples were taken every 2 weeks as recommended (D'Abramo and Brunson, 1996). Feed intake was 3% of total biomass (tilapia was fed only 6 days and fasted for one day to avoid residues of any uneaten feed.

2.2 The Investigated Treatments

The effect of different plant densities of tomato 2, 4 and 6 plants / m^2 on the tomato and fish productions in aquaponic systems as well as the rearing water quality during the two cultivated seasons. The experimental design was complete randomized blocks with three replicates. Each replicate contained an NFT system 3 m in length and a rearing water tank 1 m^3.

2.3 Measurements

2.3.1 Vegetative and Yield Parameters of Tomato

No. of leaves, total leaves area (cm^2) and plant height (cm) of tomato plants were recorded monthly at 30, 60, 90 and 120 days after transplanting at both cultivated seasons to illustrate the vegetative growth parameters.

The yield parameters (average early and total yield (kg) per plant and m^2) were collected during the production season till the end of the season in both cultivated seasons. Total soluble solids were estimated during the harvesting by collecting different samples of tomato fruits per each experimental plot.

2.3.2 N, P And K Contents of Tomato Leaves

N, P and K contents of tomato leaves, 20 full expended leave samples of each plot were collected at 120 days after transplanting and dried at 70ºC in an Air forced oven for 48 hours. Then digested in H_2SO_4 according to estimate N, P and K contents to Allen (1974). Nitrogen was determined by using the micro Kjeldahl method as defined by FAO (1980). Phosphorus content was calculated using a spectrophotometer based on (Watanabe and Olsen, 1965). Potassium content was photo-metrically measured using the Flame Photometer (Chapman and Pratt, 1961). Basil and mint oil contents were estimated by Ds Chromium 6200 Gas Chromatograph.

2.3.3 Fish Yield

The parameters of tilapia growth and yield performance were estimated during the experiment season and at the end of the season of both cultivated seasons as follows:

1. The average weight of fish

The average weight of fish = total yield of tilapia fish / No. of fishes.

2. The total yield of tilapia per each rearing tank (Kg) at the end of the study.

3. Average daily gain

ADG = (W1 – W0)/ days of feeding in the experimental periods

4. Specific growth rate

SGR % =100(Ln final weight - Ln initial weight)/period (days)

5. Survival rate

SR = (No. of fish at the final /No. of fish at the initial) * 100

2.3.4 Rearing Water of Tilapia Fish Analysis

Samples of tilapia fish rearing water were gained to estimate NO3, P, K, Ca and Mg (ppm) concentrations of fish water at 30, 60, 90 and 120 days after transplanting regarding (Rosanna Sallenave, 2016, Skar et al., 2015). The chemical analysis was done according to (FAO. 1980; Chapman and Pratt, 1961; Watanabe and Olsen, 1965).

2.4 Statistical Design and Analysis

ANOVA statistical analysis program was used to analyze the experimental data. The LSD among means was tested for significance at 0.05 levels according to (Snedicor and Cochran, 1981).

3. Results

3.1 Tomato Vegetative Growth and Yield Parameters

3.1.1 Vegetative Growth Characteristics

Table (1) illustrates the effect of plant density/m² per fish tank on vegetative growth characteristics (No. of leaves, total leaves area and plant height) during the two cultivated seasons. Increasing the plant density from 2 to 4 plants / m had a positive significant effect on No. of leaves, while increasing up to 6 plants / m had a negative significant effect. The treatment 4 plants / m gave the highest result while the lowest value was given by plant density 6 plants / m.

Regarding total leaves area, increasing the plant density from 2 to 6 plants / m led to a significant decrease in the total leaves area values. The plant density treatment 2 plants / m presented the highest record while the lowest value was recorded by 6 plants / m as Table (1) demonstrated. Similar results were obtained concerning plant height.

3.1.2 Yield Parameters

The revealed results of Table (2) indicated that reducing the plant density of tomato plants / m from 6 to 4 or 2 plants / m led to an increase in the early yield and total yield/tomato plant. The highest early yield and total yield of tomato per plant were recorded by tomato density 2 and 4 plants / m² while the treatment of 6 plants / m² gave the lowest significant results.

On the contrary, the total tomato yield per m², increasing the plant density from 2 up to 6 plants / m² had a superior significant effect that resulted in increasing the total yield per m². The highest record of total yield / m² was given by the treatment 6 plants / m² while 2 plants / m² resulted in the lowest value.

Concerning TSS results took a reverse impact while increasing the plant density from 2 up to 6 plants / m² introduced a significant reduction of tomato TSS. The treatment 2 plants / m² presented the highest value while the lowest result was recorded by 6 plants / m².

Table 1: Effect of plant density/m² on vegetative growth characteristics of tomato in aquaponics system during the two cultivated seasons.

Treatments	No. of leaves/plant	Total leaves area (cm²)	Plant height (cm)
	First season		
2 plants / m	151.9 B	7411.7 A	244.5 A
4 plants / m	168.5 A	6570.5 B	208.3 B
6 plants / m	140.7 C	5632.8 C	181.5 C
	Second season		
2 plants / m	162.2 B	7764.3 A	255.0 A
4 plants / m	175.7 A	6576.5 B	223.5 B
6 plants / m	151.9 C	5711.7 C	197.0 C

Table 2: Effect of plant density/m² on early yield (g/plant), total yield (kg/plant) and Kg/m²) and TSS (%) of tomato in aquaponics system during the two cultivated seasons.

Treatments	Early yield (g/plant)	Total yield (kg/plant)	Total yield (kg/m²)	TSS (%)
	First season			
2 plants / m	612.5 A	3.60 A	7.20 C	4.5 A
4 plants / m	615.9 A	3.60 A	14.4 B	4.3 AB
6 plants / m	417.8 B	2.96 B	17.76A	4.2 B
	Second season			
2 plants / m	717.3 A	3.82 A	7.64 C	4.7 A
4 plants / m	695.5 A	3.76 A	15.04 B	4.5 B
6 plants / m	452.5 B	3.02 B	18.12 A	4.2 C

3.2 Fish Production

Concerning the effect of tomato plant density (2, 4 and 6 plants / m²) on total tilapia fish yield (150 fish/m³), the revealed results of Table (3) indicated that increasing the plant density of tomato from 2 plants/m² up to 4 and 6 plants/m² led to increase tilapia average weight of (g), tilapia total yield (Kg/m3), average daily gain (ADG), specific growth rate % (SGR) while survival rate % (SR) didn't affect by plant density treatments. Increasing the tomato plant density had a superior significant effect on the tilapia yield parameters during both cultivated seasons referring to enhancing the rearing water quality of tilapia by increasing the capacity of removing nutrients of fish water and avoiding the different biohazards on fish production.

The treatment of 6 plants / m² recorded the highest tilapia yield parameters while the lowest values of tilapia average weight of (g), tilapia total yield (Kg/m3), average daily gain (ADG), specific growth rate % (SGR) while survival rate % (SR) were recorded by tomato plant density 2 plants / m². The significant differences among the treatments were true during both tested seasons.

Table 3: Effect of Plant Density/M² of Tomato on Tilapia Yield Parameters in Aquaponics System During the Two Cultivated Seasons.

Treatments	Average weight of fish (g)	Total yield of tilapia (Kg/ /m³)	Average daily gain (ADG)	Specific growth rate % (SGR)	Survival rate % (SR)
	First season				
2 plants	154.3 C	15.4 C	0.078 C	1.38 C	93.5 B
4 plants	245.0 B	24.5 B	0.089 B	1.57 B	95.4 A
6 plants	272.0 A	27.2 A	0.106 A	1.74 A	96.0 A
	Second season				
2 plants	161.0 C	16.1 C	0.081 C	1.41 C	95.1 A
4 plants	258.7 B	25.9 B	0.090 B	1.63 B	95.6 A
6 plants	282.7 A	28.3 A	0.110 A	1.78 A	96.7 A

3.3 Nutrient Analysis of Rearing Water of Tilapia

Figure (1,2,3,4 and 5) presented the average nutrient analysis of tilapia rearing water (NO_3, P, K, Ca and Mg (ppm)) under different tomato plant densities (2, 4 and 6 plants/m²) during the two investigated seasons. The obtained results demonstrated the significant effect of increasing the plant density from 2 up to 6 plants m² on decreasing the nutrient contents of tilapia rearing water that resulted in improving the tilapia growth and yield.

Increasing the plant density led to a decrease in NO_3, P, K, Ca and Mg (ppm) contents of fish rearing water due to the increase of the nutrients removal rate for satisfying the tomato nutrient requirements for fertilizing more plants as plant density treatments.

The tomato plant density of 2 plants /m² gave the highest values of nutrient contents (NO_3, P, K, Ca and Mg (ppm)) of tilapia rearing water while the lowest results were presented by tomato plant density of 6 plants /m²

In the context, Figs (1,2,3,4 and 5) illustrated the monthly changes in nutrient contents during the two studied seasons. The monthly changes of different nutrients varied regarding to tilapia growth stage, increasing the fish biomass and feeding rate as well as the progress of tomato growth and the needs of nutrients for each growth stage. The results also revealed that the tomato plant density 6 plants m² had a different behavior on the nutrient contents (NO_3, P, K, Ca and Mg (ppm)) of tilapia rearing water during the season time compared to the other plant density treatments that could be explained depending on enhancing the efficiency of biology filter.

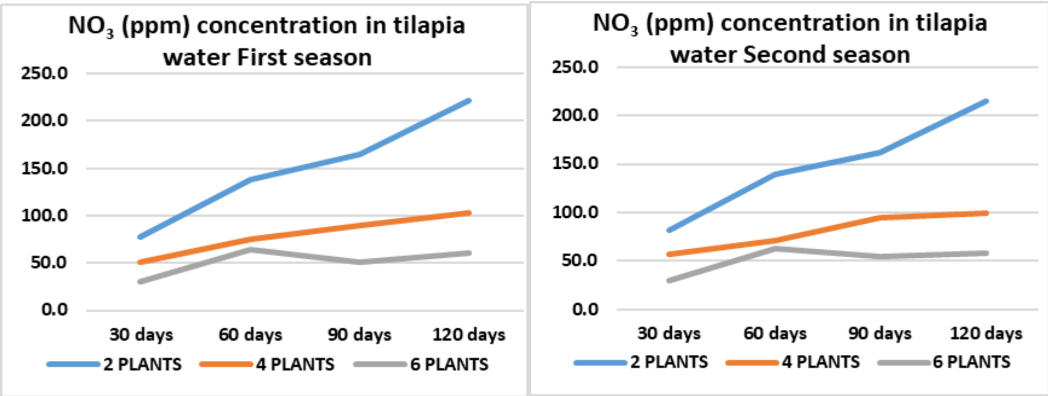

Figure 1: Effect of plant density of tomato on NO_3 (ppm) concentration in tilapia water in aquaponics system during the two cultivated seasons.

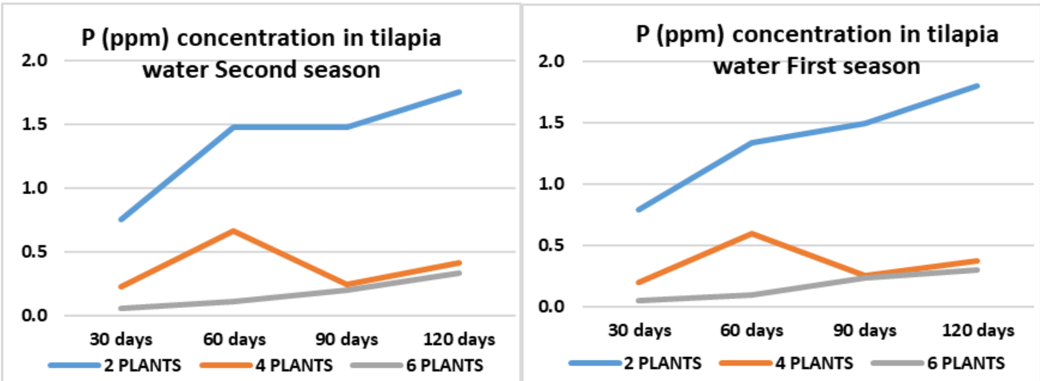

Figure 2: Effect of plant density of tomato on P (ppm) concentration in tilapia water in aquaponics system during the two cultivated seasons.

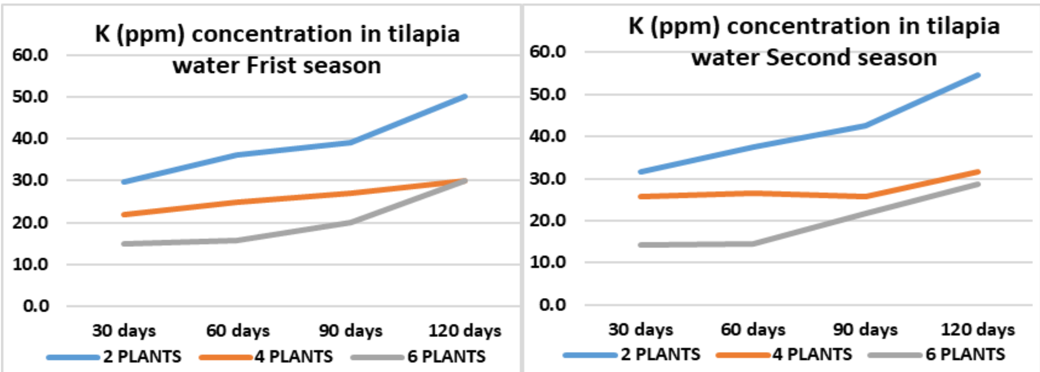

Figure 3: Effect of plant density of tomato on K (ppm) concentration in tilapia water in aquaponics system during the two cultivated seasons.

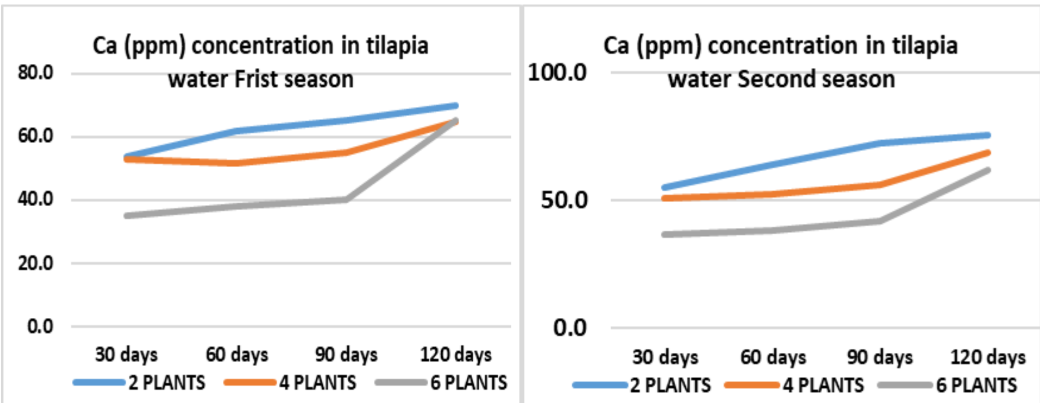

Figure 4: Effect of plant density of tomato on Ca (ppm) concentration in tilapia water in aquaponics system during the two cultivated seasons.

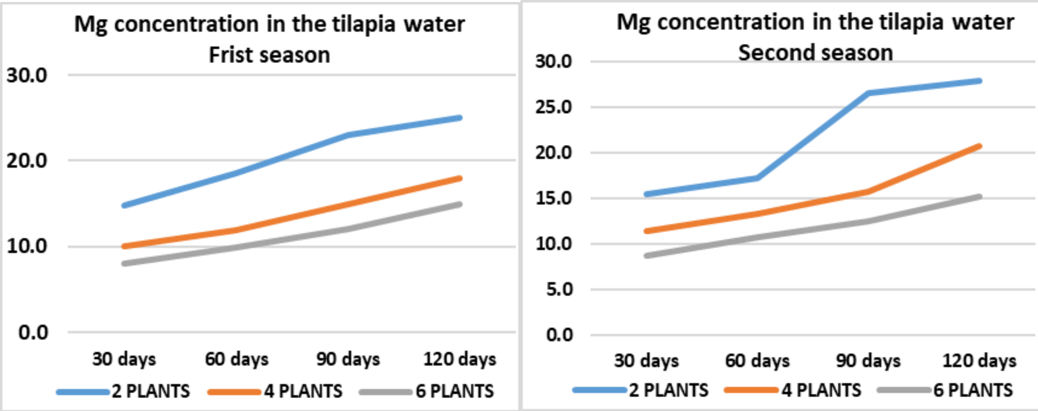

Figure 5: Effect of plant density of tomato on Mg (ppm) concentration in tilapia water in aquaponics system during the two cultivated seasons.

4. Discussion

The common clash among researchers of aquaponics concerning the plant density effect or fish density effect and which factor strongly on the production of plants and fish. The real equation here is handling the removal of soluble nutrients resulting from the fish feeder and waste regarding the fish density that led to optimum vegetative growth that gave the highest yield referring to the plant density. The equation took two directions, each direction had a great effect on the other.

The balance between nutrient input and nutrient uptake is a key element in the success of aquaponics systems. Increasing the plant density presented an increase in the potential of removing the soluble nutrients in fish rare water that increase fish production but this removing rate affected also vegetative growth characteristics and yield of tomato as a result of satisfying the plant nutrient requirement under the current study as mentioned (Neves et al., 2023).

Increasing the plant density from 2 to 6 plants / m^2 led to a significant decrease in the total leaves area and plant height values, as a result of decreasing the plant nutrient satisfaction. Increasing the plant density led to increasing the plant nutrient needs as amounts while the nutrient contents of fish rare water at the same density will be equal for all plant densities. These results agreed with (Somerville et al., 2014).

The yield parameters had an opposite point of view, while increasing the tomato plant density from 2 up to 4 plants / m^2 led to an increase in the early and total yield per plant but increasing the plant density up to 6 plants / m^2 had a negative significant impact. The disturbance of plant nutrients during the different growth stages from one side and the other side the quality of fish's rare water that is affected by plant density affect strongly on the yield of the plant. On the other hand, the result of the plant density effect on the total yield per m^2 could be explained by the increase of plant density having a superior effect rather than the yield per plant.

Reduction of the yield happened with increasing plant density without increasing the fish density referring to nutrient deficiencies due to insufficient nutrient production where the main source of nutrients is the fish feeder (**Tyson, 2007**). Under this investigation, the fish density was the standard while investigating the plant density effect that showed increasing the plant density of tomato up to 6 plants / m^2 led to decreasing the yield per plant (early and total) and increasing the fish production.

The plant density of tomato had a significant impact on the yield parameters of tilapia fish during the studied seasons as a result of the rise in the removal of N forms and other nutrients from fish water as agreed with (Wongkiewa et al., 2017; Yıldız and Bekcan, 2017).

Plants in aquaponic systems used as a bio-filter, increasing the bio-filter units (plant density) led to an increase in the removable rate of soluble nutrients from fish waste and feeders that resulted in more quality water for fish growth. This logical fact explained easily the results of NO_3, P, K, Ca and Mg that affected significantly by increasing the plant density of tomato from 2 up to 6 plant /m^2 led to decrease the soluble nutrients in fish rare water. These results agreed with who reported that optimal plant density would reduce or completely remove the need for nutrient supplements in aquaponic food production (Seawright et al., 1997). Increasing NO_3, P, K, Ca and Mg gradually through the growth period regarding the increase of fish growth and feeding rate of tilapia (Khater and Ali 2015). Has a also recommended the best NFT gulley length is 3 m to encourage the biofiltration conditions for the removal of different nitrogen forms (Khater and Ali, 2015). Bacteria convert ammonia to nitrite and then to nitrate (Nelson, 2008; Graber and Junge, 2009; Suits, 2010).

Nitrogen in the form of nitrate had no water quality problem in aquaponic fish tanks unless it reached a toxic level to fish at very high levels (300-400 mg/L). The biofiltration mechanism by plants and microflora in aquaponic systems also removes nitrates quite well and maintains their concentration at much lower levels (DeLong et al., 2009).

5. Conclusion

The study focused on the effect of tomato plant density on tomato and fish production and didn't take into consideration the water or power use efficiencies regarding the many researchers' contributions who investigated before and strongly presented the sustainable advantages of the Aquaponic system.

Logically for the highest tomato production per area unit and fish tilapia production, the study recommended the plant density of tomato 6 plants /m^2. On a commercial scale, 18 tomato plants in a 3 m NFT system length (6 plants/m^2) integrated with 150 tilapia fish in $1m^3$ under the investigation condition that could be expressed for a standard span area 540 m^2 as an integrated aquaponic system included 1800 tomato plants and 100 m^3 fish tank that contained 15000 of tilapia fish.

For small unit or urban scale farms, the investigation promotes the tomato plant density of 4 plants / m^2 in 3 m NFT system length with 150 tilapia fish density per 1 m^3 water for better tomato quality.

6. References

Allen, S. E., 1974. The satisfaction Chemical Analysis of Ecological Materials. Black-Well, Oxford, Pp. 565

Chapman, H.D., Pratt, P.F., 1961. Methods of Analysis for Soil, Plants and Water. Univ. California, Barreley, CA, USA

D'Abramo, L.R., Brunson, M.W., 1996. Production of freshwater prawns in ponds. Southern Regional Aquaculture Center (SRAC) Publication No. 484.

DeLong, D., Losordo, T., Rakocy, J., 2009. Tank Culture of Tilapia. Southern Regional Aquaculture Center, Publication No. 282.

FAO. 1980. Soil and Plant Analysis. Soils Bulletin, 38: Pp. 242-250.

FAO. 2009. Global agriculture towards 2050.

Graber, A., Junge, R., 2009. Aquaponic systems: nutrient recycling from fish wastewater by vegetable production. Desalination 246, Pp.147–156.

Khater E. S. G., Ali, S. A., 2015. Effect of Flow Rate and Length of Gully on Lettuce Plants in Aquaponic and Hydroponic Systems. J Aquac Res Development 6: 318. doi:10.4172/2155-9546.1000318

Lim, C. E., Webster, C. D., 2006. Tilapia: Biology, Culture, and Nutrition. Food Products Press, Binghamton, NY. 678pp.

Love, D. C., Fry, J. P., Li, X., Hill, E. S., Genello, L., Semmens, K., Thompson, R. E., 2015. Commercial aquaponics production and profitability: findings from an international survey. Aquaculture, 435: Pp. 67–74

Nelson, R., 2008. Aquaponic Food Production. Retrieved September 11, 2017, from https://aquaponics.com/category/nelson-and-padeblog.

Neves N. K., Zeedyk, N., Wildschutte, H., Kershaw, J., 2023.The effect of aquaponics on tomato, *Solanumly copersicum*, sensory, quality, and safety outcomes. Journal of Food Science,88, Pp. 2261–2272. https://doi.org/10.1111/1750-3841.16578.

Rakocy J. E., Shultz, R. C., Bailey, D. S., Thoman, E. S., 2004. Aquaponic production of tilapia and basil comparing a batch and staggered cropping system. Acta Hort., 648:Pp. 63-69.

Rakocy, J. E., Masser, M. P., Losordo, T. M., 2006. Recirculating Aquaculture Tank Production Systems: Aquaponics - Integrating Fish and Plant Culture. SRAC Publication No. 45: Pp. 1-16.

Rakocy, J.E., Hargreaves, J.A., 1993. Integration of vegetable hydroponics with fish culture: A review. In J. Wang (Ed.), Techniques for Modern Aquaculture. St. Joseph, MI: American Society of Agricultural Engineers. Pp. 112-136.

Rakocy, J.E., 1992. Recirculating Aquaculture Tank Production Systems: Integrating Fish and Plant Culture. So. Regional Aquaculture Center Publ.No. 454.

Rakocy, J.E., Bailey, D.S., Martin, J.M., Shultz, R. C., 2000. Tilapia production system for the Lesser Antilles and other resource-limeted, tropical areas. Pp. 651 – 662. Tilapia Aquaculture in the 21st century: Proc. from 5th Inter Symposium on Tilapia in Aquaculture, Rio de Janeiro, Brazil.

Saha, S., Monroe, A., Day, M. R., 2016. Growth, yield, plant quality and nutrition of basil, Ocimum basilicum L., under soilless agricultural systems. Annals of Agricultural Sciences, 61(2): Pp. 181-186

Salam, M. A., Asadujjaman, M., Rahman, M. S., 2013. Aquaponics for Improving High Density Fish Pond Water Quality through Raft and Rack Vegetable Production. World J. Fish Mar. Sci., 5:Pp. 251-256.

Seawright, D. E., Stickney, R. R., Walker, R. B., 1997. Nutrient dynamics in integrated aquaculture-hydroponics systems. Aquaculture, 160(3-4): Pp. 215-237.

Snedicor, G. W., Cochran, W. G., 1981. Statistical methods. 7th Iowa State Univ. Press, Iowa, USA, Pp. 225-320.

Somerville, C., Moti, C., Edoardo, P., Austin, S., Alessandro, L., 2014. Small-scale aquaponic food production: Integrated fish and plant farming.FAO Fisheries and Aquaculture Technical Paper; Rome. Iss. 589**:** Pp. 1-19, 21-81,83-121,123-139,141-155,157-161,163-167,169-181,183-189,191-203,205-207,209-247,249-265

Suits, B., 2010. Access to personal agriculture. The Aquaponics Guidebook, Volume 1, 2nd Edition , Pp. 1-12.

Sumeth W., Zhen, H., Kartik, C., Jae, W. L., Samir, K. K., 2017. Nitrogen transformations in aquaponic systems: A review. Aquacultural Engineering, 76: Pp. 9-19.

Tyson, R. V., 2007. Reconciling pH for ammonia biofiltration in a cucumber/tilapia aquaponics system using a perlite medium. Doctor of Philosophy. Florida, University of Florida.

Tyson, R. V., Treadwell, D. D., Simonne, E. H., 2011. Opportunities and Challenges to Sustainability in Aquaponic Systems. Horttechnology, 21(1):Pp. 6-13.

Watanabe, F. S., Olsen, S.R., 1965. Test of an ascorbic acid method for determining phosphorous in water and $NaHCO_3$ extracts from soil. Soil Sci. Soc. Am. Proc. 29: Pp. 677- 678.

Wongkiewa, S., Hub, Z., Chandranc, K., Leed, J. W., Khanala, S. K., 2017. Nitrogentransformations in aquaponic systems: A review. Aquac. Eng. 76: Pp. 9 –19.

Yıldız, H. Y., Bekcan, S., 2017. Role of stocking density of tilapia, Oreochromis aureus, on fish growth, water quality and tomato, Solanum lycopersicum, plant biomass in the aquaponic system. International Journal of Environment, Agriculture and Biotechnology (IJEAB). Vol-2, Issue-6, Nov-Dec: Pp. 2819- 2824.