Effect of Stocking Density on Growth Performance of Tilapia (Oreochromis Niloticus) and Lettuce (Lactuca Sativa) in A NFT Aquaponic System Under Arid Region Conditions

Sarra Benaissa*, Ayoub Hadjeb*

* Laboratory of Ecosystems Diversity and Agricultural Production Systems Dynamics in Arid Zones (DEDSPAZA), University of Biskra. BP 145 RP, 07000 Biskra, Algeria.

E-mail: sara.benaissa@univ-biskra.dz

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Abstract

Aquaponics is a sustainable food production method that combines aquaculture and hydroponics, minimizing resource demand and environmental impact. This method is still in its early stages of adoption in Algeria, and its operations and basic principles are still largely unexplored to various fish and vegetable species. This study aimed to identify the influence of fish stocking density on water quality and growth performance of the Nile Tilapia (Oreochromis niloticus) and Lettuce (Lactuca sativa) in an NFT aquaponic system under arid region conditions. Three fish stocking densities were established: 1.5 kg/m^3, 3 kg/m^3, and 4.5 kg/m^3, each with three replicates. For each stocking density, we measured plant growth performance as well as fish growth. Furthermore, water quality parameters in both the fish and the vegetable tanks were monitored. The results showed that the production of lettuce significantly varied and increased with increasing stocking density as, 196.91±2.66, 205.14±12.27 and 250.74 ± 17.7 g for 1.5, 3 and 4.5 kg/m^3, respectively. However, the final weight of Tilapia decreased when stocking density increased and was 55.97 ± 1.66, 34±1.98 and 27.35±1.97g for 1.5, 3 and 4.5 kg/m^3, respectively. The pH was approximated to be neutral and fluctuated between 6.78 ±0.04 to 7.78 ±0.02. With increased stocking density, the dissolved oxygen declined and ranged from 3.39±0.49 to 5.56±1.27 mg/L in the fish tanks. The ranges of nutrient accumulation across the different stocking densities of Tilapia were: 0.033±0.004 - 0.038±0.003 mg/ L for total ammonium nitrate (TAN); 1.13±0.032-1.38±0.022 mg /L for nitrate and 0.01±0.001- 0.07±0.062 mg/ L for nitrite. Overall, the results showed that the medium stocking density of 3 kg/m^3, which provided the best performance for the tested aquaponics system, is highly recommended.

Keywords: Aquaponics; Arid region; Lettuce; Nile tilapia; Stocking density.

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Introduction

Food security has decreased during the last 50 years on a global, regional, and local scale due to major factors such as shrinking agricultural land, climate change, conflict, and economic fluctuations **(Cottrell et al., 2019; Memon et al., 2022)**. Current forecasts indicate that by 2030, global food demand could surpass 350 million metric tons. However, it is expected that production will reach a plateau at around 200 million metric tons, resulting in a deficit exceeding 100 million metric tons **(FAOSTAT, 2018)**. Based on the Food Insecurity Experience Scale (FIES), approximately 2.4 billion individuals worldwide face varying degrees of food insecurity **(FAO, IFAD, UNICEF, 2023).**

Furthermore, The upheaval caused by the current Russia–Ukraine war, with all the human security implications this may entail, comes on the heels of preexisting challenges that have already put pressure on prices and supply chains; the COVID-19 pandemic, an energy crisis, shipping constraints and recent climate-induced extreme events **(Nicas, 2022).** After a decline during the past decade, global hunger is rising again1 and the on-going war is expected to increase this trend, experts estimate that 7.6 to 13.1 million people are threatened **(Behnassi & El Haiba, 2022).**

Regions in North Africa are susceptible to the catastrophic effects of climate change **(Hamed et al., 2018)**. Previous research has indicated that climate change is decreasing water availability in places where future annual precipitation in arid regions is projected to decrease, as indicated by rising drought indices **(Forzieri et al., 2014; Eekhout et al., 2018; Alifujiang et al., 2020)**. In Algeria, climate change and rapid population increase have put massive pressure on demand for food and a depletion of the limited natural resources creating a real challenge for the food supply **(Drouiche et al., 2012; Bouznit et al., 2023)**. Algeria is one of the Mediterranean countries where agriculture is mainly rainfed and suffers from drought, which has increased in recent years as a result of climate change, especially in the southeastern part of the country such as Biskra province, which is characterized by an arid climate and limited water resources **(Boudibi, 2021).** The average precipitation is 89 mm per year, with evapotranspiration ranging from 800 mm in the northeast to over 2,200 mm in the southeast of Algeria. According to projections of climate change, rainfall in Algeria could decrease by more than 20% by 2050 **(Hamiche et al., 2015)**. These factors, combined with other constraints of agriculture, contribute to food insecurity in Algeria, emphasizing the imperative need for comprehensive strategies to bolster food production and secure the nation's nutritional needs.

To tackle these challenges, the primary focus should be on advancing sustainable and efficient farming practices. This approach aims to optimize the utilization of water and energy resources while ensuring proximity to the market to enhance food security. To address these goals, Aquaponics could be a solution and a connection key element by using the water in an integrated way. According to **Lennard and Goddek (2019),** aquaponics is one of the integrated environmentally friendly farming technologies that combines hydroponics with a recirculating aquaculture system (RAS) in order to improve the production of fish and vegetables and offers a highly sustainable approach to food production. Recirculating aquaculture and hydroponics are both used in the Aquaponics system in a mutually beneficial relationship. The aquaculture unit's effluents provide nutrients to the hydroponically grown plants, thereby serving to cleanse the water. The consortium of nitrifying autotrophic bacteria, which is mostly made up of nitroso- and nitro-bacteria (Nitrospira species and Nitrobacter species), is responsible for making this feasible **(Goddek and Korner, 2019)**. Before becoming nitrate, which the plant absorbs for growth, the ammonia in the system is first converted by the nitroso-bacteria into nitrite **(Goddek et al., 2015)**. Tilapia and lettuce are one of the most important aquaponics integrations, and the success of this symbiotic relationship is a key factor in improving the sustainability of the agricultural production system **(Sreejariya et al., 2016; Ajitama et al., 2018)**. As a bio-integrated concept for sustainable food production, this fish and vegetable supply chain has attracted attention and garnered appeal **(Savidov et al., 2005; Kloas et al., 2015)**. Several factors impact the success of an aquaponics system, including the cultivation methods for vegetables and fish, the efficiency of the filtration system, aeration, water circulation, and the specific species of fish and plants chosen. The Nutrient Film Technique (NFT) is commonly used as a closed system and is often regarded as highly scalable. In this method, plant roots are suspended in a tube or trough with a slight gradient of 1% to 2%, and nutrients are consistently delivered to the plants from the upper to the lower end through the tube or trough, driven by gravity **(Kasozi et al., 2021).** NFT aquaponic system offers advantages, such as ease of setup, cost-effectiveness in construction, minimal waste production, and enhanced oxygen supply to plant roots.

Several parameters influence the performance of fish reared in an aquaponics system, the most important of them is the stocking density. It has an impact on fish development, feed consumption, survival, behaviour, health, water quality, and gross fish yield **(Maucieri et al., 2019; Oké & Goosen, 2019)**. Operating an aquaculture unit near to its carrying capacity (CC) enables effective space utilization, reduces feed input fluctuation, and eventually optimizes performance **(Boxman et al., 2016).**

It is crucial to identify the ideal stocking density for an aquaponic system to maximize the performance of both fish and vegetables, while still ensuring that the water quality remains uncompromised. This is a critical consideration since maintaining the economic viability of the system is also a key factor to consider. Despite the significant role of fish stocking density and feed amount in the performance of aquaponic systems, there is a limited amount of research on how these factors affect lettuce growth in these systems. The present study aimed to evaluate the influence of Nile tilapia (*Oreochromis niloticus*) stocking density on the growth performance of lettuce (*Lactuca sativa*) and the fish in an NFT aquaponic system under arid zone conditions located in the southeastern of Algeria.

Materials And Methods

Study area and experimental design

This experiment was conducted from 22th November 2021 until 17th January 2022, under greenhouse conditions at the department of agricultural science, university of Biskra. The study area (Biskra) is an arid region located in the southeastern region of Algeria, It lies between latitude 33°19' - 35°17' N and longitude 4°07' - 6°48' E, with an altitude of 120 m above mediterranean sea level. This area has a temperature range of between 12 °C and 34 °C and receives an average annual rainfall of about 155 mm. The experiment was carried out in completely randomized design. A total of 09 independent aquaponic systems which consisted of three fish stocking densities, were set up, with three replicates for each fish stocking density. The fish were stocked at densities of 1.5kg/m^3, 3kg/m^3, and 4.5kg/m^3 for treatments T1, T2, and T3 respectively. Each replicate was connected to an hydroponic unit. This gave a total of nine hydroponic units, each with three NFT troughs.

Each independent system consisted of a plastic fish-rearing tank (1000 L) with dimensions of 1 m × 1 m × 1 m (length, width and height) filled with (800 L) of tap water and continuously aerated with an air stone; this tank was connected to a mechanical filter (300 L) designed to remove solid particles and minimize floating debris, which was further connected to a bio-filter container (300 L) equipped with plastic bio-rings facilitated biological processes, notably nitrification. To support plant growth, a hydroponic nutrient film technique (NFT) unit was integrated (Figure 1). The system also included two water storage tanks, strategically placed to optimize the water flow. Each tank is equipped with a submerged water pump (18 watt capacity, flow rate 2500 L/H, Head max 2.5 m). The first tank, located before the hydroponic unit, collects the output from the bio-filter and utilizes the submerged water pump to transfer the water into the hydroponic system. The second tank, positioned after the hydroponic unit, collects the output from the hydroponics, and its submerged water pump returns the water back to the fish tank, completing the circular water cycle (Figure 1).

The hydroponics unit using NFT technology is made up of ten PVC tubes each with a length of 4 meters and a width of 11 cm. The tubes are arranged in pairs, with five levels stacked on top of each other, and each pair is placed 40 cm apart. The nutrient solution is introduced at the higher end of the top trough and flows sequentially through each trough before returning to the reservoir. The flow rate was set at 5 L/min. Water loss from the tanks due to evaporation was adjusted every week by adding ground water.

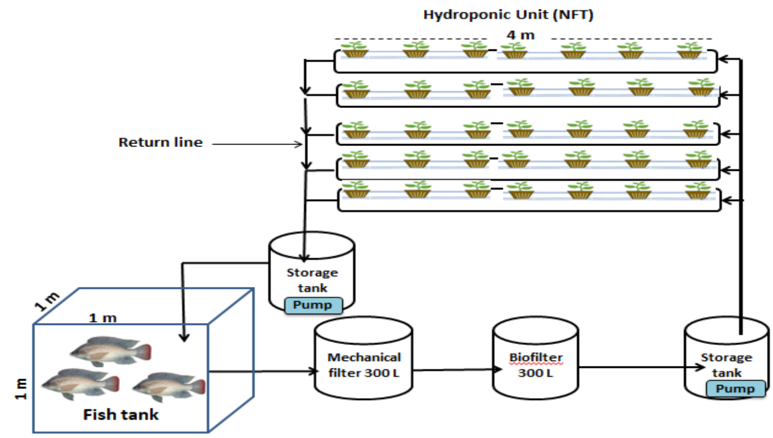

Figure1. Schematic diagram of a single experimental aquaponic system and directions of flow of water.

Fish stoking and feeding

The Nile Tilapia (*Oreochromis niloticus*) used in this study were procured from an aquaculture farm in Biskra, where the tilapia were grown in a conventional aquaculture system.At first, fishes were acclimatized for 2 weeks before running system in order to increase the ammonia concentration and foster the development of nitrifying bacteria.

A total of 1350 Nile tilapia fingerlings with an initial average weight of 20 g were used. These fish were stocked at densities of 1.5 kg/m^3 (75 fish/m^3), 3 kg/m^3 (150 fish/m^3), and 4.5 kg/m^3 (225 fish/m^3), which were designated as T1, T2, and T3, respectively. Each of these stocking densities was replicated three times. The fish were fed up to 3% of their body weight in commercial floating pellets with a size of 3.5 mm (from DZira Ponic SPA, Biskra, Algeria). The proximate nutrient composition of the fish feed was 47.47 % protein, 11.87% fat,5.48% ash, 5% fiber, and 15.26% moisture content. The fish were fed twice a day **(HADJEB et al., 2022).**

Plantation

Lettuce (*Lactuca sativa*) seeds were sown and cultivated in plastic trays within a greenhouse until they reached the suitable size for transplantation. After 10 days, the germinated plants, at the third to fourth true leaf stages, were promptly transplanted into plastic pots filled with sawdust as the growing medium. This choice was made due to its ready availability, lightweight nature, capacity to retain humidity, and cost-effectiveness.**(Depardieu et al., 2016; González-Orozco et al., 2018)**. Subsequently, these plants were transferred to nutrient film technique (NFT) hydroponic units, maintaining a planting density of 25 lettuces/m^2 and spacing of 20 cm for all treatments. No external factors such as the usage of fertilizers were introduced to the aquaponic system because the nutrients relied only from tilapia fish farming waste, both air and water temperature were also not controlled in the experiment.

Analysis of water quality

Data on dissolved oxygen (DO) concentration, pH, and temperature were determined and recorded daily in the recirculating fish rearing tanks and the hydroponic tanks using YSI 556 Multiparameter meter (YSI Inc. USA). Water samples from the two units were taken once a week for examination of total ammonia nitrogen (TAN), nitrates, nitrite, potassium, and soluble reactive phosphorus (SRP) using an optical photometer, the YSI 9500 (YSI Incorporated, Yellow Springs, OH, USA), which has a precision of 1% (YSI, I. 2014).

Measurement of fish growth performance

Fish health was monitored daily. A random sample of fish from each tank was collected for weight measurements at the beginning of the trial and then weekly until the end of experiment period. These measurements were conducted using an electronic balance (accuracy: 0.01 mg, WJEUIP, Model WA50002Y, W&J Instrument Co. LTD, China). Furthermore, the growth performance of the tilapia was determined using the following equations: weight gain (WG), specific growth rate (SGR), survival rate (SR), and feed conversion ratio (FCR) as described by **(Jimoh, 2020)** and **(Sveier et al., 2000)**;

WG (g) = Mean final weight (g) - Mean initial weight (g) (1)

$$\textbf{SGR}\ (\%per\ day) = \frac{LnWt1 - LnWt0}{t} * 100 \quad (2)$$

Where: W0 and W1 are initial and final weights respectively , t is time in days.

$$\textbf{SR}\ (\%) = \frac{Final\ number\ of\ fish\ survived}{Final\ number\ of\ fish\ stoked} * 100 \quad (3)$$

$$\textbf{FCR} = \frac{Total\ weight\ of\ dry\ feed\ given\ (g)}{Total\ wet\ weight\ gain\ \ (g)} \quad (4)$$

Measurement of plants growth performance

The lettuce plants were harvested at 56th day. Plants data were collected at the end of the experiment. Lettuce harvest head wet weight (g) was recorded using an electronic balance (accuracy 0.01 mg, WJEUIP, Model WA50002Y, W&J Instrument Co. LTD, China). The root length was also recorded. The width and length of each leaf were measured with a leaf area meter **(CI-202 Portable Laser)** in order to calculate the total leaf area at the harvested stage.

Statistical analysis

The data concerning the water quality, fish growth, and plant growth among the different stocking densities were calculated as means ± SD using MS Office Excel Professional Plus 2010 and then analyzed by a one-way ANOVA by using XLSTAT by Addinsoft software (version 25.1.1408). Differences of mean were evaluated for significance differences by Tukey HSD test with a significance level of 0.05. Box plots were used to explore differences in the mean fresh weight of plants among the different stocking densities.

Results

Water quality

The water quality parameters including temperature, dissolved oxygen (DO), pH, total ammonium-nitrogen (TAN), nitrate, nitrite, potassium, and soluble reactive phosphorus (SRP) in both the fish tanks and hydroponic units during the experiment are summarized in Table 1.

There was no significant difference ($p>0.05$) in the water temperature and pH among all treatments (1.5, 3 and 4.5 kg/m^3). The water temperature varied between 28.15±0.45 and 29.91±0.56°C. The pH levels of the water were relatively neutral across all stocking densities, ranging from 6.78 ±0.04 to 7.78 ±0.02 in fish tanks and from 6.45 ±0.04 to 7.54 ±0.02 in hydroponic units. However, there was a significant difference ($p < 0.05$) in the dissolved oxygen (DO) among the treatments, the average DO level in the fish tanks ranged from 3.39 ± 0.49 to 5.56 ± 1.27 mg/L at stocking densities of 4.5 kg/m^3 and 1.5 kg/m3, respectively. Similarly, in the hydroponic units, the dissolved oxygen levels ranged between 4.15 ± 0.14 and 5.88 ± 1.23 mg/L at stocking densities of 4.5 kg/m3 and 1.5 kg/m^3, respectively. The concentration of nitrates tended to increase with higher stocking densities in both fish tanks and hydroponic units. The highest nitrate value was recorded at high stocking densities of 4.5kg/m^3 with an average value of 1.38 ± 0.022 mg/L, whereas, the lowest concentration was observed at the stocking density of 1.5kg/m^3 with an average value of 1.13 ± 0.032 mg/L. The stocking density of 1.5kg/m^3, exhibited the lowest concentrations of nitrites and TAN, while the stocking density of 4.5kg/m^3 had the highest concentrations in both fish tanks and hydroponic units. In contrast, potassium and soluble reactive phosphorus (SRP) weren't affected with fish stocking density in this study (Table 1).

Table1. The aquaponics system's water quality characteristics (means±SD) at various stocking densities (1.5, 3 and 4.5 kg/m^3) using O. niloticus fingerlings.

Parameters	location	1.5 kg/m^3	3 kg/m^3	4.5 kg/m^3
Temperature (C°)	Fish tank ydroponic	28.15 ±0.45 28.73 ±0.58	28.83 ±0.52 28.28 ±0.22	29.91 ±0.56 29.32 ±0.65
pH	Fish tank Hydroponic	7.78 ±0.02 7.54 ±0.02	7.37 ±0.04 7.22 ±0.02	6.78 ±0.04 6.45 ±0.04
Dissolved oxygen (mg/L)	Fish tank Hydroponic	5.56 ±1.27 5.88 ±1.23	4.74 ±0.66 5.37 ±0.85	3.93 ±0.49 4.15 ±0.14
Nitrate (mg/L)	Fish tank Hydroponic	1.13 ±0.032 0.98 ±0.011	1.20 ±0.013 1.11 ±0.015	1.38 ±0.022 1.32 ±0.025

Nitrite (mg/L)	Fish tank Hydroponic	0.01 ±0.001 0.01 ±0.001	0.04 ±0.021 0.029 ±0.002	0.07 ±0.062 0.073 ±0.006
SRP (mg/L)	Fish tank Hydroponic	2.46 ±0.017 2.34 ±0.086	2.23 ±0.032 2.12 ±0.025	2.53 ±0.012 2.17 ±0.02
Potassium (mg/L)	Fish tank Hydroponic	6.14 ±0.05 5.74 ±0.04	5.87 ±0.06 5.42 ±0.04	5.98 ±0.04 5.22 ±0.06
TAN (mg/L)	Fish tank Hydroponic	0.033 ±0.004 0.026 ±0.002	0.035 ±0.004 0.025 ±0.003	0.038 ±0.003 0.028 ±0.004

Note: SRP= soluble reactive phosphorus; TAN= total ammonium–nitrogen. Values are mean ± standard deviation.

Growth performance of the fish

Table 2 shows the growth performance of the fish stoking under three different densities (1.5 kg/m3, 3 kg/m^3 and 4.5 kg/m^3). The findings stemming from the statistical analysis utilizing one-way ANOVA have indicated that the difference in the final weight, weight gain , SGR , SR and FCR of tilapia among the stocking density treatments were significant ($p<0.05$).

Table 2. Growth parameters of tilapia (O. niloticus) in the aquaponics system at different stocking densities.

Growth parameters	Fish stoking densities kg/m^3		
	1.5 kg/m^3	3 kg/m^3	4.5 kg/m^3
Initilal weight(g)	20,2± 0,01	20,35±0,02	20,35±0,01
Final weight (g)	55,97±1.66a	34±1.98b	27,35±1.97c
Weight gain(g)	35,77±0.98a	13,65±1.57b	7±1.99c
SGR (%day)	1,82	0,91	0,51
SR (%)	98.81±1.50a	94%±1.85b	92±3.02b
FCR	1,55	2,51	5,51

Note: Values are given as mean ± standard deviation. Value in the same line bearing different letters is significantly different at 5%.

The weight of fingerlings stocked at 1.5 kg/m^3 grew from 20.02 g to 55.97 g, that of fish stocked at 3 kg/m^3 from 20.35 g to 34 g, and that of fish stocked at 4.5 kg/m^3 from 20.35 g to 27.35 g. The mean final weight of tilapia at 1.5 kg/m^3 treatment was significantly higher than that at 3 kg/m^3 and 4.5 kg/m^3 densities, respectively (Figure 2). Tilapia stocked at 1.5 kg/m^3 had the highest average weight gain (35,77±0.98) compared to that rearing at 4.5 kg/m^3 (7±1.99). The specific growth rate (SGR) also showed significant differences among the treatments. The treatment of 1.5 kg/m^3 had the highest SGR (1.82 ± 0.17), indicating a higher growth rate compared to the two other stocking densities. Conversely, the stocking density of 4.5 kg/m^3 had the lowest SGR (0.51 ± 0.04), suggesting a slower growth rate (Table 2).

Regarding survival rate (SR), there was no significant difference observed between the stocking densities of 3 kg/m^3 and 4.5 kg/m^3 (p >0.05). However, the 1.5 kg/m^3 stocking density exhibited the highest survival rate (98.81 ± 1.50), indicating better survival under lower stocking density conditions. In terms of feed conversion ratio (FCR), an opposite relationship with stocking density was observed. T3 (4.5 kg/m^3), the highest stocking density, had the highest FCR, indicating less efficient feed utilization. On the other hand, the density of 1.5 kg/m^3 had the lowest FCR, suggesting more efficient feed conversion (Table 2).

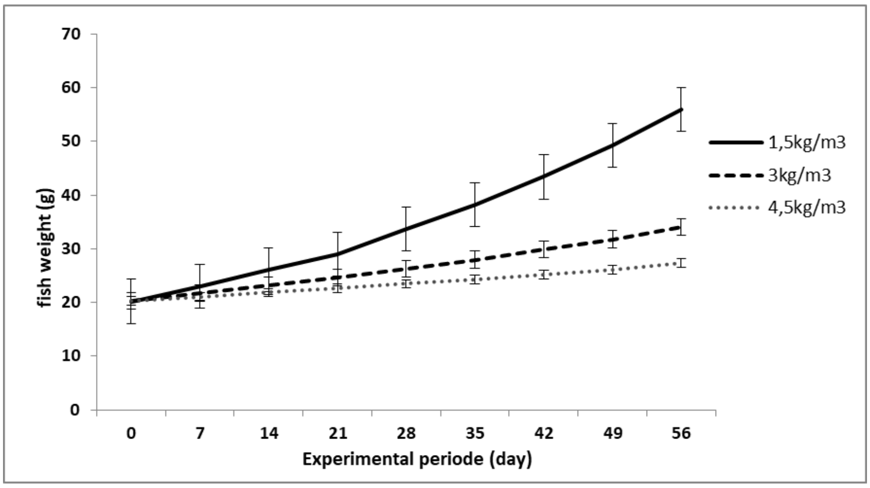

Figure 2. Weight (g) development of Tilapia fingerlings reared with lettuce (Lactuca sativa) in an aquaponic system under three stocking densities (1.5kg/m^3, 3kg/m^3 and 4.5kg/m^3).

Growth performance of lettuce plants

Three different tilapia stocking densities were tested in this study to determine their effects on lettuce growth performance on the installed aquaponics system. The results presented in table 3 showed significant differences (p<0.05) in all treatments in the final mean head weight of lettuce, biomass of lettuce, length and width of leaves except for the root length.

Note: values in the same row with different superscripts are significantly different ($p<0.05$). Lower case letters indicate significant differences among the treatments.

The results indicated a general trend of increased growth in the mean biomass of lettuce as the stocking density increased across the treatments. Lettuce biomass values ranged from 280.27±7.27g in a treatment with 1.5kg/m^3 of stocking 348.61±23.75 g in a treatment with 4.5kg/ m^3 of stocking.

Furthermore, the final mean head weight at 4.5 kg/m^3 treatment was the highest followed by that of 3 kg/m^3 and then of 1.5 kg/m^3 with 250.74±17.7g, 205.14±12.27g, and 196.91±2.66g, respectively (figure 3).

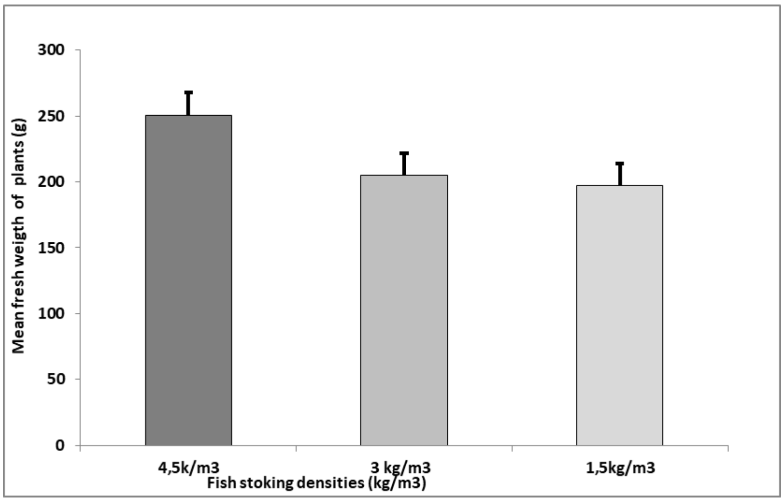

Figure 3. Bar graphs of mean head weight of Lettuce (Lactuca sativa) (g) according three treatments of fish stocking densities (1.5 kg/m^3, 3 kg/m^3 and 4.5kg/m^3).

Box plots were used to illustrate the relationship between the fish stocking density and fresh weight of lettuce plants (Figure 4). The plant weight as less variability at a stocking density of 3 kg/m^3 compared to the other two groups where it began to vary.

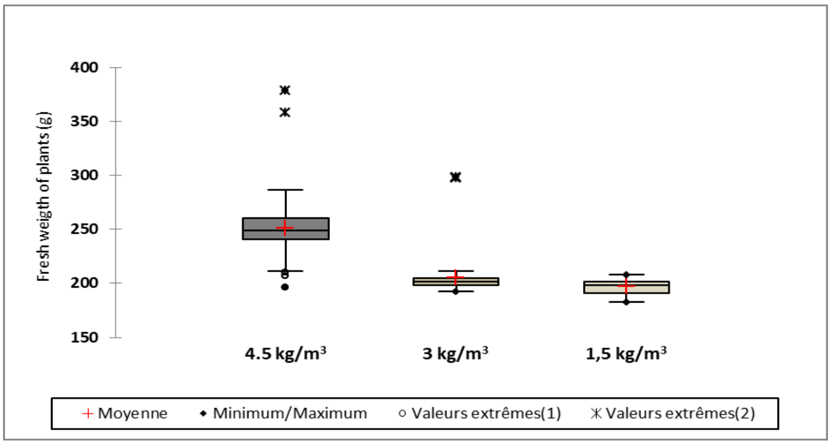

Figure 4. Box- plots of fish stocking density relative to fresh weight of lettuce plants (g).

The leaf length of Lettuce at harvest in all groups was significantly different (P≤ 0.05) and was highest at the stoking density of 4.5 kg/m^3 (29.54±30.01 cm) followed by 3 kg/m^3 (24.93±18.55 cm) and 1.5 kg/m^3 (22.41±10.67 cm). The leaf width of Lettuce at the end of 56 day varied significantly in all the treatments and was observed highest at the stoking density of 4.5 kg/m^3 (23.5±25 cm) followed by 3 kg/m^3 (19.9±13.56 cm) and 1.5 kg/m^3 (17.5±10.23 cm).

Regarding root characteristics, the length of roots did not exhibit a significant difference statistically among the stocking density treatments; the lettuce at the density of 4.5 kg/m^3 had the highest root length with 54.83±2.39 cm and the lowest one at 1.5 kg/m^3 treatment with 41.9±1 cm (Table 3).

Discussion

Water quality

Water parameters (temperature, pH, dissolved oxygen , total ammonia nitrogen , nitrite, nitrate, soluble reactive phosphorus and potassium) were within acceptable levels as reported for aquaponics **(Somerville et al., 2014; Yanes et al., 2020)**. In fact, the water temperature in rearing tanks across the three stocking densities ranged from 28.15±0.45 and 29.91±0.56˚C and was within acceptable values for tilapia growth between 27 c° and 30 C°. As one of the crucial factors in aquaponics, pH must be maintained at around 7 for successful nitrification; converting ammonia and supplying plants with nitrate **(Goddek et al., 2015; Kloas et al., 2015)**. Tilapia fish tolerate a wide range of pH but do best at levels of 6.5–8.5 **(Stone & Thomforde, 2004; Yep & Zheng, 2019)**. In view of this, the pH in our systems was within recommended ranges ideal for aquaponics systems **(ranged between 6.78 and 7.78)**, which was similar to the findings of those of (Rakocy et al., 2006; Tawaha et al., 2020). In an aquaponics system, maintaining water's pH is not only a requirement for fish growth. In fact, to improve nutrient uptake, most plants require a pH between 6 and 6.5. It is generally known that a pH below 6 disrupts the nitrification process, and could lead to ammonia and nitrite toxicity **(Rakocy et al., 2006).** Although the pH values in this study were somewhat elevated compared with the optimal value for plant growth, we did not detect any stress during the experiment, which is probably due to interactions that characterize the plant rhizosphere.

In addition to temperature and pH, dissolved oxygen (DO) also represents as one of the most critical environmental factors related to the good physiological functions of tilapia and acts as a limiting factor for fish lifespan **(Yildiz et al., 2017; Maucieri et al., 2019)**.

In the current study, there was an inverse relationship between fish stoking density and DO level. This observation is congruent with the findings of which aligns with the DO values obtained from the current study. The low concentration of dissolved oxygen observed in the water of the high stoking density can be explained by: i) accumulation of the organic matter in fish tanks due to food scraps and fish excrement, which could have improved the consumption of oxygen by microbes for oxidation, and ii) An elevated weight-to-space ratio of the fish in rearing tank.

Considering the presence of nutrients in the water of both fish tanks and vegetables units, the amount of nutrients was due to dissolved ions and organic substances produced from the biological processes of nitrifying bacteria**(Kasozi et al., 2021)**. The results of this experiment showed that the water in fish tanks had higher values than the hydroponic systems at the same stocking density for almost all parameters, suggesting the lettuce's beneficial influence. Particularly, nutrient levels significantly decreased, indicating absorption for plant growth. Moreover, the concentration of total ammonium-nitrogen (TAN), nitrate and nitrite increased with increasing fish stocking density except for potassium and soluble reactive phosphorus, this due to the higher input of feed according the treatments. Similar trends were also observed in several works conducted by **(Shoko et al., 2014; Azizah et al., 2016; Makori et al., 2017)**.

Ammonia is produced in an aquaponic system as a result of fish excretion through the gills and the decomposition of uneaten food (Eck et al., 2019). According to **(Anantharaja et al., 2017; Yildiz et al., 2017)**,the high levels of ammonia and nitrite lead to reduced fish growth and survival, and also cause considerable physiological dysfunctions in fish like the fish's ability of transport oxygen via blood. During the experiment period, the concentration of nitrite increased when the stocking density of fish increased, but it remains within the recommended value by **(Timmons & Ebeling, 2010),** which is below 1.0 mg/L.

The nitrate levels also increased with increasing stocking density, a condition that was also closely related to the amount of feed given to the fish. our findings were similar to those of **(Tawaha et al., 2020; Sabwa et al., 2022)** who reported a linear augmentation of nitrate as stocking density and feed input increased, moreover the value of nitrate in our study ranged between 1.13 and 1.35 mg/L which was close to that of **(Sabwa et al., 2022)** which was between 1.11 and 1.34 mg/L.

The removal of TAN, nitrite and nitrate therefore from the water as indicated by the lower values in the hydroponic unit as compared to the RAS unit was probably due to plant uptake **(Birolo et al., 2020)**. **(Kasozi et al., 2021)** indicated in a study, that the microorganisms present in an aquaponics systems especially Bacillus could increase lettuce growth and nitrate accumulation. In addition, the Bacillus can affect the factors that stimulate root growth, which leads to higher nutrients uptake **(Bartelme et al., 2019)**. Furthermore, the lower levels of TAN, nitrite and nitrate in the hydroponic units water in comparison to the fish rearing tanks water, probably suggesting that the removal of these nutrients from the water was due to root plants uptake. Moreover being ammonia is one of the main sources of inorganic nitrogen taken up plants, it can be absorbed by microorganisms and converted back to organic matter, removed from water via nitrification process **(Endut et al., 2011)**.

Growth performance of the fish

Based on the provided data from this study, the growth performances of tilapia under different stocking densities were evaluated, and the results indicate significant differences among the treatments. Throughout the study, fish stocked with an initial average weight of 20. g for 56 days were used to examine O. niloticus growth. The final weight of tilapia differed significantly among the stocking density treatments. the mean final weight in T1 (1.5 kg/m^3) was significantly higher than that in T2 (3 kg/m^3) and T3 (4.5 kg/m^3). This suggests that lower stocking densities result in better growth and higher final weights for tilapia.

For instance, Diem et al. (2017), Ferdous et al. (2014), Rayhan et al. (2018), and Sace and Fitzsimmons (2013) conducted a studies on the effect of stocking density in aquaponics systems and found that lower densities, similar to our T1 (1.5 kg/m^3) treatment, promoted higher final weights and better weight gain in tilapia. These results support our findings and are consistent with the inverse relationship between fish weight and stocking density. Endut et al. (2009) reported significantly higher stocking density values employed in aquacultural settings compared to what we used in our experiment.

According to research conducted by Baßmann et al. (2020) and Maucieri et al. (2019), which supported Endut et al. (2016), aquaponic systems can employ even higher stocking densities of fish than those used in RASs and conventional aquaculture. This maybe as a result of the better water recirculation employed in those aquaponic systems.

Furthermore, Palm et al. (2014) working also in the aquaponic system reported a (SGR) of 0.71% per day in Nile tilapia whose initial weight was 174 g and were initially stocked at 5.6 kg/m^3 and 0.65%/day, which are nearly similar to those found in the present study. Additionally, Greenfeld et al. (2018) found that the SGR of Koi Carp (Cyprinus carpio) decreased when fish density increased from 1.4 kg/m^3 to 2.1 kg/m^3 to 2.8 kg/m^3, with an initial weight of 4.24 g raised in an aquaponic system.

Regarding feed conversion ratio (FCR), our results correspond to the findings of Al-Harbi and Siddiqui (2000), who reported that the FCR increased with increasing stocking density, which could be attributed to the amount of feed supplied in each treatment. Moreover, several studies have found that increasing stocking density has a negative influence on fish feed conversion ratios in both aquaponic and traditional aquaculture systems **(Maucieri et al., 2019; Tran et al., 2019)**.

Growth performance of lettuce

The results indicated a general trend of increased growth in the mean biomass of lettuce as the stocking density increased across the treatments. Specifically, higher stocking densities or treatment at 4.5 kg/m^3 corresponded to greater biomass accumulation in lettuce plants, as well as the mean wet head weight, length and width of leaves and root length. This suggests a potential positive correlation between tilapia stocking density and the overall growth of lettuce, this was similar to findings reported by **(Estrada-Perez et al., 2018)**.

Several studies have reported that the main difference between the stocking densities was the concentrations of nutrients produced, which impacted the growth and development of the lettuce during this study **(Maucieri et al., 2018; Rakocy et al., 2006)**. As stated by **(Pérez-Urrestarazu et al., 2019)** aquaponics systems productivity depends greatly on lettuce type and environment conditions.

The positive relationship between fish stocking density and lettuce growth in this study can be attributed to the increased availability of nutrients derived from fish waste .As the stocking density of fish increases, the nutrient concentration in the aquaponics system rises, which in turn leads to improved nutrient availability for the lettuce plants. This increased nutrient supply promotes vigorous growth and higher biomass accumulation in the lettuce plants **(Somerville et al., 2014; Delaide et al., 2016)**.

Moreover, the positive impact of fish stocking density on lettuce growth could be attributed to the stimulation of microbial activity in the aquaponics system.**(Sas-Paszt et al., 2023**). As the stocking density of fish increases, the nitrifying and rhizosphere bacteria also increases. In turn , Nitroso-bacteria convert the ammonia in the water into nitrite before the nitro-bacteria turn it into a nitrate, which is available for uptake by lettuce plants **(Delaide et al., 2017; Goddek, 2017; Kasozi et al., 2021)**.

In general, the dominant growth-limiting plant nutrient is nitrogen, which is uptaken by plants as nitrate or ammonia, as well as this is affected by the CO_2 level in the water and other water parameters such as temperature and pH **(Somerville et al., 2014; Hu et al., 2015).** However, the poor growth performances of the lettuce observed in stoking density of 1.5 kg/m3 can be probably explained by that plants in this treatment did not receive an enough amount of nitrate for their growth comparing to plants in treatments of 4.5 kg/m^3 and 3 kg/m^3. It is expected that higher plant growth performance is achieved when nitrogen is supply in the form of a combination of ammonium and nitrate **(Maucieri et al., 2019)**.

Conclusion

The stocking density of tilapia influenced the yield of the NFT aquaponics system in terms of water quality and production of tilapia and lettuce. Moreover, the weight and SGR of fish were negatively influenced by the stocking density, but feed conversion (FCR) increased with increasing density of fish. In general, the fish growth performance was best at the lowest stocking density (1.5 kg/m^3) compared to higher ones. This does not mean that higher stocking densities cannot be adopted, especially if suitable water quality standards are respected. The lettuce yield rose with increasing fish stocking density in terms of biomass and root length. The system's ability to produce nutrients is directly impacted by the amount of feed that is supplied. Contrary to fish, stocking density had a positive effect on the growth efficiency and overall production of lettuce grown in an aquaponic system. The recorded water quality metrics were within the recommended concentrations depending of the stocking density used. Overall, the successful production of vegetables, performance, fish health, and system efficiency indicate that this cost-effective, low-tech approach can be effectively scaled up in arid regions with minimal construction expenses.

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