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Effects of Water Renewal Frequency on Growth Performance of Juvenile African Catfish (*Clarias gariepinus*) and Amaranth (*Amaranthus hybridus*) in an Integrated Fish-Vegetable System

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Abstract This study evaluated the effect of water renewal intervals of 3, 5, 7, and 9 days on the growth performance of juvenile *Clarias gariepinus* and the effects of recycled culture water on *Amaranthus hybridus* cultivation in an integrated system. A total of 180 juvenile *C. gariepinus* were stocked in plastic tanks, with each tank linked to a corresponding *A. hybridus* plot over 56 days. Findings indicated that water renewal frequency significantly influenced water quality parameters ($P < 0.05$). Dissolved oxygen levels decreased with longer renewal frequency, from 5.83 mg/L (3-day) to 5.01 mg/L (9-day). Concurrently, pH levels and water temperatures also dropped significantly with less frequent renewals. Conversely, Total Ammonia Nitrogen (TAN) and nitrate nitrogen concentrations increased over the same period. Growth performance in *C. gariepinus* showed optimal results under the 3-day renewal treatment, yielding a mean final weight of 40.06 g substantially higher than the 7 and 9-day renewal frequency. *A. hybridus* growth performance also varied, with the highest leaf count and plant height observed in the 3-day renewal frequency. The study concluded that a 3-day water renewal interval is optimal for *C. gariepinus*, while a 5-day interval is recommended for achieving a balanced production of both fish and quality vegetables, especially regarding the leaf quality of *A. hybridus*. This study provides practical insights into optimizing water management strategies for integrated aquaculture systems, contributing to efficient resource utilization and sustainable fish-vegetable production. Overall, these findings provide evidence-based guidance for improving water use efficiency and the sustainability of integrated fish-vegetable production systems, especially in water limited and climate vulnerable areas.

Keywords Water renewal frequency; Integrated aquaculture; *Clarias gariepinus*; *Amaranthus hybridus*; Fish-vegetable system

1 Introduction

Fish is an important component of diets in Nigerian nutrition, accounting for about 40% of the country's total protein intake amongst its citizens (Egun et al., 2022). Fish is generally cheaper and more available when compared to other animal sources of protein, which makes it more affordable to vulnerable households in both rural and urban communities of Nigeria (Egun et al., 2022). Despite its affordability, the fish per capita consumption (11~13kg/year) in the country remains below the world average per capita consumption (20~21 kg/year), indicating limitation in accessibility which call for improved approaches for fish distribution (Akinrotimi and Amachree, 2020). Furthermore, the country's annual fish demand is estimated around 3.6 million tonnes, but the country can only be able to provide about 1.4 million metric tonnes through all sources and hence depend on importation for the deficit of about 2.2 million metric tonnes (Esiobu et al., 2020). Aquaculture has the potential to bridge the gap between fish demand and its supply as the sector continues to grow with *Clarias* and *Heterobranchus* spp. (catfish), *Tilapia* spp. (Tilapia), *Cyprinus carpio* (Common carp) as the major species (Oluwatayo and Adedeji, 2019). Aquaculture plays an important role to the country's economy as its account for about 3.2% of Nigeria's GDP (FAO, 2021).

However, aquaculture in Nigeria faces many challenges such as water-related problems, pest and diseases, high cost of feed ingredients, poor seed, insufficient skilled labour force etc (Ogunji and Wuertz, 2023). Poor water quality or fish pond pollution is a consistent challenge in fish farming in Nigeria which leads to eutrophication, low dissolved oxygen (DO), increased level of ammonia, nitrite and nitrate (Agwu et al., 2025). Effective management of water quality parameters is the fundamental determinant of fish health, success and profitability in aquaculture systems (Hassan and Obiero, 2024). The physiological stability, growth rate, and reproductive success of farmed fish rely on maintaining physical, chemical, and biological parameters within species-specific optimal requirement (Sanni and Sule, 2025). Suboptimal water conditions induce physiological stress, reduce feed conversion efficiency, and impair immune systems of aquatic organisms (Lusiastuti et al., 2026). Consequently, poor water quality serves as the primary catalyst for pathogenic bacterial outbreaks, resulting in mortality and economic losses for fish farmers (Olowosegun et al., 2021). One of the challenges in intensive aquaculture production is managing the accumulation of toxic metabolic byproducts (Hassan and Obiero, 2024). Researchers demonstrate that substantial percentage of nutrients originating from commercial feeds specifically carbon, nitrogen, and phosphorus accumulate directly within pond (Boyd and Gross, 2000). Without systematic intervention, this accumulation accelerates unionized ammonia toxicity and lethal nitrification build up (Lusiastuti et al., 2026). Furthermore, high organic loading triggers microbial decomposition, depleting Dissolved Oxygen (DO) levels and creating hypoxic environments (Olowosegun et al., 2021). To mitigate these environmental stressors, conventional management depended on aggressive water exchange and manual aeration (Boyd and Gross, 2000). However, modern aquaculture advocates for the adoption of automated real-time sensors, advanced recirculating filtration, and specialized biofloc technologies (Hassan and Obiero, 2024). These innovations stabilize important parameters such as maintaining DO above 5.0 mg/L and regulating pH between 6.5 and 8.5 while significantly reducing wastewater discharge (Sanni and Sule, 2025).

On the other hand, water scarcity also threatens aquaculture development in Nigeria due to regional climatic differences and environmental pollution (Ogunji and Wuertz, 2023). In the arid northern region, fish farming is limited by low rainfall, intense evaporation rates, and poor soil water retention (Kassig and Obiero, 2025). Conversely, the humid southern region suffers from qualitative water scarcity as a result of industrial effluents, oil spills, and agricultural runoff that compromise water quality parameters, rendering surface sources toxic for fish farming (Olowosegun et al., 2021). Earthen ponds and open flow through systems are becoming unsustainable because they require substantial quantity of freshwater, which reduces local groundwater tables and discharges nutrient-rich wastewater that triggers eutrophication (Anani and Oti, 2025). To adjust this, authors suggest transition toward water efficient technologies like Recirculating Aquaculture Systems (RAS) and Integrated Aquaponics. RAS minimizes water consumption by over 90% by continuously filtering and recycling water in a closed loop (Aqua Ultraviolet, 2025). Integrated aquaculture-vegetable production systems, on the other hand, offers sustainable, circular economy model for modern production. This symbiotic system leverages the metabolic outputs of aquatic species to drive crop growth within a unified hydrological loop (Lal, 2023). In conventional aquaculture system, fish excrete nutrient-rich waste that becomes toxic if left unmanaged, whereas in an integrated system, the wastewater serves as an organic nutrient solution for crops (Palm et al., 2018) However, widespread adoption of this technology among smallholder fish farmers is limited by high initial capital costs, lack of technical know-how, expensive filtration components, and Nigeria's persistent electrical grid instability (RAStech Magazine, 2022).

As a result, most farmers in Nigeria adopt water changing as the routine management activity to control water pollution and maintain water quality by removing effluents (suspended solids, ammonia and nitrites) balancing pH, stabilizing dissolved oxygen (DO) and decreasing dangerous metabolites. Moderate renewal regimes have been reported to maintain acceptable level of ammonia (Dauda and Akinwole 2015; Opute and Odion, 2020). Dauda et al. (2023) researched the effect of changing water intervals at 2, 4 and 7 days' on growth performance of juvenile *Clarias gariepinus.* They reported higher yield on the treatment with 7 days' changing intervals. Similarly, Opute and Odion (2020) studied effect of six water renewal frequencies on yield of *Clarias gariepinus*. They evaluated daily, 2, 3, 5, 7, 9 and 14 days' interval. They concluded that the treatment which the water is changed at 5 days' intervals had higher growth performance indices. Likewise, Okomodo et al. (2016) reported higher specific growth rate, weight gain and survival rate from treatments where water is changed at 4 and 8 days' when compared with treatments where water is changed daily, 14 -days and no change.

Although several studies have investigated the effects of different water renewal frequencies on the growth performance, survival, and water quality of *Clarias gariepinus* (Opute and Odion, 2020; Dauda et al., 2023), their primary focus has been on improving fish growth within conventional fish farming practice. These studies consistently demonstrate that appropriate water renewal intervals improve water quality and fish growth by reducing the accumulation of toxic metabolites. However, the nutrient-rich effluent from the fish culture medium is generally regarded as waste and discharged without evaluating its potential reuse for other agricultural production.

Integrated aquaculture crop production systems offer an opportunity to transform fish culture effluents into valuable irrigation and nutrient resources, thereby improving water use efficiency and promoting circular resource utilization. While previous studies have demonstrated the agronomic benefits of aquaculture wastewater for crop cultivation, there is limited information on how different water renewal frequencies simultaneously influence fish growth, water quality, and the productivity of vegetables irrigated with the resulting effluent. Consequently, there is insufficient evidence to determine a water renewal strategy that optimizes both aquaculture performance and crop production within an integrated system. This knowledge gap is particularly important in water limited regions, where maximizing the productive use of available water is essential for sustainable food production and climate adaptation. *Amaranthus hybridus* is one of the most widely cultivated leafy vegetables in Nigeria and is highly sensitive to water availability and quality. Previous studies have shown that water stress significantly reduces its growth, biomass accumulation, nutritional quality, and market value (Adeyemi et al., 2017; Yusuf et al., 2018; Edeh and Igberi, 2019; Alabi et al., 2020; Olaniyi and Ajayi, 2021). However, little is known about the suitability of fish culture effluents generated under different water renewal intervals for irrigating *A. hybridus* while maintaining optimal fish production.

Therefore, this study evaluated the effects of different water renewal intervals (3, 5, 7, and 9 days) on the growth performance of juvenile *C. gariepinus* and assessed the suitability of the corresponding culture water for the cultivation of *A. hybridus* in an integrated fish-vegetable production system. The study aimed to identify a water management strategy that enhances fish growth while maximizing the productive reuse of fish culture effluent for vegetable cultivation, thereby contributing to sustainable water management and resource efficient integrated aquaculture systems.

2 Materials and Methods

2.1 Experimental site

The study was conducted at the Fisheries and Aquaculture Teaching and Research Farm of Federal University Gashua (FUGA), Yobe State, Nigeria (GPS coordinates 12.8710°N, 11.0460°E) as shown in Figure 1 below. The farm provided controlled conditions suitable for the rearing of juvenile *C. gariepinus* and cultivation of *A. hybridus*. The experimental area allowed for efficient management of water supply regimes, monitoring of water quality parameters, and observation of both fish and plant health.

2.2 Experimental design

The water renewal frequencies of 3, 5, 7, and 9 days were selected to represent a practical range of water management strategies commonly used in small and medium scale aquaculture, particularly in water limited regions in Nigeria. These intervals establish a gradient from relatively frequent to infrequent water exchange, they reflect realistic farming conditions and provide a practical basis for identifying a water management strategy that balances fish productivity with efficient utilization of aquaculture effluent. Each treatment was replicated three times (Figure 2) giving a total of 12 experimental *C.gariepinus* tanks and 12 experimental *A. hybridus* plots.

2.3 Fish Stocking and feeding management

2.3.1 Stocking of fish

A total of 180 juvenile *C. gariepinus* were used, with 15 fish stocked per tank (50 L capacity). Fish were individually weighed and measured prior to stocking to ensure uniformity.

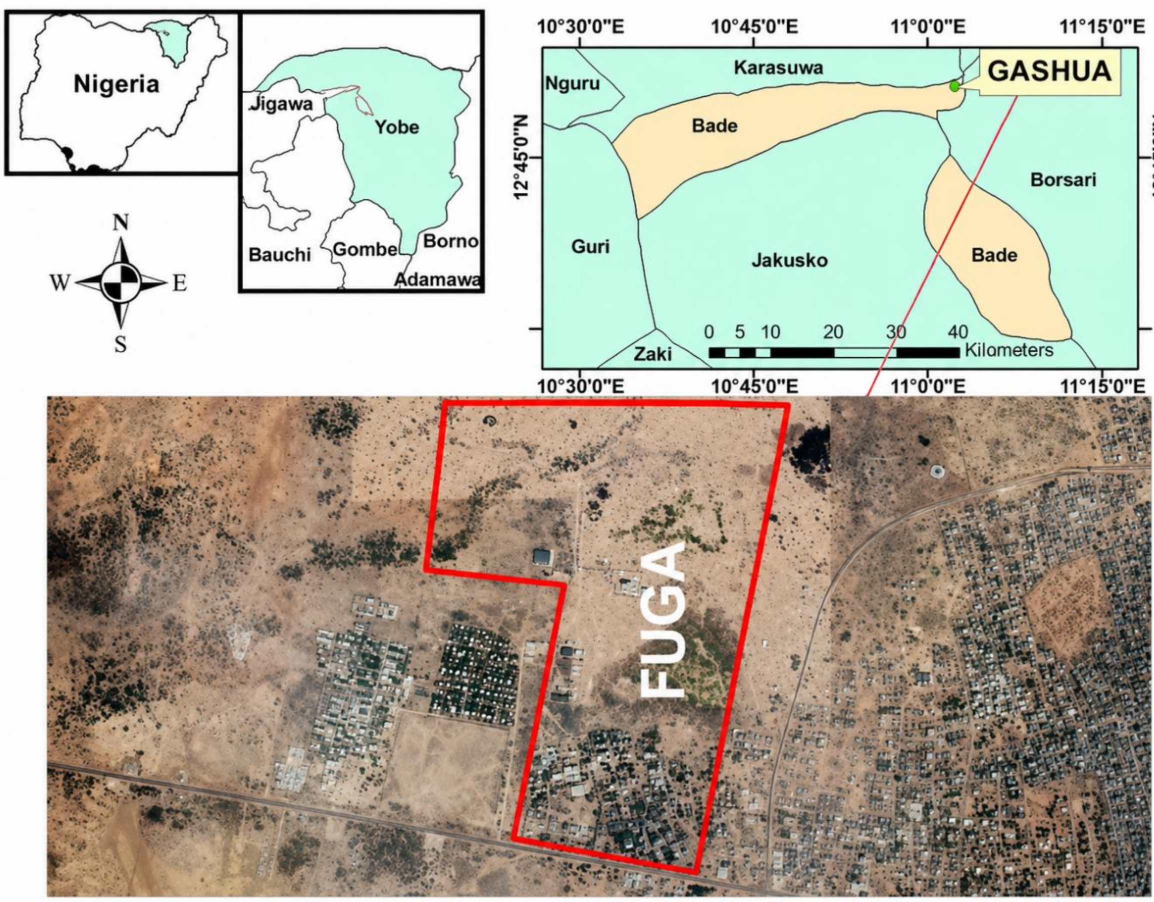


Figure 1 Location of the experimental site at Federal University Gashua, Nigeria

2.3.2 Feeding of fish
Fish were fed at 5% of their body weight with commercial pelleted feed containing 35% crude protein twice daily at 08:00 and 16:00 hours. Feed quantity was adjusted weekly based on tank biomass.

2.4 Water quality monitoring
Water quality parameters were measured weekly as the method described by Dauda and Akinwole (2015); Dauda et al. (2023). The selected parameters measured include; pH, Dissolved Oxygen (DO, mg/L), Total Ammonia Nitrogen (TAN, mg/L) and Nitrate Nitrogen (NO_3^-, mg/L).

2.5 Plant cultivation
Amaranth (*A. hybridus*) seedlings were planted in normal loamy soil at 30/bed (20 cm by 15 cm). Plant height, number of leaves, and leaf quality were measured weekly.

2.6 Growth performance and yield measurements
Weight gain (WG)
WG = Final weight - Initial weight

Condition factor (K)

$$K = \frac{W}{L3} \times 100$$

Feed conversion ratio (FCR)

$$FCR = \frac{Feed\ intake}{Weight\ gain}$$

Survival (%)

$$SR = \frac{Number\ of\ Fish\ at\ End}{Number\ of\ Fish\ at\ Start} \times 100$$

2.7 Harvesting and data collection

At the end of 8 weeks, fish were counted, weighed individually, and tank biomass calculated. Amaranth height, Number of leaves, and leaf quality were observed. Data were tabulated weekly for growth performance analysis.

2.8 Statistical analysis

Data were analyzed using one-way analysis of variance (ANOVA) in IBM SPSS Statistics version 26 to determine the effects of water renewal intervals on fish and plant growth performance. Prior to conducting ANOVA, the assumptions of normality and homogeneity of variance were assessed. Normality of the data was evaluated using the Shapiro wilk test, while homogeneity of variances was assessed using Levene's test. The assumptions were considered satisfied when $P > 0.05$. Where significant differences were detected by ANOVA, treatment means were separated using Tukey's honestly significant difference (HSD) test at the 5% probability level ($\alpha = 0.05$). Results were expressed as mean ± standard deviation, and differences were considered statistically significant at $P < 0.05$. Graphs were generated using Microsoft Excel and GraphPad Prism version 11.02.

2.8 Plant irrigation

The *A. hybridus* plots were irrigated with effluent discharged from their corresponding fish tanks. The system was designed such that the fish tanks were elevated above the cultivation plots, allowing the effluent to flow to the plants by gravity through the outlet. A schematic representation of the experimental layout is presented in Figure 2.

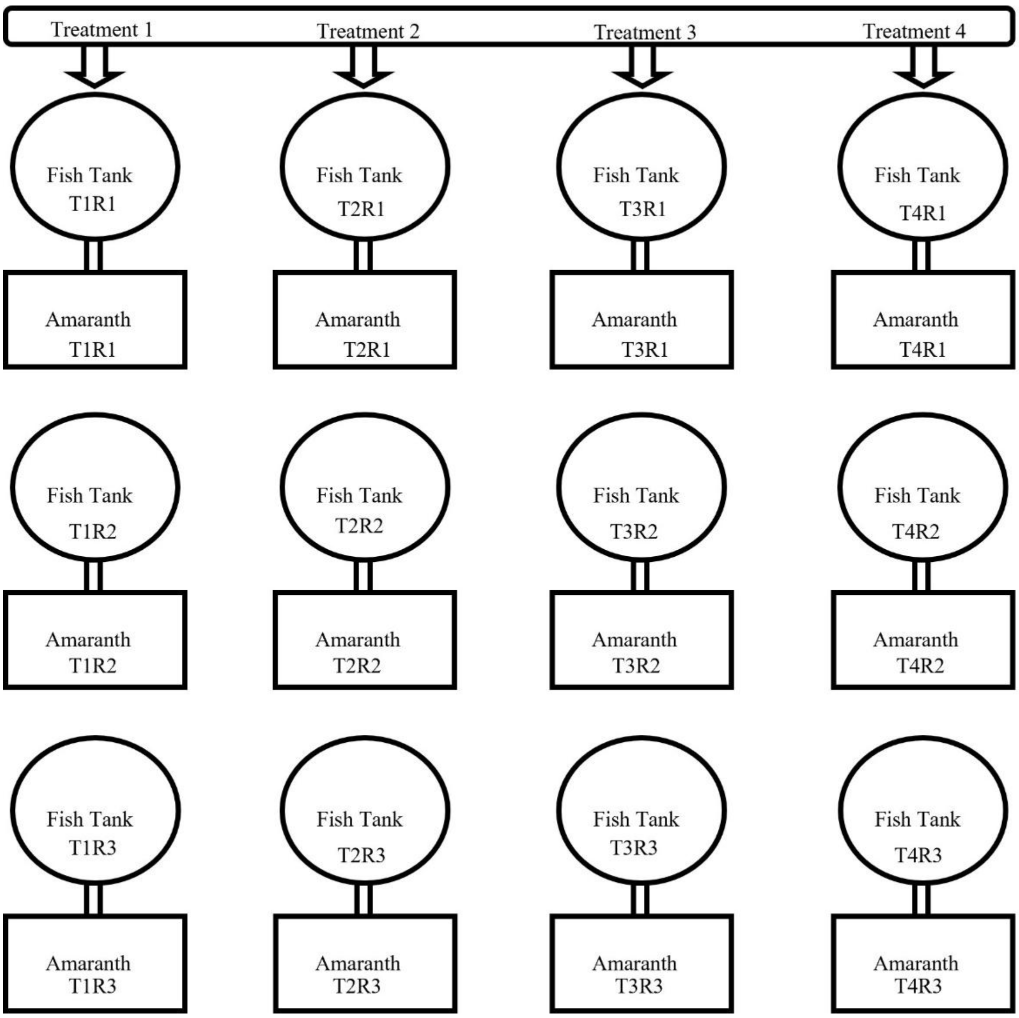


Figure 2 Layout of experimental fish tank and corresponding amaranth plot

3 Results

3.1 Water quality parameters

Table 1 and Figure 3 show that frequency of water renewal significantly affected all the selected water quality parameters measured in this experiment ($P < 0.05$). Dissolved oxygen recorded highest in the 3-day renewal frequency (5.83 ± 0.05 mg/L), but did not differ significantly from the 5-day renewal frequency (5.76 ± 0.05 mg/L), however it is significantly higher than the 7 and 9 days' renewal frequency (5.35 ± 0.05) and (5.01 ± 0.23) respectively. Water pH declined with increasing water renewal interval, with the highest value recorded in the 3-day renewal frequency (7.10 ± 0.10) and the lowest in the 9-day renewal treatment (4.61 ± 0.30). Total ammonia nitrogen and nitrate concentrations increased as the water renewal interval increased, with the lowest values observed in the 3-day renewal frequency (0.49 ± 0.01 mg/L and 0.08 ± 0.00 mg/L, respectively) and the highest values in the 9-day renewal frequency (0.64 ± 0.01 mg/L and 0.12 ± 0.04 mg/L, respectively).

Table 1 Selected water quality parameters in fish culture tanks subjected to different water renewal frequencies

Parameters	Every 3 days	Every 5 days	Every 7 days	Every 9 days
Dissolved Oxygen (mg/L)	5.83 ± 0.05^{a}	5.76 ± 0.05^{a}	5.35 ± 0.05^{b}	5.01 ± 0.23^{c}
pH	7.10 ± 0.10^{a}	6.83 ± 0.09^{b}	5.39 ± 0.11^{c}	4.61 ± 0.30^{d}
Temperature	27.75 ± 0.46^{a}	28 ± 0.05^{a}	23.38 ± 1.40^{b}	23.00 ± 1.95^{b}
Total Ammonia Nitrogen (TAN) (mg/L)	0.49 ± 0.01^{a}	0.57 ± 0.01^{b}	0.61 ± 0.00^{c}	0.64 ± 0.01^{d}
Nitrate – Nitrogen (mg/L)	0.08 ± 0.00^{a}	0.1 ± 0.01^{b}	0.11 ± 0.01^{c}	0.12 ± 0.04^{d}

Values are presented as mean ± S.E. Means within the same row followed by different superscript letters are significantly different at $P < 0.05$.

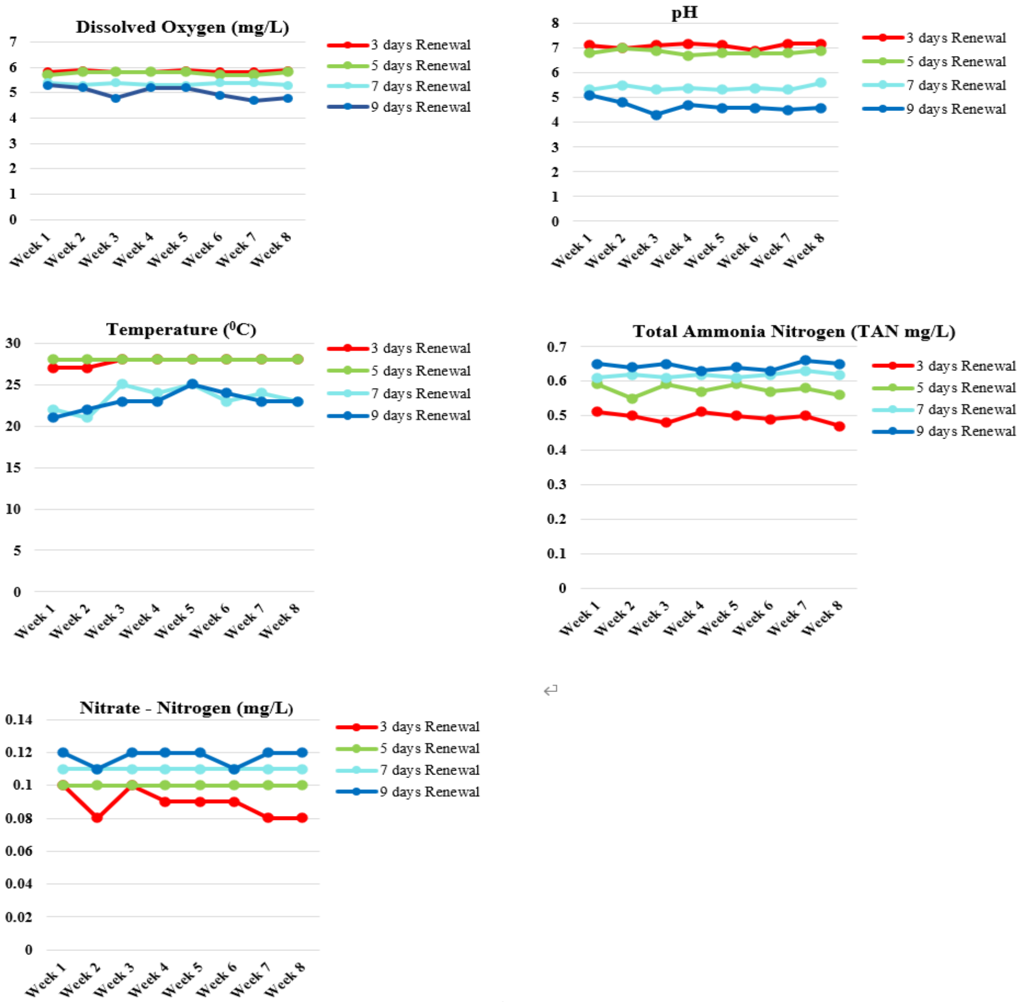


Figure 3 Graphs showing weekly changes in selected water quality parameters during the period of the research

3.2 Growth performance and feed utilization of *Clarias gariepinus*

Table 2 and Figure 4 show the mean difference in selected growth performance indices amongst the groups. All the fish had the same weight at the initial time of the experiment ($P > 0.05$). Water renewal frequency significantly affected final weight, condition factor (K), and feed conversion ratio (FCR) ($P < 0.05$). Fish designated to water renewal at every 3-day recorded the highest final weight (40.06 ± 14.60 g), which was statistically similar to those where water was renewed at every 5-day (31.75 ± 11.02 g) but statistically higher than fish where water were renewed at 7 and 9 days'. Condition factor (K) was significantly higher in tanks where water was renewed at 3 and 5 days' than at the tanks where water was renewed at 7 and 9 days'. The lowest FCR value (1.61 ± 0.03) was observed in 3-day water renewal frequency and highest was observed in the 9-day (2.04 ± 0.04). Survival was highest (100%) in both the 3 and 5days' renewal frequencies and lowest 93.33% in both 7 and 9 days'.

Table 2 Selected fish growth performance indices

Parameters	Every 3 days	Every 5 days	Every 7 days	Every 9 days
Initial weight	11.00 ± 0.01^{a}	11.00 ± 0.08^{a}	11.00 ± 0.02^{a}	11.00 ± 0.04^{a}
Mean Final weight	40.06 ± 14.6^{a}	31.75 ± 11.02^{ab}	21.75 ± 6.12^{bc}	17.5 ± 4.90^{c}
Condition Factor (K)	1.27 ± 0.12^{a}	1.16 ± 0.11^{a}	0.94 ± 0.00^{b}	0.90 ± 0.00^{b}
Food Conversion Ratio (FCR)	1.61 ± 0.03^{d}	1.86 ± 0.01^{c}	1.97 ± 0.03^{b}	2.04 ± 0.04^{a}
Survival Rate	100%	100%	93.33%	93.33%

Values are presented as mean ± S.E. Means within the same row followed by different superscript letters are significantly different at $P < 0.05$. ND means not determined.

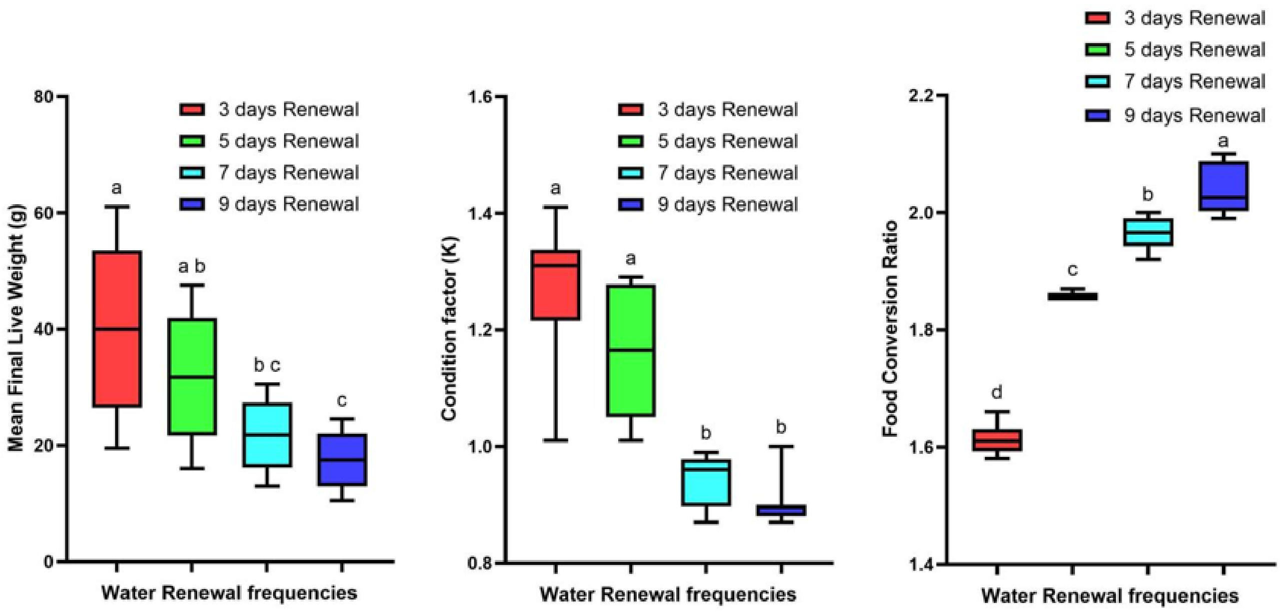


Figure 4 Graphs showing differences in some selected growth performance of C.gariepinus indices amongst the group

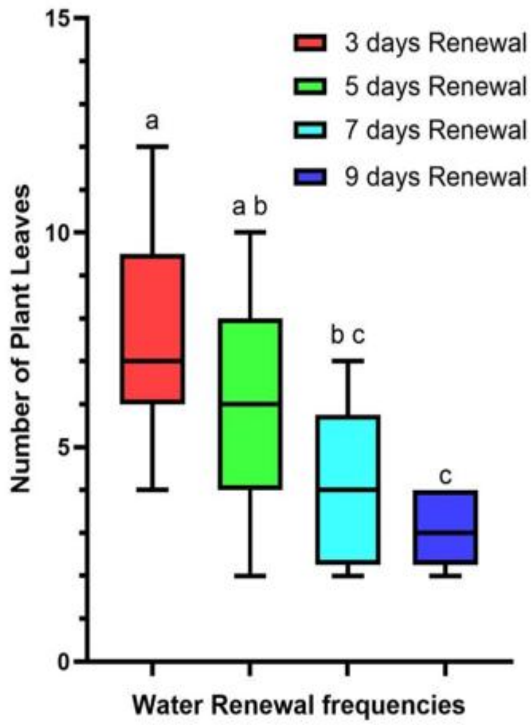
3.3 Plant growth performance indices

Table 3 and figure 5 shows mean differences in selected plant growth performance indices. Irrigation frequency from effluent of fish tanks significantly affected the growth of the plants ($P < 0.05$). Plants irrigated from the effluent of tanks 3-day renewal frequency recorded the highest number of leaves (7.50 ± 2.60), which was statistically similar to those irrigated from effluent of 5-day (6.00 ± 2.62), but significantly higher than plants irrigated 7 and 9 days'. Similarly, the highest plant height (26.09 ± 10.70 cm) was recorded under the 3-day effluent irrigation and did not differ significantly from the 5-day frequency (19.34 ± 7.45 cm). Furthermore, plant height declined significantly as the irrigation from the effluent increased, with the lowest value (8.31 ± 1.83 cm) recorded in the 9-day irrigation effluent and wilted.

Table 3 Selected plant growth performance indices

Parameters	Every 3 days	Every 5 days	Every 7 days	Every 9 days
Number of Leaves	7.50 ± 2.60^{a}	6.00 ± 2.62^{ab}	4.12 ± 1.80^{bc}	3.12 ± 0.83^{c}
Plant Height	26.09 ± 10.7^{a}	19.34 ± 7.45^{ab}	10.71 ± 3.50^{bc}	8.31 ± 1.83^{c}

Values are presented as mean ± S.E. Means within the same row followed by different superscript letters are significantly different at $P < 0.05$.



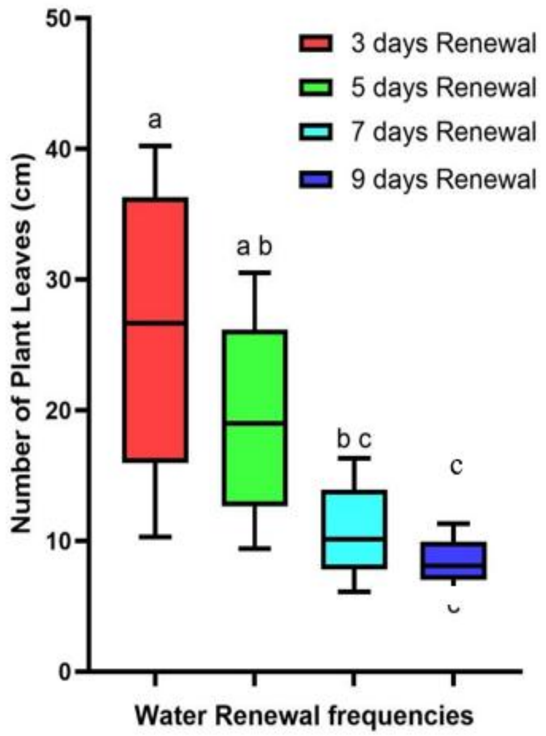


Figure 5 Graphs showing differences in some selected growth performance indices of *A. Hybridus* amongst the groups

4 Discussion

In aquaculture, water quality plays an important role in productivity as it directly influences fish metabolism, feed utilization, health status and overall performance (Boyd 2020). In this study water renewal frequency affected all the selected water quality parameters evaluated viz; Dissolved Oxygen (DO), pH, Temperature, Total Ammonia Nitrogen (TAN) and Nitrogen – Nitrate Concentrations; indicating its influence on fish growth performance and subsequent utilization of effluent for *A.* hybridus cultivation.

Higher Dissolved oxygen concentration observed in the 3-day water renewal frequency suggest that frequent changing of water improved oxygen replenishment, while concurrently reducing the biological oxygen demand (BOD) associated with decomposing organic matter. Sufficient DO is required for efficient aerobic metabolism as it supports mitochondrial oxidative phosphorylation, maximizes ATP produce from ingested nutrients and maintains other requirements for growth. On the other hand, the decline in dissolved oxygen observed in the 7 and 9 days' renewal frequency is consistent with increased microbial decomposition of uneaten feed and faeces which consumed dissolved oxygen and limits its availability. When fish are subjected to hypoxic condition, majority portion of the energy is diverted to anaerobic pathways and to physiological compensation of the condition (increased cardiac output and stressed-hormone release) consequently leaving less net energy available for somatic growth (Krista and Nelson, 2020). This agrees with the findings of Dauda et al. (2023) that reported that water exchange frequency significantly influenced ammonia accumulation and several water quality parameters in juvenile *C. gariepinus*.

Moderate temperature recorded in 3 and 5 days' water renewal frequency suggested that regular changing of water maintains the temperature while prolong renewal of water in 7 and 9 days suggested lower temperature due to still condition of the culture water. Temperature affects all enzymatic reactions and influences oxygen solubility. The lower temperatures recorded under prolonged renewal intervals likely resulted from reduced water movement and greater evaporative cooling in static systems, potentially slowing metabolic processes and growth. This also agrees with the findings of (Dauda et al., 2023). pH was observed to be declining as the water renewals frequency increased.

The relatively neutral pH maintained in the 3-day renewal frequency revealed improved buffering capacity through regular renewal of water in the culture tanks. This matches with the findings of (Jana and Sarkar, 2005; Boyd, 2020; Dauda et al., 2023; Çelik et al., 2025) that proved maintaining pH within the recommended range is crucial as extreme pH influences the toxicity of ammonia and the efficiency of microbial nitrification. Furthermore, pH influences the equilibrium between toxic unionised ammonia (NH_3) and the less toxic ionised form (NH_4^+). Even modest reductions in pH can increase the proportion of NH_3, elevating its diffusion across the gill epithelium. Extreme or fluctuating pH also impairs gill ionoregulation, reduces the efficiency of nitrifying bacteria, and alters the activity of digestive and metabolic enzymes thereby affecting growth and overall production efficiency.

Total Ammonia Nitrogen (TAN) concentration increased as the water renewal reduces, entailing the continuous production of nitrogenous wastes from branchial excretion (the primary end-product of protein catabolism) and from microbial mineralisation of uneaten feed and faeces (Hargreaves and Tucker, 2004; Boyd, 2020; Hassan et al., 2022). Frequent water renewal dilutes these wastes before they accumulate to higher concentration which explained why lower TAN was observed in the 3-day water renewal frequency. Although all the Ammonia concentrations recorded across the treatments in this study are below toxic level for the growth of African catfish, prolonged exposure to higher TAN levels has been reported to reduce fish appetite, increase stress, and impair gill function, increase stress and weaken gill function (Hassan et al., 2022). Nitrate – nitrogen concentrations recorded increasing value as the water renewal frequency decreases which also support earlier suggestion that reduced water renewal allowed continuous accumulation of nitrogenous compounds within the culture system.

C. gariepinus subjected to 3-day water renewal frequency showed the best growth performance indicators which proved the crucial role of water quality in enhancing the productivity of fish in culture system. At the beginning of the experiment, all the fish had the same initial body weight however significant difference existed amongst the treatments in their final body weight which indicated water renewal frequency substantially affected the culture system throughout the period of the experiment.

Fish tanks where water is renewed after every 3-days attained the highest final weight, in contrast those whose water is renewed after every 7 and 9 days' intervals recorded reduced growth. This pattern is consistent with the recorded deterioration of water quality, especially declining Dissolved Oxygen (DO) and associated rise in Total Ammonia Nitrogen and Nitrate concentrations. Growth, generally, depends on energy as the process requires favourable environmental conditions that support efficient respiration, nutrient digestion and metabolic activity. When water quality deteriorates, fish divert substantial metabolic energy from somatic growth to maintaining physiological homeostasis, osmoregulation and detoxification of accumulated metabolic wastes consequently less dietary energy becomes available for tissue growth, resulting in reduced weight gain (Boyd, 2020). The findings in this research, support that of Dauda et al. (2023), Kutwal et al. (2024), who demonstrated that reducing the frequency of water renewal significantly impaired the growth performance of juvenile *Clarias gariepinus*. Remarkably, fish cultured under the 5-day water renewal attained final weights that were statistically comparable to those cultured under the 3-days water renewal. This observation further suggests that moderate reductions in water renewal frequency may still maintain acceptable environmental conditions capable of supporting satisfactory growth.

Condition factor (K), also followed similar trend to that of final weight, with fish cultured under the 3 and 5 days' renewal exhibiting significantly higher values than those cultured under the 7 and 9 day renewals. The condition factor is widely used as an indicator of the general health, nutritional status and wellbeing of cultured fish. Higher condition factor values generally indicate favourable environmental conditions that promote efficient utilization of dietary nutrients and greater deposition of muscle tissue relative to body length while lower condition factor values frequently reflect chronic environmental stress, inadequate nutrition or poor physiological condition (Froese, 2006; Ighwela et al., 2011). The higher K values observed in the present study therefore suggest that frequent water renewal created an environment conducive to normal physiological development and efficient nutrient assimilation. Feed conversion ratio (FCR) recorded inverse values to that of other growth performance indices stated above, with the lowest value recorded in the 3 days' renewal frequency and gradually higher values observed as the water renewal interval increased. Since lower FCR values indicate greater feed utilization efficiency, these findings demonstrate that maintaining favourable water quality substantially improves the efficiency with which *C. gariepinus* converts feed into body biomass (FAO, 2002; Besson et al., 2024). Environmental stress associated with declining dissolved oxygen, increasing ammonia concentrations and acidic water conditions may reduce appetite, and impair digestive enzyme activity eventually resulting in poorer feed utilization (Abdel-Tawwab et al., 2019; Sun et al., 2026). Several work have similarly reported significant relationships between water quality deterioration and reduced feed efficiency in African catfish production systems. According to El-Sayed (2020), environmental stressors such as low dissolved oxygen and elevated ammonia reduce feeding activity leading to poorer feed conversion and slower growth. Likewise, Boyd and Tucker (2012) noted that improved water quality enhances digestive efficiency and nutrient. The best FCR recorded under the 3-day renewal frequency in the present study therefore reflects both improved environmental conditions and more efficient conversion of dietary nutrients into fish biomass. The survival rate remained high across all the experiments, but a slight reduction was recorded in the 7 and 9 renewal treatments. The consistently high survival rates confirm the remarkable hardiness of *Clarias gariepinus*, which is widely recognized for its ability to tolerate environmental conditions that would be detrimental to many other cultured fish species (Aderolu et al., 2022; Anetekhai and Elijah, 2024). Nevertheless, survival alone should not be regarded as a sufficient indicator of production success. Fish may remain alive while experiencing chronic physiological stress that suppresses growth.

An important outcome of the present study was the significant influence of the effluent from the tanks on plant vegetative growth. Plants irrigated with effluent from 3-day water renewal tanks consistently produced more leaves and attained greater plant height than those irrigated with effluent from the longer water renewal intervals (delay irrigation). Aquaculture effluents contain appreciable quantities of nutrients originating from uneaten feed, fish excreta and microbial mineralization of organic matter (Piedrahita, 2003; Krome, 2023; Aniyikaiye et al., 2024). The best *A.Hybridus* growth observed under the 3 and 5 day treatments may be attributed to a favourable balance between nutrient and water availability. In contrast, extending the water renewal interval to 7 and 9 days resulted in less water available to the plant, consequently led to stunted growth and wilted leaves.

The results demonstrate that enhancing water renewal frequency can simultaneously improve fish production and enhance the quality of irrigation water available for amaranth cultivation. Such dual benefits are particularly relevant to integrated aquaculture systems, where water is reused to maximize productivity while minimizing environmental impacts. These advantages are especially important in regions of northern Nigeria where freshwater availability is increasingly constrained by climate variability and expanding agricultural demands. From a practical aquaculture management perspective, the choice of water renewal frequency should not be based solely on fish growth performance, but should also consider water availability, operational costs and the management capacity of farmers. Although the 3-day renewal frequency produced the most favourable overall biological performance in the present study, more frequent water renewal necessarily requires greater and more regular access to water and may increase the labour and energy requirements associated with water pumping, transportation and system maintenance. This consideration is particularly important for small- and medium-scale farmers operating in water-limited environments, where water availability may vary seasonally and the cost of obtaining and moving water can represent a substantial component of production expenditure. The 5-day renewal interval provides an important practical alternative because fish cultured under this treatment showed performance comparable to the 3-day treatment for several production indicators. Thus, where water resources are relatively limited or the cost of water replacement is high, extending the renewal interval to 5 days may provide a reasonable compromise between maintaining acceptable fish production and reducing the frequency of water replacement. In contrast, the 7 and 9 day intervals resulted in progressively poorer water quality and reduced fish growth, suggesting that extending the renewal interval beyond 5 days may compromise production performance under the conditions of the present study.

Farmer management capacity is another important consideration in selecting an appropriate renewal interval. A 3-day renewal schedule requires farmers to monitor and maintain the system more frequently and to have reliable access to water and the necessary infrastructure for regular water replacement. Such a management regime may be more feasible for commercial or well-resourced farmers with adequate labour, water supply and pumping facilities. For smallholder farmers with limited labour, infrastructure or water access, a 5-day renewal interval may be more manageable while still supporting satisfactory production. Nevertheless, the economic implications of each renewal frequency should be evaluated under specific production environments because the present study did not directly quantify water use, labour requirements, energy consumption or operational costs. Therefore, the 3-day renewal frequency may be regarded as the biologically optimal treatment under the experimental conditions, whereas the 5-day interval may offer a potentially more practical water-saving option where resource constraints are important. Further studies incorporating water-use efficiency, production costs and labour requirements would be valuable for determining the most economically and operationally appropriate renewal frequency for different categories of aquaculture farmers.

5 Conclusion

Overall, this study demonstrates that water renewal frequency is a key management factor determining the productivity of integrated aquaculture systems. Frequent water renewal maintained favourable physicochemical conditions, resulting in better fish growth, better feed utilization and improved physiological condition while simultaneously generating effluent capable of supporting enhanced plant growth. Under the experimental conditions of this study, the 3-day water renewal frequency produced the best overall fish production performance, whereas the 5-day renewal frequency showed comparable results for several production indices and exhibited favourable signs of plant health, suggesting that it may provide a practical compromise between water conservation and production efficiency.

However, the recommendation of a 3-day water renewal frequency should be interpreted within the specific experimental conditions under which this study was conducted. Optimal water renewal frequency may vary depending on factors such as stocking density, tank or pond size, feed, climatic conditions, plant species, system design, and the availability and quality of water. Therefore, water renewal schedules should be adapted to local production and management conditions, with appropriate monitoring of water quality and fish and plant performance.

These findings provide useful guidance for optimizing water management in integrated aquaculture systems and contribute to efforts to promote sustainable fish production and efficient resource utilization in Nigeria and other water-limited regions. Further studies under different production environments and management conditions are recommended to refine the appropriate water renewal frequency for diverse integrated aquaculture systems.

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Conflict of Interest Disclosure

The authors affirm that this research was conducted without any commercial or financial relationships that could be construed as a potential conflict of interest.

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