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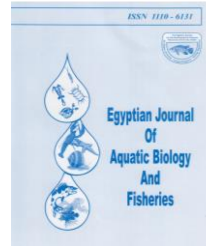

Comparative Performance of the Polycultured Nile Tilapia (*Oreochromis niloticus*) and Giant Freshwater Prawn (*Macrobachium rosenbergii*) in Conventional and Deep-Water Concurrent Rice Cum Fish Farming System

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ABSTRACT

Rice cum fish farming is an old practice of integrating the raising of fish in the production of rice. Morever, it is considered as a sustainable agricultural approach, combining rice and fish cultivated simultaneously to increase yield and enhance farmer's profit. Integrated farming with the use of deep-water system is considered a viable option, particularly in flood prone areas. This study investigated the performance of tilapia and prawn in both conventional (CCRF) and deep-water (DCRF) concurrent rice-fish systems. An experiment was conducted in a 3-month period. The result revealed that there is significant difference between the two rice-fish farming systems in terms of temperature, dissolved oxygen, total dissolved solids and conductivity (P<0.05). Meanwhile, water quality parameters such as pH, specific gravity, salt content, ammonia, nitrite, nitrate and phosphate did not bear any significant difference (P>0.05). There is also significant difference (P<0.05) between stocks in CCRF and DCRF systems in terms of harvest length and weight, indicating bigger tilapia and prawn can be obtained from deep-water than conventional system. Regarding rice performance, comparable results were observed between the two systems (P>0.05). However, economic analysis revealed that deep-water system is more viable than the conventional one. This suggests the advantage of deep-water over its conventional counterpart in simultaneously raising tilapia and prawn in rice integration.

INTRODUCTION

Rice-fish farming, also known as rice cum fish farming is defined as "the cultivation of rice with the simultaneous or rotational presence of naturally occurring fish and other aquatic species that are harvested through fisheries, and/or introduced fish populations that are cultured **(Freed *et al*., 2020)**. Based on this definition, rice-fish farming can be carried out using the simultaneous or concurrent method, which involves the introduction of juvenile fish during rice cultivation and then harvested subsequently after rice harvesting, whereas the rotational or alternating method involves rising and harvesting of fish in the same filed before rice planting **(Li *et al*., 2023)**. However, rice remained as the primary crop while fish became secondary product **(Ibrahim *et al.*, 2023)**. It has been widely practiced worldwide, particularly in the Southeast Asian region where rice and fish are regarded as staple diets **(Sathoria & Roy, 2022)**. Even though the system has been practiced thousands of years ago, it still plays an important role in increasing food production as integrated farming generates multiple benefits compared with rice monoculture in terms of resource utilization, livelihood diversification, production output, biodiversity conservation, and the quality and quantity of food produced **(Li *et al*., 2023)**. In addition, stocking fish in rice field may control crop pests and weeds, as well as leading to an elimination of disease vectors, thereby improving community health **(Frei & Becker, 2005; Campanhola & Pandey, 2019)**. Moreover, fish production may compensate for losses in rice production and associated declines in income due to natural calamities **(Saowakoon *et al*., 2021)**.

Although there are already several modifications in rice-fish farming, studies showed that the concurrent remained the most adopted method **(Li *et al*., 2023)**. In this method, the rice field is modified with the construction of small water bodies such as trenches, small ponds, or depressions that will serve as refuge for fish **(Freed *et al*., 2020)**. Adoption of conventional or modified concurrent system is dependent on the topography and contours of the land, which differentiates the preparation **(Reddy & Kishori, 2019)**. Among aquatic species, carp, catfish, milkfish, prawn and tilapia were commonly grown simultaneously with rice (**Ahmed *et al*., 2022; Ibrahim *et al*., 2023**). Intensification integrates other species within different trophic levels to optimize the utilization of agricultural resources. However, several factors should be taken into consideration when adopting such system which may include plant spacing and fish density for maximum yield, productivity and profitability **(Inayat *et al*., 2023)**.

In the Philippines, the earliest record of stocking fish in a rice field was made in 1954 **(Halwart & Gupta, 2004; Centina *et al.*, 2019)**. Rice-fish farming was introduced to farmers via field experiments conducted by the Freshwater Aquaculture Center of the Central Luzon State University in 1974 and was prioritized through the efforts of the government's National Food and Agriculture Council of the Department of Agriculture, of which thousands of farmers have adopted the system operating in irrigated rice fields of the country in 1986 when the program was discontinued **(Guerrero, 2018)**. In 2021, a total of 5.8 metric tons of aquatic commodities was harvested from rice-fish farming units, of which the majority of the produced fish was tilapia **(Bureau of Fisheries and Aquatic Resources, 2021)**. Earlier, it was reported that rice production of farmers in the Philippines ranged from 3.85 to 5.15 tons/ha from rice-fish farming system. Moreover, even with a decrease of 10% in the rice field allotted for fish habitat, there is 14-48% addition to fish yield **(Gurrero, 2018)**.

Despite several benefits that can be derived from rice-fish farming, it has not yet been broadly practiced in the country because of the inherent constraints to the conventional concurrent system. Of these, climatic changes and environmental degradation was pointed as major barrier for further development. It has been recognized that modern agriculture strategies require a major overhaul to mitigate the impact of these challenges **(Malhi *et al*., 2021)**. Hence, technological innovations should be integrated with the traditional farming systems. Many agricultural areas along the Pampanga River Basin are constantly threatened by flash floods during wet season, destroying crops and jeopardizing livelihood. Therefore, it is imperative to develop and introduce efficient farming system in accordance with the opportunities offered by the burgeoning problem.

Floating rice cultivation is considered a viable option in flood prone areas where water availability is not controlled **(Buisan & Buisan, 2019)**. This method has been practiced in Vietnam, Cambodia and Myanmar **(Dumaresq *et al*., 2020)**. Previous analysis revealed that rice cultivation using the floating system could potentially produce 5-6 tons/ha of rice **(Irianto *et al*., 2018)**. Recently, the practice was integrated with pond-based aquaculture and demonstrated a cumulative improvement in apparent feed conversion ratio of catfish and tilapia, with higher nutrient utilization efficiency compared with the traditional rice cultivation system **(Goda *et al*., 2024)**. The potential of tilapia and prawn in polyculture system, often attributed to their occupied niches, have been evaluated in previous studies **(Khan *et al.*, 2016; Dewi *et al.*, 2020)**. By combining the two species in rice-cum-fish system, farmers can use resources more efficiently, potentially increasing combined yield per area. Adoption of floating rice technology with the integration of tilapia and prawn polyculture in a deep-water concurrent farming system could optimize the potential of flood-prone agricultural areas. Moreover, this farming system could enhance agricultural productivity without causing negative impact to the environment. Hence, the study was conducted to examine the feasibility of the integrated system, particularly in the growth and survival of tilapia and prawn that aimed to provide an alternative option for traditional concurrent rice-fish farming system as a positive response to climate change.

MATERIALS AND METHODS

Research design

The study used the experimental method of research with two treatments and three replicates. The treatments of the study are as follow:

CCRF - Conventional Concurrent Rice-Fish Farming System
DCRF - Deep-water Concurrent Rice-Fish Farming System

<table>
<tr><td>CCRF</td><td rowspan="3">Reservoir</td><td>DCRF</td></tr>
<tr><td>CCRF</td><td>DCRF</td></tr>
<tr><td>CCRF</td><td>DCRF</td></tr>
</table>

Fig. 1. Experimental lay-out

Experimental plot/confinements

A 600-meter idle pond was divided into 6 100m^2 confinements with a reservoir at the center. The 3 confinements were designed following the traditional plot for planting rice with only an increase of 20cm in its dike to accommodate the fish and the prawn. Moreover, a central and peripheral canal (trench) comprising 20% of the plot were constructed to provide a refuge for the fish and prawn when the water is gradually receding. Meanwhile, three confinements were designed resembling a traditional pond with a water depth of 3 times higher than the confinements that were used for conventional system. Then floating rice beds (parallel tubes) were constructed occupying 60% of the surface area of the confinement using PVC pipes, Styrofoam floats and bamboo posts. The substrate in this floating bed was the same as the soil from the traditional rice paddy. To prevent gradual reduction of soil from the PVC pipes, the bottom was reinforced with fine-meshed net.

Experimental plant and animals

The quality of rice seeds (S6003 variety) was determined by immersing the seeds in a 3% salt solution **(Yassi *et al*., 2023)**. Immersed seeds were selected for soaking and aging in sequence of 24 hours to determine their suitability. Seeding was carried out by sowing the germinated seeds in the pre-prepared plots. Fertilization was conducted in the nursery plots using urea at rate of 15g/ m^2. After 15 days, the seedlings were transplanted to the growing plots or beds. Size #22 tilapia fingerlings were secured from a private hatchery operating inside the Pampanga State Agricultural University in Magalang, Pampanga while PL #15 freshwater prawn juveniles were requested from the Bureau of Fisheries and Aquatic Resources – National Fisheries Development Center in Dagupan City, Pangasinan. The seeds were transported using an oxygenated plastic bag. Upon arrival, the seeds were acclimated in their temporary confinement (hapa net). The quality of the seeds was evaluated. Individuals with no deformity and signs of any disease were selected for the experiment.

Rice transplanting

Seedlings of rice were taken from the nursery plots. In the conventional concurrent system, the seedlings (2 seedlings per hole) were directly planted to the substrate at a spacing of 30cm between the rows and 17cm within the rows **(Tsuruta *et al*., 2011)**. In the deep-water system, seedlings were planted in plastic cups with coco coir and soil. These cups were inserted in the holes prepared in the floating bed with the same spacing. Prior to transplanting, base dressing was done by applying 0.47kg of urea commercial fertilizer in each plot/confinement.

Fish and prawn stocking

The fish and prawn were stocked in their respective confinements 15 days after the rice seedlings were transplanted, following a rate of 3 fish/m^2 and 3 prawn/m^2, respectively **(Mendoza *et al.*, 2019; Saowakoon *et al.*, 2021)**. Prior to stocking, the length and weight of fish and prawn were measured. Using a digital caliper, the total length of the fish was measured from the tip of the snout to the tip of its tail while the total length of the prawn was taken from the tip of the rostrum to the posterior of the tail region.

Management

No water change was made throughout the period of the study; however, if necessary, particularly during the vegetative stage of rice was added using a water pump. Moreover, no fertilizer was applied. Meanwhile, the fish and prawn were fed with commercial diet in an ad libitum manner. The stocks were fed twice a day and will be given in the morning and in the afternoon.

Water quality assessment

Water quality parameters, such as temperature, dissolved oxygen, pH, ammonia, nitrite, nitrate and phosphate were monitored on a weekly basis throughout the period of the study. The temperature and dissolved oxygen of water were measured using a hand-held dissolved oxygen meter. This was done by taking a sample of water using a pail from the central part and corners of the confinement. Readings of the two parameters were taken from the sample and recorded to the nearest degrees Celsius (℃) and parts per million (ppm). The pH of the water was also taken from the sample using a pocket digital pH meter. Meanwhile, the concentrations of ammonia, nitrite, nitrate and phosphate were measured using colorimetric method in accordance with the manufacturer’s guide. About 5 mL of water from the sample was transferred to the tube. Then 6 drops from the test solutions were added to the tube. After adding all the required solutions for each parameter, the tube will be vigorously shaken for 5 seconds. The sample was allowed to stand for 3 minutes for the color to develop. The result was read by comparing the color of the solution to the appropriate color cards. The tube was viewed in a well-lit area against the white area of the card. The closest match indicated the equivalence of the parameters in ppm. All tests were done in triplicates.

Growth and survival assessment

The growth performance and survival rate of fish and prawn were evaluated at the termination of the experiment. Random sampling was employed and at least 10% of the total stocks were subjected for sampling. The weight of fish and prawn was taken using a digital weighing balance and recorded to the nearest gram unit. The growth parameters calculated are as follows:

- Total weight gain (TWG) = Final body weight (FBW) – Initial body weight (IBW)
- Daily weight gain (DWG) = Total weight gain (TWG) / Culture period (T)
- Specific Growth Rate ([log final body weight – log initial body weight]/culture period) x 100

The survival rate of fish and prawn was calculated as follows:

- Survival rate (%) = number of individuals survived / total number of individuals stocked x 100

Calculation of apparent food conversion ratio

The apparent food conversion ratio was calculated by taking consideration of the feed consumed throughout the experiment. The concept of apparent food conversion ratio considered the contribution from natural food in less intensive forms of aquaculture. Hence, quantification of the contribution of natural food in the confinements was not conducted, and therefore, the computed food conversion ratio (FCR) was mentioned in this study as apparent food conversion ratio (AFCR). AFCR was calculated as follows:

Apparent Food Conversion Ratio (AFCR) = feed intake (dry weight) / weight gain (live weight)

Rice growth and yield assessment

At the termination of the study, plant height was determined by randomly selecting 10 plants from each plot. Measurement of plant height was conducted using a meter rule from the base of to the growing tip. The number of tillers was determined by counting in the same number of plants. The same approach was employed in determining the number of panicles. In terms of grain yield, the number of grains per panicle were counted; however, filled and unfilled grains were segregated for the calculation of sterility percentage **(Karki *et al.*, 2018)**. Sterility percentage was determined using the following formula:

Sterility percentage (%) = No. of unfilled grains / Total number of grains x 100

The weight of grains was measured using a digital weighing balance. This was done by taking 100 samples of filled grains from the tillers of a single hill. The weight was recorded to the nearest gram unit.

Assessment of economic return

All expenses incurred in the production of fish, prawn and rice in different systems were recorded. The gross return was estimated by using the prevailing prices of the produced commodities. In terms of net return, all expenses were subtracted from the estimated gross return. The net profit margin was determined by dividing the gross return to the cost of cultivation, multiplied by 100% **(Dahiru, 2018)**.

Data treatment and analysis

The gathered data on research parameters was analyzed using student's T-test at 95% significant level. Analysis was aided by the Statistical Tool for Agricultural Research of the International Rice research Institute.

RESULTS AND DISCUSSION

1. Water quality parameters

The result on the analysis of important water quality parameters is depicted in Table (1). It includes temperature, dissolved oxygen, pH, specific gravity, salt content, total dissolved solids, conductivity, ammonia, nitrite, nitrate and phosphate.

Statistical analysis (Student's t-test) revealed significant difference between the two rice-fish farming systems in terms of temperature, dissolved oxygen, total dissolved solids and conductivity ($P<0.05$). Meanwhile, water quality parameters such as pH, specific gravity, salt content, ammonia, nitrite, nitrate and phosphate did not bear any significant difference ($P>0.05$).

Table 1. Average readings of water quality parameters

Treatment	Parameter	Mean	SD	SE
CCRF	Temperature (°C)	29.72*	0.187	0.108
DCRF		27.92*	0.101	0.059
CCRF	DO (ppm)	4.58*	0.084	0.049
DCRF		4.98*	0.116	0.067

CCRF	pH	6.66	0.020	0.011
DCRF		6.70	0.020	0.012
CCRF	SG	1.00	0.000	0.000
DCRF		1.00	0.001	0.000
CCRF	Salt (%)	0.06	0.006	0.003
DCRF		0.04	0.012	0.007
CCRF	TDS (ppm)	632.33*	47.163	27.229
DCRF		363.00*	11.000	6.351
CCRF	Conductivity	1263.00*	96.193	55.537
DCRF	(µs/cm)	727.33*	19.604	11.319
CCRF	NH_3 (ppm)	0.06	0.024	0.014
DCRF		0.07	0.048	0.028
CCRF	NO_2 (ppm)	0.06	0.024	0.014
DCRF		0.08	0.000	0.000
CCRF	NO_3 (ppm)	0.83	0.000	0.000
DCRF		1.11	0.481	0.278
CCRF	PO_4 (ppm)	0.43	0.284	0.164
DCRF		0.96	0.470	0.271

*Means are significantly differed at 95% level.

Water quality is an important aspect in fish farming as it dictates the growth and survival responses of stocks **(Baldoza *et al.*, 2020)**. **Aquino *et al.* (2023)** stressed that good water quality provides healthier fish, which will result to better production and profit. In contrast, poor or impaired water quality can lead to stressful condition that may lead to the outbreak of a disease, resulting in different magnitudes of mortality **(Boyd, 2017)**. Water quality is regulated by the interactions of several factors, including farm management practices, weather condition, soil fertility, etc. **(Mramba & Kahindi, 2023)**. For rice, good water quality could also positively affect growth and yield. Previous study revealed the positive correlation of rice growth with water quality metrics, such as favorable pH, dissolved oxygen, nitrate, nitrite and ammonia levels **(Victory *et al.*, 2018)**. Poor water quality stresses the plant that could result in more chalky grains.

The readings of temperature in both systems were in the range of 24.0- 32.0℃, as recommended by **El-Sayed and Kawanna (2008)** for tilapia. In addition, these levels are within the optimum range of 25.0- 32.0℃ for giant freshwater prawn **(Hirimuthugoda *et al.*, 2014)**. With the same stocking ratios, similar result on water temperature was also observed by **Mendoza *et al*. (2019)** in the aquaculture of the red tilapia and freshwater prawn under polyculture system. The differences recorded in this study can be attributed to the level of water between the two systems. The traditional concurrent system contained a smaller volume of water to absorb and dissipate heat, leading to faster warming with lesser ability to regulate temperature. However, the levels observed in this study is congruent with the previous reports for rice-fish farming systems, indicating the suitability of both systems for tilapia and prawn in mitigating the increasing temperature. According to **Mustow (2002)**, the shading effect of rice maintains the temperature of water favorable to fish during dry periods.

In terms of dissolved oxygen, the observed concentrations in both systems are not within the optimum range described by **Makori *et al*. (2017)** of 5.0- 23.0mg/ L for tilapia. However, these levels fall within the cited recommended range of 3.0- 7.0mg/ L for giant prawn farming **(Wiguno & Dewi, 2022)**. Similar findings were previously reported for rice-fish farming **(Chowdhurry *et al*., 2000; Li *et al*., 2021)**. The variations observed between the two systems can be linked to their differences in water depth, temperature level and the shading effect of rice. According to **Li *et al.* (2019)**, the integration of rice in fish farming could have positive or negative effect on dissolved oxygen levels, particularly in pond-based aquaculture. They have claimed that there is significant reduction of temperature, thus increasing the saturation of dissolved oxygen. Moreover, the waving of rice plants may promote the diffusion of oxygen from the atmosphere. Conversely, rice inhibits the penetration of light and significantly reducing nutrient levels for phytoplankton growth, which serves as primary source of dissolved oxygen in water. Dissolved oxygen at suitable range is essential for rice as microorganisms decomposing detritus utilize this form of gas, which are responsible in the release of available nutrients shared across the paddy **(Victory *et al.*, 2018)**.

pH is also an important parameter that should be maintained in concurrent farming as it has several benefits in both rice and fish. It allows the availability of nutrients and reduces the toxicity of ammonia through volatilization. **Bashir *et al*. (2020)** suggested an ideal condition of pH in the range of 6.5-9.0 for the integrated farming of rice and aquatic species. In this study, the recorded pH values are within the optimum range, implying the suitability for fish and prawn culture in these systems regarding this parameter. Additionally, the range is suitable for growing rice throughout the production cycle **(Victory *et al.*, 2018)**. At very low level, there is suppression of root growth, which may result in the reduction of nutrient uptake **(Zhang *et al.*, 2015)**. Meanwhile, at higher pH, micronutrients become less soluble and may occur, particularly in flooded soils **(Fageria *et al.*, 2010)**. In comparison to other studies, the levels of pH are relatively higher than those observed by **Kouadio *et al*. (2020)** in rice-fish ponds. The decreasing pH is often linked to the decomposition of organic matter, natural soil acidity, and the release of acids from decaying litters of plant and fish **(Liu *et al*., 2021)**.

Specific gravity, salt content, total dissolved solids and conductivity are interrelated parameters. Both systems showed lower salt contents with no significant difference. However, such variations were observed in terms of total dissolved solids and conductivity. Higher TDS and conductivity were recorded in the conventional system. Moreover, the observed level of TDS in the conventional system is beyond the optimum concentration of <400 ppm for freshwater species **(Boyd *et al*., 2016)**. Meanwhile, conductivity readings are within the recommended range of 100- 2000µs/ cm **(Stone *et al*., 2013)**. In comparison with other studies on rice cum fish, the obtained values are relatively higher **(Kouadio *et al*., 2020; Inayat *et al*., 2023)**. The observed levels can be attributed to the occasional rainfall during the period of the study. The high values of these parameters could be a result of providing artificial food in these culture units, as observed also in the study of **Sanou *et al*. (2022)**. As expected, conductivity increases with increasing TDS. Dissolved solids contain ionic compounds essential for the survival of aquatic animals. Most freshwater fishes have lower tolerable limits to TDS, especially if not adapted to saltwater **(Kalita *et al.*, 2022)**. High concentrations of TDS can negatively influence other physico-chemical parameters and can cause severe damage to aquatic organisms. Similarly, increasing EC level could be detrimental to freshwater species due to osmotic stress **(Zhang *et al.*, 2019)**.

As to the concentration of nutrient salts, the study revealed comparable results. This indicates that there is no significant effect of using the conventional and deep-water systems on some chemical components of water. In tilapia farming, the maximum concentration recommended for ammonia is <0.48 ppm **(Ortiz *et al.*, 2022)**. **Zeitoun *et al*. (2017)** observed varying levels of ammonia from 0.013 to 0.562 ppm. Meanwhile, lower detectable level of <0.1 ppm must be observed for safer giant freshwater prawn culture. The recorded concentrations in both systems fall within this range, implying the suitability of the culture medium for tilapia and prawn. In an earlier account **(MacKay, 1995)**, it was reported that the total ammonia nitrogen in rice-fish farming system is 0.80 ppm. This is quite similar to the readings in this study but varied with the report of **Victory *et al*. (2018)**, observing a maximum of 3.5 ppm. According to **Cheng *et al*. (2003)**, exposure to higher concentrations can reduce survival rate, growth and feed intake. A decrease in dissolved oxygen due to the increase in the level of ammonia would result in gill diseases **(Sanou *et al*., 2022)**. Although not studied, lower levels of ammonia observed in this study could be due to the efficient conversion of ammonium ions to its available form for plants. **Li *et al.* (2019)** demonstrated the efficiency of rice-fish co-culture for the reduction of ammonia by 24.3%. Hence, the rice component of the culture systems used in this study significantly influenced the accumulation of ammonia nitrogen despite the provision of artificial diet with high protein content.

Nitrite is the transitional form between ammonia and nitrate through the process of nitrification. It is extremely toxic to aquatic animals, and its toxicity is dependent to the length of exposure. It binds with blood hemoglobin and by oxidation methemoglobin will emerge, which inhibits blood to carry oxygen. As a result, respiratory problem may arise. As cited by **Sanou *et al*. (2022)**, the recommended limit for freshwater aquaculture is 0.1 ppm. However, **Victory *et al*. (2018)** cited that the acceptable range for integrated rice cum fish is 0.2-0.5 ppm. As noted, the values obtained for nitrite in both rice-fish farming system are relatively lower, indicating negligible effect of this parameter in the growth and survival of fish and prawn. Previous studies indicated fluctuation in the level of nitrite throughout the culture period as a result of high biological activities with inorganic loading inorganic loading in pond water as a result of low water exchange in the presence of bacteria, dead phytoplankton, decaying organic matter, accumulation of left-over protein-rich feed in the system which may support growth and yield of rice.

For nitrate, higher concentration was recorded in the deep-water system; however, this value is not significantly differed with the conventional one. Nitrate ions are not toxic to fish but can contribute to the enrichment of water that may encourage eutrophication (**Yao *et al.,* 2018)**. In previous studies, the level of nitrate was correlated with frequent fertilization. In this study, fertilizers were not applied throughout the period of the experiment; hence, the result can be attributed to the provision of supplemental diet for tilapia. The excreta are converted by soil and water bacterial populations, thereby increasing the availability of nitrogen for rice. In comparison with the study of **Victory *et al*. (2018)**, the recorded nitrates in both systems are lower. Whereas nitrate recorded from other studies are relatively lower **(Chowdhury *et al.,* 2000; Desta *et al.,* 2014; Kaewpuangdee *et al.,* 2024)**. **Victory *et al*. (2018)** cited an acceptable level of 2.0-2.5 ppm for nitrate. The concentration of nitrate is higher than nitrite because the former is unstable with the presence of oxygen. The low levels of nitrate observed in this study can be due to the effective absorption of this nitrogen form by rice. The perturbation of fish at the soil interface could influence the porosity of the soil for nutrient absorption and release, which made it available for rice **(Bhatnagar *et al*., 2014)**.

The phosphate concentration has direct relationship with the fertility of water **(Hendrajat *et al*., 2020)**. According to **Sanou *et al*. (2022)**, it is also non-toxic to aquatic organisms. However, the excessive supply will promote rapid plant growth, which subsequently leads to eutrophication. In rice-fish farming, the high levels of phosphate observed in previous undertakings could be the consequence of the use of fertilizers. In this study, the readings of phosphates are relatively lower compared with the optimal range (0.101-0.211 ppm) reported by **Wardoyo (1982)**. However, the level could be plausible as rice utilizes phosphates and other aquatic vegetations such as duckweeds, aquatic ferns and phytoplankton also consume this nutrient, as stressed by **Tsuruta *et al*. (2011)** upon observing lower levels in integrated and monoculture rice plots. The levels of phosphate recorded in this study are within the range (0.05-2.61 ppm) observed by **Chowdhury *et al*. (2000)** in rice-fish farming system. High concentrations of phosphate can be induced by agricultural and domestic discharges or by the leaching of cultivated land containing phosphate fertilizers and certain pesticides. In this study, fertilizers were not applied in the culture units; hence, quantifiable level of phosphate could be a function of feeding. According to **Sun and Boyd (2013)**, feed is the major source of phosphate (estimate of 98.9%) in feed-based aquaculture ponds. Provision of excessive feeds and accumulation of fish wastes in the pond could deteriorate both water and sediment leading to high concentrations **(Reyes *et al.,* 2021)**. If the condition is supported by the abundance of other nutrients, it will stimulate phytoplankton bloom.

2. Growth performance

The length and weight of tilapia and prawn at harvest are shown in Tables (2 and 3), respectively. Based on the result, there is a significant difference ($P<0.05$) between stocks in conventional and deep-water systems in terms of harvest length and weight. This shows that bigger tilapia and prawns were obtained from deep-water than conventional system. The recorded harvest size of tilapia is higher than individuals raised by **Frei *et al.* (2007)** for 108 days in their two experiments. However, prawns exhibit lower harvest size compared with the cultured individuals from vertical rice-prawn farming compartments **(Thawinwan *et al.*, 2022)**.

Table 2. Length and weight of tilapia at harvest

Treatment	Parameter	Mean	SD	SE
CCRF		16.20*	0.145	0.084
DCRF	Length (cm)	18.52*	0.276	0.159
CCRF		84.86*	1.661	0.959
DCRF	Weight (g)	141.72*	5.781	3.338

*Means are significantly differed at 95% level.

Table 3. Length and weight of giant freshwater prawn at harvest

Treatment	Parameter	Mean	SD	SE
CCRF		7.55*	0.557	0.322
DCRF	Length (cm)	10.36*	0.148	0.085
CCRF		3.68*	0.446	0.258
DCRF	Weight (g)	9.94*	0.536	0.309

*Means are significantly differed at 95% level.

The growth performance of tilapia and prawn in terms of total weight gain, daily weight gain and specific growth rate is presented in Tables (4 and 5), respectively. Analysis revealed that these growth parameters are significantly different ($P<0.05$) between conventional and deep-water systems. This result indicates the advantage of deep-water in growing tilapia and prawn integrated with rice.

Table 4. Total weight gain, daily weight gain and specific growth rate of tilapia

Treatment	Parameter	Mean	SD	SE
CCRF	Total Weight Gain (g)	81.69*	1.618	0.934
DCRF		138.52*	5.858	3.382

CCRF	Daily Weight Gain (g)	1.09*	0.022	0.013
DCRF		1.85*	0.078	0.045
CCRF	Specific Growth Rate	1.90*	0.018	0.010
DCRF	(%)	2.19*	0.039	0.022

*Means are significantly differed at 95% level

Table 5. Total weight gain, daily weight gain and specific growth rate of prawn

Treatment	Parameter	Mean	SD	SE
CCRF	Total Weight	3.66*	0.45	0.258
DCRF	Gain (g)	9.93*	0.54	0.309
CCRF	Daily Weight	0.05*	0.006	0.003
DCRF	Gain (g)	0.13*	0.007	0.004
CCRF	Specific Growth	1.90*	0.012	0.007
DCRF	Rate (%)	3.76*	0.031	0.018

*Means are significantly differed at 95% level.

In comparison with previous undertakings, the specific growth rate of tilapia in the conventional system is closer to the values obtained by **Inayat *et al*. (2023)**. However, they were relatively higher than the findings of **Ashaf-Ud-Doulah *et al*. (2021)** in fertilized paddies and **Saowakoon *et al*. (2021)** in organic-based system. Meanwhile, the mean value recorded from deep-water system is comparable with the report of **Billah *et al*. (2020)**, which are supplemented with artificial diet. Supplemental feeding is also essential in raising fish using an integrated system. The fish in this study were fed twice a day using the adjusted 90% of *ad libitum* feeding. However, the fish in the deep-water system showed better growth performance compared with those grown in conventional type. This is in agreement with the findings of **He *et al*. (2020)** for tilapia cultured in a pond-based rice-co-culture system.

Earlier, **Mohanty *et al*. (2001)** reported an average daily gain of 0.21 g for giant freshwater prawn combined with different species of carp in a rice-fish integration system. In the study of **Dewi *et al*. (2020)**, the prawn cultured in combination with rice at stocking densities of 10 and 15 pieces/m^2 showed a growth rate of 1.76% and 1.30% of body weight/day, respectively. These values are closer with the growth rate observed in the conventional system (1.90%) but significantly higher with the individuals in the deep-water system (3.76%). Meanwhile, the specific growth rate observed by **Saowakoon *et al*. (2021)** in organic-based system in combination with various finfishes is concomitant with the result in conventional system but relatively lower compared with the deep-water system. The specific growth rate of prawn in the deep-water system is in accordance with the claim of **Kunda *et al*. (2008)** that the species can reach 3.0% of its body weight/day when provided with commercial pellets in rice-fish culture systems.

Variation observed on the growth performance of tilapia and prawn can be attributed to environmental condition, abundance of natural food and presence of nuisance and predatory species. It was observed that the water level in the conventional system is shallow and subjected to fluctuating temperature and dissolved oxygen with significantly higher total dissolved solids and conductivity. In shallow water, fish experience increased stress, which can negatively impact their survival, growth, and reproduction. **Ibrahim *et al*. (2023)** cited that low water levels have a significant impact on the total fish biomass produced in rice fields. In this study, better growth performance in deep-water systems can be linked with improved water quality and lesser pressure exerted on the stocks.

3. Survival rate

The total number harvested, and survival rate of tilapia and prawn are presented in Tables (6 and 7), respectively. It can be noted that the total number harvested and survival rate of stocks from the deep-water system are significantly differed from the stocks from the conventional type. The obtained result may indicate the favorable response of both tilapia and prawn in deep-water system.

Table 6. Total number harvested and survival rate of tilapia

Treatment	Parameter	Mean	SD	SE
CCRF	Total Number	61.67*	3.055	1.764
DCRF	Harvested	229.33*	30.172	17.420
CCRF	Survival Rate	20.56*	1.019	0.588
DCRF	(%)	76.45*	10.055	5.805

*Means are significantly differed at 95% level

The survival rate in both systems is lower than the previous report for tilapia (*O. niloticus*) by **Salama (2003)** raised in rice fields receiving varying feeding inputs and **Saowakoon *et al*. (2021)** in organic-based integrated system. Also, the greater survival rate (80%) was recorded by **Basuki *et al*. (2013)** with the application of biofloc. In comparison with red tilapia, **Hidayati *et al*. (2019)** disclosed a relatively higher survival rate of 91.33 to 96.00%. However, the recorded recovery in the deep-water was in similarity with the use of Genetically Improved Farmed Tilapia (GIFT) stocked at a density of 20,000 fingerlings/hectare under rice-fish production system **(Ali *et al*., 2006)**. **Dan and Little (2000)** explained that tilapia can exhibit high survival rates in deep and shallow ponds (97 - 100%).

Table 7. Total number harvested and survival rate of giant freshwater prawn

Treatment	Parameter	Mean	SD	SE
CCRF	Total Number Harvested	95.67*	7.505	4.333
DCRF		252.00*	24.515	14.154
CCRF	Survival Rate (%)	31.89*	2.502	1.444
DCRF		84.00*	8.170	4.717

*Means are significantly differed at 95% level

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The survival rate of prawn in the deep-water system is greater than the report of **Dewi *et al*. (2020)** stocked in traditional concurrent system with densities of 10 (62.53%) and 15 (46.33%) pieces/m^2. Also, an earlier undertaking made by **Mohanty *et al*. (2001)** revealed a lower survival rate of 66.6%. They presumed that competition among individuals for space tends to promote fighting and cannibalism despite the provision of common and multi-level shelters. The survival rate of giant freshwater prawn tends to be low, with an average of 12-37% in outdoor systems **(Wiguno & Dewi, 2022)**. **Janssen *et al*. (1988)** explained that survival rate could vary in rice-fish production system.

Tilapia and prawn in deep-water achieved higher survival rate. Generally, deeper waters generally offer more stable conditions in terms of temperature, dissolved ions and oxygen levels. In shallow rice paddies, these factors can fluctuate more drastically due to exposure to atmospheric changes **(Ibrahim *et al*., 2023)**. Deeper waters also tend to offer more space. Moreover, shallow waters are often more exposed to predators including birds, and larger predatory fish. Fluctuation of water level in the conventional system during the conduct of the study reduces shelter availability for fish to hide against predators **(Mangi, 2024)**. Deeper waters, on the other hand, provide safer refuge, allowing fish to grow without as much threat of predation **(Becker & Suthers, 2014)**. In this study, various predatory species were also caught during the harvest period, which include snakehead, catfish and goby. Also, birds and turtles were sighted during nighttime. **Radwan (2022)** reported a production loss of ~1.59 tons due to the predatory activities of birds. The presence of birds can also increase the occurrence of diseases **(Wajsrot, 2023)**. Therefore, deep-water system provides a more conducive environment for the fish compared with the conventional type.

4. Apparent feed conversion ratio

The feed consumed and apparent feed conversion ratio of tilapia from conventional and deep-water system are indicated in Table (8). Comparable amounts were recorded for both systems in terms of feed consumption but significantly differed as to apparent feed conversion ratio (P<0.05). Apparent feed conversion ratio was used to consider the contribution of natural food present in conventional and deep-water systems such as mosquito fern, duckweed and plankton.

Table 8. Apparent feed conversion ratio of tilapia

Treatment	Parameter	Mean	SD	SE
CCRF	Feed Consumed (g)	175.00	21.702	12.530
DCRF		189.33	36.350	20.987
CCRF	AFCR	2.14*	0.287	0.166
DCRF		1.36*	0.212	0.122

*Means are significantly differed at 95% level

The observed ratio is not in agreement with those obtained by **Zead *et al.* (2008)**, who indicated a final value of 2.44 in rice fields. According to **El-Sayed (2013)**, feed conversion ratio will range from 1.5-2.5 when fish is fed with pelleted feed while ranges from 1.1-2.5 are achieved when using extruded diet. In rice-fish farming, the typical values will fall between 1.7 and 2.0. Comparing the result with this range, it can be said that deep-water system will provide better feed utilization and efficiency. The apparent feed conversion ratio was not computed for prawn as it is regarded as secondary crop. **Thawinwan *et al*. (2022)** reported a range of 1.49-178. The values obtained by these authors are higher compared with the prawn stocked in the integrated system at 10 individuals/m^2 (1.04) but comparable with 15 individuals/m^2 (1.66) **(Dewi *et al*., 2020)**.

Although not evaluated in this study, the existence of natural food could have also contributed to the growth of tilapia and prawn. Mosquito fern and duckweed in rice-fish system served multiple functions. These macrophytes were utilized by fish as protein-rich supplementary feed **(Kamil & Taha, 2022)**. Previous experiment revealed the highest growth and yield of *Puntius gonionatus* and *Oreochromis niloticus* in rice-fish culture system with mosquito fern **(Naz *et al.*, 2014)**. Similar finding was reported for *Carassius carassius* **(Tsuruta *et al.*, 2011)**. Integration of mosquito fern in rice and fish has also reduced the emergence of pests and weeds, resulting to the favorable growth of both crops **(Sow & Ranjan, 2020)**. Moreover, these plants serve as biofertilizer. **Li *et al.* (2021)** observed higher diversity and abundance of planktonic organisms in rice-fish system than in rice monoculture. **Welde *et al.* (2024)** highlighted the crucial role of planktonic communities in rice-carp coculture. It was observed that these natural foods are denser in deep-water system, significantly bolstering the growth of tilapia.

5. Rice growth parameters

The growth parameters of rice in terms of plant height, number of tillers, number of panicles, grain yield, sterility and grain weight (100 grains) are depicted in Table (9). Based on the result, the observed parameters are comparable between the two systems (P>0.05).

Table 9. Growth parameters of rice in conventional and deep-water system

Treatment	Parameter	Mean	SD	SE
CCRF		92.537	2.138	1.235
DCRF	Plant Height (cm)	98.197	2.888	1.668
CCRF		22.557	2.142	1.237
DCRF	No. of Tillers	21.933	2.296	1.326
CCRF		14.780	2.525	1.458
DCRF	No. of Panicle	15.080	2.505	1.446
CCRF		167.333	5.368	3.099
DCRF	Grain Yield/Panicle	181.757	1.875	1.082
CCRF		24.213	0.562	0.324
DCRF	Sterility	23.842	1.840	1.062
CCRF		2.600	0.265	0.152
DCRF	100 grain weight	2.967	0.153	0.088

With respect to plant height, the recorded measurements in both systems are higher than the observations of **Ujoh *et al*. (2016)** but relatively lower than the results from the experiment of **Inayat *et al*. (2023)**. The common rice varieties used in the Philippines typically have height ranges from 77 to 121 cm. The International Rice Research Institute (IRRI) classifies plant height into short (<110 cm) medium (110-130 cm) and tall (>130 cm) categories. Based on these categories, the plant height observed in this study fell in "short" category. **Aryana *et al*. (2023)** reiterated that short plants will avoid collapse due to wind, which usually decreases grain yield.

The number of tillers is considered a key factor in rice yields. Rice generally produced 2-5 panicle-bearing tillers per plant in direct-seeded fields and 10-30 in transplanted fields. Recently, **Yuan *et al*. (2024)** described that at a density of 30 plants/m^2, each plant usually forms 5–20 tillers. Meanwhile, **Yan *et al*. (2010)** reported 10-30 tillers in areas under flooded conditions. The panicle of rice is its reproductive structure that bears the spikelets which develop into grains. The panicle is an important component and closely associated with yield as it regulates the number of grains **(Duan *et al*., 2015; Yang *et al*., 2024)**. The number of panicles counted in this study is 13.67 (conventional) and 14.90 (deep-water). Based on studies, the number of panicles in rice is influenced by the variety and environmental condition. According to **Yuan *et al*. (2024)**, the number of panicles is a function of the number of tillers. Numerically, plants in the deep-water system have higher number of tillers and panicles.

Sterility was computed by dividing the number of unfilled grains to the total number of grains. As cited by **Vromant *et al*. (2002)**, there are four factors affecting the sterility to include temperature, light, water stress and nutrients. It can be noted that there is low level of sterility recorded for rice in both systems. As to the weight of grains, there is similarity with the findings of **Vromant *et al*. (2002)** using IR56279 variety in concurrent rice-fish system.

Despite the absence of continuous fertilization, growth parameter estimates for rice fell within an acceptable range, suggesting that autochthonous nutrient sources are sufficient to maintain the growth of rice in both systems. It has been recognized the beneficial effect of integrating fish into rice farming to include the elevation of carbon dioxide and nutrients, consumption and reduction of pests and maintaining crop health **(Sarangi *et al*., 2004)**. **Ren *et al*. (2023)** demonstrated the significant impacts of rice-fish farming, which include the modularity and robustness of microbial community, improving the preservation of soil organic carbon, nitrogen, and phosphorus, and has significantly increased soil pH. In the study of **Wang *et al*. (2022)**, the level of phosphorus in rice-fish-duck farming was assessed and revealed that the system can alleviate problems associated with low phosphorus activity by strongly improving fractionation. The availability of nutrients for rice was attributed by **Kaewpuangdee *et al*. (2024)** to the activities of fish that facilitate the decomposition of organic matter, and the release of these nutrients into the soil and water.

Although not subjected to analysis, the nutrients available in soil and water could still sustain the nutrient requirement of rice in both systems. Hence, comparable performance was observed in rice despite the high mortality rate in the conventional system. This can be supported by the findings of **Saowakoon *et al*. (2021)**, showing that low fish densities can still contribute to the requirement of rice for growth. The addition of fish in rice fields is considered an ecologically-sound approach to improve soil fertility by increasing the availability of nutrients such as nitrogen, phosphorous and potassium **(Noorhosseini-Niyaki & Bagherzadeh-Lakani, 2013)**.

6. Economic analysis

The simple economic analysis of the two systems used for rice and fish production is presented in Table (10). It can be gleaned that conventional system incurred an estimated loss of P 2,114.45 or a margin of -66.92%. Meanwhile, the deep-water system recorded a net income of P 1, 155.74 or a net profit margin of 26.58%. The result may indicate the viability of using deep-water system in the polyculture of tilapia and prawn integrated with rice production. This finding could be due to the disadvantages mentioned in the previous discussion such as water quality differences, varying survival rate and growth rate, and the presence of nuisance and predatory species. All these factors may have significant effect on the economic viability of the two farming systems.

Table 10. Economic analysis of rice-fish farming using conventional and deep-water concurrent systems (computed per 100 m^2 production area)

Parameter	Item Price (P)	Conventional	Deep-Water
Establishment Cost			
(a) Movement of soil	-	333.33	666.66
(b) Bed Fabrication	-	-	700.00
Operational Cost			
(a) Tilapia fingerlings	0.45/piece	135.00	135.00
(b) Prawn	1.00/piece	300.00	300.00
juveniles	900.00/bag	1,890.00	2,044.76
(c) Feeds	56.25/hour	464.06	464.06
(d) Labor	46.00/kg	15.33	15.33
(e) Ride seeds	2440.00/bag	22.45	22.45
(f) Fertilizer			
Total Cost (P)	**-**	**3,160.17**	**4348.26.**
Estimated Revenue			
(a) Tilapia	140.00/kg	732.78	4495.26

(b) Prawn	300.00/kg	105.62	751.46
(c) Rice	17.00/kg	207.12	257.28
Estimated Gross Income (P)	**-**	1,045.52	5,504.00
Estimated Net Income (P)	**-**	-2,114.45	1,155.74
Net Profit Margin (%)	**-**	-66.92	26.58

CONCLUSION

Based on the results of the study, the following conclusions were drawn:

- Temperature, dissolved oxygen, total dissolved solids and conductivity differed between systems but not in terms of pH, specific gravity, salt content, ammonia, nitrite, nitrate and phosphate.
- Growth performance in terms of length, weight, total weight gain, daily weight gain and specific growth rate or tilapia and prawn is significantly higher in deep-water.
- The survival rate of tilapia and prawn is significantly higher in deep-water compared to those grown in conventional systems.
- The apparent feed conversion ratio of tilapia in the deep-water system is better than fish cultured in the conventional one.
- The growth of rice in terms of plant height, number of tillers, number of panicles, grain yield per panicle, sterility and grain weight are comparable between deep-water and conventional systems.
- Deep-water systems are economically viable while conventional systems are not.

In accordance with the findings, it is recommended to employ a deep-water system in the polyculture of tilapia and prawn, integrated with rice. However, it is advised to conduct further investigations along this, specifically, on the significant effect of exogenous factors that could influence growth and survival of tilapia and prawn.

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