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International Journal of Biological Innovations
http://ijbi.org.in | http://www.gesa.org.in/journals.php
https://doi.org/10.46505/IJBI.2026.8201
IJBI 8(2): 147-155 **(2026)**
E-ISSN: 2582-1032

PRODUCTIVITY AND ECONOMIC VIABILITY OF LOW-COST TILAPIA-CROP INTEGRATION IN AQUAPONICS SYSTEM: A SUSTAINABLE ALTERNATIVE LIVELIHOOD FOR RURAL COMMUNITIES

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Article Info:
Research Article
Received
08.04.2026
Reviewed
10.06.2026
Accepted
05.07.2026

Abstract: Productivity and profitability of integrating tilapia and crop farming for small-scale farmers in Catanduanes in three months observation in 2m x 2m x 1.5m tanks. Utilizing 8 x 16 inches Styrofoam board and an 8-ounce Styrofoam cup. Treatment 1 performed a significant growth performance in tilapia and crops, as evidenced by the higher mean weight of 133.93 g and 96.90 g, respectively. Moreover, Treatment 1 had the highest total production of both tilapia (2009 g) and lettuce (3899.6 g). There is a significant difference in tilapia weight across treatments. Treatment 1 obtains the maximum growth rates. Authors observed a significant difference in tilapia weight and in crop weight while maintaining a water quality, with pH of 7.46, a temperature of 29.78 °C, and moderate levels of electrical conductivity (306.22 μS/cm-1) and total dissolved solids (161.22 ppm). While pH and temperature showed weak correlations with tilapia and crop weights, all parameters remained within suitable ranges for aquaculture, moreover, there is a gross income of P11, 171.26 and ROI of P5518.51, reflecting economic viability. The study highlights that integrating tilapia and lettuce in aquaponics systems offers both ecological and economic benefits making it a viable for sustainable aquaponics farming.

Keywords: Aquaponics, Cost benefits, Crop, Food security, Sustainability, Tilapia, Water parameters.

Cite this article as: Bonaos R.B., Ramos M.J.R., Bista J.K.B., Camacho C.F. and Panti H. (2026). Productivity and economic viability of low-cost tilapia-crop integration in aquaponics system: A sustainable alternative livelihood for rural communities. *International Journal of Biological Innovations*. 8(2): 147-155. https://doi.org/10.46505/IJBI.2026.8201

INTRODUCTION

Food security, agricultural practices and climate change adaptation are paramount concerns for sustainable development in today's world (Verma, 2021; Chakraborty *et al.*, 2021; Bonaos *et al.*, 2022). In Catanduanes, farmers and fishers face numerous challenges, including frequent typhoons and limited arable land, which constrain productivity and income generation. For small-scale farmers, maximizing productivity and profitability are required while ensuring environmental sustainability (Bonaos and Morales, 2024).

One innovative approach addressing such challenges is the integration of tilapia–crop production within a cost-effective aquaponics system. The combined production of crops and tilapia presents a viable alternative income source for small-scale farmers. Aquaponics is a bio-integrated system that incorporates the recirculating aquaculture with hydroponic production of vegetables, flowers, or herbs (Panda and Padhi, 2016). In this system, nutrient-rich effluent from fish culture serves as a natural fertilizer for plants, while the plants function as biofilters that improve water quality before it is recirculated back to the fish tanks (Baguio *et al.,* 2023). This symbiotic relationship promotes efficient water use, reduces dependence on synthetic fertilizers, and minimizes environmental impact.

Although aquaponics is not a new technology, the development of a cost-effective and locally adaptable system is particularly important for small-scale farmers with limited capital, restricted land area, and underutilized facilities (e.g. unused piggery tanks) who are seeking sustainable and income-generating alternatives.

The integration of tilapia and crop production in aquaponics systems offers significant advantages because it recycles water and nutrients in an environmentally friendly manner. In addition, it reduces or eliminates the need for chemical fertilizers and pesticides (Akter *et al.,* 2018). Moreover, this integrated system provides several benefits: (a) increased household income; (b) enhanced food availability and security; (c) diversified and supplementary livelihood opportunities; (d) improved crop productivity due to continuous nutrient supply; (e) potential development of alternative agribusiness ventures; and (f) ecological, environmental, and socio-economic gains. This integration is feasible because both fish and crops rely on water as a primary growth medium, allowing efficient resource utilization. Furthermore, the system optimizes space, inputs, and labor, making it economically advantageous. It also has the potential to stimulate local food production in the province, which, as an island area, relies heavily on the agricultural commodities imported from neighboring provinces.

Previous aquaponics research has primarily focused on widely cultured fish species such as tilapia, trout, and catfish, paired with commonly grown leafy vegetables including lettuce, basil, and spinach (Rakocy *et al.,* 1989; Rakocy, 2012; Love *et al.,* 2015). While these studies have significantly advanced knowledge of aquaponics, limited research has examined the productivity and profitability of a tilapia–water spinach–lettuce production system. A research gap remains regarding the technical performance, yield efficiency, and economic viability of this specific crop combination within a low-cost aquaponics system.

The current study aims to address this gap by evaluating the productivity, profitability, and sustainability of a tilapia–water spinach–lettuce aquaponics system. By building upon existing knowledge, the research seeks to expand practical aquaponics options for small-scale farmers, particularly those interested in maximizing productivity, profitability, and resource-use efficiency under conditions of limited space and capital.

MATERIALS AND METHODS

Study area and duration of the experiment

The study lasted 90 days (3 months) at the CatSU Multispecies Hatchery in Palnab Del Sur, Virac, Catanduanes. The site utilized freshwater as the primary source for the cultivation process, optimizing the hatchery conditions to accommodate the tilapia culture.

Experimental layout

The study investigated the productivity and profitability of integrating tilapia and crop farming as a source of income for small-scale farmers in Catanduanes. The research was conducted over 3 months in tanks measuring 2m x 2m x 1.5m. Each treatment (Treatment 1: Tilapia-Lettuce, Treatment 2: Tilapia-Waters spinach, and Treatment 3: Tilapia-Water spinach, -Lettuce) utilized a styrofoam board measuring 8 x 16 inches and an 8-ounce styrofoam cup that served as pots for the water spinach and lettuce (Fig. 1). The experiment was replicated 3 times to ensure the reliability and validity of the findings. Set up 9 tanks to serve as the experimental units. Each tank represented one replicate, and three tanks per treatment.

Fish Tank preparation and seedling production

The concrete tank was repaired and washed with disinfectants mixed in water. It is essential to wash the

Treatment 1 Treatment 2 Treatment 3

Fig. 1: Experimental set-up.

concrete tank before starting the fish culture to remove any chemicals. The lettuce and water spinach seeds were planted on the seedling trays for 2-3 weeks before they were planted into 8 ozstyro cup and attached to a styrofoam board (Fig. 2). The soil was kept moist by watering lightly once or twice a day with the use of fine mist or spray for watering to prevent disturbing the seeds. The seedlings are placed in an area with partial sunlight in the greenhouse.

Stocking density and feeding regime

Each tank had 10 pieces of tilapia stocked and water spinach and lettuce were planted at the same density. A proper acclimation procedure was followed before stocking. Tilapia was fed with commercial fish feed twice a day, while water spinach and lettuce were fertilized with fish waste.

Water parameters monitoring

Water monitoring was conducted monthly to ensure optimal conditions for tilapia growth. Key parameters include temperature, pH, electrical conductivity (EC), and total soluble solids (TSS). The ideal temperature for tilapia is 25-30°C; deviations can lead to growth issues or stress. The pH should be maintained between 6.5 and 7.5 to prevent stress and disease. Electrical conductivity should range from 100-200 μS/cm, and total soluble solids should be between 100-200 ppm to avoid toxicity and support healthy growth. Regular monitoring and data recording are crucial for maintaining these parameters and ensuring the health of the fish.

Growth monitoring and measurement of tilapia and crops

The growth rates of the tilapia were measured randomly to determine the body weight (g) using a weighing scale and every month crops were harvested and weighed the monthly yield. Likewise, water monitoring and recording of the water parameters such as pH, temperature, electric conductivity, and total dissolved solids were done monthly using a multiparameter tool. Proper record-keeping was followed throughout the study.

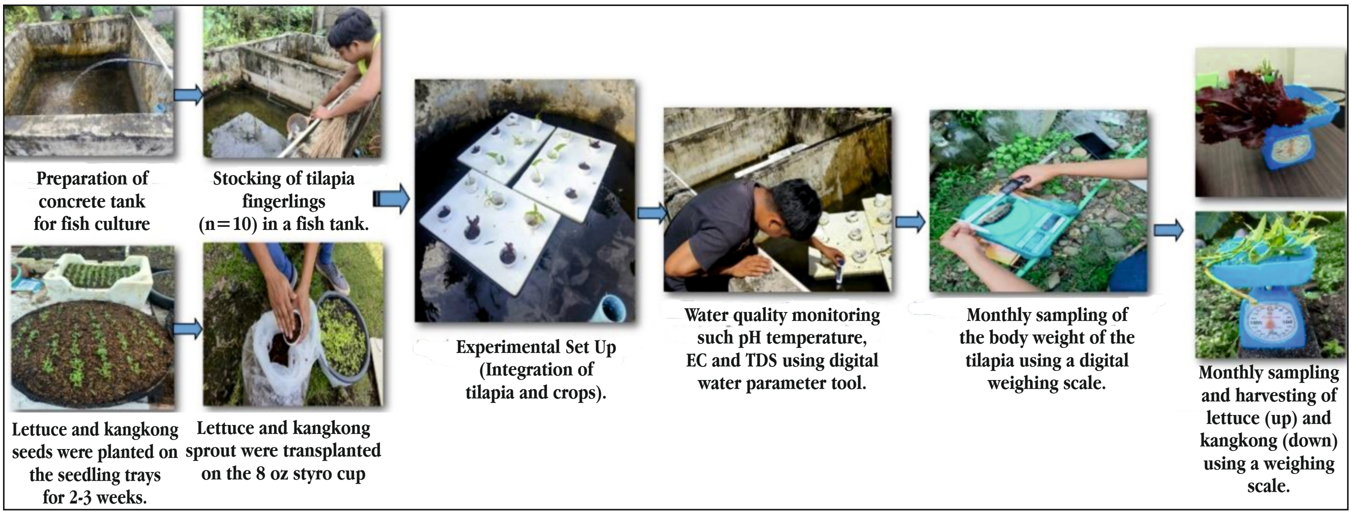

Fig. 2: Preparation, monitoring and sampling of the experimental set up.

Statistical Analysis

Descriptive statistics was used to calculate the tilapia and crop weight and water parameters using Jamovi. A one-way ANOVA (Welch's) was used to compare growth performance across conditions, followed by Tukey's HSD for pairwise comparisons if significant differences were found. Pearson correlation was used to assess the relationship between the weight of crops and tilapia and examine the relationships between water quality and growth performance. Simple and Cost analysis was computed using the following formulas:

Net Profit=Total Revenue – Total Costs

ROI= (Net Profit/Cost of Investment) x100

Payback Period= Initial Investment/Annual Cash Inflow

RESULTS AND DISCUSSION

Growth performance of tilapia in an aquaponics system

The growth performance of tilapia in an aquaponics system under 3 different conditions is shown in Figure 3. Based on the figure, Treatment 1 (tilapia with lettuce) got the highest growth rate with a mean of 133.93 g with a minimum and maximum growth rate of 105.00 g and 156.00 g respectively. On the other hand, Treatment 3 (integration of tilapia, lettuce and water spinach) had the lowest mean growth rate of 96.90 g with a minimum and maximum growth rate of 14.20 g and 132 g, respectively. Treatment 3 also exhibits the greatest variability.

For three months cultured of the 30 pcs of tilapia in each treatment, the yield in Treatment 1 had the highest production yield with 2009 grams followed by Treatment 2 (1547 g) and Treatment 3 (1453 g). Likewise, the production of crops in Treatment 1 which is the lettuce had the highest yield with 3899.6 g followed by Treatment 2 (water spinach) and Treatment 3 (water spinach and lettuce).

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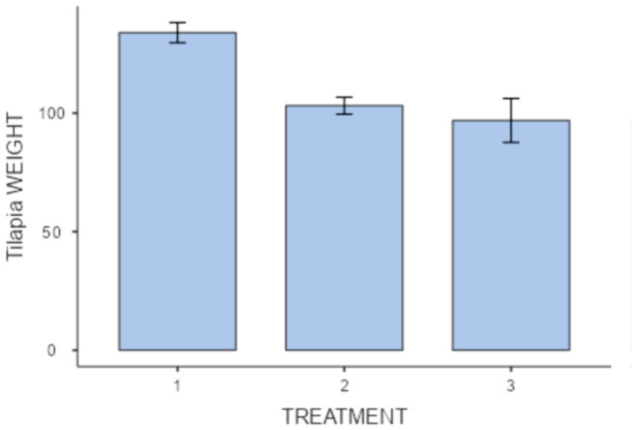

Fig. 3: Mean growth increment of tilapia in an aquaponics system under three different conditions.

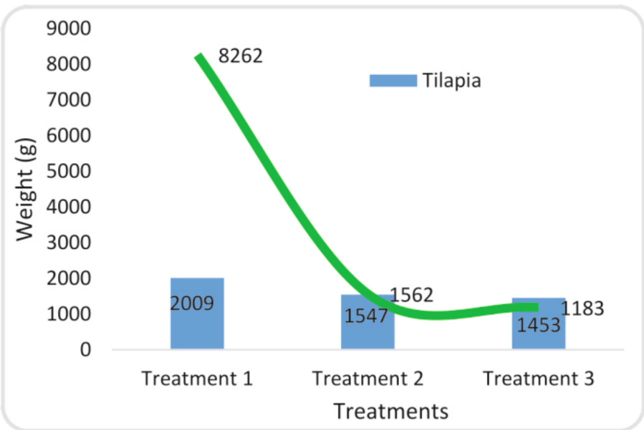

Fig. 4: Total production of tilapia and crops (g) under 3 different conditions.

On the other hand, the results from the Welch's One-Way ANOVA on tilapia weight between the three treatments differ significantly from each other with the F-statistic (16.80) and p-value of less than .001 indicating a statistically significant difference in tilapia weight across the treatments. It means that the conditions under the different treatments significantly affect the growth of the tilapia. To test which among the Treatments differ from each other, a Tukey post-hoc test was performed. Treatment 1 had the maximum growth rate, with significant differences when compared to both Treatments 2 and 3. There is no significant difference between Treatments 2 and 3 for tilapia weight. Treatment 1 has a significantly higher tilapia weight than Treatment 2 and 3 with a mean difference of 30.80 grams and 37.03 grams with p values of .003 and $< .001$, respectively.

According to the studies by Yamane *et al.* (2021) and Atique *et al.* (2022), lettuce (*Lactuca sativa*) generally performs better in aquaponic systems with tilapia compared to water spinach (*Ipomoea aquatica*). Lettuce tends to have a faster growth rate and a higher biomass yield. In this study comparing different crops in aquaponic systems, lettuce demonstrated consistent growth and effective nutrient uptake, which positively impacted the water quality for the fish.

Production potential of water spinach and lettuce in an aquaponics system

Water spinach (*Ipomoea aquatica*) and lettuce (*Lactuca sativa*) are two leafy vegetables with significant production potential in aquaponic systems. Aquaponics is a sustainable method of food production that combines aquaculture (raising fish) and hydroponics (growing plants in water), offering an innovative approach to cultivating these crops (Goddek *et al.,* 2015). This integrated system leverages the natural nutrient cycle, where fish waste provides essential nutrients for plant growth, and plants help to purify the water for fish, creating a symbiotic environment (Homme, 2012; Salam *et al.*, 2014). Figure 5 shows the mean monthly harvest of lettuce and water spinach under three different conditions within three months. In Treatment 1, lettuce had the highest mean monthly yield, with 1575.40 g, 2786.80 g, and 3899.60 g for months 1, 2, and 3, respectively.

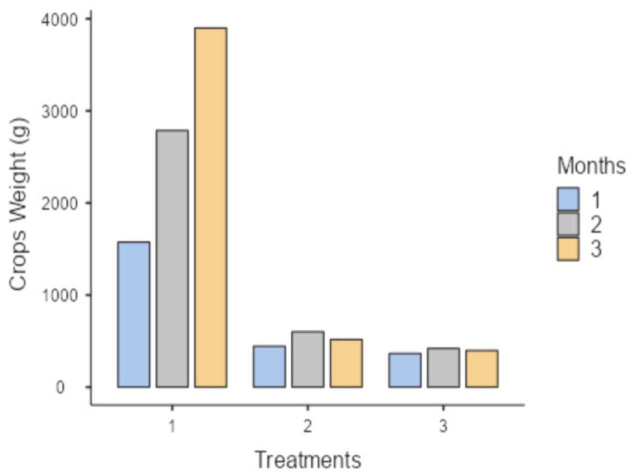

Fig. 5: Monthly harvest of lettuce and water spinach under 3 different conditions

Moreover, based on the One-Way ANOVA (Welch's) results for crop weight (g), there is a statistically significant difference in crop weight among the three treatments. This indicates that the variation in crop weight between treatments is much larger than would be expected by random chance. To determine which treatments differ from each other, a Post Hoc test was
Moreover, based on the One-Way ANOVA (Welch's)

results for crop weight (g), there is a statistically significant difference in crop weight among the three treatments. This indicates that the variation in crop weight between treatments is much larger than would be expected by random chance. To determine which treatments differ from each other, a Post Hoc test was performed. The results showed that Treatment 1 produces significantly higher crop weight compared to both Treatment 2 and Treatment 3, with mean differences of 155.17 g ($p < .001$) and 180.44 g ($p < .001$), respectively. Likewise, the weight of crops and tilapia shows a moderately positive correlation ($r=0.45$). This means that as tilapias' weight increases, crop weight tends to increase as well, but the relationship is not very strong. One reason for this is that the nutrients excreted directly by the fish, or produced through the microbial breakdown of organic waste, are absorbed by the plants grown hydroponically, enhancing their growth (Rakocy *et al.*, 1989; Adler *et al.,* 2003). In addition, the plants can be considered biofilters for fish in a symbiotic relationship with mutual benefit by absorbing nutrients from farming wastes with the action of bacteria in reducing the ammonia through the nitrification process (Salam *et al.,* 2014, Trang and Brix, 2014; Hu *et al.*, 2015).

Water quality parameters in a tilapia-crops culture system

Water quality is a critical factor in aquaculture production, directly influencing the health, growth, and profitability of farmed aquatic organisms. By maintaining optimal water conditions, producers can ensure the production of high-quality, safe products that are suitable for human consumption. To monitor and control water quality, regular measurements of key parameters are essential. This study focused on monthly monitoring of pH, temperature, electrical conductivity (EC), and total dissolved solids (TDS), which is shown in Table 1. These parameters provide valuable insights into the overall water quality and its suitability for aquaculture.

Table 1: Mean descriptive statistics for the water parameters for the tilapia-crop culture system.

Treatment	pH	Temperature (^{o}C)	Electric Conductivity (μ S/cm-1)	TDS (ppm)
1. Tilapia-lettuce	7.46	29.78	306.22	161.22
2. Tilapia-water spinach	7.30	30.01	308.22	165.89
3. Tilapia-lettuce-water spinach	7.32	30.20	238.60	134.16

The mean pH and temperature of each treatment showed no significant difference. Treatment 1 had the highest pH (7.46), while Treatment 3 had the highest temperature at 30.20 Degree Celsius. A strong negative correlation ($r = -0.84$, $p < 0.05$) was found between pH and tilapia weight, indicating that higher pH levels were associated with lower tilapia weight. A weak negative correlation ($r = -0.21$ and $p = 0.594$) was observed between pH and crop weight, but it was not statistically significant. This suggests that while higher pH levels may slightly negatively impact crop productivity, the effect is minimal. This pH level of the present study suggests a slightly alkaline environment, which can be beneficial for both tilapia growth and plant health. At the same time, pH can alter the health of the fish when it increases or decreases beyond the permissible limit and the optimum pH for freshwater fish usually range between pH 7.5 and 8.5 (Boyd, 1998). The fish species Tilapia (*Oreochromis*) is known to be disease-resistant and tolerant to large fluctuations in pH value with a tolerance between pH 3.7 and 11, but achieves the best growth performance between pH 7.0 and 9.0 (Delaide, 2017).

While the results for temperatures ranging from 29.78 to 30.20 Degree Celsius are still suitable for the growth of tilapia; if it increases to 35, it will cause harm or stress to fish (Bara *et al.,* 2005). The relationship between temperature and tilapia weight showed a weak positive correlation ($r = 0.23$, $p = 0.556$), but it was not statistically significant. The weak positive correlation in the study may suggest that the temperature was within a favorable range for tilapia growth, but the lack of statistical significance ($p = 0.556$) suggests that other factors may have played a more substantial role in determining tilapia weight, such as feed quality, dissolved oxygen, or stocking density. This finding aligns with research by El-Sayed (2006), who observed that while temperature is an important factor, growth in tilapia is often more strongly influenced by other variables, especially in aquaculture systems. Likewise, the correlation between temperature and crop weight was also weak to moderately negative ($r = -0.36$, $p = 0.335$) but not significant, suggesting that as temperature increased, crop weight tended to decrease. This might indicate mild heat stress affecting the crops, possibly leading to reduced photosynthetic efficiency and nutrient uptake. However, the p-value (0.335) indicates that the result is not statistically significant, meaning that temperature was not a key factor affecting crop weight in this case. This is consistent with findings by Resh (2012), who noted that crops in aquaponic or hydroponic systems can be sensitive to temperature fluctuations, particularly if the temperature exceeds the optimal range for growth. It is vital to monitor temperature closely to ensure that it remains within a tolerable range for all organisms involved in the aquaponics system.

The electric conductivity of Treatments 1 and 2 was not significantly different, with mean values of 306.22 μ S/cm-1 and 308.22 μ S/cm-1, respectively. Treatment 3 had the lowest total dissolved solids (TDS) at 134.16 compared to the other treatments. EC measures water's ability to conduct electricity, which is directly proportional to the concentration of ions (nutrients and salts) in the water. EC is often associated with nutrient availability for plant growth in aquaponic systems. A slight difference in EC between treatments 1 and 2 suggests that the nutrient concentration in these systems is relatively similar. However, EC levels in the study may not have reached a threshold that influences the uptake of nutrients by crops or the physiological performance of tilapia. This could explain the weak or nonexistent correlation with their respective weights.

In addition to pH and temperature, electric conductivity and total dissolved solids are crucial for tilapia and crop growth. The relationship between these parameters and tilapia and crop weight was weak or nonexistent and not statistically significant.
TDS measures the combined content of all inorganic and organic substances in water, including nutrients. The ideal TDS level for tilapia is 100-200 ppm which means that the present TDS of the 3 treatments are in the range of the ideal TDS level. If the TDS level is too low, the water may not be able to support the growth of tilapia. If the TDS level is too high, the water may become toxic to the fish lower TDS in Treatment 3 could indicate fewer available nutrients, yet this did not seem to impact crop or tilapia growth significantly. This could be due to other factors, such as the specific nutrient profile being more relevant than the total concentration. In an aquaponic system, considerably lower levels of TDS (200 to 400 ppm) or EC (0.3 to 0.6 mmho/cm) will produce good results because of continuous generation of nutrients (Rakocy, 2006). If TDS levels exceed 500 ppm, water quality degradation can occur, negatively impacting fish and plant health. Water drainage may be necessary if the TDS value is too high (Wibowo *et al.*, 2019). Maintaining these levels helps ensure that the system remains balanced and efficient.

Simple Cost and Return Analysis

Cost-benefit analysis is a crucial tool for evaluating the financial performance of various ventures, including aquaponic systems. By comparing the costs incurred with the returns generated, businesses and individuals can make informed decisions about resource allocation and strategic planning. Table 2 presents a simple cost and return analysis comparing the three treatments.

In terms of Gross Income, Treatment 1 has a gross income of 11,171.26, indicating that the integration of tilapia and lettuce was highly profitable. The revenue from lettuce significantly contributed to the overall income. Both Treatment 2 and 3 show a negative gross loss of -5,103.49 and -3,959.49, respectively. The two latter treatments possess a negative gross income due to insufficient revenue from water spinach.

Meanwhile, the return on investment (ROI) of Treatment 1 has a positive ROI of 197.63%, indicating that for every peso invested, the return was 1.97 pesos, reflecting a highly profitable venture. This positive ROI suggests that this treatment is financially viable. Treatment 2 has a negative ROI of -90.28%, which indicates a substantial loss. For every peso invested, only a fraction was recovered, leading to a significant financial deficit. Treatment 3 also has a negative ROI of -70.05%, meaning this treatment also incurred a loss, though not as severe as Treatment 2.

Table 2: Simple cost and return analysis of the three treatments.

Category	Treatment 1 (Tilapia-lettuce)	Treatment 2 (Tilapia-water spinach)	Treatment 3 (Tilapia-lettuce-water spinach)
Total Sales	16,824.00	549.25	1,693.25
Total Cost and Expenses	5,652.74	5,652.74	5,652.74
Gross Income	11,171.26	-5,103.49	-3,959.49
ROI (%)	197.63	-90.28	-70.05
Payback Period	0.5	1.11	1.43

In terms of the payback period, Treatment 1 shows the shortest payback period of 0.5 years (approximately 5 - 6 months), meaning the initial investment could be recovered relatively quickly, showing strong economic viability. Meanwhile Treatment 3 had a payback period of 1.43 indicating a recovery time of more than a year. Again, given the negative income, this recovery is theoretical and would require improvements to break even. The payback period in Treatment 2 is 1.11, which indicates that it would take slightly over a year to recoup the investment, but since there's a negative income, it suggests the system may not be sustainable as is.

Assumption of scaling up an aquaponics system with larger stocks and volume

The potential for increasing profitability in aquaponics can be observed by scaling up the system through higher stocking density and expanded production area. In this study the current setup are the following:

Tilapia stocking: 30 fish = 300 pesos (current system)
Lettuce yield: 6 cups of lettuce = 16,524 pesos (current system)
Tank area: 2m x 2m x 1m
Culture period: 3 months
Profit growth: Scaling up by increasing the volume and number of tanks to accommodate more fish and lettuce.

As shown in Table 3, the projected increase in fish stocks and lettuce volume demonstrates a corresponding growth in profit. This indicates that aquaponics systems have strong potential for scalability and can significantly enhance income when properly managed. However, it is important to consider additional costs associated with system expansion, such as infrastructure, labor, and maintenance, to ensure sustainable and efficient operation.

Table 3: Assumption of scaling up an aquaponics system with larger stocks and volume of lettuce and tilapia.

Scale	No. of Fish	Fish Sales (Pesos)	Lettuce Yield (cups)	Lettuce Profit (Pesos)	Total Profit (Pesos)	Total Expenses (Pesos)	Net Profit (Pesos)	ROI	Payback Period
Current System	30	300	6	16,524	16,824	5,652.74	11,171.26	197.60%	0.50 months
2xScale (60 fish)	60	600	12	33,048	33,648	11,305.48	22,342.52	197.60%	0.50 months
4xScale (120 fish)	120	1,200	24	66,096	67,296	22,610.96	44,685.04	197.60%	0.50 months

CONCLUSIONS AND RECOMMENDATIONS

Treatment 1 demonstrated both ecologically sustainable and economically viable in integrating tilapia and lettuce in an aquaponics system is both ecologically sustainable and economically viable. The system showed superior fish growth and lettuce yield, contributing to a positive gross income, return on investment (ROI), and a shorter payback period. Lettuce's ability to improve water quality through nutrient absorption further enhances the system's overall efficiency. Expanding such systems could significantly benefit small-scale farmers by providing a sustainable source of income. To maximize profitability, expanding plant variety and improving water quality monitoring are essential steps. Scaling up the system for commercial production and exploring alternative crops could further enhance economic returns. Moreover, the use of alternative, affordable culture setups like damaged refrigerators, tarpaulins with bamboo frames, and used drums should be considered, the set up that considered within the reach of the household farmer.

ACKNOWLEDGMENTS

The research team would like to express a gratitude to Catanduanes State University (CatSU) for providing the financial support that implemented this study possible. The authors also extend their appreciation to the fish technicians and staff of the Palnab Multispecies Hatchery, Virac, Catanduanes, for their valuable technical assistance, support in facility utilization, and guidance during the conduct of the experiment. Their cooperation and expertise greatly contributed to the successful completion of this research.

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