



Performance evaluation of a peri-urban aquaponics system

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Agricultural technology continues to advance in response to the growing challenges of food security, climate change and limited natural resources. Globally, the agricultural sector is under immense pressure to feed a growing population using less arable land and water (FAO and UNFCCC 2024). This crisis is particularly pronounced in developing economies like the Philippines, where rapid urbanisation has increasingly encroached on agricultural lands and water resources, constraining traditional farming and aquaculture practices and intensifying the need for space-efficient food production systems (Araza *et al.* 2026). In response to spatial and ecological constraints, controlled-environment agriculture and integrated agri-aquaculture systems have emerged as sustainable solutions. Aquaponics, in particular, exemplifies a circular food production system by integrating recirculating aquaculture systems (RAS) with hydroponic plant cultivation in a closed loop ecosystem that conserves water, recycles nutrients and minimises waste (Nair *et al.* 2025). Recognising its potential for regional application, Bulacan Agricultural State College (BASC) established the peri-urban garden as a platform for demonstrating resource-efficient technologies.

Prolonged underutilisation risks structural deterioration, imbalance in system dynamics and diminished operational capacity, undermining its role as a demonstration model for peri-urban agriculture. By conducting a systematic performance evaluation, this research identifies the technical and operational constraints that hinders system uptime and efficiency.

Evaluating the structural functionality, efficiency and limitations is critical to verify that a system meets its design objectives. This assesses the existing aquaponics setup to identify operational bottlenecks in system by identifying operational or technical issues that may hinder its performance, implement modifications to maximise effectiveness and evaluate biological productivity, specifically the growth kinetics and yield of loose-leaf lettuce (*Lactuca sativa* L.) and catfish (*Clarias gariepinus*).

Through this problem-driven analysis, the study established a replicable framework for restoring and optimising small-scale aquaponics, transforming stagnant infrastructure into a data-driven model for sustainable, peri-urban food security.

Methodology: The study, conducted from April–July 2025 at Bulacan Agricultural State College, Pinaod san Ildefonso (15°04'24"N and 120°57'21"E; at an elevation of 51 m amsl), Bulacan, evaluated an aquaponics system across two phases: Structural integration and performance testing with catfish and lettuce. To verify structural integrity and operational performance, the system's components including the fish tank, settling basin, biofilter, growing channels and sump, were systematically evaluated based on leak detection, circulation efficiency, aeration capacity, filtration performance and pump calibration. Each setup was stocked with 50 catfish and 150 lettuce seedlings to compare existing and modified configurations. The system was monitored twice daily for 21 days, with circulation trials confirming hydraulic behaviour, pump efficiency and leak prevention. Aeration maintained dissolved oxygen (DO) levels above 5 mg/L, while water quality parameters remained within optimal ranges (pH at 6.76, temperature at 25°C, DO at 12 mg/L and salinity at 1.2 ppt). To assess the efficacy of the modified design, growth performance and economic viability for both catfish and lettuce were monitored throughout the experimental period. Statistical significance in fish biomass and plant vegetative traits between systems was determined using an independent sample t-test.

Structural component: All major components remained structurally sound, exhibiting no visible cracks, corrosion or material fatigue despite the period of inactivity. The hydraulic network, including pipes, valves and joints, showed no signs of biofouling or leakage. Pressure tests verified that the plumbing system is well-integrated and properly sealed. Furthermore, the support framing demonstrated sufficient stability to accommodate the system's hydraulic load and biomass. These observations confirmed that the infrastructure was in optimal condition to sustain the operational demands required for the subsequent performance evaluation.

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Hydraulic trials (Table 1) yielded an average flow rate of 2.60 L/min, higher than the 1.5 L/min reported by Outa *et al.* (2025) and the 0.8–1.6 L/min evaluated by Justin *et al.* (2026) in Nutrient Film Technique (NFT)-based aquaponics systems. These studies demonstrate that NFT aquaponics can operate effectively across a range of flow rates, although system performance varies with hydraulic configuration, crop requirements and water-quality conditions. The higher flow rate provided continuous water circulation through the system, indicating adequate hydraulic operation.

Initial testing revealed clogging and non-uniform water distribution across the NFT grow channels, likely due to elevation differences and hydraulic losses. Following channel leveling and biofilter modifications, flow was stabilised at 2.0 L/min, improving water and nutrient distribution throughout the system. Effective solids management and nutrient flow are important for maintaining reliable NFT aquaponics operation (Abdissa *et al.* 2025, Lama *et al.* 2025).

Lighting assessment showed that the original setup utilised only 10 LED grow lights, producing an average light intensity of $150 \pm 50 \mu\text{mol}/\text{m}^2/\text{sec}$. Illumination was concentrated only in the 2nd and 4th grow channels, leaving the remaining channels below the recommended 200–300 $\mu\text{mol}/\text{m}^2/\text{sec}$ required for optimal lettuce growth (Pennisi *et al.* 2020, Miao *et al.* 2023). Light intensity and regulation strategies can substantially influence lettuce growth, photosynthetic performance, biomass accumulation, nutritional quality and energy-use efficiency (Chen *et al.* 2025).

To standardise exposure, 15 additional LED grow

lights were integrated into the modified system, increasing light intensity to $250 \pm 150 \mu\text{mol}/\text{m}^2/\text{sec}$. This recalibration improved the lighting conditions for leafy-green production under controlled-environment conditions, while the more uniform Photosynthetic photon flux density (PPFD) distribution promoted more consistent canopy photosynthesis and contributed to improved growth and productivity (Min *et al.* 2023).

Operational performance: Lettuce in the existing setup grew taller (15–19 cm) (Fig. 1) compared to the modified system (13–17 cm), slightly exceeding the typical range for mature loose-leaf cultivars (12–15 cm). The greater height observed was due to etiolation, a response to insufficient light, as the system initially delivered only $150 \pm 50 \mu\text{mol}/\text{m}^2/\text{sec}$, below the recommended 250–300 $\mu\text{mol}/\text{m}^2/\text{sec}$ for optimal growth (Miao *et al.* 2023). Productivity assessment revealed significantly higher fresh weights in the modified system (43.82 g vs. 22.91 g), consistent with expected yields, attributed to improved hydraulic consistency, nutrient availability and root-zone oxygenation (Acharya *et al.* 2022, Veazie *et al.* 2022).

Independent sample t-tests revealed significant differences in both plant height ($p < 0.001$) and fresh weight ($p < 0.001$) between the two systems (Table 2). The modified setup produced more uniform growth with lower variance in both plant height and fresh weight, indicating better stability and consistency. Consistent growth and yield are critical performance metrics for aquaponics efficiency and reliability (Zamani *et al.* 2025, Justin *et al.* 2026).

African catfish reared in the modified aquaponics system achieved a higher mean harvest weight (353 g) than those in the existing system (305 g), representing a 15.7% improvement in growth performance. These values fall within the 300–400 g benchmark recommended by Bureau of Fisheries and Aquatic Resources (BFAR) and Southeast Asian Fisheries development Center (SEAFDEC) for marketable catfish at 20 weeks, underscoring the production suitability of the modified system for peri-urban aquaculture. These outcomes reflect the benefits of system modifications that improved water distribution, aeration

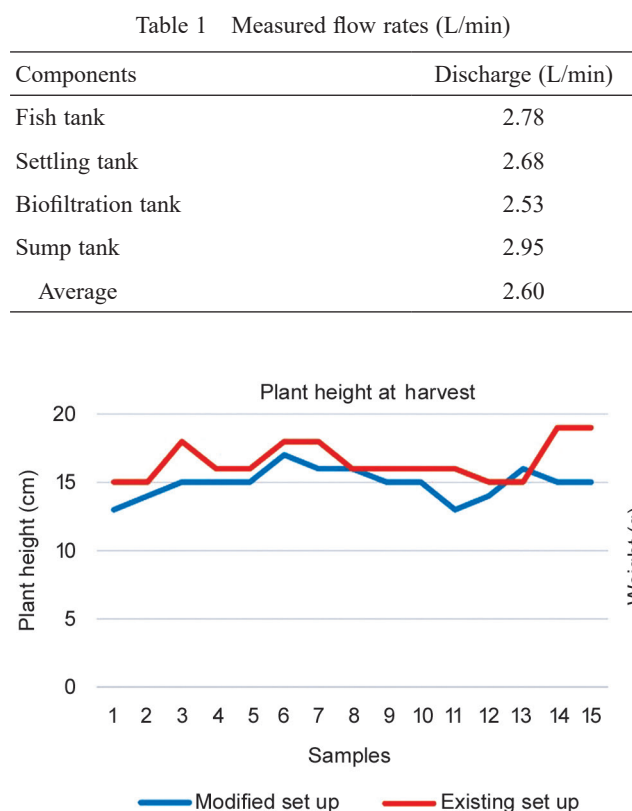


Fig. 1 Comparison of plant height (cm) and fresh weight (g) of lettuce between two systems.

Table 2 Independent samples t-test results for lettuce plant height, fresh weight and African catfish weight

System	Mean	Variance	<i>p</i> -value
Plant height (cm)			
Modified	14.93	1.21	0.00
Existing	16.53	2.12	
Fresh weight (g)			
Modified	43.82	3.64	0.00
Existing	22.91	6.17	
	African catfish weight (g)		
Modified	353	353.67	0.00
Existing	305	266.67	

and biofiltration, supporting water quality, fish and plant performance. Similar benefits have been reported in NFT-based aquaponics systems, where effective water-quality management contributed to improved fish growth and overall system productivity (Outa *et al.* 2025).

Statistical analysis confirmed a highly significant difference between systems ($p < 0.001$), validating the effectiveness of the modifications in boosting aquaculture productivity. These findings highlight the potential of the modified peri-urban aquaponics system as a scalable model for sustainable, community-based food production.

Economics: The modified aquaponics system demonstrated markedly superior financial performance compared to the existing system. A Return on Investment (ROI) of 57.71% was achieved, equivalent to ₱0.58 net profit/peso invested. This profitability is underpinned by enhanced biomass productivity, with mean fish weight reaching 353 g and mean lettuce yield averaging 43.82 g/plant. In contrast, the existing system yielded only 6.17% ROI, a level insufficient to safeguard small-scale entrepreneurs against market fluctuations or operational risks in peri-urban context. Capital recovery analysis further highlights the commercial advantage of system modification. The modified system achieved a payback period of 1.73 years, a timeframe highly favourable for resource-constrained farmers seeking rapid re-investment cycles. Conversely, the existing system required 16.21 years to recover initial capital, rendering it commercially unfeasible for production-oriented ventures (Table 3).

SUMMARY

The study, conducted from April to July 2025, evaluated the performance of a peri-urban aquaponics system,

Table 3 Return on investment and payback period for aquaponics systems under different configurations

System setup	ROI	Payback period
Modified setup	57.71%	1.73 yr
Existing setup	6.17%	16.21 yr

ROI, Return on investment.

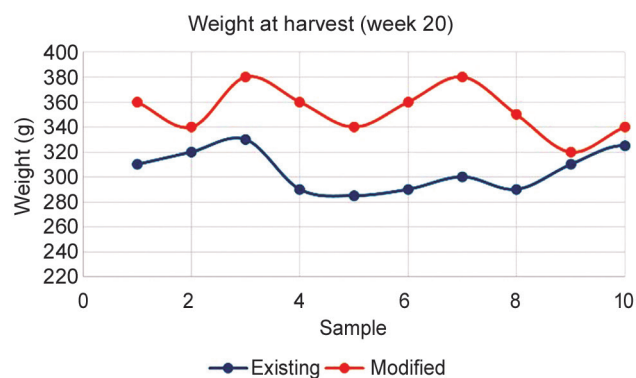


Fig. 2 Weight of harvested African catfish under the modified and existing aquaponic systems.

focusing on structural integrity and operational efficiency. The evaluation of the system demonstrated that structural integrity remained intact despite prolonged inactivity, providing a sound basis for operational testing. Hydraulic trials confirmed flow rates within recommended ranges and subsequent adjustments achieved uniform distribution, ensuring nutrient availability and system stability. Lighting modifications standardised exposure across grows channels, aligning with controlled environment standards and improving canopy photosynthesis.

Operational results showed that lettuce in the modified system produced significantly higher fresh weights (43.82 g vs. 22.91 g) despite slightly shorter heights, reflecting improved productivity under optimised light and hydraulic conditions. African catfish exhibited a 15.7% increase in mean harvest weight (353 g vs. 305 g), meeting BFAR and SEAFDEC benchmarks for marketable size at 20 weeks. Independent sample t-tests confirmed highly significant differences in both plant and fish performance, validating the effectiveness of system modifications. Economic analysis further underscored the benefits of optimisation, with the modified system achieving a 57.71% ROI and a payback period of 1.73 yr, compared to only 6.17% ROI and 16.21 yr for the existing setup. These findings highlight the technical, biological and financial viability of the modified aquaponics system as a replicable model for sustainable, community-based peri-urban food production.

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