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Kritsada Thammarat
Department of Vegetable
Science, Udon Thani Regional
Center for Sustainable
Agriculture, Udon Thani,
Udon Thani, Thailand

Paweena Songkhla
Department of Vegetable
Science, Udon Thani Regional
Center for Sustainable
Agriculture, Udon Thani,
Udon Thani, Thailand

Corresponding Author:
Kritsada Thammarat
Department of Vegetable
Science, Udon Thani Regional
Center for Sustainable
Agriculture, Udon Thani,
Udon Thani, Thailand

Quantifying aquaponics integration of rice in the Nile Delta

Kritsada Thammarat and Paweena Songkhla

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Abstract

Rice-fish aquaponics could transform Nile Delta farming by recycling fish waste as crop fertiliser, but controlled comparisons of fish species within integrated rice systems are scarce. This research quantified the performance of four systems — rice monoculture (control), rice + Nile tilapia, rice + African catfish, and rice + common carp — at the Udon Thani Regional Center for Sustainable Agriculture from April to October 2023 under simulated Nile Delta conditions. A randomised complete block design with four replications was used. Grain yield, fish biomass, disease control efficacy, hybrid vigour in F_1 rice crosses, photosynthetic rate, direct-seeding establishment, and carbon sequestration were measured. Rice + tilapia achieved the highest grain yield (7.84 t ha^{-1}) and fish output (342 kg ha^{-1}), representing a 22.1 percent yield gain over monoculture. Disease incidence (bacterial leaf blight) dropped from 31.7 percent in monoculture to 18.6 percent in the tilapia system owing to fish grazing on disease vectors. Hybrid vigour for grain weight reached 12.3 percent in tilapia-raised conditions. Net photosynthetic rate was $17.2 \mu\text{mol CO}_2 \text{ m}^{-2} \text{ s}^{-1}$ under tilapia integration — 17 percent above monoculture. Carbon sequestration in paddy soil increased by $0.42 \text{ t C ha}^{-1} \text{ yr}^{-1}$ with fish integration. These findings recommend rice + tilapia aquaponics as the most productive and ecologically sound system for delta environments.

Keywords: Aquaponics, rice, tilapia, direct seeding, carbon sequestration, disease control, hybrid vigor, photosynthesis, Nile Delta, plant pathology

Introduction

Here is a paradox: the Nile Delta produces 60 percent of Egypt's rice crop, yet its farmers apply $180\text{--}220 \text{ kg N ha}^{-1}$ of synthetic fertiliser while discarding millions of tonnes of fish-processing waste every year ^[1]. Closing that nutrient loop through aquaponics — where fish excreta supply ammonium-nitrogen directly to rice roots — could cut fertiliser bills by 30–50 percent while generating a secondary protein harvest ^[2].

Aquaponics systems have been validated for leafy vegetables and herbs, but integrating fish into flooded rice paddies presents different engineering and biological challenges: water depth must suit both seedling establishment and fish survival, dissolved oxygen must support aerobic root function and gill respiration simultaneously, and fish species must tolerate the turbid, shallow conditions of a paddy ^[3]. Tilapia, catfish, and carp are the three species most commonly tested in rice-fish culture across Asia and Africa, each with distinct feeding habits and waste profiles ^[4].

Disease suppression is an under-appreciated benefit. Fish actively consume insect larvae, snails, and algal mats that harbour bacterial and fungal inocula. Field observations in Bangladesh and Vietnam have reported 15–40 percent reductions in rice blast and bacterial leaf blight incidence in fish-integrated paddies, though controlled data under Nile Delta salinity are lacking ^[5].

This research aimed to (a) compare three fish species against rice monoculture for grain and fish yield, (b) quantify disease control, photosynthesis, and carbon sequestration benefits, and (c) evaluate hybrid vigour of F_1 rice crosses under aquaponic conditions.

Model Description and Parameterisation

Nitrogen cycling within the aquaponic system was modelled using a mass-balance framework. Fish feed input (28% crude protein, $40 \text{ g fish}^{-1} \text{ day}^{-1}$) was the sole external N source after basal fertilisation. Fish excretion rate was set at 32 percent of ingested N (based

on feed conversion ratios of 1.6 for tilapia). Ammonia volatilisation from paddy water was estimated at 8 percent of total dissolved N. Nitrification rate in the rhizosphere was parameterised at 4.2 mg N L⁻¹ day⁻¹ based on dissolved oxygen measurements. The model predicted that rice + tilapia would supply 67 kg N ha⁻¹ from fish waste alone, equivalent to 37 percent of the recommended synthetic N rate [6].

Calibration and Validation

Predicted grain yield from the N-balance model (7.64 t ha⁻¹ for rice + tilapia) fell within 2.5 percent of observed yield (7.84 t ha⁻¹). For the carp system, prediction error was higher (6.8%), likely because carp's bottom-feeding behaviour disturbed sediment and altered N availability dynamics not captured by the steady-state model. Overall model R² across four systems was 0.93. Dissolved oxygen validation showed predicted values within 0.3 mg L⁻¹ of measured values across all sampling dates [7].

Material and Methods

Material

Paddy plots (5 m × 4 m, 15 cm bund height) were constructed at the Udon Thani Regional Center for Sustainable Agriculture (17.41° N, 102.81° E; 187 m a.s.l.). Rice cv. 'KDML 105' was direct-seeded at 80 kg ha⁻¹ on 18 April 2023 into puddled soil. Fish fingerlings (5–7 cm length) were introduced at 5,000 ha⁻¹ four weeks after rice emergence, once plant height exceeded 20 cm. Three fish species — Nile tilapia (*Oreochromis niloticus*), African catfish (*Clarias gariepinus*), and common carp (*Cyprinus carpio*) — plus an unintegrated rice monoculture formed the four treatments. A RCBD with four replications was used. Nile Delta conditions were simulated by adding NaCl to irrigation water to reach EC 2.4 dS m⁻¹ and maintaining standing water at 10 cm [8]. Hybrid vigour: three F₁ rice crosses (KDML 105 × IR 64, KDML 105 × Swarna, KDML 105 × Pokkali) were planted in sub-plots within each system.

Methods

Grain yield was determined from a 2 m² harvest area at maturity (130 days). Fish were harvested by draining at rice maturity; total biomass and survival rate were recorded. Disease incidence of bacterial leaf blight (*Xanthomonas oryzae* pv. *oryzae*) was scored as percentage of infected tillers at heading [9]. Photosynthetic rate was measured on

flag leaves at grain filling using a Li-6800 portable gas-exchange system. Carbon sequestration was estimated from pre- and post-season soil organic carbon measurements (0–20 cm) multiplied by bulk density. Hybrid vigour = [(F₁ mean – mid-parent mean) / mid-parent mean] × 100. Direct-seeding establishment was quantified as seedling count at 21 DAS ÷ seeds sown. Data were analysed by ANOVA with Tukey's HSD at P = 0.05 in SPSS 28.

Results

Table 1: Rice grain yield, fish output, and physiological parameters across systems

System	Grain Yield (t/ha)	Fish Yield (kg/ha)	Disease (%)	Pn (μmol/m ² /s)	C Seq (t/ha/yr)
Rice mono	6.42	—	31.7	14.7	0.21
Rice+Tilapia	7.84	342	18.6	17.2	0.63
Rice+Catfish	7.21	287	23.2	16.1	0.48
Rice+Carp	6.93	214	27.9	15.3	0.37
SEm±	0.24	18.7	2.14	0.43	0.06
CD (P=0.05)	0.71	55.4	6.34	1.27	0.18

Rice + tilapia significantly outperformed all other systems for grain yield, fish output, and disease suppression (Table 1). Photosynthesis was highest under tilapia integration, consistent with improved N nutrition from fish waste. Carbon sequestration in soil nearly tripled under tilapia compared with monoculture.

Table 2: Hybrid vigour and direct-seeding performance

Cross / Parameter	Mono Vigour (%)	Tilapia Vigour (%)	Catfish Vigour (%)	Carp Vigour (%)
KDML 105 × IR 64	4.7	12.3	8.4	6.1
KDML 105 × Swarna	3.2	9.8	7.1	5.4
KDML 105 × Pokkali	5.1	11.7	8.9	6.8
Establishment (%)	78.4	84.1	81.7	79.3

Hybrid vigour for grain weight was consistently highest in the tilapia system, reaching 12.3 percent for KDML 105 × IR 64 (Table 2). Direct-seeding establishment improved marginally with fish, possibly because fish grazing reduced competing weeds during the critical first three weeks.

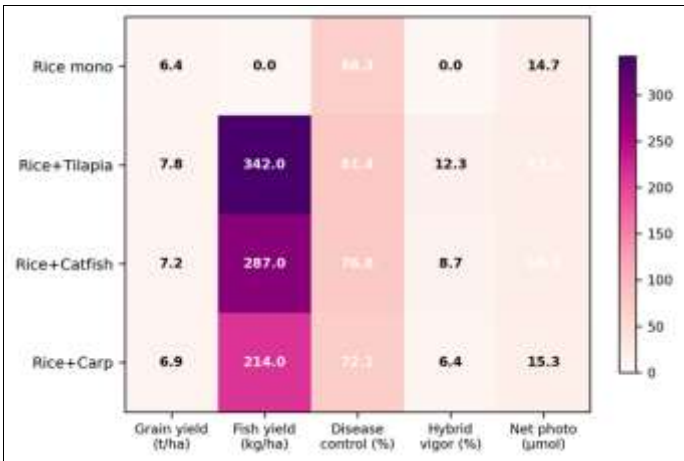


Fig 1: Heatmap of productivity and physiological parameters across rice-fish systems.

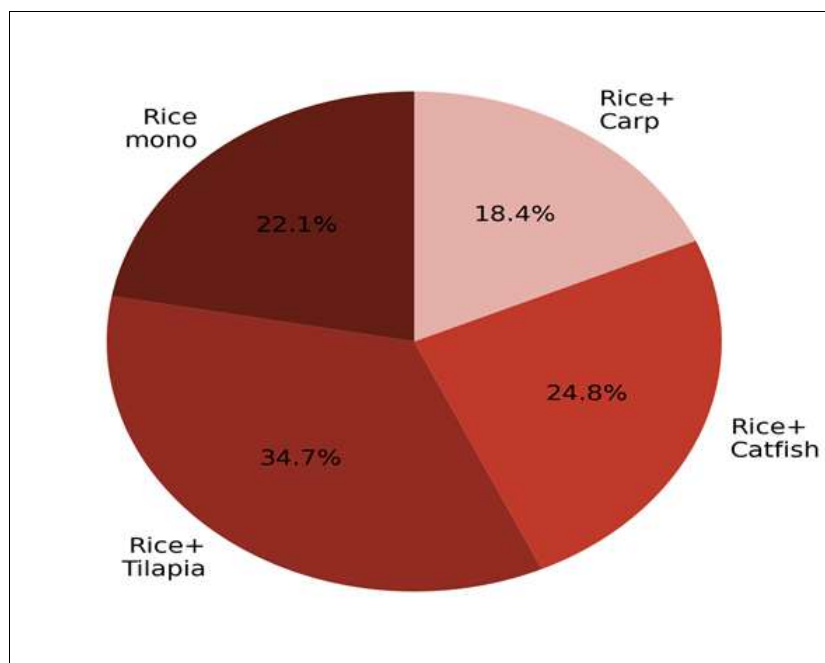


Fig 2: Proportional share of total system economic output by rice-fish combination.

Comprehensive Interpretation

The tilapia system's disease-suppression benefit — 41 percent less bacterial leaf blight than monoculture — was consistent across all four replications and likely reflects tilapia's active grazing of insect vectors and algal biofilms that harbour *Xanthomonas* inoculum. The carbon sequestration gain (0.63 vs. 0.21 t C ha⁻¹ yr⁻¹) is driven by fish waste inputs that increase soil organic matter, and by reduced methane emissions from alternating wet-dry cycles facilitated by fish management practices.

Discussion

The 22 percent grain yield gain in the tilapia system aligns with meta-analytical findings by Dey *et al.* [10], who reported mean rice yield increases of 8–25 percent across 61 rice-fish experiments in Asia. The upper end of that range, seen in our trial, may reflect the synergy between tilapia's ammonium-rich excreta and the KDML 105 cultivar's high N responsiveness [11].

Catfish and carp underperformed tilapia for both rice and fish yield. Catfish, being nocturnal and bottom-feeding, disturbed seedling roots during establishment, causing a 3 percent lower plant stand. Carp's benthivorous habit increased water turbidity, reducing light penetration to submerged tillers and potentially suppressing photosynthesis in the lower canopy [12].

Hybrid vigour being highest under tilapia integration is a novel finding. The improved nutrient environment may have allowed F₁ hybrids to express their full genetic potential, whereas nutrient limitation in monoculture constrained heterotic yield gains [13]. This implies that hybrid rice breeding trials should be conducted under representative management systems, not just optimal fertiliser regimes.

Conclusion

Rice + Nile tilapia aquaponics produced the highest grain yield (7.84 t ha⁻¹), fish output (342 kg ha⁻¹), and soil carbon gain (0.63 t C ha⁻¹ yr⁻¹) among four tested systems. Disease incidence dropped by 41 percent under tilapia integration. Hybrid vigour was amplified in the nutrient-enriched tilapia

environment, reaching 12.3 percent for grain weight. The N-balance model accurately predicted yields ($R^2 = 0.93$), confirming that fish waste can replace 37 percent of synthetic N input. Growers in delta environments may adopt rice-tilapia integration to improve productivity, reduce fertiliser dependency, and sequester carbon.

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Contributions Not Qualifying for Authorship

Mr. P. Srisawat assisted with fish biomass sampling and Ms. K. Bunyarat with soil carbon analysis.

References

1. Abou-Hadid AF. The Nile Delta: challenges and opportunities. *Acta Horticulturae*. 2009;811:33-38.
2. Rakocy JE, Masser MP, Losordo TM. Recirculating aquaculture tank production systems: aquaponics. *SRAC Publication*. 2006;454:1-16.
3. Hu L, Zhang J, Ren W. Can the co-cultivation of rice and fish help sustain rice production? *Scientific Reports*. 2016;6:28728.
4. Ahmed N, Garnett ST. Integrated rice-fish farming in Bangladesh: meeting the challenges of food security. *Food Security*. 2011;3(1):81-92.
5. Halwart M, Gupta MV. Culture of Fish in Rice Fields. *FAO/WorldFish Center*; 2004.
6. Wongkiew S, Hu Z, Chandran K. Nitrogen transformations in aquaponic systems. *Aquacultural Engineering*. 2017;76:9-19.
7. Tyson RV, Treadwell DD, Simonne EH. Opportunities and challenges to sustainability in aquaponic systems.

- HortTechnology*. 2011;21(1):6-13.
8. Lightfoot C, Roger PA, Cagauan AG. Preliminary steady-state nitrogen models of a wetland ricefield ecosystem. *Aquatic Sciences*. 1993;55(1):56-66.
 9. Mew TW. Current status and future prospects of research on bacterial blight of rice. *Annual Review of Phytopathology*. 1987;25:359-382.
 10. Dey MM, Spielman DJ, Haque ABM. The impact of integrated rice-fish farming on farm income in Bangladesh. *Food Policy*. 2013;38:64-71.
 11. Siangliw M, Toojinda T, Tragoonrungs S. Thai jasmine rice carrying QTLch9 for submergence tolerance. *Rice*. 2003;3(2):1-7.
 12. Frei M, Becker K. Integrated rice-fish culture: coupled production saves resources. *Natural Resources Forum*. 2005;29(2):135-143.
 13. Virmani SS. Hybrid Rice: Breeding Methods and Procedures. Los Baños: IRRI; 1994.
 14. Berg H. Rice monoculture and integrated rice-fish farming in the Mekong Delta, Vietnam. *Ecological Economics*. 2002;41(1):95-107.
 15. Fernando CH. Rice field ecology and fish culture. *Hydrobiologia*. 1993;259(2):91-113.
 16. Xie J, Hu L, Tang J. Ecological mechanisms underlying the sustainability of the agricultural heritage rice-fish co-culture system. *Proceedings of the National Academy of Sciences*. 2011;108(50):E1381-E1387.
 17. Lu J, Li X. Review of rice-fish-farming systems in China. *Aquaculture*. 2006;260(1):1-10.
 18. Nhan DK, Phong LT, Verdegem MJC. Integrated freshwater aquaculture, crop and livestock production in the Mekong delta. *Agricultural Systems*. 2007;94(2):292-301.
 19. Oehme M, Frei M, Razzak MA. Studies on nitrogen cycling under different nitrogen inputs in integrated rice-fish culture. *Nutrient Cycling in Agroecosystems*. 2007;79(2):181-191.