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*Review Article*

# Sustainable Aquaculture and Integrated Fish Farming in Sub-Saharan Africa: Tilapia and Catfish Production, Pond Management, Feed, and Integrated Agriculture-Aquaculture Systems

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## Abstract

Capture fisheries in sub-Saharan Africa (SSA) are stagnating or declining, while demand for fish, the cheapest and most accessible animal protein for many households, is rising with population, urbanisation, and income (FAO, 2024; Béné et al., 2015). Aquaculture, especially farming of Nile tilapia (Oreochromis niloticus) and African catfish (Clarias gariepinus), has grown more than six-fold in Africa between 2000 and 2024, led by Egypt, Nigeria, Ghana, Uganda, and Zambia, yet it remains underdeveloped relative to its potential (FAO, 2024). This article synthesises peer-reviewed evidence published between 2000 and 2025 on sustainable aquaculture and integrated fish farming in SSA. It reviews the main production systems, earthen ponds, cages, tanks, and recirculating systems, the biology and feeding of tilapia and catfish, water quality and stocking density, feed costs and alternative ingredients, fish health, and integrated agriculture-aquaculture (IAA) systems in which ponds, crops, and livestock exchange nutrients. Evidence shows that integrated ponds in Tanzania produced fish yields about 60 percent higher than non-integrated ponds, and that IAA in the Kenyan highlands reduced nutrient depletion by 23 to 35 percent while increasing agricultural production by 2 to 26 percent (Prein, 2002; Nhan et al., 2007; Jamu and Ayinla, 2003). Stocking density is a critical trade-off: in a Kenyan trial, high-density tilapia showed 38 percent less weight gain, a worse feed conversion ratio, and lower survival than low-density tilapia. The article proposes a practical, low-cost integrated pond system for smallholders and identifies priorities for fingerling quality, feed, water governance, markets, and extension. The central argument is that sustainable aquaculture in SSA should not copy intensive, high-input models from elsewhere, but should build on integrated, nutrient-recycling systems that fit smallholder farms, local feeds, and local markets.

**Keywords:** *aquaculture; integrated agriculture-aquaculture; Nile tilapia; African catfish; pond management; feed; sub-Saharan Africa*

## 1. Introduction

Fish is central to food security in SSA. It provides high-quality protein, essential fatty acids, vitamins, and minerals, and it is often more affordable and more widely available than meat or milk, especially for low-income households (Béné et al., 2015; FAO, 2024). In many coastal and lakeside communities, fish is the main animal protein, and in inland communities, dried and smoked fish are traded far from water bodies. Yet capture fisheries, from lakes, rivers, and the sea, face overfishing, habitat

degradation, climate variability, and weak governance, and they cannot meet rising demand alone.

Aquaculture is the fastest-growing food production sector globally, and Africa is the region with the largest untapped potential because of its land, water, climate, and market demand (FAO, 2024). Egypt alone accounts for about two-thirds of African aquaculture, followed by Nigeria, Ghana, Uganda, and Zambia, with cage farming of tilapia on Lake Victoria reaching about 134,000 tonnes in 2024, more than four times the 2015 level. Outside these leaders, aquaculture remains small-scale, with many ponds underused, abandoned, or producing far below capacity because of poor fingerlings, expensive feed, poor water quality, and weak markets.

Integrated fish farming, also called integrated agriculture-aquaculture (IAA), offers a different model. Instead of a stand-alone fish pond that depends entirely on purchased feed, IAA links the pond to crops, vegetables, livestock, and household waste, so that nutrients circulate: pond water irrigates vegetables, pond mud fertilises crops, crop residues feed fish, and livestock manure fertilises the pond (Prein, 2002; Jamu and Ayinla, 2003). This article asks three questions. First, which species and systems are most suitable for smallholders in SSA? Second, how do stocking density, feeding, and water quality affect growth, survival, and profit? Third, how can IAA be designed, managed, and supported so that it actually improves food security and income, rather than adding complexity without benefit?

## 2. Species, Systems and Production Potential

Two species dominate SSA aquaculture: Nile tilapia and African catfish. Tilapia is a hardy, omnivorous, fast-growing fish that tolerates a wide range of temperatures, dissolved oxygen, and water quality, and it can be grown on low-protein feeds, natural pond food, and agricultural by-products (El-Sayed, 2006). It reaches market size of 400 to 600 grams in about six months under good management, with a feed conversion ratio (FCR) of about 1.5 to 1.8. Catfish is a carnivorous, air-breathing fish that tolerates low oxygen and high stocking density, grows to 1 kilogram or more in four to five months under intensive feeding, and requires higher protein feed, 35 to 40 percent crude protein, with an FCR of about 1.3 to 1.6 under good management (FAO, 2024).

Production systems vary in cost and intensity. Earthen ponds are the most common for smallholders: they are low-cost, use natural food, and can be integrated with crops, but they require land, water, and careful management of seepage and predators. Cage culture in lakes and reservoirs allows high density and good water exchange but requires capital, quality fingerlings and feed, and governance to avoid conflict and pollution. Concrete tanks and recirculating aquaculture systems (RAS) allow intensive production in urban areas with limited land, but they require electricity, filtration, and skilled management. For most smallholders, earthen ponds are the starting point, with cages and tanks as later options if capital and markets allow.

The potential is large. More than 30 percent of the geographical area in 40 SSA countries, covering 9.2 million square kilometres, is suitable for some form of aquaculture (Prein, 2002). In practice, suitability depends on water availability, soil that holds water, access to fingerlings and feed, and access to markets. Ponds should be sited where water is available year-round or where rainwater can be harvested, where soil has sufficient clay to hold water, and where the pond can be integrated with a vegetable garden or livestock unit.

## 3. Pond Management: Water Quality, Stocking Density and Feeding

Water quality is the master variable in fish farming. Dissolved oxygen should generally be above 4 mg per litre for tilapia and catfish, pH between 6.5 and 9.0, and temperature between 25 and 30 degrees Celsius for optimal growth (El-Sayed, 2006). Ammonia, nitrite, and hydrogen sulphide accumulate from uneaten feed and faeces, and they can kill fish if not controlled by water exchange, aeration, and proper feeding. Farmers should monitor water colour, transparency, and fish behaviour daily: fish gasping at the surface, reduced feeding, or sudden mortality are warning signs of low oxygen or ammonia toxicity.

Stocking density is a critical trade-off between total production and individual growth. A comparative study in Kisumu, Kenya, found that high-density tilapia showed 38 percent less weight gain, 73.1 grams versus 117 grams in low density, a worse FCR, 2.4 versus 1.6, and lower survival, 74 percent versus 93 percent, than low-density tilapia. The lesson is clear: overstocking does not produce more fish; it produces smaller, sicker fish at higher cost. Smallholders should start with low to moderate density, for example 2 to 3 tilapia per square metre

in fertilised earthen ponds, and increase only as management, feeding, and water exchange improve.

Feeding is the largest cost, typically 60 percent or more of production cost, and the most important management decision (FAO, 2024; Béné et al., 2015). Fish should be fed 2 to 3 times daily, with a ration based on body weight, temperature, and growth stage, and uneaten feed should be removed to avoid water pollution. Tilapia can be fed a combination of natural pond food, stimulated by organic fertilisation, and supplementary feeds made from rice bran, maize bran, soybean meal, and other local ingredients. Catfish require higher protein and more complete feeds, and they are more dependent on purchased feed, which makes them more profitable but also more risky when feed prices rise. Alternative ingredients, including black soldier fly larvae meal, poultry by-product meal, and plant proteins, are being tested as replacements for fishmeal, with promising results for both tilapia and catfish, but they require quality control and formulation based on digestible nutrients.

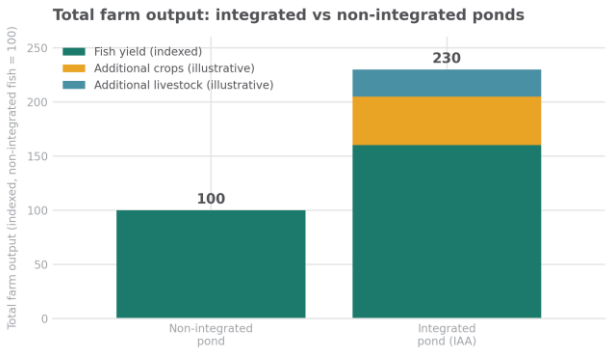



**Figure 1.** Integrated ponds produce fish plus crops and livestock from the same land and water, raising total output. Fish component is indexed from the reported ~60% higher fish yield in IAA ponds in Tanzania; crop and livestock components are illustrative only.

*Source: synthesised from Prein (2002); Nhan et al. (2007).*

## 4. Integrated Agriculture-Aquaculture (IAA): How Integration Works

IAA is based on a simple principle: waste from one enterprise becomes input for another. Pond water, rich in nitrogen and phosphorus from fish faeces and uneaten feed, can irrigate vegetables, reducing fertiliser need. Pond mud, dredged at harvest, can fertilise crops. Crop residues, such as rice bran, cassava leaves, and vegetable waste, can feed fish directly or fertilise the pond to stimulate natural food. Livestock manure, applied in small, controlled amounts, can fertilise the pond, but over-application can cause oxygen depletion and fish mortality, so it must be managed carefully (Prein, 2002; Jamu and Ayinla, 2003).

Evidence for IAA is consistent. In Tanzania, integration of tilapia and vegetables was the most common IAA system, and fish yield from IAA ponds was about 60 percent higher than from non-IAA ponds because of more frequent use of on-farm resources and better management. In the Kenyan highlands, ideotyping studies found that IAA reduced nutrient depletion by 23 to 35 percent, increased agricultural production by 2 to 26 percent, and improved nutrient use efficiency, because ponds acted as nutrient traps, capturing nutrients from erosion, leaching, and farm residues that would otherwise be lost (Nhan et al., 2007). In Malawi, Ethiopia, and Nigeria, socioeconomic assessments of IAA showed promising results for poverty reduction and malnutrition, with fish providing protein and income, and vegetables providing vitamins and cash.

Rice-fish farming is a specific form of IAA with particular promise. Fish in rice paddies control pests, weeds, and mosquito larvae, while rice provides shade and food for fish, and fish faeces fertilise rice. Trials in Asia and Africa have shown that rice-fish systems can increase rice yield, reduce pesticide use, and provide fish without additional land. The system requires water management that suits both rice and fish, selection of fish species that tolerate shallow, warm water, and protection from predators and pesticide drift.

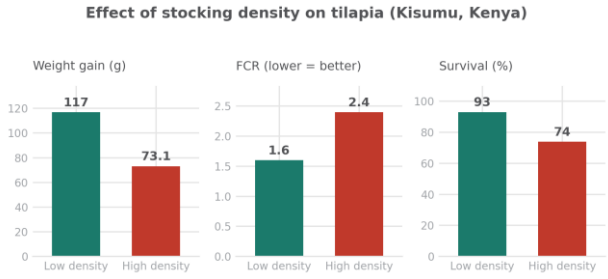



**Figure 2.** High density reduces individual growth, worsens FCR, and lowers survival, so moderate density is more profitable for smallholders.

*Source: Kisumu, Kenya comparative trial as reported in the text (weight gain 73.1 g vs 117 g; FCR 2.4 vs 1.6; survival 74% vs 93%).*

**Table 1.** Common integrated agriculture-aquaculture systems in SSA.

| IAA type | How it works | Main benefit | Main risk / management |
|---|---|---|---|
| Fish + vegetables | Pond water irrigates vegetables | More food, less fertiliser | Water sharing, timing |

| | | | |
|---|---|---|---|
| Fish + livestock | Manure fertilises pond | Lower feed cost | Over-fertilisation, oxygen loss |
| Fish + rice | Fish in paddy | Pest control, extra protein | Pesticides, water depth |
| Fish + crops (mud) | Pond mud on fields | Soil fertility | Labour for dredging |
| Fish + fruit trees | Trees shade pond, leaves feed fish | Shade, feed, income | Leaf litter, oxygen |

## 5. Fish Health, Fingerlings and Biosecurity

Fish health is often neglected until a disease outbreak causes mass mortality. Prevention is cheaper than treatment: buy fingerlings from reputable hatcheries, quarantine new fish, avoid overstocking, maintain water quality, and feed a balanced diet (El-Sayed, 2006). Common diseases in SSA include bacterial infections, fungal infections, and parasites, often triggered by stress, poor water quality, or handling. Antibiotics should be used only under veterinary guidance, with correct dose and withdrawal period, because misuse can cause residues, resistance, and market rejection.

Fingerling quality is a binding constraint. Many smallholders buy fingerlings of unknown age, species, or health, leading to slow growth, high mortality, and mixed species. Hatcheries should provide monosex tilapia where appropriate, to avoid uncontrolled breeding and stunting, and should provide fingerlings of uniform size, good condition, and known species. Farmers should inspect fingerlings before purchase: they should be active, uniform, without lesions, and from a hatchery that can explain its broodstock and feeding. Community hatcheries, cooperatives, and mobile fingerling suppliers can improve access, but they require training and quality assurance.

Biosecurity includes not introducing fish from wild sources without quarantine, not sharing nets and equipment between ponds without disinfection, and not dumping dead fish in waterways. Climate change adds new risks: higher temperatures increase oxygen demand and disease, floods can cause escapes and introductions of invasive species, and drought can reduce water availability. Farmers should have a contingency plan for water shortage, including partial harvest, reduced feeding, and aeration.

## 6. Economics, Gender, Markets and Adoption

Economics determine whether aquaculture is adopted and sustained. A pond requires upfront investment in construction, fingerlings, and feed, with income only at harvest months later. This cash-flow gap is a major barrier for smallholders, and it is why many ponds are abandoned after one cycle (Béné et al., 2015). Partial harvesting, where some fish are harvested early for home consumption or sale, can smooth income and reduce density. Group ownership, cooperatives, and savings groups can share costs and risks, and can negotiate better prices for fingerlings, feed, and fish.

Markets are as important as production. Fish is perishable, and without cold storage, ice, or processing, farmers must sell quickly at harvest, often at low prices. Drying, smoking, and salting can extend shelf life and reach inland markets, but they require fuel, labour, and quality control. Women dominate fish processing and retail in many SSA markets, yet they may not control pond decisions or income (FAO, 2024). Programmes that channel ponds, training, and credit through women's groups, and that support processing, storage, and transport, are more likely to reach those who actually sell fish and to sustain adoption.

Adoption is shaped by water, land, knowledge, and trust. Farmers adopt ponds when they have water, when they see a neighbour succeed, and when they can sell fish at a profit. They abandon ponds when water runs out, when fingerlings or feed are unavailable, when predators or theft cause losses, or when markets collapse. Extension should therefore not only teach pond construction, but also help farmers plan water, feed, and markets for the full cycle, and should link farmers to hatcheries, feed suppliers, and buyers.

**Table 2.** Aquaculture systems and their suitability for smallholders in SSA.

| System | Typical scale | Capital / skill | Suitability |
|---|---|---|---|
| Earthen pond | 0.05–0.5 ha | Low / moderate | Smallholders, IAA |
| Cage (lake / reservoir) | 10–100 $m^3$ | Medium / high | Groups, commercial |
| Concrete tank | 5–50 $m^3$ | Medium / high | Urban, intensive |

| | | | |
|---|---|---|---|
| Recirculating (RAS) | Small, intensive | High / high | Urban, high-value |
| Rice-fish | 0.1–1 ha paddy | Low / moderate | Rice farmers |

## 7. Research and Policy Priorities

Several gaps remain. First, long-term, multi-location trials that measure not only fish yield but also crop yield, income, nutrition, and water use in IAA systems are still scarce. Second, research on low-cost, locally formulated feeds, including alternative proteins and pond fertilisation, should be prioritised, because feed is the largest cost. Third, research on fingerling quality, on monosex tilapia, and on hatchery management should be embedded in extension, not treated as separate. Fourth, research on cage culture governance, on water quality in lakes, and on climate resilience should be prioritised as cage farming expands.

Policy should align incentives with sustainability. Public investment should support hatcheries, feed mills, and cold chains, with quality standards for fingerlings and feed. Water governance should ensure that pond and cage farming do not degrade lakes, rivers, or aquifers, and that smallholders have secure access to water and land. Extension should teach integrated management, not only fish production, and should link farmers to markets, credit, and insurance. Regional coordination on fish trade, on disease surveillance, and on standards can improve food safety and market access for all (FAO, 2024).

## 8. Conclusion

Sustainable aquaculture and integrated fish farming offer a practical path to more fish, more vegetables, and more income from the same land and water in SSA. Tilapia and catfish are well-suited to smallholder systems, IAA can raise fish yields by about 60 percent and reduce nutrient depletion by 23 to 35 percent, and moderate stocking density, good water quality, and balanced feeding are more profitable than overstocking and overfeeding (Prein, 2002; Nhan et al., 2007). The challenge is not a lack of technology; it is the challenge of making quality fingerlings, affordable feed, water, and markets available to millions of smallholders, especially women and youth who process and sell fish. If that is achieved, aquaculture can turn ponds from a risky, stand-alone enterprise into a nutrient-recycling hub that strengthens the whole farm, and fish from a scarce, expensive protein into a reliable source of nutrition and income.


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## Conflict of Interest

The authors declare no conflict of interest.

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