Aquaculture Technology Toolkit Catalogue

TAAT Clearinghouse

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The Technologies for African Agricultural Transformation (TAAT) is funded through a grant from the African Development Bank and is implemented by the International Institute of Tropical Agriculture (IITA) in close collaboration with other centers of the Consultative Group for International Agricultural Research (CGIAR) and specialized institutions such as the African Agricultural Technology Foundation (AATF), the Forum for Agricultural Research in Africa (FARA), the International Fertilizer Development Center (IFDC) and others. For more information, email contact: i.musabyimana@cgiar.org or plwoomer@gmail.com.

Front cover photos: Lining a new fishpond in Kenya (upper left), an earthen fishpond network in Nigeria (upper right), catfish harvested using nets (bottom left) and smoking oven for aquaculture products (bottom right). Photos from WorldFish and IITA Youth Agripreneurs

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Aquaculture Technology Toolkit Catalogue

A Report by the Technologies for African Agricultural Transformation Clearinghouse, April 2022

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TAAT offers to become your broker of modernizing agricultural technologies!

Purpose and Introduction

This catalogue describes a series of technologies related to the modernization of aquaculture in Africa. It is developed through a collaborative effort from the Technologies for African Agricultural Transformation (TAAT) program from the African Development Bank that seeks to increase stakeholder usage of proven agricultural technology, and its Aquaculture Compact project partners. The compilation is also supported by the Project Platform for Agricultural Solutions (ProPAS), an information portal where innovations are systematically characterized for open access. Both activities are addressing the imperative to better connect proven technologies to those who need them, but each undertakes this goal in a very different manner. Aquaculture is one of nine commodity compacts with proven technologies that has potential to ensure self-sufficiency in fish production and increase yields and benefits for upscaling. Fish is also targeted as an agro-industrial commodity for processing and trading on domestic and regional markets. The TAAT Aquaculture Compact, led by WorldFish, informs a wide variety of stakeholders through capacity development and technological outreach, and this catalogue assists them to do so. The countries targeted by the Aquaculture Compact are Benin, Burundi, Cameroon, Cote d'Ivoire, Democratic Republic of Congo, Ghana, Kenya, Malawi, Nigeria, Tanzania, Togo, and Zambia. The TAAT Program identified proven technologies that advance fish production and we have compiled them into a "Toolkit Catalogue" meant to promote understanding and stimulate adoption and investment. This is one of several such catalogues produced as a joint TAAT-ProPAS activity. For more information on the featured technologies or other solutions toward transformation of aquaculture in Sub-Saharan Africa, contact Prof. Bernadette Fregene at b.fregene@cgiar.org.

About TAAT. Weaknesses in the production and supply of commodities are viewed as responsible for Africa's food insecurity, need for excessive importation of food, and unrealized expansion of Africa's food exports. The TAAT Program led by the International Institute of Tropical Agriculture (IITA), pioneers new approaches to the deployment of proven technologies to African farmers. TAAT arose as a common effort of IITA and the African Development Bank (AfDB); and is an important component of the latter's "Feed Africa Strategy". Currently, TAAT is advancing 100 carefully selected technologies through 88 interventions in 31 countries organized around 15 "Compacts" that represent priorities in terms of achieving Africa's potential in achieving food security and advancing its role in global agricultural trade. Nine of these Compacts relate to specific priority value chains of fish, small livestock, common bean, rice, wheat, maize, cassava, sweet potato, sorghum and millet. Together these Compacts design interventions in collaboration with national programs to introduce technologies and innovations that are designed to meet ambitious targets for agricultural development. In many cases, these targets are addressed through the implementation of projects resulting from sovereign country loans awarded by development banks, where TAAT's role in the design, planning and execution of these loan projects is a vital element of their success and uptake.

About ProPAS. The Product Platform for Agricultural Solutions (ProPAS) provides a mechanism to compile and access innovations and manage technologies and products needed for Africa's agricultural transformation. The platform provides two pathways: it permits users to enter their proven and promising solutions into a database, and then encourages others to sort through its options to reveal a suite of opportunities that can assist their agricultural objectives. ProPAS results from the recognized need by IITA to more systematically compile the full range of agricultural solutions available to modernize and transform African agriculture. Its overall goal provides ready access to different institutions or individuals in order to to accelerate technology uptake and progress towards agricultural transformation in Africa. Many solutions are available to improve and modernize Africa's food systems but many beneficiaries are too often unaware of the best options at hand. In addition, multiple solutions are in the research and development pipeline that can best be advanced through wider exposure and validation. Solution profiles are submitted by technology holders, compiled into a user-friendly software platform and released in a systematic manner for use by an expanding base of clients. A small committee of agricultural experts oversees this process while recognizing that its strength is through open-ended access to a marketplace of solutions. ProPAS is therefore managed through a three-phase process that involves solution submission, database management, and client access. The database allows for solutions to be identified through selection of several search fields related to the form, type, commodity application and target beneficiaries of a given solution, sequentially narrowing the number of platform recommendations.

The TAAT Top 100 Technologies. The Clearinghouse developed a database of the Top 100 Technologies that are transforming African agriculture. It is based upon the approaches of the TAAT Commodity Compacts but also includes those from the CGIAR Collaborative Research Programs that are recently described as ready for next user. These technologies are divided between those involving improved genetics and plant and animal breeding (23%), manufacturing and use of input products with proven efficacy (21%), management practices for protection of crops and livestock against pests and diseases (27%), labour-saving mechanized equipment available on the market (26%), and applications for distribution of digital information (3%). These technologies have a direct role towards extension messaging and campaigns in view of achieving the Sustainable Development Goals related to farm productivity, food security and hunger reduction, responsible food consumption, improved household nutrition and diets, economic growth, climate-smart innovation, partnerships for the goals, and improved human equity and empowerment.

The Top 10 Aquaculture Technologies. This catalogue presents ten technologies that serve to modernize aquaculture stocking and production systems, feed formulation and manufacturing, and post-harvest handling and value addition in Africa. These technologies include: 1) Mono-sex male tilapia fingerlings for higher feed conversion and production rate, 2) Fast-growing and hybrid African catfish with greater survival and hardiness, 3) Mass production of fingerlings in "hapa" nets to save space and feed, 4) Durable pond lining for water conservation, 5) Tank and cage culture systems for intensive, land-based production, 6) Flow-through and recirculatory aquaculture systems with enhanced water quality and economy, 7) In-pond raceway systems for optimizing water and feed control, 8) Low-cost formulation and pelleting of low cost fish feed, 9) Integrated fish and vegetable production with mutual benefits and income diversification, and 10) Processing and preservation techniques that increase market access and commodity value. Details on each of these ten technologies are included in the catalogue.

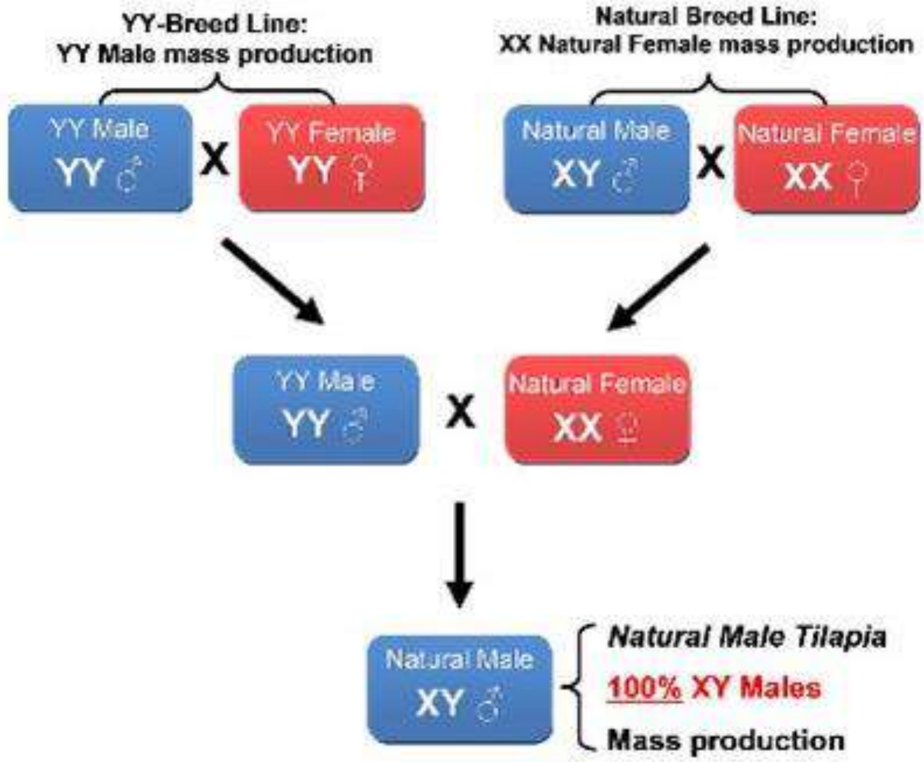
Use of Improved Breeds of Fish. Aquaculture is an ancient art but throughout much of its history wild and cultivated fish were no different. This is unlike the steady domestication of farm animals. More recently, the gap between aquaculture and farm animal industries in the use of improve breeds is narrowing. Through these improved fish breeds, gains in growth rate of 12% or more per generation are achieved, and fish selected for faster growth also show improved feed conversion, higher survival, and better utilization of space. Two fish of greatest interest in Africa are tilapia and catfish. The introduction of Genetically Improved Farmed Tilapia (GIFT) by WorldFish results in greatly improved productivity. So too does the Genetically Improved Abbassa Nile Tilapia (GIANT) strain. The rearing of improved African catfish offers similar advantages: it grows fast and consumes a large variety of feeds, it tolerates adverse water quality conditions and can be raised in high densities, it fetches a higher price and can be sold live at the market but does not spontaneously reproduce in captivity. Different catfish can be hybridized resulting in still greater productivity and better-quality meat. Genetic improvement of important aquaculture species offers a means of reducing poverty and increasing protein security, but requires responsible application of genetic, environmental, and social principals. The genetic risks posed by the development and use of improved strains are greatest when there are wild populations within reach of aquaculture escapees. The development, multiplication and dissemination of improved fish strains should be conducted in a way that minimizes the impact on the aquatic environment and other fish species and ensure that small-scale fish farmers benefit from it.

Technology 1. All Male Tilapia Fingerlings with Greater Yield and Uniformity

Summary. Tilapia is one of the most important farmed fish and is historically among the first breeds cultivated by humans. The group belongs to the Cichlid species that originated in Africa. Tilapia is easy to farm in different systems ranging from low-tech earthen ponds to intensive high-tech tanks and cages. Some of the limitations in producing tilapia are its small size, slow growth rate and frequent reproduction in captivity. This is because large amounts of metabolic energy go toward reproduction in gestating female tilapia, their growth rate is slowed down and the conversion of feed to flesh is reduced. Male tilapias are bigger and more attractive for production because more of their metabolic energy is channeled toward weight gain, which increases their growth rate and conversion of feed to flesh. Males grow faster and larger, they are therefore more profitable for producers and more acceptable to consumers. The mono-sex male technology was introduced by WorldFish and has rapidly gained popularity with small-scale producers in Africa. For more information on this technology please contact Prof. Bernadette Fregene of the TAAT Aquaculture Compact at b.fregene@cgiar.org

Technical Description. Mixed sex tilapia culturing is technically easy but is associated with lower yields and smaller and non-uniform harvests. Mono-sex culture is more complex, but it is possible to produce all male tilapia fingerlings — as high as 98%. A mono sex, all male tilapia stock is obtained through manual sex selection, hormonal alteration or YY natural male technology (NMT). Genetically improved farmed tilapia (GIFT) transferred from selective breeding programs is ideal for commercial production. In the manual selection, female and male fingerlings are visually separated at the start of the production cycle but this is time-consuming, and nearly half of the stock will be discarded. Alternatively, for commercial production, hormonal alteration of fry is performed by application of the masculine hormone α-Methyltestosterone to the fry feed converting the sex of most fish (98%) from female to male. However, research findings show that hormone levels in tilapia fall to normal levels 5 days after the withdrawal of hormone feed. Most tilapia hatcheries in Egypt produce monosex fry by applying the masculine hormone 17 α-Methyltestosterone (MT). The process of monosex production using MT hormone is not prohibited, as the European Union and United States markets allow tilapia to be imported from countries producing monosex tilapia. The ministerial decree organizing this issue states that mixing hormone with feed should be done with caution in feed mills. Another approach to sex management relies upon temperature change up to 36^{o} C shortly after hatching, converting the sex of most fish (86%) from female to male, although many of the

Sex differentials in tilapia fingerlings fry may perish in the process. The end-product of NMT is a complete natural male stock with XY-chromosome, whereas for hormone sex-reversed 50% of the phenotypically males are genetically female with XX-chromosomes. The GIFT technology is based on selective breeding processes where brood parents are carefully monitored to obtain improved performance for certain traits that are important for production and marketing. These genetic gains are cumulative and permanent, unlike for other breeding methods with short-lived advantages.



Schematic overview of all male production with YY technology
(Source: https://til-aqua.com)

Uses. Culturing mono-sex tilapia is of great importance to aquaculture practice in all African countries because temperatures are highly suitable for fast growth. It offers substantial benefit in terms of its growth and yield per unit area with uniform sizes at harvest. Improved mono-sex tilapia is more resistant to disease, tolerant to adverse weather, and can tolerate broader temperature (12-40°C) and salinity levels (12-15 ppt). Farming of mono-sex tilapia is especially attractive in countries with a strong demand for tilapia such as DR Congo, Ghana, Malawi, Nigeria, Uganda, and Zambia.

Composition. A large range of tilapia breeds can be used for manual selection, hormonal treatment, YY male technology and GIFT but improved lines are most favorable as they possess traits that further benefit growth rate, feed conversion, size, and hardiness. Crossbreeding of male Blue tilapia (*Oreochromis aureus*) or Wami tilapia (*O. urolepis*) and Greenhead tilapia (*O. macrochir*) with female Nile tilapia (*O. nilotica*) results in 100% male offspring. Male Blue and Zanzibar tilapia (*O. hornorum*) that brood with Mozambique tilapia (*O. mossam*bicus) also have exclusively male offspring. Nile tilapia is highly popular due to its faster growth and ability to grow to larger size over a wide range of environmental conditions. Its disease resistance and ability to efficiently utilize very diverse food sources also make it an ideal candidate for culture. A range of sterile transgenic breeds has been developed that can achieve a harvest weight up to 2 kg.

Application. Successful farming of mono-sex tilapia requires hatcheries to select and manage brood stock for high quality and quantity of fish seeds. Younger brooders (1 to 1.5 year old) weighing at least 300 g and free of wounds and parasites are needed for establishing a broodstock population with high reproductive efficiency and prolonged life. It is advisable to rejuvenate the broodstock every three years or at the age of 4 to 5 years old. Normally, brooders are stocked into the spawning units (tanks or hapas) about 15 days before the spawning season. They are collected during the daytime when the temperature is warm, and males and females are moved separately into the hatchery. Keep males and females in separate tanks or hapas for feeding before spawning. Feeding starts as on the day following stocking. The water temperature should be raised gradually up to 26°C. After confirming that females are ready to ovulate, both sexes are stocked into the spawning units at a rate of 2 females to 1 male. The average weight of broodstock in each spawning unit must be kept almost equal. Female brood stock must be regularly checked for eggs. If they carry eggs in their mouths, collect the eggs and transfer into the hatching jars, where the incubation period is completed until hatching occurs. After 10-12 days (according to temperature) have elapsed, the newly hatched fish, also called "fry", can be moved from brooder basins to rearing units. The hormonal mono-sex technology uses a rate of 60 mg artificial testosterone per kilogram of feed. Fry have to be continuously fed with the hormonal agent for 21 days to ensure sexual inversion to a male rate of 98%. After treatment, there should be a few fry under 14 mm in size. However, if more than 5% of the fry are 13 mm or smaller, remove the fry because 25% of them are likely to be females. In the GIFT method, full-sibling families of fish are reared in small, separate enclosures after which they are tagged to track growth against siblings and other individuals. Following this approach, major improvements of tilapia stocks can be achieved over only three to five years.

Commercialization and Start-up Requirements. The introduction of mono-sex tilapia in Africa occurred progressively over the past three decades and currently mono-sex tilapia is produced and distributed in many African countries. Fish farmers need to consider the following steps when starting mono-sex tilapia production: 1) Selecting a good location with access to water that is free of pollutants, 2) Availability of matured and fecund brood stock, 3) Installation of aerators for oxygen supply, and 4) Provision of hapa-style nets to raise the fingerlings (see Technology 3).

Fingerling farm of all male tilapia for increasing local fish production

Production Costs. The use of manual sexing and hormonal treatment for obtaining all male stocks are less expensive over the short term but investment must be made during each production cycle. Advanced breeding of the YY male and GIFT methods attract greater startup costs but the maintenance of stocks over the long-term is less. In Kenya mono-sex fingerlings of one month are sold at US $0.1 per individual, whereas mixed-sex stock is 20% cheaper. At a stocking rate of 1,000 fish per cubic meter of water, the cost for farmers is US $100. Fingerlings of mono-sex tilapia for starter stocks are sold at US $0.05 in Nigeria and Zambia. All male fingerlings stocked in earthen ponds or cages can reach 300-900 g in 5 to 8 months of culture, leading to greater profits assuming that feed is accessed or produced in an efficient manner (see Technology 8).

Customer Segmentation and Potential Profitability. Markets for mono-sex tilapia are diverse, including other hatcheries and producers at small or commercial scales. Genetically male tilapia stocks that are bred through the YY technology offer a 2.5-fold greater net return over mixed-sex tilapia and a 90% greater net return compared to hormonally sex-reversed tilapia. Larger sized tilapia may be exported as whole fish or fish fillets. Improved strains of tilapia reach harvestable size faster, and more than 30% increase in harvest volume has been found with GIFT breeds compared to previously used “improved” tilapia breeds, suggesting steady improvement with time. Enhancing the access of fish farmers to improved mono-sex tilapia seed is a viable opportunity that will raise the profitability of hatcheries and African fish farmers alike.

Licensing Requirements. Management of tilapia broodstock described in this technology is offered as a Regional Public Good by WorldFish and the TAAT Program, but some of its constituent materials and equipment are protected under commercial patent.

Technology 2. Fast Growing and Hybrid African Catfish

Summary. The African catfish is excellent for inland freshwater farming and has large potential to boost local and regional production and improve human nutrition and protein security across Africa. Catfish are native to all Sub-Saharan African countries and are widely consumed. Rearing catfish started fifty years ago in West and Central Africa. They grow fast and are omnivorous (including many low-cost agricultural byproducts), they are hardy against common pests and tolerate low water quality, they can be farmed at high stocking density with potential annual production of 6-16 ton per hectare, they mature and reproduce easily in captivity, and they can be sold live, fetching a higher price than tilapia. One favorable characteristic is their ability to gulp air when oxygen levels are low, making pond aeration less difficult and risky. Catfish breeds can grow up to 1.5 meter long and weigh up 30 to 60 kg although most are harvested when smaller from culture systems. Scarcity of quality fingerlings from improved catfish breeds by local hatcheries is a major hurdle to enhancing yields and returns of farmers and meeting demand from local markets. As a result, too many fish farmers collect fish eggs from the wild or purchase poor quality fingerlings. Lack of knowledge on pond and fish health management among farmers also leads to high mortality, limited growth and poor feed conversion and must be addressed through training and advisory services. More information from Prof. Bernadette Fregene of the TAAT Aquaculture Compact at b.fregene@cgiar.org

Technical Description. The most popular catfish breeds for farming are the African sharptooth catfish (*Clarias gariepinus*), which has a dark gray or black coloration on the back, fading to a white belly; and the African catfish (*Heterobranchus bidorsalis*) with greyish brown on the back and sides, a pale brown on the belly and some individuals showing a marbled coloration at the rear of the body. Both species are fast-growing and well adapted to conditions in Sub-Saharan Africa. Crossbreeding female *C. gariepinus* with male *H. bidorsalis* produces a hybrid offspring (Hetero-Clarias) that has a superior growth rate, higher survival, and hardiness compared to the parents. It does not spend energy on reproduction because the hybrid is sterile and has a high feed conversion. The hybrids also have a white meat which is usually preferred by consumers. The two species do not mate with one another naturally. Hybridization requires that female catfish are given a hormone injection, which induces the release of eggs. They are anesthetized, and eggs are "stripped" by gently pushing the belly. Male catfish are killed to harvest their seminal fluids, also known as milt, which is subsequently mixed with these eggs. Fish farmers can perform the process themselves after short-term training, particularly focused on ensuring that hormone dosages, egg, and sperm are prepared correctly, along with other hatchery practices.

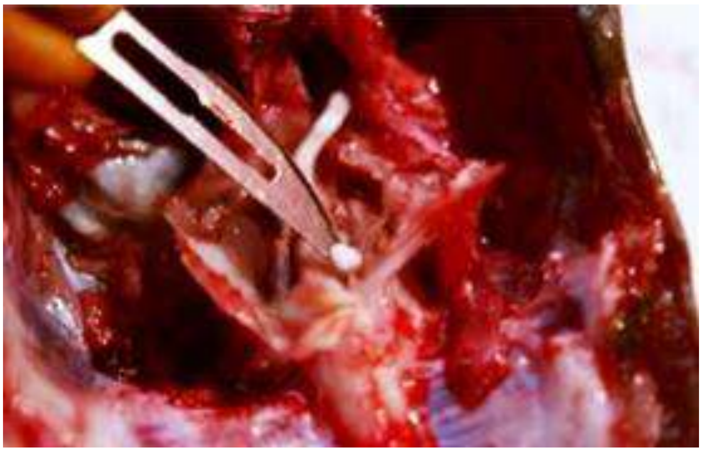
Sex differentials in African catfish; male (left), female (right)

Uses. Catfish can be cultured in ponds, cages, and raceways. A larger percentage of catfish are produced in earthen ponds. Warm water is needed for good growth, with 27^{o}C to 29^o C being the optimum. Fish will also survive in temperatures as low as 16°C but feeding rate will reduce. All regions of Sub-Saharan Africa are suitable for commercial production of catfish, even in highland regions where temperatures drop during the night. A location with reliable access to clean water is needed to maintain the quality of ponds and to achieve desired growth rates and feed conversion.

Composition. A hatchery typically includes indoor units and outdoor structures, efficient waste management for environmental health, understanding and compliance with biosecurity issues, water storage tanks, hatching/incubating troughs, and water filtration to remove all mineral solids and debris from the water. Other materials include buckets to transport larvae and fry, a water testing kit, rectangular or circular fry tanks, nursery ponds for fingerlings, and pumps for water and air. Hatchery operations require superior broodstock (fertile and healthy), syringes, hormones to induce female broodstock, and knowledgeable and skillful hatchery operators.

Application. Fish farming starts with sourcing quality fry or fingerlings from an improved breed that grows fast and converts feed to flesh more efficiently. Certified hatcheries offer a safe route to increase local supply of fast-growing and hybrid catfish. Producing seed requires selection of fertile broodstock. Females should weigh 1 to 4 kg and be at least one year old.

Female catfish are injected with ovaprim hormone or freshly extracted pituitary can be used to promote egg maturation. Seminal fluid (or milt) is collected from male brooders that weigh 2 to 3 kg which can fertilize eggs from 20 females. Milt incubation in saline water extends its lifespan and ensure that all eggs are fertilized. Stripping eggs from female brooders requires two people to hold the fish and extract eggs mass. Collected eggs can be weighed to forecast the number of fry, each gram contains approximately 600 eggs. Fertilizing eggs is best done in a narrow container, water temperature should be higher than 25°C, and eggs hatch within only 20 and 36 hours. Larvae do not require feeding until three days after hatching because they are feeding on their yolk sacs. Aeration is necessary because fry is very active and require more oxygen. Feed them for 5-8 days with cultured zooplankton or finely powdered shrimp, fishmeal, or special feed. Water quality is very important to managing fish health and monthly antibiotic treatment of ponds can greatly reduce the risk of infection. The pH of water in ponds must be maintained between 6.5 and 9.0, if the pH drops below 6.5 and total alkalinity and hardness below 10 ppm, limestone can be applied to the ponds. A successful farm requires a dissolved oxygen concentrations of 5 ppm or higher. Treat wastewater from ponds before discharge to avoid pollution of local waterways.



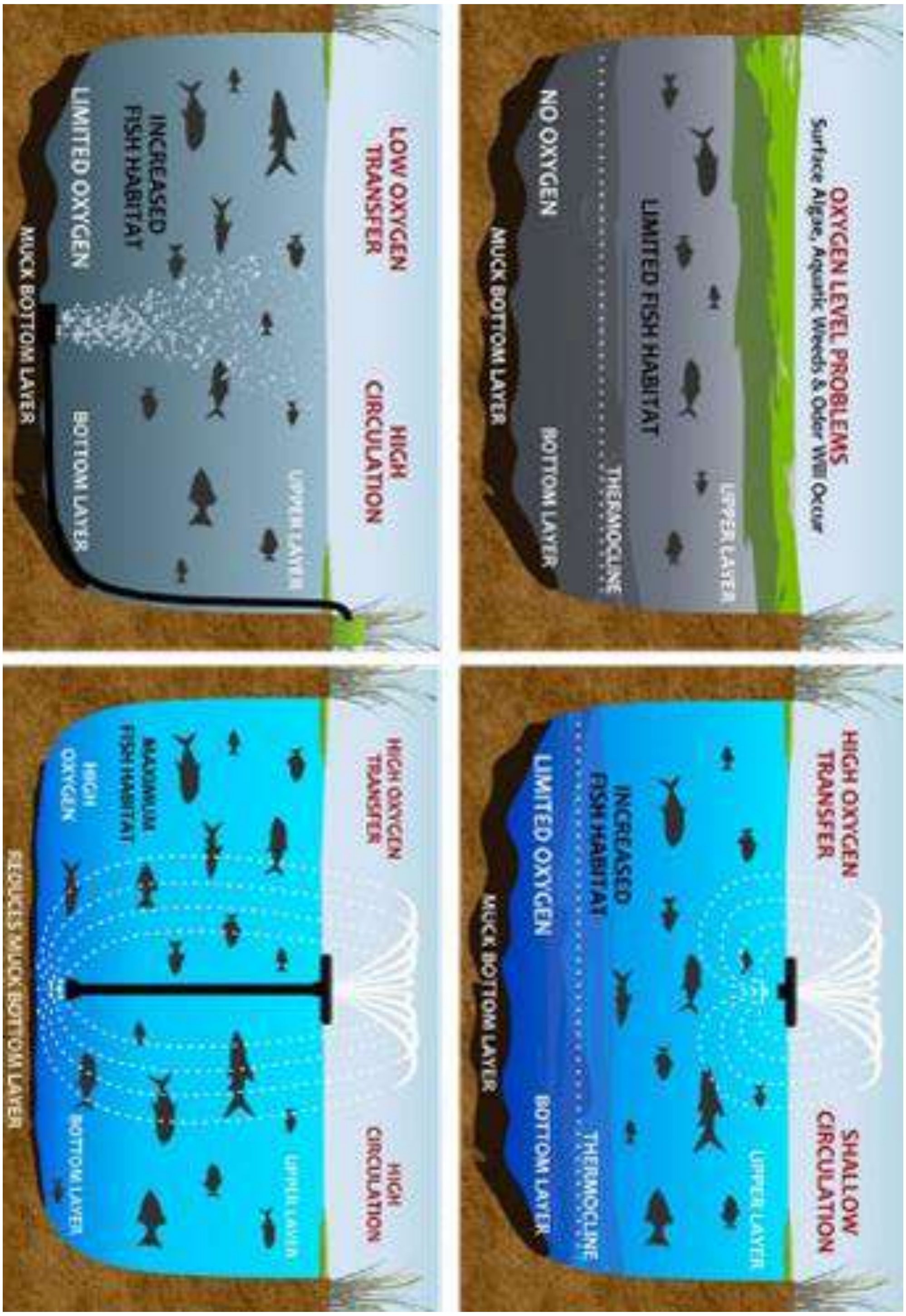
Extraction of pituitary gland from selected fish

Commercialization and Start-up Requirements. Hatcheries in many African countries sell pure and hybrid catfish fingerlings in conjunction with promotional campaigns among fish breeders and fish farmers. The following steps need to be considered before starting catfish hatcheries and farms: 1) Select or construct a pond in an open place free of flooding with direct sunlight, 2) Provide a reliable source of quality water, 3) Purchase matured and fecund improved breed of broodstock or fingerlings and 4) Supply well-balanced feed that is free of aflatoxin and contaminants.

Production Cost. Catfish fingerlings may be produced and marketed for US $0.025 cents per gram and sold for up to US $0.05 cents per gram; with two-month-old juveniles sold for US $0.09. In Kenya, five- to six-week-old fingerlings of common catfish are sold at US $0.12 per individual. At a stocking rate of 600 fish per cubic meter of water, this cost is US $72. Hybrid catfish fingerlings can cost 2-2.5 times more than the non-hybridized breeds. Feed for a one-hectare pond stocked with 8,600 fast-growing catfish is about US $2,500, while feed inputs for 10,000 hybrid catfish are approximately US $3,500, making feed the greatest recurrent production input.

Customer Segmentation and Potential Profitability. There is a diverse customer base for improved breeds of African catfish, including hatcheries and small and commercial producers. Access to fast-growing and hybrid catfish breeds from hatcheries is a major opportunity to increase production and profitability farmers. Hybridized catfish increases the production of farmers by 20% to 30% compared to pure non-hybridized catfish breeds.

Licensing Requirements. In its simplest form, catfish nurseries may be conducted as a cottage industry for the supply of local pond operators based upon the access to Regional Public Goods through WorldFish and the TAAT Program. Within larger, commercial-scale operations, hybrid production relies upon complex arrays of equipment and materials, many of which are protected by patents. In many cases, operations may be streamlined by local ingenuity and materials described elsewhere in this catalogue.

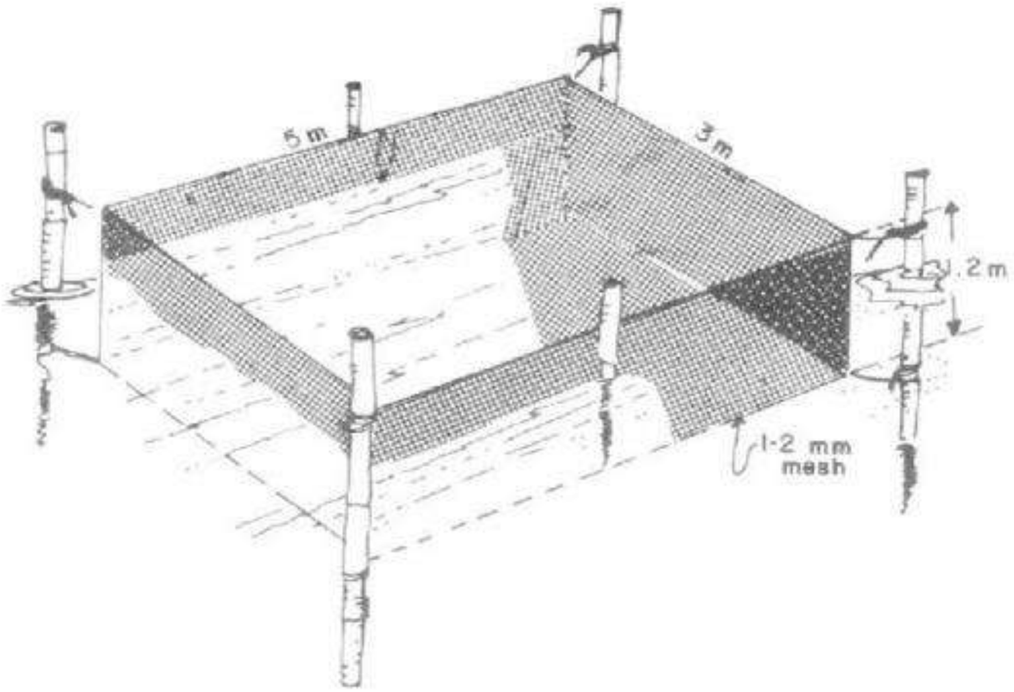


Pond health under different aeration techniques: a) Passive oxygen, b) Surface aerator, c) Bottom diffuser, and d) Surface aerator with draw tube (Credit: WaterSmith Systems)

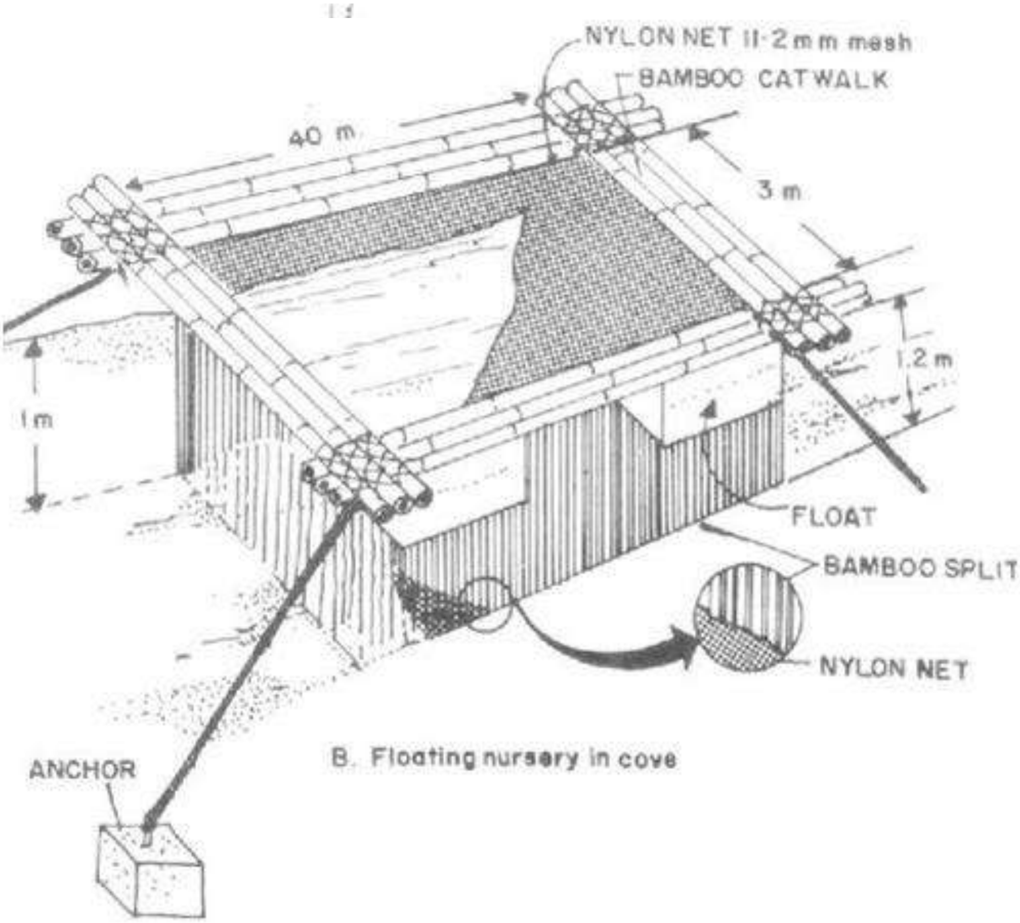
Technology 3. Hapa Nets for Mass Fingerling Hatchery Production

Summary. Inadequate supply of high-grade fingerlings from improved fish breeds is one of the main constraints to the expansion of the aquaculture industry across Sub-Saharan Africa. This situation discourages investments and reduces the viability of aquaculture enterprise. Poor and uneven growth rates, and high fingerling mortality present major limitations in open ponds. Birds such as kingfishers, pelicans and herons, reptiles like lizards, snakes and turtles, amphibians such as frogs and toads, and even aquatic insects like dragonflies can cause massive losses in stocks of young fish. Artisanal and commercial hatcheries must achieve rapid and uniform production of fish stock for reliable supply to the local aquaculture industry, thereby allowing stable returns on investment. Small cage-like enclosures, referred to as "hapa" nets established within a pond are well suited to keeping brooders, hatchlings, and juveniles so they are readily accessible and protected from predators and other fish. Hapa are simple to build with fine mesh screen netting material and wooden poles or floating barrels, making them affordable for any size of hatchery. This technology eases management of the brooder, fry, and fingerlings, as it enables operators to monitor the performance of their stock more closely and adjust breeding, feeding or aeration regimes. Hatcheries can realize higher fertilization rates of eggs, even growth of fish seed and reduced mortality, increasing production of fry and fingerlings per unit area with the right management of hapa enclosures. For more information about the hapa technology please contact Prof. Bernadette Fregene of the TAAT Aquaculture Compact at b.fregene@cgiar.org.

Technical Description. Using hapa is a convenient means of collecting fry from the mouth of a tilapia brooder and rearing fingerlings inside a pond. The stocking density of the hapa affects fish survival, size variation and production rate, so it must be considered when determining the method and profitability of a hatchery. This simple containment system offers large benefits for all male fingerling production through manual sexing, hormonal reversal or YY male technology. However, management of brooders, fry and fingerling in the net enclosure is more demanding compared to traditional open-pond methods. Complete feeding regimes



Design of a fixed hapa sunk into pond bottom are required within the enclosure and must be adjusted during different stages of growth. Severe injury and mortality may occur due to aggressiveness among fish during spawning. Net materials degrade in sunlight and require periodic replacing. Storms, winds, or heavy rainfall can damage structures causing stock to escape. Hapa mesh becomes clogged over time and limits water circulation and aeration unless cleaned. Higher localized feeding can also lead to poor water quality within the net without adequate circulation.



Design of a floating hapa with poles or barrels on pond surface

Uses. Brooders, fry, and fingerlings from all common aquaculture species such as tilapia, catfish, carp, and prawn and crayfish can be stocked in hapa nets. The net enclosures may be installed in earthen ponds, riverbeds, and large concrete tanks, and the shape and size adjusted to the dimension and depth of a water body. In ponds that are fitted with a plastic liner (see Technology 4), there is need of floating types of hapa. Hapa can be set up in ponds that are stocked with other fish without risk of competition. They are suitable for shallow water (less than 1.6 m deep) with low water flow rate and level of fluctuation.

Composition. Various shapes and sizes of hapa are used, most commonly the enclosures measure about 3 m long, 3 m wide, and 1.5 m deep. Hapa are made of wooden poles that are sunk into the bed of the pond and a screen with mesh size of 0.01 mm to 2.5 mm depending on whether fry, fingerlings or fish are inside. Bamboo is ideal for constructing hapa since it is flexible in high wind. Polyethylene material is the most durable and cost-effective for nets. The net is attached to poles with nylon thread and double stitched to prevent splitting. A cover on top of the hapa prevents brood fish from jumping out and prevents birds from attacking the fish inside.

Application. In fingerling production, use of hapa requires periodic scrubbing because the mesh will get clogged, therefore limiting water circulation. It could also result to poor water quality due to accumulation of uneaten feed and fish waste. They are easily cleaned by scrubbing with a brush whilst washing with pond water. Dirty hapa nets can be removed from the pond, soaked with urea for 72 hours, and washed with cleaner and rinsed. Fry production in hapa is normally done with brooders of 300 g average weight at a male to female ratio of 1:2 or 1:3, and stocking density of 4-5 brooders per square meter. Hapa should be inspected for fry every day, which are subsequently transferred into other hapa tanks or rearing ponds. The hatchery operator must record the number of fry and fingerlings that are harvested from individual hapa along with feed input to monitor and achieve high levels of rearing efficiency.

Commercialization and Start-up Requirements. Net material for hapa is available from a broad range of suppliers in African countries. When starting production in hapa, operators of hatcheries must: 1) Determine a good position and size within the pond, 2) Source net materials with the right sized mesh opening, 3) Calculate the optimal stocking density of fish or fry, 4) Ensure supply of high-grade feed at a low cost for fast growth and high profit, and 5) Promote use of cultured fingerlings within the local aquaculture industry.

Production Costs. Installing hapa enclosures inside a pond or waterway is not expensive and does not require highly skilled labour. The materials for a hapa made of bamboo poles and fine mesh net costs about US $1 per square meter with finer meshes costing more. More solid or floating structures are required in less secure waters, thereby increasing this cost.

Customer Segmentation and Potential Profitability. Using hapa for fingerling production is applicable for small-scale and commercial hatcheries. The use of hapa for mass production of fingerlings in ponds allows a higher survival rate. Monthly production of fingerlings in hapa ranges from 150 per square meter to over 900 per square meter. With hapa nets, a single hatchery can supply between 8 and 20 fish farmers, resulting in huge benefits to the local aquaculture industry.

Collection of fingerlings from hapa

Licensing Requirements. The technical knowhow of fingerling production in hapa nets is a Regional Public Good disseminated by WorldFish. Netting must be purchased but other structural materials may be fabricated from local materials.

Technology 4. Pond Liners to Save Water and Ease Maintenance

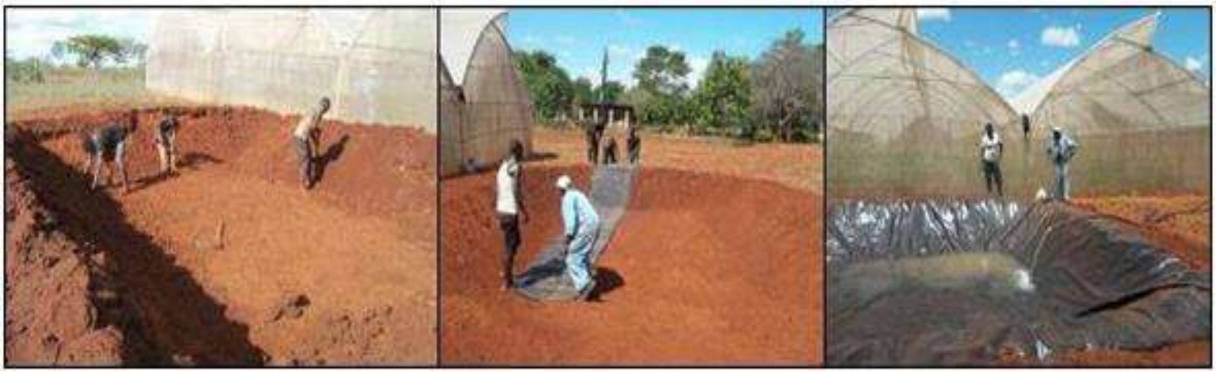
Summary. Sheets of ultra-violet resistant polyvinylchloride, polyethylene or similar materials form an impermeable layer between the water and the soil which decreases water losses through seepage. It also reduces evaporation, improves temperature regulation, helps prevent algal blooms, and promotes nutrient cycling between water and sediment. Many soils require liners to hold water, particularly sands and silts. The technology is easy to install and maintain and is environmentally friendly. Liners are resistant to puncture, UV light, oxidation, and chemical reactions. Quality lining material that is properly installed has a low chance of leakage or breakage, making the technology an affordable solution for small-scale and commercial fish farming. For more information about the technology, contact Prof. Bernadette Fregene of the TAAT Aquaculture Compact at b.fregene@cgiar.org.

Technical Description. Pond lining is an adaptation strategy to preserve water, reduce the spread of pathogens, and realize higher biosecurity. Synthetic "geomembranes" keeps water cleaner and make ponds easier to maintain. Rubber or plastic liner material is affordable for smaller sized fishponds. They may last for more than ten years. Plastic liners for sealing tend to be stiff and more difficult to install in small ponds but they are stronger than rubber liners. Water in fishponds also serve as reservoirs for irrigation as a cushion against drought. Pond liners are most important in areas with sandy soils or locations away from water bodies.

Excavated pond with liner

Uses and Composition. Liners are installed into ponds constructed on flat or gently sloping land. This water conservation technology is most suitable for areas with porous soil and/or poor access to running freshwater. Liners can be fitted into any size or shape of pond. Rubber sheets are more flexible and conform to the contours of pond features quite easily but are not as strong as plastics. Pond liner is available in different types of material including polyvinylchloride (PVC), reinforced polyethylene (RPE), ethylene propylene diene monomer (EPDM) or high-density polyethylene (HDPE). These come in different thickness ranging from 0.5 mm to 3.0 mm which are suitable for different sized ponds and surface roughness. Liners must be stable to exposure from UV light. RPE is usually recommended as it is stronger, lighter, and less expensive than EPDM and HDPE, but stiffer to work with. The PVC is least expensive but less puncture resistant. Under layers of woven polyester or polypropylene may be included as well to offer greater protection from sharp rocks, probing roots and burrowing rodents. High-density polyethylene liners are the most widely available. They are heavy duty, puncture resistant, can be connected into large sheets by "hot wedge welding", flexible and UV stable. They have fish-safe properties and readily conform to pond surfaces. Their density is about 0.94 g/cm^3 and they are nearly pure, with small amounts of carbon black added for UV protection and antioxidants added to increase durability. They are available in thicknesses from 0.5 to 1 mm, with thinner widths suitable for smaller ponds without stones and thicker widths needed for larger projects and stony conditions. An internet search for suppliers of pond liners in Africa revealed hundreds of suppliers.

Application. The amount of liner required depends upon the dimensions of the pond, its intended volume, and the slope of its walls. One can use a simplified formula: Volume = (d/6) x (A_t + A_b + 4 A_m), where V is volume, d is depth, A_t is the area on top, A_b is the area at the bottom, and A_m is the area at half the depth. An extra 50 cm must be added where sheets are overlapped to ensure watertight seals. For seaming two sheets, clean a strip of 25 cm along both edges with rubbing alcohol so the adhesives bond well, then apply primer in a 15 cm strip along the top of one piece of liner and lastly glue the two sheets with double-sided tape. Polyethylene may be heat sealed as well. Remove shoes when stepping on the liner to prevent it from getting pierced. When filling the pond with water, pull and tuck the liner into shape to ensure a neat finish.



Establishing a small fishpond (left to right): 1) excavating and smoothing the pond, 2) spreading the PCV liner and burying the edges, and 3) filling the pond

Commercialization and Start-up Requirements. Pond liners are being marketed by aquaculture supply companies in all Sub-Saharan countries, yet availability from local retailers is limited in many locations. Based upon the expansion of aquaculture in Africa, the pond liner industry is expected to exhibit a strong growth rate over the next decade.

Production Costs. Plastic lining materials are less expensive than rubber. Through local suppliers, the cost of sheet plastic is about US $2 per square meter for a thickness of 0.5 mm and increases to US $3.50 for a 1 mm thickness. A plastic liner of 0.5 mm together with sealing and installation for a pond of 15 m long, 10 m wide and 1 m deep is about US $500. Sealing the bed of a pond to save on costs of construction and water supply is money well spent.

Customer Segmentation and Potential Profitability. Pond lining tends to be sold more by hardware suppliers than agrodealers, and is offered as rolls alongside similar construction materials, and tend to be limited within any given location. In some cases, farm engineering companies offer full lines of products, including those with textured surfaces. Lining a pond with a rubber sheet can decrease water loss through seepage and evaporation up to 50%, making it applicable to both smaller and large commercial operations. A comparative analysis of 700 fish farmers in south-western Nigeria that accounted for costs of stock, feed, water, utilities, and maintenance showed that ponds with plastic liners offer significantly greater net profits than unsealed earthen ponds.

Licensing Requirements. Pond liners are commercial products, and the different materials are protected by patents and trade secrets. One of those secrets relates to the form of trace addition to antioxidants that increase product durability.

Technology 5. Tank and Cage Systems for Fish Culturing

Summary. Tanks are enclosures placed on land to culture fish that are suitable for intensive production near urban centers with high market demand. Tank culture is a preferred alternative to ponds if limited amounts of water or land is available and the economics are favorable. Cage culture production involves growing of fish inside floating netted containers that are suspended within larger waterbodies. These cages require a comparatively low capital investment if locally produced. Cages also serve to clean waters through feeding activities. More information about these specialized fish farming technologies can be obtained from Prof. Bernadette Fregene of the TAAT Aquaculture Compact at b.fregene@cgiar.org.

Technical Description. Tanks should be constructed where there is year-round availability of quality water. Fish farming in tanks requires a complete feed diet with proteins, vitamins, and minerals as there is little to no natural foods available within the system. For cage culture, choosing the right location has a major influence on the economic viability of the operation. Inappropriate positioning of cages may cause poor fish growth, high mortality, and conflict with other water users. Feeding regimes for extensive cage culture rely upon natural foods and detritus, benthos, whereas more intensive culture also supplies fish feed.

Uses. Concrete tanks are best for rearing species such as catfish that can be farmed at high stocking density. Tilapia species can also grow well at high densities in tanks when excellent water quality is maintained. Extensive cage culture without additional feeding is better suited for microphagous tilapia species, such as *Oreochromis niloticus*, *O. mossambicus* and *O. aureus*; more than the macrophagous tilapia species, *Coptodon zilli* and *C. rendalli*. Flexible open cage systems are affected by the water flow that at higher velocities causes horizontal drag on the net and may reduce its volume. Suitable current speeds inside cages range from 0.1 m/s to 1 m/s for different aquaculture species.

A concrete tank for raising catfish

Composition. Fish farming tanks are made of concrete, wood, plastic, fiberglass, or steel in a variety of shapes, but the most common forms are circular and rectangular tanks. Different types of water and air supply systems can be used in tanks, including flow-through and recirculation (see Technology 6). There are four basic types of cages: fixed cages, floating cages, submerged cages, and submersible cages. Cage frames are built with floatable pipes or barrels made from high density polyethylene, galvanized iron, or PVC plastic. Usually, a 1 to 2 inch (2.5-5 cm) nylon net is mounted on the cage frame to hold fish. Finer mesh sizes contain smaller fish but decrease flow inside the cage and increase horizontal drag because of water flow, which poses risk of damage under high current.

Application. For catfish in tanks, 25-gram fingerling can be stocked at 1,500 fish per cubic meter to produce 50- to 60-gram harvests within 5 weeks, or at 1,000 fish per cubic meter to produce 100-gram fish in 9 to 10 weeks. To minimize mortality by cannibalism in tanks or cages, the stock must be sorted every two weeks, and faster maturing individuals removed. In tanks and cage systems it is important to remove uneaten feed or feces that accumulates underneath, avoiding proliferation of parasites and diseases. Adequate space below the cage (at least 3 m) ensures adequate water circulation through the cage and minimizes unwanted accumulation beneath.

Floating cage for tilapia farming inside Lake Victoria
(Credit: Erick Ochieng Ogello)

Commercialization and Start-up Requirements. Both tanks and cages are commercially available or can be easily constructed. Key factors to be considered for tanks: 1) Secure access to a reliable source of water, and 2) Choose the appropriate type and size of tank with respect to that water supply system (see Technology 6). Key factors for starting up cage culture are: 1) The water surface area should be at least 0.2 ha, 2) Nearby lands should be free of water erosion and waters should not contain weedy aquatic vegetation for preventing oxygen depletion, 3) At least 5m from lowest water level for floating cages. Less than 5m can be used for fixed cages 4) The depth of water column should allow a free space of about 4-5 meters between the bottom of the cage and bottom of the water body during minimum recorded water level for floating cages. However, this space should not be less than 2 meters, and 5) The location should have adequate prevailing winds to prevent water stagnation. Tank and cage farming systems require high quality fry or fingerlings from improved breeds to achieve desired production rate and feed conversion (see Technologies 1, 2 and 3).

Production Costs. The price involved with constructing tanks and cages depends on the size and materials used. Premade suspended tanks made of metal frames and polyethylene with a volume of 2000 liter may be purchased in China for as low as US $120. Concrete tanks are more expensive but are last longer. Epoxy-coated galvanized iron frames are a lower cost option but suitable for small-scale production. A fish cage of 8 cubic meter with galvanized steel and floating barrels that are locally manufactured costs as little as US $150 depending on the mesh size of the netting.

Customer Segmentation and Potential Profitability. Cages are more feasible for fishermen that can access waterbodies and have rights to their waters. Tanks are available to all fish farmers. A concrete pond measuring 3 by 4 meters and 0.85 meter deep with a stocking rate of 50 fish per square meter and best management practices can harvest up to half of a ton (500 kg) of fish every 9 months. A floating cage of 8 cubic meter with 1,000 fish raises about US $1,500 per harvest and has a gross margin of US $330 after deducting costs for cage construction, feed, and labor.

A low-cost polyethylene fish tank with metal frame

Licensing Requirements. Specific national laws governing the use of public waters guide cage site location. Information on tank and cage construction is a Regional Public Good advanced by WorldFish.

Technology 6. Flow-Through and Recirculatory Water Systems in Tanks

Summary. A recirculatory aquaculture system is a technology where water is recycled after filtration to remove suspended matter. This method is used for higher density culture of fish, allowing for maximum use of limited land and water. Water movement into and out of the tank maintains peak water quality conditions despite dense stocking rates. As water passes into the tank it provides oxygen and when it leaves it carries away waste products. Intensive aquaculture in tanks that operate at high stocking densities is furnished with a flow-through system that discharges water, cleans water, and pumps it back through the system. Tanks with a conventional flow-through systems are simpler in design but require an affordable and reliable source of quality water that can be used with minimal pre-treatment. Recirculatory systems are more complex and costly to install but have higher water use efficiency, higher feed conversion, and more exact disease control. For more information about these water flow systems, contact Prof. Bernadette Fregene from WorldFish and leader of the TAAT Aquaculture Compact by email at b.fregene@cgiar.org.

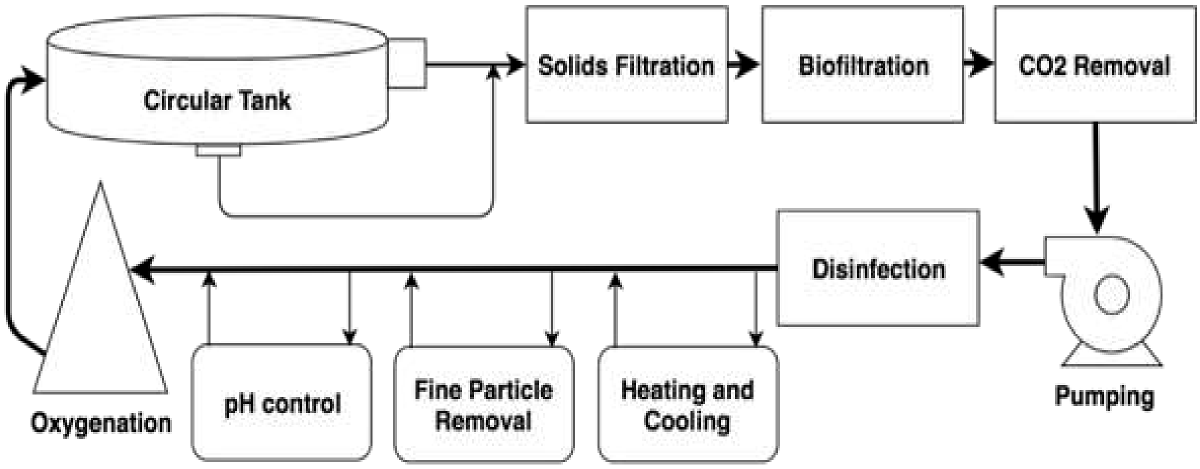
Technical Description. For successful fish farming in tanks, the water must have the required oxygen level and temperature for the cultured species. Tank volume and water flow determine the turnover rate, and the required time to replace the entire volume of a unit. Turnover rate is specific to the species being reared and their rearing density, but one turnover per hour is a good place to start for many species. Water passing through tanks simulates a current that can be adjusted by changing the position and direction of water flow. Fish should not struggle against this current, but rather be able to remain stationary with gentle movement. In a recirculatory system, water filtration is continuous, keeping the tank clean and providing a healthier environment for the fish. Waste products are either removed or converted into non-toxic products that can be used for cultivating crops (see Technology 9). The purified water is then re-saturated with oxygen and returned to the fish tanks.

Flow-through tanks with single use of water

Uses and Composition. Flow-through and recirculatory systems can be fitted to rectangular or circular tanks made of plastic, galvanized steel, or reinforced concrete. For both technologies, water pumps and flow meters are needed, with further sets of filtration and conditioning units for recirculating tanks. A settling pond is usually placed before water reaches the tanks to remove high loads of sediment and algae. The most suitable location for a flow-through system is where there is reliable water availability from a river or lake, but limited access to electricity. In contrast, the best option for recirculating tanks is near cities with lower-cost and more reliable electricity but where temperatures are sufficiently high to avoid the need of heating.

Application. Setups of flow-through or recirculatory systems are determined by the water inflow and outflow rates, the tank shape and size, the water depth, the wall roughness, the inlet devices, and the presence of elements inside the tank. Circular tank designs have more stable flow patterns, a more homogeneous distribution of dissolved oxygen and metabolites and better self-cleaning features but are ultimately less space efficient than rectangular tanks. In a flow-through system valves are usually operated manually, and the visible turbidity of water direct the turnover in tanks. In recirculating systems, constant fish respiration can raise carbon dioxide levels high enough to interfere with oxygen levels and lower the pH of the water, thus requiring a buffering system. A series of components can be fitted before the tank inlet to regulate water temperature, oxygenation, and nutrient level.

Commercialization and Start-up Requirements. Equipment to build and operate flow-through and recirculatory systems for fish tanks is marketed by suppliers in most fish farming areas across Sub-Saharan Africa. The main steps toward adopting the technology are: 1) Choose the most suitable water management for tanks based on farm setting and investment needs, 2) Acquire skills to install and operate the equipment under optimal conditions, and 3) Test the water quality at the point of source and discharge to establish pre- and post-treatment needs.



Schematic diagram of a recirculatory system

Production Costs. A flow-through tank with a fixed volume of 200 liter requires 800 liter of water per hour, equivalent to a turnover rate of four. For a tank of 130 m^3 the approximate cost of the recirculation pumping and piping is US $22,000 and the mechanical, physical, biological and chemical treatment is US $44,000. Costs of water supply and treatment are hugely influenced by the position and type of drainage. The charges of contractors to build a settling pond are US $1.5 to $5 per square meter for different soil types and lining materials (see Technology 4).

Customer Segmentation and Potential Profitability. The improvements in controlling water quality by flow-through and recirculatory systems directly reduce mortality rates, disease control, and feed inputs. In Nigeria, grow-out tanks for tilapia with a flow-through system have been found to break even on fixed and variable costs in the first production cycle, with incremental profits in subsequent cycles. Recirculatory systems need to be implemented at a large scale and with high value freshwater fish such as trout or Nile tilapia to offset capital costs and be financially sustainable.

Licensing Requirements. Sophisticated recirculatory water filtration systems require commercially available equipment that is protected by patents. Information on these systems is a Regional Public Good advanced by WorldFish and available from the TAAT Program.

Technology 7. In-Pond Raceway Systems

Summary. An in-pond raceway system is a sophisticated aquaculture technology where optimal water chemistry is ensured by maintaining interrupted water flow and waste disposal management, allowing for a high density of fish stocking. Traditional fish farming is land and labor intensive. For instance, catfish farming in static ponds typically yields only 4,500 to 5,500 kg ha^{-1}. Production is more efficient and profitable with techniques that maintain optimal water quality, in particular oxygenation and feed management. An in-pond raceway system (IPRS) is an inland aquaculture method where fish are kept in channels constructed within the pond and provided with constant water circulation. This allows fish farmers to use stocking densities as high as 150 kg per cubic meter, and thereby increase production levels and efficiency. The IPRS recreate the fish's natural environment making them grow out at a faster rate and keeping them free of diseases and stress. The advantage of this fish farming method is that higher quality fish can be produced in less water and through more efficient feed conversion. In comparison to traditional ponds the IPRS technology has been found to produce 200-300% more fish. More information about this modern aquaculture technology can be obtained by email from Dr. Ahmed Nasr-Allah at a.allah@cgiar.org and Prof. Bernadette Fregene at b.fregene@cgiar.org.

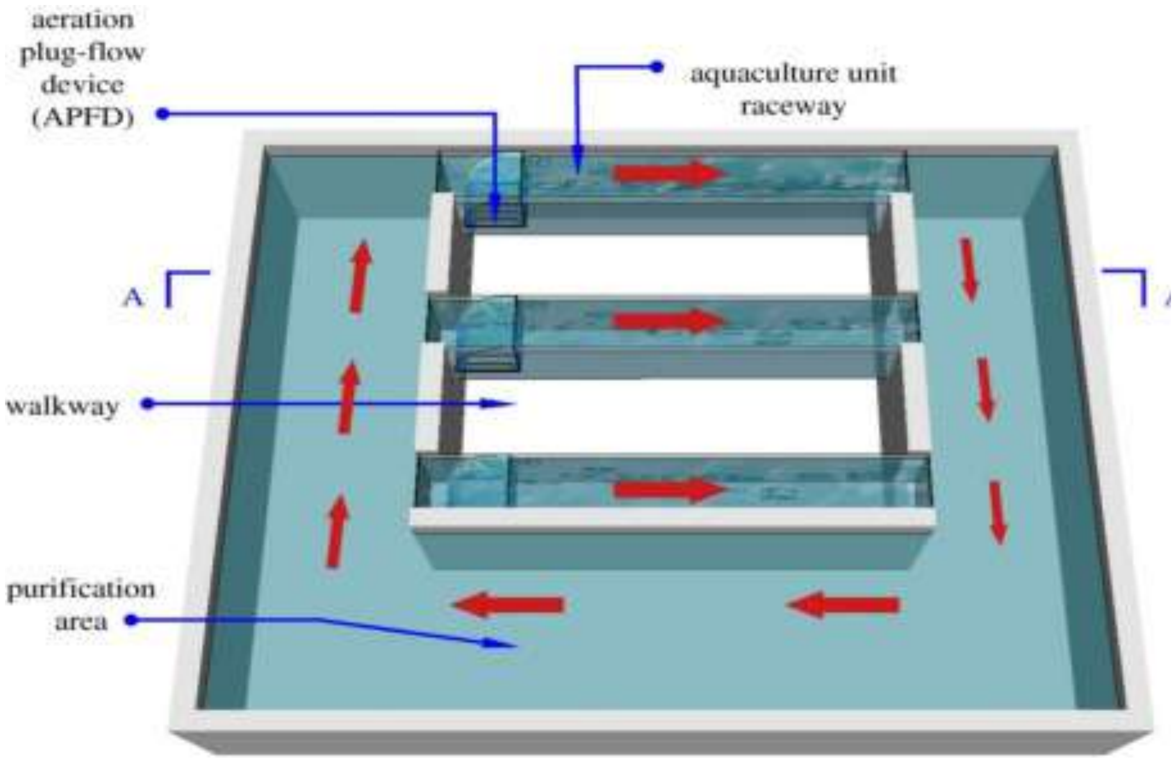


Diagram of an IPRS with aeration plug-flow device for control over water flow and quality (Source: Li et al. 2019)

Technical Description. Water flow is a very important factor in aquaculture production as it stimulates the growth of fish in response to velocity distribution and turbulence. Turbulence has a critical role in the transport and dispersal of excreta, nutrients, and pollutants. Another critical factor is dissolved oxygen of the pond water that must be greater than 5 mg per liter for fish to be active, behave normally, respond to feed, and avoid mass mortality. The IPRS intensify production by concentrating fish in less water volume. Airlifts or paddle wheels are used to create water flow inside the raceway channel to remove fish waste at a low energy cost. Fish waste is collected and sucked out of the water body. Continuous forced aeration is required in the system to supply fish with high levels of dissolved oxygen which further assists in their growth. Unused water serves as biological filter and is recirculated to the production area by a pump. The IPRS technology offer multiple benefits for farmers, markets, and the environment: higher fish production per cubic meter, lower cost per unit of fish, greater feed conversion ratios and feeding efficiency, more effective fish health management and pond maintenance, sustainable use of water resources and zero discharge to local rivers or the environment. The controlled environment of an IPRS assists fish farmers to better adhere to food safety and discharge standards.

Uses. Raceways have several advantages compared to ponds. Raceway production is much higher per unit volume and offer a much greater ability to observe fish; making feeding more efficient and disease problems easier to detect. Raceways also allow better inventory estimates than ponds, making size grading and harvesting less difficult. The disadvantages of raceways are related to their need for large flows of high-quality water, an asset not widely available. Another limitation is related to release of effluent because there is little or no retention time allowing for natural processes. In-pond raceway systems are suitable for intensive aquaculture practice in regions with high water availability and limited land resources. The technology is best deployed in medium- to large-scale fish farms near urban centers or trade corridors because of its sophisticated engineering. A large variety of fish can be stocked and grown efficiently including freshwater species such as catfish, trout, tilapia, perch, and bass. Rectangular raceways are most used, while circular units are best for broodstock production because they have more thorough circulation but make less efficient use of available floor space.

Composition. Raceways are made of three main components: an aeration area, a fish culture area, and purification area. One or more high-power pumps are used to pump water through the culture channels, forcing the water to flow through the raceways and into the purification area, thereby circulating it and forming a pathway for fish. The flow patterns in the original aquaculture raceways offer uniform velocity, causing water quality and dissolved oxygen to vary significantly from inlet to outlet. Improved aeration systems are available such as the plug-flow device that consists of a curved baffle and a set of micro-bubble tubes. It is positioned at the inlet of the raceway and the micro-bubble tubes are submerged at a specific depth, so that air is pumped into the tubes and floating bubbles are formed. A baffle curtain made of woven plastic fiber can be installed diagonally inside the pond to direct how the water flow circulates.

Application. For a channel that is 4.9 m wide and 1.7 m deep, a paddlewheel with a water movement of 0.026 m per second generates a flow rate of 9 m^3 per minute and full turnover every 5 minutes or 12 turnovers per hour. Typically, the greatest water velocities occur at mid-depth, with slightly reduced velocities at the air-water interface and greatly reduced velocities along the raceway bottom. Fitting improved aeration like the plug-flow device in an IPRS improves water recirculation and adds dissolved oxygen to the aquaculture pond. Average daily feed rates for catfish production in an IPRS range from 70 to 90 kg ha^{-1}, and maximum daily feed rates go up to 300 to 350 kg ha^{-1} when fish weigh more than 0.5 kg. The growth rate of Channel catfish in this system reaches 1.8 g per day with feed conversion ratios of about 1.7:1. This efficiency is greater than that achievable in a conventional pond.

Commercialization and Start-up Requirements. Few engineering and contracting companies in Africa are building IPRS, but the technology represents a viable opportunity for business expansion. The TAAT Aquaculture Compact adopted this technology for tilapia production in Kenya through a partnership with the Aquacultural Association of Kenya (AAK) and a demonstration center near Nairobi. Owners of fish farms wanting to install IPR systems for intensive production need to take the following steps: 1) Identify design and size of raceway that matches available capital and production objectives, 2) Provide access to a high-quality water source and supply of affordable electricity for constant flow, and 3) Train staff on operation and maintenance to minimize energy and feed cost.

A network of parallel raceways (left) and red tilapia in an intensively managed raceway (right, credit: Global Seafood Alliance)

Production Costs. The cost of building an IPRS varies depending on the size and the materials used. A reinforced concrete raceway of 5 m long, 1.2 m wide and 1.2 m deep costs about US $ 4,000. If constructed properly, an IPRS should have a life of 5 to 10 years. Culturing catfish with an IPRS over an 8-month period in the US has total variable costs of US $1.57 kg^{-1}, and fixed costs of US $0.31 per kilogram. Similarly, red tilapia produced in an intensively managed runway grew from 48 g to 473 g per fish after 71 days, resulting in an overall return on investment of 1.49. In Mexico, tilapia raised in an area of 875 m^2 produced a harvest of 47,139 kg with an average fingerling survival of 78.2 percent and feed conversion ratio of 1.36. Despite their higher initial investment, IPRS have a lower break-even variable cost point per harvest as compared to traditional static ponds because of higher labor efficiency and feed conversion ratio.

Customer Segmentation and Potential Profitability. IPRS technology is primarily for commercial fish production because of the needed investment and technical expertise. Fish farmers dependent upon IPRS technology may achieve a 30% increase in profit margin while at the same time practicing water conservation. Building concrete enclosures and maintenance of the pumps and filters offer opportunities to equipment suppliers, engineering firms and local contractors. The system is climate smart in terms of land, water, and feed efficiencies, leading to multiple benefits to diverse actors.

Licensing Requirements. Technical support for IPRS requires commercially available equipment that may be protected by patents, including pumps, filters, and aerators. Information on the design of these systems is a Regional Public Good advanced by WorldFish and available from the TAAT Program.

Technology 8. Formulation and Pelleting of Low-Cost Feeds

Summary. Aquaculture production in Sub-Saharan Africa is constrained by the high price of suitable fish feeds. Between 60% and 70% of operating expenses by fish farmers go to feed input because their ingredients are either imported or blended overseas. For this reason, formulation, and manufacturing of affordable fish feed in Africa is an integral part of creating more profitable fish farming business. Feed producers need to understand which ingredients and processes provide expected results to fish producers. Supply of low-cost fish feed can be promoted by the combination of locally grown crop and animal products and through the application of available extrusion and pelleting technologies. Compared to simple ingredients such as unprocessed grains, pelleted fish feed is more stable in water, improving nutrient transfer and reducing pollution. Pellets are also easier to store, package and transport, and their buoyancy can be crafted to suit the feeding requirements of different species. Pelleting has a modest investment requirement that provides quick returns, making it an attractive business venture. For more details about low-cost feed production contact Dr. Yossa Rodrigue of WorldFish by email at r.yossa@cgiar.org.

Fish feed production line (left to right): hammer mill, vertical mixer, extruder, and dryer

Technical Description. A nutritionally balanced and adequate diet are important factors that maximize fish production and profitability, particularly as fish production systems intensify. The main objectives of formulations for aquaculture are to meet dietary requirements, particularly the relatively high need for crude protein, to minimize production and delivery costs, and reduce waste and pollution in ponds. Judicious selection of feed ingredients based on availability, price, and the quality of the nutrients is key in the process. Pelleted feeds can be manufactured through two processing technologies: dry-type extrusion which operates on friction to generate heat, and wet-type extrusion which utilizes drying as a binding process. State-of the-art extrusion combines raw materials under conditions of high temperature, moisture and pressure that results in partial gelatinization and deactivation of anti-nutritional elements. It also sterilizes pathogens, increases digestibility, and shapes pellets into different sizes. The buoyancy and stability of pellets in water allows producers to better monitor and regulate feeding behaviors. In this way, fish feed production presents challenging business opportunities.

Uses. Pelleted feeds are suitable for all types of farmed fish and are customized to match different species and their growth stages. Specific formulations are recommended for omnivorous species like tilapia, carp and trout, and carnivorous species like catfish and perch. Feeding habits are matched to feed properties: floating pellets are used for surface feeders like tilapia and carp and sinking pellets for bottom feeders like catfish and perch. Temperatures, moisture, and pressure in the extrusion process further adjust feed properties.

Composition. Feed formulations are composed of ground ingredients in varying proportions to meet nutritional requirements of a particular fish. The common raw materials for omnivorous tilapia include wheat bran, soybean cake, fish meal and maize. For carnivorous catfish, the main ingredients are soybean meal, fish meal, rice, wheat bran and bone meal. When feedstuffs for the desired nutrient composition have been selected, they can be prepared through a process of milling, mixing, and pelleting. Oil may be added to improve buoyancy for floating feed.

The dry matter, crude protein, and fiber contents of several common feedstock ingredients in tropical climates are presented in the table below. Comments are also provided to guide formulation including the maximum content within feed rations. Note that ingredients are of both animal and plant origin and those materials from animals and legumes have the higher crude protein contents. Blood meal and feather meal have the highest protein contents, but these are added at lower levels to reduce anti-nutritional factors. Earthworms tend to be applied as supplemental feeds produced through vermiculture. Soybean meal and fish meal are the most common protein sources, and these soybeans are best cooked to reduce their anti-nutritive properties. Prawn meal, the carapace, and shells of crustaceans, stimulate feeding response in addition to being moderately high in protein. The remaining materials provide energy and other properties including binding of pellets and floatation. Addition of a commercial vitamin/mineral mix at low concentrations is also recommended. Formulations may be relatively simple (e.g., with 3 or 4 ingredients) or complex depending upon the

Some common ingredients used in fish feeds

Ingredients	Dry matter	Crude protein	Crude fiber	Comment
	-------------	%	-------------	
Blood meal	91	85	7	use up to 5% ration
Feather meal	93	85	3	improves floatation
Earthworms	17	49	1	supplement in fresh form
Soybean meal	92	48	7	major protein source
Groundnut cake	92	45	11	use up to 15% ration
Fish meal	94	42	6	major protein source
Prawn shell waste	94	32	23	stimulates feeding
Cottonseed cake	92	26	21	use up to 15% ration
Brewery grain waste	91	26	16	use up to 15% ration
Coconut meal	81	19	45	high energy content
Rice bran	92	13	14	use up to 5% ration
Wheat bran	91	12	11	aids in binding
Vitamin/mineral mix	81	10	0	use from 0.5% to 1%
Maize meal	91	9	2	energy source, binding agent

availability and cost of various feedstock. A reliable feed for fish production contains about 30% crude protein. This level may be achieved through the combination of similar ingredients in different ways. Blend 1 relies upon fish meal and soybean meal, with maize and bran used as energy sources and binders. Blend 2 replaces blood meal with some fish meal and soybean meal. Blend 3 replaces brewery waste with some fish meal. Blend 4 restricts its animal-based ingredients through greater reliance upon soybean. Groundnut cake may replace soybean meal as needed. Addition of prawn waste greatly stimulates feeding response, particularly for blends containing greater proportion of plant ingredients. Buoyancy is an important trait of fish pellets, and ingredients with more fiber and oil tend to float longer. Note that some ingredients bind pellets, sealing them against too rapid water infiltration and these properties are enhanced by extrusion and drying. Fish at different stages of development require different crude protein contents to maintain rapid growth. Fry require 40% to 50% crude protein, and in some cases are fed pure fishmeal. The accompanying Table shows a formulation of 80% fish meal that also contains wheat bran, soybean, and maize meal. Fingerlings require about 34% crude protein, allowing for the use of less expensive ingredients. An "Easy" formulation useful in pond production of larger fish consists of 22% fishmeal and 78% broiler feed. Formulate fish feed is based upon the size of the fish. Feeds ranging in size from 0.5 mm to 8 mm are available. Feed for fry is about 0.5 mm in size, pellets for fingerlings are about 1.6 mm and those for larger fishes are from 4 mm to 8 mm. In general, feed pellets should be 25% to 50% of the width of a fish's mouth. The weight of the fish determines the amount of feed required. There is an advantage in producing your own feed and using them more efficiently because purchased fish feed is expensive.

Formulation of different fish feeds

Fish Feed Design	Blend 1	Blend 2	Blend 3	Blend 4
Crude protein	30%	30%	30%	31%
Ingredients	------------	**content (%)**	------------	
Fish meal	40%	35%	30%	3%
Blood meal	0%	5%	0%	3%
Brewery waste	0%	0%	15%	3%
Soybean meal	20%	15%	20%	46%
Maize meal	30%	30%	20%	35%
Rice or wheat bran	10%	15%	15%	10%
Total	**100%**	**100%**	**100%**	**100%**

Fish feed types for different stages of fish development

Stage	Fry	Fingerling	Adult/ Broodstock
Crude protein	40%	34%	28%
Ingredients	-------------	**content (%)**	-------------
Fish meal	80%	20%	22%
Soybean meal	12%	46%	0%
Maize meal	4%	24%	0%
Rice or wheat bran	4%	10%	0%
Broiler feed	0%	0%	78%
Total	**100%**	**100%**	**100%**

Application. The most important consideration in manufacturing pelleted fish feeds is the use of quality feed ingredients that are locally sourced and competitively priced. In feed formulation, the upper limits of toxins and lower limits of substances that influence palatability and water stability must be considered. The first step in the production process is grinding raw materials with a hammer mill into a fine powder. Smaller particle sizes have greater digestibility, cohesiveness, and water stability. Materials should be sun or oven dried before grinding. Different ingredients must have a uniform size. The second step in the process is mixing the ingredients and can be homogenized by hand to form a mash before wet extrusion. A mechanical mixer can be used for large-scale feed production. If cereals in the formula are not adequate to bind the particles of the feed mixture, cassava starch or a similar product can be added as a binder. Just before extrusion, the raw materials are moistened so that they adhere. Wet-type steam pelletizers gelatinize starch which further improves nutritional value and lubricates the materials for faster processing, lowering costs and extending machine life. For most adult fish, the diameter of pellets should be at least 4 millimeters. After pelleting, when possible, the pellets should be dried in an oven rather than in the sun to avoid deterioration of fatty acids. Following drying, pellets are screened, and the fines collected for feeding fingerlings. Final products are packed in water impermeable bags to prevent mold and insects. Wastewater and solid waste from fish feed factories must be treated in accordance with environmental regulations.

Feed formulation before (left) and after dry extrusion (right)

Commercialization and Start-up Requirements. Localized manufacturing of pelleted fish feed represents a viable enterprise opportunity in support of fish production. Steps to enter feed manufacturing include: 1) Organize continuous supply of low-cost raw ingredients, 2) Locate production site conveniently close to fish farms and transportation corridors, 3) Procure and install appropriate, serviceable equipment, 4) Provide sanitary packaging and storage of feed, 5) Market feed products to fish farmers, agro-dealers, extension agents, and when possible 6) Pre-arrange contracts with fish farms at a profitable and competitive price.

Production Costs. Raw ingredients account for 60% to 70% of the total cost. The principle of choosing raw materials for fish feed is to select the lowest cost material that meets the required nutrient composition. Note that localized cost of ingredients for pelleted feeds can be reduced by utilizing waste from fish markets and landing centers. Other costs for manufacturing fish feed are the purchase and maintenance of equipment, training and payment of skilled labor, and supply of utilities. Manufacturing fish feed with a motorized pelletizer is slightly more expensive than the use of a manual pelletizer because it requires more advanced equipment and a power supply. A fully automated line consisting of a vertical mixer, double screw extruder, dryer, and flavoring machine with conveyors and hoisters with a capacity of 120-150 kg per hour costs about US $18,000 excluding shipment and taxes. The equipment setup for a production capacity of 4 to 5 ton per hour costs about US $85,000. The use of pelleted diets for catfish culturing in Kenya has demonstrated to achieve a better feed conversion and growth rate, and higher net return compared to the same formulation of non-pelletized feeds. High-quality pellets can fatten stocks quickly for sales on local fresh markets for whole fish or processed products.

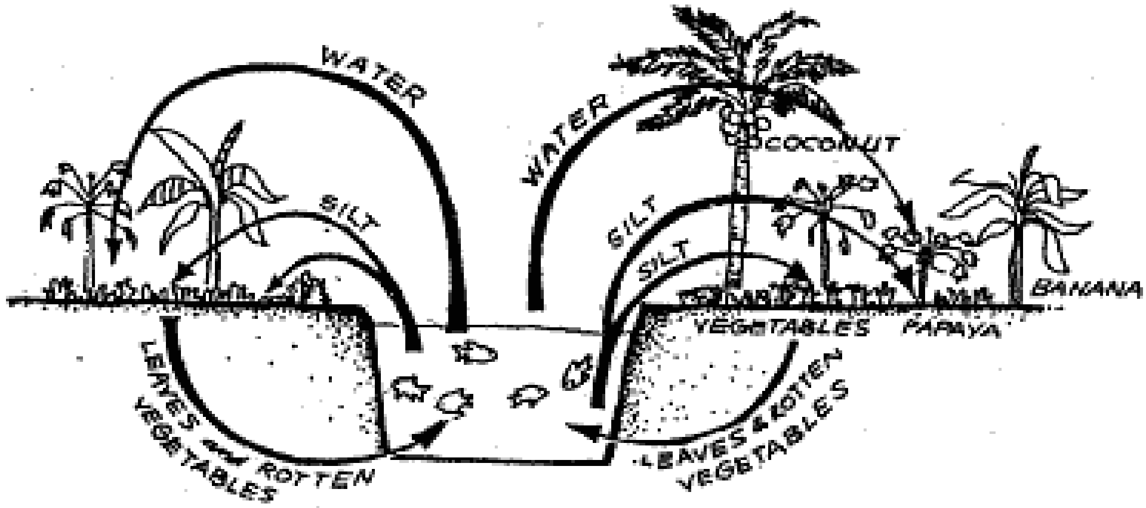
Customer Segmentation and Potential Profitability. The manufacturing of fish feed pellets with locally sourced ingredients and automated equipment is relevant for privately owned or community-based enterprises. Companies that supply, engineer, and build feed production lines need to maintain close contacts with local producers, distributors, and government agencies for delivering services that match market conditions. Generally, the total cost of producing and marketing pelleted fish feed is around US $1,200 per ton which can then be sold for up to US $1,500, suggesting low profit margins but high sales volumes. Fish feeds can be profitably retailed by agro-dealers and at local markets servicing fish producers.

Five common fish feed ingredients: maize meal (upper left), fish meal (upper middle), rice brain (upper right), wheat bran (lower left) and soybean meal (lower middle)

Licensing Requirements. Food safety audits and certifications are required to manufacture and sell fish feeds in many African countries that are required for regular testing of nutritional value and the presence of pollutants. Knowhow for feed production is readily available as a Regional Public Good provided by WorldFish across Africa.

Technology 9. Integrated Aquaculture and Agriculture Systems

Summary. Integrated aquaculture involves linking two or more farming activities where at least one is related to fish-farming. This integration offers opportunity through interlocking production systems and recycle of farm waste, which provides households with additional protein. The basic principle of aquaculture and agriculture integration entails that water and sediment from the pond goes onto the crop for irrigation and fertilization, and that crop residue wastes go to the pond for feeding fish. Linking both systems allows fish to be cultured with less purchased feed and for crop yields to be increased with fewer external inputs. The most commonly combined crops are rice, other wetland crops, and vegetables. Crops irrigated with pond effluent yield more than those irrigated with water alone. In this way small-scale and commercial farm enterprises can make their production systems more productive, diverse, and profitable. Further information on fish-crop integration is available from Prof. Bernadette Fregene by email at b.fregene@cgiar.org.



Concept of integrated fish and crop production (Source: FAO)

Technical Description. Placing fishponds or tanks near croplands or greenhouses makes it possible to double up on the use of their water and nutrients. Traditional pond or tank systems can be combined with open-field cropping practices or more complex aquaponics systems where plants are cultivated in pond effluent. Integrated systems can also circulate water between fish enclosures and irrigated crop beds. On the one hand, excreta from fish in the water is converted into nutrients that fertilize plants and on the other hand, biomass waste and excess nutrients from crops provide nourishment for fish. When properly established, this interchange saves on the cost of feed, fertilizer and irrigation water while producing more per input investment and land area. Rice paddy fisheries either rely upon the migration of wild fish from rivers and channels or stocking into submerged rice fields. Irrigation with pond effluent is performed in vegetable fields or greenhouses during or after a fish production cycle.

Uses. This integration is applicable to many locations. It is useful in drylands where water from seasonal rainfall is captured and retained, and reservoirs stocked with fish. The system is equally suitable for regions with high rainfall or near rivers that have abundant access to water. The technology can be practiced in lowland areas that are seasonally flooded by rainfall and floodplains extending from the edges of rivers and lakes, but on hill crests and highlands to store gravity-fed water.

Composition. Fish culture can be integrated with all types of crops, but vegetables and rice are the most common. The size and type of fishpond and associated crops may widely vary depending on production objectives and level of investment. In the simplest form, integrated aquaculture and agriculture systems operate near a rearing pond or settling basin or linked through combined pumping operations. For advanced aquaponics systems, additional filters, raised or floating beds, and recirculation piping may also be required.

Application. Ponds or tanks should be positioned adjacent to fields or greenhouses for ease of operations and minimized pumping. Fish rearing ponds and settling reservoirs should be sufficiently large to meet irrigation requirements during dry spells while also meeting pond needs. In addition, farmers can strengthen the channels and pond walls by planting them with crops. Adjacent open field crops or greenhouses are best irrigated with furrows because pond effluents contain too many sediments for sprinkler or drip irrigation without cleaning. Alternatively, water may be withdrawn from the surface of settling basins using floating intake valves and then filtered. A wide range of aquaponic arrangements exist, including Styrofoam rafts floating inside fish tank and recirculating containers with a continuous flow of water between fish tanks and hydroponic crop beds. Description of these systems is beyond the scope of this catalogue.

A floating aquaponic system

Commercialization, Start-up Requirements and Production Costs. Supplies for fishponds or tanks and water pumping needed to establish simpler integrated aquaculture-agriculture systems, as well as greenhouses and hydroponics for advanced aquaponics, are readily available in many African countries. Adopting this technology entails the following steps: 1) Develop a business model with start-up costs and production and sales forecasts, 2) Identify the appropriate location for fishponds within field or greenhouse, and 3) Train staff on appropriate operations and maintenance. Simple integrated fish and crop production systems consisting of rearing ponds and open field cultivation require investment for labor, pond instillation and water movement. In Nigeria, the annual cost for labor, fingerlings, feeds, seeds, fertilizer, and depreciation of pond and pump for a 0.5 ha fish-vegetable farm is about US $2,000. A survey in Nigeria revealed that fish-vegetable farms earn an average net income of US $2,466 per acre. Aquaponic setups come at a much higher cost depending upon their design but include greenhouse structures, fish tanks, pumps, and filtration. Hydroponic beds made of plastic cost between US $50 and $100 per square meter but are not widely available. Constructing a fully equipped aquaponic system can cost upwards to US $250,000 for 0.5 ha.

Customer Segmentation, Potential Profitability and Licensing Requirements. Combined aquaculture and agriculture systems appeal to small-scale fish farmers and commercial agribusinesses. Cooperative or bank loans may be needed to meet the investment and labor requirements of economically viable units. Generally, the profit from fish culture can be increased by 30% to 40% through integration with vegetables. No licenses are needed to integrate fish and crop production systems, but local regulations pertaining to both apply. Information on this topic is available as a Regional Public Good provided by WorldFish.

Technology 10. Mechanized Processing and Value Addition

Summary. Fish processing refers to the processes associated with fish and their products from the times they are harvested to when they are offered to consumers. Fish is a highly perishable food that requires proper handling and preservation to extend its shelf-life and retain its desirable taste and nutritional value. Processing technologies also add value to fish products by improving their palatability and market acceptance. The key to delivering quality fish-based foods requires close attention to harvesting, handling and storage. Solar tent dryers and smoking kilns are among the most popular, low-cost, and widely used fish preservation technologies. By reducing the moisture present in fish these two methods avoid the need for refrigerated transport and storage. A wide range of value-added products that can be manufactured include fish powder, fillets, brochette, sausages, fingers, crackers, samosas, and cakes. Contact Prof. Bernadette Fregene of WorldFish for more information by email at b.fregene@cgiar.org.

Range of fish processing tools (left to right): scaler, cutter, skinner, and de-boner

Technical Description. Basic procedures used in fish processing include drying and smoking, cold storage and freezing, heating, canning, and irradiating. Historically, the first technique has the greatest importance in Africa, but cold storage is also becoming widely available. Fresh fish spoils easily after harvesting due to high temperature which accelerates activities of bacteria and chemical oxidation. Losses are minimized by processing and preservation. Removing the scales and gut, washing, and filleting of fish are the first steps to achieve short-term storage, and to manufacture value-added products. Various food preparation methods like drying, smoking, frying, grilling, and baking can be used to improve appeal, taste, and finishing. Equipment used for scaling, filleting, skinning, and deboning allow for quick, and safe processing of fresh compared to manual operations. Solar dryers provide a low-cost alternative and are constructed with readily available materials. Different sizes of solar dryers can be built, with the smaller units measuring two meters in height and 1.7 meter in length and width. Smoke contains antibiotic substances that kills microorganisms, and the heat dries the fish. Traditionally brick and drum kilns are used for smoking, but quality and hygiene are difficult to ensure in these units because no mechanism is present for collecting and draining oils. An improved design with a motorized fan system has been introduced to fish production regions that drastically reduces energy consumption and processing time and improves smoke control and hygiene. At the same time, options exist to reduce the dependency on complex equipment and create job opportunities in processing while meeting stringent sanitation requirements.

Uses and Composition. All types of fish may be processed using electric scaling, cutting, skinning and de-boning machines, and preserved with solar dryers and improved smoking kilns. The equipment is suitable for different sized fish, but the processing time varies accordingly. Electric scalers have a rotating spindle head with serrated teeth that lifts the scales and pulls them as they are moved across the skin, and a splash cover that avoids the spraying of fish scales. A cutter has a small double conveyor belt which takes the fish through a vertical blade and produces equal-sized fillets. The key part of deboning and skinning machines is a ribbed or tooth roller head that is horizontally moved over the inside and outside of fillets, removing small bones. A solar dryer is made of a wood or metal frame structure that is covered with polythene sheets, trapping the sun's heat inside. Fish are spread out on wire mesh shelves so excess water can drip through and desiccate the product evenly. An improved smoking kiln consists of four main components: an air-tight chamber with stacked trays to hold fish and an oil collection pan at the bottom, a fan for even flow of heat and smoke, a thermometer for monitoring chamber temperatures, a chimney with a damper to filter soot and diffuse smoke. Charcoal is used in the kiln for generating heat and smoke, although soaked woodchips may be added to add a distinctive taste.

Processing tilapia in an easy-to-install solar dryer

Application. Processing starts with the removal of scales and gut contents from whole fresh fish after which they can be cut into fillets, skinned, and deboned. Pliers may be used to pull skin away from flesh and bones, particularly for catfish that lack scales. Tools and surfaces used for processing need to be regularly sanitized with clean water and disinfectant. Staff hygiene is critical to ensure food safety and requires the use of gloves, hairnets, and overalls. After cleaning, the fish is ready for drying and other forms of value-addition processing. In solar tent dryers, sunlight falls onto the transparent polythene surface to heat up the air inside which gently desiccates the fish, and a motorized fan accelerates convection and air circulation. Well-constructed units are rainproof and may even be operated in bad weather. Tents must be fully exposed to sunlight and should be positioned facing the prevailing wind to improve air movement. The optimal temperature for smoking ranges from 45° C to 70° C. Excessively high temperatures will result in the flesh being "cooked" and losing desired texture. Smoking fish for one or two hours provides an appetizing taste and short-term preservation but must be extended for four to six hours for complete drying depending on the prevailing temperature and size of the fish. Trays can be stacked inside a kiln, leaving space on the sides for smoke to circulate. After drying or smoking, the finished products are packed into bags or boxes to ensure that taste and cleanliness are maintained until sales.

Commercialization and Start-up Requirements. Equipment for fish processing, solar drying and smoking can be readily purchased or constructed across Africa. There is a large scope for value addition of fish to increase marketability, expand the sector and promote regional trade. Establishing a fish processing and value-added operation requires: 1) A business plan and mobilization of funds for investment in equipment and premises, 2) Training staff on the safe and hygienic processing, 3) Regular and adequate supply of fish to operate the facility at planned capacity, 4) Access to reliable and affordable utilities and fuel, and 5) Contracted marketing of finished products to minimize storage and maintain cash flow.

Smoking kiln suitable for processed fish products

Production Costs. An imported, handheld electric fish scaler costs US $1,500 and a filleting equipment is sold for US $1,000. Tabletop equipment for skinning and deboning with a capacity of 10 to 20 fish per minute is sold on international markets at US $2,500. A large greenhouse-style solar dryer 15 m long and 8 m wide on a concrete floor that has a carrying capacity of 850 kg fish per batch can be constructed for about US $2,000. Small Plexiglas dryers 1.75 m long and 1.5 m wide cost only US $400. Manually operated fish smoking kilns of medium-sized units running on charcoal and with a thermometer, able to smoke and dry up to 100 kg of fish cost about US $700 to build. A fully automated kiln with a capacity of 150 kg fish per batch that is available on international markets sells for US $3,500. Charcoal, and electricity may represent 30% to 40% of the operational expenses.

Customer Segmentation and Potential Profitability. Processing and value addition techniques are useful among fish farmers that produce excess quantities of fish but lack market access for immediate sales. Post-harvest services may be offered as a small independent business or be integrated into fish farming cooperatives. Larger-scale processing is a commercial enterprise. Complex automated facilities are needed for cleaning, drying, smoking, and packaging fish in ways compliant with food Safety and environmental regulations. Lower-cost solar dryers and ready access to markets allow small-scale processors to recover initial investment within 3-6 months. Improved designs of smoking kilns reduce processing time to a few hours where otherwise traditional methods require days to produce similar products. Considering moisture loss, dried fish are worth three or four times their initial value. For example, one kilogram of well smoked catfish is sold for US $18 on local markets Nigeria. This section does not describe other, more industrialized forms of value addition including canning and freezing, but these too offer value addition opportunities.

Licensing Requirements. Cottage-style traditional fish processing is often conducted without licensing restriction, but commercial operations are subject to a variety of regulatory requirements. In some case, simply butchering a fish requires licensing like that of poultry or livestock and must be performed on a stainless-steel table. The manufacture of fish processing equipment is protected by patent, but many facilities, particularly solar driers and smaller kilns may be constructed using locally available materials. Additional information on fish processing is available from WorldFish as well as the IITA Agripreneur Movement, because the youth have built successful businesses around fish processing.

Fish farming and Processing as a Youth-Led Enterprise

Youth entrepreneurship is a critical ingredient of Africa's agricultural transformation and their engagement with modernized aquaculture reflects this opportunity. The most widespread opportunity is through the establishment of fishponds and reliant upon many of the technologies presented in this catalogue. These include the rearing of improved broodstock (Technologies 1 and 2) within water efficient systems (Technologies 4 and 6) raised using nutritious feeds sequenced to different stages of growth (Technology 8). This goal is readily achieved through collective action within youth groups. As early innovators, youth groups can establish a pilot fish farming enterprise, develop skill set around its management, and then replicate the enterprise on individual holdings. Literacy and smart phone access contribute to this advantage. Fish farming generates ready profits even when start-up costs are considered. A youth-led fish enterprise raising tilapia in Nigeria invested about US $8,300 and within two years net profits totaled US $8,280, indicating an

Young farmer, big catfish

annual rate of return of about 50%. A similar enterprise for catfish required US $6,062 and two years later profits were US $9,666. In the process, hundreds of other youths received training in pond operations.

Youth are also positioned to provide commercial services to the aquaculture sector including the establishment and operations of hatcheries and fingerling nurseries; construction, periodic maintenance, and upgrades of production units; local blending and pelleting of feeds; and value addition to fish. Producing fry is not difficult, as it involves simply combining eggs and milt in clean, aerated water, and then removing the young fish after only a few days. It does require access to improved broodstock that may be kept in smaller ponds. Raising fingerlings is only slightly more complicated, but these fish must be provided a high protein diet until they are sufficiently large for release into production units. Fry and fingerlings may be produced collectively by a youth group for rearing by their members and sale to the larger fish farming community. A modern, youth-led hatchery in Ibadan, Nigeria was established for US $26,450 and over the following 6 years produced almost 2 million fingerlings worth US $0.06 each, resulting a value of US $118,990. These fingerlings included the all-male Genetically Improved Farmed Tilapia described in Technology 1 of this catalogue, accelerating the distribution of this improved breed. This facility provides employment to 10 youth as well.

A youth-led fish hatchery in action

Youth appreciate the opportunities from integrating fish farming with cropping and animal rearing (see Technology 9). In Kenya, a youth group that established a model farm in association with the University of Nairobi established a network of four fishponds among several vegetable greenhouses. The area was sandy, so these ponds were lined (see Technology 4) and serves as a source of irrigation water during times of drought. These youth developed their own fish feed as well, relying in part upon leaves of local trees and blood from a nearby abattoir processed to blood meal, producing low-cost, air-dried pellets using a hand operated mincer. At the end of every fish production cycle, nutrient-rich pond effluent is pumped between the beds of cucumbers and tomatoes, greatly reducing their requirements for fertilizer, and eliminating the need for discharge into a nearby seasonal stream. A youth in Nigeria first established fishponds, later expanded into poultry and swine, finding creative ways to link their operations, created 21 new jobs, suggesting that this enterprise rests on a sound commercial foundation.

Adding value to fish offers another line of opportunity to youth, particularly when linked to high levels of production and reliable supply chains. The immediate opportunity is based upon drying and smoking in ways that reduce the perishability of fresh fish and add versatility and taste to the product (see Technology 10). Preparation of stews and native soup from dried catfish is widely practiced throughout Nigeria, so consumers seek reliable sources. In response, three youth trained within an agribusiness incubation established Frotchery Foods Limited (Nigeria) to produce and market smoked dried catfish. Their product resembles traditional smoked catfish but is prepared using modern techniques and packaged in ways acceptable to supermarkets. After some effort, they registered their products with Nigerian authorities and then marketed them across Nigeria, with sales expanding to DR Congo, Kenya, the United Kingdom, and the USA. Recently, their product line expanded to include fish feed.

Smoked catfish ready for sale

Youth are well positioned to adopt the technologies offered in this catalogue, and these technologies were selected based upon that attraction. Educated youth that find themselves un- or under-employed can appreciate the complexities of aquaculture in ways that older, more conventional farmers cannot, and can move into the sector. These youth are also better connected to information flows via the internet and social media. One disadvantage they experienced a shortage of collateral and creditworthiness that translate into loan opportunities. This shortcoming is recognized as an incentive for youth participation within development programs based upon sovereign country loans that are increasingly offered, including those promoting the aquaculture sector. When it comes to engagement in aquaculture, it gives youth a chance! *Information courtesy of ENABLE TAAT.*

Make TAAT Your Technology Broker of Choice

The TAAT Program offers its services toward the advancement of modernized agriculture. It brokers a wide range of needed technologies and bundles them through a process of co-design into winning solutions. It recognizes that modernized agriculture must serve as the main engine for economic growth in Africa and operates accordingly. Change is intended to achieve not only food and nutritional security but also to meet obligations under climate agreements allowing collaborative efforts to better combine global, national, and community-level interests. TAAT operates from a unique perspective to mobilize innovative solutions through better partnering that includes honest technology brokerage and effective, scalable skills development through five key mechanisms.

- ☑ **Unique understanding:** Expertise is offered in the areas of site characterization and problem identification.
- ☑ **Innovative solutions:** Leadership is provided in technology brokerage and solution bundling based upon a dynamic portfolio of candidate technologies.
- ☑ **Better partnering:** Assistance is offered in the better co-design and management of projects prompting agricultural transformation.
- ☑ **Replicable approaches**: Assistance is available to advance skill sets in technology brokerage and project management through customized Training of Trainers activities.
- ☑ **Honest brokerage:** An independent capacity for impact assessment and constructive learning is achieved through standardized monitoring and evaluation.

These partnership mechanisms are applied to the technologies featured in this catalogue as follows:

1. **Improved Fish Breeds.** Fast producing, climate and disease strains of tilapia and catfish are provided by TAAT to national agencies and farmers, and upon release, assistance is provided in the design of fingerling systems that accelerate community-based production. *These services are arranged by TAAT with its partner WorldFish.*
2. **Quality Fingerling Production.** Once superior fish breeds are available, TAAT helps in their scaling through the design and cost-efficient operations of fish hatcheries and fingerling nurseries. *These designs can be incorporated into larger development projects through Public-Private Partnership.*
3. **Efficient Pond, Tank and Cage Management.** This catalog describes a variety of rearing facilities such as ponds, tanks and cages suited to a variety of conditions, but greater understanding is needed by project managers and investors before they can be installed. *Services are offered through TAAT to assist the public and private sectors in planning, marketing, and scaling efficient fish production systems across Africa*.
4. **Local Feed Production.** This catalogue demonstrates that balanced formulations of fish feed can be manufactured using readily available ingredients and equipment that increases access, lowers costs, and creates new businesses. *TAAT and its partner WorldFish assist in the dissemination and commercialization of fish feed technologies.*

5. **Water Conservation.** Water is a precious commodity and the technologies presented in this catalogue offer several options on how it may be effectively conserved and recycled. *TAAT and WorldFish assist national programs in the design of these integrated management systems.*
6. **Value Addition.** This catalogue describes a limited number of value-added products that present business opportunities, needed materials and equipment, but more importantly it identifies that more products are realizable within the scope of agricultural transformation. Aquaculture is an important contributor to achieving protein security, and processing fish products is good business. *The TAAT Clearinghouse is ready to assist in the design of national projects for development banks, including the African Development Bank.*

TAAT is prepared to partner with development investors, national projects, and the private sector in a demand-driven manner.

A large catfish raised in an earthen pond by Nigerian youth

Conclusions

This catalogue provides a wide variety of options for improving and modernizing aquaculture in Africa. It identifies ways to improve yield through genetically improved fish and ways to multiply them at community and commercial scales. It provides options for improved production systems of both catfish and tilapia, although other types of fish may be raised as well. It provides production methods in aquaculture by emphasizing the importance of Better Management Practices including better feeding and value addition. The diversity of production systems beyond simple earthen ponds recommends scope for companies that specialize in providing advice, engineering, and construction, through the use of approaches and technologies described within this catalogue. Options for adding value to fish are briefly described but there are more possibilities for many other commercialized products. Clearly, fish is an important but underutilized protein source for humans and can be processed into a large variety of commercially marketable products. This catalogue was prepared with a variety of users in mind. They include producers, extension agents, managers of agricultural development projects and private sector investors. Fish breeders, farmers and processors can use this catalogue as production guidelines. Those from the public sector can utilize the catalogue to assist in the design agricultural projects advancing aquaculture production. Indeed, the Technologies for African Agricultural Transformation Program's Clearinghouse welcomes feedback on its contents.

Information Sources

Better Management Practices for Tilapia Hatcheries in Egypt.
https://digitalarchive.worldfishcenter.org/handle/20.500.12348/4697

Extension Manual on Mono sex Tilapia Production and Management
https://digitalarchive.worldfishcenter.org/bitstream/handle/20.500.12348/4742/be9aa837e0ad40e04776847c88c0c970.pdf?sequence2=

GIFT Technology Manual: An aid to Tilapia selective breeding
http://pubs.iclarm.net/Pubs/GIFTmanual/pdf/GIFTmanual.pdf

Extension Manual on Quality Low-Cost Fish Feed Formulation and Production https://digitalarchive.worldfishcenter.org/bitstream/handle/20.500.12348/4819/14d2f741e60875a1425cec5acbe8236e.pdf?sequence3=

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Technologies for African Agricultural Transformation (TAAT) and its Clearinghouse Office

The development objective of TAAT is to rapidly expand access of smallholder farmers to high yielding agricultural technologies that improve their food production, assure food security, and raise rural incomes. This goal is achieved by delivering regional public goods for rapidly scaling up agricultural technologies across similar agro-ecological zones. This result is achieved through three principal mechanisms; 1) creating an enabling environment for technology adoption by farmers, 2) facilitating effective delivery of these technologies to farmers through a structured Regional Technology Delivery Infrastructure and 3) raising agricultural production and productivity through strategic interventions that include improved crop varieties and animal breeds, accompanying good management practices and vigorous farmer outreach campaigns at the Regional Member Country level. The important roles of sound policies, empowering women, and youth, strengthening extension systems and engaging with the private sector is implicit within this strategy. The Clearinghouse is the body within TAAT that decides which technologies should be disseminated. Moreover, it is tasked with the responsibility to guide the deployment of proven agricultural technologies to scale in a commercially sustainable fashion through the establishment of partnerships that provide access to expertise required to design, implement, and monitor the progress of technology dissemination campaigns. In this way, the Clearinghouse is essentially an agricultural transformation incubation platform, aimed at facilitating partnerships and strengthening national agricultural development programs to reach millions of farmers with appropriate agricultural technologies.

Dr. Innocent Musabyimana, Head of the TAAT Clearinghouse

Back cover photos: Pelleted fish feed (upper left), harvested catfish (upper right), harvested tilapia (bottom left) and smoked catfish (bottom right). Photos from WorldFish and IITA Youth Agripreneurs.

Technologies for African Agricultural Transformation

Aquaculture Technology Toolkit Catalogue

IITA
Transforming African Agriculture

WorldFish

In collaboration with:

International Water Management Institute

FARA
Forum for Agricultural Research in Africa