IMPROVING AQUACULTURE SYSTEMS

DEVELOPING PRODUCTIVE SYSTEMS UNDER VILLAGE CONDITIONS

M.M.J. Vincke
Fisheries Department, FAO, Rome, Italy

1. CHARACTERISTICS OF VILLAGE AQUACULTURE

Currently, aquaculture in Africa is generally practised at three levels:

(i) small-scale rural fish farming or village fish farming (also known as small-holder fish farming, or fish farming in home-ponds, or family fish farming);

(ii) medium-size or artisanal fish farming involving fish-farmers/ entrepreneurs;

(iii) large-scale commercial or industrial aquaculture.

Out of these three categories of aquaculture, only small-scale and artisanal fish farming is so far practised in rural Africa, due to the socio-economic conditions prevailing in the rural areas.

1.1 Village fish farming or small-scale rural fish farming

'Village fish farmers' or 'small-scale rural fish farmers' should be considered as the owners of one or more small fishponds of an average surface area of between 100 and 300 m2 per pond, with yields of 10 to 30 kg fish per 100 m2/year (or 1 to 3 tons/ha/year), consuming a relatively important part of their production whilst marketing a small surplus. The ponds are generally fertilised using compost and manure and the fish fed with different locally available ingredients.

In village fish farming, investment is typically self-financed and the fishponds are managed by the owner and his family.

1.2 Artisanal or medium-size fish farming

An 'artisanal fish farmer' or 'medium size commercial fish farmer/ entrepreneur' is generally an already experienced small-scale fish farmer, the owner of one or several relatively bigger ponds (from $300m^2$ to 2000 or 3000 m^2) producing over 3 t of fish per ha/year. This type of fish farmer could also be the owner of some floating cages (each about $20m^3$) installed in a reservoir or a barrage-pond. The artisanal fish farmer generally practises polyculture and fish culture integrated with animal husbandry. An artisanal or medium-size fish farmer may have received financing and will apply intensive fish rearing techniques: fertilisation of the ponds, intensive feeding of the fish and fish culture combined with animal husbandry.

Based on experience in some African countries (Central African Republic, Ivory Coast and Zambia, for example), it is fully possible that, starting with small-scale rural fish farming, after 2-3 years of intensive extension work, some progressive fish farmers (about 15-20 percent of the 'small-scale' rural fish farmers) would be capable of improving their yields through more intensive fish farming techniques such as polyculture and integrated fish farming with animal husbandry (pigs, ducks and chicken, for example).

2. MEANS OF IMPROVING THE PRODUCTION OF FISH IN PONDS

According to Huet (1975), non-biological and biological methods can improve fish production in ponds.

2.1 Non-biological methods

2.1.1 Maintenance of ponds and their improvement

Apart from normal maintenance of dykes, banks and water inlet and outlet, other actions are to be taken to maintain and improve the ponds: weed control and maintenance and improvement of the pond bottom fertility.

(i) Action to prevent infestation by aquatic plants: is only necessary when weeds become excessive or when they are not useful as food for fish. It should, however, be borne in mind that aquatic vegetation in ponds is an important element in the biological cycle in ponds (macrophytes, phytoplankton, periphyton), but only when growing in a relatively small part of the pond area. Excessive aquatic vegetation competes indirectly with the fish using the nutrients for their own growth, accelerates silting, creates a pond bottom rich in cellulose, provides refuge for predators, hinders the use of seines and other nets during intermediate fishing for sampling and makes pond drainage and harvesting operations very difficult.

Maintenance of ponds is far more easy when unwanted plants are regularly removed than when the pond has to be completely restored when invaded by weeds and is silted up. Removal of excessive aquatic weeds may also reduce snails, some of which are intermediate hosts of bilharziasis or schistosomiasis. Weed removal also reduces the potential breeding areas of mosquitoes, vectors of malaria.

There are three methods used to control excessive aquatic vegetation: mechanical cutting, chemical methods and biological methods. In village fish farming, fish farmers usually remove excessive weeds by hand, but the principal biological method is the use of herbivorous fishes (*Tilapia rendalli, T.zilli* and the grass carp *Ctenopharyngodon idella*, is also recommended.

(ii) Maintenance and improvement of pond bottom fertility: is necessary to improve the physical, biological and chemical condition of the soil. The soil of the pond bottom, and particularly mud, are the 'production laboratory' of the pond, since the nutrients are absorbed by the mud. The nutrients contained in fertilisers act on the mud and the pond bottom, and indirectly on the water mass or the organism in suspension.

Ponds are generally drained for cropping and left without water over a certain period. The drying out of the pond must be effective, to benefit from drying and exposure to the sun and air. To allow drying out, the pond bottom should have a good network of drainage ditches, which have to be cleaned out after the water has been drained off. The drying out period must be short, to avoid a loss in production. It should only last long enough to obtain the mineralisation of the mud, which will be evident when the bottom surface cracks (Huet, 1975).

Light tillage of the dried out pond bottom and the working in of lime and manures restore pond productivity. It is also during the drying out period that excessive mud or silt should be removed from the pond. This mud is generally very fertile and can be used as fertiliser in vegetable gardens.

Repairs and maintenance work should also be carried out during this period (repairs to outlet, inlet and monk; filling of cracks; removal of weeds and other unwanted vegetation rooted in the bottom in the shallow part of the pond, etc.).

2.1.2 Liming and fertilisation of ponds

Liming has not yet become a current practice in small scale rural fish farming in Africa, even if liming of ponds is considered beneficial and has a favourable action on some biological factors of production and on the health of fish.

The most important reason for liming in village ponds is to avoid or to correct acid conditions in the pond (pH less than 6-6,5) and when the alkalinity is too low. Testing the water and soil quality is necessary when planning fish farming and is one of the many tasks of the fish farming extensionist: the pH could be between 4.0 and 6.0.

Fertilisation of the ponds increases fish production substantially and, apart from artificial feeding, fertilisation provides the best means of increasing fish production in ponds.

Either inorganic or organic fertilisers may be used. Recent increases in the price of mineral fertilisers has greatly limited their use in rural areas, taking also into account local transport problems, especially in remote areas. Inorganic fertilisers (mineral or chemical fertilisers) include single and double superphosphate, ammonium sulfate, urea, etc.). Organic fertilisers might include animal manures, compost and artificial manure; the latter is made by composting vegetable matter and adding urea or some other source of nitrogen. Artificial manure is not yet commonly used in fish ponds in Africa but could be of interest in countries where chemical fertilisers and animal manures are scarce.

The principal aim of fertilisation is to increase the quantity of natural food in the pond. In fact, fish production depends on the relative quantity of inorganic nutritive substances available in the pond, provided that there is enough heat and light.

Organic fertilisers such as animal manures (mainly from chickens, pigs and cattle) and compost are often found only in relatively small quantities and, therefore, their use in large commercial fish farms is limited, due to the bulk involved and the cost of labour. On the contrary, the use of such organic fertilisers has become more and more popular in village fish farming in some African countries, since they are easily and locally available and cost the farmer almost nothing.

Animal manures contain nearly all of the nutritive substances indispensable for a normal biological cycle in the pond, which is not the case when using mineral fertilisers. The application of manure to fish ponds stimulates plankton growth and can increase fish production several times over natural production.

In newly built ponds, where the pond bottom is relatively sterile due to the absence of mud, the application of manure is recommended to improve the pond bottom.

The rates of manuring ponds depend again on the natural fertility of the pond. Several authors recommend different rates of application, according to the prevailing physico-chemical conditions in the ponds in tropical areas.

Quoted from Huet (1970), Snow *et al* (1964) and the Centre Technique Forestier Tropical (1972), Miller (1976) has summarised the advantages and disadvantages in the use of organic fertilisers.

When manure is not readily available in the village, one can utilise compost for the fertilisation of ponds, as is practised in rural ponds in the Central African Republic, Kenya, Ivory Coast and in other countries where village level fish farming is practised.

The use of compost to maintain pond fertility will reduce the farmers' dependence on chemical fertilisers which are generally imported and paid for in foreign currency.

There are two methods to convert organic matter into compost for fertilisation of ponds:

(i) the anaerobic method: consists of organic matters (grasses, spoiled fruits, leaves, wastes from soaking cassava, etc., and some cattle or chicken manure) stacked underwater in a pile in the corner of the filled pond. For a 100 m2 pond about 50-60 kg of organic matter is required to start with. The heap of organic matter in the pond is placed in a small fenced enclosure of crib made of wooden poles and bamboo. Weekly doses of 8-10 kg organic matters are generally added to the pile. To collect, transport and pile the organic matter for composting a 100 m2 pond, a farmer may spend an average of 28 hours a year;

(ii) the aerobic method: consists of the decomposition (rotting) of organic matter in compost piles in the open air, and thus not underwater; the biological process requires adequate aeration and the compost pile should be turned over regularly.

Natural productivity in ponds in Central Africa is about 150-200 kg per ha/year. In the monoculture of *Tilapia nilotica* (stocking density: 2 fingerlings/m2, the average production from ponds where anaerobic compost is used, is 1500 kg of fish/ha/year. In the same conditions, but using aerobic prepared compost, production can reach 3,000 kg of fish/ha/year, with an application rate of 20-30 tons compost per ha/year (CTFT, 1972). These results were obtained with the composting of not only grasses, but also manure and wood ashes (rich in minerals).

Another technique for manuring fish ponds is the combined rearing of fish with pigs, ducks or chickens, in enclosures built beside or over the fish ponds. These integrated farming systems are well adapted to the socio-economic conditions of small-scale farmers, who make up the bulk of the rural population in almost all African countries. Associated rearing of fish and livestock have yielded some of the highest levels of fish production in ponds in Africa (up to 10,000 kg of fish/ha/year), utilising only excrement and waste feed from the animals (Miller, 1976; Vincke, 1976).

Fish/livestock integrated farming systems, suitable for small-scale farmers, are presented in section 3.3.

2.1.3 *Artificial feeding of the fish*

As village fish farming is based on simple and unsophisticated techniques, the available feedstuffs are not processed, except for some ingredients which are milled using a hammer mill, if available in the village. Other ingredients are only crushed in a mortar (cotton seeds, for example). The different raw ingredients are mixed and scattered by hand over the pond surface. Only hand feeding is practised in village ponds and allows the farmer to see the fish every day and to check their behaviour. He can also, at the same time, check the water level in the pond, clean the screens, etc.

Even if there is a lack of information on the vitamin requirements of tilapia and on their mineral requirements (Jauncey and Ross, 1982), fish feeding technologists still recommend the incorporation of vitamins and dietary minerals in diets for tilapia raised in ponds. They also recommend the use of animal proteins in tilapia feeds. It seems that tilapia reared in ponds get all their vitamins and required minerals, and a fair amount of protein, when consuming the natural food available in the pond.

The results of experiments in ponds have demonstrated two facts: it is not always necessary to feed a pelleted feed to obtain the best yields in tilapia culture in ponds; animal proteins may not be required in rations for tilapia reared in ponds, if the animal proteins are replaced by adequate vegetable proteins.

It has been demonstrated (Swingle, 1968) that there was significant benefit, to feed conversion rate, for channel catfish (*Ictalurus punctatus*) and common carp (*Cyprinus carpio*) if the feedstuffs were pelleted. This is however not the case for *Tilapia nilotica*, as shown by Miller (1977), and for *T. aurea*, as demonstrated by Allison *et al* (1976). This finding is of practical significance to those who wish to culture *T. nilotica* or *T. aurea* in ponds and who are considering the acquisition of a pelletiser, on the supposition that pelleting feedstuffs is necessary for efficient utilisation of food in ponds (Allison *et al*, 1976).

The experiments on the comparative use of animal and vegetable protein conducted by Hastings (1973) in *T. nilotica* monoculture in ponds have demonstrated that vegetable proteins in pellets can be substitutes for animal proteins in rations of 30 percent protein. A greater production (7.167 kg/ha/year) was obtained in feeding the 30% vegetable protein diet, compared to the animal protein diet (4.718 kg/ha/year), according to Miller and Maletoungou (1976).

2.2 Biological methods

2.2.1 Careful choice of species

The choice of species should not only be based on technical criteria (easy reproduction of fish, rapid growth etc.), but bearing in mind also socio-cultural aspects (the habit of not consuming fishes without scales, for example) and economic aspects (choice of species to be cultured depending on the purchasing power of the consumers).

2.2.2 Control and adaptation of pond stocking

Stocking density depends on the total productivity of the pond. The total productivity of a pond is the sum of natural productivity and the added productivity due to fertilisation of the pond and artificial feeding (or supplemental feeding) of the fish. The stocking density depends on the productivity of the pond, aiming at obtaining maximum quantity and quality of fish under the best economic conditions (lowest financial inputs).

High stocking densities result in a better use of natural food than reduced stocking, and, generally speaking, leads to a higher yield or higher quantitative production. Quantitative production means a production which will give the total maximum weight possible, but the fish will not be graded and not be of the best quality. This is the case in village fish farming, where tilapias of less than 60 g are easily sold in local markets. Thus stocking large numbers of fingerlings will result in an increase in total production, but in a reduction in the average weight and the size of the individual fish produced.

As demonstrated by Micha (1973), when using *Tilapia nilotica* fingerlings at stocking densities of 10.000, 20.000, and 30.000 per ha (or 1,2 or 3 fingerlings per m^2) and fed brewery waste (draff), the total yield during a rearing period of about 7-8 months, passes from 1700 kg/ha/year with a stocking rate of 10,000 fingerlings per ha to 4.390 kg/ha/year with 30,000 fingerlings/ha. The average weight of the adult fish is 136g at the density of 10,000/ha; 101 g at 20,000/ha and only 82 g at 30,000/ha.

The stocking densities should thus be adapted to meet the requirements of the villagers. The demand is generally for a maximum production even if the fish produced is not of a large size. In tilapia pond culture the recommended stocking rate is about 20,000 fingerlings/ha or 2 fingerlings per m^2.

2.2.3 Control of temperature and oxygen content in ponds

The water temperature is one of the most important external factors which influence fish production, since temperature has an important influence on breathing, growth and reproduction of fish. This considerable influence of water temperature is due to the fact that fish are cold blooded, which means that their body temperature varies, with the temperature of their environment.

Each species is adapted to a more or less wide range of water temperatures, including minimum and maximum temperatures, outside which they cannot live. Maximum growth of the fish and the maximum production of the pond occurs also in a scale of intermediate temperatures.

Optimum growth of common carp (*Cyprinus carpio*) is between 18 and 28°C and the optimum water temperature for reproduction is 18-20°C. The commonly cultured Tilapia species have their optimum growth between 20 and 26°C and the optimum reproduction temperature is 21 to 23°C. Fish kills can occur in ponds when the water temperature is too high and reaches the upper lethal limit (generally 35°C for Tilapia).

The best way to control the water temperature is to increase the quantity of water admitted to cool down the water in the pond and, alternatively, to reduce the inflow if the temperature should be increased.

The dissolved oxygen content depends on the pond water temperature, the submerged aquatic vegetation and the presence of organic matter. The warmer the water, the lower the dissolved oxygen content. Pure water at 0°C contains 14.62 mg/litre and only 7.63 mg/litre at 30°C (Huet, 1975).

The dissolved oxygen content should be 9 mg/litre for salmonids (trout), around 6-7 mg/litre for cyprinids (common carp, Chinese carp, etc.) and around 2-3 mg/litre for tilapia. It should be noted that some tilapia species are able to survive oxygen levels as low as 1mg/litre. This is also true for *Clarias lazera*.

The decomposing organic matter will absorb dissolved oxygen in the water and, if decomposing organic matter is too abundant, the dissolved oxygen content could then fall below the minimum level acceptable to the fish. The fish will then come to the surface in an effort to breathe air and other fish will group together near the fresh water inlet. The danger is particularly great in warm and thundery weather.

Given the present nature of village aquaculture, only inexpensive measures can be taken to increase the dissolved oxygen content in pond water. These measures are:

(i) to build into the water supply canal, small cascades or waterfalls to aerate the water;

(ii) the water inlet should be above the water surface of the pond and water can splash over a perforated screen, which will allow good contact with the air and enrich the water with oxygen;

(iii) introduction of semi-submerged water plants, such as watercress (*Nasturtium officinale*), fool's watercress (*Apium nodiflorum*) in the water supply channel to replenish the oxygen in the water;

(iv) introduction of submerged plants into the pond, such as horn-wort (*Ceratophyllum* sp.), water milfoil (*Myriophyllum* sp.) and pondweed (*Potamogeton* sp);

(v) reducing the organic matter by working it into the pond bottom;

(vi) cutting the emergent weeds to promote the penetration of light;

(vii) letting into the pond of fresh, good quality water, particularly during hot and thundery weather, when 'gulping of air' is noted in the ponds.

2.2.4 *Improvement in reproduction and selection*

Tilapia species, generally used in Africa for stocking village ponds, reproduce naturally in growing ponds (uncontrolled natural reproduction) and without difficulty. In some cases, however, they reproduce too frequently, leading to overpopulation in the pond and dwarfing (or stunting) if the production cycle is too long.

Other species reproduce naturally in ponds but with some difficulties and the number of fry and fingerlings obtained in ponds is relatively low. This is the case for species such as common carp, *Clarias lazera* and *Heterotis niloticus*. The reproduction of these species can be improved or be induced using special techniques that, up until now, were only applied in fingerling production centres.

Common carp are reproduced in spawning ponds (controlled natural reproduction) using 'Kakabans'. The 'kakabans' covered with eggs are removed from the spawning ponds and put into special cages for incubation and hatching. This is to avoid predation during the first life cycle of the fry.

Induced spawning using pituitary extracts and hormones which provokes the spawning of *Clarias lazera* and common carp and the use of techniques of artificial incubation of the eggs has made it possible to obtain a high number of fry, not only during the normal natural spawning period, but even during other periods of the year. This has extended greatly the culture of these species, even if some difficulties have to be overcome.

Undesirable production can be controlled by introduction in the tilapia ponds of voracious or carnivorous species such as *Lates niloticus, Hemichromis fasciatus* and also *Clarias lazera.*

Since the males of tilapia have a superior growth rate to the females, monosex cultivation (or rearing of all males) is also a way of improving yields in ponds. In male mono sex culture, the adverse effect of prolific breeding and low growth rates are avoided. It is thus a means of eliminating unwanted spawning in production ponds and stunting.

There are several methods to obtain all male fingerlings for stocking production ponds: manual sorting of males, hybridisation and sex reversal, but of these methods, only sorting of sexes could be practised in rural fish farming.

Selection has shown important possibilities for increasing production. This is particularly true for common carp and has produced races of different colour, different squamation (scales, mirror, naked) and different shape indices.

The possibilities of increasing production through selection of indigenous fishes have not yet been sufficiently used in Africa, but it is known, for example, that there are different strains of *T. nilotica* having differences in growth.

2.2.5 *Mixing of species and age groups*

The aim of the mixing of species and age groups is to improve quantitative, qualitative and economic production. A well planned combination is beneficial to each of the groups raised together in ponds.

Several combinations are possible, but in village fish farming only some of these are suitable.

An association of different age groups of the same species (also called mixing of non-voracious species) such as *T. nilotica* (adults mixed with juveniles and small fingerlings) will increase the quantitative production of fish for consumption. Fish from different age groups of the same species have generally different feeding habits and when mixing them in the pond, better use is made of food and the total production is increased. It appears that these different age groups do not compete with each other.

This method, known as the mixed age group method or the mixed method, produces a high quantity of small size tilapia. This simple method was used in the fifties and has now almost been abandoned everywhere and replaced by the so called separate age method. This is in fact a monoculture, stocking the production ponds only with fingerlings of almost all the same size. This is now the method used in small-scale rural fish farming in most of the African countries where fish culture is practised.

It is well known that a single species (monoculture) cannot use completely all the nutritive resources of a pond since each species has its own feeding habits and shows food preferences. Thus by mixing different species, more food resources of the pond will be consumed and the total production will be increased.

At the beginning of fish farming in Africa, the herbivorous *T. rendalli* (previously known as *T. melanopleura*) was cultured in polyculture with the microphageous *T. macrochir*. In Madagascar, common carp and tilapia species are cultured together in ponds and in irrigated rice fields, without harm since they have complementary feeding habits.

In Central Africa, *T. nilotica* is raised together with *Clarias lazera* and in this polyculture yields up to 4,950 kg/ha/year (average of 5 trials) were obtained during a production period of 100 days. In monoculture of *T. nilotica* in almost the same conditions (stocking density 2 fingerlings/m^2 and production cycle of 120 days or 4 months) the average yield of 6 trials was 3.651kg/ha/year. The increase in production due to the polyculture was thus 1.299 kg/ha/year.

Polyculture will only be successful if the species reared together have complementary feeding habits and occupy different ecological niches in the pond.

2.2.6 *Successive production cycles throughout the same year*

To obtain maximum production, it is recommended that ponds are kept under water as long as possible and produce several fish crops during the same year, if climatic conditions (particularly water temperature) allow normal growth of the fish during the whole year, and if fingerlings are available, when required.

At the end of each production cycle of between 3 and 6 months, the ponds are drained for harvest and, after a short drying out period, are restocked for a new production cycle. During a short production period, and in order to obtain table sized fish, it is necessary to stock the ponds with relatively large fingerlings (10 - 20 g) and to fertilise the pond and feed the fish regularly.

In order to avoid too high a percentage of tilapia fry and small tilapias, it is recommended, when stocking the pond, to add 10 -15 small *Clarias lazera* fingerlings (average weight 10 - 12 g) per 100 m^2 of pond. They will eliminate a large part of the tilapia fry born in the pond during the production period.

2.2.7 *Intermediate fishing*

Intermediate fishing (using cast nets, lines, seine nets, etc) is necessary when the density of the population in the pond has become too high. It could also be that the farmer wants to sell some of the fish during the rearing period and before the final harvest. This thins out the fish of saleable size which will provide remaining fish of small size more room and food to reach adult size.

It is generally accepted that intermediate fishing of large fish in the pond will increase the total population, but there is also the risk that the remaining smaller fish (particularly tilapia) will also start spawning and this will accentuate the overpopulation in the pond. Intermediate fishing cannot be repeated several times. Periodical drying out of the ponds is necessary to control overpopulation or overstocking and to remove unwanted species which will have entered the pond through the water supply channel or inlet.

2.2.8 *Actions against predators, parasites and diseases of fish*

In some countries, the most important predators of fish in ponds are otters. They may be trapped but the best way of protecting fish ponds against otters is to put a fence around the pond.

In other countries, birds such as cormorants, herons, hamerkops, kingfishers and fish eagles are the worst predators. Of these the cormorants are the greatest fish eaters and should be controlled under all circumstances.

Frogs, snakes and some aquatic insects eat young fish but no special action is generally taken against them, except drying out the ponds or by poisoning the pond water.

Predatory fish sometimes get into the ponds coming down from the water supply channel. This can be avoided by using appropriate screens at the pond inlet.

Parasites occur under natural conditions in rivers, lakes, reservoirs and also in ponds. According to Roberts and Sommerville (1982), parasitic infections of tilapias have generally shown no evidence of clinical effects on the fish and in most wild populations of tilapias, it would seem that parasites are a normal occurrence of little consequence, at least in low density systems such as rural fish ponds.

It has been admitted that in properly managed ponds, regularly harvested and dried out, there should not be any serious or fatal disease of fish. Tilapias are extremely resistant and are not known to succumb to endemic diseases when reared in ponds at adequate densities.

3. PRODUCTIVE SYSTEMS SUITED TO VILLAGE AQUACULTURE

Going by the experience of forty years in rural African small-scale fish farming, the systems best suited to village fish farming are: the culture of tilapia in earthern ponds (monoculture), polyculture in ponds using tilapia as the main species, mono or polyculture of tilapia combined with animal husbandry and rice-cum-fish culture or rizipisciculture.

In recent years cage culture of *T. nilotica* has been practised by artisanal fish farmers, namely in the Ivory Coast, although this is still on a pilot scale.

3.1 Monoculture of tilapia in ponds

This production technique is, so far, the easiest, and also the most successful method, for starting village level freshwater aquaculture. The main tilapia species cultivated in monoculture on village level in Africa are *Tilapia nilotica* (the most cultivated species in Africa), *T. Anderson ii* (confined mainly to Zambia) and *T. shirana* (only in Malawi).

Stocking densities, in tilapia monoculture in ponds, are generally between 1 and 2 fingerlings per m^2 (or 10 000 to 20 000 fingerlings per ha). Average size of fingerlings varies between 5 and 10 g.

The ponds are fertilised using manures or compost. Artificial feeding of the fish, using locally available ingredients, is generally practised, but is irregular and limited to a small variety of foodstuffs, often of low nutrient value.

With this kind of pond fertilisation and feeding of the fish, the production cycle is about 5-6 months and the yields are between 1.500 and 4.000 kg of fish per ha/year (or 15 to 50 kg per year in a 100 m^2 pond). These annual yields are obtained in two production cycles per year.

At harvest, the percentage of food fish (average weight between 60 and 100 g) is generally between 60 and 80% of the total weight and the rest is composed of fry and fingerlings, a proportion of which will be used to restock the pond for the next production period.

This rearing system is well adapted to village level fish farming and is particularly suited to beginners. Once they have mastered the elementary techniques involved and have gained sufficient technical skills, they can start the implementation of more intensive production systems such as polyculture and integrated systems.

A production of 15 to 40 kg fish per year in a 100 m^2 pond is usually not considered very impressive but for a villager, who consumes only about 6 to 8 kg of meat or fish a year, this fish that he has produced himself is a big improvement in his diet and can produce an additional income for his family.

3.2 Polyculture in ponds

Natural food in ponds, increased by fertilisation, and supplemental feeds, is not completely consumed if only one species is cultured in the pond. Higher yields can be obtained with polyculture, compared to tilapia monoculture.

In most of the polycultures, tilapias have been the main species used; this has been largely due to the difficulty in obtaining fingerlings of other species, such as *Clarias lazera, Heterotis niloticus* and common carp on a regular basis.

Polycultures are now practised in several African countries using *T. nilotica* as the main species, combined with *C. lazera*, common carp and sometimes *Heterotis niloticus*. Other combinations are *I. Andersonii* with common carp (Zambia), *T. shirana* and common carp (Malawi) and common carp and silver carp (*Hypophthalmichthys molitrix*) or grass carp (*Ctenopharyngodon idella*) in Lesotho.

In Central Africa, in polyculture of *T. nilotica* (200 fingerlings/100 m^2) and *C. lazera* (between 50 and 150 fingerlings/100 m^2, fed 30% vegetable protein pellets, the total production reached 4 950 kg/ha/year (average of 5 trials) during a production period of about 100 days. In *T. nilotica* monoculture (200 fingerlings/100 m^2), fed the same pellets and during a rearing period of 200 days, the yield was 3.651 kg/ha/year (average of 6 trials).

The species to be used in polycultures should live in different ecological niches and should have complementary feeding habits.

Several combinations have been proposed by different authors, depending on the kind of natural food available in the ponds and the kind of supplemental feed distributed. The most common associations are:

- Tilapia species (plankton feeders) and common carp (omnivore)
- *T. nilotica* + *Hemichromis fasciatus* (predator)
- Tilapia species + *Heterotis niloticus*
- *T. nilotica* (phytoplankton feeder) + *T. rendalli* (herbivore).

To these combinations, one can add some *Haplochromis mellandi* or *Arsatoreochromis alluaudi* fingerlings (about 10 fingerlings/100 m^2) to control snail populations (vectors of bilbarzia).

3.3 Fish culture combined with animal husbandry

Simultaneous production of fish in ponds, combined with pig, duck or chicken rearing in pens, beside or over the ponds, is now considered as one of the most promising productive systems for rural Africa.

This production technique constitutes a continual organic fertilisation of the pond by the livestock and is very productive, not only in polyculture of *T. nilotica* or *T. Anderson ii* with common carp, but also in other combinations. This practice increases the efficiency and rentability of both livestock farming and fish culture through the profitable utilisation of animal and feed wastes. In this system the fish do not generally receive any artificial feed. This integrated farming system has produced some of the highest fish yields in ponds in Africa (Vincke, 1976).

3.3.1 Fish-cum-pig culture

Pigs are reared in pens or styes built on the margin of the ponds or constructed over the ponds on piles. The number of piglets recommended is 100 per ha (or 1 piglet per 100 m^2 of pond). It is estimated that an adult pig produces an average of 3 tons of manure/year. Piglets are weaned at two months (weight between 12 and 15 kg) and are ready for fattening. With proper feeding, the average weight of market pigs is 70 - 72 kg after 6 months and about 85 kg at seven months.

In ponds stocked with *T. nilotica* at a rate of 2 fingerlings/m^2, the production can reach 8,000 kg of fish per ha/year and 6,000 to 9,000 kg of pigs (on the hoof) per ha/year (Vincke 1976).

With *T. Andersonii* (monoculture), combined with pigs, 7,000 kg of fish per ha/year were obtained in Zambia. Monoculture of *Clarias lazera* with pigs yielded 7,510 fish per ha/year in Central Africa. The grow-out period was 90 days and the daily growth rate of *C. lazera* was 2.9 g/day.

In polyculture (*T. nilotica*: 200-300 fingerlings/100 m^2 + *C. lazera*. 10, 15, 20 and 100 fingerlings/100 m^2), with pigs (1 to 2 pigs per 100 m^2 of pond) and small quantities of brewery wastes and spoiled flour (directly fed to the fish in the pond), the average yield was 11.140 kg fish per ha/year (average of 4 trials).

If for socio-cultural reasons pig farming is not possible, the combination of chickens or ducks and fish is recommended.

3.3.2 Fish-cum-duck culture

Ducks are reared in pens over the ponds at a density of 1,000 to 1,500 ducklings/ha (10 to 15 per 100 m^2). Peking and Musocvy ducks are generally raised in Africa. The shelter where ducks are fed and spend the night is built over the pond on poles. The floor is made of lattice work to permit droppings and feed wastes to fall into the water. Under good conditions ducks reach 2 kg after 8 to 9 weeks. (Vincke, 1976). Peking ducks are preferred over Muskovy ducks since they stay on the water for much longer periods of the day than the Muskovy ducks. The ducks should be kept away from the dykes since they search for insects, frogs and snails, damaging the walls with their beaks and provoking erosion and the collapse of the dykes. Fencing inside the ponds is therefore recommended.

Ducks are known to eliminate almost all the snails in ponds in depths of up to 30-40 cm, thus controlling the intermediate hosts of bilharziasis.

In fish-cum-duck culture, ponds are stocked with tilapias, common carp or *Clarias lazera* at the rate of 2 to 3 fingerlings/m^2, without artificial feeding of the fish. Production can reach 2 500 to 4 500 kg fish per ha/year and 1 500 kg of duck per ha/year (Vincke, 1976).

In Zambia, using *T. Anderson ii* combined with Peking ducks, yields of 5 t fish per ha/year were obtained.

For large-scale extension of fish-cum-duck culture, a well-operated breeding and duckling distribution centre is needed. The production of ducklings is, of course, dependent upon the maintenance of an adequate brood stock (1 male to 4-6 females) of a selected strain. During one laying season, and under good conditions, a Peking duck will lay 120 to 160 eggs. During peak production, two eggs are laid every three days. One female duck will produce 70 to 80 one-day-old ducklings during a laying period of eight months under suitable conditions (Woynarovich, 1979).

3.3.3 Fish-cum-chicken culture

Chickens are reared in pens beside or over the ponds in roughly the same conditions as ducks, at a density of 10 to 30 chickens per 100 m^2 of ponds (1 000 - 3 000 chickens per ha).

It is estimated that one chicken produces about 40 g of excreta per day, or about 14-15 kg droppings/year and that a laying hen will produce enough manure to generate about 6-8 kg/year of fish biomass (Kassar, 1983).

Chicken culture is combined with polyculture of *T. nilotica* (2 fingerlings/m^2) and *Clarias lazera* (1 fingerling/m^2). One can also utilise common carp. After a rearing period of 4 to 5 months the production of fish can reach between 3 500 and 5 000 kg/ha/year (or 35 to 50 kg/year per m^2 of pond surface). At each harvest of the ponds, the production of chickens (live weight) is between 40 and 60 kg per 100 m^2 pond, depending on the number of chickens raised and the type of breeds used (Vincke, 1976).

The egg production (about 120 to 200 eggs/year per layer) can give a very interesting supplementary income.

3.4 Rice-cum-fish culture or rizipisciculture

Fish can be cultivated in association with irrigated rice culture. Rice will be the principal harvest and the fish production is considered as a complementary production.

Fish culture in rice fields is one of the best ways of using available aquatic resources in that additional protein production is obtained from irrigated rice areas (Coche, 1967). As a rule, the water in rice fields reaches a level of 5-25 cm. As the soil of the rice fields is highly fertile, the production of zoo and phytoplankton is high. These resources can be fully utilised by fish, thus converting into edible food what rice plants do not utilise (Vincke, 1979).

Since rice remains the main crop, fish culture has to be adapted to its requirements. Firstly it is essential to have complete control over the water and to provide drainage outlets in the rice fields. Secondly, one or more refuges must be made for the fish when the water level is lowered in the rice fields.

The species of fish to be used must be able to survive in shallow water, and to endure high water temperatures and low dissolved oxygen levels. Fish species should also be sedentary, have rapid growth and be able to withstand turbid water. Madagascar is the only country in Africa where rice-cum-fish culture is practised on a large scale, using common carp and some tilapias at stocking densities of about 2,500 fingerlings per ha (or 25/100 m^2 of rice field). The fish are harvested after a rearing period of about 120 - 140 days, and the yield is generally between 150 and 200 kg of fish per ha/year.

3.5 Fish culture in cages

Even if cage culture in rural areas is still practised on a pilot level, as in the Ivory Coast, cage culture is possible in almost all the small reservoirs and conservation dams built all over Africa during the last years.

Fish culture in cages and the conditions under which it is undertaken have been described by Coche (1976, 1977, 1978, 1979, 1982), Campbell (1978a, 1978b, 1983), Vincke *et al* (1981) and Balarin and Haller (1982).

Cage culture is a more sophisticated method than pond culture and can be practised on an artisanal level. Artisanal cage culture is more capital intensive than pond culture and good results, with economic returns, can only be obtained through intensive feeding (feed with protein content between 24-30%).

In rural areas, cages should be stocked with *T. nilotica* fingerlings, weighing at least 20 g each and harvested after 150 days of intensive culture. Fingerlings weighing 40 g on average can be harvested 30 days earlier. To maximise production and profit, high stocking densities of fingerlings are recommended, with a suggested initial biomass of about 20 kg/m^3. Experimental production in 1 m^3 cages ranged between 35 and 64 kg/m^3) in four months, with an average rearing mortality of 5.9%. Food conversion rates normally range around 2.0 with pelleted feed.

According to Campbell (1983) the main constraints for development of cage culture in the Ivory Coast have been the following:

(i) The lack of calibrated fingerlings, their availability throughout the year, at a normal price.

(ii) Availability of adequate pelleted feeds.

(iii) The occurrence of bacterial diseases at high stocking rates, especially in brackish water cage culture.

(iv) Marketing problems for large quantities of fresh fish (purchasing power of the consumers).

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