On-farm feed management practices for Nile tilapia *(Oreochromis niloticus)* in Thailand

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ABSTRACT

This document describes the on-farm feed management practices used in the culture of the Nile tilapia (*Oreochromis niloticus*) in Thailand. A survey was undertaken to establish the feed practices used in pond grow-out systems, river-based cage systems, and hatcheries. Pond culture is common in Thailand, especially in rural areas. Almost all of the subsistence tilapia farms employ polyculture systems whereas most of the commercial farms practice single species all-male tilapia culture. Silver barb (*Barbonymus gonionotus*), snakehead (*Channa spp.*), hybrid catfish (*Clarias gariepinus* x *C. macrocephalus*), common carp (*Cyprinus carpio*), and some Chinese and Indian major carps are among the species used for polyculture. Almost all the farmers fertilize their ponds with either chicken manure and/or chemical fertilizers to enhance the natural productivity of the culture systems. Feeding is undertaken on a supplementary basis. Although good quality aquafeeds are available in Thailand, their high prices and the low price attained for pond-grown fish make their use currently uneconomic. The cheapest feeds and feed by-products available are used to minimize production costs, thereby maximizing profits. Almost all the farmers surveyed employed hand feeding twice per day, and generally reported FCR values of less than 1:1. However, as the fish receive a considerable amount of nutrients from the natural productivity in the ponds, the true FCR values accruing to the supplementary feeds are difficult to establish. The feeds/ingredients that are used are not of a standard quality in terms of nutrient composition and moisture which further exacerbates the problems associated with establishing accurate FCR values. In recent years, cage farming in rivers and canals has become a popular culture option. Almost all the cage farmers practice monoculture, using varieties of red or black Nile tilapia. Although commercial pellets are used, the feeds are normally of a low quality with a low crude protein level (~20 percent). On average, cage farmers feed three times a day, and attain FCR of 1.4–1.8:1, and growth rates of 2–3 g/day.

In terms of feed distribution, feeds and feed ingredients are transported in pick-up trucks by the farmers or delivered by the manufacturers/feed dealers. Farmers store their feeds in sacks in cool storage areas. Prior to feeding, the feeds are normally kept in large plastic buckets at the pond sites or at the riverbanks, and the quality of these feeds often deteriorates as a result of the high humidity and the extreme heat of the sun during the daytime. In general, raising tilapia using high quality commercial feeds is not profitable, and thus the selection of appropriate feeds is one of the most important decisions that farmers make in terms of ensuring the profitability of their farming operations. Training in feed production and improving their feed management practices is required to assist the farmers in increasing their profitability. This training should include the selection of feed ingredients, storage systems, and feed management practices. In this regard, the production and distribution of a training manual in local languages outlining best farming practices would be useful.

1. INTRODUCTION

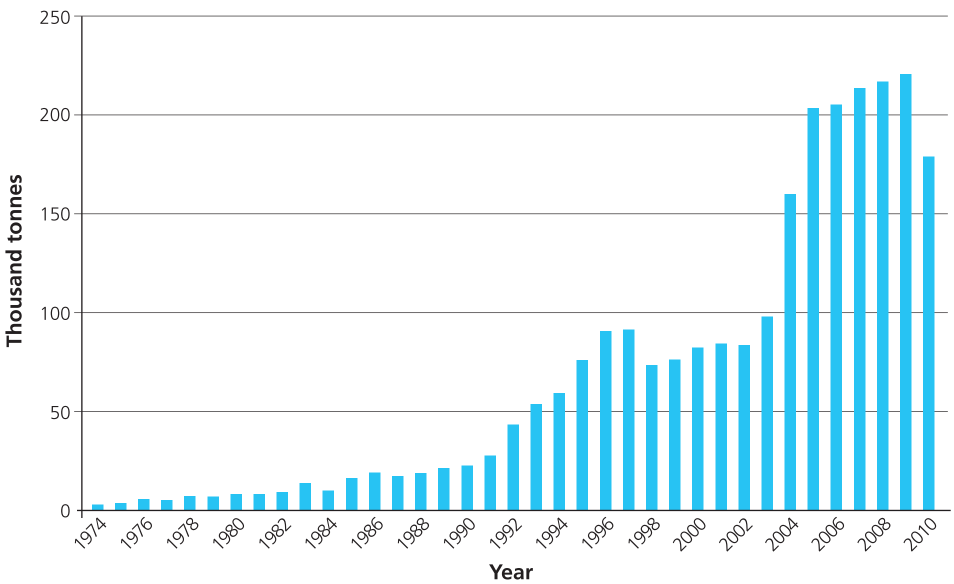
Nile tilapia (*Oreochromis niloticus*) were first introduced to Thailand in 1965 when 50 fry were imported (Pullin, 1998). These fish represent the founding stock for Nile tilapia culture in Thailand, and are popularly known as the 'Chitralada' strain. Since the 1960s, tilapia culture has expanded rapidly, and it is now the main fish culture species in the country. As tilapia grows well under adverse environmental conditions, it has become the culture species of choice for many poor farmers. Indeed some shrimp farmers started to culture the species in rotation with shrimp when production in that sector was impacted by disease in the mid-1990s. The Nile tilapia 'Chitralada' strain has been used as the founder stock for tilapia culture in many countries, including Bangladesh, Brazil, Cambodia, Laos, the Philippines, Myanmar, Nepal, and Viet Nam. Over the past two to three decades, broodstock, fry, and associated production technologies have been transferred to these countries.

Since the 1960s, other strains of Nile tilapia have been introduced into Thailand. For example, in the late 1990s, the Genetically Improved Farmed Tilapia (GIFT) strain and the red tilapia – a hybrid of Nile tilapia (*O. niloticus*) and Mozambique tilapia (*O. mossambicus*) have been introduced. At the same time, other red hybrid varieties such as Taiwanese red and the Malaysian red have been developed through selective and cross breeding programmes. The Thai Department of Fisheries (DoF) has also developed its own strain, known as 'Thai red'. The local name given by the His Majesty the King of Thailand, for red tilapia is 'Thapthim', meaning 'ruby'. The development of this strain provided a boost to the industry by increasing the price of the fish and, in this regard, many people consider 'Thapthim' as a premier tilapia product.

In, 2006, Thailand produced 2.8 million tonnes of fish and became the ninth world producer nation (FAO, 2009). In terms of export earnings (US$5.2 billion), the country became the third largest exporter of aquaculture products after China and Norway, and Thailand is now sixth in the world in terms of producing food fish from aquaculture (FAO, 2013). Annual per capita fish consumption in Thailand is about 35 kg, indicating that fish is an important dietary component for the Thai people (FAO, 2009). Aquaculture production has risen steadily since 1950, and in the past 20 years it has increased by approximately 800 percent (Bhujel and Stewart, 2007). In terms of freshwater production, more than 300 000 farmers currently culture fish in over 0.1 million ha. Over 97 percent of the total farming area comprises of ponds, and the remaining 3 percent comprise tanks, raceways, ditches and cages. Combined, the total Thai freshwater aquaculture production has reached about half a million tonnes per annum with the top five species being Nile tilapia (*O. niloticus*), hybrid walking catfish (*Clarius macrocephalus* x *C. gariepinus*), silver barb (*Barbonymus gonionotus*), freshwater prawns (*Macrobrachium rosenbergii*), and snakeskin gourami (*Trichogaster pectoralis*), respectively.

Nile tilapia, known as *Pla Nin* amongst the Thais, constitutes the largest production sub-sector, eclipsing hybrid catfish production in the mid-1990s. Although it was introduced to farmers in the field by the Department of Fisheries (DoF) in the mid-1960s, tilapia production did not significantly increase until 1990 (Figure 1). This was probably a result of a lack of production technologies, including breeding and feed management protocols. The increase in production coincided with the development of seed production systems, and notably the introduction of sex-reversal technologies. Once this technology was developed and commercialized, production exponentially increased. During this period, tilapia production surpassed catfish production to become the major culture species in the country. It has not been established why production remained stagnant between the mid-1990s and the mid-2000. However, it is possible that production levelled off as a result of a saturated domestic market and high production costs, which made the penetration of export markets problematic. Nevertheless, since 2004 production has increased, possibly as a result of the promotion of cage culture in rivers, reservoirs and canals, and notably the culture of red tilapia (Thapthim) under contract farming agreements. Recent estimates based on a market survey and seed production data show that total production has been underestimated at least by 50 percent (Belton *et. al*., 2009; Bhujel, 2009). The annual tilapia production reported in 2010 is over 179 000 tonnes (FAO, 2013); this is over 10 times more than the production level reported in 1987.

FIGURE 1
Total production of tilapia in Thailand (1970–2010)



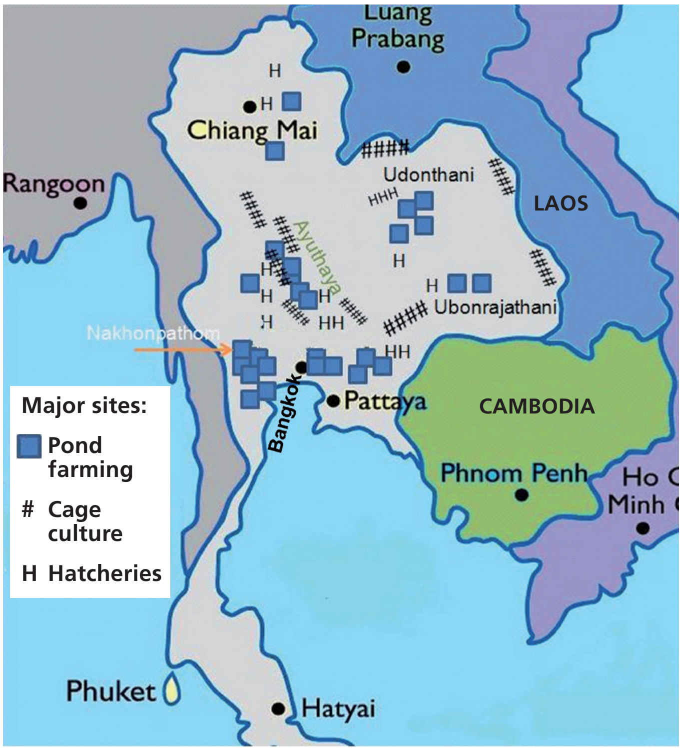
Source: FAO (2012).

2. CASE STUDY METHODOLOGY

2.1 Survey method

An interview survey was undertaken at a regional level in various parts of Thailand (Figure 2). Approximately one fourth of the respondents was met personally and interviewed using semi-structured questionnaires. Others respondents were contacted telephonically and interviewed using the same questionnaire. Information regarding the feeds and feeding management practices that are applied to broodstock and fry were derived from 13 tilapia hatcheries. Information pertaining to the

FIGURE 2
Map of Thailand showing the major sites of tilapia hatcheries, ponds and cages contacted/visited for the collection of information



Source: R.C. Bhujel.

Note: tilapia hatcheries (H), ponds (■) and cages (##) contacted/visited.

use of grow-out feeds and feeding methods was based on 60 grow-out farmers, 20 percent of whom were cage farmers. Among the pond farmers, the majority of farmers used polyculture systems. Almost all of the subsistence tilapia farms use polyculture systems, whereas most of the commercial farms produce single species all-male tilapia. Silver barb (*Barbonymus gonionotus*), snakehead (*Channa* spp.), hybrid catfish (*Clarias gariepinus* x *C. macrocephalus*), common carp (*Cyprinus carpio*) and some Chinese and Indian major carps are among those species used in the polyculture systems. In contrast, all the cage farmers practised monoculture, either of red (*Oreochromis niloticus* x *O. mossambicus*) or Nile tilapia (*Oreochromis niloticus*).

2.2 Description of the surveyed areas

Although tilapias are farmed throughout Thailand there are some clusters or concentrations of production systems in specific regions of the country. Tilapia culture is primarily concentrated in the inland areas, with shrimp farming dominating at the coast. The most common production system that is used in Thailand is pond culture. Either monoculture or polyculture systems using catfish and various carp species are used. Bangkok and the surrounding provinces, including Nakhon Pathom, Pathumthani, Ayuthaya, Suphanburi, Prachinburi, Chachoengsao, Chonburi and Samutprakan, are the main areas where tilapia farming has become a well-established commercial activity. These areas are particularly suitable for tilapia culture because:

- There is low land where abundant water is available throughout the year.
- There is warm weather throughout the year with temperatures rarely falling below 25 °C.
- There is a good market in Bangkok and the surrounding areas.
- There are good facilities in these areas including transportation, processing and packaging.
- Cheap feeds are available (e.g. restaurant wastes, wastes from chicken factory).

Other areas where tilapia farming has become common include the northeast of the country, in an area popularly known as Isan. The major provinces in this region include Udonthani, Uborachathani and Nongkhai. This region is considered the poorest region of the country, and various community development organizations are promoting tilapia as a mechanism to promote food security and reduce poverty. Although the region is in a drought-prone area, tilapia is currently grown in almost every village; however, the majority of farmers have to wait until the rain starts to stock their fish. As one of the most popular destinations for tourism in Thailand, Chiang Mai also has a high demand for fish and seafood, and tilapia farming in this area is also expanding. Although, in comparison with the rest of the country winters are slightly cooler, tilapia can still breed and grow in this northern region.

In the late 1990s, cage culture systems were developed and they have now expanded to many parts of Thailand. These systems are primarily located along the banks of major rivers and canals. One of the most important rivers is the Chayophraya River and its tributaries that connect Bangkok to Chiang Mai. The cage systems are particularly popular in Pathumthani, Ayuthaya and Supanburi provinces. Another important river that has been used for tilapia cage farming is the Mekong River along the border with Laos, particularly in Nong Khai, Mukdahan and Ubonrajathani provinces of the northeast region.

3. MAJOR FINDINGS

3.1 Traditional fry production method and feeding

Mixed-sex tilapia seed are produced through natural spawning in small and medium earthen ponds. The production system comprises three basic components, *viz*. broodstock collection and management, natural spawning and fry collection, and the rearing of the fry in nursery ponds.

Broodstock are normally purchased from hatcheries that are known for the production of high quality fish. The fish are stocked at 3–4 fish/m^2 in small to medium sized broodstock rearing earthen ponds. Ponds size are normally between 1 000–1 600 m^2, with depths ranging between 1.0 to 1.5 m. Prior to stocking, all predator and other fish are eradicated using pesticides such as rotenone and potassium cyanide, and the ponds are limed at 250–500 kg CaO/ha. About a week after the liming process, the ponds are manured and fertilized with chicken manure at 800–1 000 kg/ha, and with urea and triple super phosphate (TSP) at 25 kg/ha each.

During the broodstock growth and conditioning period, some farmers use formulated or commercial feeds. These contain 25–30 percent crude protein. Feeding rates vary between 1–3 percent of body weight per day during the adult stage, and up to 10 percent at the younger stages of production. It is common that during rearing, seven to fourteen day old fish are fed to satiation and then placed on restricted rations thereafter. When formulated feeds are not available or are of dubious quality, the hatchery owners may elect to use alternative farm-made feeds. Typically these comprise mixtures of 60 percent rice bran and 40 percent soybean cake or 75 percent rice bran and 25 percent fishmeal. These feeds are fed at 3–5 percent biomass per day over two rations.

In the nursery ponds, the tilapia fry are reared using a two-stage process. In the first stage, fry are stocked in well prepared nursery ponds at 500–600 fry/m^2. Early fry are fed with powdered feeds that comprise a mixture of rice bran and mustard oil cake (1:1 ratio) at 12–15 percent initial body weight. The ration is fed over 3–4 feeds per day. The fry are reared for about 21 days in these ponds to attain an average weight of about 1 g. At this point some of the fry are usually sold directly to buyers, or reared in another series of nursery ponds at stocking densities of between 200 and 300 fry/m^2.

Second stage (or advanced fry) production produces larger fish over a further 40–60 days, These fish are reared at stocking densities ranging between 100–200 fry/m^2 in well-prepared nursery ponds. During this stage of production, the fry are fed formulated feeds and the feeding rate is reduced to 8–10 percent biomass per day. The fish are fed 2–4 times per day until fingerlings attain the average body weight of between 8–10 g each.

Concrete tanks are often used for tilapia seed production. The tanks that are constructed do not require large areas of land, and are therefore often located in the towns and cities. Tilapia breeding tanks are generally simple and smaller in comparison to the grow-out tanks. Normally farmers use rectangular tanks of various sizes – between 2.0–10.0 m long, 2.0–4.0 m wide, and with a depth of 0.8–1.0 m. Sexually matured broodstock weighing between 80–100 g each are stocked in the breeding tanks at a density of 3–4 fish/m^2, and at a sex ratio of 1 male to 3 females. Usually the breeders are replaced when they attain an average weight of 250 g or more.

A mixture of 60 percent rice bran and 40 percent mustard oil cake, or 75 percent rice bran and 25 percent fishmeal is fed to the broodstock at 3–5 percent of body weight per day. Feeding is undertaken twice a day. While mouth brooding the females do not consume artificial feeds, and thus feed rations are reduced during this period to minimize feed wastage and to maintain good water quality.

For the first week after mouth brooding, fry are stocked at 1 000–1 200/m^2 and fed with a high protein powdered feed containing at least 35 percent crude protein, and at 15–20 percent of body weight per day. Feeding is undertaken between 4 to 6 times per day. After a week, the density of the fry is reduced to 500–600/m^2, and feeding rates are reduced to 12–15 percent of body weight per day. After the second week, the density is again reduced, and the fry are stocked at 300–400/m^2, and fed at 10–12 percent of body weight per day. Once the fry attain a weight of 1 g, they are usually sold. Advanced fingerlings (20–30 g) may be produced by rearing for a longer period in tanks, and at stocking rates of 100–150 fry/m^2, using formulated feeds containing crude protein levels of approximately 30 percent for a further 40–60 days.

3.2 Mono-sex fry production and feeding

The techniques for producing high quality mono-sex tilapia fry on a large scale using hormonal sex-reversal was developed early 1990s at the Asian Institute of Technology (AIT). A series of research trials established the production techniques in hapas (suspended enclosures in water bodies). The process involved the collection of eggs, artificial incubation, the rearing of the larvae in trays, and sex-reversal using the hormone methyl testosterone. The technology spread throughout the country once a private hatchery farm successfully commercialized the technology. After continuous efforts to transfer the technology through public and private sector channels, the technology has spread all over the world, and now accounts for the production of an estimated two billion mono-sex tilapia fry per year (Bhujel, 2009). It has been estimated that Thailand alone produces over a billion fry per year using this technique; about one fourth of this is believed to be red tilapia. In Thailand there are over 40 private hatcheries and, according to a DoF staff member, every provincial fisheries station now has a tilapia hatchery using this technology. The technique is becoming increasingly popular in Bangladesh, Brazil, P.R. China, Indonesia, Myanmar, the Philippines, Viet Nam and several other countries. Assuming 60 percent of the stocked fry survive and are sold, nearly one million tonnes of tilapia (i.e. about one third of the global tilapia production) is produced using this technique per annum – this is sufficient to supply 60 g of high quality protein (of fish meat) twice a week to over 30 million people. Although, tilapia production in Thailand has been formally estimated at about 200 000 tonnes per annum, actual production is believed to be much higher, possibly 50 percent higher (Belton *et. al*., 2009; Bhujel, 2009); however, as most tilapia are sold in local markets and consumed at home, it is difficult to keep accurate records.

3.2.1 Breeding system and feeding management

Broodstock fish are a key element of the hatchery production process, and their quality and management affects the quality and quantity of seed production. A large-scale mono-sex tilapia hatchery farm supplying over 10 million fry per month maintains

FIGURE 3
Breeding hapas and egg collection

a large number of brooders, working broodfish, and new batches for replacement every two years. Feed represents the major production cost for the hatchery operators. The production of mono-sex tilapia is undertaken using hapa-based systems. For example, on the Nam Sai (Prachinburi) and other large farms, breeders are stocked in large nylon hapas of 120 m^2 (24 m x 8 m, Figure 3) and covered with bird nets to deter predation and to reduce heat stress. Some other farms, such as AIT (Pathumthani) and the hatcheries in Udonthani (Provincial hatchery, Agriculture College, and Isan Aquatics), use smaller size hapas (40–60 m^2). Depending on the scale of the operations, the farms may maintain up to 100 000 broodstock. Males and females are stocked at ratios of 1:1 or 1:2 (male:female) and at various densities. Typical broodstock stocking densities are 2/m^2 in ponds, 6/m^2 in hapas and 10/m^2 in tanks.

Feed management practices need to be optimized in order to supply the nutrient requirements of the broodstock, maintain water quality and keep production costs low. Feeding up to 25–50 percent of satiation produces more eggs (e.g. *O. mossambicus*, Mironova, 1977). Applying supplementary feeding regimes, Nile tilapia fed at 1 percent of body weight per day produce more seed than fish fed at 0.5 percent or 1.5 percent biomass. In a study with *O. niloticus* (Bhujel, 1999) in hapas, a feeding rate of 1.4 percent of body weight per day was more productive than feeding at 0.7 percent of body weight per day; however, on the higher ration, the broodfish grew too large to handle within 3–4 months. A feeding rate of about 1.0 percent of body weight per day is suitable for tilapia broodfish in greenwater production systems, whereas in clearwater production systems a feeding rate of 2.0 percent of body weight per day is optimum. In greenwater systems, a feeding frequency of twice per day as opposed to once per day produces more seed when the feed ration is reduced (0.5 and 1.0 percent of body weight per day), but less seed were produced when the ration was increased to 1.5 percent of body weight per day. Tilapia females incubating eggs and fry in their mouths do not feed. However, on cessation of mouth brooding, they compensate for the restricted feed intake. Higher feeding rates for the first 2–3 days after seed harvesting followed by lower feeding rate may prove to be an economical feed management practice (Bhujel, 2000). Alternatively, it is possible that for the first one to two days after each seed harvest, feeding rates of twice or thrice a day followed by once a day thereafter might produce similar results. As tilapias do not eat early in the morning, feeding is undertaken after 8 am, followed by a second feed before sunset.

Similarly, small pellets or high-energy rations with low feeding rates seem to produce better results than large pellets or high feeding rates; this could possibly be due to differentials in feed intake and nutrient utilization. If they are available and affordable, floating pellets are recommended for the broodstock. Resource-poor farmers may simply use rice bran in combination with oil cakes and/or fishmeal. These feeds usually contain between 25–30 percent crude protein, 12 percent moisture, 4 percent fibre and 8 percent lipids (Bhujel, 2001; Bhujel *et. al*., 2001).

Prior to broodstock stocking, ponds are drained and sun-dried for at least a week, and limed at 500–1 000 kg per ha. Ponds are fertilized with urea and TSP at 28 kg N and 14 kg P/ha. This is undertaken on a weekly basis to enhance the natural productivity of the ponds and thus provide additional supplemental feed to the broodstock. Some hatcheries, such as Chamnoeng Farm in Chiang Rai, use tanks (100 m^2 stocked with 200 females and 100 males). If the broodstock are in clearwater systems, they are fed commercial feeds (35 percent protein) at 2–3 percent body weight per day, twice daily. It is interesting to note that recent unpublished research shows that using greenwater systems with supplementary feed produces better egg production compared that achieved when using commercial pellets in clearwater systems (no fertilization in ponds).

3.2.2 Broodstock fry rearing and feeding

Broodstock are normally replaced after 2–3 years when they grow to over 400 g. This is due to the fact that large fish are difficult to handle while collecting eggs from their mouths. Depending upon the scale of operation, new batches of brood fry have to be prepared to replace breeding stock. During broodstock rearing, most hatcheries in Thailand use mixtures of rice bran and fishmeal, although some hatcheries use commercial pelleted feeds. Table 1 provides a summary of the procedures used for broodstock fry rearing and maturation.

TABLE 1

Normal procedures for broodstock rearing and maturation

Month	Stage	Stocking density (number/m^2)	System	Feeds and feeding
0–2	1st nursing	1 000	Hapa	Rice bran and fishmeal (3:1), 5 times daily, *ad libitum*
2–4	2nd nursing	200	Hapa	Rice bran and fishmeal (3:1), 5 times daily, *ad libitum*
4–6	Maturation	1	Pond	Same as above or pellets (~30% CP), twice daily, *ad libitum*

Source: Bhujel (2012).

3.2.3 Egg incubation and larval rearing

Harvested eggs are separated according to their five developmental stages:

- Stage I: freshly laid eggs, normally yellow in colour.
- Stage II: 1-day old embryos with a reddish colour, two small eye spots may be seen.
- Stage III: 2-day old embryos with protruding eyes and a small tail.
- Stage IV: 3–4 day old yolk-sac fry after hatching.
- Stage V: Well developed swim-up fry.

Stage I–III are incubated artificially in plastic, fibreglass or simple plastic glass jars supplied with clearwater that has been treated, either using slow sand filtration, UV treatment or alternative filtration systems. When the eggs hatch and mature to stage IV (or are collected from the broodfish), they are moved to shallow trays. Most hatchery operators do not feed during these stages. However, some start feeding hormone-laced feed (see 3.2.4) for about a week as the fry start to swim-up i.e. Stage IV. The rationale is to habituate them to external feeds before they go to the sex-reversal hapas/tanks.

3.2.4 Sex-reversal and feeding management

The early nursing of fry is normally undertaken in hapas in ponds – this method represents the cheapest production paradigm. However, some hatchery operators use tanks fitted with re-circulation systems. Fry are treated with a hormone (17α-methyltestosterone, hereafter referred to as MT) to produce all-male populations. The fry at their first feeds are fed for 21 days on a mixture of fishmeal and MT hormone five times a day. This process produces phenotypically all-male populations, which prevents breeding in grow-out systems, and results in growth rates that are approximately 20 percent faster than those of untreated populations (comprising 50 percent females). Sex-reversal feed is prepared (Figure 4) according to the following protocol:

- 60 mg of 17μ-methyl-testosterone (MT) is mixed with 1 kg of fishmeal and 10 g of vitamin C.
- As the hormone is insoluble in water, ethyl alcohol is used as a solvent. Normally a stock solution of 5 g of hormone in 10 litres of ethyl alcohol is prepared, and stored in a refrigerator. The stock solution can be stored for 6 months.
- The hormone is added to the feed by adding 120 ml of the stock solution and 120 ml of fresh alcohol and mixing.
- The alcohol is evaporated off by spreading the mixed feed under shade for about an hour. The feed is dried under mild sunlight as the efficacy of the hormone declines in the presence of high heat and bright light.
- After drying, the feed is packed in plastic bags or kept in the container with tight lid and stored in a room at low temperature.

Tilapia fry accept feed immediately after yolk-sac absorption. There is no need to feed live feeds such as algae, *Artemia* and rotifers. Normally, tilapia fry are fed with fishmeal, rice bran or oil cakes separately or in combination, either in a powdered form or as dough. However, feeding practices depend on the production systems in use. Some commercial hatchery operators in Thailand use shallow trays in re-circulation systems and feed fine fishmeal (~60 percent CP) to supply dietary nutrients, and to initiate/habituate the fish to feeding on artificial feeds. This is done so that when they are transferred to hapas in ponds, they readily accept pelleted feeds. This practice ensures improved food intake and the ingestion of sufficient hormone to ensure sex-reversal. Feeding larvae after yolk-sac absorption appears to be beneficial to the fry; however, accumulated uneaten feed can pollute the system, necessitating frequent cleaning. The swim-up fry reared in recirculation systems are transferred to fine mesh hapas suspended in greenwater ponds.

To achieve sex-reversal, the fry are stocked at a density of 5 600–6 000 fry/m^2 in hapas installed in ponds/tanks (Figure 5), and are fed with the MT mixed feed at 70, 150, 250 and 420 g/day for 30 000 fry (in 5.4 m^2) during the periods (days) 1–5, 6–10, 11–15 and 16–21, respectively. A total of 4.87 kg of MT feed is required to sex-reverse 30 000 fry. The feeding rates range from about 30 percent of the fry biomass per day at the beginning of the process to about 10 percent at the end. Fry are fed 5 times a day, normally at 08.30, 09.30, 11.30, 13.30 and 15.30 hours. The size of the hapas that are used during the 21 day hormone treatment depends on the scale of production. The smallest hapas are 5.4 m^2 and the largest 20 m^2. Hatchery operators who do not practice sex-reversal, feed their fry

FIGURE 4
Locally designed feed mixer with 15 kg capacity for sex-reversal feed production

COURTESY OF FAO/R.C. BHUJEL.

FIGURE 5
Feeding sex-reversal feed to tilapia fry reared in a hapa using a bamboo stick

with a mixture of rice bran and fishmeal (2:1 or 3:1). Nursing the fry normally begins when the fry attain a weight of 0.2 –1.0 g. While many farmers feed rice bran alone 4–5 times daily, others rely on natural food enhanced with organic/inorganic fertilizers, or feed small pellets prepared for catfish or shrimp.

Good quality (high protein /palatability) fishmeal is used to promote feeding and ensure that the required level of hormone intake is attained. Local Thai fishmeal is cheaper (35 Baht/kg[1]) but it is lower in quality than imported products. The use of the local fishmeal generally results in a lower percentage of males. Fishmeal imported from Peru or Chile has been found to be of a suitably high quality and results in a high percentage of males. However, the imported fishmeal is relatively expensive (38 Baht/kg), and can often only be sourced in bulk (27 tonnes/container) – this often makes it unavailable to the smaller hatcheries. As a result, hatchery operators in Thailand are trying to identify alternate, low-cost feeds. In this regard, silkworm pupae were found to be a good fishmeal replacement; however they are only available in small quantities, and are thus only a partial solution. Similarly, some hatcheries use a high quality shrimp starter feed with 40 percent crude protein (42 Baht/kg); while the price of this feed is even higher than the imported fishmeal, it is readily available in the local market. This suggests that feed price is not the major factor in deciding what feed to use during sex-reversal, but rather that quality and availability are the key determinants.

3.2.5 Nursing/holding

Grading fry is very important in the latter stages of the fry production process, as it minimizes cannibalism related mortality and the development of dominance hierarchies. The first grading is undertaken after one month of hatching, followed by a second grading one week later, or a few days prior to sale. Fry are usually grouped into 3–4 size categories – small, medium, large and very large. The fry nursing period ranges from a few days to a month or so, and is dependent upon the demand for fry. During nursing, fry are kept in hapas at a density of 1 000–2 000 fry/m^2. The size of hapas range from 20 to 120 m^2, depending upon the scale of the operation. On some farms, fry are fed a mixture of rice bran and fishmeal (2:1 ratio, Table 2), 4–5 times a day and at 25–50 g/m^2/day. In contrast many farms use small floating pellets.

TABLE 2
Simple farm-made feed for tilapia nursing used by Nam Sai Farm, Thailand

Feed ingredients	Proportion (%)
Fishmeal	33.3
Rice bran	66.7
Total	**100.0**

Source: Field survey (2010).

[1] US$ 1 = Baht 32.5

Small (<2 cm) fry are susceptible to predation by other fish and birds. They are also less tolerant to poor water quality, which is a common feature in ponds that are fertilized with organic manures. The first month of the production cycle is crucial to survival, and if the fry can be nursed for at least a month before stocking them into the grow-out ponds, their survivorship can be increased significantly. The following guidelines are commonly used during fry production:

- Cages or hapas in ponds, reservoirs and lakes are ideal for nursing. The systems must be well protected from birds and other predatory fish or animals.
- Smaller ponds (50–500 m^2) are prepared, drained and dried completely for at least a week. Ponds are limed at 500–600 kg/ha, and filled with the predator-free water.
- A week before stocking the fry, the ponds are fertilized with urea and TSP to promote natural productivity. After fertilization, uneaten feed and their excreta will maintain pond productivity. Excessive productivity (greenwater) is undesirable during nursing, and therefore organic manures are not applied to the nursery ponds.
- The stocking density applied to nursing fry is 500–1 000 fry/m^2 in hapas/cages, and 100–200 fry/m^2 in ponds.
- Fry are fed floating pellets or a mixture of rice bran and fishmeal (2:1), 2–4 times a day, and at 5–10 percent of body mass per day, or to satiation.
- For convenience purposes, some tilapia hatchery operators use small catfish pellets – however, these pellets are often too large for the fry to ingest, and need to be crushed.
- The nursing period normally lasts for one month. During this period fry attain a weight of 1 g which is large enough to stock into the grow-out ponds.
- Farmers time their fry purchases according to their production cycles and take into consideration nursery production and fry availability, the preparation of the grow-out pond and fry stocking times. The farmers purchase their fry one to two weeks prior to the harvest of the grow-out pond, as it takes at least two weeks to prepare (drying, liming, fertilization and filling) a pond during which fry are nursed in small ponds or hapas.

3.3 Grow-out and feeding

Tilapia culture practices throughout the world are varied and are probably the most diverse for any cultured species. Tilapia can be cultured at different scales and densities, depending on the economics of the operations and the availability of resources. For example, tilapia can be cultured in backyard and/or home garden ponds to supplement incomes and as a source of food security or, alternatively, on an industrial scale in large intensive commercial farms.

From a nutritional perspective, one of the advantages of tilapia culture over other culture species is that it is a low trophic feeder. Most tilapia are omnivores, feeding on algae, aquatic plants, small invertebrates, detritus and the associated bio-flocs (Bowen, 1976; 1982). They are also somewhat opportunistic in their feeding behaviour, and are able to utilize many disparate food sources. This is an important benefit to farmers as the fish are able to make use of nutrients arising from the natural productivity in the culture systems, and this helps to reduce feed costs. They can also be cultured in extensive systems, and remain entirely dependent on natural productivity to provide their nutrition (AIT, 1994).

In extensive culture systems, tilapia are grown at low densities, consume algae and detrital matter, and are not fed artificial feeds. In intensive systems, tilapias are fed a formulated feed that includes a high percentage of plant proteins. Complete formulated feeds are used in culture systems that have no capacity to produce natural feeds – such systems include intensive water re-circulating systems, cages placed in water bodies that have low productivity, and high density pond systems that are unable to provide sufficient natural productivity to supply the nutritional requirements of the fish. Supplemental diets, as opposed to complete diets, are designed to provide only a portion of the nutritional requirements of the fish, and when they are used, it is assumed that the fish will obtain the remaining portion of their feed requirements from the natural productivity of the culture system. Supplemental diets are usually much less expensive than complete diets, and are typically low in protein and high in carbohydrates. Some supplemental diets serve dual purposes – to supply nutrients directly to the fish, and to fertilize the pond waters, thus enhancing natural food production.

Commercial feeds are used as supplementary feeds in Thailand as their use as complete feeds provides limited profits. Feeds prepared for catfish and carps are commonly in use in tilapia culture. Alternative cheap feed sources have been assessed (e.g. fruit and vegetable wastes, crop by-products, leguminous fodders and aquatic plants). Among these, duckweeds (*Lemna* sp.) grown on-site, have been found to provide a suitable tilapia feed that can be fed at 3–5 percent body weight per day (dry weight basis) and produce fish of up to 100 g. However, a combination of duckweed and formulated pellets produces larger tilapia and at a relatively low cost (AIT, 1994). Several researchers have tried to test alternate vegetable proteins such as oil seed meals as fishmeal replacements; however, the growth attained with these materials is inferior to fishmeal. Despite this, many can be used as partial fishmeal replacements – often up to 50 percent of the fishmeal can be replaced without compromising growth. Commonly used fishmeal replacements include water hyacinth, fish silage, poultry by-product meal, feather meal, and meat or bone meals.

Attempts have been made to produce large tilapia across a number of culture systems – large tilapia fetch higher prices in both export and domestic markets. In ponds, it has been demonstrated that a combination of applying both feed and fertilizers as opposed to the use of either feed or fertilizer alone, is the most efficient way to produce large (500 g) tilapia (Diana, Lin and Jaiyen, 1994. In this regard, a similar study demonstrated that the most profitable way to grow large tilapia was to use greenwater systems until the fish were 100 g, followed by supplementary feeding (Diana, Kohler and Ottey, 1988).

Recently, Thai farmers have started to grow both black and red tilapias in cages along the borders of rivers, lakes, reservoirs and the coastline. To maximize growth, formulations containing 25–35 percent crude protein are fed *ad libitum*. These fish generally receive premium prices (US$1–2/kg), especially in the north and north-eastern parts of the country. Restricted feeding is recommended when the fish are cultured in ponds, as the tilapia can utilize the natural productivity in the pond waters. In terms of determining an appropriate level of restricted feeding, a study at AIT demonstrated that feeding Nile tilapia at 08.00 hours once-a-day resulted in low yields when compared with feeding twice or thrice daily. As there was no difference between the latter two options, twice daily is deemed the most economic feeding regime for this production scenario.

In semi-intensive culture systems, over 90 percent of pond farmers practice polyculture utilizing natural food enhanced through fertilization (Belton *et al*., 2009). Although a large majority of farmers still apply semi-intensive technologies, tilapia farming is rapidly becoming intensified, especially in cages in canals, rivers and reservoirs. These systems now contribute approximately one-third of the total production of this species in Thailand.

3.3.1 Pond culture

Tilapia pond culture practices are, in almost all cases, undertaken under static conditions, where water is only changed between grow-out cycles, and aeration is rarely used. In a normal pond culture system, both the initial investment and variable production costs are low. This makes the system affordable for poorer farmers in rural communities. Most of the pond culture systems employ semi-intensive technologies using fertilizers and supplementary feeds. In this way, ponds produce low-cost fish that contribute to national food security. Other forms of livestock production can also provide sources of nutrients for tilapia farming (Figure 6). Over the past decade, low and high-tech culture systems have been developed by farmers and corporate groups alike. In this regard, small-scale farmers have started to introduce tilapias into their traditional carp polyculture systems. At a larger scale, entrepreneurs are now exploring ways to farm tilapia for the international markets using relatively high-cost intensive culture systems and complete feeds (Edwards, Lin and Yakupitiyage, 2000).

FIGURE 6
A pig shed by the side of a pond (left) and a chicken house above the fish pond (right); uneaten pig and chicken feed and litter represents cheap sources of nutrients for the fish

Pond culture is the most popular method of growing tilapia in Thailand (Belton *et al*., 2009). The pond systems in use range from extensive systems, using only organic or inorganic fertilizers, through semi-intensive systems, using fertilizers and supplementary feeds, to intensive systems that use high protein feeds, aeration and water exchange. The major drawback to pond culture is the high level of precocious breeding that can occur when mixed-sex tilapia are used. The problem arises when the juvenile tilapia from the precocious breeding compete for food with the adults. The original stock becomes stunted, yielding only a small percentage of marketable fish of 400–500 g or more. In mixed-sex populations, the weight of recruits (derived from the precocious breeding) may constitute up to 70 percent of the total harvest weight. In terms of pond sizes, ponds tend to be shallow (1–1.5 m), and range between 0.1 ha and 5 ha. Farm sizes generally range from 1 ha up to over 20 ha.

Many farmers still grow mixed-sex tilapia fry because they are approximately one third of the price to produce than mono-sex fry (Bhujel and Nadtirom, 2002). Most farms using mixed-sex fry are small, use low inputs, and primarily produce for home consumption, with some fish being sold in the local market. In Central Thailand, a recent estimate showed mixed-sex culture accounts for up to 20 percent of production (Belton *et al.,* 2009). Normally, the tilapia are stocked with other species (e.g. carps, catfish, snakeskin gourami), and they are harvested before or soon after they reach sexual maturity. This practice is designed to minimize the effects of precocious breeding. However, the practice restricts the culture period and the size of fish that can be harvested. Nevertheless, this is the cheapest production method, and it is used in instances in which the size of the fish is not of major importance. In these systems, the tilapia are usually stocked at low densities to reduce the competition for food and to promote rapid growth. Approximately one month-old, 1 g fry are stocked at 5 000 to 15 000/ha in grow-out ponds for a 4 to 5-month culture period. Newly hatched fry are used, because older, stunted fish, such as those held over winter, will reach sexual maturity at a smaller, unmarketable size. Supplemental feeds containing 25 to 30 percent crude protein are generally used. At harvest, average weights range between 200–250 g, and total production is approximately 3.8–7.8 tonnes/ha/cycle. The fish are stocked at 20 000–30 000/ha, and two production cycles are normally undertaken per annum. In general, farmers prefer to stock larger fingerlings (5–20 g) as they are hardier, resulting in higher survival and production rates.

Over 80 percent of the farmers culture mono-sex tilapia because they grow faster than mixed sex fry, and remain uniform in terms of size distribution. Mono-sex populations grow to around 500 g in 4–6 months and up to a kilo in 8–10 months. Mixed-sex populations normally reach 200–300 g, whereas larger tilapias (500 g–1 kg) can be harvested from mono-sex populations. Mono-sex populations are mostly produced by collecting the fry, incubating them as larvae, followed by a 21-day hormonal treatment to ensure that over 99 percent of the fish are males. The technology was refined and commercialized by AIT (Little, Turner and Bhujel, 1997; Bhujel, 2009).

Females always use substantial amounts of energy for egg production, and do not eat when they are incubating eggs. Male mono-sex culture permits the use of longer culture periods, higher stocking rates and fingerlings of any age. Currently, mixed-sex tilapia culture is in decline, and farmers are moving towards mono-sex tilapia culture to produce larger and more uniform sized tilapia. High stocking densities reduce individual growth rates, but yields per unit area are greater, and if growing seasons can be extended it is possible to produce fish weighing 500 g or more. Typical survival rates for all-male tilapia culture systems are around 90 percent, or greater. However, one disadvantage of male mono-sex culture is that female fingerlings are discarded – this problem has been overcome by producing sex-reversed male tilapia fry through hormone treatments. The production of mono-sex male tilapia fry represents a significant breakthrough in tilapia culture. The technology was developed in Thailand, and is now being transferred all over the world. However, the main drawback of mono-sex tilapia culture is its higher cost. In this regard, mono-sex tilapia is useful for commercial farms, but remains costly for poor small-scale farmer. The stocking densities and culture methods applied to mono-sex male culture depend on the economics of the farming operation. As stocking density increases more investment is required for feed and its procurement and management. Depending on the intensification of the culture methods, the range of stocking densities varies between 18 000 and 50 000 fry/ha with production varying between 5 000 and 10 000 kg/ha accordingly. Generally, 18 000 fish/ha represents a common stocking density in central Thailand, while higher stocking densities (resulting in smaller sizes at harvest) are generally applied in the north and northeast of the country where the price of the fish is higher. Table 3 presents recommended farming techniques for mono-sex populations (Bhujel, 2012).

TABLE 3

Recommended mono-sex tilapia farming techniques and production in Thailand

Stocking density (numbers/ha)	Rearing techniques	Amount of feed (kg)	Expected production (kg/ha)
18 000	Pond fertilization only	–	3 000
25 000	Pond fertilization only + limited feeding	–	5 000
31 000	Fertilization and feed for last 1 month	1 800	6 250
37 000	Fertilization and feed for last 2 months	3 750	7 500
44 000	Fertilization and feed for last 3 months	5 600	8 750
50 000	Fertilization and feed for last 4 months	7 500	10 000

Source: Bhujel (2012).

It was established that while many farmers lack training or guidance in feed management practices, they often attempt to minimize feed costs. The survey demonstrated that all the farmers feed in the morning, and only once a day. All the farmers use, and encourage others to use, chicken manure as the cheapest way of enhancing the natural productivity of their ponds. The rate of application was reported to vary between 63 kg/ha and 2 500 kg/ha (average 86 kg/ha). The price of chicken manure ranges from 0.4–1.6 Baht/kg (US$0.01–0.05). Farmers normally do not use pelleted feeds as they are deemed too expensive. The price of pelleted feeds ranges between 15–20 Baht/kg, and in some cases can be higher. Usually, farmers avoid commercially produced feeds and select the cheapest feeds available, which usually cost less than 15 Baht/kg. It was established that almost all the pond farmers use maize meal as a supplementary feed. Currently, maize meal costs less than one-third of the formulated feeds (6.0–6.5 Baht/kg; US$0.18–0.20). Locally available rice bran, costing 7.5 Baht/kg, is also used as a supplementary feed. Some farmers were found to use left-over or waste chicken feeds which cost 4 Baht/kg. However, this option is not always available. One farmer reported using food wastes from restaurants which could be procured for less than 1 Baht/kg.

Feeding and fertilization management protocols are presented in Table 4. Farmers generally produce 3–8 tonnes of tilapia per ha over a grow-out period of 8–9 months. The final sizes of fish vary greatly, and range from 300 g to 500 g or larger.

TABLE 4
Results of a survey on tilapia pond-based farms in Thailand: grow-out period of 8–9 months

	Average	Minimum	Maximum
Farm size (ha)	12.2	1.9	24.0
Stocking density (fry/m^2)	2.36	1.88	3.13
Yield (tonnes/ha)	6.1	3.8	7.8
Amount of feed (kg/ha/day)	128	39	375
Use of chicken manure (kg/ha)	866	63	2 500
Feed price (Baht/kg)	12	7	20
Sale price of fish (Baht/kg)	32	18	37

Currency: Thai Baht 32.5 = US$1.
Source: Field survey (2010).

Various forms of polyculture are practiced in Thailand. For example, mixed-sex Nile tilapia are grown in fertilized ponds with carnivorous fish such as the snakehead (*Channa* sp.) and catfish (*Clarias* sp.). The predator fish feed on the tilapia recruits that are produced as a result of precocious breeding, and this enables the original stock to attain a larger size. The level of predator fish must be small, normally comprising <1 percent of the population, and they are stocked when the tilapia begin to breed. Tilapia polyculture with carps is also common in Central Thailand where 80 percent of farmers surveyed have adopted this farming practice (Bhujel and Nadtirom, 2002). Silver barb (*Barbonymus gonionotus*), often called Thai carp, is one of the preferred species as it is attractive, easy to breed, serves as a water quality indicator, and is widely consumed as fermented or processed fish. Rohu (*Labeo rohita*) was found to be used by about 20 percent of the tilapia farmers. The reason that polyculture systems have been developed is that they utilize the various natural foods available in ponds, thereby increasing productivity. The practice also enables farmers to supply a variety of fish to the consumers. Mono-sex tilapias are also cultured in polyculture systems. A typical polyculture production scenario is presented in Table 5. The scenario is designed for a

5 ha pond in Pathumthani Province, central Thailand. Under this production paradigm, the farmers grow the fish for an 8 month period, feeding maize meal (6.5 Baht/kg; US$0.20). Occasionally, farmers will use left-over or waste products from chicken feed factories, where the wastes can be purchased for only 4 Baht/kg. Applying these feed resources, a total production of 20–30 tonnes of fish is possible from a 5 ha pond per crop. Such a system would produce a profit of approximately 1 million Baht (approx. US$30 000).

TABLE 5
Typical polyculture stocking in a large pond (5 ha) in central Thailand

Species	No. of fry/fingerlings
Nile tilapia (*Oreochromis niloticus*)	100 000
Silver barb (*Barbonymus gonionotus*)	10 000
Rohu (*Labeo rohita*)	3 000
Grass carp (*Ctenopharyngodon idella*)	1 000
Common carp (*Cyprinus carpio*)	1 000
Total	**115 000**

Source: Field survey (2010).

Other polyculture systems comprise tilapia and freshwater prawns (*Macrobrachium rosenbergii*). In such systems the survival and growth of tilapia and prawns are independent, and supplemental feeding is only supplied for the fish. The prawns, which are unable to compete for the feed, utilize waste feed and the natural productivity of the pond waters. The prawns are stocked at 1–2 g at 10 000–90 000/ha. Typically, a density of 20 000 prawns/ha is used to obtain a high percentage of market sized prawns (>25 g), and yields of about 600 kg/ha are attained. Tilapia are stocked at densities ranging from 2 000 to 4 000 per ha.

3.3.2 Cage culture

Around 1997, cage culture was introduced to Thailand by the Charoen Pokphand (CP) Group of Companies. Approximately one-third of the tilapia produced in Thailand is currently derived from cage culture. Culturing mixed-sex populations usually results in relatively slow growth rates and high feed conversion ratios (FCR), e.g. ±1.8:1. In contrast, faster growth rates and lower FCR (±1.4:1) are attained using mono-sex populations and thus, for production efficiency reasons, the culture of mono-sex populations is the preferred option (Belton *et. al*., 2009). The difference between the FCR attained using these two types of systems equates to a difference of 10 Baht/kg (US$0.31) in production costs.

The CP Company operates specialized hatcheries to produce red tilapia 'Thapthim' fry, which they supply to 'contract farmers'. The company provides the farmers with seed, feed, and loans for cage construction. The farmers under contract form associations in each production area. These associations assist in buying seed in large quantities and at cost effective prices, and provide communal labour during harvesting. Red tilapia culture has been heavily promoted by the company along the Chaophraya and Bangpakong rivers. In addition, culture areas have expanded to reservoirs and irrigation canals. In Pathumthani (Klong 13), about 45 km north of Bangkok, an average farmer would have 6–7 cages, referred to as a unit. However, some other farmers may have 30 or more cages. The investment cost for one cage is approximately 4 000 Baht (approx. US$125). Plastic drums are used for buoyancy, and the cages themselves are made of wood. Most cages are 54 m^3 (6 m x 6 m x 1.5 m). The stocking rates for this size of cage would be 20 000 fry per cage. The cages are arranged in such a way that one unit is isolated and used for growing fry to fingerlings, a process that usually takes 45 days. The fingerlings are then transferred into the production cages at a density of 2 800 for 120 days prior to harvesting. Typically, yields range between 1.8–2 tonnes per cage over a 6-month production cycle. Survival is normally over 95 percent. On completion of the grow-out cycle, the CP Company buys the fish from the farmers, deducting their loans from the value so that the farmers receive the difference as their net earnings. Farm-gate prices for tilapia grown in Thailand are in the region of 35–39 Baht/kg (US$1.08–1.20). However, the red tilapia sells for 82 Baht/kg (US$2.52). Fry are sourced from specialized hatcheries, and most sites are well linked by good roads to markets. Commercially manufactured feeds are generally used in cage culture production systems.

Cage culture has been introduced along the Mekong River on the border between Laos and Thailand. Cage sizes on the Mekong River tend to be similar to those found in Canal 13, Pathumthani Province, i.e. 45 m^2 (5 m x 6 m x 1.5–2.0 m depth). Stocking densities of 80 fish/m^3 are used, whereas in Viet Nam density may be as high as 100 fish/m^3. [In Viet Nam, higher stocking densities are feasible as the water flow in their rivers is faster, and thus water quality can be maintained.] Cages are stocked with 30–50 g fingerlings which are grown out over a 5 month period. Two crops per annum are produced using this system. The fish are fed good quality floating commercial pellets containing 30–35 percent crude protein, and at 2–5 percent of body weight per day. The price of caged tilapia is around 50–60 Baht/kg. Feed prices are approximately 20–25 Baht/kg. Due to these feed costs, FCR that are above 1.5:1 would make these ventures unprofitable. Cage production systems produce up to 2–2.5 tonnes of fish per annum, and produce fish ranging from 900–1 000 g. Fish are harvested and lifted from the cages to the roadside by a motorbike connected to a pulley. Harvested fish are transported by truck, and normally sold fresh in the domestic market.

Pond-based cage culture is currently being trialled in Thailand. The move to culturing the fish in ponds is a result of some large-scale mortalities that occurred in 2004 in the Chaophraya (in Ayuthaya/Pathumthani area) and Bangpakong Rivers (in Prachinburi province). According to the local farmers, the first mass mortality was caused by the release of large quantities of sugar/molasses from a boat that sank in the Chaophraya River. The second event was caused by the release of a large amount of pesticides that had previously accumulated in the river sediments. The chemicals were released during the sudden opening of a canal sluice gate. Both cases affected hundreds of families, and thus both private companies and farmers are trying to reduce their production risks by placing cages in large ponds instead of river systems. An example of cage-based pond culture was assessed on a farm in Chiang Rai (northern Thailand), where the farmer had 1–2 ha ponds, and used 32 m^3 cages (4 x 4 x 2 m^3) to farm the fish. Under production trial conditions, the tilapia were raised in cages at varying stocking densities (800, 1 600, 2 400 and 3 200 per cage) with Mekong giant catfish (*Pangasianodon gigas*), the giant catfish from the Mekong River, being cultured in the ponds. Tilapia were fed with commercial floating pellets (28 percent crude protein), 3 times a day at 3 percent of biomass per day.

The survey revealed that the average number of cages operated by each farmer is 20, with a minimum of 4, and a maximum of up to 200 (Table 6). The size of the cages that are used varies from 13.5 m^3 up to 120 m^3, and stocking densities range between 3 and 100 fry/m^3. Under these production conditions, the amount of tilapia that could be produced varies from 9 to 83 kg/m^3. Although cage farmers use expensive commercially produced pellets, they still can make profit as their fish attain high market prices, i.e. 50 Baht/kg (range 35–62). The data showed that the price of feed accounts for approximately half of the production costs.

TABLE 6
Characteristics of cage based tilapia grow-out farms in Thailand

	Average	Minimum	Maximum
No. of cages/farmer	20	4	200
Cage size (m^3)	41	13.5	120
Stocking density (fry/m^2)	47	3	100
Yield (tonne/m^3)	39	9	83
Feeding frequency (time/day)	3	2	3
Amount of feed (kg/cage/time)	4	3	5
FCR	1.6	1.4	1.8
Feed price (Baht/kg)	23	18	31
Sale price of fish (Baht/kg)	50	35	62

Currency: Thai Baht 32.5 = US$1
Source: Field survey (2010).

3.3.3 Culture in tanks and raceways

A few hatcheries employ re-circulating tank technology for rearing fry but commercial grow-out using this method is not currently practiced in Thailand. However, tanks represent a suitable technology in areas where land and water are scarce. Research has shown that tilapia grows well at high densities in tanks; however this requires good water quality to be maintained. Water quality is maintained by aeration and frequent or continuous water exchange to remove metabolic wastes. Intensive tank culture offers several advantages over pond culture. The high stocking densities in tanks disrupts the breeding behaviour of the fish, and allows both males and females to be grown together to marketable size. In addition, tank culture enables the farmer to exert a relatively high degree of environmental control over the culture parameters (e.g. water temperature, DO, pH, waste), and these can be adjusted to maximize production.

Intensive tilapia culture in re-circulating or flow-through tanks/raceways is one of the preferred techniques for large-scale commercial production. Water re-circulating systems generally replace 1–10 percent of the volume of the system per day. The rearing tanks are aerated as in flow-through systems, and use low water exchange rates. These practices ensure high yield per unit area and/or unit volume of water. Important processes in these systems include the removal of solids and dissolved metabolites. Significant volumes of water are needed for this purpose. In water-limited areas, intensive tank and raceway culture requires water treatment and recirculation (Cole *et. al*., 1997). In tanks and raceways, tilapias are cultured under high density conditions. These systems are especially attractive in areas in which the effluent streams can be used for field crop irrigation as they provide a good source of fertilizers (Fitzsimmons, 1997).

In raceway systems, fingerlings (25–30 g) are stocked at 150–300 fish/m^3. The grow-out period for these fish is usually in the region of 120–150 days. Fish are fed formulated feeds at 3 percent of body mass per day at a feeding frequency of 3–4 times a day. Bi-weekly sampling is undertaken to establish growth rates, and the fish sizes are used to adjust the feeding rates. Fish are harvested when they reach 200–250 g. Stocking densities in raceway systems is in the region of 40–60 kg/m^3. Currently in Thailand, the high capital costs required for tank construction and the operational costs associated with using formulated feeds are prohibitive; under the prevailing economic conditions farmers using these systems were not able to make profits. Thus tilapia farming is currently primarily pond based, and uses cheap feeds. Should the economic fundamentals change, intensive tank culture may become profitable – particularly if

Thailand starts to export large volumes of high value product. In 2006, Thai tilapia exports were only ~5 000 tonnes (Belton *et al*., 2009) and, in recent years, low cost production in China has precluded the development of a viable tilapia export sector in Thailand.

3.4 Feed production and management

Tilapia are capable of utilizing a wide variety of food sources, either as single sources or as components of compound feeds. Tilapia accept feed as dry meal, moist meal and pellets. Particle size is also an important consideration for tilapia culture as they generally prefer smaller feed particles than other cultured fish species.

In terms of commercial production, farmers use formulated pelleted aquafeeds and apply relatively low levels of fertilizer to stimulate the natural productivity in the culture waters. At high culture densities, natural feeds play an insignificant role in providing nutrition to the fish. In terms of feed management, the fish can either be fed to satiation or *ad libitum* or fed a restricted ration. Feeding *ad libitum* may result in higher growth rates but may not be the most economical way to culture the fish; as it is difficult to determine satiation levels in fish, feeding to satiation can lead to overfeeding, feed wastage, and poor water quality. Feeding restricted rations is therefore recommended. Calculating rations requires various factors to be taken into consideration, including body size, temperature and water quality. Most farmers do not adjust feed rations but feed near to satiation; however, weekly adjustments based on body size can be used as guidelines (Table 7). Grow-out fish are generally fed between 1 and 4 times a day with the amount of feed being reduced if the feeding response is poor. Demand feeders may be used.

TABLE 7

Feeding rates based on the fish weight and culture system

Weight of fish (g)	Feeding rate (% of body weight per day)	
	Intensive	Semi-intensive
0–15	15	10
15–60	18	5
60–100	5	3
100–200	3	2
200–300	2.25	1.5
300–500	2	1.4
>500	1.6	1.3

Source: Aquanutro (2002).

Red tilapia are raised using high quality commercial aquafeeds, normally in cages. The production is designed to supply local restaurants, superstores (e.g. TESCO, Big C) and the more affluent urban consumers. In contrast, Nile tilapia is mostly raised using manures and other recyclable wastes in earthen ponds at low cost, and with little attention to quality. Most Nile tilapia producers and consumers are located in rural areas and are relatively poor.

Tilapia are reared in tanks, cages or earthen ponds both in freshwater and in brackishwater up to 25 ppt salinity. Red tilapia are more tolerant of high salinities than the Nile tilapia, and some strains can even be raised in full strength seawater. Concomitant with some other species, tilapia has the ability to consume phytoplankton, and as a result, pelleted feeds are not necessary for growing tilapia at low densities in nutrient-enriched, ‘greenwater systems’. These systems can produce marketable fish of

300–500 g within six months In addition to phytoplankton, tilapia can also consume zooplankton, detritus, aquatic plants and insects. Commercial pellets, waste foods, and most other food sources with the exception of meat, can be fed to the fish. Stocking densities, the size at stocking and culture methods are important considerations in terms of managing feed and feeding systems (Table 8). As stocking density increases, more investment is required in feed, and production costs will increase. In most parts of Thailand, farmers using supplementary feeding stock 18 000 fry of 2–3 cm (0.2 g), or 10 000 fingerlings of 9–10 cm (30 g) per ha in fertilized ponds. Higher stocking densities and investment in aeration are appropriate production strategies in areas where tilapia prices are high To make viable returns on investment on a per kilogram basis, fish prices must be at least double the cost of good quality commercial feeds. Red tilapia, for example, command a high market price (70–80 Baht/kg), and are raised at 2–3 fish/m^2 to 700 g using high quality commercial pellets. Typical harvest volumes using these parameters are in the region of 12–18 tonnes/ha.

TABLE 8

Feeding and other inputs suggested for tilapia culture in ponds in Thailand

Fertilization and feeding regime	Number of fish stocked/ha			
	2–3 cm	4–5 cm	6–7 cm	8–9 cm
Fertilization only	15 000	12 500	11 250	10 000
Fertilization only, higher density	20 000	16 500	15 000	14 000
Fertilization, supplemental cheap feed	21 250	17 800	16 250	15 300
Fertilization, supplemental cheap feed, higher density	28 750	23 750	21 250	20 000
Complete feed, no aeration, low density	16 000	13 400	12 000	11 250
Complete feed, aeration, high density	32 000	27 000	24 000	22 800

Source: Field survey (2010).

3.4.1 Natural foods

Greenwater systems provide natural feeds for the fish. The algae remove nitrogenous compounds and produces oxygen for the fish. The greener the pond, the more natural food there is available and, depending upon stocking densities, little or no supplemental feeding may be required. However, if a pond is too green, fish mortalities can result from insufficient dissolved oxygen levels, especially early in the morning when the algal biomass utilizes the dissolved oxygen in the water.

In order to create a plankton bloom, it is necessary to add nitrogen and phosphorous (N and P, respectively) – the two major limiting nutrients to plankton growth in water. The recommended application levels of these elements are 1–2 kg P/ha/day and 4 kg N/ha/day. The N and P can be derived from many sources, including chemical fertilizers, animal manures, 'ami ami' (monosodium glutamate factory waste), and composts. While the use of chemical fertilizers represents the most expensive option, in comparison with the other fertilizers, their use results in the best water quality. Fertilization is usually carried out every few days or on a weekly basis. Generally, the amount of fertilizer that is required is determined by the level of the existing algal bloom.

In general, there is an increase in fertilizer requirements throughout the growth period. Less fertilizer will be required where commercial feeds are applied, as they also contain N and P that can be utilized by the algae. Table 9 presents typical fertilizer inputs that are commonly applied in static semi-intensive ponds, and serves as a guideline. Farmers producing more fish use higher densities and supplementary feeds, and fertilize the ponds.

TABLE 9
Inputs used by the farmers for tilapia farming in ponds in Thailand

Type of input	Amount used (kg/ha/week)
NPK (16-20-0) chemical fertilizer	188
46-0-0 (urea) + 0-46-0 (phosphate)	56 + 69
Fresh chicken manure	1 875
Fresh chicken manure + 46-0-0 (urea)	1 100 + 25
Fresh pig manure	5 000
Cow/buffalo manure	6 250
'Ami ami'	12 500

NPK = nitrogen, phosphorus and potassium
Source: Bhujel (2012).

Chemical fertilizers are applied weekly (or more frequently if required) by dissolving them in water, and broadcasting the solution over the surface of the pond. There are no strict guidelines for the application of animal manures. Most farmers either broadcast the materials over the pond water, or apply the manure to a few selected spots located around the edge of the pond. Frequent manuring in small amounts is advisable, and usually one application per week is sufficient.

3.4.2 Feeds in pond culture

There is an important relationship between feeding and stocking density. Production costs increase with increasing stocking density, and feed is only required once pond biomasses rise to 4 000–5 000 kg/ha. However, feed can be used to increase growth rates and so reduce culture periods. For example, while red tilapia will attain a size of 700 g within 4 months in ponds when fed a complete formulated commercial feed, the same fish could be raised to 700 g in 6 months using a lower ration and/or a cheaper formulation, It is therefore important to determine whether the fast grow-out period justify the increased feed costs necessary. When considering the use of feeds and their effect on culture periods and production prices, other factors such as land, water and pond excavation costs also need to be considered. Where the cost of land rental or purchase is expensive, higher density feed-lot type systems become more economic.

As the prices of tilapia grown in ponds are very low in Thailand, it has not been economically worthwhile to feed expensive commercially formulated feeds to date; the prices of good quality commercially formulated feeds are almost similar to the sale price of the fish. As a result, pond farmers need to identify alternative, cost effective, cheap feed inputs. Currently these include:

- waste food from restaurants, hospitals and schools.
- rice bran, broken rice and oil cakes.
- bread, wafers, yeast and other edible factory wastes.
- waste animal feeds.

In contrast, the price of tilapia raised in cages are approximately twice those of pond-reared fish, and the use of good quality commercially produced feeds are cost effective. The advantages of using high quality floating feeds are increased ingestion rates, decreased feed losses and improved digestion, resulting in faster growth, and a reduction in effluent streams. Farm-made sinking pellets are generally cheaper to produce than commercially produced floating aquafeeds, and are prepared from a multitude of feedstuffs using simple grinders and mixers. However, as these feeds sink and the farmers are unable to monitor feed consumption, feed wastage tends to be higher than when floating feeds are used. Sinking pellets are not used for cage culture as they tend to be lost through the bottom of the nets; thus cage farmers tend to use more expensive floating commercial pellets. However many indicate that they have issues in terms of the quality and price of these feeds. As the extruders that are required to produce floating pellets are expensive, almost all farmers produce sinking pellets. The floating commercial pellets that are available on the market are fairly standard, and primarily differ in terms of crude protein level and pellet size. Prices increase with an increasing level of protein. Protein levels under 20 percent are not recommended for tilapia, as poor palatability tends to be an issue. During the survey, it was established that most farmers use feeds containing around 25 percent crude protein during the final grow-out period; they reported that this protein level/cost was the most cost-effective to use.

3.4.3 Feeds in cages

Tilapia cage culture is widespread in rivers, canals and reservoirs in Thailand. Large scale cage culture has in cases been shown to be problematic as it can obstruct boat traffic and cause substantial pollution to natural waterways. Many farmers are attracted to tilapia cage culture as it negates the need to buy or rent land, and capital investments are relatively low. However, the disadvantages of using these systems are that running costs are higher than pond based systems, and large amounts of commercial feeds have to be used. Production risks are also a factor and are deemed to be relatively high – water quality and disease cannot be controlled easily, and there is always the possibility of fish escaping from the cages. Tilapia cage culture is only economically profitable when the prices for the fish are high, and it is for this reason that the more valuable red tilapia are mainly raised in cages in Thailand. Floating pellets are essential in cages, and most farmers feed *ad libitum* and 2–3 times daily. A range of commercial feeds is illustrated in Figure 7. A band of fine netting material is installed inside the cage at the water surface to avoid floating pellets from moving beyond the cages. The crude protein levels in these feeds range between 25 and 36 percent and, while food conversion ratios are generally lower for the high protein feeds, they are more expensive.

FIGURE 7
These commercial feeds, with differing levels of crude protein, are especially formulated for tilapia farming in Thailand

COURTESY OF FAO/R.C. BHUJEL.

3.5 Feeding methods in commercial farming

Tilapia can either be fed by hand or by automatic or demand feeders. Hinshaw (1999) suggested that irrespective of whether feeding was by machine or by hand, feed should be distributed throughout the pond to allow all the fish access to the feed, and that feed should not be allowed to accumulate on the bottom of the ponds. Nile tilapia feed throughout the water column, and thus both floating and sinking feeds are suitable for this species. Webster and Lim (2002) suggested that demand feeders may provide the best feeding method in cages as they supply feed at a low labour cost. In this regard, Jaruwan (2008) demonstrated that mobile blower feeders used more feed than the fixed station feeders; thus production costs using blower systems, although not great, were higher than those when other feeding systems were used. The same study found that there was no significant difference in terms of fish production between using fixed station feeders and mobile blower feeders; however, it was recommended that fixed station feeders instead of mobile blower feeders should be used as the former resulted in slightly higher profits and lower feed and labour costs.

Water quality can affect fish growth. Feeding should be reduced or ceased when water quality is poor. Dissolved oxygen levels higher than 5.0 ppm are considered optimum for growth. When DO declines below this optimum, the feeding rate should be reduced, and ceased once DO falls below 3.0 ppm. Ammonia concentrations are related to feeding practices, and are dependent on temperature, feeding rates, the size of fish and the feed quality (Riche and Garling, 2003). Appetite is also temperature related, and the fish usually stop feeding when temperatures fall to 15 °C or below. In addition, Tongdee (1995) demonstrated that when the pH is 5 or below, there is a sharp decline in feed consumption.

3.5.1 Hand feeding

In Thailand, feeding is primarily undertaken by hand using broadcast methods from the pond dykes or from boats. Some of the larger farms use mechanical feeders (blowers/demand feeders). As these machines are expensive, most of the smaller farmers use hand feeding. However, in those areas where labour is difficult to find, automatic/demand feeders are used. Automatic/demand feeding requires lower labour inputs but normally results in increased feed wastage. In addition, feeding manually provides an opportunity to observe the fish and to monitor their condition, and also provides an opportunity for corrective actions. However, with an increase in farm size and intensification, mechanical feeding is rapidly becoming indispensable. Feeding methods are designed to suit the culture systems, and take into consideration pond sizes, species, budget, and the type of feed used.

3.5.2 Fixed station feeder

There are a number of types of fixed station feeders. Demand feeders are cost effective, and use minimal labour and respond effectively to the appetites of the fish. However they have disadvantages in that they can only deliver feed to a localized area, and cannot be used with fish smaller than 20 g. In contrast, compressed air feeders distribute feed over a wider area, and can service up to 5 000 fish per feeder. Some of the large commercial tilapia farms (e.g. Manit Farm) use sophisticated pneumatic fixed station automatic feeders. These feeders disperse feed using compressed air. Pneumatic feeders are specifically designed for feeding in large ponds or raceways. These systems have the advantage of distributing large amounts of feed (up to 120 kg dry feed) through multiple distribution pipes. The disadvantages of these feeders are that they require electrical power and are relatively expensive to operate.

3.5.3 Mobile blower feeders

Mobile feeders can be used to distribute feed to ponds that have suitable road access. These feeders are manually operated, and are usually mounted on trucks, push carts, or towed by tractors. The feed is distributed at a velocity of 0.53 m/second to distance of 4 and 10 m into the pond. It has been observed that the use of fixed station feeders can result in poor water quality in the vicinity of the feeder and, due to competition for feed around the feeders, variable fish sizes at harvest. These problems can be resolved by using mobile feeders that distribute the feed evenly throughout the pond.

3.6 Feed industry, transportation and storage

In general feed companies deliver the feed to the famers. The farmers can purchase their feed from a number of feed companies; the main companies offering tilapia feeds in Thailand are the CP Company, Thai Luxe, AquaStar, and Cargill Inc. These companies produce feed types according to market requirements, and they generally have branch factories across the country with distributors working in almost every district, especially in the central region.

Feed ingredients are also delivered by the feed traders and distributors. When purchase volumes are low, the farmers are usually responsible for transporting the feed to their farms. Once the feed or feed ingredients are delivered to the farms they are either stored in a feed storage area in a house or near the ponds. Prior to use, the farmers often store their feed for a week or so in large buckets at the pond or cage sites (Figures 8 and 9). Although these buckets are covered by lids, excessive heat can in some cases negatively affect the nutrient composition of the feeds.

4. SUMMARY AND RECOMMENDATIONS

4.1 The current status of the pond and cage culture sectors

In the past tilapia culture in Thailand has been viewed as a subsistence activity; however, in recent years it is increasingly becoming seen as a viable commercial proposition. Currently, the domestic market for tilapia has stabilized but export markets still need to be developed. Current production is primarily based on pond and cage culture systems; a comparison between these production systems is presented in Table 10. In terms of comparing the various production technologies, cage culture has an advantage over pond farming in that the fish that are produced are larger, are of a better quality with improved organoleptic properties, and are suitable for export. However, cage culture usually requires the use of relatively expensive manufactured aquafeeds that are in the region of twice the cost of those feeds used in pond culture (pond culture: 12 Baht (US$0.37)/kg feed; cage culture: 23 Baht (US$0.71)/kg feed; Table 10).

FIGURE 8
Feed stored in plastic bucket on-site for tilapia fry nursing

COURTESY OF FAO/R.C. BHUJEL.

FIGURE 9
Buckets containing feed on-site (left) and feeding operations in cages (right)

COURTESY OF FAO/R.C. BHUJEL.

TABLE 10
Summary of findings of survey on tilapia farming in Thailand

Parameter	Pond culture	Cage culture
Average stocking density (fry/m²)	2.4	47
Feeding frequency (time/day)	2	3
Application of chicken manure (kg/ha)	866	–
Amount of feed (kg/ha/day)	128	4 (per cage)
Average yield (tonnes/ha)	6.1	39 kg/m³ cage
Fish growth (g/day/fish)	1–1.5	2–3
Final size of fish (g)	200–500	500–1 000
FCR	0.6	1.4–1.8
Average feed price (Baht/kg)	12	23
Average sale price of fish (Baht/kg)	32	50

Currency exchange rate: Thai Baht 32.5 = US$1.0.
Source: Field survey (2010).

Cage farmers also have to feed more often than pond farmers (3 times a day or more in cages), with feeding rates for the cage cultured fish typically being between 3 or 4 times higher than fish grown in ponds. The higher feeding rates and frequencies used in cages result in higher daily growth rates (2–3 g/day), but lower food conversion (FCR: 1.4–1.8:1). In general, Nile tilapia are still considered low-priced fish in Thailand but production prices remain higher than fish produced in other countries such as China. In this regard, Thailand is trying to compete on production costs, and to explore potential export markets for Thai tilapia. The extensive adoption of high quality feeds for use in pond culture systems will only be possible if Thai pond farmers can develop sufficient economies of scale to reduce production costs in line with other exporting countries. As cage culture systems require floating pellets and the extruders that are needed to produce pellets are normally expensive, it is a real challenge for the farmers to prepare appropriate farm-made feeds. Importantly, the use of low quality feeds and feed ingredients negatively impacts the quality of the fish that are produced. A wide range of commercial pellets are available in the country. However, the careful selection of cost effective feed is an important consideration that farmers do not always address appropriately. Fish farmers need training to improve their feed management practices, formulations, preparation, and storage practices. Appropriate record keeping to determine those feeds and management practices that result in improved production is also an issue that need to be addressed. In this regard, the production and distribution of a manual outlining these practices should be considered.

A major contributory factor to the recent growth of the tilapia industry in the country is the availability of quality sex-reversed tilapia fry. A single hatchery can produce up to 20–30 millions of fry per month, generating considerable revenue streams. The success of the technology and the development of various hatchery business models has attracted both local and foreign private sector investors, and created significant employment opportunities. At present, one large scale hatchery in central Thailand employs in the region of 200 local staff/workers, and several NGOs/Missionaries/Foundations are using tilapia culture as a tool to promote rural development. The development of suitable broodstock farm-made feeds or the purchase of suitable commercial feeds at reasonable prices remains an issue for the hatchery operators. Similarly, the use of fishmeal, MT hormone and alcohol for sex-reversal are the major cost concerns. To reduce the reliance on expensive MT and alcohol, research is underway to find alternatives to MT, e.g. papaya seed, herbal plants and/or other sources of natural hormone. Cheap mono-sexing methods would be beneficial to the hatchery owners, and any protocols avoiding the use of these chemicals would allay the environmental fears that are sometimes attributed to their use.

The major problems that are currently encountered by tilapia farmers in Thailand include the following:

- The high price of good quality commercial pellets is problematic and makes cost effective production difficult.
- Farmers often lack the necessary information needed to formulate well balanced farm-made feeds; there is lack of farm-made feed formulations that provide examples for the farmers.
- Poor organoleptic properties or ‘off-flavours’ are frequently reported in fish that are produced in greenwater systems; this reduces their value and marketability.
- There are variations in the sizes of fish harvested from pond culture systems.
- The research community places insufficient emphasis on developing on-farm trials involving farmers.
- There are no dedicated broodstock feeds available, and farmers have to rely on commercial grow-out feeds.
- There are no commercially available nursery feeds.
- Only expensive fishmeal are used during the sex-reversal process, and as a result, the price for fry is high; currently, there is no viable alternative to fishmeal.
- Feed quality monitoring systems are inadequate, especially in terms of farm-made feeds.
- Tilapia farms, feed manufacturers and distributors need to be certified.

4.2 Future scope and needs

High quality commercially produced aquafeeds are expensive and many farmers try to limit their use as they increase production costs. The development of good quality farm-made aquafeeds could potentially increase productivity, improve profits and promote sectoral growth. Currently, farm-made aquafeeds are uncommon in Thailand, especially so for tilapia. Most farmers use formulated feeds as opposed to preparing their own feeds. Usually, pond farmers either buy cheap commercially produced pellets, or use cheap by-products as feed. To date, no research has been carried out to compare the performance of these dietary formulations in terms of growth, survival, food safety, or the economic implications of using these feeds and feeding practices.

While some farmers actively investigate potential alternatives to purchasing pelleted feeds, they typically use by-products that are high in carbohydrates but low in protein. As protein promotes growth in fish, the addition of at least one of the locally available protein sources, e.g. soybean meal, chicken feather meal, etc., would greatly enhance the quality of the feeds they use. This could be achieved without adding substantial cost to the formulations. Providing feed formulation, preparation, storage and feed management training to the farmers could significantly improve the efficacy of formulations and farm feed management practices. While a significant amount of research has been undertaken to establish the nutritional requirements of the species group, most of the results of this research has not been communicated to the farmers. Simple informative training manuals and the conduct of participatory feeding trials in farmers' ponds could improve their understanding, and promote the use of effective farm-made feeds.

In general, the animal wastes and agricultural by-products that are used in feed formulations are of low nutritive value, and are poorly digested by the fish. Their use can result in negative environmental impacts as the undigested nutrients accumulate in the environment. In order to limit the negative environmental impacts accruing to the use of these feed ingredients, it would be appropriate to develop regulations. For example, minimum digestibility coefficients of 60 percent could be used to promote the use of digestible feedstuffs. Pond water quality and improvements in water quality management are also issues that need to be addressed. Poor pond water quality can cause poor flesh quality and taste, resulting in low product values. While this is not an issue among domestic consumers, it remains an important consideration when penetrating export markets.

While tilapia farming has become increasingly popular in Thailand over the past decade, there remain significant constraints to penetrating export markets and competing in the global markets with low cost producers such as China and certain countries in South and Central America. Attempts have been made to reduce production costs and explore niche markets in the Gulf countries and Europe. In addition to promoting more cost effective production technologies, there is also a need to improve traceability and product safety. In this regard, maintaining quality standards and food safety has been the focus of a national policy for the shrimp industry. The tilapia industry could benefit from the application of those practices that have been developed for the shrimp sector.

The following recommendations have been developed to improve tilapia farming in Thailand:

- The promotion of farm-made feeds using locally available ingredients needs to be prioritised. Farmers and researchers need to collaborate, conduct trials and disseminate the proven formulations to the industry.
- Farmers require training to improve their feed storage and management practices.
- Research is required to resolve the poor flesh quality that is associated with growing tilapia in pond culture systems.
- The negative environmental issues associated with nutrient enrichment through the use of poorly formulated feeds and their application needs to be resolved. Similarly, the use of methyl-testosterone to produce mono-sex populations should be controlled.
- The tilapia dialogue facilitated by the World Wide Fund for Nature (WWF) has developed guidelines for responsible tilapia culture. These guidelines should be applied in Thailand. Alternatively, Good Aquaculture Practices (GAP) or similar certification programmes should be made mandatory for those wishing to export tilapia.
- A manual for producing good quality tilapia using farm-made feeds should be published and distributed to the farmers.

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ANNEX 1

On-farm feeds and feed ingredients used in tilapia farming in Thailand and their prices

	Feeds/feed ingredients	Price (*Baht/kg)	Price (US$/kg)	Remarks
1	Urea	22	0.68	
2	TSP (triple super phosphate)	23	0.71	
3	Lime (CaO)	5.6	0.17	
4	Chicken manure	0.4–1.6	0.01–0.05	
5	'Ami Ami' **	1.0	0.03	Small quantity = 10 Baht/kg
6	Maize meal	6–6.5	0.18–0.20	
7	Left over/wastes of chicken feed	4.0	0.12	Cheapest feed
8	Rice bran (fine)	7.50	0.23	
9	Cassava flour	35	1.08	
10	Soybean meal	40	1.23	
11	Fishmeal (local)	35	1.08	
12	Fishmeal (imported)	38	1.17	
13	Catfish pellet (25% CP)	17.25	0.54	
14	Catfish pellet (30% CP)	19	0.58	
15	Catfish pellet (35% CP)	24.5	0.75	
16	Catfish pellet (40% CP)	49	1.51	
17	Shrimp starter (40% CP)	42	1.29	
18	Vitamin C	150	4.62	
19	Methyl testosterone (per g)	749	23.05	
20	Alcohol (ethyl alcohol 95%)	78	2.40	
21	Tilapia feed (floating, 30% CP)	23	0.71	
22	Food wastes from restaurant	0.71	0.02	
23	Salt	3.25	0.10	
24	Mineral mix	45	1.38	
25	Vitamin mix	240	7.38	

* US$1 = Thai Baht 32.5.

** Wastes from monosodium glutamate factory; CP = crude protein.

ANNEX 2

Prices and composition of major feed ingredients in Thailand

Feed ingredients	Approx. price (US$/kg)*	Moisture (%)	CP (%)	EE (%)	CF (%)	Ash (%)	Ca (%)	P (%)
Broken rice	0.3	12.57	7.02	1.12	0.43	0.75	0.01	0.16
Cassava root	0.2	10.34	2.14	0.62	2.05	2.69	0.09	0.07
Maize bran	0.3	12.50	7.58	3.62	5.63	2.21	0.04	0.26
Cassava leaves	0.1	12.32	27.39	7.17	10.90	7.02	1.20	0.30
Chicken viscera meal	0.6	8.00	56.50	22.30	2.70	4.11	3.60	1.54
Maize grain	0.3	12.56	8.71	4.13	1.71	1.29	0.01	0.26
Coconut oil meal	0.3	10.00	21.00	6.00	12.00	7.00	0.20	0.20
Fishmeal (60% CP)	1.0	8.00	55.20	8.01	1.00	26.00	7.70	3.80
Kapok oil meal	0.2	10.24	32.58	2.38	21.62	7.22	0.40	1.03
Duckweed (Lemna minor)	0.1	9.50	29.00	4.21	7.26	20.30	0.02	0.63
Leucaena leaves	0.2	10.05	23.54	7.70	7.68	9.71	2.52	0.17
Leucaena seed	0.3	10.30	27.80	7.06	10.25	4.04	0.39	0.05
Parboiled rice bran	0.2	9.07	13.32	27.25	9.72	9.44	0.14	2.08
Sago stem	0.3	10.14	1.23	1.80	13.32	8.88	0.84	0.02
Sesbania leaves	0.1	7.85	29.56	4.85	7.47	10.55	2.30	0.30
Tofu waste	0.4	90.53	2.60	0.82	1.83	0.39	0.06	0.02
Water hyacinth	0.1	92.73	1.65	0.26	1.27	1.37	0.13	0.06
Winged bean	0.5	9.31	6.79	0.23	36.95	8.89	0.44	0.09
Peanut oil meal	0.4	7.59	49.91	5.79	3.95	8.18	0.14	0.65
Rice bean (extract)	0.2	11.08	15.73	2.35	10.26	12.87	0.17	2.26
Sesame meal (black)	0.3	7.46	33.84	16.42	5.57	12.23	2.52	1.22
Shrimp head meal	0.6	10.26	30.59	3.77	10.55	n.a.	8.16	1.60
Soybean meal	0.5	9.50	44.30	5.30	5.70	6.00	0.83	0.66
Sunflower seed meal	0.4	7.57	21.64	7.61	29.05	6.75	0.63	0.67
Wheat flour	0.5	13.10	15.40	1.90	0.50	0.90	0.06	0.13

*Prices have been updated based on the current situation.

Source: Proximate composition from Somsueb (1993) and Thongrod (2007).