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

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ABSTRACT

China is the largest tilapia producer in the world. The majority of production is located along the southeastern coast, including the provinces of Guangdong, Guangxi, Hainan and Fujian. In 2010, production from these four provinces was 1 198 000 metric tonnes, representing 90 percent of national production. Although an exotic species in China, Tilapia represents the sixth largest production sub-sector after silver carp (*Hypophthalmichthys molitrix*), bighead carp (*Hypophthalmichthys nobilis*), grass carp (*Ctenopharyngodon idella*), common carp (*Cyprinus carpio*), and crucian carp (*Carassius auratus*). Nile tilapia (*Oreochromis niloticus*) is the most popular species used for aquaculture in the country. This paper reviews on-farm feeds and feed management practices in tilapia aquaculture in Guangdong and Hainan provinces. The review describes on-farm feeding and feed management practices in different tilapia farming systems, and assesses the economic viability of these operations. Particular attention is given to the current status of feeds and feed management practices. Practical measures to improve the efficiency of feed resources are recommended.

1. INTRODUCTION

1.1 Brief introduction to aquaculture in China

Aquaculture has been practiced in China for over 3 000 years, and the country is currently the world leader in aquaculture production. In 2010, Chinese production reached 36.7 million tonnes, representing 61.4 percent of global aquaculture production (FAO, 2012). Currently, more than one-third of animal protein in the diet of the Chinese people is sourced from fish and other aquaculture products, and the sector has become an important industry in terms of maintaining food security through the provision of income and employment.

Carps, especially the domestic silver carp (*Hypophthalmichthys molitrix*), bighead carp (*Hypophthalmichthys nobilis)* and grass carp (*Ctenopharyngodon idella*) are the main species that are cultured in ponds. The diversification of culture species is one of the stated goals of aquaculture development in China (Liu and Li, 2010). The production of non-indigenous (exotic) species increased from 780 000 tonnes in 1998 to 2.5 million tonnes in 2006, representing 5.9 and 11.7 percent of the total inland aquaculture production in China, respectively (Liu and Li, 2010). Some exotic species have come to play an important role in both aquaculture production and in the economy. Of these, tilapia is the most important exotic species currently cultured in China.

1.2 Overview of tilapia culture

Tilapia are arguably ideal candidates for aquaculture because of their tolerance to wide pH fluctuations, high ammonia and nitrite levels and low dissolved oxygen levels (Ardjosoediro and Ramnarine, 2002). Some species can even be cultured at high salinities (Costa-Pierce and Rakocy, 2000), and they are resistant to many fish diseases and parasites (Costa-Pierce and Rakocy, 2000). In addition, tilapia are fast growing and omnivorous, with an ability to utilize a wide range of feed ingredients such as detritus, blue green or green algae, diatoms, macrophytes and bacteria (Bhujel *et al.*, 2001; Gonzales and Brown, 2006). Currently, tilapia culture is one of the fastest growing forms of aquaculture worldwide, with more than 3 497 390 tonnes produced in 2010 (FAO, 2013). Of the tilapia group, the most popular culture species is the Nile tilapia (*Oreochromis niloticus*), accounting for 73 percent of the total production of tilapia in 2010, with China contributing 39 percent of the global production of Nile tilapia (FAO, 2013). The species has been introduced widely around the world, and it is being cultured in at least 57 tropical and subtropical countries (Pullin *et al.*, 1997). In recent years, the volume of world tilapia production has increased significantly. This increase in production is primarily attributed to aquaculture production in Asia, and especially in China (TBCAPMPA, 2009).

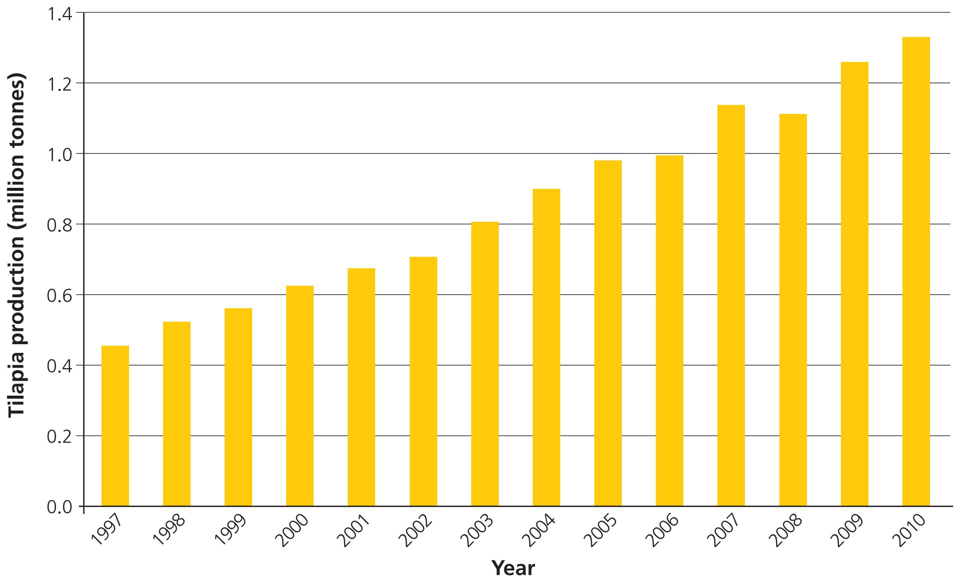
1.3 Tilapia aquaculture in China

Tilapia were first introduced into the country in the 1950s, and are now some of the most successful exotic species cultured in the country (Liu and Li, 2010). Initially the sector developed very slowly. This was attributed to a number of technical issues including the development of breeding and husbandry protocols, the adaption of the farming technologies to the local conditions, and marketing. Initially, the culture techniques that were used for tilapia were the similar to those applied to the Asian carps and other common carp species; and, prior to the 1970s and the introduction of commercial formulated feeds for tilapia, production was based on extensive polyculture systems. Since tilapia have different biological characteristics to the Asian carps, the culture techniques adopted for tilapia aquaculture need to be different. To date, more than eight species of tilapia have been introduced into China; of these, Nile tilapia was found to be the most suitable in terms of cost effective production (Li *et al.*, 2007).

In 1995, the total production of tilapia in China was 32 000 tonnes (He *et al.*, 2009). Over the past thirteen years, national tilapia aquaculture production has increased at an average annual growth rate of 14.6 percent (FBMA, 1998–2011). In 1997, aquaculture production of tilapia was 480 000 tonnes. By 2010, it had grown to 1.33 million tonnes (Figure 1). At a global level, China is now the major producer nation (Lei *et al.*, 2009; FAO, 2013). It is anticipated that in the short term, Chinese production will continue to increase. The anticipated increase is attributed to a favourable market prognosis (Costa-Pierce and Rakocy, 2000), and the low production costs in China (Chen, 2006). In addition, the value and production chains are now well established and the sector enjoys strong governmental support – particularly in Guangdong, Hainan, Guangxi and Fujian provinces. In recent years culture technologies have also greatly improved in China.

Notably, the development of over-wintering technologies using warm spring waters in northern China has enabled production to move further north, to Beijing and Xinjiang. Furthermore, farmers are increasingly recognizing the importance of fish health, product quality and the problems associated with the use of unauthorized therapeutants.

FIGURE 1
Tilapia production in China from 1997–2010



Source: FBMA (1998–2011).

1.4 Regional distribution of tilapia production

Although tilapia are cultured throughout the country, the majority of the production capacity is based in the southern Chinese provinces of Guangdong, Hainan, Guangxi and Fujian, where optimum culture conditions prevail. In 2010, Guangdong produced 624 000 tonnes of tilapia, Hainan produced 251 000 tonnes, Guangxi produced 214 000 tonnes, and Fujian produced 109 000 tonnes (Table 1). The share of tilapia production from these four major producer provinces accounted for 90 percent of the national production in that year, which totalled 1 330 000 tonnes (FBMA, 2011) (Figure 2). In recent years, the growth in production capacity has been substantial. For example, in Yunnan province production increased by 25.5 percent between 2009 and 2010 (Table 1).

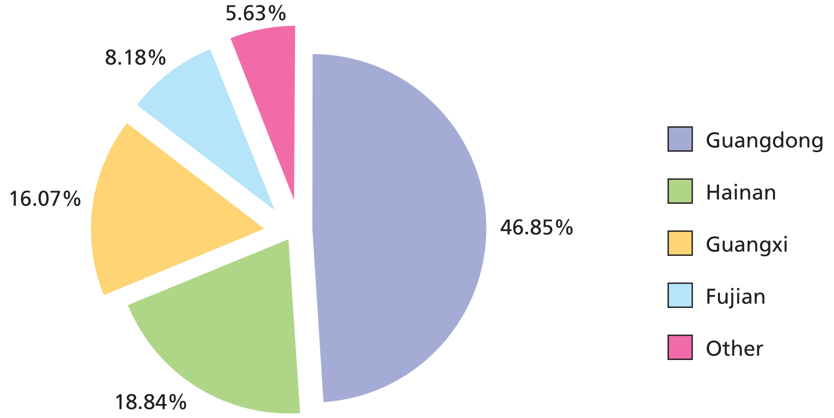
TABLE 1
Yield of tilapia in main tilapia aquaculture provinces in China

Province	2010 (thousand tonnes)	2009 (thousand tonnes)	Increase (thousand tonnes)	% increase
Guangdong	624	584	40	6.9
Hainan	251	246	5	2.0
Guangxi	214	193	21	10.9
Fujian	109	108	1	0.9
Yunnan	59	47	12	25.5

Source: FBMA (2010–11).

China is the largest consumer of tilapia products in the world. In 2006, 66.2 percent of the national production was sold in the domestic market, with the remaining 33.8 percent (375 000 metric tonnes; US$368 million) being exported (Yang, 2008).

FIGURE 2
Main producers of tilapia in China in 2010



Source: FBMA (2010–2011).

1.5 Production systems

1.5.1 *Broodstock management*

The size of broodstock ponds ranges between 1 to 3 mu1 (667 to 2 000 m²) with water depths ranging between 1.5 to 2 metres (Yang, 2006a). Prior to stocking, ponds are disinfected using quick lime at a rate of 100 to 150 kg/mu (1.5 to 2.25 tonnes per ha), and then filled with water from rivers, lakes or underground water sources. Water temperatures should be over 18 ºC. The ponds are fertilized with fermented husbandry wastes or fermented organic fertilizers, such as grass or vegetables, at a rate of 1 500 to 2 250 kg/ha. One week after fertilization, the broodstock tilapia (250–300 g) are stocked at sex ratios ranging between 3:1 to 5:1 (females: males), and stocking densities of 3 750 to 4 500 per hectare.

In order to induce gonadal development, formulated feeds are fed two or three times a day at a rate of three to five percent of body weight per day. Broodstock ponds should maintain good water quality conditions with sufficient dissolved oxygen. When necessary, new water is added to stimulate spawning. When the water temperature is above 20 °C the broodstock are ready to spawn. Nile tilapia are mouth brooders and the fertilized eggs hatch out in the mouth of the females. When the water temperature is around 25 °C, the fry swim in groups to the water surface. At this time they are ready for harvest. Fry harvesting is normally conducted in the morning or the dawn hours (Huang and Lu, 2005).

1.5.2 *Fry production*

The ponds used for fry production are 1 to 2 mu (667 to 1 334 m²). One week prior to fry stocking, ponds are filled with clean water to a depth of 50 to 80 cm. In order to promote natural productivity, organic fertilizers are applied at a rate of 400 to 600 kg per mu (6–9 tonnes/ha). A stocking density of 750 000 to 1 500 000 fry/ha is applied. After stocking, the water depth of the pond is increased gradually to1.5 metres. Between 1.5 and 2 kg of soybean milk powder per mu is added to fry ponds as supplemental feeds twice a day, once in the morning and then late in the afternoon. After five to seven days, the fry will have grown to 2 cm. From this moment, rice bran is fed twice a day at a rate of 1.5 to 2.0 kg per 10 000 fry. The feeds should be consumed within two hours of feeding; if they are not, the ration is adjusted to prevent over-feeding. After 10 to 15 days of rearing, the tilapia will have grown to 3 cm and will be transferred to a fingerling rearing facility (Yang, 2006b).

[1] 1 mu = 666.7 square metres.

As an alternative to the conventional fry production systems, GenoMar produce GIFT tilapia seed using broodstock that were originally sourced from the Philippines. Concrete ponds serve as both spawning and rearing ponds. Larval feeds (48 percent protein) are imported from Holland and fed to the larvae six to eight times per day. Feed conversion ratios of 1.2:1 to 1.5:1 are achieved with this feed. Fry and fingerling production is pond based, using locally produced extruded feeds.

1.5.3 Fingerling production

Suitable pond sizes for fingerling production range between 2 to 4 mu (1 334 to 2 667 m²), and 1.2 to 1.5 metres deep. Rice bran or formulated feeds are used to feed the fingerlings twice a day. Feeds should be consumed within two hours of feeding. After 10 days of rearing, tilapia will have grown to five centimetres, and are ready for grow-out production.

1.5.4 Grow-out production

The grow-out systems that are applied to tilapia culture comprise either ponds (Huang and Lu, 2005) or cages (Yang, 2006c). In pond culture, either monoculture or polyculture systems may be employed. However, tilapia cage culture is only undertaken under monoculture conditions.

Polyculture systems are usually employed by small-scale farmers in China. A typical farm size in Southern China would be between one to two hectares. In these systems, tilapia are normally cultured with the domestic carps, principally silver carp, bighead carp, grass carp, common carp, and mud carp (*Cirrhinus molitorella*). Polyculture systems are used as they result in an increase in the utilization efficiencies of feeds and fertilizers, improved water quality, and make full use of water column and natural food organisms in the ponds (Liu and He, 1992). Normally two methods are adopted for polyculture. The first is to culture tilapia as the primary species, accounting for 70 to 80 percent of pond production. In this case, fingerlings of about five cm are stocked in the summer at a density of 30 000 to 37 500 fish/ha. If fingerlings are to be over-wintered, they are normally stocked at 12–15 cm, and at a lower stocking density of 22 500 to 30 000 fish/ha; since the size of over-wintering fingerlings are larger than the summer stocked fingerlings, the survival rates are also higher. The other species stocked include silver carp (size: 250 g/fish; density: 3 750/ha), bighead carp (250 g; 450 to 600/ha), grass carp (500 g; 750/ha), and common carp (100 to 250 g; 150/ha). Production in these systems varies between 9 000 to 12 000 kg/ha. The second method is to culture domestic carps as the primary species and the tilapia as a supplementary species. In this case, 6 000 to 9 000 over-wintering tilapia fingerlings/ha or 12 000 to 18 000 summer-produced fingerlings/ha are stocked. The rationale for the two stocking rates is outlined above. In these culture systems, total production can reach 12 500 kg/ha, of which tilapia accounts for 2 250 kg/ha.

In China, tilapia polyculture systems are normally integrated with other animal husbandry systems. Integrated fish farming is a traditional farming system with a long history in China (Hu and Liu, 2000), and it is widely considered as a model for utilizing waste products, saving energy, and optimizing the use of local resources in an environmentally sustainable manner (Wan and Wan, 2002). Typically, investment costs are low and as the economic returns are good, the practice is widely adopted by small farmers in areas such as the Pearl Delta Area in southern China. In the developed areas of China, labour and pond rentals are high, and it is necessary to integrate the farming systems to maximize economic returns. Normally, these systems are based on integrating fish farming activities with the rearing of ducks, chickens or pigs. With respect to the aquaculture component, the culture methods that are used are similar to those applied to the polyculture systems. However, the integrated systems provide animal faeces, as well as grasses planted on pond dykes to be used as fertilizers or feeds (Zhao and Ye, 2001).

Tilapia monoculture is the system practiced by large-scale fish farmers. The production from these farms range from hundreds to thousands of tonnes per annum. In contrast to the polyculture systems, the monoculture systems require higher investment costs but result in higher production and economic returns. The size at first stocking is between 3–5 cm (summer stocking) or 8–12 cm for over-wintering fingerlings. Stocking densities between 45 000 and 60 000/ha are used for summer stocking. In contrast, when over-wintered fingerlings are stocked, the stocking density is reduced to 37 500/ha. Grow-out periods range between five to seven months, at which point some of the fish will have grown to >500 g. Typically, productivity ranges between 8 000 and 12 000 kg/ha; however, under optimal conditions, production rates of over 15 000 kg/ha can be achieved. Monoculture is more common in Northern China, where the climate is cooler. Tilapia farming in the North is normally located in areas where there is access to cheap warmwater sources, for example hot spring waters or the cooling waters of power stations. As these systems typically use tanks with high water flow rates, stocking densities can be several times those used in ponds.

Ponds are fertilized using manures, husbandry wastes and fermented silages. Fertilization rates vary between 1 500 to 3 000 kg/ha and depend on the type of fertilizer applied. To reduce costs, the fertilizers normally originate from plants or the faeces of livestock reared on or near the pond dykes. A number of feed sources are available for grow-out. These include trash fish, rice bran, wheat bran, soybean cake, residues from soybean curd production, peanut cake, rapeseed cake, lees (dead or residual yeast), silkworm pupae, duckweed and insects. With respect to maintaining water quality, basic chemical parameters, such as water temperature, pH, dissolved oxygen and transparency are recorded daily. Fertilizers are applied on an *ad hoc* basis to maintain the natural productivity of the system. During the summer months, there is an increase in pond water temperatures, and fresh water is added such that 20 to 30 percent of the pond water is replaced every week. Currently, pond discharge waters are rarely monitored. Disease can be a major production constraint, and thus the use of prophylactic treatments to prevent disease outbreaks is commonplace. In this regard, fingerlings are treated prior to stocking with five percent salt water, or a potassium permanganate solution at a concentration of 0.1 milligram per litre, for 10 to 15 minutes. Ponds are disinfected with quick lime at an application rate of 45 to 75 kg/ha for three to five days, and at monthly intervals. This also enables the pH of the water to be optimized. To maintain dissolved oxygen levels, aerators are used at dawn for 30 to 90 minutes during the main growing season from May to October. During summer, when pond waters become stratified, they may be used in the afternoon for 30 to 120 minutes.

1.5.5 Feeding techniques

Fish are usually fed twice a day and feeding is ceased as the fish reach satiation. Depending upon the weather, farmers may select to feed more than twice a day, or restrict feeding to once a day. It is important to note that feeding frequency has a significant impact on tilapia growth performance. In China, tilapia are commonly fed by automatic feeding machines. Ponds are equipped with one or several feeding machines, according to the size of the pond.

Tilapia cultured in pond systems have access to natural feeds (e.g. protozoans, rotifers, cladocerans, copepods, bacteria, algae and grasses) and therefore, compared to fish that are cultured in systems that have restricted or no access to natural feeds (e.g. tanks and raceways), they require lower levels of supplemental feeding.

In pond polyculture systems, natural feed resources are efficiently utilized by different fish species that feed at different trophic levels (Zweig, 1985; Tacon and De Silva, 1997), making polyculture systems energetically efficient and widely adopted.

Feeds used in Chinese tilapia farming systems comprise three major groups, viz. crude feed ingredients, low protein feeds and high protein feeds. Crude feed ingredients include low-value agricultural by-products, such as rice bran, and are used in low productivity systems (production >2 500 kg/ha). Low protein feeds usually contain 24 percent crude protein, and include vitamin and mineral supplements. Low protein feeds are used in moderately stocked ponds ranging from 2 500 to 10 000 kg/ha. When outputs are greater than 10 000 kg/ha, high protein feeds are used. The latter usually contain 28 to 32 percent crude protein, and include vitamin and mineral supplements (Lu, 1996).

Aquafeed manufacturing is regulated by the All-China Feed Administration Office, a branch of the Ministry of Agriculture. In 1999, to ensure the development of a responsible aquafeed industry, the State Council enacted the Administration Regulations on Feed and Feed Additives (SCPRC, 1999). Under these regulations, all the feed manufacturers must be certified by the Certification and Accreditation Administration of China (CAAC). Certification is undertaken in accordance to the Feed Product Certification Administration Methods (CAAC, 2003) co-published by the CAAC and the Ministry of Agriculture (MoA) of the People's Republic of China. In order to control feed quality strictly, the Ministry of Agriculture has published more than 100 regulations, standards and rules related to aquafeeds. With respect to tilapia, the national standard Formula Feed for Tilapia was enacted in 2005 (MoA, 2005). This standard provides detailed guidance on issues such as product category, sizes of fish and feeds, processing quality parameters, nutritional composition, labelling, packing, transportation and storage. Currently, there are hundreds of aquafeed manufactures in China and, despite the attempts of central and local governments to regulate them, applying the regulations is often problematic; thus it is often difficult for fish farmers to compare the quality of feeds from different manufacturers.

Tilapia are commonly fed high protein feeds in intensive polyculture and monoculture systems. The total annual amount of feed consumed by tilapia in China is estimated to be about 2 million tonnes (FBMA, 2009). Many of the feed ingredients that are commonly used in aquafeeds, such as cotton seed cake, peanuts, corn, soybean, maize, rice, dried fish, shrimp and fishmeal, have frequently been found to be contaminated by mycotoxins and aflatoxins (Fegan, 2005). Mycotoxins and aflatoxins are a widespread source of contamination of foods and feed worldwide. Aflatoxins exert a substantial impact on fish production, causing disease, high mortality, and a gradual decline in stock quality (Santacroce *et al.*, 2008). Aflatoxin contamination of aquafeeds is widespread, especially in countries with humid tropical climates where substandard methods of feed processing and storage exacerbate the problem (Kong, Lin and Guan, 2013). Though the serious effect of aflatoxins on tilapia has not been observed in China, it is possible that it could become a problem in the future.

2. METHODOLOGY

2.1 Geographic scope of the survey

Guangdong and Hainan provinces were selected for this survey because they represent the top two producer provinces in China (Figure 3). Both Guangdong and Hainan lie in the south of China. Guangdong province is in the sub-tropical monsoon climate zone. Annual temperature fluctuations range between 19 °C and 24 °C. Hainan province is in the

FIGURE 3
Investigation sites in southern China

Source: This review.

tropical monsoon maritime climate zone. Annual temperature fluctuations range between 22.5 °C to 25.6 °C. Both provinces are highly suitable for tilapia aquaculture.

In Guangdong province, the main tilapia aquaculture districts are Guangzhou, Zhaoqing, Maomin and Zhanjiang. The area under tilapia production in Guangzhou, Zhaoqing, Maomin and Zhanjiang is about 7 333, 4 000, 14 667 and 6 667 ha, respectively (Lei *et al.*, 2009). In Hainan province, tilapia aquaculture has developed rapidly in recent years, especially in Wenchang. By 2008, the total area under tilapia production in Hainan province was about 30 000 ha (www.cctv.com/program/mrnj/20080426/101765.html). The main tilapia aquaculture districts in Hainan province are Wenchang, Danzhou, Chengmai, Haikou and Qionghai.

A total of nine tilapia farms and one tilapia hatchery were surveyed (Table 2). The chosen production facilities provide a representative sample of the types of tilapia farms currently in operation across Southern China.

TABLE 2
Farm sizes and number of stakeholders interviewed in different categories

Stakeholders	Sample size	Locations	Areas
Hatchery operators	1	Hainan province	Hatchery (20 ha)
Grow-out farmers	9	Guangdong and Hainan provinces	Ranging from 2.67 to 33.3 ha

Source: Field survey (2010).

TABLE 3
Basic information of investigated commercial aquaculture farms

Farm code	Location	Area (ha)*	Pond rent (US$/ha/year)*	Culture system	Years in operation
A	Shaxi Village, Jianggao Township, Guangzhou, Guangdong	2.67	3 308	Integrated polyculture	18
B	Datian Village, Jianggao Township Guangzhou, Guangdong	4.00	2 867	Integrated polyculture	13
C	Bopu Township, Zhanjiang, Guangdong	4.00	2 647	Integrated polyculture	14
D	Bopu Township, Zhanjiang, Guangdong	4.00	2 867	Integrated polyculture	15
E	Bopu Township, Zhanjiang, Guangdong	2.67	2 867	Integrated polyculture	17
F	Sanjiang Farm, Sanjiang Township, Haikou, Hainan	33.33	1 323	Revised monoculture**	12
G	Sanjiang town, Haikou, Hainan	26.67	1 102–1 544	Revised monoculture**	10
H	Huaqiao Farm, Tanniu town, Wenchang, Hainan	26.67	1 320–1 544	Revised monoculture**	20
I	Baofeng Village, Dazhi Township, Wenchang, Hainan	20.00	1 320–1 544	Revised monoculture**	14

*These data were originally expressed as mu – a unit of area used in China. One mu equals 666.7 m^2. Fifteen mu equates to one hectare.

**Revised monoculture refers to tilapia that are cultured as the dominant species. Bighead carp are also stocked into ponds to make use of the natural food organisms.

Source: Field survey (2010).

2.2 Data collection and analysis

The farmer surveys were undertaken from 9 to 21 January 2010. Fish farmers were visited and asked to respond to a predefined questionnaire. Follow up visits were undertaken from 14 to 18 August 2010. These follow-up visits were used as an opportunity to clarify issues and collect additional data.

A total of nine tilapia grow-out farms (Table 3) and one hatchery were included in the survey. Data from the facilities were collected and collated into an MS excel spreadsheet for analysis.

3. RESULTS

All the famers in the survey were tenant fish farmers, and thus rented their production ponds. Farm owners are township governments or state-owned agricultural farms. All the fish farmers in the survey had been in the industry for between 10 to 20 years (Table 3). All the ponds were earthen, with sizes ranging between 0.33 ha to 3.3 ha (Figure 4). Five of the farms that were included in the survey used integrated polyculture systems, and the remaining four used revised monoculture production systems. Revised monoculture refers to tilapia that is cultured as the dominant species with bighead carp being a supplementary species that is stocked to make use of the natural productivity of the ponds. Integrated farming systems are widely adopted in southern China; in these farms pond dykes are planted with terrestrial plants, which are used as fish or livestock feed (Figure 5).

FIGURE 4
Typical earthen pond used for tilapia aquaculture in southern China

COURTESY OF FAO/JIASHOU LIU.

FIGURE 5
Example of the cultivation of terrestrial plants along the pond dykes in Guangdong province, China

COURTESY OF FAO/JIASHOU LIU.

In Guangdong province, pond rentals ranged between 18 000 to 225 000 yuan (US$2 600 and US$3 300) per hectare per year. This rental rate was two to three times that reported by farmers from Hainan province. The pond areas that were rented by family farmers in Guangzhou and Zhanjiang in Guangdong province were smaller than those in Haikou or Wenchang in Hainan province. Typically, in Guangdong province the farms are small and family operated. In contrast farms in Hainan province tend to be larger, and the farmers have to employ farm workers to assist in the operation of the facility (Table 4).

TABLE 4
Number of workers, aerators and automatic feeders equipped at each aquaculture farm

Farm code*	Province	Number of workers	Number of aerators	Number of automatic feeders
A	Guangdong	2	4	3
B	Guangdong	2	6	4
C	Guangdong	2	9	6
D	Guangdong	2	10	6
E	Guangdong	2	6	6
F	Hainan	10	50	50
G	Hainan	6	80	80
H	Hainan	4	60	60
I	Hainan	4	40	50

*The farm code in the table is the same as that is presented in Table 3, and is also used in the following tables.
Source: Field survey (2010).

All the farms were equipped with aerators and automatic feeding machines. Due to the need to supply oxygen to the ponds in a cost effective manner, aerator selection is based on pond depth, surface area, biomass, and the efficiency of the aerators, and their running costs (Table 5). Two types of aerators were reported. Turbine aerators (Figure 6) are both efficient and cost effective, and are the most commonly used in China. They are normally deployed in ponds that are more than 1 metre deep, and have a surface area of more than 0.33 ha. Paddlewheel aerators (Figure 7) are usually used in shallow ponds that have a deep layer of silt. The use of turbine aerators in these ponds would be inappropriate as they would re-suspend the silt, resulting in the deterioration in the water quality.

TABLE 5
Installation of aerators for a 0.67 ha (10 mu) tilapia pond

Category	Case 1	Case 2	Case 3	Case 4	Case 5	Case 6	Case 7
Fish production (kg/ha/year)	6 000	7 500	9 000	10 500	12 000	13 500	15 000
Oxygen consumption (kg/hour)	4.0	5.0	6.0	7.0	8.0	9.0	10.0
Number of aerators used (any of the types outlined below)							
1.5 KW turbine	1–2	2	2–3	3	3	3–4	4
3.0 KW turbine	1	1	1	1–2	1–2	2	2
1.5 KW paddlewheel	2	2	3	3	4	4	4–5

Source: Field survey (2010).

In order to increase aerator efficiencies, farmers reported adopting the following measures:

- If a few tilapia are observed rising to the surface to gulp air, aerators are operated from midnight until sunrise. If many tilapia start to rise to the surface, the aerators are started immediately.

- On warm rainy days, aerators are started at 03.00 hours to 05.00 hours in the morning and operated until sunrise. Cloudy and rainy conditions decrease photosynthesis and this can result in the depletion of dissolved oxygen levels in the early morning hours. In super-eutrophic ponds, aerators should be started earlier in the night.
- In the summer, aerators are started at 14.00 hours and run for one to three hours to de-stratify the pond waters.

In recent years, the use of automatic feeders has become widely adopted. The correct siting of these feeders in fish ponds is an important consideration, as it significantly affects their efficiency. Normally, the machines are placed in ponds that are between 0.3 and 0.6 ha and 1.5 to 2.5 m deep. The distance between the machine and the water surface is between 30 and 50 cm, enabling the feeds to be sprayed over a wide distance (Figure 8). A typical automatic feeder would have a storage capacity of approximately 65 kg, a power rating of 120 watts, and a spraying radius of 3 to 20 metres. The maximum feed delivery rate is about 160 kg per hour.

While feeding is normally undertaken twice a day, the automatic feeders have the capacity to feed up to ten rations per day. The pellet size used is dependent on the fish size (Table 6).

FIGURE 6
Turbine aerator in a fish pond in Hainan province, China

COURTESY OF FAO/XIAOWU LI AND YAOHUA WANG.

FIGURE 7
Paddlewheel aerator in a pond in Hainan province, China

COURTESY OF FAO/XIAOWU LI AND YAOHUA WANG.

FIGURE 8
Winter scene showing automatic feeders used by tilapia farmers in Hainan province, China

COURTESY OF FAO/XIAOWU LI AND YAOHUA WANG.

TABLE 6

Tilapia sizes and related pellet sizes used in southern China

Category	Body weight (g)	Pellet size in diameter (mm)
Fry	<0.2	0.3–0.6
	0.2–1.0	0.6–1.0
Fingerlings	1.0–1.5	1.0–1.5
	1.5–10	1.5–2.0
Adult fish	10–50	2.0–3.0
	50–250	3.0–3.5
	>250	4.0–4.5

Source: Xiaowu Li and Yaohua Wang, Institute of Hydrobiology, Chinese Academy of Sciences, Wuhan, China, personal communication, 2010.

3.1 Culture technologies and culture species

As discussed, there are two primary culture techniques that are used in Guangdong and Hainan provinces, *viz.* integrated polyculture systems using tilapia as the primary culture species, in which tilapia production is integrated with grass carp, bighead carp, crucian carp, ducks, chicken or pigs; and the revised monoculture systems that are based solely on tilapia and the use of formulated feeds. In some cases, bighead carp are added to the ponds to make use of the natural productivity and maintain water quality at acceptable levels.

Tilapia, grass carp, bighead carp, crucian carp, ducks, chicken and pigs are cultured throughout the year in both Guangdong and Hainan provinces. Most tilapia farmers stock 3 cm tilapia fingerlings in March, and harvest before November (Table 7). Depending on the size and market conditions during the production cycle, small numbers of tilapia may also be harvested between August to October. Where temperatures permit in Hainan province, some farmers over-winter their stock. In winter, grass carp and bighead carp fingerings (>15 cm length) are stocked into ponds and grown out over a year. Crucian carp fingerlings (10–12 cm length) are generally stocked in winter, however some farmers stock fry in April, and harvest in winter. Ducks, chicken and pigs are cultured throughout the year (Table 7). While the use of organic fertilizers, such as fermented grass is limited (dyke areas cannot support the large scale cultivation of grasses), pond fertilization using duck, chicken or pig faeces is commonplace, and is practiced throughout the year. In summer, small amounts of therapeutants may be applied to control diseases. The stocking rates are summarized in Table 8. Typical stocking rates of fingerlings/ha in polyculture systems are 30 000 tilapia, 3 000 grass carp, 450–700 bighead carp, and 750 crucian carp. Some farmers reported culturing GIFT strains of tilapia, as these reportedly have growth rates between 5 and 30 percent higher than conventional strains of tilapia (Li *et al.*, 1997; Li *et al.*, 1998; Dong *et al.*, 2008).

TABLE 7
Polyculture production cycle

Month	Stocking with type of fish/size				Type of livestock			Type of fertiliser		Application of drugs
	Tilapia	Grass carp	Crucian carp	Bighead carp	Duck	Chicken	Pig	Organic (chicken/duck faeces)	Inorganic	
January		15–25 cm		15–20 cm	x	x	x	x		
February		x		x	x	x	x	x		
March	3 cm	x	10–12 cm	x	x	x	x	x		
April	x	x	x	x	x	x	x	x	x	
May	x	x	x	x	x	x	x	x	x	
June	x	x	x	x	x	x	x	x		x
July	x	x	x	x	x	x	x	x		x
August	x	x	x	x	x	x	x	x		x
September	x	x	x	x	x	x	x	x		x
October	x	x	x	x	x	x	x	x		x
November	Harvest size 0.4–0.6 kg	x	x	x	x	x	x	x		
December		Harvest size 2–4 kg	Harvest size 0.2–0.5 kg	Harvest size 2–4 kg	x	x	x	x		

Source: Field survey (2010).

TABLE 8
Summary of reared species, initial size and amount of farmed species

Species	Initial size	Number (individuals/ha)
Tilapia	1–5 cm	22 500–37 500
Grass carp	100 g/fish	3 000
Crucian carp	50 g/fish	600–750
Bighead carp	100–150 g/fish	450–700
Ducks	Duck layers	450–750
Chicken	Table chicken	300

Source: Field survey (2010).

3.2 Feed selection

With the exception of two farms in Zhanjiang, Guangdong province, all the farms reported using commercially manufactured feeds (Figure 9) for fish and ducks. The two farms that did not use commercial feeds processed their own feeds, according to formulations and using ingredients supplied by a local feed manufacturer. Farmers selected feed manufacturers based on their awareness of the brand, the price and growth performance of the fish, or past experiences of using their feeds. However, though the prices of those feeds that were produced by small factories the quality was unsatisfactory, with pellet sizes being uneven, with many of the pellets being received in a powdered form (Figure 10).

FIGURE 9
Various sizes of pelleted feed used for tilapia, Zhanjiang, Guangdong province, China

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Farmers who used commercially produced aquafeeds in Guangdong province preferred to use extruded floating feeds; in contrast, farmers in Hainan province used sinking feeds. To reduce feed costs, the use of domestic waste (kitchen scraps) was reported by farmers in Guangzhou, Guangdong province. In Hainan province, some farmers reported that the use of extruded feed caused liver-gallbladder syndrome, and hence they chose to use sinking feeds. While these were the perceptions of some farmers, they could not be validated by the study However, liver-gallbladder syndrome is a common disease that is also found in other cultured fishes, such as grass carp (Shi and Wei, 2010), common carp (Wang, 2009), sturgeons (Zhu, 2008) and channel catfish (*Ictalurus punctatus*) (He, 2006). Liver-gallbladder syndrome manifests as lesions and bleeding of the liver.

A wide variety of ingredients are used in tilapia feeds. These include rice bran, wheat bran, soybean cake, residues from soybean curd production, peanut cake, rapeseed cake,

FIGURE 10
Poor quality feeds produced by small factories, Zhanjiang, Guangdong province, China

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silkworm pupae, duckweed, and occasionally insects. Some of the main ingredients used for commercial/farm-made feeds are listed in Table 9. The proximate composition of commercially available tilapia aquafeeds is presented in Table 10. It is interesting to note that the protein content in the adult tilapia feeds is higher than that suggested by the national standard (25 percent; MoA, 2005). Feed costs ranged between US$536/tonne and US$589/tonne. Feeds are either purchased with cash or on credit. If commercial feeds are not available for a short period of time, or the price of corn is low, farmers may choose to change feeding regimes, and to feed a combination of different grains for a short period of time.

TABLE 9
Feed ingredients used in tilapia feeds in southern China

Ingredients	Proportion of farmers using this ingredient (%)	Type of feed	Codex number (IFN)
Cottonseed cake (solvent extracted)	10–20	Pellet	5-01-632
Peanut meal (mechanically extracted)	0–5	Pellet	5-03-649
Corn flour	20–50	Pellet; farm-made feed	4-08-024
Soybean meal	20–30	Pellet; farm-made feed	5-04-600
Rice bran	0–20	Pellet; farm-made feed	4-03-928
Dried fish	0–5	Farm-made feed	
Shrimp	0–5	Farm-made feed	5-04-226
Fishmeal	50–100	Pellet	5-01-977

Source: Field survey (2010); IFN = international feed number.

TABLE 10
Proximate composition of industrially manufactured sinking and extruded pellets used in tilapia production

Feed ingredients	Proximate composition (%)		
	Fry	Fingerlings	Adult fish
Crude protein	35–38	28–30	27–29
Crude lipid	8	6	5
Fibre	3	6	6 – 8
Ash	16	14	12

Source: MoA (2005).

3.3 Feed management and feeding practices

Feed management practices are summarized in Table 11. In general, farmers fed their fish once or twice a day, ceasing feeding during inclement weather. The use of automatic feeders was reported on all farms (Figure 11). Typically, feeding was to satiation and undertaken over a 30 to 45 minute period, with the farmers monitoring the feeding activity, and adjusting the rations accordingly. Depending on the growth of the fish and the biomass in the ponds, the automatic feeders were recalibrated every 10 to 15 days.

Feeding rates ranged between 3 and 1.6 percent of body weight per day. Recording feed data varied considerably between the farmers, with some farmers calculating feed conversion ratios (FCR), and determining ration portions according to fish size, mortality, biomass, temperature, and observations of the fish feeding response. In contrast, other farmers fed at a fixed rate of two percent of body weight per day throughout the production cycle, with many failing to adequately record feed data or feed efficiencies.

FIGURE 11
Automatic feeder in action (left) and tilapia response to feeding (right)

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It was estimated that there are approximately 60 feed manufacturers in Guangdong and Hainan provinces. Most of these are small-scale manufacturers with a production capacity ranging between 100 and 1 000 tonnes per month. They supply feed to the local fish farms. Locally produced extruded fry, fingerling, grower and broodstock feeds are available. The cost of the feeds range between US$380/tonne for a simple sinking pellet, to US$955/tonne for specialized fry feeds (Table 12).

TABLE 11
Summary of feed management practices and farm incomes

Farm Code	Farm size (ha)	Feed category	Feed type	Feeding frequency (times/day)	Feeding rate (% body weight/day)	Feed additives	FCR	Maximum time feed stored (days)	Storage facility	Fertilizer	Number of automatic feeders	Net revenue (US$/year/ha)
A	2.67	Complete	Extruded	2	Not available	Water quality improver	NA[3]	15	Brick-tile house	Chicken and Duck faeces	3	10 234
B	4.00	Complete	Extruded	2	2–2.5	Probiotics	NA	10–20	Simple wooden house	Duck faeces	4	2 895
C	4.00	Complete	Extruded	2	2	Not used	NA	20–30	Concrete house	Duck faeces	6	10 047
D	4.00	Farm-made[1]	Sinking	2	2	Not used	NA	20–30	Brick-tile house	Chicken and pig faeces	6	3 547
E	2.67	Farm-made[1]	Sinking	2	1.8–2	Vitamin mix	NA	15	Brick-tile house	Duck faeces	6	1 418
F	33.33	Complete	Extruded	2	2	Probiotics	1.2–1.5	10–15	Concrete house	Organic fertilizers	50	1 377
G	26.67	Complete	Sinking	2	3, 2, 1.6[2]	Probiotics	1.6	10	Concrete house	Carbamide	80	3 840
H	26.67	Complete	Sinking	2	2	Vitamin and mineral mix	1.6–1.7	20	Brick-tile house	None	60	1 033
I	20.00	Complete	Sinking	2	2	Vitamin and mineral mix	1.6–2.0	20	Brick-tile house	Inorganic fertilizers	50	2 128

[1] Feeds used by farm D and E were farm-made feeds. The feed formula was suggested by a feed factory nutritionist, and the feed ingredients were bought from the feed factory, and processed into pellets.
[2] When fish were very small the feeding rate was about 3 percent body weight per day. The feeding rate decreased slowly as fish grew.
[3] NA = not available.
Source: Field survey (2010).

TABLE 12
Major tilapia feed producers in Guangdong and Hainan provinces

Name of feed brand	Price (US$/tonne)	Type of feed
GenoMar	955	Extruded feed for tilapia fry
Tongwei	485	Extruded feed for fingerlings
	455	Extruded feed for adult tilapia
Haida	470	Extruded feed for fingerlings
	440	Extruded feed for adult tilapia
Zhonglian	500	Extruded feed for broodstock
Raoping	380	Sinking feed

Source: Field survey (2010).

Feed is usually stored in well ventilated brick or concrete feed sheds (Figure 12). Storage periods are relatively short, with the majority of feed being used within 20 days of arrival on the farm (Table 11). Feed spoilage was not considered a problem by the farmers.

FIGURE 12
Tilapia feed storage in Guangdong and Hainan province, China
(left: brick storage cell in Guangdong province; right: concrete storage cell in Hainan province)

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3.4 Fertilizers, disinfectants, feed additives and probiotics

Fertilizers, disinfectants, medicaments, feed additives and probiotics are used by some farmers (Table 13). As farmers in Guangdong province usually rear livestock on their farms and plant grasses on the pond dykes, they use chicken, duck, or pig faeces or grasses as fertilizers in their ponds. In contrast, in Hainan province, livestock farming is not commonplace, and thus inorganic fertilizers are often used to replace the livestock faeces.

Prior to application, green grasses are fermented. Typically, grasses are put into a sheltered corner of the pond where they receive maximum sunlight. The grass is covered with dry faeces and stirred every two or three days to promote fermentation. When the grass stems and leaves have rotted, the manure can be used as a fertilizer. Prior to use, the animal faeces also require fermentation. Faeces are usually fermented in tanks and subsequently transferred into the corner of the pond for use. Application rates of both faeces and plant materials vary between 2 000 to 3 000 kg/ha per production season. Grasses and faeces may also be fermented together, and then applied to the ponds in small quantities. Fertilizer application rates are dependent on water quality and transparency. In Hainan Province, fish farmers use inorganic fertilizers during the early stages of their production cycles.

The inorganic fertilizers include nitrogen, phosphorus and calcium. A typical fertilization regime would comprise a mixture of urea and calcium superphosphate at an application rate of 30 to 50 kg/ha every 10 days for the first one or two months post stocking.

TABLE 13

Fertilizers, isolation/disinfection regimes, disinfects, feed additives, and probiotic use on each of the surveyed farms

Farm code	Fertilizer use	Isolation/Disinfection regime	Disinfectants	Feed additives	Probiotics
A	Chicken and duck faeces	Isolated annually	Not used	Quality improver	Not used
B	Duck faeces	Isolated annually	Not used	Immunostimulants	Not used
C	Duck faeces	Isolated annually	Not used	Not used	Not used
D	Chicken and pig faeces	Disinfected every 1–2 year	Unclear	Not used	Not used
E	Duck faeces	Disinfected every 1–2 year	Tea seed cake	Growth promoter	Not used
F	Organic fertilizers	Disinfected every 1–2 year	Quick lime, chlorine dioxide	Immunostimulants	Photosynthetic bacteria, bacillus subtilis, EM fungi[1]
G	Carbamide	Disinfected annually	Quick lime	Immunostimulants	Bacillus subtilis, EM fungi[1]
H	Not used	Disinfected annually	Quick lime	Vitamin C, etc.	Bacillus subtilis, EM fungi[1]
I	Inorganic fertilizers	Disinfected annually	Quick lime	Vitamin C, etc.	Bacillus subtilis, EM fungi[1]

[1] Ectomycorrhizal fungi.

Source: Field survey (2010).

Prior to stocking, the ponds are disinfected with quicklime at a rate of 1 000–1 500 kg/ha or, alternatively, calcium chloride is applied at a rate of 200 kg/ha. Three days after treatment, fertilizers are applied and the fingerlings are stocked between five to seven days later. Prior to stocking, the fingerlings are normally placed in a bath containing salt water (five percent saline) or potassium permanganate (0.1 mg/l) for 10 to 15 minutes. The treatment is designed to kill bacteria and parasites. During the growing season, quicklime is added to the ponds as a disinfectant at a rate of 45 to 75 kg/ha over three to five day periods. It is also used to maintain optimal pH in the pond water. This process is undertaken on a monthly basis throughout the grow-out period. Prior to the grow-out season, farmers sterilize the pond bottoms by drying the ponds in the winter, and ensuring that they are exposed to a minimum of 15 days of isolation.

Feed additives are widely used by the farmers. These include immunostimulants such as vitamin C, ß-dextran, amino acids, and feed attractants (Table 13). The use of feed additives varied between the famers. Normally, amino acids are added to the diet at a rate of 0.05–0.10 percent of the daily ration. Vitamin mixtures are added at doses of 200 to 300 g per tonne of feed. Combined trace minerals are added at doses of 0.2–0.5 percent of the feed.

The use of probiotics to improve water quality was reported in Hainan province, but not in Guangzhou province. Photosynthetic bacteria, *Bacillus subtilis* and Ectomycorrhizal fungi (EM fungi) were the most commonly used. While all the probiotics were commercially available, many make unsubstantiated claims of efficacy, and the active ingredients are not always listed on the product labels. An example of a probiotic where the active ingredients are listed, which is marketed by the Dabeinong Group Co. Ltd. (http://kh.dbn.cn/) under the trade name 'Lishuisu' – meaning beneficial for water quality (Chinese). The product labelling indicates that it is designed to decompose organic waste, improve water quality, rapidly decrease ammonia nitrogen, nitrite and hydrogen sulphide concentrations, promote natural productivity, prohibit the reproduction of harmful organisms, decrease the amount of therapeutant drugs required, and improve fish quality. The suggested dose is 5 kg/ha and, to be effective it should be applied three times or more. The main components of the product are listed in Table 14. Probiotics are not used in traditional tilapia and Chinese carp pond culture; however the use of probiotics in other production systems is increasing (Dai, 2010).

TABLE 14

Ingredient composition of 'Lishuisu'

Ingredients	Quantity (per 500 g)	Ingredients	Quantity (mg/500 g)
Bacillus subtilis spp.	1 700 billion CFU	Vitamin K	2 200
Saccharomyces spp.	1 200 billion CFU	Vitamin B_1	200
Vitamin A	1 000 000 IU	Vitamin B_2	580
Vitamin D3	150 000 IU	Vitamin B_6	120
Vitamin E	7 000 mg	Vitamin B_{12}	1

Source: http://kh.dbn.cn.

3.5 Fish pathology

The surveyed farmers indicated that disease was a perennial issue, and that disease outbreaks normally occurred between June and August. Farmers usually attribute disease events with poor water quality or poor feed management. On encountering a disease outbreak, most farmers decrease feeding rates or cease feeding. Therapeutants used including florfenicol, and various Chinese medicinal herbs are routinely applied. Florfenicol, an antibiotic that is designed for animal use, is added to the feeds at 0.5 kg/tonne. The fish are medicated for a one week period. Fifty–seven Chinese medicinal herbs, amounting to 32 percent of the fish therapeutants available in China, are used; however most are not formally licensed for use as veterinarian drugs.

3.6 Cost-benefit analysis

A financial analysis of the fish farms surveyed in this study is presented in Table 15. The net profits per hectare per annum in Guangdong province ranged between US$1 418 to US$10 234 (mean: US$5 628). In Hainan, net profits ranged from US$1 033to US$3 840 (mean: US$2 095). Evidently, the mean net profit per hectare of production in Guangdong province was 2.7 times that in Hainan province. The relative production costs of the farm inputs are presented in Table 16. Feed costs ranged between 68 and 84 percent of total production cost, and represented the single greatest production cost. Pond rental costs represented the second largest production cost. In Hainan province pond rental accounted for between 5.7 to 7.8 percent, and in Guangdong province, these costs ranged between 9.8 and 16.2 percent. In Guangdong province, the labour cost was the third largest cost. The proportion of fish seed cost in both provinces was similar, ranging from 2.0 percent to 3.8 percent.

Income derived from each culture species in the polyculture systems is presented in Table 17. There is a difference in those derived from the integrated polyculture system in Guangdong province and the revised monoculture system in Hainan province. In the integrated polyculture system, the income derived from tilapia ranged from 57 to 72 percent, while in the revised monoculture system, it ranged from 95 to 97 percent. In Guangdong province, the income from livestock accounted for 20 to 30 percent of total income. Since pond rentals are higher in Guangdong province, the use of integrated farming systems could compensate for the rental high cost, and still provide adequate economic returns.

TABLE 15

Production costs and income streams of tilapia farms in Guangdong and Hainan Provinces

Farm code	Cost (US$/year)								Total costs (US$/ year)	Income (US$/ year)		Total income (US$/ year)	Net income (US$/ farm)	Farm size (ha)	Net earnings (US$/ year/ha)
	Pond rental[1]	Labour[2]	Utilities[3]	Feed	Drugs	Feed additives	Pro-biotics	Fish seed		Tilapia	Other income[4]				
A	8 823	5 294	955	37 205	808	220	0	1 323	54 628	44 117	37 835	81 952	27 324	2.67	10 234
B	11 470	5 294	1 176	58 823	1 102	367	0	2 058	80 290	66 176	25 693	91 869	11 579	4	2 895
C	10 588	5 294	3 676	58 823	0	0	0	1 617	79 998	82 352	37 835	120 187	40 189	4	10 047
D	11 470	5 294	2 573	88 235	0	0	0	2 205	109 777	95 588	28 375	123 963	14 186	4	3 547
E	7 647	5 294	3 676	58 823	0	220	582	2 205	78 447	55 882	26 352	82 234	3 787	2.67	1 418
F	44 117	26 470	44 117	414 705	16 911	5 147	4 411	14 705	570 583	588 235	28 235	616 470	45 887	33.33	1 377
G	35 294	15 882	13 235	514 705	14 705	3 676	2 941	22 794	623 232	705 882	19 764	725 646	102 414	26.67	3 840
H	38 235	10 588	14 705	485 294	9 558	1 470	2 205	18 382	580 437	588 235	19 764	607 999	27 562	26.67	1 033
I	28 676	10 588	11 764	294 117	6 617	1 470	0	13 970	367 202	397 058	12 705	409 763	42 561	20	2 128

[1] As some fish farmers rent ponds at different rates, pond rental costs were calculated as mean costs.
[2] Labour costs assumed that each worker was paid 220 US$/month.
[3] Utilities primarily refer to water and electricity costs.
[4] Other income refers to income generated from other farming activities, e.g. income derived from the sale of other fish species and/or livestock.

Source: Field survey (2010).

TABLE 16
The relative farm input costs at each of the surveyed fish farms (% total cost)

Farm code	Pond rental	Labour	Utilities	Feed	Drug	Feed additive	Probiotics	Fish seed
A	16.15	9.69	1.75	68.11	1.48	0.40	0.00	2.42
B	14.29	6.59	1.47	73.26	1.37	0.46	0.00	2.56
C	13.24	6.62	4.60	73.53	0.00	0.00	0.00	2.02
D	10.45	4.82	2.34	80.38	0.00	0.00	0.00	2.01
E	9.75	6.75	4.69	74.98	0.00	0.28	0.74	2.81
F	7.71	4.63	7.71	72.49	2.96	0.90	1.03	2.57
G	5.65	2.54	2.12	82.39	2.35	0.59	0.71	3.65
H	6.58	1.82	2.53	83.50	1.64	0.25	0.51	3.16
I	7.76	2.87	3.18	79.62	1.79	0.40	0.60	3.78

Source: Field survey (2010).

TABLE 17

Income derived from reared species and their proportion to the total income for each farm

Farm code	Species	Income (US$/year)	Proportion of total income (%)
A	Nile tilapia	44 117	57.39
	Duck	18 823	24.49
	Chicken	4 517	5.88
	Grass carp	8 470	11.02
	Crucian carp	941	1.22
B	Nile tilapia	66 176	72.03
	Duck	21 176	23.05
	Crucian carp	1 129	1.23
	Bighead carp	3 388	3.69
C	GIFT tilapia	88 235	69.99
	Duck	35 294	28.00
	Bighead carp	2 541	2.02
D	Nile tilapia hybrid*	95 588	77.11
	Chicken	25 411	20.50
	Bighead carp	2 964	2.39
E	Nile tilapia hybrid*	55 882	67.95
	Duck	23 529	28.61
	Bighead carp	2 823	3.43
F	GIFT tilapia	588 235	95.42
	Bighead carp	28 235	4.58
G	GIFT tilapia	705 882	97.28
	Bighead carp	19 764	2.72
H	GIFT tilapia	588 235	96.75
	Bighead carp	19 764	3.25
I	GIFT tilapia	397 058	96.90
	Bighead carp	1 2705	3.10

*Nile tilapia hybrid (*Oreochromis niloticus* × *O. aureus*).

Source: Field survey (2010).

4. DISCUSSION

4.1 Feed management

The survey revealed that the majority of farmers did not feed their fish according to the proscribed rates suggested by feed tables, and failed to take into consideration ambient temperature, body mass and pond biomass when determining feed rations. Furthermore, farmers tended to keep poor feed records. In this regard, it is interesting to note that the one farmer in the survey that kept feed records and adjusted feed rates according to the proscribed feed tables reported the best FCR in the survey. There is therefore a clear need to train famers in feed management systems, promote the use of feed tables, and ensure that farmers maintain adequate feed records.

On-farm feed storage periods were in the region of two to three weeks. While this period may be acceptable during cooler months, cold storage systems are not used and this may lead to a deterioration in feed quality in the warmer summer months. Poor feed storage is a particularly important problem associated with the use of moist feeds, and the vitamin mixes that are easily degraded. Many farmers 'top dressed; their feeds with supplements in the belief that they improved the quality of the feeds. While this increased costs, there was no evidence of the efficacy of this action. In terms of feed storage, it is recommended that farmers store their feed on their farms for as short a period as possible. This will reduce the potential for the nutritional quality of the feeds to deteriorate prior to use.

Farm made-feeds reduce investment costs and are used by the poorer farmers. However, processing and formulation techniques need to be improved; to ensure the quality of feed, small batches should be made so that they are not stored for long periods prior to use. Where farmers can afford them, high quality extruded feeds should be used. Although investment costs are higher, the economic returns are greater, and the environmental impact associated with their use is lower than those associated with farm-made feeds.

Farmers often store their feed in substandard conditions. While storage structures varied between farmers, it was evident that feed spoilage due to rain and the opportunistic consumption by animals (e.g. rodents) was problematic. In this regard, there is a need to improve on-farm storage systems so that the feed is kept away from moisture and animals.

4.2 Culture systems

Polyculture has a long history in China, and to optimize feed use and animal wastes it is normally integrated with livestock farming. Fish farmers culture several fish species, and in doing so take full advantage of natural pond productivity, and in addition, maximize water use. Farmers in Guangdong province commonly rear livestock such as ducks, chicken, and pigs on their farm land or on the pond dykes. Farmers use livestock faeces as fertilizers to promote natural productivity in their ponds. They also plant grass or vegetables in the pond mud, which serve as a feed for herbivorous fish or livestock. Though pond rental is high in Guangdong province, the incomes from livestock accounted for 20 percent to 30 percent of total income, which still provides farmers with good economic returns on their farming operations.

In contrast, in the integrated farming systems, it is hard to control the amount of faeces applied to the ponds because ducks excrete directly into the water. In such cases, pond waters can easily become eutrophic, resulting in water quality problems, and in some cases promoting fish diseases and economic losses. Integrated tilapia farming is a cost effective farming method that is suitable for adoption by small-scale farmers. Feed supply and maintaining hygienic culture conditions can be a problem in the rural areas, and large amounts of faeces released into water may cause eutrophic waters, or even food safety problems. To reduce these risks is important to ferment the faeces prior to use.

4.3 Water quality management

Water quality in the ponds in Guangzhou, Guangdong province was found to be poor. This was attributed to two main reasons. Firstly, water supplies were of a poor quality and were likely to be sub-standard in terms of promoting optimal production. Farmers reported that, due to shortages in the area, the quality of the water that was available to them was becoming worse over time. Secondly, farmers operated their systems at relatively high densities and integrated their production systems with terrestrial livestock. The use of faecal material as a pond fertilizer often results in the development of eutrophic conditions. To reduce production costs, the fish farmers generally refused to use probiotics. The economic returns from fish farming are currently greater than those associated with traditional terrestrial farming and, as a result, many landowners are increasingly entering the sector, placing further pressure on the limited water resources. Furthermore, poor water quality is often associated with an increased incidence of disease, poor product quality, and lower market prices.

Managing pond waste waters is a serious issue in China. Environmental impact assessment agencies operate at the central, provincial and local government levels and are primarily concerned with the environmental impacts associated with industrial wastewater discharges. Normally they ignore the issues associated with waste water discharge from aquaculture ponds. The Ministry of Agriculture of China (MoA) and the attached agricultural bureaus at provincial and local levels are the responsible agents for regulating and monitoring water intake and effluent discharge. In 2007, the MoA developed standards for water quality discharges from freshwater aquaculture ponds (Table 18). Two levels of standards are given. If the effluent waters are discharged into drinking water sources, hatcheries or first class ecological reserves, the water must comply with the 'first class standards'. If the effluent waters are discharged into other water bodies, the 'second class standards' apply.

TABLE 18

Standards for waste water discharged from freshwater aquaculture ponds

Items	First class standards	Second class standards
Suspended matter (mg/l)	≤50	≤100
pH	6.0–9.0	6.0–9.0
COD (mg/l)	≤15	≤25
BOD (mg/l)	≤10	≤15
Zinc (mg/l)	≤0.5	≤1.0
Copper (mg/l)	≤0.1	≤0.2
Total phosphorus (mg/l)	≤0.5	≤1.0
Total nitrogen (mg/l)	≤3.0	≤5.0
Sulphide (mg/l)	≤0.2	≤0.5
Total chlorine (mg/l)	**≤0.1**	**≤0.2**

Source: MoA (2009).

In practice, it is very difficult to implement these water quality standards and, unless the waste water is discharged into drinking water sources or reserves containing endangered species, it is normally difficult to have the discharges monitored. The costs associated with monitoring are high and fish farms are widely dispersed, making monitoring expensive and difficult to implement. In future there will be an increasing need to monitor effluents arising from aquaculture operations.

The Ministry of Agriculture is also responsible for monitoring aquafeed production; in contrast to farm effluent monitoring, the feed manufacturing industry is strictly monitored.

4.4 Feed selection

Farmers assessed feed quality as the primary factor affecting their selection of feed. Farmers in Guangdong province prefer to use extruded floating feeds while farmers in Hainan province prefer to use sinking feeds. Many farmers identified the importance of using high quality feed ingredients but were unaware that feed processing also has a significant effect on feed quality. In many instances, the feedstuffs that were bought by the farmers were poorly milled and failed to conform to the feed process standards as outlined by the National feed guidelines (MoA, 2005). With feed costs accounting for up to 80 percent of production costs, there is a need to ensure that these standards are adhered to, and that cost effective high quality feeds are available to the farmers. Furthermore, there is also a need to develop high quality low-cost feeds, using cheap protein sources.

5. RECOMMENDATIONS

The following recommendations should be implemented to improve feed and feed management:

- On-farm feed management was generally found to be acceptable; however improved feed efficiencies could be attained by improving feed management protocols.
- Feed manufacturers should develop feed tables to optimize ration sizes. These should be distributed to the farmers and used to improve their feed management practices.
- Prior to being used, feeds are currently stored on the farm for periods of up to two to three weeks; ideally this period should be reduced.
- Where possible, high quality extruded feeds should be used; although the price of these feeds is higher than their farm-made counterparts, they promote improved growth and FCR and minimize environmental pollution.
- On many farms, feed storage facilities should be improved; this will minimize losses to pests and assist in maintaining feed quality.

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