

Bachelor's thesis

Degree Programme of Fisheries and Environmental Care

Aquaculture

2014

Antti Hänninen

PRODUCTION AND UTILIZATION OF TILAPIA FEED IN RURAL ZAMBIA



TURUN AMMATTIKORKEAKOULU
TURKU UNIVERSITY OF APPLIED SCIENCES

Antti Hänninen

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The overall objective of the study was to promote aquaculture development in Luapula Province, in Zambia, by carrying out research activities regarding tilapia feeding in semi-intensive culture (SIC). The field work was conducted in the province in two periods (2013 and 2014). The research included mainly identification of locally available feed materials, development of performing feeding regime, nutrient-rich and affordable feed formulae and implementation of trials to assess feed performance.

The feed formulae were made from locally available materials sorted by types, namely crops, wild plants, animal protein sources, and mineral and vitamin sources. The study indicated that local wild plants e.g. blackjack (*Bidens pilosa*) and amaranths (*Amaranthus*), are nutrient-rich, affordable for farmers and palatable for tilapia. They are storable to access them throughout the year. Cassava, soybeans, maize bran and termites proved also to be highly potential materials in tilapia feed. Ash, as a part of fish feed, was found to provide necessary minerals for the fish.

Based on the material availability, three different feed formulae were designed. The formulation was conducted so that all the feeds met tilapia dietary requirements in terms of primary macronutrients (proteins, lipids and carbohydrates). It was discovered that the feed is easy to make on a farm with minimal equipment. Station-based testing of different formulae was conducted to assess the growth response to greenhead tilapia (*Oreochromis macrochir*). The feed formula which included 1 part of fish meal, 1.5 parts of soybean meal, 3 parts of maize bran and 1 part of ash showed the highest performance in the experiment.

The study showed that the most efficient feeding regime for tilapia can be achieved with a combination of pond fertilization and supplementary feeding. Algae, the production of which is supported through pond fertilization, proved to be the most important source of food for fingerlings. Manure from livestock and plant-based materials were found to be adequate fertilizers. Manuring was also found to be a cheaper and more effective way to feed juvenile fish than providing supplementary feeds. According to the study, supplementary feeding should be started when the fish have reached 50–150 grams. According to the observations on the field and previous findings, efficient feeding rate for tilapia in SIC systems is approximately 3 % feed of the fish body weight daily.

KEYWORDS:

aquaculture, development, feeds, food security, perciforms, Zambia

Antti Hänninen

TILAPIAREHUJEN TUOTANTO JA KÄYTTÖ SAMBIAN MAASEUDULLA

Tutkimuksen tavoitteena oli edistää vesiviljelyn kehitystä Luapulan Provinssissa, Sambiassa, tekemällä tutkimusta tilapian ruokinnasta semi-intensiivisessä kasvatusympäristössä. Kenttätyö provinssissa tehtiin kahdessa jaksossa (2013 ja 2014). Tutkimus sisälsi pääasiassa saatavilla olevien rehumateriaalien tunnistuksen, toimivan ruokintarytmin, ravinnerikkaiden ja edullisten rehujen kehittämisen sekä kasvukokeen toteuttamisen rehujen suorituskyvyn arvioimiseksi.

Tilapia rehut tehtiin paikallisesti saatavilla olevista materiaaleista kuten viljelykasveista, luonnonvaraisista kasveista, eläinperäisen proteiinin lähteistä ja mineraali- sekä vitamiinilähteistä. Tutkimus osoitti, että paikalliset luonnonvaraiset kasvit kuten *Bidens pilosa* ja revonhännät (*Amaranthus*) ovat ravinnerikkaita, edullisia viljelijöille ja maittavia tilapialle. Ne ovat varastoitavissa ja siten saatavissa läpi vuoden. Kassava, soijapavut, maissileseet ja termiitit osoittautuivat myös olevan erittäin potentiaalisia materiaaleja kalanrehuissa. Tutkimuksessa tuhkan todettiin tarjoavan tarvittavat mineraalit kalalle osana rehua.

Perustuen raaka-aineiden saatavuuteen, suunniteltiin kolme erilaista rehua. Suunnittelu tehtiin niin, että kaikki rehut vastasivat tilapian ravintotarpeita ensisijaisten makroravinteiden (proteiinien, rasvojen ja hiilihydraattien) suhteen. Tutkimuksessa havaittiin, että rehu on helppo tehdä alkeellisissa oloissa ja vähin tarvikkein. Laitospohjainen kasvukoe toteutettiin, jotta voitiin arvioida rehujen aikaansaama kasvuvaste tilapialle (*Oreochromis macrochir*). Rehu, joka sisälsi 1 osan kalajauhoa, 1,5 osaa soijapapujauhoa, 3 osaa maissileseitä ja 1 osan tuhkaa saavutti korkeimman suorituskyvyn kokeissa.

Tutkimus osoitti, että tehokkain ruokinta tilapialle voidaan saavuttaa lammikon lannoituksella ja rehujen käytöllä. Levät, joiden kasvua tuetaan lannoituksella, osoittautuivat tärkeimmäksi ravintolähteeksi poikasille. Karjan lannan ja kasviperäisten materiaalien todettiin olevan sopivia lannoitteita. Lannoituksen todettiin myös olevan halvempi ja tehokkaampi tapa ruokkia nuoria kaloja kuin tarjoamalla rehuja. Tutkimuksen mukaan rehujen käyttö tulisi aloittaa, kun kala on saavuttanut 50–150 gramman painon. Havaintojen ja aiempien tutkimusten mukaan tehokas ruokintaprosentti tilapialle semi-intensiivisessä kasvatuksessa on noin 3 % kalan painosta vuorokaudessa.

ASIASANAT:

ahvenkalat, kehitysyhteistyö, rehut, ruokaturva, Sambia, vesiviljely

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1 INTRODUCTION

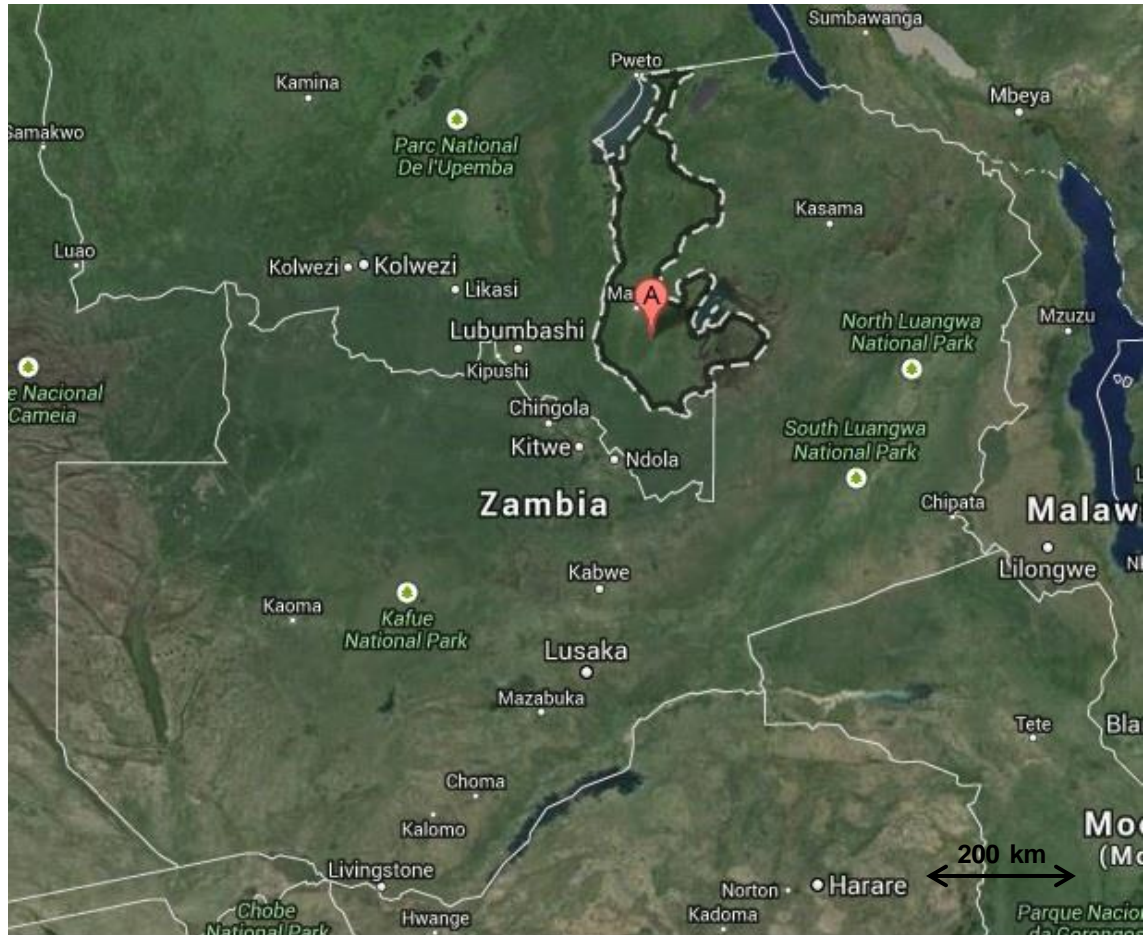
Zambia is located in the interior parts of Southern Africa and has an estimated population of 14.1 million (2012 data). Approximately 60.5 % of Zambia's total population lives in rural areas, obtaining their income mainly through small-scale agriculture. In 2012, 20.5 % of the GDP came from the agriculture sector, over half of which was contributed by livestock, aquaculture and capture fisheries. (J. Chiti, private communication 19.08.2013; CIA 2013.)

Aquaculture plays an important and increasing role in Zambia's economy. There is high unsatisfied demand for high quality fish in the country. The demand is caused by declining per capita fish supply, increasing purchasing power and changing consumer preferences. Declining per capita fish supply is the result of population growth that aquaculture production has not been able to follow. (R. Otsamo, private communication 28.01.2013.)

Luapula Province is one of Zambia's ten provinces. It is located north of the country, sharing much of its western boundary with the Democratic Republic of Congo (DRC) both on land and water (Picture 1). The province covers a land surface area of 50,567 km². It has a population of about 1 million people, of which over 80 % live in rural areas. The population density is approximately 20 persons per km². The population is growing at about 2.5 % per year. Around 60 % of the population is below 20 years of age and 75 % below 30 years old. The number of households in the province is about 200,000. The province is among one of the poorest areas in Zambia. The demographic data describes the situation in 2012. (R. Otsamo, private communication 28.01.2013.)

Tilapia (*Tilapia*) is the most farmed fish species in Luapula Province. The species create the majority of the income from local aquaculture. Most of the production is made through extensive and semi-intensive culture (SIC). Tilapias have the advantage over other species because of their minimal environmental requirements, fast growth and excessive breeding. Tilapia species are found

also in natural waters all over the country. (H. Bwalya, private communication 15.08.2013; Windmar 2008.)



Picture 1. A map of Zambia with Luapula Province highlighted (Google 2014).

In Luapula Province, the tilapias are usually allowed to feed and breed freely in earthen ponds, without proper supplementary feeds or stock control. The main method of feeding is supporting algae production in ponds by adding fertilizers such as livestock manure or plant material. Nutrient intake is limited when the fish is grown by using only this method. Also the excessive breeding of tilapia is a limiting factor in growth. Breeding results in high densities and remarkable sized fish cannot be grown. Inadequate knowledge of farming methods and not fully exploited resources will realize as financial loss.

Therefore, there is a justified need to look at ways to improve tilapia production in Luapula Province. The development of quality low-cost feeds, effective feeding regimes and information dissemination will play a major role in increasing aquaculture productivity and food security in the province. By higher aquaculture production the fishing pressure in natural waters will also decrease, so that the over-exploited fish stocks have a possibility to recur.

2 OBJECTIVES

The field work was located in Mansa, Luapula Province, Zambia. The field work was conducted in two periods; from August to November in 2013 and from May to August in 2014. The overall objective of the study was to support income generation and food security in the province. The specific objective was to promote aquaculture development by carrying out research activities regarding tilapia feeding in SIC.

The study discusses the following questions;

- Which locally available farm-based materials are nutrient-rich and of high potential as fish feed?
- What are the affordable sources of animal proteins in the fish feed?
- What are the combinations of feed materials that are appropriate for fish feed?
- How are the materials prepared to make quality and palatable fish feed?
- What is the most cost-efficient feeding regime for tilapia?
- What kind of possibilities are there to use polyculture in order to improve production?
- How to use integrated farming methods efficiently?
- How should information be distributed to the farmers for the best adoption?

3 BACKGROUND AND LITERATURE REVIEW

The study starts with a background research to the current status of aquaculture in Zambia and Luapula Province. This is followed by a review of general biology and dietary preferences of tilapia. The study discusses also other potential species for polyculture purposes with tilapia. This information creates the foundation for preparing adequate feeding and culture conditions for tilapia.

3.1 Aquaculture in Zambia and Luapula Province

The first attempt to farm fish in Zambia dates back to the 1950s (Maguswi 2003). The statistical records of aquaculture date back to 1977. The first boost raised the production up to 4,000 tonnes in the early 1990s. The second sudden increase started in 2008. The production hit 10,000 tonnes in 2010 (Figure 1). In 2012, aquaculture production in Zambia was 12,988 tonnes per year (J. Chiti, private communication 19.08.2013).

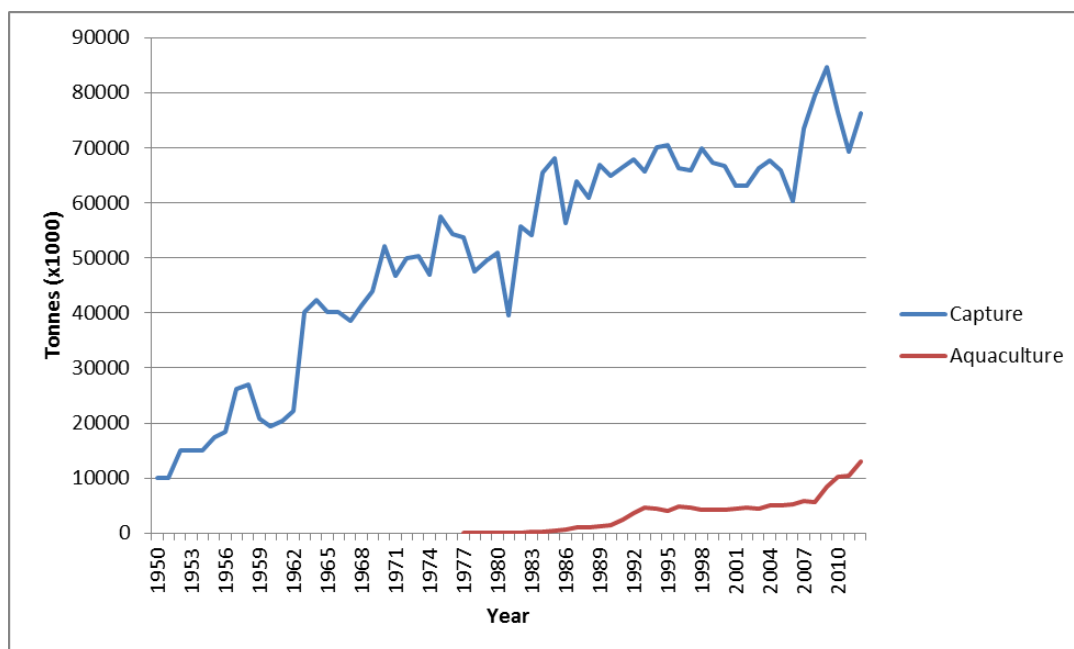


Figure 1. Reported aquaculture and capture fisheries production in Zambia (FAO 2014).

The value of the aquaculture output is currently over USD 40 million (FAO 2014). This volume is produced by over 6,000 smallholders and small-scale fish farmers throughout the country and large commercial fish farms spread along the railway line in Copperbelt and Southern provinces where ideal business conditions exist (Maguswi 2003). There are also a number of fish cage culture projects in Lake Kariba and one in Bangweulu. Aquaculture therefore makes an increasingly significant contribution to the total fish production, including capture fisheries, in Zambia estimated at 76,214 metric tonnes in 2012 (J. Chiti, private communication 19.08.2013).

Fish farming methods range from intensive to extensive and from mono-species to multi-species culture. The small-scale fish farms are usually family based and they use extensive methods with a few ponds producing between 1–2 tonnes/ha/year. Smallholders make their production through semi-intensive culture systems – the production depends largely on the ponds' natural food which is increased over basic levels by fertilization and sometimes by the use of supplementary feed to complement natural food. These farmers may have several ponds, their own livestock and hired labour to do various tasks. Production varies between 2–2.5 tonnes/ha/year. Intensive fish farms with high value investments are uncommon and run by commercial companies. They are market oriented and may include processing for specialized markets. Commercial companies may reach 6 tonnes/ha/year in production. (Maguswi 2003.)

Most of the aquaculture products are consumed locally. The output of small-scale farmers is unprocessed and sold in villages, street stands or nearby market places. At the same time, supermarkets are selling commercially produced domestic or even imported Asian tilapia products. The price for locally produced tilapia varies from ZMK 10 to 30 (USD 1.6–4.9) per kilogram, depending on the location, season, availability of buyers and quality. The price is nearly the same at the market level for imported frozen fish that is imported to the country from China.

Aquaculture in Luapula Province is mostly practiced by small-scale farmers and smallholders. There is one commercial aquaculture producer in the province which uses cage culture in Lake Bangweulu. According to the aquaculture survey conducted in the province in 2012, the number of fish farmers in Luapula was about 1,267. These farmers had 2,093 ponds in total. The average farmer had about three fish ponds with the size ranging from 100 to 600 m². The average pond size was estimated at 572 m². The total area under these fish ponds was assessed at 384,150 m². In 2012, aquaculture production in Luapula was in the range of 100–120 tonnes per year. Capture fisheries still provided the major part of fish in the province producing approximately 20,000 tonnes per year. (Windmar 2008; R. Abila, private communication 02.10.2013.)



Picture 2. Catching fish in Fiyongoli Aquaculture Research Station.

Aquaculture development in Luapula Province has been supported by international organisations and joint development projects. It is currently reinforced by the Programme for Luapula Agricultural and Rural Development – Phase II (PLARD II) and US Peace Corps. The approach of PLARD II is to

develop integrated fish-crop-livestock production systems by training extension staff and farmers and establishing demonstration units; develop capacity for aquaculture research, supply of fish fingerlings and affordable quality fish feeds through Fiyongoli Aquaculture Station (Picture 2) and advanced farmers; improve information dissemination through farmers field days, exchange visits, shows and exhibitions and video documentaries and; create linkages with other aquaculture projects and service providers to enhance extension service delivery. Support is also provided to the Department of Fisheries (DoF) under the Ministry of Agriculture and Livestock (MAL) (Appendix 1) for effective supervision, backstopping and coordination of aquaculture component activities, including holding regular technical meetings for planning and review. US Peace Corps volunteers provide free extension services to fish farmers on a continuous basis. (R. Otsamo, private communication 28.01.2012.)

3.1.1 Potential for aquaculture production

Aquaculture can contribute significantly in the alleviation of poverty and malnutrition and improve the local livelihood in Zambia due to the following reasons: 1) from a global perspective aquaculture is one of the fastest growing protein-producing systems in the world – over half of the fish consumed by the human is currently produced through aquaculture; 2) over 85 % of the world's aquaculture production comes from the developing countries; 3) aquaculture is becoming an important component of increasing food security in situations where increasing population pressure will limit dependence on natural fisheries. (El-Sayed 2006, 176.)

Compared to other African countries, Zambia, particularly Luapula Province, has a relatively large water resource suitable for fish farming and therefore has high potential for aquaculture. It is estimated that 4,000 hectares in the province can be brought under pond culture. Approximately a million hectares of the country's water bodies, including lakes, dams, rivers and reservoirs, are potential sites for cage culture. Cage culture is a type of intensive aquaculture and does not require large areas of land; however, it needs to be conducted

with caution due to high risks of environmental degradation. Cage culture has relatively lower capital investments compared to land-based intensive farms; however, it requires closer monitoring to avoid predators, fish escapes and water pollution. There are two large lakes in Luapula Province, Lake Bangweulu and Lake Mweru, with high potential for cage culture (J. Chiti, private communication 19.08.2013). DoF has carried out environmental impact assessment and identified suitable sites for cage culture in Bangweulu and Mweru-Luapula.

3.1.2 Constraints and limitations to aquaculture production

There are numerous constraints that can hamper the development of aquaculture in Zambia. The overall limiting factors are: 1) political and economic instability which may affect the quality of extension services and threaten the economic viability of aquaculture enterprises and security of investment; 2) low incomes by local consumers leading to small markets and reliance on external markets; 3) poor infrastructure including poor storage, poor marketing channels and poor maintenance of farming facilities; 4) inadequate knowledge by tilapia farmers in biological, technical, environmental and social factors related to aquaculture (The Economist 2009).

In Luapula Province, tilapia are mostly grown without proper supplementary feeds. The fish farmers are poor and most of them cannot afford feed materials and pond fertilizers. The main method to feed fish is to support algae production in ponds by adding livestock manure or plant material into water. Nutrient intake is limited when the fish is grown by using only this method. Lack of on-farm made fish feeds is one of the major drawbacks in aquaculture development in the province. There are nutrition-rich ingredients available in the province, but people are lacking experience and knowhow to fully utilize these resources. The greatest challenge in terms of raw materials is to satisfy the needs in terms of animal proteins. In the aquaculture survey that was carried out in Luapula Province in 2012, about 32 % of farmers indicated that they apply formulated feeds to their fish, although the types of formulae were not verified (R. Abila,

private communication 02.10.2013). In addition to supplementary feeds, some farmers lack knowledge of efficient use of integrated agriculture-aquaculture (IAA) and polyculture.

One of the main drawbacks associated with tilapia culture in SIC systems is their continuous and excessive breeding. Breeding results in overpopulation in the pond, causing low production of remarkable sized fish due to the competition for food and space (El-Sayed 2006, 60). The lack of knowledge in fish breeding and the methods of controlling reproduction are therefore additional constraints. Local farmers are not familiar with the use of predatory species such as the African catfish (*Clarias gariepinus*) to control tilapia stock. Instead they tend to remove all predatory species from the culture systems because they think that these will cause loss in production. In addition, there are a few groups (e.g. Seventh day Adventists) in Luapula Province, who do not farm African catfish due to religious issues.

Some of the smallholders produce their own fingerlings in Luapula Province. The farmers typically harvest a proportion of the larger fish in the ponds for sales 1–2 times per year. The smaller fish in the ponds are often reintroduced into new ponds or sold as fingerlings. The major constraints in producing quality fingerlings are inbreeding among the individuals of small fish population within a pond, continuous removal of fast growing fish and poor marketing channels. Some of the fingerling farmers lack the knowledge of how to manage the system. (Windmar 2008.)

The production is also reduced by a number of sub-optimum management practices including: 1) selection of pond sites without considering the risk of flooding, water availability and the need to be able to drain the ponds; 2) selection of pond sites without considering the risk of predation and theft; 3) selection of the pond sites without considering transportation; 4) insufficient water quality management; 5) insufficient pond maintenance and farming methods. (Windmar 2008.)

3.2 Tilapia (*Tilapiini*)

The most farmed fish in Luapula Province is tilapia (*Tilapiini*). The three most popular species of tilapia in the province are redbreast tilapia (*Tilapia rendalli*), greenhead tilapia (*Oreochromis macrochir*) and three spotted tilapia (*Oreochromis andersonii*). All of these three species live low in the food chain and are benthopelagic – they feed near the bottom as well as in midwaters or near the surface (FishBase 2014). In optimal culture conditions in SIC systems these species can reach the market size in six months to eight months.

3.2.1 General biology and ecology

Tilapia belongs to the order of *Perciformes*. The fish have their place in *Tilapiini* tribe which is part of *Cichlidae* family. Tilapia cover three main genera: *Oreochromis* spp., *Sarotherodon* spp. and *Tilapia* spp. These genera cover over 70 known species in total. (Lim & Webster 2006, 3.) The specific taxonomic classification is still confusing and under continuous modification (El-Sayed 2006, 33). Tilapia have their origin in Africa and the Middle East where they have been cultured for a long time. The first known tilapia were farmed in the ancient Egypt over 4000 years ago. Introductions to other areas started in 1920. (Lim & Webster 2006, 1.) Nowadays China is the largest tilapia producer, followed by Egypt (Rakocy 2005).

Tilapia are used mostly as an aquaculture and aquarium species and also to clear ponds of plants and algae (MIT Sea Grant Coastal 2006). The most cultured species worldwide is Nile tilapia (*Oreochromis niloticus*) (Rakocy 2005). Other fast growing and commonly farmed species are Israeli tilapia (*Oreochromis aureus*) and Mozambique tilapia (*Oreochromis mossambicus*) (Lim & Webster 2006, 4). Tilapia are low in the aquatic food chain, feeding mostly on algae and plant-based materials. This makes them easy to cultivate even in rural conditions. (El-Sayed 2006, 28–29). Among the cultured species of the world, tilapia have the third place in terms of production. Only carp and salmon are ahead of tilapia (El-Sayed 2006, 6).

Because of their widespread use, tilapia can be found from all continents, except Antarctica. Tilapia that have escaped to natural waters have usually managed to do well in the prevailing conditions and reproduced. As an alien species, they have caused harm to native species and the environment. Especially Nile tilapia is a very dominant species and for this reason, it is not allowed to be introduced to Luapula Province. Tilapia species have good adaptability in terms of temperature and salinity. In good conditions they reproduce very fast. Most of the species have optimal conditions in shallow and warm waters. However, they can live also in streams, big lakes, and oceans. (Chapman 2006.)

Tilapia are basically freshwater fish but all the species grow and reproduce in brackish water till the salinity of 1–2 %. Although the fry endure brackish water, the fingerlings are vulnerable to salinity. The optimal salinity level for fingerlings is under 1 %. (Lim & Webster 2006, 30.) Some species, such as Mozambique tilapia, can tolerate salinities over 4.5 % and even reproduce in these conditions (MIT Sea Grant Coastal 2006; Chapman 2006). Mozambique tilapia have optimal growing conditions in 1.75 % salinity. In optimal salinity conditions, the fish do not use energy to maintain salinity level of its body by osmoregulation so it can manage in an environment that has low oxygen levels. (Lim & Webster 2006, 30.)

Compared to other species, tilapia can tolerate very low oxygen levels. They survive in water that has less oxygen than 0.5 mg/l. This ability is caused by the haemoglobin that can absorb and carry the oxygen effectively. The fish have adopted to take the oxygen from the surface if there is not enough of it in water. This ability makes tilapia a good species to farm in conditions, where there are no possibilities to maintain oxygen levels. To ensure the welfare and growth of fish, 2 mg oxygen per litre is optimal. (Lim & Webster 2006, 31.) On the other hand, tilapia can stand extremely high oxygen levels, reaching over 400 % saturation, which usually occurs because of high photosynthesis caused by blooming algae near the surface (El-Sayed 2006, 42).

Tilapia survive in a wide environment with a pH 5–11. In lower acidity levels the dissolved carbon dioxide limits the physiological functions of the fish more than the acidity itself. Carbon dioxide impairs the haemoglobin capacity of tilapia to bind and transport oxygen. Long-term exposure to water that has the content of CO₂ above 50 mg/l leads to the death of the fish. (Lim & Webster 2006, 32.)

The ideal temperature for most of the species is 25–30 °C. However, the fish survive in varying temperatures. For example, Israeli tilapia can cope with 10 °C water (Nico & Fuller 2013; MIT Sea Grant Coastal 2006). The water temperature of 40–42 °C is extreme for the fish and lethal in prolonged exposure. Fish size, species, health and strain caused by the environment have an effect on fish survival in extreme temperatures. (El-Sayed 2006, 35.) The right temperature has great importance for the growth of tilapia. El-Sayed and Kawanna (2008) studied the growth of the Nile tilapia at temperatures of 24, 28, and 32 °C in recirculation tanks. The result showed that the fish grew up to a half faster at 28 °C temperature than at 4 °C colder or hotter water. Okeyo and Montgomery (1992, 8) study, carried out on the Israeli tilapia and three different water plants at 15–25 °C water, showed that the fish ate, grew, and took advantage of the available food more effectively in warmer water. Deep enough ponds play an important role here, so it is possible for the fish to seek the proper temperature from different depths.

The time of sexual maturity is dependent on age, species, size and environmental factors. In nature tilapia reaches maturity even a half faster in flowing water than in standing water. Natural sex-selection mechanisms are not well-known. Genetic factors mainly affect these mechanisms but also temperature, density and feed have an effect on the sex-selection. (Lim & Webster 2006, 17 and 26–27.)

In tropical countries, tilapia breed all year around. Photoperiod, temperature and lunar-period have an effect on the tilapia breeding cycle (El-Sayed 2006, 123). The breeding temperature depends on the species. Most of the tilapia breed at water temperature between 22 and 35 °C. The optimal breeding temperature is around 28 °C. (El-Sayed 2006, 121–122.) Tilapia lay eggs usually close to

shore where the water depth is less than 1 metre. In good conditions tilapia can breed again after 22 to 44 days. If the eggs are collected from the female's mouth before they hatch, the fish is likely to breed again very soon. (Lim & Webster 2006, 19–20.)

Tilapia genera differ from each other in terms of breeding. *Tilapia* spp. make a spawning nest to a shallow shore where they can lay their eggs. They protect the nest until the fry hatches. *Oreochromis* spp. and *Sarotherodon* spp. incubate and hatch their eggs in the mouth (Picture 3). Both parents of *Sarotherodon* spp. can take care of the eggs when *Oreochromis* spp. females hatch them. (Lim & Webster 2006, 14–15.) Also the mouthbreeders lay their eggs first in the nest where the male fertilizes them. After fertilization the fish collects the eggs to its mouth. The spawning act lasts from 15 to 30 minutes. In big schools, females can easily take eggs of other fish into their mouths. (Lim & Webster 2006, 21.)



Picture 3. *Oreochromis* spp. and *Sarotherodon* spp. incubate and hatch their eggs in the mouth (Shareef 2012).

All tilapia species have sinking fry. The fry differs in terms of stickiness and size. *Tilapia* spp. fry, unlike the fry of other genera, includes slimy secretions that keep the fry on aquatic plants and rocks on the bottom. The fry itself is small with 1.1–2 mm in diameter. *Oreochromis* spp. eggs are 2.8–4.3 mm and *Sarotherodon* spp. eggs are 2.4–3 mm. The number of eggs that the female produces depends on the fish size. The average amount of eggs is between 1000 and 2500 eggs. (Lim & Webster 2006, 21–22.)

Breeding females do not usually open their mouths or move gills much when incubating eggs. They can also be recognized by a bulging on their necks. (Lim & Webster 2006, 20.) Tilapia keeps the fry in its mouth till the yolk sack has absorbed. The mouth breeding takes usually two weeks and then the fingerlings can swim freely. They stay nearby the parent and they can go back to the mouth if they are in danger. (Rakocy 2005.) When the yolk period is over, the female leaves fingerlings to a shallow place, covered with plantation (Lim & Webster 2006, 21).

3.2.2 Feed selection and dietary preferences

The main focus of this thesis is to help the reader understand how to satisfy the dietary needs of cultured species of *Tilapiini* tribe. The tilapia have an increasing importance as an aquaculture species. Therefore, it is important to understand the food preferences and feeding regimes of tilapia on their natural habitats in order to prepare suitable diets and adopt appropriate feeding regimes under culture conditions.

Tilapia are omnivorous fish. Wild tilapia eat aquatic plants, algae, invertebrates, fish larvae, insects, plankton, detritus, and decomposing organic matter. Tilapia fingerlings feed mainly on plankton whereas adult diets are more variable. Plankton is filtered from the water by long gill-rakers. (Lim & Webster 2006, 35.) Food preferences vary according to the genus and environment. *Oreochromis* spp. and *Sarotherodon* spp. feed mostly on micro-organisms while *Tilapia* spp. use a wide variety of different food items (El-Sayed 2006, 32–33).

Seasonality has an effect on the food preferences of tilapia. At different times of the year, there are various types of food available. In temperate zones, the fish feed most actively in the summer than winter (El-Sayed 2006, 32–33). Not only do seasons affect on the feeding preferences of tilapia as El-Sayed (2006, 32) refers to a research (see Richter et al. 2003), which found that the size of the fish has an effect on the time of feeding. Adult Nile tilapia, 31.5 g, fed throughout the day from morning to evening, while the smaller tilapia, 9.8 g, ate in two periods, in the morning after sunrise and in the evening before sunset. Generally, the feeding is more active when the water temperature is optimal (G. Kujala, private communication 20.06.2014).

Tilapia prefer protein-rich and easily digestible diets. The structure of the wall of a plant cell has an effect on the validity as a food. A complex cell wall can resist stomach acids of the fish and does not digest well. The digestive system of tilapia is primitive with a length of up to six times more than the entire length of the fish. This feature facilitates plant food digestion and absorption. In addition, the fish have specialized teeth along with strong gastric acids with pH of less than 2. (Lim & Webster 2006, 35–36.)

Tilapia can cope with plant-based diets, but to optimize the growth they need some animal protein (Okeyo & Montgomery 1992, 2). Okeyo and Montgomery (1992, 9–10) state in their study that Israeli tilapia eat mostly water plants with high protein content (*Elodea Canadensis* and *Myriophyllum spicatum*). However, plain plant-based diet decreased the tilapia weight. In the experiment, fish fingerlings lost proportionally less weight than adult fish, which may indicate their ability to take better advantage of plant-based protein sources. For fish fingerlings, protein intake is particularly important as they are in a faster growth curve (Lim & Webster 2006, 36–37).

3.2.3 Species for aquaculture in Luapula Province

Greenhead tilapia (*Oreochromis macrochir*) (Picture 4), also known as longfin tilapia, is a native to Zambia and the upper Zambezi Basin. It has been introduced for stocking ponds and dams in other parts of Africa and in Oceania.

It is the second most common species among fish farmers in Luapula Province (R. Abila, private communication 02.10.2013). The fish can be recognized by its greenish head and long pectoral fins. The fish prefers naturally quiet, deep waters (5–14 m) associated with aquatic vegetation, but it has also been collected in other habitats. Greenhead tilapia live at temperatures between 18 and 35 °C. As a native of inland waterways, it has very low salinity tolerance. Occasionally the fish form schools. It is mainly diurnal, i.e. primarily active during the daylight. The fish feed mostly on detritus, blue-green algae and diatoms. It can reach the length of 43 cm. (Marshall & Tweddle 2007; Trewavas 1983, 583.)



Picture 4. Greenhead tilapia (*Oreochromis macrochir*).

Three spotted tilapia (*Oreochromis andersonii*) (Picture 5) are native to the Zambezi Basin and the third most common species in Luapula Province (R. Abila, private communication 02.10.2013). The fish can be found in river and swamp habitats. It prefers deep, quiet water with some weed cover; hippo pools are favoured hiding places. The fish can be recognized by vertical series of three spots on its sides.



Picture 5. Three spotted tilapia (*Oreochromis andersonii*) (Van der Bank 2009).

Three spotted tilapia are hardy fish, tolerating fresh and brackish water up to 2 % salinity. Adults occupy deep open waters and juveniles remain inshore among vegetation. The optimal depth range is from 3 to 6 meters. The temperature range for the fish is 18–33 °C. Three spotted tilapia forms schools and are mainly diurnal. They feed on fine particulate matter, including algae, diatoms, detritus and zooplankton. Larger fish also feed on insects and other invertebrates. The feeding regime is variable and the diet changes according to food availability. Three spotted tilapia have reached up to 61 cm. (Trewavas 1983, 583.)



Picture 6. Redbreast tilapia (*Tilapia rendalli*) (Uys 2012).

Redbreast tilapia (*Tilapia rendalli*) (Picture 6) is a native inhabitant of Sub-Saharan Africa, including Congo, Niger and the Zambezi Basin. In Luapula Province, it is the most reared species with over 50 % of farmers having it (R. Abila, private communication 02.10.2013). The fish prefers quiet, well-vegetated water along river littorals or backwaters, floodplains and swamps. It can be recognized by its dark-olive coloured head and back. The body has vertical bars and the breast is reddish. It lives at a wide range of temperatures (8–41 °C) but the optimal temperature is between 24 and 28 °C. It can tolerate salinity up to 1.9 ‰. Redbreast tilapia form schools and are mainly diurnal. The juveniles feed on plankton, while adults mainly feed on higher plants, tadpoles, insects and crustaceans. Redbreast tilapia can be used for control of tadpoles and aquatic vegetation. This species prefers a sloping spawning ground near the marginal fringe of vegetation. The fish build nests in shallow waters where both parents guard the eggs and fry. In optimal conditions, redbreast tilapia can reach the length of 45 cm. (Teugels & Kullander 2013; Awaiss et al. 2010.)

3.3 Other potential species

There are other species than tilapia that are not well-known in Luapula Province, but have a high potential in polyculture systems. Polyculture means farming more than one species in the same production unit. The main objective of polyculture is to introduce species that have different feeding niches into the same pond. It is understood that properly conducted polyculture results in higher net yield than mono-species culture due to more efficient utilization of pond resources. For maximizing tilapia production in polyculture systems, it is essential to fully understand the relationships between the species and environment. (El-Sayed 2006, 59.) The recommended species for polyculture with tilapia in Luapula Province are common carp (*Cyprinus carpio*) and African catfish (*Clarias gariepinus*). These species typically reach a large size and the rearing period is 2–10 years (H. Bwalya, private communication 01.08.2014).

Common carp (*Cyprinus carpio*) (Picture 7) are native to Eurasian – they evolved in the Caspian Sea and migrated naturally to the Black and Aral Seas.

Currently carp are introduced throughout the world. In Zambia, the fish was first introduced in Chilanga fish farms in 1980. The colour of the species varies; carp are brownish-green on the back and upper sides and golden yellow on sides, with two barbells. Common carp are rare in Luapula Province. (Peteri 2004; Kottelat 2007.)

Carp are tolerant of a wide variety of conditions but generally favour large, well vegetated environments, with slow flowing or standing water and soft bottom sediments. The ideal temperature for the fish is from 23 to 30 °C. Common carp can tolerate salinity up to 0.5 %. The optimal pH range for the fish is 6.5–9. The species manage low oxygen concentration (0.3–0.5 mg/litre) as well as supersaturation. The average size of wild carp is 40–80 cm and 2–14 kg, but it can weigh even up to 30 kg. (Peteri 2004; Kottelat 2007.)



Picture 7. Common carp (*Cyprinus carpio*) (NANFA, 2014).

Larval common carp feeds primarily on zooplankton. In the wild, juveniles and adults feed on benthic organisms, vegetation, detritus and plankton. The common carp are very active when feeding and their movements often disturb

sediments and increase turbidity. This may cause problems in water quality if the carp are major species. On other hand, when carp stir up the bottom sediments, they facilitate the efficient utilization of organic and inorganic matter. This process reduces the accumulation of ammonia and nitrite and makes nutrients more available for large-size algae. This is why common carp are good for polyculture with tilapia. Carp can gain 0.6–1.0 kg weight within one season in the polycultural fish ponds of tropical areas. The quantity of common carp in a polycultural system should be in accordance with the productivity of natural food organisms. The average stocking ratio of carp in multi-species SIC system is 20–25 % of the total fish stocked. (Peteri 2004; El-Sayed 2006, 59.)



Picture 8. African catfish (*Clarias gariepinus*) (Trailin 2010).

African catfish (*Clarias gariepinus*) (Picture 8) are of the family *Clariidae* – catfishes with the ability to breathe air. The fish has a large and flat head with small eyes, four pairs of barbels and long dorsal and anal fins. The colour of the back and sides varies from sandy yellow to dark greenish brown. Belly and the ventral parts of the paired fins are light coloured. The species are found native in Africa as well as the Middle East. The African catfish have been introduced

within Africa and several countries in Europe, Asia and South America. (Pouomogne 2010.)

The diet of African catfish typically includes insects, worms, gastropods, crustaceans, fish, aquatic plants and debris, terrestrial seeds and even birds and small mammals. The fish have relatively large mouths so they can swallow the food without chewing. Like tilapia, larvae catfish are more dependent on zooplankton than adult. African catfish digest high-protein diets better than carbohydrates. Most of the feeding activity takes place at night. The fish grow fast and they can reach the maximum size in two years. (Pouomogne 2010.)

African catfish are found in lakes, streams, rivers, swamps and floodplains, many of which are subject to seasonal drying. The accessory air breathing organs allow them to survive in conditions where other fish would die. African catfish undertake migrations from lakes, in which they feed, to temporarily flood marginal areas in order to breed. The fish matures at about 12 months of age. Under optimal conditions, females may lay 60,000 eggs per a kilogram of body weight. After mating, adhesive eggs stick to aquatic vegetation or rocks and hatch in 20–60 hours depending on the temperature. The larvae grow fast in the warm and nutrient rich floodplains reaching 3–7 g within 30 days. As flooded marginal areas may dry up, the fish make their way back to deeper water. (Pouomogne 2010.)

Controlling overpopulation is essential for profitable tilapia culture. As predatory species, African catfish have high potential in stock control. The fish can control overpopulation by feeding on tilapia fry and fingerlings. This leaves more space for remarkable sized fish to grow. The predatory species are also harvestable and can be an important source of revenue. In Luapula Province, their use is not yet common. By promoting African catfish distribution and offering information on farming methods, the farmers will become familiar with the use of the fish. By this polyculture method, farmers will gain a higher output from aquaculture. The correct stocking density that allows good predation of tilapia offspring is one catfish per ten tilapia. (Pouomogne 2010; El-Sayed 2006, 59–60.)

4 MATERIALS AND METHODS

The main methods to feed tilapia in SIC systems are IAA and supplementary feeding. The study about supplementary feeds includes identification of locally available feed materials and their approximate nutritional value and introduction of different ways to formulate feed depending on available resources and feed making. Information of these methods was received through interviews, literature search, meetings and observations. Based on them three different supplementary tilapia feeds were prepared and trials were conducted to assess the growth response to greenhead tilapia (*Oreochromis macrochir*).

4.1 Integrated agriculture-aquaculture (IAA)

IAA builds relationships between fish farming and agriculture and other existing household activities. It modifies the farming system so that the inputs of one activity are provided from the waste or by-products of another. The major pathways to carry out IAA are: 1) using agricultural and household waste as pond fertilizer; 2) using pond water to irrigate agricultural crops and watering troughs for cattle; 3) using pond sediments to fertilize agriculture crops; 4) using aquatic plants and low-value fish to feed livestock (Appendix 2). (Windmar 2008; Ngugi et al. 2007, 7.) All of these methods are focused on raising the fish, crops and livestock by fully utilizing the available resource and by keeping the inputs low, but still targeting at relatively high production. In each case consideration is needed in terms of economic and social factors which affect the farming.

4.1.1 Pond fertilization

The main objective of pond fertilization is to stimulate autotrophic and heterotrophic production in fish ponds (El-Sayed 2006, 47). This means adding nutrient-rich agricultural or household waste to fish ponds. The major inputs in pond fertilization are *nitrogen* (N), *phosphorus* (P) and *carbon* (C). El-Sayed (2006, 47) refers in his study to a research (see Hickling 1962), which reveals

that *potassium* (K) is considered more as part of supplementary feed, since it has no effect on pond productivity as a fertilization element.

Primary productivity increases in water once the nutrients are released. Pond fertilization is recommended always in semi-intensive tilapia culture. It has the greatest effect when combined with supplementary feeding. Pond fertilization is particularly important in nursery ponds as fingerlings feed mainly on algae. During the rainy season, pond fertilization is essential as water exchange is high. Greenish water colour is the easiest indicator to observe algal production. Maintaining plankton density that allows a farmer to see 30–45 cm into the water is proper for tilapia. This is the depth where you can just see the palm of your hand if you extend your arm into the water up to your elbow (Picture 9, b). Agricultural sources for pond fertilization are animal and plant-based materials. (El-Sayed 2006, 47–48; J. Chiti, private communication 15.08.2013.)



Picture 9. (a) Crib for plant-based pond fertilizers; (b) Proper pond fertility can be checked by hand (Ngugi et al. 2007, 54).

Sufficient local plant-based materials for pond fertilization are the leaves, fruits and soft stems of banana, sunflower, pigeon pea, cassava, okra, avocado, sunn hemp, millet, blackjack, African daisy, cow pea, *Lantana camara*, *Senna spectabilis*, *Senna obtusifolia*, *Leucaena leucocephala*, guava, mango, papaya and cabbages. Almost any crop and soft plant material and organic household waste is usable. Once added, the materials should readily decompose. Plant-based fertilizers are placed into cribs in a corner of a pond (Picture 9, a). The sticks prevent the materials from escaping and allow them to rot. Within two weeks the algae starts to grow. New material should be added at least every second week. (J. Chiti, private communication 15.08.2013.)

Fresh animal manure has a great and an immediate effect on algae production. It is recommended to add fine particles all around a pond to release the nutrients all at once. Fresh manure disintegrates in water in colloidal particles which are easily attacked by bacteria and readily incorporated into the food web. Therefore, it is preferred to dry manure. In aquaculture survey in Luapula Province in 2012, about half of the fish farmers indicated that they apply some form of manure to their fish ponds (R. Abila, private communication 02.10.2013).

All livestock waste available in the province are suitable for pond fertilization. However, pig excrement has shown better results as a pond fertilizer compared to poultry manure in an experiment conducted at Fiyongoli Research Station. The quality of livestock feeds is likely to have an impact on the effectiveness of the manure. (El-Sayed 2006, 51; J. Chiti, private communication 15.08.2013.) Fertilization strategies are often evaluated based on their ability to improve fish production. Excessive manuring may increase nutrient levels too much, decrease dissolved oxygen and water transparency and finally lead to reduced fish yields, or even death of the fish. Pond fertilization should be conducted carefully because manure, fish yield, the pond's fertilization history and water quality have an effect. Generally, 4 kg of manure to 300 m² pond per day is a good fertilization regime in fresh water for tilapia (El-Sayed 2006, 48–49). Also, cost-efficiency should be considered. It is usually not economical to transport

pond fertilizers from far away as they can be produced on the farm or obtained nearby.

4.1.2 Other methods of IAA

Tilapia-duck culture is a profitable way for pond fertilization. Ducks are rarely farmed in fish farms in Luapula Province. Many farmers think that ducks will feed on their fish and cause loss in fish production. Ducks actually promote algae production by manuring the pond. Ducks eat unwanted vegetation in and around fish ponds, but also feed on small insects, tadpoles, worms, snails and a variety of floating food in the pond. Occasionally they can eat small fish fry but this is not their preference. They also increase dissolved oxygen in the water by enhancing circulation when they play. Even a very low number of ducks make a great effect on fish growth, yield and system profitability. Usually, a good number of ducks in a fish pond is 2000–4000 ducks/ha. Muscovy ducks (*Cairina moschata*) are not suitable for effective tilapia culture as they do not stay in water long enough to produce sufficient manure load. Peking ducks (*Anas peking*) are appropriate for manuring. They also nest near the water, so they may need a special area for nesting if the pond has steep slopes. (El-Sayed 2006, 64–66; R. Abila, private communication 09.08.2013.)

Periphyton-based pond culture is a simple and cheap way of producing natural food for tilapia, but not yet adopted in Luapula Province. In this system bamboo sticks, woody branches or other hard substrates are planted or fixed in shallow waters to allow the growth of sessile autotrophic and heterotrophic aquatic biota, known as periphyton. This culture system has shown considerable success in tilapia farming. It can be a partial or total substitute for supplementary feed in tilapia production. Moreover, periphyton-based culture results in significant reduction in production costs. (El-Sayed 2006, 52–53.)

4.2 Supplementary feeding

One of the key elements of tilapia feeding in SIC systems is nutrient-rich and affordable supplementary feed, which ideally should be made from locally available resources. Because feed comprises the major costs of a fish farming activity, a well-performing and cost-effective feed formula and feeding regime are important considerations in making fish farming viable.

4.2.1 Feeding in semi-intensive culture (SIC)

Tilapia feeds can be categorized as commercial and supplementary feeds. Commercial tilapia feeds are rarely used in Luapula Province. They are made by commercial feed production companies and meant to provide a complete food for the fish farmed in intensive culture systems. The aquaculture survey (2012), indicated that fish feed was purchased only by 1 % of local fish farmers. Commercial feeds are not economical investment for most of the smallholders or small-scale farmers. Advanced fish farmers in Luapula, who have the purchasing power and relatively intensive culture system, can make a profit out of the commercial feeds. (R. Abila, private communication 02.10.2013.)

Supplementary feeds are provided to fish to supplement the pond's natural food production. Because tilapia are produced mainly for subsistence and their farm gate price is relatively low, farming costs need to be low in order to make some income. Farmers can produce supplementary feeds on the farm using locally available feedstuffs to minimize the production costs. The material is good for fish feed if it is unconventional for human consumption, low-cost, although nutritious and locally available. On-farm made fish feeds do not have to be very high in protein since the fish get some of their protein requirement from natural food available in earthen ponds. The protein content in plankton can reach up to 83 %. (Leaves & Sorgeloos 1996.)

In feed formulation it is also possible to combine on-farm made and commercial products. An option for advanced farmers is to apply micro-nutrient premixes which contain necessary minerals, lipids, vitamins and proteins. Farmers can

mix these nutrients with carbohydrate sources that can be easily produced on-farm such as cassava and maize. (R. Abila, private communication 02.10.2013.)

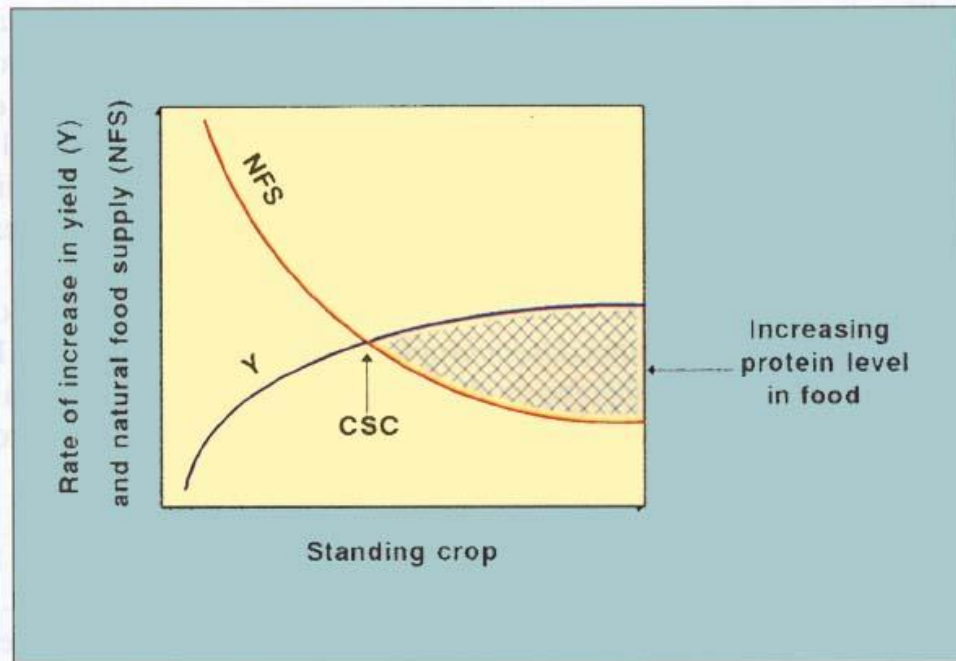


Figure 2. Changes in natural food organisms and fish yields, in relation to standing crop (Michael & Imre 1995).

Tilapia can rely totally on natural food, produced through pond fertilization, up to a certain size. This is known as the critical standing crop (CSC). Beyond CSC, fish growth will slow down, because natural food would be insufficient to meet their protein requirement. At this size, supplementary protein becomes necessary to sustain fish growth (Figure 2). Feeding smaller size of fish with protein-rich feed will be a waste of resources and an unnecessary increase in operating costs. Therefore, the farmers on SIC, should rely completely on pond fertilization till CSC has reached. (El-Sayed 2006, 53–54.)

The most suitable timing of supplementary feeding in SIC is 40–150 days after stocking. The timing is dependent on species, stocking size and pond fertilization. The most effective results have been achieved when fish are about

50–150 grams. Until this size, tilapia is best to grow with natural fertilizers only, if they are available. Supplementary feeding before they reach this size is conducted in intensive systems, but is considered wasteful in SIC as feeding on natural food supply, supported through pond fertilization, gives a better economical return. (El-Sayed 2006, 54–55.)

Table 1. Feeding rate for tilapia fed 25 % protein feed in monoculture at 24 °C (Michael 1987).

fish size (g)	feed: g/fish/day	feed: % of biomass
50–70	2.0	4–2.9
70–100	2.4	3.4–2.4
100–150	2.7	2.7–1.8
150–200	30	2.0–1.5
200–300	37	1.9–1.2
300–400	45	1.5–1.1
400–500	52	1.3–1.0
500–600	60	1.2–1.0

Feeding rates are another important factor affecting the cost-efficiency of tilapia culture. Since algae produced through pond fertilization is the main source of food in ponds, excessive supplementary feeding may cause an economic loss. Feeding regimes are dependent on the size of the fish, species, water temperature, type of feed, fish health and culture system. The person applying feed must be willing to reduce the amount of feed if fish is not feeding. This may happen, for example, if the water temperature is extremely hot or cold or if the fish is sick. An increased feeding rate is required for broodstock. (El-Sayed 2006, 54–55.) Table 1 shows the tilapia size in relation to the proper feeding rate in intensive culture systems.

Once tilapia have reached the size of 50–150 grams, the supplementary feeding can be started. According to the research conducted by Abdelghany & Ahmad in 2002, the most efficient feeding rate for Nile tilapia in polyculture with common carp is 2.67 % of the fish body weight fed daily. In tilapia monoculture the feeding rate can be slightly higher (around 3 %) if the tilapia is stocked with normal SIC stocking density of 1–2 fish per m². If farming becomes more intensive, higher feeding rate can be applied. The best time for feeding fish in tropical areas is in the morning (10 a.m.) and in the afternoon (4 p.m.). These are the times when the fish is most active and the water is warm. The feeding should be always conducted at the same time and in the same place so that the fish learn when and where the feeding will be conducted. (J. Chiti, private communication 21.9.2013.) There are two ways to define the proper daily feed amount.

- 1) If a reliable scale is available, a farmer can weigh the fish. This should be performed every second week. For a reliable sample, the fish can be taken from the pond with a seine net and scoop net into a bucket filled with water. By subtracting the weight of water the total weight of the fish can be determined. The number of fish is counted when released. Once the individual mean weight is determined, it is multiplied by the number of fish in the pond. Then the daily feed amount is calculated with the following formula.

$$\frac{\text{fish weight (g)} * \text{number of fish}}{100} * \text{feeding \%} = \text{feed per day (g)}$$

e.g. $\frac{80 \text{ g} * 300}{100} * 3 \% = 720 \text{ g}$

- 2) If the farmer does not have any scales, he can use a predetermined feeding schedule, based on the estimated growth. The estimation is made on rearing time and final weight. If the fish is farmed for seven

months and they are expected to be 300 grams in the end, the individual monthly growth is 42.9 grams. This figure is added monthly to the previous weight of the fish. Based on the monthly adjustments, the desired feeding rate can be determined. At the beginning the farmer should have an access to a scale to predetermine the feed weight relation to volume. With a can or tin which has the feed weight levels drawn to the side, the farmer can easily measure the proper feeding rate.

$$\frac{\text{size when harvesting (g)}}{\text{months of farming}} = \text{weight gain per month (g)} \quad \text{e.g. } \frac{300 \text{ g}}{7} = 42.9 \text{ g}$$

4.2.2 Feed materials and their nutritional value

There are various potential feed materials available in Luapula Province. The materials are sorted by types, namely: crops-based materials, wild plants, animal proteins and vitamins and minerals. This thesis considers only primary macro-nutrients. Protein, carbohydrate and lipid content were defined for each feed material based on literature and previous research. However, these values may vary depending on the exact species and the source of information (USDA 2011). Figure 3 introduces the main components of a food.

Proteins are used for fish growth. This happens only if adequate levels of fats and carbohydrates are present in the feed. In other cases, protein may be used for energy and life support rather than growth. Proteins are formed by individual amino acids. Over 200 amino acids occur in nature, but only 10 are essential amino acids that cannot be created by tilapia. The essential amino acids are: *methionine*, *arginine*, *threonine*, *tryptophan*, *histidine*, *isoleucine*, *lysine*, *leucine*, *valine* and *phenylalanine*. Of these, *lysine* and *methionine* are often the first limiting amino acids. Fish feeds prepared with plant-based protein sources are low in *methionine*; therefore, full growth performance cannot be reached with plant-based proteins only. (UNDP 1980.)

Lipids are nutrients with high energy. They can be also used to partially substitute for protein. Lipids supply about twice the energy as proteins and carbohydrates. Lipids supply essential fatty acids (EFA) which are required for biological processes. They also serve as transporters for fat-soluble vitamins A, D, E and K. Fish usually require alpha-linolenic acid (omega-3) and linoleic acid (omega-6), depending on the species. Tilapia in particular, requires omega-6 fatty acids. (UNDP 1980.)

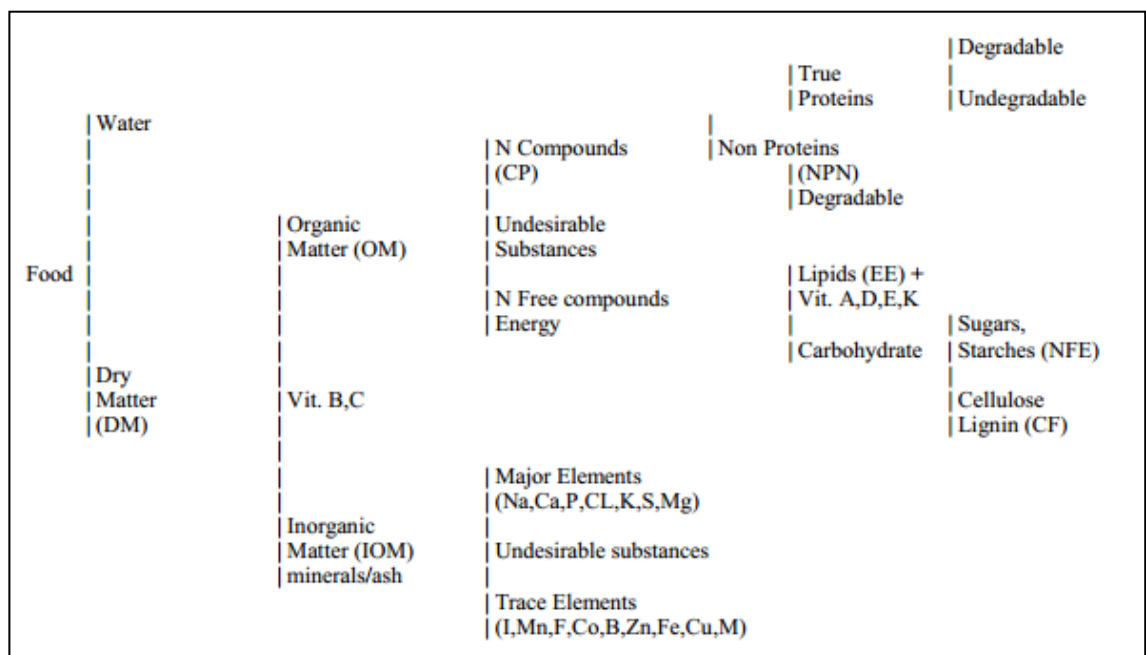


Figure 3. The main component of a food (Naseri 2005).

Carbohydrates (starches and sugars) provide energy for tilapia. As tilapia is mainly herbivorous, it can utilize dietary carbohydrate more effectively than carnivorous fish. They are the most economical and inexpensive sources of energy for fish feed. Carbohydrates are included in fish feeds to reduce costs and for their binding activity during feed manufacturing. Cooking starch during the manufacturing process makes it more biologically available to fish. (El-Sayed 2006, 106.) Carbohydrates and other primary macro-nutrients of the

studied ingredients are shown in the following tables 2–4. Any materials rotten should not be given to the fish.

Table 2. Crop-based materials for fish feed.

feedstuff	proteins	lipids	carbohydrates	notes
beans	15 %	1 %	40 %	
beer waste	22 %	-	-	dry well
cassava leaves	21 %	6 %	13 %	makes the dark colour
cassava meal	5 %	-	37 %	
groundnut cake	49 %	-	-	expeller-extracted
groundnuts	26 %	49 %	16 %	
maize bran	8 %	1 %	65 %	makes the feed buoyant
maize meal	8 %	4 %	77 %	
millet	11 %	4 %	73 %	
okra	2 %	0 %	7 %	
rice bran	8 %	12 %	50 %	makes the feed buoyant
sorghum	11 %	3 %	75 %	
soybean meal	38 %	21 %	35 %	
sunflower cake	28 %	30 %	14 %	mechanically-extracted
sunflower seeds	21 %	51 %	20 %	

Cassava is a widely cultivated crop in Luapula Province. It is an affordable and a good source of carbohydrate for tilapia. The leaves are high in protein content at 21 %. Rice and corn bran are available in Luapula Province at the two main milling companies, however, these may not be readily accessible to farmers in the districts. Bran is usually slightly more nutritious than a refined meal from the same crop. As by-products, bran is a good material for fish feed and it also floats well. Soybean has a very high nutritional value in terms of proteins and lipids as well as groundnuts and beans. They are high-value crops that go

usually for direct human consumption. If available, sunflower cake is a good feedstuff for tilapia. It is a by-product from oil extraction, but still has a high nutritional value. Regarding cakes, the values may vary depending on the level of processing. Nutritional values may also differ in other materials depending on the strains.

Some materials need processing before they are ready to be used as fish feed. Soybeans, beans and cassava need to be soaked, roasted or boiled in order to extract poisonous ingredients such as cyanide. After this, the feedstuffs need to be dried and pounded to create meal. For cassava leaves drying and pounding is enough processing. Beer waste needs to be dried well before giving them to the fish. Moist beer waste may still make alcohol and kill the fish.

Table 3. Wild plants for fish feed.

feedstuff	proteins	lipids	carbohydrates	local name
<i>Amaranthus</i> (amaranth)	13 %	7 %	65 %	bondwe, lenga-lenga
<i>Bidens pilosa</i> (blackjack)	3 %	1 %	56 %	nsonzonzu, kasokopyo
<i>Sesbania sesban</i>	20 %	6 %	61 %	misekelele, akanchense

Wild plants are cheap ingredients for on-farm made feeds in Luapula Province because they are found widely. Amaranths are a good source of lipids. *Sesbania sesban* is a good source of protein. The wild plants are most accessible during the rainy season. For a farmer it is wise to collect the wild plants during the time the leaves are young and soft, but before the plant has seeded. At the early stage, leaves have the highest protein value. In later stages, most of the nutrients go to the seeds. Once the wild plants are collected, they are dried, pounded and stored to be used during the dry season. (R. Abila, private communication 15.10.2013.) Most of the wild plants give dark green colour to the feed. Tilapia find dark coloured feed more palatable than lighter one (El-Sayed 2006, 111).

Animal proteins are a very important part of tilapia feed to supply the essential amino acids. They allow a good growth performance that is not possible with only plant-based proteins. This is why animal proteins are a very important part of tilapia feed, even in small amounts. The animal based proteins are also the single most expensive raw materials in fish feed. Affordable sources of animal proteins are challenging to find in most of the local markets. By-products of fish or meat processing are mainly available at processing and market places.

Table 4. Animal protein sources for fish feed.

feedstuff	proteins	lipids	carbohydrates	notes
blood meal	81 %	1 %	-	
bone meal	16 %	4 %	-	
fish meal	62 %	6 %	-	
meat meal	-	-	-	
worms	-	-	-	
insects	-	-	-	
termites	55 %	3 %	35 %	given directly

Termites and different types of insects and worms are available in Luapula Province and may be a source of natural animal proteins. Termite mounds are abundant in some areas. Tilapia feeding can be carried out by breaking a mound apart and hitting the pieces together on the fish pond, to get the termites out from the mound structure. Termites can also be farmed. This is done by digging a pit on the ground which is 30–60 cm in depth. The pit is located on an area where termites naturally live. On the bottom of the pit hay, crops, leaves or other dry and organic matter is placed. The pit is finally covered with soil. After three to five days there will be termites that can be harvested and given to the fish. Insects can be attracted and trapped at the night time by the help of light. (R. Abila, private communication 01.8.2014).

Minerals are important to maintain the tilapia immune-system and metabolic functions. Organic ash provides the most vital minerals (e.g. *potassium*), and may help raise the pH in acidic water. The use of charcoal or timber at household level offers high amounts of ash which is usually an unutilized resource. (C. Green, private communication 28.10.2013.) Organized collection and storing is needed in order to have high quality ash without sand, stones or moisture. Micro-nutrient premixes are the potential options instead of ash. Vitamin supplements are not necessary for tilapia grown in SIC systems, but can be used. Fruits, such as lemon have a value in terms of vitamins. (El-Sayed 2006, 107; P. Stevens, private communication 12.10.2013.)

4.2.3 Feed formulation

The optimal nutrition for tilapia in SIC system varies depending upon the stage of a pond's natural food supply, fish size, species and the level of sexual maturity. The protein requirement is particularly high for fingerlings and broodfish. These groups require 40–45 % protein in their diets. Broodfish require this for optimum reproduction, spawning efficiency and fingerlings for larval growth and survival. Most of the protein should be from animal protein sources. Optimal diets for adult tilapia contain around 20–30 % proteins, 10–15 % lipids and 30–70 % carbohydrates. Increasing the amount of carbohydrates results in an efficient use of dietary protein for growth. (El-Sayed 2006, 95–107.)

Once the nutritional value of the feed material and the needs of the target fish are known and the pond's natural food supply has been evaluated, a feed can be formulated. Advanced farmers may utilize a spreadsheet or feed formulating software that makes formulating easy. For example, Network of Aquaculture Centres in Asia-Pacific (NACA) provides a reliable and free Excel-based diet formulator on their webpages (NACA 2013). This software is designed to formulate complete feeds for intensive culture but can be used for supplementary feeds as well. However, to formulate a feed and calculate the nutritional value of it in terms of proteins, a farmer needs only a pen and paper. A detailed explanation of manual formulation is provided below.

In this example, a farmer uses fish meal, soybean meal, cassava meal, maize bran and ash to formulate a feed. The tilapia requirement is 25 % of crude protein in the feed. The ingredients are categorized by sources of protein (fish meal and soybean meal) and energy (cassava meal and maize bran). These ingredients are formulated in proportions 1:1 and 1:1. The ash is an additive ingredient and its predetermined inclusion level is 15.38 % (1 / 6.5).

The method that is used to determine the rations is called Pearson's square which follows the next steps (M. Kujila, private communication 02.07.2014).

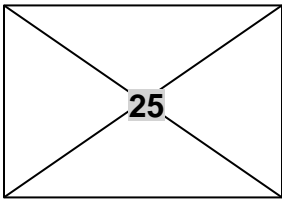
- 1) Calculate the average level of protein and energy sources.
- 2) Place the averages to the left corners of the square. The desired protein amount is placed in the middle.
- 3) Calculate the difference between the corner figures and the figure in the middle; the difference is marked to the opposite corners of the square.
- 4) The two figures, on the right side corners, are divided by the difference between the numbers on the left side of the square (i.e. $50 - 4 = 46$) and multiplied with the total inclusion of these ingredients. The total inclusion is 100 minus the inclusion of the additives, such as ash in this case ($100 - 15.38 = 84.62$). To obtain the proper ingredient amounts, the figures are divided by two.

Protein source:

*Fish meal (FM) = 1 * 62 = 62 %*
*Soybean meal (SB) = 1 * 38 = 38 %*
Average of these = 100 / 2 = 50 %

Energy source:

*Cassava meal (CM) = 1 * 1 = 1 %*
*Maize bran (MB) = 1 * 7 = 7 %*
Average of these = 8 / 2 = 4 %

<i>FM + SB</i> 50		<i>FM + SB = 21 / 46 * 84.62 = 38.63 %</i>
		<i>1 part of FM = 38.63 / 2 = 19.32 %</i>
		<i>1 part of SB = 38.63 / 2 = 19.32 %</i>
<i>CM + MB</i> 4	25	<i>CM + MB = 25 / 46 * 84.62 = 45.99 %</i>
		<i>1 part CM = 45.99 / 2 = 23.00 %</i>
		<i>1 part MB = 45.99 / 2 = 23.00 %</i>

In a formulation process, it must also be considered that it is not easy for fish farmers to mix feedstuffs using precise weight ratios, but for convenience they can mix ingredients based on volume, for example by a measuring can. The feedstuffs are then mixed according to the ratios calculated during the formulation process. In the example, this would be 1.5 parts of cassava meal and maize bran, 1.25 parts of fish meal and soybean meal and 1 part of ash. Feed can be made in any batch size as long as the proportion of ingredients stays the same.

4.2.4 Feed making

The method to make the feed has been adopted from Makasa farming community in Samfya district. The equipment needed for feed making is: a mortar and pestle or mill, a pot and brazier, a big mixing bowl, a water bucket, a measuring can, a sieve and sacks.



Picture 10. Dried and grinded feed materials are mixed before adding water.

All the feedstuffs are first pounded into fine particles and the equipment is prepared. Roasting, soaking or boiling is required for soybeans, beans and cassava in advance. Grinding is an important part of the feed making as it

makes the digestion easier for the fish and allows the materials to mix well. It is recommended to filter all the ingredients with a sieve in order to extract indigestible particles. Especially ash may contain a lot of charcoal and stones. Then, the dry ingredients can be mixed in the bowl according to the chosen ratios (Picture 10). A sufficient amount of water is added in small quantities to the bowl and thoroughly mixed with the feed material. Water is added till the matter forms thick paste.

Thorough mixing is important in feed making to ensure that the fish gets all the ingredients in the small pieces of feed it swallows. After mixing, the paste is spread on the sacks or other surface, for example on a mat, and broken into small pieces (Picture 11). An alternative option is to use simple meat mincer if accessible to extrude pellets. Thinly spread material dries fast. In the sun it takes around three hours to dry but it may also take a couple of days depending on the weather. Solar drier makes the feed drying possible in the rainy season. Protection of the feed from animals and rain is important while drying.



Picture 11. The feed is spread thinly on the sacks or other surface to dry.

Once dry, the feed can be gently pounded into finer form depending on the structure of the matter and the size of the target fish. The feed is stored in the sacks and kept in a cool and dry place, away from pests. The batch sizes should be relatively small, as the feed may become spoiled if it is for a long time. The farmer should use the feed within one month. This is important if the feed contains a high amount of lipids.

4.3 An experimental setup

The experiment involved the development of three different supplementary tilapia feeds (Figure 4, Appendix 3). The ingredients were chosen according to the costs, nutritional values and availability. Although wild plants would have been adequate ingredients for these feeds, at the time of the experiment, the dry season limited the access to these plants. Blackjack was the only wild plant that was accessible in small quantities and was used in Feed 3. Feeds 1 and 2 had the same ingredients but different inclusions were used. The feeds were formulated with an Excel-based formulator (NACA 2013). The trials took place in Fiyongoli Aquaculture Research Station in Mansa in the end of 2013.

The feeds for the experiment were made at the station by using the feed making method explained earlier (4.2.4). Processing was required only for soybeans, blackjack and cassava leaves as other ingredients were readily processed. Cost-benefit analysis was not conducted to determine the relative profitability of each feed formula. However, the costs of each formula were recorded; Feed 1 and 2 are the most expensive ones since they incorporate the highest protein content of fish meal and soybean meal. In contrast, Feed 3 is the least expensive as it has the lowest protein content and it incorporates cheap ingredients such as blackjack plant, cassava leaves and cassava meal.

The station-based testing of the feeds was conducted in two levels; in concrete tanks and in net confinements (hapas). The concrete tanks with water volume of approximately 7.5 m³ and depth of 1.2 meters were first cleaned and filled with fresh water from a nearby pond. The hapas had about the same volume and depth as the concrete tanks. They were located approximately 1.5 meter offshore

within the same earthen pond. The total number of units was 12, six tanks and six hapas. During the trials new water to the units was provided occasionally to maintain water levels. The dry season did not allow continuous water supply.

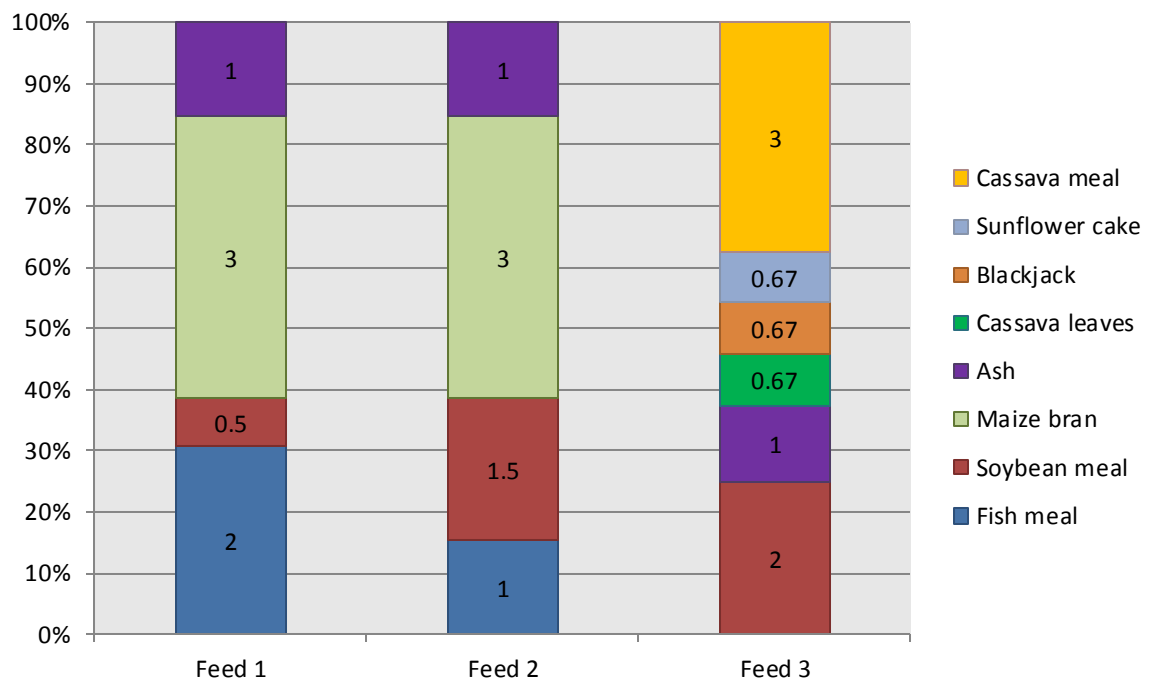


Figure 4. Ingredient inclusion (based on volume) in the developed feeds.

The tilapia species for the experiment was chosen according to good availability and the origin within the province. Greenhead tilapia (*Oreochromis macrochir*) was chosen to be the species for the experiment. The units were stocked with 75 fish each. The tanks were stocked with tilapia between 40–60 grams. The fish for hapas were between 5–15 grams. The fish in hapas was smaller due to the lack of bigger sized fish. All the 900 fish were measured in total length and weight. The fish were collected from several ponds within the station.

As IAA is an important part of tilapia culture, and especially for smaller sized fish, part of the feeding was conducted through pond fertilization. The concrete tanks were fertilized by a kilogram of dry chicken manure weekly. The manure

was kept in ventilated bags to prevent the accumulation of the matter on the bottom of the tanks. The pond where hapas were was fertilized weekly by 30 kilograms of the same manure by spreading it around the pond in small particles. The pond fertilization was kept lower than in normal SIC systems in order to obtain reliable results of the effectiveness of the feeds and to make contrasts more visible.

The feeding was conducted by hand. This allowed the feeder to observe fish behaviour and feeding. Feed was given to the fish twice a day as adult tilapia may prefer this feeding schedule also in natural habitat (3.2.2). The feeding took place at 8–10 a.m. and 3–5 p.m. The feeding rate of 5 % of the fish body weight daily was used. This percentage was chosen to replace the minimal pond fertilization and highlight the performance between the experimental feeds. The feeding rate involved all the units. The feeding amount was adjusted after every sampling according to the average weight. This was conducted separately in each combination of units which had different feed and starting weight (i.e. six different feeding amounts were calculated between all the units).

The experiment started on 10 October 2013 and lasted for three months till 2 January 2014. The samplings of the fish were conducted every second week for one third of randomly selected fish per unit. The data about the total length, weight and water temperature were recorded. The fish weight was measured with a tolerance of one gram and the length with a tolerance of one millimetre. The temperature was measured between 9 a.m. and 10 a.m. from the depth of 50 cm. Also some observations about mortality, feeding activity, breeding and fish behaviour were collected.

5 RESULTS

After the experiment quantitative data was analysed by IBM SPSS Statistics and Microsoft Excel. The mean weight and length of the fish on different feeds were calculated. Feed conversion ratio (FCR), specific growth rate (SGR) and Fulton's condition factor (K) were also calculated to highlight certain aspects.

$$\frac{\text{Mass of food consumed}}{\text{Increase of mass in fish produced}} = FCR$$

FCR is an efficiency ratio which shows the amount of fish feed (kg) which is taken to grow one kilogram of fish. FCR of 1.5 means that to produce 1 kg of fish 1.5 kg of fish feed is needed. FCR is used to guide a farmer on how to efficiently use feed. (Alyshbaev 2013.)

$$\frac{\ln \text{final weight (g)} - \ln \text{initial weight (g)}}{\text{Time between weighings (days)}} * 100 = SGR$$

SGR is the daily growth rate of fish body weight in percentage. It is useful to obtain the rate at which a fish is growing. The rate of growth in the fish depends on factors such as species, age, water temperature and food. Young fish are capable of gaining weight in a much shorter time than the older ones due to the fast growth rate. For farming purposes it is useful to know the specific growth rate at different ages of the fish. (Alyshbaev 2013.)

$$\frac{\text{Weight (g)}}{\text{Length (cm)}^3} * 100 = K$$

Fulton's condition factor, K, is widely used in aquaculture, fisheries and fish biology research. This factor is calculated from the relation between the weight and length of a fish. The intention of the factor is to describe the "condition" of that individual. (Nash et al. 2006.)

5.1 Tank experiment

The most reliable results of the performance of the feeds were obtained from the concrete tanks because the fish were proper size (40–60 grams) for supplementary feeding, they had access to the feed all times and they were not as dependent on algae as smaller fish. The most noticeable differences in the performance of the feeds were obtained from the concrete tanks.

Table 5. Fish mean weight (g) and standard error (\pm) in the tanks.

	10-Oct	23-Oct	07-Nov	21-Nov	05-Dec	19-Dec	02-Jan	
Feed 1	48.37	57.72	61.44	67.34	74.26	69.68	70.08	
	± 1.26	± 1.45	± 2.16	± 2.37	± 1.9	± 1.89	± 1.57	
Feed 2	50.44	65.94	73.64	71.32	71.44	68.24	71.76	
	± 0.88	± 1.46	± 1.58	± 1.86	± 1.96	± 1.94	± 1.6	
Feed 3	49.79	60.60	62.76	64.96	69.32	63.92	70.06	
	± 1.03	± 1.67	± 1.48	± 1.83	± 1.93	± 1.82	± 1.89	

Table 5 shows the mean weight with standard error of individual fish fed on developed feeds in the tanks. Black bars in the charts indicate the highest value. It can be observed that the fish on Feed 2 reached the maximum weight (73.64 g) within a month. Feed 1 reached the maximum (74.26 g) within two months and Feed 3 (70.06 g) in three months. The performance of Feed 2 is significant compared to Feed 1 and 3 in Post Hoc Tukey's B test which evaluates if the means of subsets are homogenous. From the results it is possible to see that the growth levels off among all the fish after 21 November.

The nutritional value of Feed 2 is good; it contains 21.9 % crude proteins (CP) and 6.2 % lipids. Even if Feed 1 has the highest amount of fish meal and 25.7 % of CP, it has a lower percentage of lipids with 3.8 %. Feed 3 instead has the highest amount of lipids with 8.5 % but no animal proteins (Appendix 3). These can be the disadvantages regarding Feed 1 and 3. The fish on Feed 2 had the highest average weight at the beginning of the experiment which may have caused minor error to the results.

Table 6. Fish mean length (mm) and standard error (\pm) in the tanks.

	10-Oct	23-Oct	07-Nov	21-Nov	05-Dec	19-Dec	02-Jan	
Feed 1	139.76	145.32	150.64	154.80	161.26	164.42	160.40	
	± 1.42	± 1.46	± 1.73	± 2.00	± 1.60	± 1.28	± 1.14	
Feed 2	142.26	151.70	161.38	156.58	158.68	160.69	163.62	
	± 1.21	± 1.35	± 1.30	± 1.63	± 1.46	± 1.72	± 1.46	
Feed 3	139.59	148.46	154.78	153.38	156.36	156.62	160.50	
	± 1.57	± 1.53	± 1.32	± 1.47	± 1.49	± 1.55	± 1.47	

The individual mean length of the fish in the tanks (Table 6) correlates significantly with the fish weight. The weight change is reflected to the length of the fish with a delay; i.e. from 5 to 19 December the mean weight of the fish decreased among all the fish. However, during the same period all the fish still grew length. The highest mean length (164.42 mm), as well as the highest mean weight (74.26 g) was reached with Feed 1.

Table 7 shows water temperature, FCR, SGR and K based on the measuring data. The water temperature in the tanks over the experiment period stayed stable. The temperatures were low compared to the optimal 25–30 °C. The temperatures were measured at 9–10 a.m. The fish could have achieved the optimal temperature range later in the afternoon. FCR and SGR on Feed 2 show the fast growth till 7 November. Feed 2 did not cause a significant effect

on the growth of the fish after this date. It can be seen that on 19 December all the parameters declined and FCR was infinite. The reason for this is likely too heavy manuring as the experiment was not efficiently monitored. During the last two weeks of the experiment all the fish died in one of the concrete tanks on Feed 1 because of manuring.

Table 7. Mean water temperature, FCR, SGR and K in the tanks.

	Parameter	10-Oct	23-Oct	07-Nov	21-Nov	05-Dec	19-Dec	02-Jan
Feed 1								
	Water °C	20.50	21.00	25.00	20.00	22.00	23.00	21.50
	FCR	-	3.62	10.86	7.29	6.81	∞	121.94
	SGR	-	1.26	0.45	0.65	0.70	-0.45	0.04
	K	1.77	1.88	1.80	1.82	1.77	1.57	1.70
Feed 2								
	Water °C	20.50	21.00	25.00	20.00	22.00	23.00	21.50
	FCR	-	2.28	5.99	∞	416.03	∞	13.59
	SGR	-	1.91	0.79	-0.23	0.01	-0.33	0.36
	K	1.75	1.89	1.75	1.86	1.79	1.64	1.64
Feed 3								
	Water °C	20.50	21.00	25.00	20.00	22.00	23.00	21.50
	FCR	-	3.22	19.64	19.97	10.43	∞	7.29
	SGR	-	1.40	0.25	0.25	0.46	-0.58	0.66
	K	1.83	1.85	1.69	1.80	1.81	1.66	1.69

In the tank experiment Feed 2 had the best growth response to tilapia. Feed 1 reached the highest points in weight and length. However, the difference between the maximum weights between Feed 1 and 2 was only 0.65 grams. The maximum with Feed 2 was reached within a month while it took two months with Feed 1. So for a farmer it could be more efficient to farm the fish with Feed 2 as the rearing period could be shorter.

5.2 Hapa experiment

The hapa experiment was conducted with small fish (5–15 g). The results are not as accurate for evaluating feed performance as juvenile fish feed mostly on algae. The supplementary feed intake was also low because the feed stayed accessible only for a limited time as it sank through the bottom of the net confinements.

Table 8. Fish mean weight (g) and standard error (\pm) in the hapas.

	10-Oct	23-Oct	07-Nov	21-Nov	05-Dec	19-Dec	02-Jan	
Feed 1	7.59	10.36	11.68	12.72	14.66	14.52	16.04	
	± 0.46	± 0.67	± 0.73	± 0.73	± 0.70	± 0.75	± 0.65	
Feed 2	7.85	8.90	11.44	12.64	13.64	14.86	16.56	
	± 0.43	± 0.40	± 0.52	± 0.61	± 0.59	± 0.58	± 0.68	
Feed 3	8.75	10.68	11.84	13.38	13.96	13.26	14.88	
	± 0.50	± 0.34	± 0.54	± 0.46	± 0.58	± 0.56	± 0.45	

Table 8 describes the fish mean weight in hapas over the experiment. As fingerlings feed mostly on algae, the supplementary feed did not have a significant effect on the fish growth. The experiment did not contain control pond units to see how the fish grow without any supplementary feed, which would have been relevant as a point of comparison. However, it can be observed that the differences that are visible between the feeds in the tanks are barely noticeable in hapas. Yet, it can be seen that Feed 2 has good performance. From 5 to 19 December the mean weight of the fish on Feed 1 and 3 decreased while the fish on Feed 2 continued growing. The fish on Feed 2 reached also the maximum weight of all (16.56 g) at the end of the period.

The mean length of the fish in hapas (Table 9) correlates with the mean length. The high mean length of the fish on Feed 3 on 21 November is noticeable. The

fish on Feed 3 were slightly bigger at the beginning in weight and length than the fish on Feed 1 and 2. This may cause an error to the results. The length of the fish in hapas was also affected by tail eating (5.3). This may have had an effect to the data about the mean length. The mean length figures show that the fish on Feed 2 reached the maximum length of all (97.32 mm) at the end of the experiment on 2 January. The fish on Feed 3, despite the highest mean length at the beginning, had the lowest mean length at the end of the period.

Table 9. Fish mean length (mm) and standard error (\pm) in the hapas.

	10-Oct	23-Oct	07-Nov	21-Nov	05-Dec	19-Dec	02-Jan	
Feed 1	70.15	78.68	83.38	84.36	92.10	91.30	95.98	
	± 1.64	± 1.55	± 1.8	± 1.68	± 1.56	± 1.7	± 2.18	
Feed 2	71.81	74.98	82.30	86.14	89.42	90.80	97.32	
	± 1.42	± 1.35	± 1.43	± 1.46	± 1.64	± 1.39	± 1.54	
Feed 3	74.35	81.10	82.24	88.42	90.52	90.16	93.84	
	± 1.54	± 1.1	± 1.23	± 1.11	± 1.31	± 1.29	± 0.96	

Table 10 shows water temperature, FCR, SGR and K based on the measuring data from the hapas. The mean temperatures in the pond were slightly higher than in the concrete tanks. Concrete had probably stored low temperatures during the night and slowed down warming in the daytime. The experiment started at the end of the dry season and ended during the rainy season. Even if not measured, this change has likely had an effect on oxygen and nutrient levels in the water.

Negative SGR and infinite FCR on Feed 1 and 3 from 5 to 19 December show that the growth of the fish declined. Feed 2 had positive growth response to the tilapia during the period. At the beginning (23 October) Feed 2 had low SGR while Feed 1 and 3 had a higher rate. After this date the fish on Feed 2 managed better. According to K all the fish were in better condition at the start

as K was above 2, but the condition became poorer towards the end of the rearing period. This could be caused by minimal pond fertilization and increased water exchange.

Table 10. Mean water temperature, FCR, SGR and K in the hapas.

	Parameter	10-Oct	23-Oct	07-Nov	21-Nov	05-Dec	19-Dec	02-Jan
Feed 1								
	Water °C	20.00	26.00	23.00	24.00	25.00	20.00	21.00
	FCR	-	1.92	5.49	7.86	4.59	∞	6.69
	SGR	-	2.22	0.86	0.61	1.01	-0.07	0.71
	K	2.20	2.13	2.01	2.12	1.88	1.91	1.81
Feed 2								
	Water °C	20.00	26.00	23.00	24.00	25.00	20.00	21.00
	FCR	-	5.21	2.45	6.67	8.85	7.83	6.12
	SGR	-	0.90	1.79	0.71	0.54	0.61	0.77
	K	2.12	2.11	2.05	1.98	1.91	1.99	1.80
Feed 3								
	Water °C	20.00	26.00	23.00	24.00	25.00	20.00	21.00
	FCR	-	3.17	6.44	5.38	16.15	∞	5.73
	SGR	-	1.43	0.74	0.87	0.30	-0.37	0.82
	K	2.13	2.00	2.13	1.94	1.88	1.81	1.80

The hapa experiment showed slightly better growth response to fingerlings with Feed 2 in length and weight than with Feed 1 and 3. The growth was also continuous with Feed 2. The hapa experiment was not affected by reproduction so the results are clearer in this matter. On the other hand, the outflow of the feeds from hapas did not allow the fish to feed all of the given feed.

5.3 Observations

During the first days it was observed that the fish were shy and fed underwater. Within one week the fish started to go to the surface to feed. At the beginning it was also noticed that maize bran allowed feeds to float. Tilapia consumes both sinking and floating feed efficiently (El-Sayed 2006, 111). However, sinking feed

was a disadvantage in the hapas, where the feed went through the bottom net and was unreachable for the fish. Feed 1 and 2 were buoyant while Feed 3 sank. Therefore, Feed 1 and 2 were easy to observe as they stayed on the surface for a long time. However, Feed 3 had an advantage over the others because of the dark colour (4.2.2). Cassava leaves and blackjack gave the feed this feature.

After two weeks the fish in the concrete tanks started to reproduce. During the first sampling many of the fish had fry in their mouths and fingerlings were present in the water. This was because the size of the fish (approximately 50 g) was proper for breeding and the conditions right. Fingerlings were not considered in the samplings even if they increased the total fish biomass.

The hapa experiment had a challenging start. Few days after stocking the fish started to die. It was concluded that the main reason for the high mortality was the lack of dissolved oxygen. During the dry season water inflow was very limited and the fish could not move closer to the inlet as they were in the hapas. By regulation more water could be provided to the pond and the mortality rate decreased. At the time of the first sampling it was observed that the fish ate each other's tailfins. This was likely triggered by hunger as part of the feed provided to the fish escaped through the bottom nets to lower depths where the fish could not reach it. The problem was solved by increasing pond fertilization from 20 kg to 30 kg of manure per week.

6 GENERAL DISCUSSION

Food security in Luapula Province is highly contributed by local agriculture and aquaculture practices. Aquaculture in the province is carried out mainly by using extensive and semi-intensive culture methods. One of the greatest constraints that hamper the activity is the lack of proper feeding of cultured fish. Knowledge and skills are needed also in other sectors of fish farm management (e.g. in polyculture). The study reveals whether fish farmers in the province can respond to the challenges. Pond fertilization and supplementary feeding with self-formulated and self-made feeds were the methods used to carry out practical trials.

The study showed that numerous farm-based materials (wild plants, crops, animal protein sources and by-products) are possible options for improving tilapia nutrition. The first step in the general use of a feed material in fish diets is reliable knowledge of the nutritional composition and availability of the material. The wild plants such as *Sesbania sesban*, *Bidens pilosa* and *Amaranthus* are adequate materials for fish feeds. Foliage from these plants has high nutritive value and lowers the feed cost. However, owing to the characteristics of wild plants, the leaves are shed during the dry season. Therefore, conservation of plants by sun-drying could be a suitable option to achieve access to these feed ingredients throughout the year. Regarding nutrients, the protein content is an important characteristic. Proteins should supply essential amino acids that cannot be created by tilapia. Fish feeds prepared with plant-based protein sources are low in *methionine*, which is usually one of the first limiting amino acids. Therefore, a full growth performance can be reached only with animal proteins as part of the tilapia diet. (UNDP 1980.) The results corroborate with this finding by displaying poor performance of Feed 3 which had no animal proteins.

The access by fish farmers to animal protein sources is challenging especially for those who live in rural villages. The most inexpensive source of these proteins are termites which can be farmed on the areas they are abundant. Part of the animal protein can be also produced by zooplanktons in the ponds. The

growth of these planktons can be supported through pond fertilization by adding livestock manure to the ponds. Manuring is particularly important for fingerlings that use algae as the main source of food. The results support and augment earlier findings by showing that any supplementary feed did not have significant growth response to fingerlings. Pond fertilization can be conducted with plant-based materials as well, but it was not found as effective as livestock manure.

Pond fertilization should be conducted all the time in SIC systems. Generally, 4 kg of manure to 300 m² pond per day is a good fertilization regime in fresh water for tilapia (El-Sayed 2006, 48–49). As the fish grows and reaches CSC, pond fertilization is not enough to provide sufficient food for tilapia. After this stage supplementary feed should be applied. With tilapia this point, CSC, is reached when the fish is 50–150 grams. The average feeding rate is approximately 3 % of the fish body weight daily. The study corroborates with previous findings, although it was noticed that differences may exist between earlier research and the results obtained on the field. Therefore, observations and record keeping are needed to evaluate biologically and economically good feeding system in each case.

Anti-nutritional substances in crops can limit supplementary feed performance unless proper processing is conducted. These ingredients (e.g. soybeans, beans and cassava) should be soaked, roasted or boiled in order to extract anti-nutrients. These and other ingredients must be dried, grinded and sieved before they can be used as a feed material. After this the ingredients are mixed according to the predetermined ratios based on volume. In the study the most performing feed (Feed 2) contained 1 part of fish meal, 1.5 parts of soybean meal, 3 parts of maize bran and 1 part of ash. A small quantity (0.5 parts) of cassava meal and wild plant meal can be added to this formula. The additions make the feed cheaper, firmer and darker in colour still maintaining good performance. As the ingredients are mixed, some water is added until the feed forms thick paste. The paste is spread on a mat to dry and then stored in a cool and dry place. The study extends previous research by proving the performance of the feed making method in practice.

To utilize the available resources in the best way, polyculture is a good option. The suitable species for polyculture with tilapia are African catfish (*Clarias gariepinus*) and common carp (*Cyprinus carpio*). African catfish feeds on unwanted fingerlings and frogs, leaving more space for remarkable sized fish to grow. Common carp facilitates efficient utilization of organic and inorganic matter as it stirs up bottom sediments. The trials with supplementary feeds were conducted in monoculture with tilapia and therefore, the study refers only to previous findings regarding polyculture.

Luapula Province is a rural area with limited infrastructure. The total adult literacy rate in the province is low. Information distribution to fish farmers is challenging but important to increase the use of available resources and improve aquaculture productivity. The available channels to disseminate information are TV, radio, leaflets, practical training programmes for farmers and trainers from governmental and non-governmental institutions, vocational education and exhibitions. For the interest of long-term information deliverance, the governmental institutions and public education systems are appropriate. In Luapula it is first more viable to enhance training and extension services to “set the stage” than adopt new aquaculture technology that requires care and expertise. A large part of aquaculture and research stations built and equipped in Africa have been finally abandoned due to the lack of experience and funds (EI-Sayed 2006, 186).

The results from the present study are mostly valid and reliable. They are in agreement with many other studies regarding e.g. tilapia dietary needs, the effect of different nutrients on the fish, pond fertilization and feeding regime. Although the results are valid, the nutritional values of feed ingredients may differ between the tables presented in this study (4.2.2) and the ingredients used on the field. The values are dependent on strains and the level of processing. Therefore, the macro-nutritional values presented can be used as a guideline for tilapia feed formulation.

Regarding the feed ingredients in the tested feeds, wild plants would have been adequate to use in all the feeds. Instead Feed 3 could have had some animal

proteins and maize bran included to provide essential amino acids and buoyancy. Cassava proved to be good binding material and would have been good to use only in small quantities in all the feeds. To see the actual effect of supplementary feeds, some of the units could have been managed with pond fertilization only. These control units would have been relevant to see the point of comparison.

The station-based feed experiment was carefully monitored during the first month. After this the monitoring was conducted by fewer people, so the results from the analysis may not be that accurate. However, the performance of Feed 2 is credible. At the end of 2014 a farm-based experiment is started to assess the feed performance in an authentic pond environment. The experiment takes place in Mansa, Samfya, Mwense, Kawambwa, Nchelenge and Chiengi districts involving 12 fish farmers and 24 fish ponds. To assess if Feed 2 and the feeding regime are profitable, fish farmers' record books and gross margin analysis (Appendices 4–7) which were developed especially for rural farmers as part of this study, are used. The local farmers are highly involved in the trials. By this way they are trained in on-farm production and the utilization of tilapia feed. The trials are still being conducted.

7 FUTURE RESEARCH

The present study about possible feed materials concerned primary macro-nutrients (proteins, carbohydrates and lipids). Further research can be made considering also micro-nutrients. Regarding proteins, also amino acid composition could be examined to satisfy tilapia dietary needs in terms of *lysine* and *methionine* which are often the first limiting amino acids. New feed materials can be also explored. The use of duckweed (*Lemnaceae*) and other aquatic plants as fish and animal feed is an option to increase productivity.

Tilapia can be cultured in rice fields. It has received good attention in recent years as a means of sustainable rural development, food security and poverty alleviation in several developing countries. China is currently the leading tilapia producer from rice fields. (El-Sayed 2006, 61–64.) Rice farming is conducted in the northern part of Luapula Province but it is rarely combined with tilapia culture. As raising fish in rice fields has many advantages, the effectiveness of the method could be studied and adopted also in Zambia to increase aquaculture production.

The use of human excrement (commonly called “nightsoil”) for pond fertilization has been tried in some parts of the world with promising results (Bo 1993). An average adult excretes 790 kg/year of waste material, which can yield up to 22 kg/year of ammonium sulphate, $(\text{NH}_4)_2\text{SO}_4$. Nightsoil has not been utilized for fish farming in Zambia and would need more research. To be used as fertilizer, nightsoil must be fermented before application. This is done by storing the manure in anaerobic conditions for 2–4 weeks. The decomposition of human excrement produces a lot of ammonia. Under airtight conditions, the accumulation of ammonia can sterilize the waste. 1–2 % quicklime and 0.1–0.2 % formalin are effective in killing the harmful pathogens in nightsoil. (Shigang 1989.) Nightsoil can be also used to fertilize plants that are used as fish feed or pond fertilizer.

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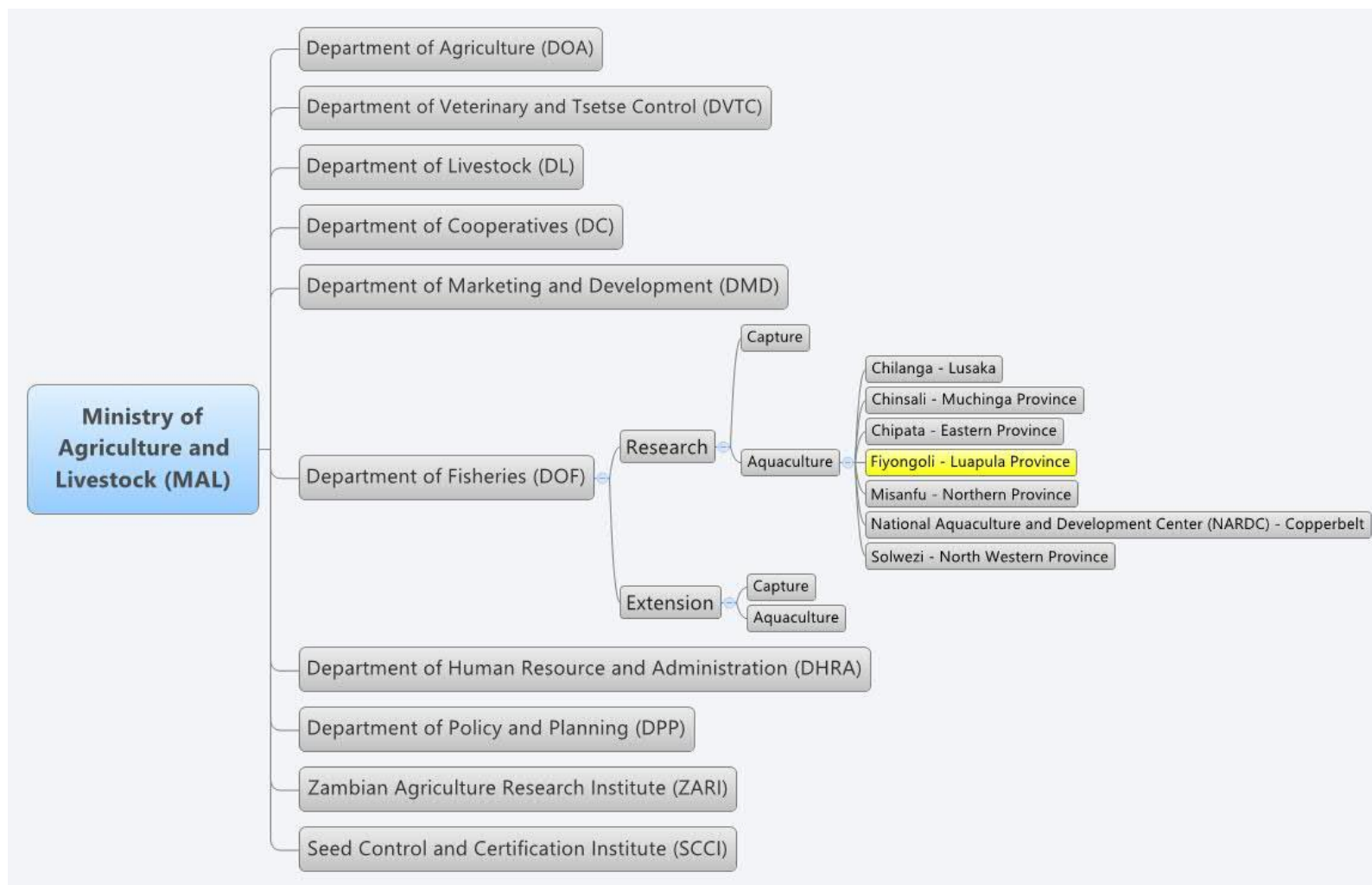
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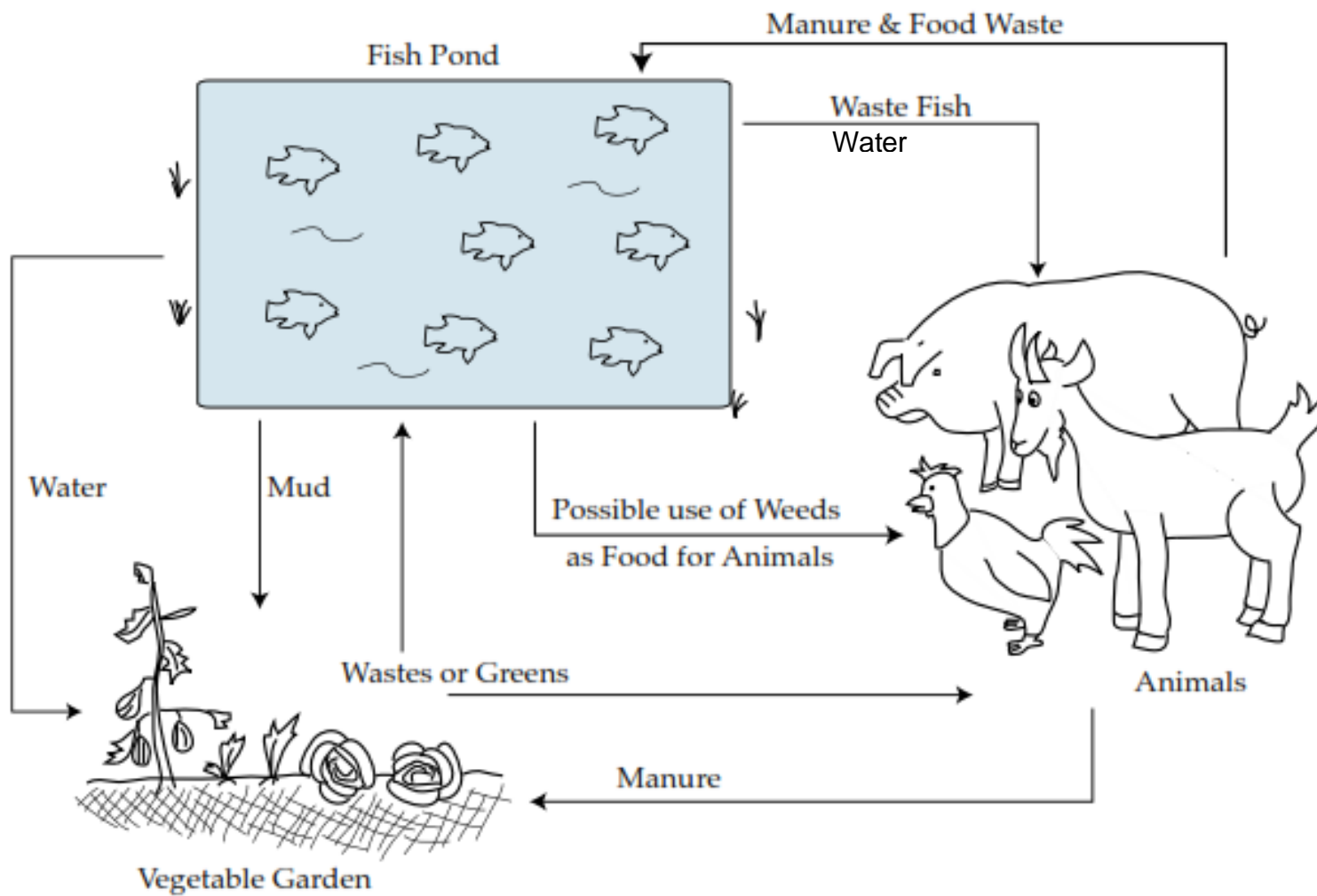
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The structure of **Zambian Ministry of Agriculture and Livestock (MAL)**



The pathways to carry out integrated farming



Formulae used in the station-based feed experiment¹

FEED 1		FEED 2		FEED 3	
INGREDIENT	INCLUSION	INGREDIENT	INCLUSION	INGREDIENT	INCLUSION
Fish meal (62%)	2	Fish meal (62%)	1	Cassava leaf meal	0.67
Soybean (full-fat)	0.5	Soybean (full-fat)	1.5	Soybean (full-fat)	2
Maize bran	3	Maize bran	3	Blackjack	0.67
Ash	1	Ash	1	Sunflower cake	0.67
TOTAL	6.5	TOTAL	6.5	Cassava meal	3
				Ash	1
				TOTAL	8.01
DM%	95.2	DM%	95.3	DM%	90.5
Ash%	21.9	Ash%	19.5	Ash%	15.5
GE MJ/kg	12.1	GE MJ/kg	12.0	GE MJ/kg	15.7
DE MJ/kg	6.7	DE MJ/kg	6.2	DE MJ/kg	4.6
CP%	25.7	CP%	21.9	CP%	16.3
Dig CP%	19.8	Dig CP%	16.4	Dig CP%	10.4
Lipid%	3.8	Lipid%	6.2	Lipid%	8.5
Fibre%	0.6	Fibre%	0.8	Fibre%	1.4
LOA (18:2n-6)%	0.8	LOA (18:2n-6)%	2.4	LOA (18:2n-6)%	2.6
LNA (18:3n-3)%	0.1	LNA (18:3n-3)%	0.3	LNA (18:3n-3)%	0.4
ARA (20:4n-6)%	0.0	ARA (20:4n-6)%	0.0	ARA (20:4n-6)%	0.0
EPA (20:5n-3)%	0.1	EPA (20:5n-3)%	0.1	EPA (20:5n-3)%	0.0
DHA (22:6n-3)%	0.4	DHA (22:6n-3)%	0.2	DHA (22:6n-3)%	0.0
Total n-3%	0.7	Total n-3%	0.6	Total n-3%	0.4
Total n-6%	0.9	Total n-6%	2.4	Total n-6%	2.6
n3:n6	0.8	n3:n6	0.3	n3:n6	0.1
Total phospholipid%	0.8	Total phospholipid%	0.8	Total phospholipid%	0.7
Cholesterol%	0.0	Cholesterol%	0.0	Cholesterol%	0.0
Astaxanthin (mg/kg)	0.0	Astaxanthin (mg/kg)	0.0	Astaxanthin (mg/kg)	0.0
Arginine%	1.3	Arginine%	1.2	Arginine%	0.8
Histidine%	0.5	Histidine%	0.4	Histidine%	0.3
Isoleucine%	1.1	Isoleucine%	0.9	Isoleucine%	0.6
Leucine%	1.7	Leucine%	1.4	Leucine%	0.9
Lysine%	1.7	Lysine%	1.3	Lysine%	0.7
Methionine%	0.6	Methionine%	0.4	Methionine%	0.2
M+C%	0.8	M+C%	0.6	M+C%	0.3
Phenylalanine%	1.0	Phenylalanine%	0.8	Phenylalanine%	0.6
P+T%	1.7	P+T%	1.4	P+T%	1.0
Threonine%	0.9	Threonine%	0.8	Threonine%	0.5
Tryptophan%	0.3	Tryptophan%	0.2	Tryptophan%	0.2
Valine%	1.2	Valine%	0.9	Valine%	0.6
Ca%	1.9	Ca%	1.0	Ca%	0.1
Available P%	1.5	Available P%	0.9	Available P%	0.1
COST: ZMK/kg	2.4	COST: ZMK/kg	2.4	COST: ZMK/kg	1.6

¹ Feed formulator provided by the Network of Aquaculture Centres in Asia-Pacific (NACA 2013)

Record book: pond stocking and construction²

DATE	POND #	PERSONAL HOURS (h)	TYPE OF WORK	COST (K)	STOCKING				REMARKS
					species	number	t. weight (g)	ave. size (g)	
1/1/14	1	2	stocking	150	<i>O.macrochir</i>	300	750	2.5	
1/1/14	2	2	stocking	150	<i>O.macrochir</i>	300	750	2.5	
1/3/14	1	1	stocking	30	<i>C.gariepinus</i>	30	150	5	
3/5/14	1	5	fixing leak	50					some fish died
8/5/14	1 and 2	8	plant removal	0					plants for pigs
TOTAL									

² Data in the record do not relate to the research

Record book: feeding, pond fertilization and monitoring³

WEEK	FERTILIZERS		FEEDS		COSTS (K)		PERSONAL HOURS (h)	OTHER ACTIVITY OR INPUT		REMARKS
	type	weight (kg)	type	weight (kg)	feeds	fertilizers		type	cost (K)	
1	pig, plant	20, 30	-	-	0	0	4	airtime, transportation	10, 80	stocking
2	pig	20	-	-	0	0	3	-	0	
3	chicken	20	-	-	0	5	3	-	0	
4	pig, plant	20, 30	Fiyongoli SUP	2	30 (1 st batch)	0	7	transportation	20	feed made for the next month
5	pig, plant	20, 30	Fiyongoli SUP	2	0	0	3	-	0	
6										
7										
8										
9										
10										
11										
12										
13										
14										
TOTAL										

³ Data in the record do not relate to the research

Gross margin analysis⁵

Item	Units	Unit price	Kwacha value
OUTPUT INCOME			
1. Output			
a) kg of table size fish	159	25	3,975
b) number of fingerlings	1,550	0.5	775
2. Income			
a) sales of fish (ZMK)			4,600
b) quantity consumed (ZMK)	17	25	425
Total output income			5,025
VARIABLE COSTS			
1. Fingerlings (number and costs)			
a) species	600	0.5	300
b) species	30	1	30
c) species			0
2. Construction costs (ZMK)	1	50	50
3. Feeds (kg)	500	2.5	1250
4. Fertilizers (kg)	1	350	350
5. Personal labour days (a day/8h)	18	80	1440
6. Other costs			
a) transportation	1	210	210
b) airtime	1	100	100
c) electricity	1	100	100
d) packing	1	0	0
e) any other	1	0	0
Total variable costs			3,830
GROSS MARGIN (OUTPUT INCOME – VARIABLE COSTS)			1,195

⁵ Data in the record do not relate to the research