ASSESSMENT OF POTENTIAL OF SMALL-SCALE CONTINUOUS FLOW BARRELPONICS SYSTEM

MSc. (AQUACULTURE) THESIS

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ABSTRACT

Barrelponics systems have potential to develop and contribute toward food and nutrition security in Malawi. However, there is limited information regarding its performance. Research was conducted at the Lilongwe University of Agriculture and Natural Resources (LUANAR) to assess growth of lettuce, *Lactuca sativa*, and tilapia, *Oreochromis karongae* in small-scale continuous flow barrelponics system. The study also assessed the financial performance of the system. The system used solar power as a sole source of electricity. Three week old *L. sativa* seedlings were transplanted at 25 seedlings/m^2. *O.karongae* of 10.86±1.98g mean weight were stocked at 200 fish m^{-3}. The experimental period was 42 days and data was collected on water quality and tilapia and vegetable growth parameters. Additional data was collected on water use and systems total costs and revenue for estimation of system financial performance. Water temperature followed diurnal trends, but overall, mean temperatures per week ranged from 20.17±1.38 to 23.30±1.61℃, and this variation was not significant throughout the study period. The levels of ammonia did not significantly vary diurnally ($P<0.05$) and between the main units: 0.31±0.01 mg/l in the grow beds, and 0.24±0.01 mg/l in the fish tanks. Similar trends were observed in nitrite levels; ranging from 0.53 ±0.21 mg/l to 0.6 ±0.20 mg/l in the fish tank, and 0.2mg/l to 0.8mg/l in the grow beds, respectively. However, nitrate levels were significantly higher at 6.92 ±0.22 mg/l in the grow beds than 4.82±0.21 mg/l in the fish tanks ($P<0.05$). Phosphate levels were low in the first two weeks but increased to an average of 1.2mg/l by the sixth week. These results suggest that the system was capable of managing itself throughout the experimental period.

Fish Specific Growth Rate was 2.04 %day^{-1} while Food Conversion Ratio was 1.93. Mean final weight was 25.63g with a mean weight gain of 14.77g. The survival rate was 100%. Mean harvest weight of lettuce was 504g per head. Gross margin analysis showed that the system has potential to be profitable with 63% gross profit margin ratio. Sensitivity analysis showed that the system still experienced positive gross profit margin ratio of 2% despite a 30% increase in operating costs and 30% decrease in revenue. Discounted payback period showed that the system would take about 4.4 years to break even, at a return rate of 10%. The research highlights that the system has potential to sustain growth of *O.karongae* and lettuce. However, since this research was only done for early stages of fish development, further research should focus on factors that can increase its productivity and profitability potential, by increasing study period across full fish growth cycles and different seasons in Malawi.

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BEP	Break Even Point
CF	Cash Flow
DO	Dissolved Oxygen
GM	Gross Margin
IAA	Integrated Agriculture Aquaculture
KWh	Kilowatt hour
LUANAR	Lilongwe University of Agriculture and Natural Resources
NPV	Net Present Value
PV	Photo voltaic
RAS	Recirculating Aquaculture Systems
TAN	Total Ammonia Nitrogen
VC	Variable Cost
Wh	Watt hour
WHO	World Health Organization

CHAPTER ONE

1.0 INTRODUCTION

1.1 Background

Malawi's economy is characterized mainly by agriculture which contributes over 30% to GDP. About 60 to 80% of the population still lives in rural areas, earning a livelihood directly or indirectly from agriculture (CIA, 2015). The Malawi government developed some initiatives in order to increase agricultural production and to alleviate famine and malnutrition. Some of the initiatives include increasing budget allocations to the food production sector, especially agriculture, in order to boost food production. Examples of budgetary allocations to the food production sector include the farm input subsidy program (FISP) and the Greenbelt Initiative. However, these initiatives are facing glitches such as: very low land holding sizes (on average less than 0.85 ha of land per smallholder) and the heterogeneous nature of rain-fed agriculture that is highly dependent on stable climate (Tchale, 2009; Mungai et al., 2016).

Aquaculture is one of the fastest growing food producing sectors in the world, contributing about 50% of global food fish production (Mathiesen, 2015; FAO, 2016). Forecasts indicate the global demand for fish production will continue to increase over the next decade, powered predominantly by rising populations (Lehane, 2013). The nutritional benefits of fish consumption have a positive link to increased food security and decreased poverty rates in developing countries. Therefore, aquaculture is recognized as a sustainable industry for food security and increased dietary nutrition in developing countries such as Malawi (Chagnon, 2015).

Malawi is one of the African countries with a rapid increase in aquaculture production (FAO, 2009). Conventional aquaculture may have the potential to alleviate poverty and improve food security and nutrition, nonetheless this is at the expense of the ecosystem (Beveridge et al., 2010). Malawi would venture into commercial cage aquaculture but Braaten and Bergheim, (2007) highlight that the main challenge is how to prevent the aquaculture activities from causing damage to the environment. Verreth et al., (2007) did case studies in Bangladesh, Thailand, and Vietnam on farming and sustainability in which they argued that producing food without compromising environmental integrity would require exceptional control, suitable legal structures, strong institutions with good institutional capacity and the introduction of adaptive management.

Of the total land area in Malawi, about 11,650 km^2 (approx. 12 %) has potential for aquaculture but Malawi has one of the highest population growth rates at the annual level of 2.9% and the average land holding size is now less than 0.85 ha of land per smallholder farmer. Many farmers would prefer to use their small piece of land for agriculture rather than aquaculture since it's easy to perceive profits (Russell et al, 2008; Tchale, 2009; and PHC, 2018).

Since fish consumption is a strong cultural tradition for many Malawians, there is a need to develop sustainable effective aquaculture practice for the endemic finfish species as an alternative to improving food production and alleviate famine and malnutrition (Russell et al., 2008). Teaching people to grow their own food; assisting small farmers to implement simple and effective technology and providing the education and training necessary for replication, maintenance and sustainability can be a long-term solution to hunger and poverty. Future expansion of aquaculture is more possible with species that do not compete with humans and livestock i.e. herbivorous fish or systems that use waste material for resources. Aquaponics seems to be a potential alternative if aquaculture is to expand in Malawi.

Hughey (2005) suggests that there are lots of maize and cassava in African countries compared to vegetables and protein sources such as fish. Fish catches in Lake Malawi are dwindling due to increase in fishing pressure arising from increase in human population. Cage culture can be one of the measures to ensure high fish production and adequate supply of fish protein. However, the government of Malawi has taken a precautionary approach to the development of the cage aquaculture industry and only a few private sector investors e.g. Maldeco Aquaculture Limited and a few pilot scale producers such as Total Land Care are allowed to produce fish in cages (Anon, 2011). The prices of fish on the market are continuously increasing making it difficult for local people to afford the fish hence per capita fish consumption for the country (12.47 kg/person/year) is still clinging below the World Health Organization (WHO) recommended consumption standard of 15 kg/person/year (GOM, 2018). Singini (2014), argues that despite the low fish consumption levels, fish supply continues to play a significant role in the country's nutrition and food security.

Integrated Agriculture-Aquaculture systems, e.g. aquaponics systems, have the ability to utilize land at optimum level and they can also utilize waste or byproducts from other subsystems as their inputs to produce fish and vegetables. Aquaponics system is a food production system that combines conventional aquaculture (raising aquatic animals such as snails, fish tanks) with hydroponics (cultivating plants in water) in a synergetic environment (Rakocy, 2006). Aquaponics system can raise both crops and fish by using marginal land and less water and have the potential to increase farm productivity up to six-fold (Dey et al., 2010). Teaching people to grow their own food, assisting small farmers to implement simple and effective technology and providing the education and training necessary for replication, maintenance and sustainability can be a long-term solution to hunger and poverty. However, aquaponics systems seem to be more complex since they are technologically intensive and that there is no detailed information about their potential to sustain indigenous species. In addition, aquaponics systems require interminable and stable electricity patterns so the implementation of this technology is held back due to the limited access to electricity grid, especially in poorly developed rural areas (Lekang, 2007).

Bernstein (2013), categorized aquaponics into the media-based system (MBS) where plants are grown into grow beds supported with substrate such as gravel; nutrient film technique (NFT) where plant roots are dipped in pipes that carry water containing nutrients; and deep-water culture (DWC) where plant roots are directly submerged in nutrient water supported by rafts. Hughey, (2005) devised a step by step method for producing a type of MBS aquaponics called the barrelponics system. Barrelponics systems are said to be economical and less technical since they use locally and readily available materials. This kind of systems would be ideal for densely populated African countries such as Malawi. This system typically uses solar energy to circulate the water hence it can be installed in remote areas that are not connected to the main grid.

According to Hughey (2005), barrelponics system was basically invented for typical low-income countries. As simple as the system looks to the eye, the fundamentals of the fittings are somehow complex since most of the fittings are not available in some parts of Africa, especially in Malawi. Furthermore, not much research has been done on the systems operation in a typical Malawian environment and its potential to sustain specific Malawian indigenous tilapia. Knowing the specific fittings that can be used in Malawi and their modifications, the fish species that can be sustained and the system operation in typical Malawian conditions is necessary for achieving maximum yield in the barrelponics system.

1.2 Problem statement and justification

In Malawi, about 43.6% of total dietary protein and 72% of the dietary animal protein consumed is from fish (Ecker and Qaim, 2011). Rapid growth in population has led to harvest stagnation and overexploitation of popular indigenous fish species from Lake Malawi and other water bodies, leading to a low per capita consumption of fish 12.47kg/person/year despite an increase in aquaculture production from an estimated 3,705 tons in 2013 to 12,217 tons in 2017 (Russell et al, 2008; FAO, 2015; GOM, 2018).

There has been exploration of sustainable aquaculture production systems, necessitated by climate change impacts on aquaculture and the need for increased fish production. Aquaponics is one of the systems with potential meet the two demands. However, high investment and running costs make conventional aquaponics systems too expensive to be practiced by smallholder farmers.

Barrelponics systems can be taken as an alternative to conventional aquaponics systems in areas where resources are limited. Barrelponics systems are constructed from locally available materials such as used plastic barrels and they require relatively low technical knowhow as they are small, with few parts compared to conventional aquaponics.

Nevertheless, it is still difficult for people to adopt the barrelponics systems since there is no detailed information about the benefits and efficiencies of such systems. Barrelponics systems use low cost fittings and pipes. However, just like conventional aquaponics systems, barrelponics systems require interminable and stable electricity patterns thus the implementation of this technology is held back due to limited access to electricity grids, especially in rural areas (Lekang, 2007).

Potential of integrated agriculture aquaculture systems such as barrelponics systems in Malawi has not been explored since most people are not aware about the technology and research has not revealed much on the systems performance with indigenous fish species. Love et al., (2015) did an international survey on aquaponics and from their findings concluded that more research and development need to be done to determine if these systems are worthy investing in. Therefore, it was necessary to conduct this research using the indigenous species in typical Malawian conditions and document the results for the producers to know some of the technical and financial requirements for them to venture into barrelponics as an alternative source of livelihood in Malawi.

1.3 Research objectives and questions

1.3.1 *Main objective*

The main objective was to assess potential of small-scale continuous flow barrelponics system for adoption by smallholder farmers.

1.3.2 *Specific objectives*

The specific objectives of the study were as follows:

a) To assess the quality of water in a barrelponics system for the survival and growth of *O.karongae* and *L.sativa*

b) To assess the growth of *O.karongae* in the barrelponics system

c) To assess the growth of *L.sativa* in the barrelponics system

d) To assess financial performance of a barrelponics system

1.4 Research Questions

a) Is water quality in barrelponics system within tolerable limits for the survival and growth of *O.karongae* and *L.sativa*?

b) Do *O.karongae* grow in a continuous flow barrelponics system?

c) Do *L.sativa* grow in a continuous flow barrelponics system?

d) Is barrelponics system financially feasible?

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Origin of sustainable aquaculture

In the mid-1960s, scientists developed high yielding crop varieties which were rapidly adopted in tropical and subtropical regions with good irrigation systems or reliable rainfall and it was characterized as “Green Revolution.” In the period 1981 to 2000, food production in developing countries increased by 86% (Evenson and Gollin, 2003). Evenson and Gollin (2003), further suggest that the green revolution was successful in raising the health status of infants and it substantially reduced child mortality through increase in food production which subsequently improved the caloric intake per capita in the developing world.

The Green Revolution came under severe criticism during the 1970s for ecological and socio-economic reasons regardless of its successes (Glaeser, 1987). Horne and McDermott (2001), further claim that the Green Revolution is deservedly on trial for causing serious environmental, health, and safety problems that endanger natural resources and future food supplies, through the intensification of input use such as fertilizers and chemicals.

Aquaculture industry has in recent years undergone massive scientific and technological advancement. According to VanderZwaag (2006), aquaculture development is proving to be the route for future development since people are able to farm in the natural waters but not purely relying on natural stocks. This remarkable emergence of aquaculture as an important and highly productive agriculture activity is known as the Blue Revolution. We cannot overlook the fact that the Blue Revolution has also a cost attached to it as this may be evidenced by the impacts some aquaculture practices such as cage farming do have on the environment. Braaten and Bergheim

(2007) emphasize that the main issue in aquaculture activities is the reduction of adverse impacts such as eutrophication on the environment. Horne and McDermott (2001), propose that there is a need to test whole new farming systems that do not need a lot of chemicals and fertilizers to be productive. This can be done by learning from natural ecosystems and linking the ecology with agriculture which will subsequently lead to sustainable resource use.

2.2 Aquaculture and sustainability in Malawi

Malawi is a small but densely populated country in southern Africa and about 90 % of the rural households rely on agriculture as their major source of income (World Bank, 2021). The household nutritional status is low with an estimate of 66 percent of the population consuming less than the minimum daily calorie requirement (Jamu and Chimatiro, 2004).

Fish is very important for the nutrition of Malawians constituting about 43.6% of total dietary protein and 72% of the dietary animal protein (Ecker and Qaim, 2011). However, due to doubling of the population since the 1970s and overfishing in natural water bodies, the per capita annual consumption of fish greatly decreased with the corresponding increase in fish prices (Dey et al., 2006).

With the prevalence of negative impacts on natural fish production, aquaculture was considered to be a viable option two decades ago as suggested by Williams, (1997). According to Beveridge et al., (2010), aquaculture addresses poverty and food insecurity by offering a means for smallholder farmers to diversify production, thereby providing nutritious food for their own families. It also creates farm income and employment opportunities throughout the value chain.

Russell et al., (2008) argues that potential for aquaculture to meet national demand for high value species like Tilapia could be significant. However, the study by Njaya (2015) indicates that fish farming in Malawi accounts only for about 2% of the country's total fish production, approximately 3500 tonnes. This low productivity and the doubling of the population since the 1970s has therefore made it very difficult for the aquaculture industry to respond effectively to the growing market demand.

Aquaculture was designated by Malawi Government's Department of Fisheries to play a complementary role to the capture fisheries subsector (ICLARM and GTZ 1991). The study by Dey et al (2006) showed that despite interventions from several donor organizations such as the ICLARM, German BMZ/GTZ and the Japanese International Cooperation Agency (JICA), the success is relatively insignificant as most of the farmers tend to discontinue production as soon as the project terminates. This may be because most of the interventions to boost the aquaculture industry have relied much on the use of traditional intensification approaches that fail to meet the current demands, making aquaculture as one of the less profitable ventures.

2.3 Need for Sustainable Aquaculture Technologies in Malawi

It is estimated that the world population will increase by 35% reaching 9 billion by the year 2050, which will increase food demand by 70% (Bruinsma 2009; Cribb 2010). According to Adams et al., (2004) and Sachs et al., (2009) hunger is not linked much to the quantity of food produced globally but to poverty, since small holder farmers who have the small land holding size are the backbone of global food security rather than the large-scale commercial farmers (World Bank, 2007; Chappell and LaValle, 2011; Horlings and Marsden, 2011).

Agricultural intensification is ideal for alleviating poverty. Pretty et al., (2011) defines traditional agricultural intensification in three different ways: increasing yields per hectare, increasing cropping intensity (i.e. two or more crops) per unit of land or other inputs (water), and changing land use from low value crops or commodities to those that receive higher market prices. However, traditional agricultural intensification often results in contamination by pesticides and fertilizers, which can affect human health and create non-target effects on wildlife and functional agro biodiversity (Dutcher, 2007; Gibbs et al., 2009; Geiger et al., 2010; Meehan et al., 2011). Dobbs and Pretty (2004) defined these intensification impacts as “negative externalities” because they impose costs that are not reflected in market prices.

Malawi therefore has to review the above definition of agricultural intensification if hunger is to be alleviated. This idea now brings about the concept of sustainable agricultural intensification (SAI). Sustainable agricultural intensification is defined as producing more output from the same area of land while reducing the negative environmental impacts and increasing contributions to natural capital and the flow of environmental services (Pretty, 2008; Royal Society, 2009; Conway and Waage, 2010; Godfrayet al., 2010). With the Malawian population growing at a high rate, there is a need to diversify from traditional farming to sustainable agriculture intensification.

Despite the potential land Malawi has for aquaculture, farmers prefer to venture into crop agriculture rather than aquaculture since it is hard for them to realize returns from aquaculture due to technicality problems and duration of culture. Additionally, we cannot overrule the fact that the population is growing rapidly and hence we have to devise some farming mechanisms that will marry ecology with aquaculture in order to prevent facing the same fate as during the green revolution. With this, Recirculating Aquaculture Systems (RAS) seem to be the best alternative if the fish consumption is to increase in Malawi. Recirculating Aquaculture Systems are those systems that reuse the effluent instead of disposing them into receiving water bodies.

RAS provides engineering solutions to a number of bottlenecks that impede the development of other aquaculture systems (pond, cage, etc.) which include scarcity of water resources, water quality deterioration, land pressure, low productivity and many other challenges.

2.4 Principles of aquaponics

Aquaponics systems integrate recirculating aquaculture systems (RAS) and hydroponic crop production (Rackocy, 2004). In RAS, small volume of water is used to grow large quantities of fish. The efficiency of the system is assured by removing toxic waste products from the water and reuse it. Organic matter accumulates in the RAS as the water is being reused, hence aquaponics allows crops to use these by-products as their nutrients and in return efficient water purification is achieved and the economic value of the culture system is maximized (Rakocy et al., 2006).

Over 80% of fish waste is excreted as ammonia which is very harmful to fish even in small concentrations causing impairment to gill tissues, reduced growth, reducing the ability of the fish to resist diseases, and even death. Ammonia must be removed from the water or converted to less harmful forms such as nitrates to put up with the high amounts of feed input necessary to sustain desirable growth rates and stocking densities. (Wood 1958; Randall and Wright 1987; Blidariu and Grozea 2011). Chemoautotrophic bacteria Nitrosomonas and Nitrobacter have the capability to convert ammonia to nitrite and nitrate, respectively. The nitrate form of nitrogen is preferred for growth of higher plants; hence it can be used as fertilizer for the crops. Aquaponics therefore has an ability of converting these dissolved waste nutrients to plant tissue hence ensuring efficient water purification in the system (Rakocy et al., 2006; Hu et al., 2015).

2.5 Types of aquaponics systems

A basic aquaponics system setup consists of a fish component and a hydroponic component. A fish component can be a tank or a pond whilst the hydroponic component can be a grow bed or a raft directly placed onto the water. Different authors have categorized aquaponics system designs in different ways.

Bernstein (2013) categorizes aquaponics into Media Based System (MBS), Nutrient Film Technique (NFT), and Deep Water Culture (DWC). Similarly, Tezel (2009) also gave three designs: the NFT, Ebb and Flow, and Raft Systems. In the NFT, water runs through the entire system continuously by means of a pump. MBS can either use Ebb and Flow or constant flow method. The Ebb and Flow is also known as the Flood and Drain system or the reciprocating flow. Unlike in NFT, in reciprocating flow the water is pumped periodically to the grow bed and it is allowed to drain out into the fish tank or the sump by means of a pump. In constant flow, water is delivered to the grow beds and simultaneously drains back to the fish tanks continuously. Raft systems are similar to DWC where plants absorb nutrients directly from the fish rearing facility. The plants get anchorage from Styrofoam which are floated on top of the fish rearing facility (Lennard and Leonard, 2004 and 2006; Rakocy et al., 2006; Tezel, 2009).

Preference of these three subsystems depends much on the user and their level of investment. Wren (1984) did an experiment to compare efficiencies of the MBS with the NFT subsystems. He found out that MBS were more efficient in terms of plant or fruit yield as compared to the NFT subsystems. This is similar to the results by Lennard and Leonard (2006) who compared all the three subsystems and affirmed that NFT is significantly less efficient compared to DWC and MBS in terms of yield, nitrate and phosphate removal, water use and buffering capacity. Tezel (2009) added that although NFT is the simplest to build, the roots may be shocked due to lack of oxygen.

2.6 Benefits of aquaponics

2.6.1 *Water conservation*

As one type of RAS, aquaponics systems have the ability to treat and reuse water with less than 10% of the total water volume replaced per day. They contain biological (vegetables) and mechanical filters that help to maximize the process of water purification and help to control potential diseases within the system. This allows for intensive fish production in areas where water is relatively scarce (Blidariu and Grozea, 2011).

Additionally, aquaponics safeguards the natural water bodies from contamination. Aquaponics is mostly organic hence there is no run off of harmful chemicals into natural water bodies. A study done by Pedersen et al., (2008) converted flow-through trout farms into RAS and there was reduced impact on the environment with removal efficiencies of between 85% and 98% for organic matter and suspended solids. The removal efficiencies for phosphate was between 65% and 96%.

2.6.2 *Land conservation*

Rapid population growth has some constraints on agricultural output. In aquaponics systems, crops are grown on soilless media hence it maximizes the utilization of space since it can equally use marginal land. According to Balcom (2015), aquaponics can grow crops ten times more efficiently than conventional farming methods.

2.6.3 *Health and Nutrition*

As civilization is advancing, the human race is becoming more aware of health and nutrition. People are eager to eat what will not compromise their health in future. Sharpe and Irvine (2004) stipulate that excess use of chemicals may have adverse impacts on human health. With the aquaponics technology, no synthetic chemicals are needed for the crops to grow as they are obtained from the fish waste, hence the crops produced are organic (Rakocy et al., 2006).

2.7 Status of Aquaponics in Malawi

Globally aquaponics has advanced especially in developed countries such as the United States of America, with about 3000 to 5000 systems and Australia with over 5000 systems. In Malawi, aquaponics is mostly practiced by the faith-based organizations at small scale and some few subsistence households. Examples of the few published systems in Malawi are: system by Lakeland University installed for research purposes near Nsundwe trading center in Lilongwe (Dunn, 2017), Morning star fishermen and the Irish ministries system at Bangula orphanage, in 2009, whose aim was to boost food security at the orphanage (morningstarfishermen.org), and J.T Nelson unit at African Bible College in Lilongwe (Epperson, 2013).

2.8 Barrelponics systems

Bernstein (2013) defines barrelponics as a style of aquaponics system that can be produced from reused plastic barrels that are locally available. Barrelponics systems are defined as autopilot systems since they require very minimum labour as their ecosystem (fish, plants, bacteria, water circulation) makes them self-sustaining (Hughey, 2005). The barrelponics system was introduced in 2003 by an American, Travis Hughey, whose main intention was to scale it out to African countries. One of the main advantages of the system is the use of reused materials such as plastic barrels which are inexpensive and readily available.

Basically, the barrelponics system has three main components as highlighted by Hughey (2005). The first component is the fish component which consists of a fish tank. The second is a hydroponic component which consists of grow beds. Lastly there is a holding tank that regulates water flow to the grow beds (Fig.1). The barrelponics system can be operated in either flood and drain or constant flow.

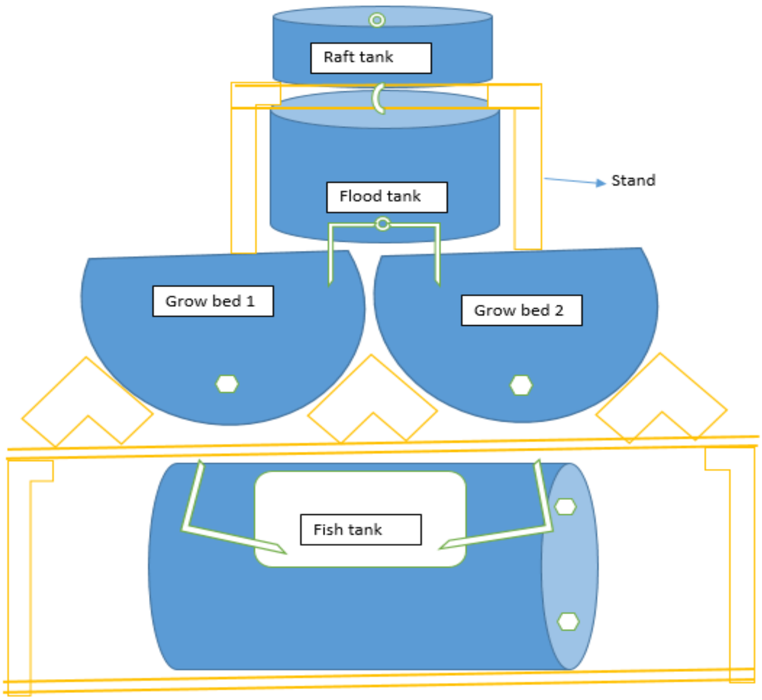

Figure 1 Drawing of the barrelponics system setup reproduced from Hughey (2005).

In flood and drain mode, water is pumped from the fish tank into the holding tank located on top of the grow beds. The holding tank has a valve connected to a siphon and a plastic bottle outside the tank. As water level in the tank increases, the siphon draws the extra water to the bottle outside which when full it counterweights and pulls the valve open to allow water to be drained to the grow beds. The nutrient rich water in the grow beds is utilized by the plants and slowly drain back to the fish tank.

In constant flow, there is a bypass from the siphon. The passage to the counterweight bottle is closed as such the water comes out of the holding tank constantly through the overflow pipe into the grow beds. A study by Lennard and Leonard (2004) revealed that constant flow regime has significantly higher levels of DO compared to reciprocating flow regime. The whole system has the capability of draining all the water to the fish tank in case the system has malfunctioned (Bernstein, 2013). This can be achieved through the overflow tube in the holding tank and grow beds.

2.9 Stocking densities in barrelponics systems

Fish tank volume is mostly used as a metric on how many fish to stock. Fish tank volume to fish ratio method is more ideal when the system is entirely dependent on internal filters to maintain the water quality within species tolerable ranges (Stout, 2013). Bailey et al., (2000) recommends 200fish/m^3 as the best stocking rate for survival, growth and reproduction for tilapia in aquaponics systems. However, in aquaponics it is somehow difficult to use the tank volume to fish ratio alone especially when dealing with media-based systems. This is because filtration of water is done in the grow beds which are a separate component of aquaponics systems. In particular, the rate of ammonia filtration depends on the biological activities by the nitrifying bacteria present in the grow beds. It is therefore imperative to consider the capacity of bio and mechanical filters when stocking the fish in aquaponics systems (Bernstein 2013; Stout, 2013).

While most stocking rate rules of thumb prioritize the fish component of the system, Maucieri et al., (2020) argues that both high and low stocking densities have a significant effect on the productivity of vegetables. According to Maucieri et al., (2020), aquaponics at low stocking densities increase plant yield without compromising vegetable quality whereas high densities improve vegetable quality at the expense of yield hence it is imperative to attest if the chosen stocking rate is compatible with a given growing space.

Rakocy (2007) elucidates the use of feeding rate ratio as the best method in attesting the correct stocking densities in aquaponics systems. Feeding rate ratio is the amount of feed given to the fish daily per square meter of growing space. According to Rakocy et al., (2004), 60 to 100g feed/day/m^2 plant area is ideal to prevent nutrient accumulation or deficiency in the system. However, this is on assumption that the feed intake will remain constant as such, the intended final weight of the fish at harvest is used (Smith, 2013). Rakocy et al., (2004) used 99.6g/day/m^2 for Nile tilapia and basil and no deficiency appeared in the crop.

2.10 Solar energy for aquaculture

According to Petrea et al., (2016), electricity cost represents more than half of total variable costs of production in an aquaponics system. Malawi is one of the least electrified countries globally currently at 11% overall, with 42% of the urban and only 4% of the rural population connected to national grid (IEA, 2017). There is a great need to explore off grid and renewable energy alternatives if aquaponics is to be adopted by rural Malawians.

Markvart (2000) articulates that solar electricity is relatively affordable compared to other small power sources like diesel generators. According to Tsoutsos (2005), solar energy systems are more environmentally friendly than conventional energy sources, hence contributing to sustainable human activities. Most people who are off-grid prefer using diesel generators backed up with batteries. Hoffmann (2006) enlightens that this conventional combination increases electricity production cost per kWh since the gen sets have to be constantly maintained and the batteries are of limited lifetime. Therefore, incorporating solar energy as a supplement to national hydroelectricity in Malawi would be ideal.

2.11 Energy use in barrelponics systems

Recirculating aquaculture systems such as barrelponics systems are deemed as part of sustainable agriculture intensification methods. However, their constant energy demands pose as a limitation to their adoption (Love et al., 2015). In opinion, it is significant to consider using devices that consume relatively less power to minimize energy costs for running the system throughout the year.

Energy use in barrelponics systems is less as compared to individual hydroponic and RAS. This is because some energy needs overlap for fish and vegetables, hence farming them together will significantly reduce the energy requirements (Delaide et al., 2017).

In opinion, most aquaponics systems consume more energy through the heaters, water pumps, and aeration pumps. For barrelponics systems, some of these costs may be reduced since aeration can be partially achieved by the water falls created at the grow beds outlets, and sometimes the same water pump can be diverted to create air pumps.

2.12 Lettuce as barrelponics crop

Choice of plant species for the hydroponic component in barrelponics may depend on stocking density and the nutrient concentration in the hydroponic influent. Lettuce (*Lactuca sativa*) is one of the crops alongside herbs and specialty greens whose nutritional demands are low to medium making them more suitable than others for barrelponics systems (Diver, 2016). Fruit yielding plants such as cucumbers and tomatoes have higher nutritional demands compared to leafy plants like lettuce hence they grow well when the system is heavily stocked and well established (Diver, 2016).

L.sativa is an annual plant of the daisy family Asteraceae. It is most often grown as a leaf vegetable, but sometimes for its stem and seeds. According to Tezel (2009) lettuce can sustain growth in water, hence it is more suitable in barrelponics. *L.sativa* is a good source of vitamin A and potassium, as well as a minor source for several other vitamins and nutrients. It grows best in full sun in loose nitrogen-rich soils with a pH of between 6.0 and 6.8 (Ryder, 1979; Mou, 2008). Heat generally prompts lettuce to bolt, with most varieties growing poorly above 24 °C; cool temperatures prompt better performance, 16 to 18 °C being preferred and as low as 7 °C being tolerated (Zhao and Carey, 2009).

Besides production for subsistence use, Aoyama (2014) articulates that lettuce has also been successfully employed in commercial production. It is estimated that in the year 2013, the global commercial production of lettuce was about 24.9 million tons of which China contributed about 13.5 million tons (FAO, 2013).

2.13 *Oreochromis karongae* as barrelponics fish

Tilapia fish are suitable for recirculating aquaculture systems. They are also very resilient to changes in pH, pollutants, and temperature (Johanson, 2009). Childress (2003) also commended Tilapia for quick growth, good food conversion rate, and better palatability. Kapeleta (2001) explains that *Oreochromis karongae* has the highest market value amongst the Malawian Tilapia, which certainly qualifies it as the potential candidate for this experiment.

2.14 Water quality in barrelponics systems

Water is vital to all forms of life in barrelponics systems. Fish, plants, nitrifying bacteria and worms require water of very specific parameter ranges for survival and growth. Growth rate of fish is influenced by a variety of factors such as dissolved oxygen (DO), water temperature, pH, metabolites, nitrates and phosphates. Limited oxygen supply can result in reduced DO concentrations in the water to harmful levels (Bernstein 2013; Stout, 2013). Bernstein (2013), further recommends DO concentrations of at least 6mg/l for Tilapia growth. In reciprocating flow systems, high DO level is achieved by draining of the grow beds which creates pore spaces within the media. In constant flow, high DO levels are achieved by the water falls existing in the holding tank and the outlet pipes from the grow beds into the fish tanks. Furthermore, DO can also be supplemented by aerators depending on total DO demand in the system.

Tilapia is tolerant to a wide range of temperature (8-41^{o}C) however, there is a need for temperature tradeoff in a system containing about 3 life forms (fish, plants, bacteria) (Bernstein, 2013). According to chapman (2000) most hybrid tilapia is best suited in temperature ranges of 25-32^{o}C. Water temperatures below 16^{o}C will stress tilapia and they will stop eating. As far as ambient temperature plays a major role in increasing water temperature, lettuce will suffer when the former is above 18^{o}C (Tezel, 2009). Putting shelter on hydroponic component will help to attain preferable ambient temperature levels while water heaters will supplement the heat to a desirable range in. Tyson et al., (2008) recommends 25^{o}C for Tilapia and nitrifying bacteria.

According to Delaide et al., (2017), pH of around 6.8-7.0 is regarded as a tradeoff value for fish, plants and nitrifying bacteria. pH levels in barrelponics system can fluctuate due to temperature and respiratory activities. Nitrification of ammonia produces hydrogen ions which also leads to dropping of pH. Bernstein (2013) explains that some grow medium have high calcium carbonate levels that creates high pH environments in the water as such it is ideal to test the media before employing it into the system.

About 90% of ammonia nitrogen in barrelponics system comes from fish excreta (Timmons et al., 2002). The total ammonia in the system is expressed as Total Ammonia Nitrogen (TAN), and it is the summation of NH_4^+ and NH_3 (Wongkiew et al., 2017). TAN needs to be oxidized to NO_3^- since high concentrations of greater than 2mg N/L may stress the fish, at worst causing mortalities. According to Wright (2018), 20 tilapia can produce about 3300 mg of TAN in 11 hours with minimal to no feed provided. NO_3^- is relatively harmless as compared to TAN, and a system can withstand high levels of up to 300mg N/L (Graber and Junge, 2009; Hu et al., 2014). A study done by Monsees (2018), revealed that nitrate concentrations of greater than 500mg N/L significantly affects growth and health status of the fish negatively. Furthermore, it showed that specific growth rate (SGR) increases significantly at optimal levels of 200mg N/L confirming the recommended realistic nitrate concentrations for RAS.

Conversely, it is vital to control the nitrate concentrations in barrelponics systems since imbalances occur when NO_3^- generation rate exceeds the utilization rate by the plants (Wongkiew et al., 2017). With time, nitrate concentrations may increase or decrease. The balance is obtained when the required concentration stays constant with time.

Phosphorous is one of the major limiting nutrients in aquaponics systems besides nitrate. According to White (2016), phosphorous is largely used for root growth, development of flowers and blooming of the plant. The main source of phosphorous in aquaponics system is the remains of fish feed that get trapped in the growing media and decompose, releasing phosphorous in form of orthophosphate. Solid wastes from fish is also another source.

2.15 Water reuse in barrelponics systems

In traditional RAS, the effluent is reused. Theoretically no portion from the effluent is removed from the system, and only a small volume is added to compensate for evapotranspiration and leakages (Lekang, 2008). In areas where availability of water is limited, reuse can be very significant. However, this may depend on the effectiveness of the filters present in the system. For a typical barrelponics system, water treatment methods include: Primary settling of large particles in the sedimentation tank; mechanical filtration of the remaining solid particulates in the grow beds; and biological filtration of the dissolved nutrients with the aid of nitrifying bacteria and hydroponic plants. These water treatment levels are capable of purifying the water to acceptable ranges (Stout, 2013).

However, Bernstein (2013) clarifies that anaerobic environments may be created in circumstances where the grow beds are overloaded with solid particulates that accumulate at the bottom. Bernstein (2013) further explains that this situation can lead to system shock with time and incorporation of worms (red wigglers) into the grow beds can prevent these problems since the worms will decompose the solid particulates rapidly. Water reuse is also ideal in circumstances where heating systems are used in the fish tanks. Heating water requires energy hence reducing the new incoming water will consequently reduce water heating costs (Lekang, 2008).

For typical barrelponics systems, the batch mode is used. All the water from the fish tank goes into the grow beds for treatment and returns back to the fish tank. Water is only added to the system to compensate for evapotranspiration, and in some cases dilute the nutrients if the plants seem to be exhausted. Bernstein (2013), highlights that replacing a huge portion of water in aquaponics systems may tamper with the integrity of nitrifying bacteria, slowing the colony buildup. This means that it is necessary for the water treatment methods in aquaponics systems to be more effective in order for the bacteria community to flourish and create a perfectly functioning ecosystem.

2.16 The financial feasibility of producing fish and vegetables

Petrea et al., (2016) mentioned that although barrelponics is a sustainable method for food production, its primary purpose is to maximize profits. While the study objectives focus much on systems technical potential, it is significant to get a glimpse of systems financial performance as this may ascertain systems adoption. According to the global study conducted by Love et al., (2015), less than one-third of the 257 assessed aquaponics farms were profitable. Some of the factors modeled related to profitability of these farms include: whether the farm specializes in selling both aquaponic-raised fish and plants or single product, of which those that sold both products were twice as likely to be profitable; whether the farms were more or less knowledgeable about aquaponics of which the more knowledgeable were twice as profitable; whether they regarded aquaponics as their primary source of income, of which they were five times more likely to make a profit; and climate of which respondents from mild winter areas were likely to be more profitable than those from colder climates. However, Bosma (2017) argued that the reasons for the losses have been poorly analyzed and hence he assessed some factors that may contribute to appropriate levels of returns. While some of the factors presented by Bosma (2017) hold for general aquaponics systems, others may not hold for the case of Malawi.

Results from an international survey done by Love et al., (2015) showed that the three largest variable inputs in barrelponics are: fish feed, energy and water. Mackenzie (2016) found that it would take about three years for a typical barrelponics system to return total fixed cost. He further explained that this could be achieved if there is access to operational information, reliable electricity, and stable climate to support year-round production.

Financial performance of a system or an enterprise can be assessed through various techniques. Most common methods used are: gross margins, break even analysis, payback period, net present value, net cash flow (NCF), internal rate of return (IRR) and return on investment (ROI).

2.16.1 *Gross margin analysis*

Gross margin is the measure of profitability of a farm or product. Gross margin profit is the difference between the annual financial output of the product and the variable costs that are directly associated with the product. Costs of running the system may be divided to fixed and variable costs. Variable costs may fluctuate with the production level. Fixed costs (overhead costs) are incurred notwithstanding the level of production hence they are ignored when constructing a gross margin (Rural Solutions 2012 and 2017). High gross margins defines high profitability of product or enterprise. Morgan (2018) elucidates that many small investments operate within the parameters of having a gross profit margin of between 25 percent and 35 percent

Tsorakidis (2011) articulates that total costs of production are significantly affected by long term investments that produce fixed costs. Since fixed costs are not included when calculating gross margins, using gross margins alone would undervalue the total cost of production hence it is important to use the gross margins together with the break-even analysis.

2.16.2 *Sensitivity analysis*

Gross margins can be affected by enterprises that are more sensitive to variations. These variations may result from fish or vegetable prices, seasonal conditions, pests and diseases, thus it is important to do sensitivity analysis in order to assess the risk. This can be done by comparing gross margins obtained from varying levels of inputs (Rural Solutions 2012 and 2017). The model employed in sensitivity analysis is also called simulation analysis as it predicts the outcome of a decision given a certain range of variables (Brigham & Ehrhardt, 2005; San Ong, 2013).

2.16.3 *Break-even analysis*

According to Berry (2010), break even analysis can help determine how much sales are required for the enterprise to cover the production costs. It determines the minimum level of product sales to ensure that the enterprise is not making any loss. Tsorakidis (2011) defined break-even analysis as the determination of the break-even point (BEP), where total revenue equals the projected total costs (total fixed costs+ variable costs). A study by English (2015) on three products (Basil, *L.sativa* and tilapia) aquaponics system showed that Basil was more profitable seconded by *L.sativa* while tilapia had a negative profit margin.

Barrelponics systems produce more than one type of product which are fish and crop. On the assumption that the sales mix of both products are known and that they would remain constant over the planning period, Tsorakidis (2011), proposes the use of multiproduct break-even point. In this case, the sales mix would refer to the ratio of the sales volume for the fish and crop.

2.16.4 *Payback Period*

For some investors to choose a technology or project, they would want to make sure that the particular technology will recover the original investment at some point in time. Payback period is a capital budgeting technique that determines the point in time at which the initial investment is paid off (Satzinger, 2011). According to Ross (2010) and San Ong (2013), an investment becomes acceptable when it has a payback period which is less than some pre-specified number of years. Shorter payback periods are preferred since they indicate that the project has greater liquidity hence it is less risky (San Ong, 2013).

Payback period can be calculated using cash flow amounts or present value. The limitation with cash flow amounts is that it does not consider the time value of money and it does not consider the returns from the project after its payback period (Brigham & Ehrhardt, 2005; San Ong, 2013) as such discounted payback period method is mostly used (Satzinger, 2011). According to San Ong (2013), discounted payback period is used to assess if the future yielded cash inflows are profitable. Discounted payback period will compare the present value of money and the future value of that same amount of money while considering the interest rate and inflation. A project is accepted if the discounted payback period result is shorter or equal to the pre-specified return period.

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 Research site and period

The research project was conducted at the Lilongwe University of Agriculture and Natural Resources, LUANAR, in Malawi (14°10’25.6”S, 33° 48’21.6”E).

The project was carried out within a period of six months from January to July, 2018, of which the first months were used for system construction, trials and cycling to allow for proper establishment of bacteria colonies in the grow media. The experiment was conducted in the last 42 days of the project.

3.2 Experimental Set-up and System description

The barrelponics system design was modified from the flood and drain design presented by Hughey (2005), who used three plastic barrels as grow beds and fish tank (Fig.1). The system used a space of 2.2m × 1.3m, with a height of 2.1m. The barrels used were 250L compared to 210L used by Hughey (2005) thus increasing the production area. The first plastic barrel was used as a fish tank with an active volume of $170m^3$ (Appendix 1, Fig.12). The second barrel was cut longitudinally into two (0.87m by 0.58m each) and used as media-based grow beds giving $1.0092m^2$ as total systems growing space with $80m^3$ water holding capacity after they were filled with grow media. The remaining barrel was cut horizontally where one part was used as a $125m^3$ water holding tank to increase total systems volume and the other was used as a $30m^3$ sedimentation tank. The total system volume (405L) was determined by summing the volume active capacity of all the system tanks. Since some tanks had overflow pipes, the top of the overflow pipe was regarded as the total active tank capacity as explained in table 1. The system was supported by a wooden frame which was rested on eight concrete blocks (Appendix 1). The grow beds, holding tank and sedimentation tank were rested on top of the frame whilst the fish tank was laid under the frame.

Table 1 System volumetric attributes

System component	Volume description	Volume (L)
Floating Sedimentation tank	To overflow pipe	30
Holding tank	To siphon	125
Grow beds x2	To overflow pipe	80
Fish tank	To mark	170
Total system volume		**405**

The system used solar as a sole source of energy. To size the pump and the PV array requirement, power required by the pump and power required from PV array were calculated as follows:

According to Al-Badi et al. (2018), the pump power requirement was calculated as:

$$P = \frac{\rho \times g \times Q \times H}{\eta} \qquad (3.1)$$

Where P is the pumping power in W; ρ is the density of water (1000 kg/m^3); g is acceleration due to gravity (9.81m/s^2); Q is the water flow rate (0.00026 m^3/s enough to circulate fish tank volume twice per hour); H is the total pumping 5m (system head plus inefficiencies) and η is the assumed pump efficiency (75%).

Hughey (2005) recommends using water pumps at only 60% of their capacity as such the pump flow rate was oversized by 40.04%. An additional 25% (75% efficiency) was added to the result to cater the inefficiencies due to pipe frictions and bends, and an extra 30% (212 L) for diverting the water back into the fish tank (3.54L/min) in order to aerate the water as the pump was also used as an aerator (venturi effect). This ensured dissolved oxygen concentrations of above 6mg/l as recommended by Bernstein (2013).

Total power require from the PV array was calculated as:

$$P1 = \frac{P}{\eta s} \tag{3.2}$$

Where P1 is the total power required from PV array in W; P is 12.55W obtained from eq.(3.1); ηs is the assumed efficiency of the system (50%).

From the above calculations, a 24v monocrystalline solar module of 30 W (from a 25W required) was planted outside the greenhouse, 6 meters from the barrelponics system. The module was mounted at a 40 degrees angle to ensure maximum energy harvest.

Electrical cables were installed from the panel to the charge controller and battery monitor which was placed inside the greenhouse. Two 12 volts backup 122Ah batteries were connected in series to the charge controller with a battery voltage of 12/24V, maximum, solar input voltage of 75V and a maximum charging current of 15A.

A 24 volts 1,135 lph (18W) adjustable DC runner solar powered pump (PULACO Company) with a maximum head of 6.1m was connected from the charge controller DC socket, pumping water to the systems maximum head of 2.1m from the fish tank at a set flow rate of 340lph to circulate the fish tank volume twice per hour as recommended by Hughey (2005). The solar modules were wiped once every month to remove dust. Figure 2 illustrates the system connectivity layout.

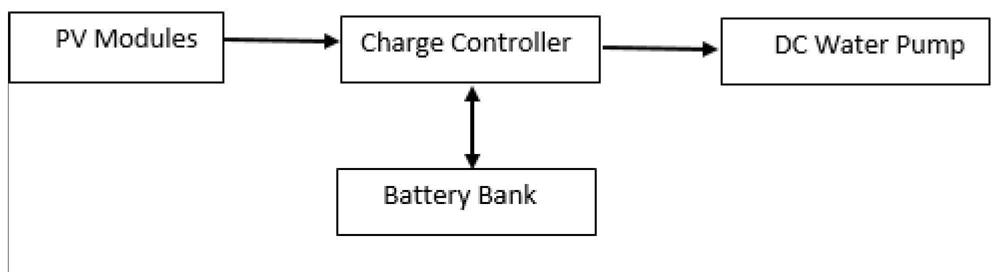

Figure 2 Water pump wiring for the barrelponics system

Water was pumped through a 1 inch hosepipe from the fish tank to the sedimentation tank which was placed above the holding tank. The sedimentation tank had a standpipe which would drain overflow water down to the holding tank. The holding tank had a standing pipe and an overflow siphon connected at the same heights. The holding tank operated as a reservoir that directed water to the grow beds continuously. The siphon was left open to act as an overflow in case the standing pipe was blocked. Water moved continuously from the holding tank to the grow beds and from the grow beds to the fish tank, and back to the sedimentation tank (Fig. 3). The DC runner pump was opened and cleaned with running water once every month to get rid of algae and clogged particulates.

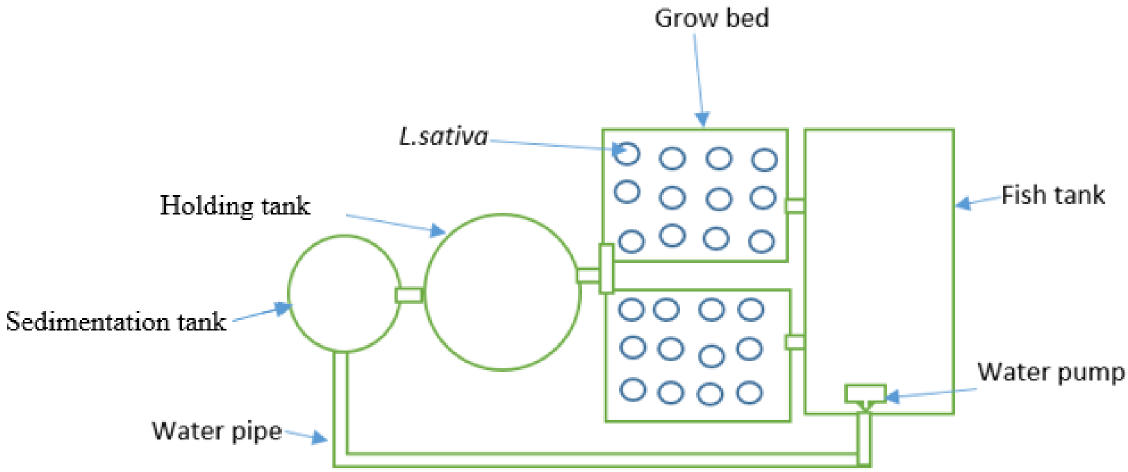

Figure 3 barrelponics the system setup

3.3 Nitrogen cycle regulation (System Fishless Cycling)

According to Tezel (2009) it takes approximately 4 weeks for the barrelponics system to start running smoothly although the bacteria colonies continuously grow. The system was operated for two days before putting any fish or crop just to make sure there were no leakages. Fishless cycling was conducted to speed up production of nitrification bacteria. To build the bacteria colonies in the system, 2gm of pure ammonia was added to achieve ammonia concentrations of about 5mg/l as recommended by Bernstein (2013). This was done twice every week for the first three weeks as the ammonia level would drop below 1mg/l after 3 days. The total amount of pure ammonia added during cycling was 12gm.

Using an Aqua-media test kit, TAN, nitrite and nitrate levels were measured daily in the first three weeks to establish the trend of the nitrogen cycle. The first observation of nitrate (fourth week) in the system indicated that the Nitrobacter were now in position and the system was now capable of nitrifying fish waste. Stocking of experimental fish was done after 30 days when the ammonia and nitrite levels were again below 1mg/l, and the nitrate level was 10mg/l.

3.4 Lettuce sowing and transplanting

Clean and healthy lettuce seed was obtained from one of the certified seed producers (Sakata Seed Ltd). The seed was sown in trays (50 by 30cm) for 21 days. 25 seedlings with an average weight of 10g each were transplanted into the grow beds at a spacing 20cm apart (25 seedlings/m^2). The seed producers recommended plant spacing of 45-60cm. However, Bernstein (2013) explains that in aquaponics systems plants may be closer to one another since nutrients are readily available, and competition between the plants is low. Before planting, the seedling roots were carefully flushed with water to remove the dirt.

3.5 Fish stocking and feeding

Before stocking the tilapia into the system, Acclimation was done for two weeks to eliminate weak tilapia and orient them to the confined environment in the tanks. During the acclimation period, the fingerlings were quarantined in salt bath at 2ppt for 30 minutes before putting them into the system in order to prevent the risk of infections (Hallam, 2013).

Thirty three *O.karongae* fingerlings with a mean weight of 10.86±1.98g were stocked at a rate of 200fish/m^3 as recommended by Bailey et al., (2000). Using a feed rate ratio method, the stocking density (33 tilapia/ 170L) was verified to be at 99g/day/m^2 feeding rate ratio. This meant that for the given grow area (1m^2), the system would accommodate a maximum feed input of 99g/day. According to Rakocy (2007) this stocking density was within the ideal range of 60-100g/day/m^2. This was done under the assumption that the tilapia would be harvested at a mean weight of 150g, being fed at 2% of their body weight in the harvest month. The following formula was used:

$$FRR = (N \times R \times WF)/A \tag{3.3}$$

Where FRR is the feed rate ratio, N is the number of tilapia stocked (33), R is the feed ration per day (2%), WF is the intended final weight (150g) and A is the available growing area (Rakocy, 2007).

The tilapia were fed a 32% CP diet (Bailey et al., 2000), containing meal worms, gluten, soybean, maize bran, wheat flour and vitamins. Feeding was done twice every day at 9:00hrs and 15:00hrs. Immediately after feeding was initiated, a 300g of worms (red wigglers) was introduced into the grow beds in order to accelerate breakdown of solid metabolites and uneaten feed.

3.6 Data collection and analysis

The research focused on water quality analyses, lettuce and tilapia performance. In consideration of systems profitability, simple financial analyses were also employed. The data collected was in three sections: water quality data; tilapia and lettuce production data and financial data.

3.6.1 *Water quality data, tilapia and lettuce data*

For the water quality parameters, data was collected for forty two days on: dissolved oxygen (DO); pH; and water temperature. The data was collected from the fish tank twice daily (9:00am and 2:00pm) to find out if the parameters were changing diurnally. Phosphate, TAN (NH_3 and NH_4^+); nitrite (NO_2) and nitrate (NO_3) were recorded daily before system cycling and three times a week after cycling at 9:00am and 2:00pm (Lennard and Leonard, 2006). Since the system has two components (fish and hydroponic) data for phosphate, TAN, NO_2 and NO_3 was collected in both components to check the uniformity.

For the fish component, data was collected weekly on: mortalities, tilapia weight, standard length, total length, and the amount of feed given. These were used to calculate the following indices:

a) Percent weight gain (%WG).

$$\%WG = \left[\frac{[Wf - Wi]}{Wi}\right] * 100 \tag{3.4}$$

Where: W_f is the mean final weight, Wi is the mean initial weight (Westers, 2001).

b) Feed intake (g/fish) calculated as the total dry feed intake (feed) divided by the number of surviving tilapia (N_f) (Westers, 2001).

$$Feed\ intake\ = [\frac{feed}{Nf}] \tag{3.5}$$

c) Feed conversion ratio (FCR) calculated by dividing the dry weight of feed (g) offered in a given period by wet weight gained (Δ Biomass) by the fish in grams (Stickney, 1994).

$$FCR = Feed/(\Delta\ Biomass) \tag{3.6}$$

d) Specific growth rate (SGR) calculated as:

$$SGR(\frac{\%}{day}) = 100[\ln Wt - \ln Wi]/\mathrm{t} \tag{3.7}$$

Where: ln (W_t) is the natural logarithm of weight at time t, ln (W_i) is the natural logarithm of initial weight and t is time in days (Westers, 2001).

e) Survival rate (SR%) calculated as:

$$SR\% = \frac{No.fish\ survived}{initial\ number\ of\ fish} \times 100 \qquad (3.8)$$

For the lettuce component data was collected three times a week on number of leaves produced and the leaf length. Mean seedling weight, and lettuce head weight were recorded.

To measure the first three objectives (water quality, tilapia and lettuce growth performance). The water quality data, tilapia weight and length data, and lettuce length data collected was entered in Microsoft Excel 2013. The means of these parameters were subjected to one-way Analysis of Variance using Genstat statistical package (Gen18ed). Duncan's multiple-range test was then employed to separate means of the parameters that were statistically different ($p<0.05$).

3.6.2 *System financial data*

3.6.2.1 System costs and revenue

To perform system financial analyses, total costs (fixed and variable) of the system had to be recorded (Appendix 2). These were recorded starting from system construction to the end of the experiment. The total fixed costs included the equipment and installation costs (initial outlay). Total variable cost was calculated by summing up the variable costs for lettuce and tilapia. Costs shared by both tilapia and lettuce (labour and water costs) were segregated to easily conduct analyses that required independent product costs as shown in table 10.

On water usage cost, water was being refilled to the fish tank whenever it gets below the 170L mark to compensate losses due to evapotranspiration and siphoning during system cleaning. Data was collected on any batches of water added into the system which was later used to calculate water used to produce a kg of each product (tilapia and lettuce), total water added in the system and water added per day (table 8). The collected water usage data was analyzed using Microsoft Excel 2013 for the respective calculation.

$$L = Wt/B \tag{3.9}$$

Where

L= added new water per kg of tilapia or lettuce in litres per kg

Wt= Amount of water added during the experimental period in litres

B= tilapia or Lettuce Biomass in Kgs

Tilapia and lettuce biomass were used to estimate revenue and cash flow. The prices for tilapia and lettuce were obtained from average of local market prices. Revenue was estimated as the product of the market price and the biomass. Table 9 shows a brief description of the total fixed costs for the system. The detailed description of pipes and fittings and other costs from each component is presented in the appendix 2.

3.6.2.2 Costs and revenue forecasting

To assess the financial feasibility of the system, four capital budgeting techniques (Marginal analysis, Break even analysis, Payback period and sensitivity analysis) were employed. Some of these techniques had to use projected cash flows as such costs and revenue forecasting was conducted to come up with five year cash flows (table 25). Both qualitative and quantitative forecasting were employed using Microsoft excel 2016 with inflation and increment rates from statista.com (table 23 and 24).

3.6.2.3 Gross margin

Gross margin was calculated in Microsoft Excel using the following formula Rural Solutions (2012; 2017):

$$GM = \left(\frac{GP}{SR}\right) \times 100 \tag{3.10}$$

GM= Gross Margin,

GP= Gross profit= (Sales revenue- Variable costs of products)

SR= Sales revenue= (total revenue from lettuce + total revenue from tilapia)

3.6.2.4 Sensitivity analysis

Sensitivity analysis was calculated by scenario manager in excel using assumed range of variables. These variables included the production costs, biomass and selling price of tilapia and lettuce. Three assumed scenarios were assessed to see the system profitability. These scenarios were: worst case (which assumed 30% decrease in productivity and revenue, and 30% increase in production costs); realistic case (which assumed 10% decrease in productivity and revenue, and 10% increase in production costs); and best case (which assumed 10% increase in productivity and revenue, and 10% decrease in production costs)

3.6.2.5 Break-even analysis

The break-even analysis (B.E.P) for each of the two products was calculated first, and then multiproduct B.E.P was also employed to determine how many units of each product are supposed to be sold to break even. This was done by multiplying the B.E.P value with the ratio of each products revenue to total revenue as illustrated below (Tsorakidis, 2011).

$$BEP = TFC/(SP - VC) \qquad (3.11)$$

Where

TFC = Total Fixed Costs, SP= Selling Price per unit, VC=Variable Cost per unit

However, since the selling price of tilapia and lettuce per Kg are different, the weighted average of the price and cost variables were computed first. Therefore, the multiproduct breakeven point was as follows:

$$BEP = TFC/(WASP - WAVC) \qquad (3.12)$$

Where:

WASP= Weighted Average Selling Price per unit = (Sale price of tilapia × Sales percentage of tilapia) + (Sale price of lettuce × Sale percentage of lettuce)

WAVC=Weighted Average Variable Costs per unit = (Variable expenses of tilapia × Sales percentage of tilapia) + (Variable expenses of lettuce × Sales percentage of lettuce)

And:

Sales percentage of tilapia= Sale price of tilapia/ (Sale price of tilapia + Sale price of lettuce) × 100

Sale percentage of lettuce= Sale price of lettuce/ (Sale price of tilapia + Sale price of lettuce) × 100

But:

Weighted Average Selling Price per unit – Weighted Average Variable Costs per unit = Weighted Average Contribution Margin per unit (WACM).

Therefore:

$$BEP = TFC/WACM \tag{3.13}$$

To find specific amount in Kgs for each product (P), the following formula was employed:

$$Amount = BEP \times Sales\%\ of\ P \tag{3.14}$$

3.6.2.6 Discounted Payback Period

The discounted payback period (DPP) used the following formula (San Ong, 2013):

$$DPP = \ln(1/(1 - \frac{Oi \times r}{CF}) \div \ln(1 + r) \quad (3.15)$$

Where

Oi = Initial investment (outflow)

r= assumed rate of return (10%)

CF= Periodic cash flow = (Cash input) – (Cash output)

The payback period was calculated on assumption that the system would have a useful life of about 10 years (Appendix 3, table 26) with proper management and maintenance. This means that the systems payback period result was preset to less than 10 years as the system cannot bring desirable returns when it has reached its salvage value. To find the total useful life of 10 years, useful life of some individual components were given by manufacturers while others had to be estimated using standard factors that affect usefulness. Depreciation was calculated as by Stárová (2010) (Appendix 3, table 27).

CHAPTER FOUR

4.0 RESULTS AND DISCUSSION

This chapter is subdivided according to the specific objectives of the research. Each subsection presents results combined with a discussion based on the particular objective.

4.1 Water quality parameters

4.1.1 *Dissolved oxygen*

Figure 4 shows that the DO levels fluctuated diurnally from week one to week six. Morning values have a similar trend from week one to week six. Afternoon values have also a similar trend from week one to week six. DO recorded a mean level of 7.43±0.20 mg/l in the morning and 6.74±0.24 mg/l in the afternoon. According to Mallya (2007) oxygen has a lower solubility in high water temperatures than low water temperatures. This may be the reason why DO levels were higher in the morning hours than afternoon hours as water temperature was increasing. Makori (2017) recommends 5mg/l as optimal DO levels for growth of tropical fresh water fish. DO levels of 6.61mg/l to 9.91mg/l have a positive effect on tilapia growth and FCR, while levels below 4.96mg/l and above 11.57mg/l negatively affect growth and FCR (Mallya, 2007). Despite the diurnal fluctuations of DO in the barrelponics system, the levels were still within the recommended range for survival and growth of the tilapia. This could also be attributed to the modified water pump that supplemented DO to the required levels.

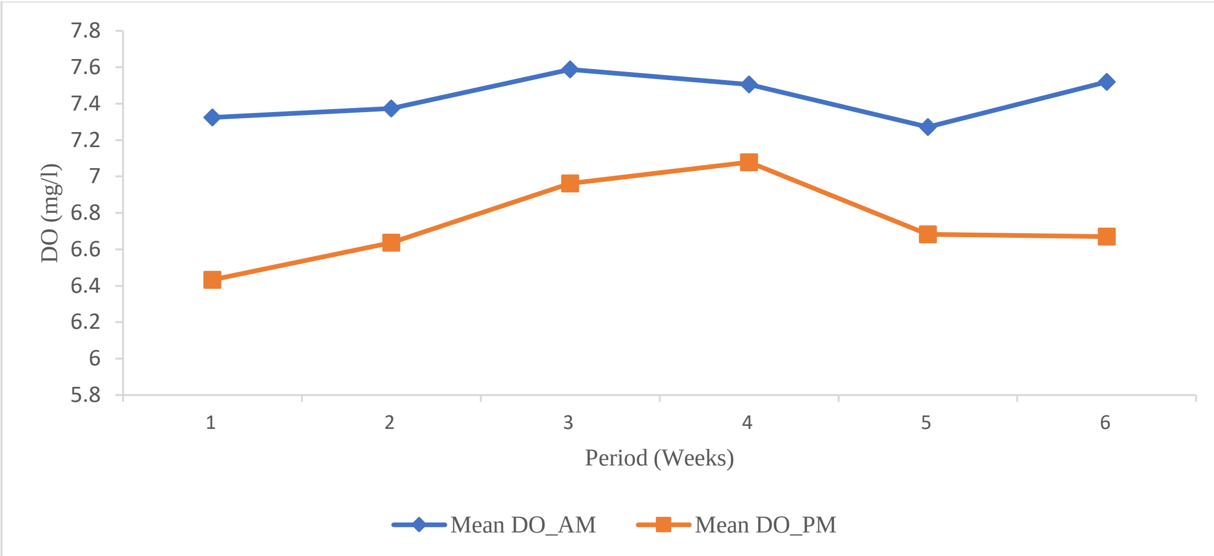

Figure 3 Diurnal trends of DO

4.1.2 *Water temperature*

Water temperature registered diurnal changes and there were significant differences during the day with a mean of 18.5±1.7 ^{0}C in the morning and 24.5±1.3 ^{0}C in the afternoon at $p<0.05$ (Fig 5). Overall, mean temperatures per week ranged from 20.17±1.3 to 23.30±1.6.

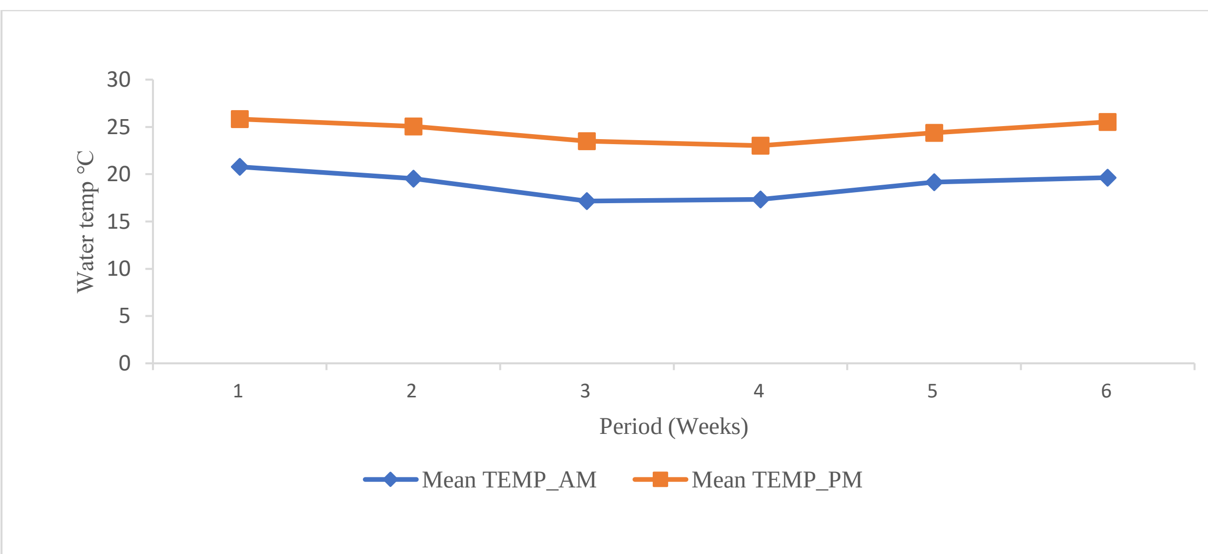

Figure 4 Diurnal trends of water temperature

According to Ngugi et al., (2007), ideal range for tilapia culture is between 20℃ and 35℃. However, tilapia growth increases with increase in temperature within the tolerable range (Khater, 2017). Although the mean overall temperature for the present study (20.17±1.3 to 23.30±1.6) was within the optimal range for growth, the minimum diurnal value (18.5±1.7 ^{0}C) was below the recommended range. This might have affected tilapia growth in the present study, although it cannot be definite since temperature was not a controlled variable. In addition, it is assumed that the temperature levels would be much higher if the study was conducted during the summer time, which would consequently improve tilapia growth. Nevertheless, tilapia survived and they were able to grow with the present temperature range.

4.1.3 *pH*

Mean pH was 6.89±0.11 with a minimum of 6.88±0.13 and a maximum of 6.90±0.16 meaning that there were no significant variations diurnally and throughout the study (Fig. 6). This could have resulted from the weekly removal of sediments through siphoning, which prevented formation of anaerobic zones within the system that could have possibly change the pH. According to BEAR (1992), tolerable pH range for growth of tilapia is between 6.5 and 9.0 although Crane (2006) noted that 6.5 to 7.0 is ideal for freshwater aquaculture and that levels below 5.5 limited tilapia growth and reproduction. The overall pH in this study was therefore suitable for survival and growth of tilapia as further concurred by Bernstein (2013) who provided a rule of thumb of 6.8 to 7.0.

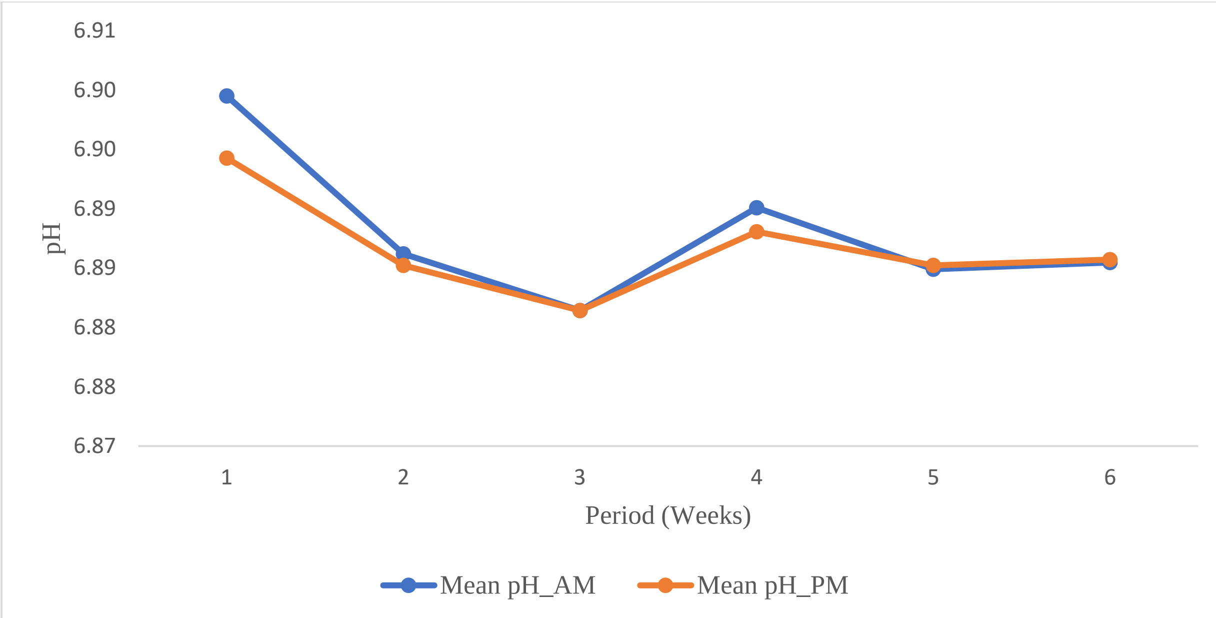

Figure 5 diurnal trends of pH

4.1.4 *Metabolites, nitrates and phosphates*

4.1.4.1 Total Ammonia Nitrogen

Trend of ammonia in bed is different from the trend in tank. Diurnally, the trend in the bed is similar, so as in the tank (Fig. 7). In addition, the trend shows that week one had relatively higher ammonia levels than the rest of the weeks. This could be that the bacteria colonies were still multiplying as such their effectiveness in nitrifying the ammonia improved with time.

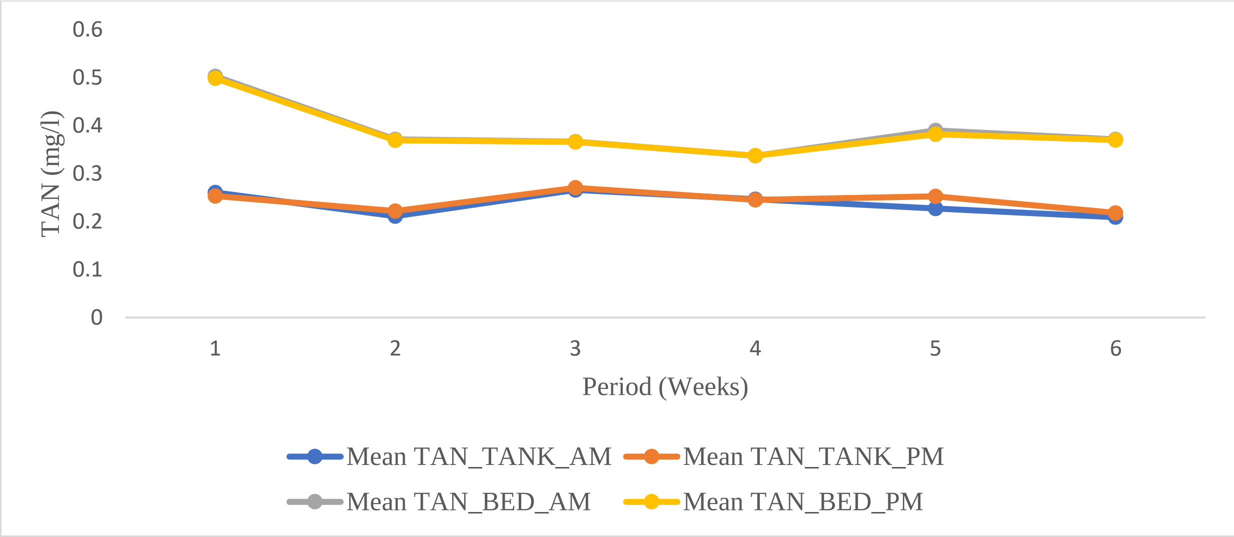

Figure 6 trends of ammonia in grow bed and fish tank

Despite the difference in the trend as shown in figure 7, table 2 shows mean ammonia levels were not significantly different in the morning and the afternoon at $p>0.05$. Furthermore, mean ammonia level in the grow beds, 0.39±0.01 mg/l, was not significantly different from fish tanks, 0.24±0.01 mg/l at $P>0.05$. According to Bernstein (2013), ammonia levels in barrelponics systems should be not more than 0.5mg/l. the system therefore operated within the tolerable ammonia range, which could be attributed to frequent removal of solid particulates through siphoning that kept other water quality parameters like DO in check.

Table 2 Mean ammonia levels in grow bed and fish tank

WEEK	TAN_TANK_AM	TAN_TANK_PM	TAN_BED_AM	TAN_BED_PM
1	0.27±0.05[a]	0.25±0.02[a]	0.50±0.03[a]	0.45±0.08[a]
2	0.21±0.03[a]	0.22±0.04[a]	0.37±0.05[a]	0.37±0.01[a]
3	0.27±0.01[a]	0.24±0.06[a]	0.37±0.01[a]	0.37±0.04[a]
4	0.25±0.03[a]	0.25±0.05[a]	0.34±0.06[a]	0.34±0.03[a]
5	0.23±0.06[a]	0.24±0.03[a]	0.39±0.08[a]	0.38±0.07[a]
6	0.20±0.09[a]	0.21±0.04[a]	0.37±0.05[a]	0.37±0.05[a]

4.1.4.2 Nitrite

Nitrite levels varied insignificantly throughout the reporting period with a mean level of 0.54 ±0.18 mg/l in the fish tank and 0.30 ±0.21mg/l in the grow bed (Table 3).

Table 3 Mean nitrite levels in grow bed and fish tank

WEEK	NO2_TANK_AM	NO2_TANK_PM	NO2_BED_AM	NO2_BED_PM
1	0.83±0.06[a]	0.83±0.01[a]	0.82±0.03[a]	0.82±0.03[a]
2	0.28±0.08[a]	0.28±0.06[a]	0.38±0.05[a]	0.31±0.06[a]
3	0.75±0.03[a]	0.75±0.04[a]	0.75±0.01[a]	0.74±0.01[a]
4	0.47±0.05[a]	0.47±0.01[a]	0.58±0.08[a]	0.58±0.02[a]
5	0.45±0.02[a]	0.45±0.05[a]	0.57±0.01[a]	0.55±0.09[a]
6	0.45±0.05[a]	0.45±0.04[a]	0.57±0.05[a]	0.56±0.01[a]

However, the trend shows that the concentration dropped in week one (Fig. 8). This could be that the tilapia had not produced enough ammonia to be nitrified as such the plants were only using the nitrate produced from cycling stage. In week two, the concentration started increasing. Tilapia at this point may have produced more ammonia that was being nitrified. In week three the concentration started going down until week four where it was stable to week six. The stability could be related to overall systems stability starting from biofilter effectiveness, to the tilapia becoming used to the system. According to Deswati (2020), nitrite is toxic to tilapia at levels of 5mg/l and keeping it as low as 1mg/l is ideal for growth of tilapia, plants and bacteria in aquaponics systems. Overall nitrite concentrations in the barrelponics system was less than 1mg/l making it an ideal environment for tilapia.

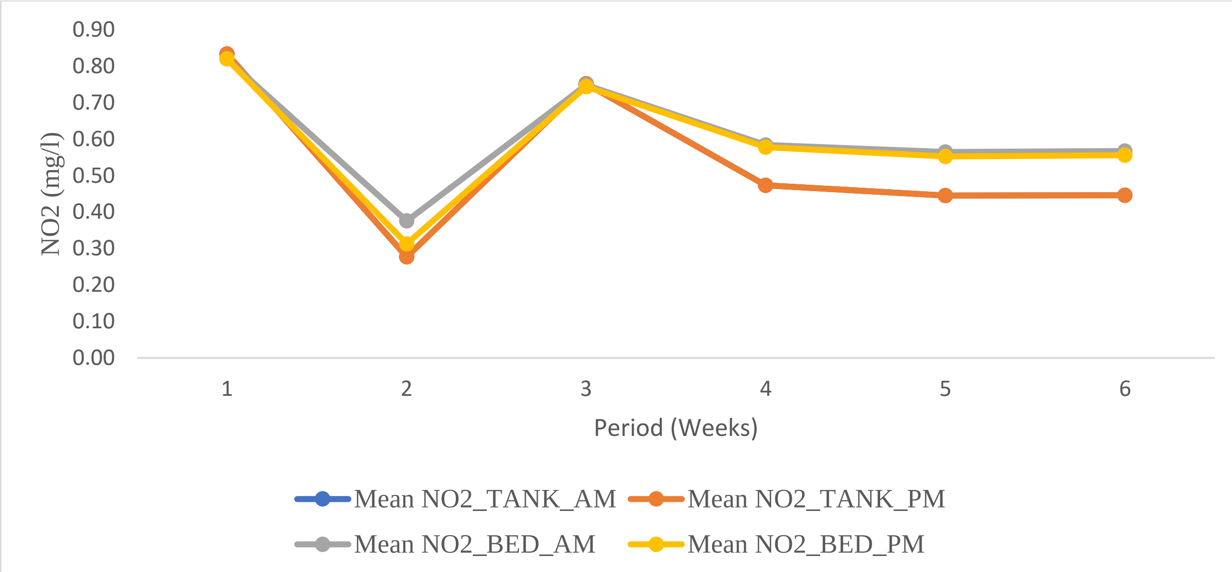

Figure 7 trend of nitrite in grow bed and fish tank

4.1.4.3 Nitrate

Conversely, nitrate levels significantly varied during the reporting period with the minimum of 1.08±0.21 mg/l and maximum of 12.75 ±0.18 mg/l. Levels of nitrate were higher in grow beds than fish tank with a mean of 6.92 ±0.22 mg/l and 4.82±0.21 mg/l, respectively (Table 4). This could be because most of the nitrifying bacteria stay in grow bed media as such some of the ammonia is nitrified when it reaches the bed.

Table 4 Mean nitrate levels in grow bed and fish tank

Week	NO_3_tank_AM	NO_3_tank_PM	NO_3_bed_AM	NO_3_bed_PM
1	8.53 ± 0.03^{c}	9.02 ± 0.14^{c}	12.76 ± 0.13^{c}	12.50 ± 0.13^{c}
2	2.14 ± 0.21^{a}	2.24 ± 0.05^{a}	3.08 ± 0.06^{a}	3.04 ± 0.11^{a}
3	1.08 ± 0.12^{a}	1.10 ± 0.13^{a}	1.45 ± 0.01^{a}	1.36 ± 0.14^{a}
4	7.34 ± 0.13^{c}	7.34 ± 0.11^{a}	11.02 ± 0.12^{c}	11.02 ± 0.08^{c}
5	4.51 ± 0.04^{b}	4.53 ± 0.13^{b}	6.66 ± 0.24^{b}	6.65 ± 0.13^{b}
6	4.73 ± 0.33^{b}	4.74 ± 0.17^{a}	6.98 ± 0.15^{b}	6.98 ± 0.11^{b}

Weekly trends (Fig. 9) show that nitrate levels dropped abruptly in the second and third week allegedly due to the nutrient demands by the newly transplanted lettuce. From third week the concentration went up again as tilapia might have produced a significant amount of ammonia that was being nitrified up to week four. In fourth week the concentration fairly dropped again until it became stable in fifth week. This could be that nutrient demands from lettuce were increasing with time, until the optimum level was reached. According to Nhan et al., (2019), it is challenging to maintain nitrate concentration balance in aquaponics systems as plants have different nutrient requirements at different ages. The present concentrations were however within optimal range for the growth of lettuce as highlighted by Deswati (2020) who recommended a range of 5 to 150mg/l.

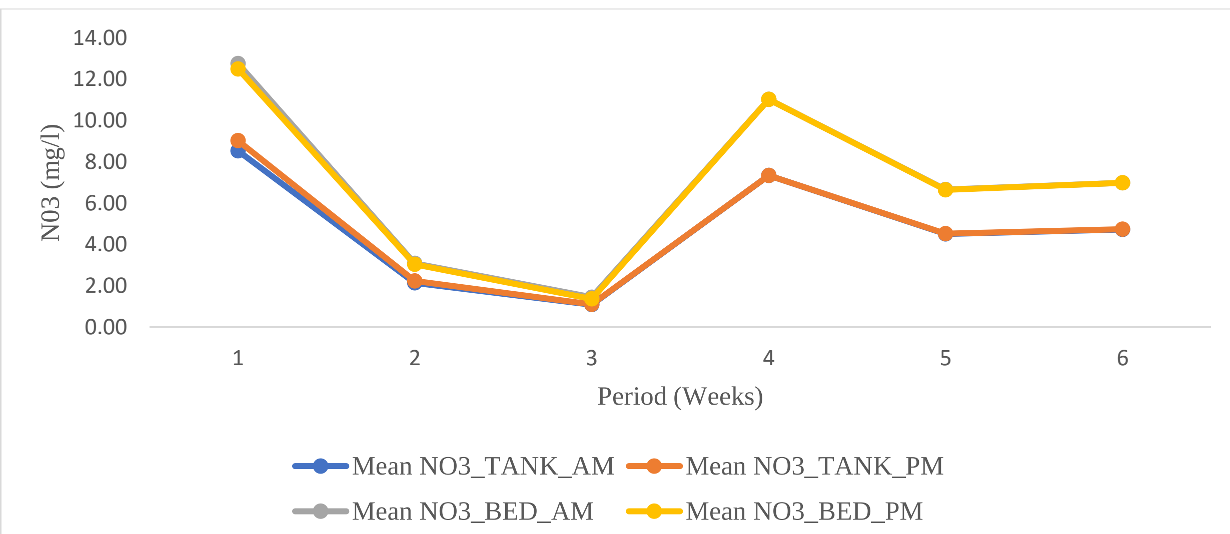

Figure 8 diurnal trends of nitrate in grow bed and fish tank

4.1.5 *Phosphate*

In figure 10, phosphate levels in fish tank were low compared to the grow beds. This could be because decomposition occurs in the grow beds. Phosphate levels were low in the first two weeks with a maximum of 0.6±0.28 mg/l. since the primary source of phosphate in aquaponics systems is the decomposition of uneaten feed and solid tilapia excretes (Bernstein, 2013), these low levels would be because the system was new and the solid particulates had not yet decomposed to traceable amounts.

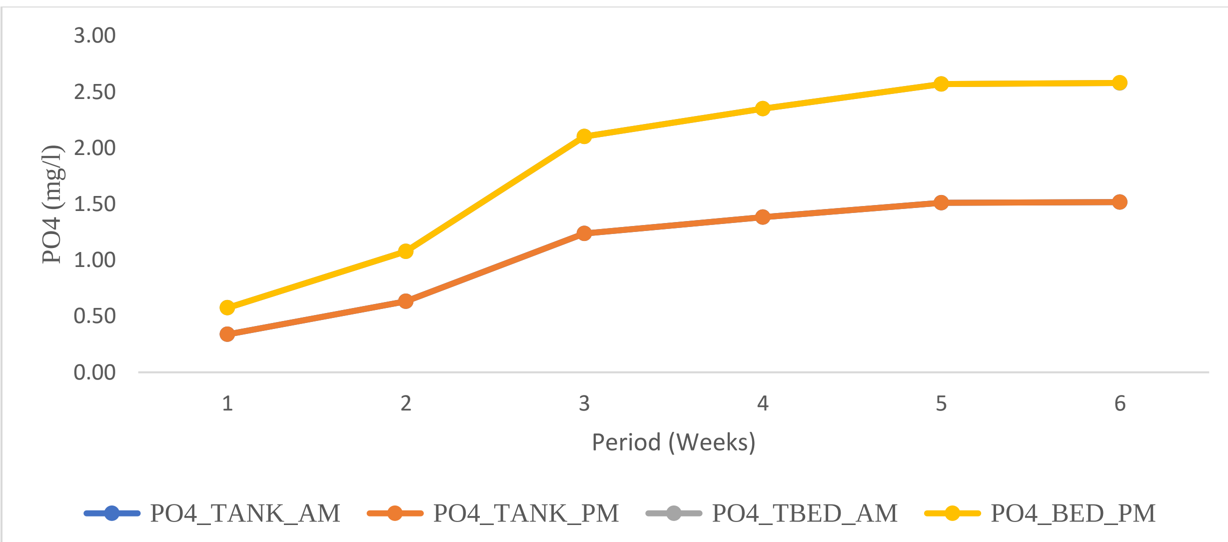

Figure 9 diurnal trends of phosphate in grow bed and fish tank

On the third week, phosphate levels changed abruptly to a mean of 1.2±0.31 mg/l with a maximum of 2.5±0.42 mg/l in the sixth week (Table 5). This could be that the decomposed particulates now released traceable amounts of phosphate. According to da Silva and Fitzsimmons (2016), most plants need 1.9 to 2.8mg/l as the optimal phosphate concentration for growth therefore the system had optimal ranges for lettuce growth.

Table 5 Mean phosphate levels in grow bed and fish tank

WEEK	PO4_TANK_AM	PO4_TANK_PM	PO4_BED_AM	PO4_BED_PM
1	0.34±0.13	0.34±0.01	0.57±0.01	0.57±0.05
2	0.63±0.05	0.63±0.12	1.08±0.03	1.08±0.01
3	1.24±0.07	1.24±0.11	2.10±0.02	2.10±0.02
4	1.38±0.11	1.38±0.10	2.35±0.04	2.35±0.01
5	1.51±0.13	1.51±0.14	2.57±0.01	2.57±0.04
6	1.52±0.02	1.52±0.04	2.58±0.04	2.58±0.01

4.2 Growth Performance of *Oreochromis Karongae* in Barrelponics Systems

Figure 11 shows that tilapia weight, standard length and total length had a similar trend and they were increasing throughout the experimental period.

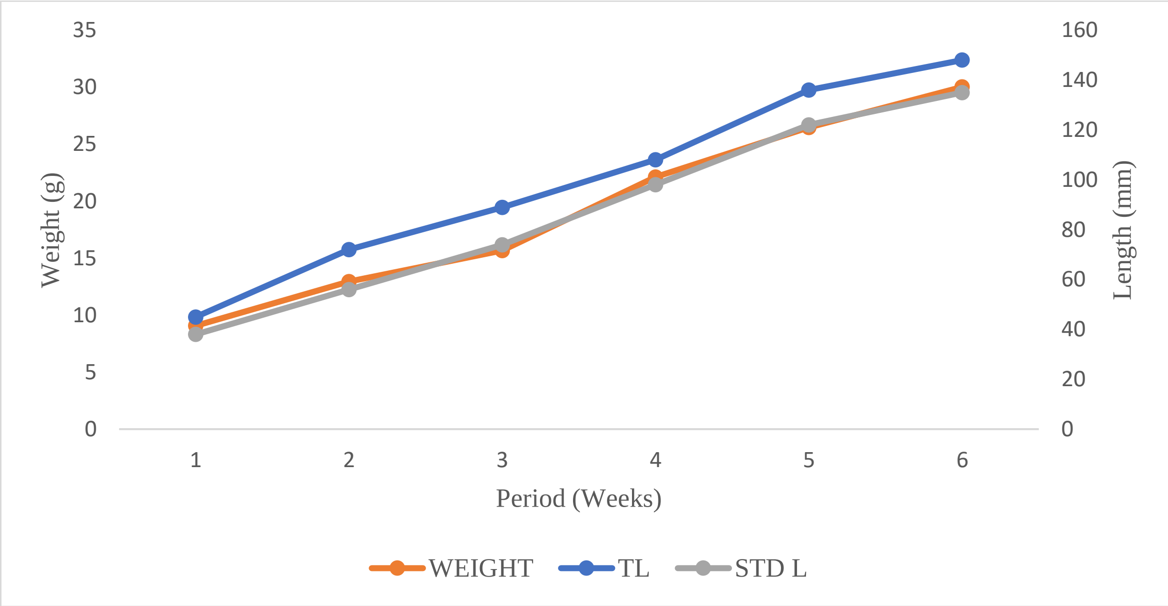

Figure 10 growth of O. karongae in weight, total length (TL) and standard length (STD L)

Results from table 6 showed that the tilapia grew progressively over the 6 weeks from an individual initial weight of 10.86±1.15 g to a final mean body weight of 25.63±1.18 g. The total yield from 33 tilapia stocked in the tank at the total weight of 0.43kg was 0.82kg, indicating a net yield of 0.82 Kg. Average growth rate (AGR-gday^{-1}), Specific growth rate (SGR%), Survival rate (SR%), and feed conversion ratio (FCR) of the tilapia were 0.35g/day, 2.04 % day^{-1} , 100%, and 1.93, respectively.

Table 6 Growth performance of tilapia cultured for 42 days in barrelponics

Parameter	**Value**
Stocking rate	200fish/m^3
No. of Fish	33
Mean Stocking Weight	10.86 g fish^{-1}
Minimum Stocking Weight	8.8g
Maximum Stocking Weight	12.9g
Total weight stocked	0.43 Kg
Survival rate	100%
Mean harvest weight	25.63 g fish^{-1}
Minimum harvest weight	24 g
Maximum harvest weight	28 g
Total harvest weight	0.82 Kg
Total weight gain	0.39 Kg
Mean weight gain	14.77 g
Total Yield	4.82 Kg/m^3
AGR[a]	0.35 g/day

SGR[b]	2.04 %day^{-1}
FCR[c]	1.93

[a] absolute growth rate
[b] specific growth rate
[c] feed conversion ratio

Table 6 shows that tilapia survival rate was 100% which is excellent for Tilapia raised in tanks compared to 97.2% reported by Castillo et al. (2016) and 98.3% reported by Rakocy et al. (2004) for tilapia raised in aquaponics systems. The FCR was 1.93 which is lower compared to 2.03 and 2.59 reported by Msiska and Costa-Pierce (1997), and Nyirenda et al. (2000), respectively, for *O.karongae* raised in ponds. SGR of 2.04%day^{-1} was close to 2.10 %day^{-1} reported by Nyirenda et al. (2000) and higher compared to Maluwa et al. (1995) and Msiska and Costa-Pierce (1997) who reported SGR of 0.96 %day^{-1} and 0.49 %day^{-1}, respectively, for *O.karongae* raised in conventional pond aquaculture. This means that Barrelponics systems can be regarded as a potential method of growing tilapia in Malawi.

4.3 Growth Performance of Lettuce in Barrelponics System

From table 7, lettuce grew significantly from a mean number of 3 leaves per plant to a final mean of 7 leaves per plant during the 42 days of trial. The leaf length and breadth increased from 3cm and 2cm to 27cm and 13.33 cm, respectively, during the reporting period. The average fresh weight for the lettuce increased from 10 to 504 grams.

The 42-day Lettuce yield (14.54 kg m^{-2}) in the present study was better than the results by Lennard and Leonard (2006) (21-day lettuce yield of 4.97 kg m^{-2}) and Seawright et al., (1998) (28-day lettuce yield of 2 kg m^{-2}). Growth rates of the lettuce were comparable with the results from other studies (Seawright et al., (1998); Lennard and Leonard (2006)).

Table 7 Lettuce growth performance in 42 days

Parameter	Mean no. leaves	Weight/plant (g)	Mean leaf breadth (cm)	Mean leaf height (cm)
Planting	3±1.27	10±1.16	2±1.13	3±1.18
Harvest	7±1.34	504±1.14	13±1.18	27±1.12

4.4 Financial Performance of Barrelponics Systems

4.4.1 *Water use and cost*

On water data collected (Table 8), the total system volume was 405 litres. A total of 520 litres of water was added into the system during the 42 days to maintain the standard water quality and quantity levels for both Tilapia and lettuce. This translates to 12.4L/day.

Table 8 Water usage by Tilapia and Lettuce

Parameter	**Value**
Internal flow rate at pump level 3 of 10 (L/min)	5.7
Total water added in 6 Weeks (L/week)	520
Added water per day (L/day)	12.4
Water used/kg Tilapia (L/kg)	564.02
Water used/kg Lettuce (L/kg)	31.90

The total water added at the end of the experimental period was 520 litres which represents 128% of the total system volume. This water was regarded lost through evapotranspiration and during system cleaning. The production of 1 kg lettuce required about 31.90 litres of water which is lower than 104 and 244 litres reported by Love et al., (2015) and Delaide et al, (2017), respectively. However, in terms of water needed to produce 1 kg tilapia, the system recorded about 564 litres which is more than 278 litres and 292 litres reported by Delaide et al, (2017) and Love et al., (2015), respectively, showing that the system was comparatively more efficient in producing vegetables than it is in producing fish at a given volume of water. Total water used was simulated to 12 months to find total annual cost of water for the system, charged by Lilongwe Water Board at 496.00 MK/m^3 (tarrifs.ib-net.org).

4.4.2 *Fixed costs*

The total fixed cost for the system is presented in table 9 below. Individual materials used are presented in appendix 2.

Table 9 Total fixed costs for the system

Component	Quantity	Unit Price (MK)	Total Cost(MK)
Holding tank pipes and fittings	1	28,350.00	28,350.00
Sedimentation tank pipes and fittings	1	3,500.00	3,500.00
Grow beds pipes and fittings	1	13,900.00	13,900.00
Fish tank pipes and fittings	1	500.00	500.00
250L Barrels	3	15,000.00	45,000.00
Growing media	1	6,000.00	6,000.00
Wooden stand	1	48,000.00	48,000.00
Cement blocks	8	500.00	4,000.00
Water pump	1	45,000.00	45,000.00

Extension	1	2,500.00	2,500.00
Solar panel	1	23,000.00	23,000.00
Backup battery	2	50,000.00	100,000.00
Installation cost	1	50,000.00	50,000.00
Total			**369,750.00**

4.4.3 *Variable costs*

Variable costs (VC) of tilapia were segregated from variable costs of lettuce to easily conduct individual product analyses. Shared costs like water and labour were divided between tilapia and lettuce components. The cost for labour is very minimal as the system is not labour intensive since it runs on autopilot (self-sustaining ecosystem) and the only work needed is about 10 minutes per day of cleaning and feeding.

Table 10 simulated annual variable costs for tilapia and lettuce in a barrelponics systems

	Commodity	Rate	Quantity	Unit Price (MK)	Total Cost (MK)
	Labour	40MK/day	360days	40.00	14,400.00
TILAPIA VC	Fingerlings	30MK/fish	66fish	30.00	1,980.00
	Feed	600MK/kg	5.94kgs	600.00	3,564.00
	Water costs	496MK/m3	5.55m^3	496.00	2,752.80
				Total	**22,696.80**
	Labour	40/day	360days	40.00	14,400.00
LETTUCE VC	Water costs	496/m3	5.55m^3	496.00	2,752.80
	Lettuce seed	70/g	80g	70.00	5,600.00
				Total	**22,752.80**

4.4.4 *Marginal analysis*

Financial analyses were conducted on assumption that the system would be operating with 2 tilapia cycles and 8 lettuce cycles per year, with approx. 6 months per cycle of tilapia and 40 days per cycle of lettuce. Since the system would only hold 33 tilapia harvested at an average weight of 170g as shown in the methodology, mean total harvest of tilapia per year would be 11kgs. For lettuce, mean harvest per year would be 100kgs. This translates to a revenue of MK 33,660 and MK 90,000 at selling price of MK 3,000/kg and MK 900/kg of tilapia and lettuce, respectively. Gross profit from both products was MK 78,210.40 while gross profit margin ratio was 63% (table 12).

Table 11 simulated annual revenue and profit for barrelponics system

Total revenue [c] (MK)	123,660.00
Gross profit[b] (MK)	78,210.40
Gross Profit Margin Ratio [a] (%)	63

[a] Gross Margin ratio= (gross profit÷ Sales revenue) ×100
[b] Gross Profit = (Sales revenue- Variable costs of products)
[c] Sales revenue= (total revenue from lettuce + total revenue from tilapia)

The gross profit margin ratio of 63% means that running the system is profitable at 63% since the ratio is positive (Rural Solutions, 2012; 2017). Similarly, it means that for every MK100 that is realized as revenue, there will be MK37 left to cover the basic operating costs and the rest is profit. Morgan (2018) elucidates that many small investments operate within the parameters of having a gross profit margin of between 25 percent and 35 percent while the present study showed that a typical barrelponics system can be operated at relatively high gross profit margins. However, the present gross margin is relatively high because the system incurs few operating costs (Morgan,

2018) as it uses technologies like solar power. Additionally, since the system runs on autopilot, cost for labour is significantly reduced.

4.4.5 *Sensitivity analysis*

From table 13, gross profit and gross profit margin ratio results are subject to the changes in input variables. On the assumption that the total variable costs and revenue will go down and up, respectively by 10%, the gross margin ratio will increase from 63% to 73% (best case). This is on assumption that system productivity would increase due to increase in selling prices and experience that would consequently reduce direct costs of production.

On the assumption that the total variable costs and revenue will go up and down, respectively by 10%, the gross margin ratio will decrease from 63% to 52%. This is regarded as the realistic case as it acknowledges uncertainties that may occur even if the system was properly managed. Similarly, on the assumption that the total variable costs and revenue will go up and down, respectively by 30%, the gross margin ratio will decrease from 63% to 2%. This is regarded to be the worst case scenario and assumption would be that the costs of production have gone up and the system is poorly managed lowering the revenue. However, all the results are positive at 30% (worst case), 10% (realistic case) and 10% (best case) indicating that the productivity would have to go down beyond 30% for the system to realize losses. Similarly this means that the flexibility in increasing variable inputs and decreasing productivity would go to about 30% for the system to start observing negative gross profit margin ratios.

Table 12 sensitivity analysis summary

	Current Case:	Worst Case [A] (-30%)	Realistic Case [B] (-10%)	Best Case [C] (+10%)
Changing Variables:				
TILAPIA_BIOMASS	11	8	10	12
LETTUCE_BIOMASS	100	70	90	110
TILAPIA_PRICE	3,000.00	2,100.00	2,700.00	3,300.00
LETTUCE_PRICE	900.00	630.00	810.00	990.00
TILAPIA_VC	22,696.80	29,505.84	24,966.48	20,427.12
LETTUCE_VC	22,752.80	29,578.64	25,028.08	20,477.52
Output				
GROSS_PROFIT	78,210.40	1,185.52	49,635.44	107,925.36
GROSS _MARGIN RATIO	63%	2%	50%	73%

[a] 30% decrease in revenue and 30% increase in costs of production
[b] 10% decrease in revenue and 10% increase in costs of production
[c] 10% increase in revenue and 10% decrease in costs of production

4.4.6 *Break-even analysis*

From table 13, break-even yield for both products was 526kg. Tilapia break-even yield was 53kg while Lettuce had a break-even yield of 473kg. This means that for the system to return the total fixed costs, a total of 526kgs of produce should be realized in the proportions of 53kg tilapia and 473kg lettuce as the sales mix. The break-even point in monetary terms for both products was MK584,618.99 in proportions of MK159,142.10 and MK425,486.89 for tilapia and lettuce, respectively. This means that under the assumption that the tilapia and lettuce mix will remain constant during the planning period, the system will return the projected total costs if it sells the tilapia and lettuce produce amounting to MK584,618.99 in the above proportions in line with Tsorakidis (2011).

The results show that tilapia is contributing only 27.22% to the sales revenue with lettuce contributing 72.78%. These findings suggest that tentatively, lettuce is more profitable than tilapia in typical barrelponics systems, but bearing in mind the synergetic effects between the two enterprises.

Table 13 summary of variables used in calculating multiproduct break-even point

Total fixed cost (MK)	369,750.00
Tilapia selling price (MK/kg)	3,000.00
Lettuce selling price (MK/kg)	900.00
Variable costs of tilapia per kg	2,022.89
Variable costs of lettuce per kg	227.53
Sales percentage of tilapia [a]	10%
Sales percentage of lettuce [b]	90%
Weighted average Contribution margin [c]	703.20
Break-even yield for lettuce and tilapia (Kgs)	526
Break-even yield for lettuce (Kgs)	473
Break-even yield for tilapia (Kgs)	53
Break-even sales for lettuce and tilapia (MK)	584,618.99
Break-even sales for lettuce (MK)	159,142.10
Break-even sales for lettuce (MK)	425,486.89

[a] Tilapia biomass÷(tilapia biomass+ lettuce biomass)×100
[b] lettuce biomass÷(tilapia biomass+ lettuce biomass)×100
[c] Weighted Average Contribution Margin per unit = Weighted Average Selling Price per unit – Weighted Average Variable Costs per unit

4.4.7 *Payback Period*

From table 15, the discounted cash flow payback period was 4.4 years. On the assumption that the cash flow (CF) will be affected by inflation and increased production experience (Appendix 3, table 26), the system should take about 4.4 years to return the total capital invested at 10% rate of return. On the assumption that the gross profit is initially used to pay fixed costs, profits should be realized after 4.4 years as the initial outlay will have been paid. From the scenario summary (Table 12), worst case would have the longer payback period since it has less gross profit followed by realistic case, current case then the best case. For a system with a useful life of about 10 years (Appendix 3, table 26), this means that the system will pay back the fixed costs while it has used only about 50% of its usefulness.

Table 14 discounted method payback period

Rate	**10%**					
Year	0	1	2	3	4	5
Undiscounted CF [a]	-369,750.00	78,210.40	87,526.73	108,298.29	137,153.62	186,267.60
Present Value CF [b]	-369,750.00	71,100.36	72,336.14	81,366.11	93,677.77	115,657.53
Balance [C]	-369,750.00	-298,649.64	-226,313.49	-144,947.39	-51,269.62	64,387.91
Discounted PP [d]						**4.4**

[a] Annual revenue-Annual costs
[b] Found in Microsoft excel using PV model
[c] Initial outlay-PV CF
[d] Summation of final negative balance and final negative year plus first positive year balance

CHAPTER FIVE

5.0 CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

This study has shown that small scale continuous flow barrelponics system has potential to grow tilapia and lettuce, and the water quality can be maintained within the desirable levels. This is an important step in the area of aquaponics development in Malawi. Growth of lettuce in the studied system was high relative to other typical aquaponics systems. The results have shown that the system can relatively produce more vegetables per unit volume of water added compared to fish.

Financially, we may conclude that the system is feasible as gross margin ratios were positive even when subjected to worst case scenario of sensitivity analysis where costs of variable inputs increased by 30% and revenue decreased by 30%. In addition, the system is paying back the initial outlay while it has used only 50% of its life expectancy, indicating potential of making profits in the subsequent years. However, despite the system being profitable, hydroponic component is more productive compared to the fish component as described by the sales mix of the break even analysis.

5.2 Recommendations

The system was found to be technically good and financially viable and it can be a potential business for Malawian farmers. However since there is need for further thorough investigations on the system, it is therefore recommended primarily for subsistence use. Future studies in barrelponics systems should consider assessing suitability of other fish species and vegetables that are equally/mostly farmed in Malawi in order to meet most farmer preferences. To maximize profits, it is recommended to explore other high value vegetables in Malawi for more revenue. This research was only done for early stages of fish development, therefore it is recommended that further research should focus on other factors that can increase productivity and profitability potential, by extending study period across full fish growth cycles and different seasons in Malawi.

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APPENDICES

Appendix 1 Barrelponics system construction

Figure 11 cutting barrels into respective system parts

Figure 12 ground levelling and system installation

Figure 13 system components assembled

Figure 14 measuring water quality parameters

Figure 15 Lettuce growing in barrelponics system

Appendix 2 system parts, materials and cost in year 2018

Table 15 materials used to construct a water holding tank

Quantity	Description	Unit Price (MK)	Total Cost (MK)	Subtotal (MK)
1	ELF Cistern Siphon50mm	5,000.00	MK 5,000.00	
1	PVC Socket 50mm (Plain)	750.00	MK 750.00	
1	Valve Socket 50mm (Grey)	850.00	MK 850.00	
1	PVC Bend 50×40mm (Long radius type)	1,500.00	MK 1,500.00	
1	Reducing Bush 40×32mm	950.00	MK 950.00	
1	Reducing Bush 32×25mm	850.00	850.00	
1	24.5 " long PVC pipe 25mm (3/4") size	700.00	700.00	
3	PVC adaptor (3/4") size	500.00	1,500.00	
1	PVC tee (Plain) 25mm (3/4") size	800.00	800.00	
2	PVC pipe 25mm (3/4") size	1,200.00	2,400.00	
2	IPS elbows 25mm (3/4") size	500.00	1,000.00	
1	Male adaptor 1/2" size	850.00	850.00	
2	IPS sockets 1/2" size	600.00	1,200.00	
1	PVC tap 1/2 " size (Plastic)	1,500.00	1,500.00	
1	Flexible connectors 1/2 "	1,500.00	1,500.00	
1	1m Twine (for Fishing)	300.00	300.00	
1	60cm Wire rod #9	500.00	500.00	
1	Big Pinfold	200.00	200.00	
1	2L Sobo Plastic bottle	100.00	100.00	
12	Big Washers	150.00	1,800.00	
1	Male Female Socket 1/2" by 1/2" size	500.00	500.00	
3	IPS elbows (1/2") size	500.00	1,500.00	
2	IPS nipples 1/2" (for syphon)	500.00	1,000.00	

1	13" long IPS pipe 1/2" (for syphon)	1,000.00	1,000.00	
1	12" long PVC pipe (for extending siphon length)	100.00	100.00	
Total				**28,350.00**

Table 16 materials used to construct a sedimentation tank

Quantity	**Description**	**Unit Price (MK)**	**Total Cost (MK)**	
1	PVC Bulb	500.00	500.00	
1	IPS Nipple 1/2"	500.00	500.00	
1	IPS Socket 1/2" F/M by 1/2"	500.00	500.00	
1	Female adaptor 25mm (3/4") size	1,000.00	1,000.00	
1	Male adaptor 25mm (3/4") size	1,000.00	1,000.00	
Total				**3,500.00**

Table 17 materials used to construct grow beds

Quantity	**Description**	**Unit Price (MK)**	**Total Cost (MK)**
2	HDPE Bends 1/2" (for outflow)	950.00	1,900.00
2	HDPE Bends 1" (for overflow)	1,500.00	3,000.00
2	6" long PVC Pipe 1/2" (for outflow)	500.00	1,000.00
2	6" long PVC Pipe 1/2" (for overflow)	500.00	1,000.00
2	10" long PVC Pipe 1/2" (for outflow)	500.00	1,000.00
2	10" long PVC Pipe 1/2" (for overflow)	500.00	1,000.00
2	HDPE Female adaptors 1/2 " (for outflow)	500.00	1,000.00
2	HDPE Male adaptors 1/2 " (for outflow)	500.00	1,000.00

2	20" long PVC Pipe 1/2" (for inside)	500.00	1,000.00	
2	20" long PVC Pipe 1" (Placed outside the inside pipes)	800.00	1,600.00	
4	disposable tumblers (prevents outlets blockage)	100.00	400.00	
Total				**13,900.00**

Table 18 materials used to construct fish tank

Quantity	**Description**	**Unit Price(MK)**	**Total Cost(MK)**	
1	HDPE Male adaptors 3/4 " (for outflow)	500.00	500.00	
Total				**500.00**

Table 19 cost and description of barrels

Quantity	**Description**	**Unit Price (MK)**	**Total Cost(MK)**
3	Blue Plastic Barrels (250L each) to cater for sections below: 1 Sedimentation tank 8" deep 1 Holding tank 22.5" deep 2 Grow Beds (2 halves of 1 barrel) 1 Fish tank cut a rectangular opening at 28.4" long and 12.4" wide	15,000.00	45,000.00
Total			**45,000.00**

Table 20 materials for constructing wooden stand

Quantity	**Description**	**Unit Price (MK)**	**Total Cost(MK)**
4	Timber 2×4 size 28" long (Flood tank side support)		

2	Timber 2×6 size 24" long (Sedimentation tank base)			
4	Timber 2×4 size 16" long (Holding tank base side support)			
2	Timber 2×4 size 23" long (Holding tank base support)			
4	Timber 2×6 size 28" long (Holding tank base side support)			
2	Timber 1×8 size 13" long (Holding tank base)			
4	Timber 2×8 size 44" long (Grow bed + Fish tank triangular side support)			
4	Timber 2×6 size 44" long (Grow bed + Fish tank triangular side support)			
4	Timber 2×4 size 54" long (Grow bed base, front and back)			
2	Timber 2×6 size 12" long (Grow bed triangular support raise)			
4	Timber 2×4 size 60" long (Stand foundation)			
2	1 kg Pack of 5" Nails	1,200.00	2,400.00	
2	1 kg Pack of 4" Nails	1,200.00	2,400.00	
1	1 kg Pack of 3" Nails	1,200.00	1,200.00	
Total				**48,000.00**

Table 21 power source materials

Description	Unit Price (MK)	Quantity	Total Cost (MK)
Water pump	45,000.00	1	45,000.00
solar module	23,000.00	1	23,000.00
batteries (backup)	50,000.00	2	100,000.00
Power Extension	2, 500.00	1	2, 500.00
Total			**170,500.00**

Table 22 other additional costs

Description	Unit Price (MK)	Quantity	Total Cost (MK)
Cement blocks (Stand Groundwork)	500.00	8	4,000.00
1 Barrel full Pea size gravel (grow media)	6,000.00	1	6,000.00
Total			**10,000.00**

Appendix 3 revenue and cost forecasts, and cash flow

Table 23 Revenue forecast

Year	Projected Inflow(MK)	Profit Increment Rate (%)
0		
1	123,660.00	1
2	136,026.00	1.1
3	156,429.90	1.15
4	187,715.88	1.2
5	239,337.75	1.28

Table 24 Operating costs forecasts

Year	Projected Outflow(MK)	Inflation
0	**369,750.00**	
1	45,449.60	6.71%
2	48,499.27	5.53%
3	48,131.61	5.05%
4	50,562.26	4.96%
5	53,070.14	3.63%

Table 25 five year projected cash flow

Year	Projected Inflow(MK)	Projected Outflow(MK)	Cash flow(MK)
0		**369,750.00**	
1	123,660.00	45449.60	78,210.40

2	136,026.00	48499.27	87,526.73
3	156,429.90	48131.61	108,298.29
4	187,715.88	50562.26	137,153.62
5	239,337.75	53070.14	186,267.60

Table 26 straight line depreciation of the system

Year	Book Value (Beginning of year)(MK)	Depreciation(MK)	Book Value End of year) (MK)
1	369,750.00	35,975.00	333,775.00
2	333,775.00	35,975.00	297,800.00
3	297,800.00	35,975.00	261,825.00
4	261,825.00	35,975.00	225,850.00
5	225,850.00	35,975.00	189,875.00
6	189,875.00	35,975.00	153,900.00
7	153,900.00	35,975.00	117,925.00
8	117,925.00	35,975.00	81,950.00
9	81,950.00	35,975.00	45,975.00
10	45,975.00	35,975.00	**10,000.00**

NOTE: Useful life for some system individual materials was given by the manufacturers and for others was estimated using standard factors that affect usefulness.

Table 27 depreciation of the system

Straight Line Depreciation Method	
Asset cost [a] (MK)	369,750.00
salvage value [b] (MK)	10,000.00
useful life [c] (yrs.)	10
Annual depreciation expense [d] (MK)	35,975.00
straight line depreciation rate [e]	10%

a= fixed asset (initial outlay)

b=estimated value of the system after 10 years

c= estimated based on life of systems individual components

d= (asset cost - salvage value) ÷ useful life

e= (annual depreciation expense) ÷ (asset cost - salvage value)