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Research Application Summary

Assessment of technical and economic feasibility of a portable aquaponic system

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Abstract

In Malawi, about 43.6% of total dietary protein consumed is from fish. However, rapid growth in population has led to harvest stagnation from Lake Malawi and other water bodies, leading to a decline in per capita consumption of fish from 14 to about 5.6 kg/person/year despite an increase in aquaculture production from an estimated 200 tonnes in 1995 to more than 3000 tonnes in 2010. Information and data available indicate that 10–25 percent of the total land area in Malawi is suitable for pond aquaculture. However there are questions as regards to sustainability and negative environmental impacts of pond aquaculture. Commercial cage aquaculture would be an alternative however Malawian Government has taken a precautionary approach to prevent the aquaculture activities from causing damage to the aquatic environment. But this requires exceptional control, suitable legal structures, strong institutions with good institutional capacity and the adoption of adaptive management. Integrated Agriculture-Aquaculture systems e.g. aquaponic systems, are deemed sustainable for their ability to utilize land at optimum level. Aquaponic systems have the potential to increase farm productivity up to six fold. However, aquaponic systems seem to be more complex and expensive due to their technicality. Full potential of aquaponics in Malawi has therefore, not been explored due to lack of information on associated costs, benefits and efficiencies. Thus the major goal of this research was to design a portable aquaponic system made from locally available materials and assess it technically and economically as a potential alternative source of livelihood.

Key words: Aquaculture, aquatic environment, fish consumption, harvest stagnation, Malawi

Résumé

Au Malawi, environ 43,6 % des protéines alimentaires totales consommées proviennent du poisson. Cependant, la croissance rapide de la population a entraîné une stagnation des récoltes du lac Malawi et d’autres plans d’eau, entraînant une baisse de la consommation de poisson par habitant de 14 à environ 5,6 kg/personne/an malgré une augmentation de la production aquacole d’environ 200 tonnes en 1995 à plus de 3 000 tonnes en 2010. Les informations et les données disponibles indiquent que 10 à 25% de la superficie totale du Malawi conviennent à l’aquaculture en étang. Cependant, il y a des questions concernant la durabilité et les impacts environnementaux négatifs de l’aquaculture en étang. L’aquaculture commerciale en cage serait cependant une alternative; Le gouvernement du Malawi a adopté une approche de précaution pour empêcher les activités aquacoles de causer des dommages à l'environnement aquatique. Mais cela nécessite un contrôle exceptionnel, des structures juridiques adaptées, des institutions fortes dotées d'une bonne capacité institutionnelle et l'adoption d'une gestion adaptative. Systèmes intégrés agriculture-aquaculture, par ex. Les systèmes aquaponiques sont réputés durables pour leur capacité à utiliser les terres à un niveau optimal. Les systèmes aquaponiques ont le potentiel de multiplier par six la productivité agricole. Cependant, les systèmes aquaponiques semblent être plus complexes et coûteux en raison de leur technicité. Le plein potentiel de l'aquaponie au Malawi n'a donc pas été exploré en raison du manque d'informations sur les coûts, les avantages et l'efficacité associés. Ainsi, l'objectif principal de cette recherche était de concevoir un système aquaponique portable fabriqué à partir de matériaux disponibles localement et de l'évaluer techniquement et économiquement comme une source alternative potentielle de moyens de subsistance.

Mots clés: Aquaculture, milieu aquatique, consommation de poisson, stagnation des récoltes, Malawi

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Introduction

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

The numbers of fish in Lake Malawi is decreasing at an increasing manner due to rapid increase in Malawi population. Cage culture can be one of the measures to ensure adequate fish protein. However the Government of Malawi prohibits cage aquaculture and to date, only a few private sector investors are allowed to produce fish in cages at a pilot scale (Anon, 2011). The prices of fish on the market are going up making local people not able to afford the fish hence fish consumption for the country has gone down from 14 kg in the 1970s to about 5.6 kg/person/year (GOM, 2012). However, Singini (2014) argues that despite the decline in fish consumption, fish supply continues to play a significant role in Malawi nutrition and food security.

While conventional pond aquaculture has the potential to alleviate poverty and improve food security and nutrition, nonetheless this is at the expense of the ecosystem (Beveridge *et al.,* 2010). Additionally, Malawi has one of the highest population growth rate, at annual level of 3% while the average land holding size is now less than 1.0 ha of land per smallholder farmer. Many farmers would prefer to use their small piece of land for terrestrial agriculture rather than aquaculture since it is easy to realize the profits (House and Zimalirana, 1992). Since fish consumption has a strong cultural tradition for many Malawians, there is a need to develop sustainable effective aquaculture practices 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 education and training necessary for replication, maintenance and sustainability can ameliorate hunger and poverty.

Integrated Agriculture-Aquaculture systems (aquaponic systems) have the ability to utilize land at optimum level and they can also utilize waste or byproducts from other subsystems as their inputs. The efficiency of the system is assured by removing toxic waste products from water and allowing 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). Aquaponics seems to be a potential alternative if Malawian aquaculture is to expand.

However, high investment and running costs make aquaponic systems too expensive to be practiced by smallholder farmers. Full potential of integrated agriculture aquaculture systems in Malawi has not been explored due to lack of information on associated costs, benefits and efficiencies. Love *et al*. (2015) did an international survey on aquaponics and from their findings they concluded that more research and development needs to be done to determine if these systems can be profitable food production methods. Therefore, it was necessary to conduct this research and document the results for the producers to know whether or not it is viable to venture into aquaponics as an alternative source of livelihood in Malawi.

Materials and Methods

Research site and period.The Fish-lettuce aquaponic system was constructed in the green house at the Lilongwe University of Agriculture and Natural Resources LUANAR (14°10’25.6”S 33° 48’21.6”E). The greenhouse was used to ensure that the system was in a fully secured and controlled environment, and block other environmental factors that may interfere with the experimental results. The experiment was carried out within a period of 6 months to allow for proper establishment of bacteria colonies in the quarry media.

System design and description. The experiment used a shallow wooden box (25cm deep and 100cm^2 area) as grow bed; Tilapia (*Oreochromis karongae*) as experimental fish; and Lettuce as experimental crop. Fine gravel was filled into the box as a growing medium because it has the ability to retain water and moisture simultaneously. Three plastic buckets (60 litres each) that hold water were used as fish tanks.

Fish stocking and lettuce transplanting. The *Oreochromis karongae* male fingerlings were produced from Bunda fish farm and they were stocked at the rate of 200fish/m^3 and weight of ±10g to avoid the black box of genetics. Acclimation was done for two weeks for the fish to eliminate the weak and orient them to the confined environment in the tank. Clean and healthy lettuce seed was sowed in trays (50cm by 30cm) in the greenhouse for 21 days and then transplanted into the growing beds.

Data collection and analysis. The technicality of the system was reflected by fish and lettuce growth performance in relation to the measured parameters which were later compared with the performance of the University of Virgin Islands standard aquaponic system. For the economic analysis, marginal and break-even analyses were done for both the hydroponic and fish culture component to find out the profitability and how long it would take for each component to break even respectively.

This means that the data collected were in two sections: Fish and crop performance data; and system economic data, for the fish component data were collected on: food conversion ratio (FCR); specific growth rate (SGR); and mortalities. Biomass was determined by fish weight and sampling was done once every two weeks. For the Physical/chemical parameters data were collected daily on: dissolved oxygen (DO); pH; and conductivity.

For the hydroponic component data were collected weekly on number of leaves produced, leaf area index, initial plantlet fresh weight (g), and final plant fresh weight (g). For system economic data, the data collected included all the projected total costs (Total fixed costs + Total variable costs) for the system and the revenue from the fish and hydroponic component yield.

Subsequently, the fish and crop production data were subjected to analysis using Microsoft excel. The survival rate for the fish was also calculated.

Marginal Analysis for the system

Gross margin was calculated using the following formula:

Gross Margin= (gross profit Sales revenue) 100…………………….. Eq. (1)

Where: Gross Profit = (Sales revenue- Variable costs of products)

Sales revenue= (total revenue from lettuce + total revenue from fish)

Break-even analysis

For the break-even analysis the following formula was used:

B.E.P in Kilograms = Fixed costs / (sales price per kg – Variable cost per kg) …….. Eq. (2)

Break-Even Yield (BEY) for lettuce production

Projected total costs = (Total fixed costs+ variable costs for lettuce)

Projected total costs (mk) = (9,100+ 8,970)

=mk 18,070

BEY= (Projected total costs ÷ Expected Price/kg)

Then BEY (kg) = (18,070 1,750)

= 10.3 kg

Break-Even Yield (BEY) for fish production

BEY= (Projected total costs expected price/Kg)

Then BEY (kg) = (18,070 3,080)

=5.9 kg

=52% (First production cycle)

Marginal Analysis for the system

Gross Profit = (Sales revenue- Costs of products)
Where sales revenue= (total revenue from lettuce + total revenue from fish)

Gross Profit = (8,568+9,137)-(8,970)
Gross Profit = (17,705- 8,970)
Gross Profit = MK8, 735

Gross Profit Margin= (gross profit Sales revenue) x 100
Gross Profit Margin= (8,735 16,753) x 100

Results and discussion

Fish growth. Since the primary objective of this experiment was to design and assess the profitability of a portable aquaponic system, the fish growth trial was not replicated. Results showed that *O. karongae* grew steadily over the 4 weeks from the mean weight of 8.4 grams to final mean weight of 10.3 grams. The total harvest after 4 weeks was 0.515 kg. Based on these means the projected one cycle production would give 2.9664 kg (Table 1 and 2).

Lettuce yield. The lettuce started growing healthy and fast after two weeks (Figures 1 and 2). This may be because the ammonia in the fish water was now oxidized to the usable form. As suggested by Tezel (2009), it takes proximately 4 weeks for the nitrosomonas and the nitrobacter bacteria to convert the unionized ammonia to the form which is usable by the plants (Table 3 and 4.

Technical interpretation. The system proved to sustain the life of fish. This is reflected by the high survival (96%) which is even greater than a standard (89.9%) of UVI standard aquaponic system (Rakocy, 2004). The system was also able to sustain the life of lettuce since no transplanted seedling died although growth was low in the first week but this may be because the lettuce was adapting to the new gravel environment form the soil.

Economic interpretation. The break-even yield for lettuce was 10.3 kg. This means that the lettuce yield of 10.3 kg covered all the costs related to the growth of lettuce. This also means that it takes at least two cycles for the yield of 10.3 kg to be attained. The full investment costs only apply in the first production for construction of the system. From second cycle the fixed cost will keep on decreasing such that only 20% of the initial fixed cost will be applied as a fixed cost in the second production cycle because the system has a depreciation rate of 20%.

For the fish component, a yield of at least 6 kg is required for the component to break even. The yield of fish after adjusting for mortality is 2.9664 kg. This means that it will take not more than two cycles for the system to break even since the depreciation value is 20% meaning that the fixed cost will decrease by 80% in the second production cycle making the break-even yield to be 3.5 kg instead of 6 kg. This is under an assumption that there will be no hyper-inflation in the short-run that may significantly alter the variable costs and that all the environmental parameters will still be in the tolerable ranges for both the fish and lettuce.

The gross profit margin for the system is positive (52%) and this shows that the system is profitable and after running it for at least two cycles it would break even. However; the profitability of fish is not high as that of lettuce. This may be because the fish tanks had few fish (0.5 fish/m^3) which is very little for a recirculating system with such effective waste filters (gravel + lettuce) for the good growth of fish. Hence this means that the system was being underutilized. According to McConnell (2009), the per-unit cost of production is high when a system is producing below its full capacity. In this case it means that there is a need to assess where the profit for the fish component can be maximized and this can be done through further research.

Table 1. Growth performance of fish during the trial

Total number of stocked fish	50
Mortalities	7
Mean stocking weight (g)	8.4
Mean harvest weight (g)	10.3
Gain (sgr % day 1)	0.5%
Survival rate%	96%

Growth performance of lettuce.

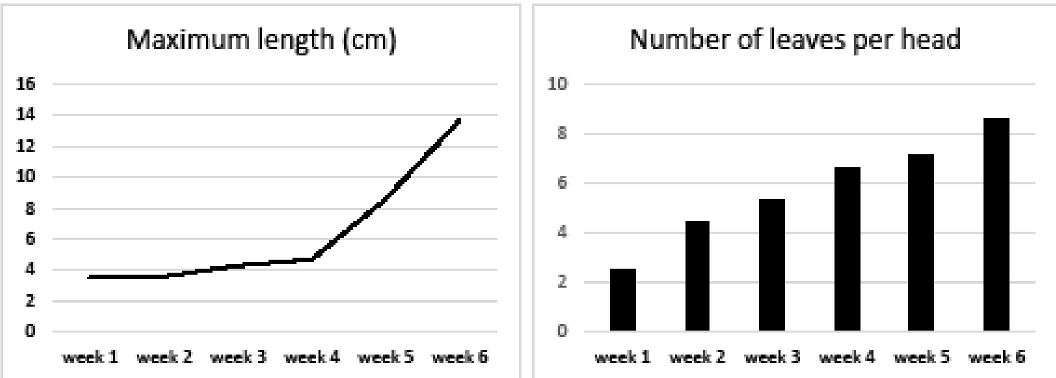

Figure 1. Growth performance of lettuce

Fish-lettuce yield and sales.

Table 2. Total fish yield and sales

Amount stocked	1 month yield (kg)	6 month yield (kg)	total yield (mk) adjusted for survival rate (96%)	price/kg (mk)	total price (mk)
50	0.515	3.090	2.9664	3080	9,137
Total sales (mk)	-	-	-	-	9,137

Table 3. Total lettuce yield and sales

Amount planted (head)	weight per head (g)	total weight (kg)	price/kg (mk)	24 heads sales (mk)
24	204	4.896	1,750	8,568

mk is Malawi Kwacha where 1 US$ = 1007 mk on average

Conclusion

The research provided evidence that locally available materials can be used to produce an aquaponic system which is more similar to the non-local and that the system it can sustain life of the fish with high survival rate (96%) and with a recorded mean weight gain of ±1.9g. In addition to that, it is also possible to grow lettuce successfully in this system as proven by the ±204g mean weight per head.

The research also showed a positive gross profit margin and this indicates that the system was profitable since it showed capacity to produce vegetables and fish on just 1 m^2 area which is almost impossible for conventional aquaculture and Horticulture.

It can therefore be concluded that a portable aquaponic system made from local materials is feasible in terms of economic and technical aspects.

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