DEVELOPMENT OF LOW-COST AQUAPONIC SYSTEMS FOR KENYA- PART I

Production System Design and Best Management Alternatives/Experiment/13BMA05AU

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ABSTRACT

The activities of the University of Eldoret involved the designing and testing of small-scale low-cost aquaponics system that can be used for training and extension. This system is specifically suitable for small-scale fish hobbyists in water deficient situations and urban/semi urban areas where land is scarce. The small-scale was developed and its efficiency assessed using different fish stocking densities. The small-scale aquaponic system consisted of a rectangular fish culture tank rising to 460 mm from the bottom and a plant bed rising to 270 mm from a raised platform, both units being arranged in a vertical tier. Water overflow from the fish unit was passed through a bio-filter made of shredded plastic material to increase the surface area. These units acted as a nitrification chamber before the water was flowed by gravity into the plant beds. The effluent water from the plant beds was pumped back to the fish tank units using a submersible lift pump for the small-scale system as shown in the appendices. Water discharge from the plant unit flows back to the fish unit by gravity thereby elimination the need for double pumping in the small-scale system. The prototype units were constructed at University of Eldoret and were tested using all male tilapia (*Oreochromis niloticus*) fry for 42-105 days to the fingerling and juvenile stages. Results from the trial show that fish stocking density has an effect on the nutrient budget of the system. High nitrate content in the fish unit was associated with high stocking density of 80 fish per tank as compared to 60 Fish per tank for the small-scale system and 150 kg as compared to 100 kg in the medium-scale system. The nitrification unit exhibited high efficiency since ammonia was not detected in the plant beds in both systems. Quantities of ammonia detected in the fish tanks after 35 days was close to the target values of zero. All-important water quality parameters for both the aquaponic systems such as DO, pH, alkalinity and Temperature were within optimum values. The results facilitated the development of a moderate-scale aquaponic system that was tested in the field in collaboration with local farmers though they preferred to use the African catfish and kales due to personal preferences. It is concluded that the systems is viable and self-regulating in terms of nitrogen cycle. The only limiting factor is the provision of other nutrients required for plant growth by supplemental fertilization. Farmers have opted to overcome nutrient limitations in the plant beds by adopting gravel plant bed units instead of floating rafts. This report provides both design specifications and technical drawings of the aquaponics system developed during this activity. The unit offers good opportunities for rapid commercialization by the private entrepreneurs but there is need to improve on energy requirement through solar technology.

INTRODUCTION

Millions of people around the world find a source of income and livelihood in the fisheries and aquaculture sector. Recent estimates indicate that 58.3 million people were engaged in the primary sector of capture fisheries and aquaculture in 2012 (Somerville et al. 2014). Fisheries and aquaculture play important roles in providing food and income in many developing countries, either as a stand-alone activity or in association with crop agriculture and livestock rearing. The harvest, sale and processing of fish contribute indirectly to food security by increasing purchasing power at individual or household level, nationally and also regionally. Demand for fish as source of protein is expected to

increase substantially, at least in line with other animal-based food products, particularly in South and South-East Asia (Allison et al. 2015).

Current global per-capita supply of fish is 17 kg per year; nearly half of this supply comes from aquaculture (Somerville et al. 2014). The availability of fish is unevenly distributed, with supply constraints faced by some undernourished populations in developing countries with high dependence on fish, particularly in sub-Saharan Africa, the least developed countries of South and South East Asia, and small island states in the Pacific Ocean (Allison et al. 2015; Frediani 2011).

There is growing need for innovative production methods to enhance production of fish from the wild and through technology-enhanced aquaculture. Aquaponics, the integrated culture of fish and other aquatic organisms with plants is one such technology which has gained considerably mileage in areas with water scarcity. However, this technology remains largely un-tapped in Kenya and much of Africa.

The potential of an opportunity for Aquaponics are several and includes: its contribution to community transformation, Aquaponics industry development, industrial change and development and the implementation of policies and programs on food security, technology and income generation within many economic contexts in Sub-Sahara Africa. Though it has a great potential for Kenya and other developing countries, Aquaponics is a young science and the development of newer technology in the field is still progressing (IBM Report 2011).

Aquaponics describes the combination of two principal growing processes working in harmony to deliver one, self-sustained and ecologically balanced culture system; aquaculture and hydroponics. Aquaculture component involves farming of aquatic animals, in controlled marine or fresh water environments. The hydroponics component involves growing edible plants within the unit. The idea is to combine these techniques together within the same system, so that the positives of both are multiplied and negatives of each are minimized by each unit.

The integrated system of aquaponics has benefits not achievable when aquaculture and hydroponics are applied separately (Timmons and Ebeling 2010). In fact existing production units have demonstrated that aquaponics permits the producer to be more efficient with water, energy, and to protect the crops from soil borne diseases. Furthermore, aquaponics can bring a new approach to the sustainability of landscapes, urban agriculture and the sustainability of cities by turning wastes into resources and transforming disused urban spaces to provide not only food, but resilient resilience to many possible livelihood shocks (Price 2009).

Theoretically, the nutrient content of a diet used in aquaponics can be manipulated to make the relative proportions of nutrients excreted by fish more similar to the relative proportions of nutrients assimilated by the plant component. There must then be an optimal fish to plant ratio, however, this ratio depends on the plant and fish and often requires experimentation to determine (Price 2009; Singh *et al.* 1999). This project therefore aimed at investigating the performance of Nile tilapia (*Oreochromis niloticus*) under an aquaponics system as a means to increase productivity and control the usually harmful effects of waste water from the traditional aquaculture systems.

OBJECTIVES
1. Design a small-scale aquaponic system for educational purposes and hobby production of fish and vegetables.
2. Construct a small-scale system to develop proof of concept and training.

MATERIALS AND METHODS

The study was conducted at the University of Eldoret at the hatchery unit. The experimental protocol involved the growth trials of all monosex *Oreochromis niloticus* fry for 5 weeks to attain the fingerlings stage with lettuce in the hydroponics system. All the fry were obtained from Sagana National Aquaculture Research and Development Centre (NARDC). The second study was conducted in a greenhouse with the medium-scale aquaponic system.

Design of small-scale and medium-scale aquaponic systems
Preparation of floating Styrofoam
Styrofoam of dimensions 1m x 0.5m x 0.03m (length, width and thickness) were used. Each Styrofoam sheet had 8 evenly drilled holes of diameter 4 cm. The sheets were placed on in the hydroponic system. This is where the plants were anchored. Each of the drilled holes had a plastic plant pot which was used to support and suspend the plants. The pots had 6-9 open strips to allow plant roots to freely develop and tap the nutrients.

Source of plants
Lettuce seeds used in this experiment were sourced from a reputable agro vet shop in Eldoret. The seeds were then planted in plastic trays placed in a greenhouse. The seeds were carefully inserted in wet cotton sheets to allow them germinate. After 8 days all the seeds germinated. The germinated plants were immediately introduced into nursery hydroponic system units where they grew and developed roots fully for a period of 7 more days. All the healthy plants with well-developed roots were uprooted and planted in the in the rafts.

Experimental design
The study was done using completely randomized design (CRD). Nine tanks of 100 L were used during this experiment. Two aquaponic treatments were each stocked with Monosex Nile tilapia fry at stocking densities of 60 fry/tank and 80 fry/tank, respectively, and replicated four times. Each treatment was subjected to lettuce plants from the University of Eldoret Horticulture Department at a density of plants 16 per m2.

Experimental setup
The experiment to test the aquaponics system was set up using a randomized block design as outlined in Table 1. The hydroponic unit consisting of the plant beds was independently attached to each of the fish tanks.

Table 1. Experimental setup: treatments

Tank and Stocking Density		Tank and Stocking Density		Tank and Stocking Density	
Tank 1 =	80 Fish	Tank 2 =	60 Fish	Tank 3 =	80 Fish
Tank 4 =	60 Fish	Tank 5 =	80 Fish	Tank 6 =	60 Fish
Tank 7 =	80 Fish	Tank 8 =	80 Fish	Tank 9 =	60 Fish

Feed preparation
The fingerlings were fed with locally formulated feeds of crude protein 30%. The constituents of the feed used included wheat bran, rice polish, *Rastrineobola argentea* fish meal, and cottonseed cake. The sun-dried *R. argentea* were bought from Kisumu market. All ingredients was ground individually into fine powder using an electrical grinding mill, measured in the respective proportions then mixed and subjected to proximate analysis. The proximate analysis was determined at the University of Eldoret Fisheries laboratory following procedures described by AOAC (1984). Equal proportions of sunflower oil and cod liver oil (1:1) were added as lipid source in the test diets.

Data collection: *Water quality*
Data for dissolved oxygen, pH and temperature were collected daily in the recirculating fish rearing tank, hydroponic tank and lastly the sump. Once a week the nutrient load in the three main sections of the system was also be monitored and recorded. Parameters checked were ammonia, nitrates, dissolved oxygen pH, and temperature. This was done using water test kits, YSI DO and temperature Meter (Y540) and pH meter Y333.

Nitrates and Ammonia were analyzed using the following procedures respectively:
i) An EPA and ASTM approved and preferred method for estimating nitrate in water is the Strickland and Parsons (1968) Cadmium Column Reduction Method.
ii) Ammonia by direct nesslerization (APHA, AWWA, WEF 2012).

Fish growth
Random samples of 30% fish stocked in each tank were taken from each of the nine tanks for weight and length measurement after every week. On the first sampling occasion the fry were weighed together on an electronic balance (readability 0.01 mg, model VI-200) and average weight computed. The lengths of each fry were then measured using a meter rule to the nearest 0.1 mm.

Plant data collection
Plant height: After every three days the height of individual plants was measured in centimeters. The height was from the Styrofoam surface to the top of the main plant stem. Leaf numbers -- the number leaves of leaves for each plant were counted. The tips of newly emerging plants was also counted and recorded.

Leaf length: The lengths of individual leaves were measured in centimeters. The length was from the base of the leaf to the tip of the leaves. The width of individual leaves was also taken and recorded.

Data analysis
The general water quality parameters -- dissolved oxygen, pH, temperature and alkalinity -- were subjected to 2-sample t-test among treatments. Treatments were the different fish stocking densities per tank (80 Fish/T and 60 Fish/T).

The amount of Nitrates in the fish rearing unit and in the plant rearing units over time were compared using regression slopes with treatments as factors. Ammonia concentrations were also compared over time, using regression among treatments as factors for the fish tank only since it was not detectable in the plant rearing units.

Fish growth in length and plant growth in height against time were compared using regression slopes among treatments on assumption of linear relationship for fry-fingerling growth phase and plant height. The slopes provided an indication of growth rate between the 80 Fish/T and 60 Fish/T treatments for fish as well as for plants respectively.

Lastly, a Neural Network Bayesian classifier was used to verify the robustness of the results by classifying all the observations according to treatment and using Nitrates, Ammonia and Alkalinity as factors in the model.

RESULTS
General water quality parameters for aquaponics
The critical water parameters in the aquaponics system; Dissolved Oxygen, Temperature, pH and Alkalinity were not significantly different on a weekly basis nor were they significantly different throughout the experiment (Table 2).

Table 2. Mean±SE of general water quality parameters required for balancing aquaponics system taken over the experimental period.

Time (Weeks)	60 Fish	80 Fish	2-Sample t-test
		Dissolved Oxygen	
Week 1	4.24±0.488	5.10±0.442	$t_{0.05,8}$ = 0.406499; p-value = 0.69
Week 2	5.25±0.266	5.45±1.001	$t_{0.05,8}$ = -0.147370; p-value = 0.88
Week 3	5.09±0.386	5.17±0.871	$t_{0.05,8}$ = -0.136778; p-value = 0.89
Week 4	5.47±0.464	5.33±0.776	$t_{0.05,8}$ = 0.406499; p-value = 0.69
Week 5	4.97±0.283	5.37±0.888	$t_{0.05,8}$ = 0.034579; p-value = 0.97
		Temperature	
Week 1	17.73±0.131	17.66±0.254	$t_{0.05,8}$ = 0.349459; p-value = 0.73
Week 2	18.45±0.240	18.28±0.260	$t_{0.05,8}$ = 0.143007; p-value = 0.89
Week 3	18.18±0.197	17.70±0.184	$t_{0.05,8}$ = -0.445821; p-value = 0.66
Week 4	17.85±0.240	17.78±0.237	$t_{0.05,8}$ = 0.349459; p-value = 0.73
Week 5	18.23±0.149	17.68±0.193	$t_{0.05,8}$ = -0.391346; p-value = 0.70
		pH	
Week 1	8.01±0.164	8.11±0.159	$t_{0.05,8}$ = -0.413396; p-value = 0.69
Week 2	8.15±0.169	8.51±0.231	$t_{0.05,8}$ = -1.211390; p-value = 0.26
Week 3	8.16±0.167	8.47±0.221	$t_{0.05,8}$ = -1.057100; p-value = 0.32
Week 4	8.06±0.111	8.16±0.194	$t_{0.05,8}$ = -0.426447; p-value = 0.68
Week 5	8.18±0.177	8.44±0.249	$t_{0.05,8}$ = -0.828957; p-value = 0.43
		Alkalinity	
Week 1	183.83±4.275	201.90±6.415	$t_{0.05,8}$ = -2.208160; p-value = 0.06
Week 2	192.25±8.138	201.64±6.366	$t_{0.05,8}$ = -0.924325; p-value = 0.38
Week 3	175.23±10.712	170.96±9.348	$t_{0.05,8}$ = 0.300927; p-value = 0.77
Week 4	175.33±10.765	177.76±8.696	$t_{0.05,8}$ = -0.178245; p-value = 0.86
Week 5	175.28±10.679	194.84±8.680	$t_{0.05,8}$ = -1.439040; p-value = 0.19
		Individual Parameters	
Dissolved Oxygen	5.66±0.598	5.5472±0.603	$t_{0.5,43}$ = 0.2715090; p-value = 0.78
Temperature	20.94±0.280	20.928±0.325	$t_{0.5,43}$ = 0.0797688; p-value = 0.93
pH	8.11± 0.136	8.3384±0.193	$t_{0.5,43}$ = -1.897030; p-value = 0.06
Alkalinity	180.38±8.368	189.42±8.615	$t_{0.5,43}$ = -1.536880; p-value = 0.13

Nitrate in fish tanks

The output shows the results of fitting a linear regression model to describe the relationship between Nitrate, Days and Treatment in the fish tanks. The equation of the fitted model is:

$$Nitrate = 75.3 - 1.09 \times Days + 21.71 \times (Treat = 80\ Fish) - 0.62 \times Days \times (Treat = 80\ Fish)$$

Where the terms similar to Treatment=80 Fish are indicator variables which take the value 1 if true and 0 if false. This corresponds to 2 separate lines, one for each value of Treatment. For example, when Treatment=60 Fish, the model reduces to:

$$Nitrate = 75.3 - 1.09 \times Days$$

When treatment=80 fish, the model reduces to:

$$Nitrate = 97.0 - 1.71 \times Days$$

Because the p-value in the ANOVA table ($F_{0.5,3,41}$=344.3; p-value<0.00005), was less than 0.05, there was a statistically significant relationship between the variables at the 95.0% confidence level

(Table 3). The R-Squared statistic indicates that the model as fitted explains 96.2% of the variability in Nitrate.

The adjusted R-Squared statistic, which is more suitable for comparing models with different numbers of independent variables, was 95.9%. The mean absolute error (MAE) was 2.5 and is the average value of the residuals. The Durbin-Watson (DW) statistic used tests the residuals to determine any significant correlation based on the order in which they occur in the data file was 1.4 (p-value=0.0045) showing that there is no indication of possible serial correlation at the 95.0% confidence level.

Table 3. ANOVA for regression of nitrates on time by treatment in fish unit.

Source	Sum of Squares	df	Mean Square	F-Ratio	p-value
Model	10331.1	3	3443.69	344.27	0.00005
Residual	410.115	41	10.0028		
Total (Corr.)	10741.2	44			

R-Squared = 96.18 percent   R-Squared (adjusted for d.f.) = 95.9 percent
Standard Error of Est. = 3.162   Mean absolute error = 2.448
Durbin-Watson statistic = 1.391 (P=0.0048)   Lag 1 residual autocorrelation = 0.299

Statistical test ($F_{0.5,1,3}$=344.3; p-value<0.00005) show that the slopes for treatment were statistically significant at 99% confidence level because the p-value for the slopes is less than 0.01. Because the p-value for the intercepts is less than 0.01, there are statistically significant differences among the intercepts for the various values of Treatment at the 99% confidence level (Table 4 and Figure 1).

Table 4. ANOVA for variables in the order fitted for regression of nitrates on time by treatment in the fish unit.

Source	Sum of Squares	df	Mean Square	F-Ratio	p-value
Days	9080.18	1	9080.18	907.76	0.00005
Intercepts	829.44	1	829.44	82.92	0.00005
Slopes	421.467	1	421.467	42.13	0.00005
Model	10331.1	3			
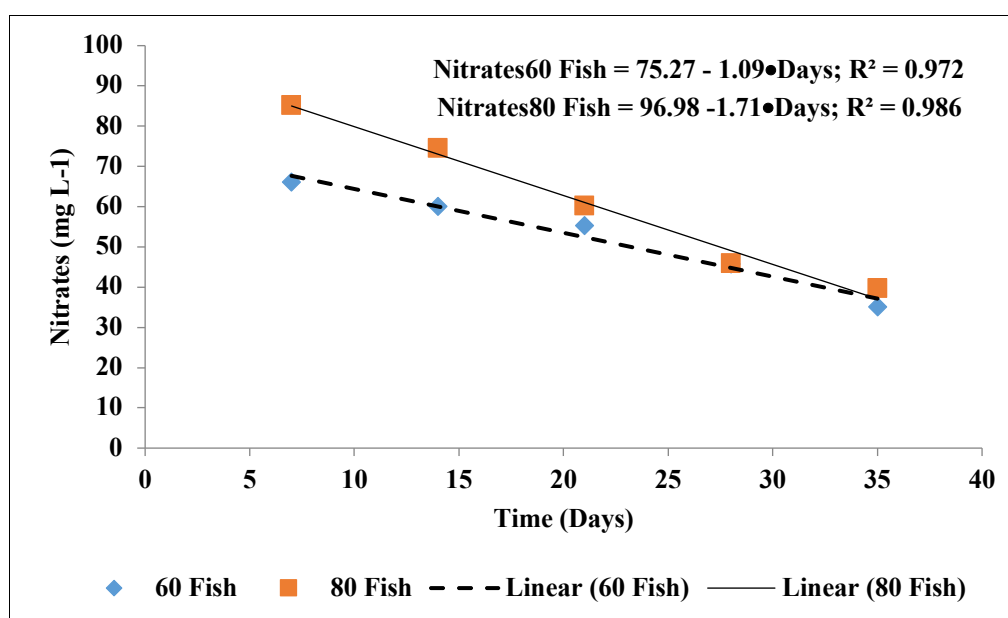
Figure 1. Nitrate concentration in the fish rearing tanks during the experimental period showing a decline for both treatments.

Nitrate in Hydroponic Units

The output shows the results of fitting a linear regression model to describe the relationship between Nitrate, Days and Treatment in the hydroponics tanks. The equation of the fitted model is:

$$Nitrate = 0.20475 - 0.00068 \times Days + 0.34125 \times (Treat = 80 \; Fish) - 0.004521 \times Days \times (Treat = 80 \; Fish)$$

Where the terms similar to Treatment=80 Fish are indicator variables which take the value 1 if true and 0 if false. This corresponds to 2 separate lines, one for each value of Treatment. For example, when Treatment=60 Fish, the model reduces to:

$$Nitrate = 0.20475 - 0.00068 \times Days$$

When Treatment=80 Fish, the model reduces to:

$$Nitrate = 0.546 - 0.0052 \times Days$$

Because the p-value in the ANOVA table (F0.5,3,41=62.7; p-value<0.00005), was less than 0.05, there was a statistically significant relationship between the variables at the 95.0% confidence level. The R-Squared statistic indicates that the model as fitted explains 82.1% of the variability in P-Nitrate. The adjusted R-Squared statistic, which is more suitable for comparing models with different numbers of independent variables, was 80.8%. The mean absolute error (MAE) was 0.063 and is the average value of the residuals. The Durbin-Watson (DW) statistic used tests the residuals to determine any significant correlation based on the order in which they occur in your data file was 1.93 (p-value=0.24) show that there is an indication of possible serial correlation at the 95.0% confidence level (Table 5).

Table 5. ANOVA in regression of nitrates on time by treatment in plant unit.

Source	Sum of Squares	df	Mean Square	F-Ratio	p-value
Model	0.74	3	0.2471	62.65	0.00005
Residual	0.16	41	0.0039		
Total (Corr.)	0.90	44			

R-Squared = 82.09 percent   R-Squared (adjusted for d.f.) = 80.78 percent
Standard Error of Est. = 0.062   Mean absolute error = 0.0498378
Durbin-Watson statistic = 1.933 (p-value=0.24)   Lag 1 residual autocorrelation = 0.029

Statistical test (F$_{0.5,1,3}$=5.64; p-value<0.02) show that the slopes for treatment were statistically significant at 95% confidence level because the p-value for the slopes is less than 0.05 (Table 6).

Table 6. ANOVA for variables in the order fitted for regression of nitrates on time by treatment in the plant unit.

Source	Sum of Squares	df	Mean Square	F-Ratio	p-value
Days	0.04489	1	0.04489	11.38	0.0016
Intercepts	0.67404	1	0.67404	170.92	0.00005
Slopes	0.02226	1	0.02226	5.64	0.0223
Model	0.74119	3			
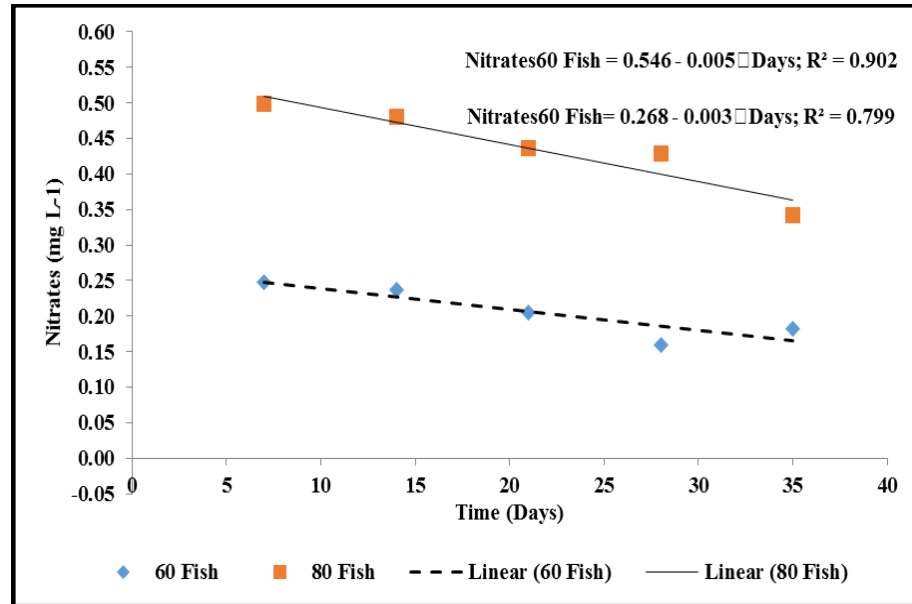
Figure 2. Nitrate concentration in the plant rearing tanks during the experimental period showing a decline for both treatments.

Ammonia in fish tanks

The output shows the results of fitting a linear regression model to describe the relationship between Ammonia, Days and Treatment in the fish tanks. The equation of the fitted model is:

$$Amm = 0.0027 - 0.0000087 \times Days + 0.0175 \times (Treat = 80\ Fish) - 0.00061 \times Days \times (Treat = 80\ Fish)$$

Where the terms similar to treatment=80 fish are indicator variables which take the value 1 if true and 0 if false. This corresponds to 2 separate lines, one for each value of Treatment. For example, when Treatment=60 Fish, the model reduces to:

$$Amm = 0.0027 - 0.000087 \times Days$$

When Treatment=80 Fish, the model reduces to

$$Amm = 0.0202 - 0.0007 \times Days$$

Because the p-value in the ANOVA table ($F_{0.5,3,41}=11.6$; p-value<0.00005), was less than 0.05, there was a statistically significant relationship between the variables at the 95.0% confidence level. The R-Squared statistic indicates that the model as fitted explains only 45.91% of the variability in ammonia. The adjusted R-Squared statistic, which is more suitable for comparing models with different numbers of independent variables, was 41.95%.

The MAE was 0.0065 and is the average value of the residuals. The DW statistic used tests the residuals to determine any significant correlation based on the order in which they occur in your data file was 0.764 (p-value<0.00005) show that there is an indication of possible serial correlation at the 95.0% confidence level (Table 7).

Table 7. ANOVA for regression of ammonia on time by treatment in fish unit.

| Source	Sum of Squares	df	Mean Square	F-Ratio	p-value
Model	0.00145539	3	0.000485129	11.60	<0.00005
Residual	0.00171476	41	0.0000418234		
Total (Corr.)	0.00317014	44			

R-Squared = 45.90 percent R-Squared (adjusted for d.f.) = 41.95 percent
Standard Error of Est. = 0.006 Mean absolute error = 0.003
Durbin-Watson statistic = 0.763 (p-value<0.00005) Lag 1 residual autocorrelation = 0.612

Statistical test ($F_{0.5,1,3}$=344.3; p-value=0.003) show that the slopes for treatment were statistically significant at 99% confidence level because the p-value for the slopes is less than 0.01. Because the p-value for the intercepts is less than 0.05, there are statistically significant differences among the intercepts for the various values of Treatment at the 95% confidence level (Table 8 and Figure 3).

Table 8. ANOVA for variables in order fitted for regression of ammonia on time by treatment in the fish unit.

Source	Sum of Squares	df	Mean Square	F-Ratio	P-Value
Days	0.000807404	1	0.000807404	19.31	0.0001
Intercepts	0.000237653	1	0.000237653	5.68	0.0218
Slopes	0.00041033	1	0.00041033	9.81	0.0032
Model	0.00145539	3			

$\text{Ammonia}_{80\ Fish} = 0.0027 - 0.0000087 \cdot \text{Day}; R^2 = 0.960$
$\text{Ammonia}_{60\ Fish} = 0.0202 - 0.0007 \cdot \text{Days}; R^2 = 0.803$
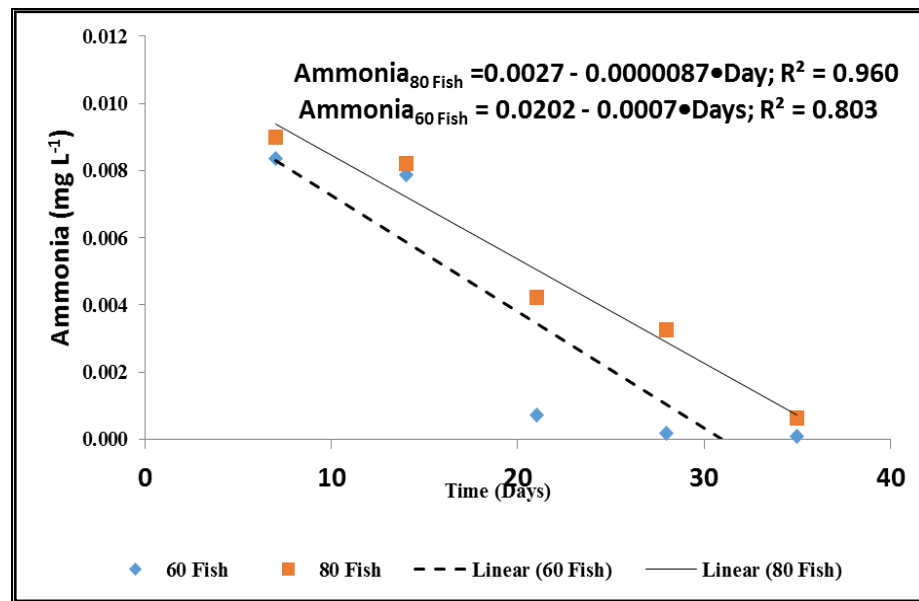
Figure 3. Nitrate concentration in the plant rearing tanks during the experimental period showing a decline for both treatments.

Fish growth in length

The output shows the results of fitting a linear regression model to describe the relationship between Fish Length, Days and Treatment in the fish tanks. The fitted model equation is:

$$Length = 3.24 + 0.83 \times Days + 2.1 \times (Treat = 80\ Fish) - 0.23 \times Days \times (Treat = 80\ Fish)$$

Where the terms similar to Treatment=80 Fish are indicator variables which take the value 1 if true and 0 if false. This corresponds to 2 separate lines, one for each value of Treatment. For example, when Treatment=60 Fish, the model reduces to:

$$Length = 3.24 + 0.83 \times Days$$

When Treatment=80 Fish, the model reduces to:

$$Length = 5.33 + 0.60 \times Days$$

Because the p-value in the ANOVA table ($F_{0.5,3,41}$=399.46; p-value<0.00005), was less than 0.05, there was a statistically significant relationship between the variables at the 95.0% confidence level. The R-Squared statistic indicates that the model as fitted explains only 96.69% of the variability in ammonia. The adjusted R-Squared statistic, which is more suitable for comparing models with different numbers of independent variables, was 96.5%.

The MAE was 1.18 and is the average value of the residuals. The DW statistic used tests the residuals to determine any significant correlation based on the order in which they occur in the data was 0.631 (p-value<0.00005) show that there is an indication of possible serial correlation at the 95.0% confidence level (Table 9).

Table 9. ANOVA for variables in the order fitted for regression

Source	Sum of Squares	df	Mean Square	F-Ratio	P-Value
Model	2326.44	3	775.481	399.46	<0.00005
Residual	79.5947	41	1.94134		
Total (Corr.)	2406.04	44			

R-Squared = 96.69 percent   R-Squared (adjusted for d.f.) = 96.44 percent
Standard Error of Est. = 1.393   Mean absolute error = 1.178
Durbin-Watson statistic = 0.630 (p-value<0.00005)   Lag 1 residual autocorrelation = 0.655

Statistical test ($F_{0.5,1,3}$=30.68; p-value<0.00005) show that the slopes for treatment were statistically significant at 99% confidence level because the p-value for the slopes is less than 0.01. Because the p-value for the intercepts is less than 0.01, there are statistically significant differences among the intercepts for the various values of Treatment at the 99% confidence level (Table 10 and Figure 4).

Table 10. ANOVA for variables in the order fitted.

Source	Sum of Squares	df	Mean Square	F-Ratio	P-Value
Days	2178.77	1	2178.77	1122.31	<0.00005
Intercepts	88.1095	1	88.1095	45.39	<0.00005
Slopes	59.5613	1	59.5613	30.68	<0.00005
Model	2326.44	3			
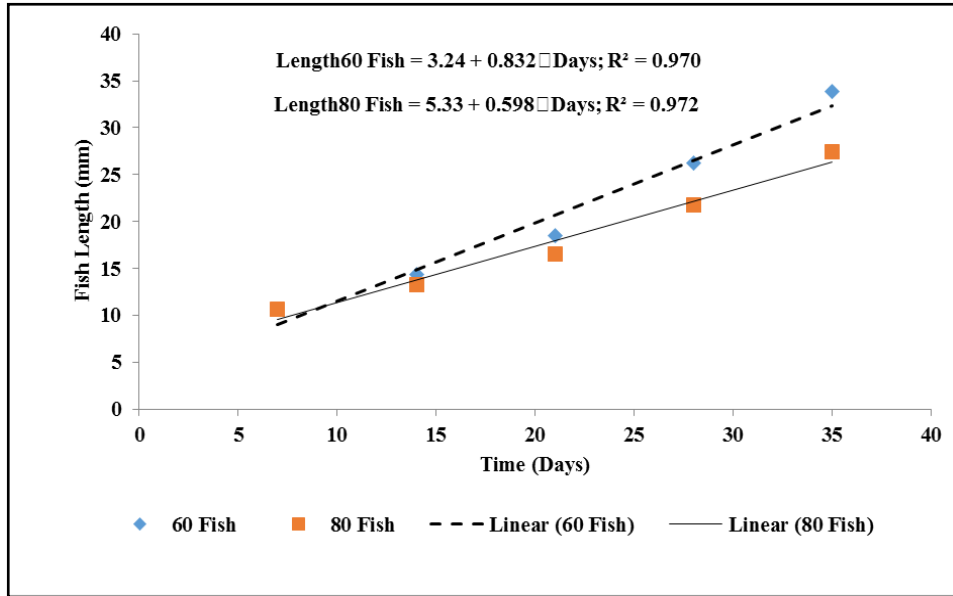
Figure 4. Size variation in length (mm) of monosex *O. niloticus* fry with time and treatment.

Growth in plants

The output shows the results of fitting a linear regression model to describe the relationship between Plant Height, Days and Treatment in the fish tanks. The equation of the fitted model is:

$$Height = 12.12 + 0.97 \times Days - 9.76 \times (Treat = 80\ Fish) + 1.46 \times Days \times (Treat = 80\ Fish)$$

Where the terms similar to Treatment=80 Fish are indicator variables which take the value 1 if true and 0 if false. This corresponds to 2 separate lines, one for each value of Treatment. For example, when Treatment=60 Fish, the model reduces to:

$$Height = 12.12 + 0.97 \times Days$$

When Treatment=80 Fish, the model reduces to:

$$Height = 2.36 + 2.43 \times Days$$

Because the p-value in the ANOVA table ($F_{0.5,3,41}=177.77$; p-value<0.00005), was less than 0.05, there was a statistically significant relationship between the variables at the 95% confidence level. The R-Squared statistic indicates that the model as fitted explains only 92.9% of the variability in ammonia. The adjusted R-Squared statistic, which is more suitable for comparing models with different numbers of independent variables, was 92.3%. The MAE was 3.39 and is the average value of the residuals. The DW statistic used tests the residuals to determine any significant correlation based on the order in which they occur in your data file was 2.62 (p-value=0.955) show that there is no indication of possible serial correlation at the 95.0% confidence level (Table 11).

Table 11. ANOVA for variables in the order fitted for regression

Source	Sum of Squares	df	Mean Square	F-Ratio	P-Value
Model	21215.1	3	7071.69	177.77	<0.00005
Residual	1630.94	41	39.7789		
Total (Corr.)	22846.0	44			

R-Squared = 92.86 percent	R-Squared (adjusted for d.f.) = 92.3 percent
Standard Error of Est. = 6.30705	Mean absolute error = 3.38738
Durbin-Watson statistic = 2.62124 (p-value=0.9551)	Lag 1 residual autocorrelation = -0.315011

Statistical test ($F_{0.5,1,3}$=58.36; p-value<0.00005) show that the slopes for treatment were statistically significant at 99% confidence level because the p-value for the slopes is less than 0.01. Because the p-value for the intercepts is less than 0.01, there are statistically significant differences among the intercepts for the various values of treatment at the 99% confidence level (Table 12 and Figure 5).

Table 12. ANOVA for variables in the order fitted for regression

Source	Sum of Squares	df	Mean Square	F-Ratio	P-Value
Days	14038.8	1	14038.8	352.92	<0.00005
Intercepts	4854.9	1	4854.9	122.05	<0.00005
Slopes	2321.42	1	2321.42	58.36	<0.00005
Model	21215.1	3			
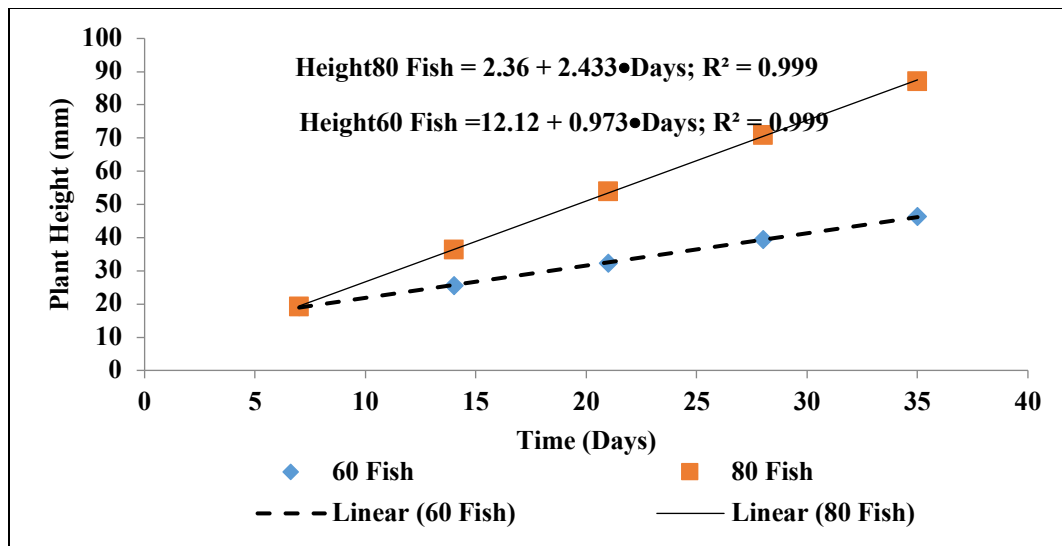
**Figure 5.** Size variation in height (mm) of lettuce with time and treatment.

Neural network Bayesian classifier for treatment

Four input factors; Nitrates in the fish tanks (F-Nitrate), ammonia in the fish tanks (Ammonia), Nitrates in the hydroponics units (Nitrate), and alkalinity, and using a probabilistic neural network (PNN) classified 100% of the treatment cases correctly. The best architecture for the network was 4-45-2-2 (Figure 6).
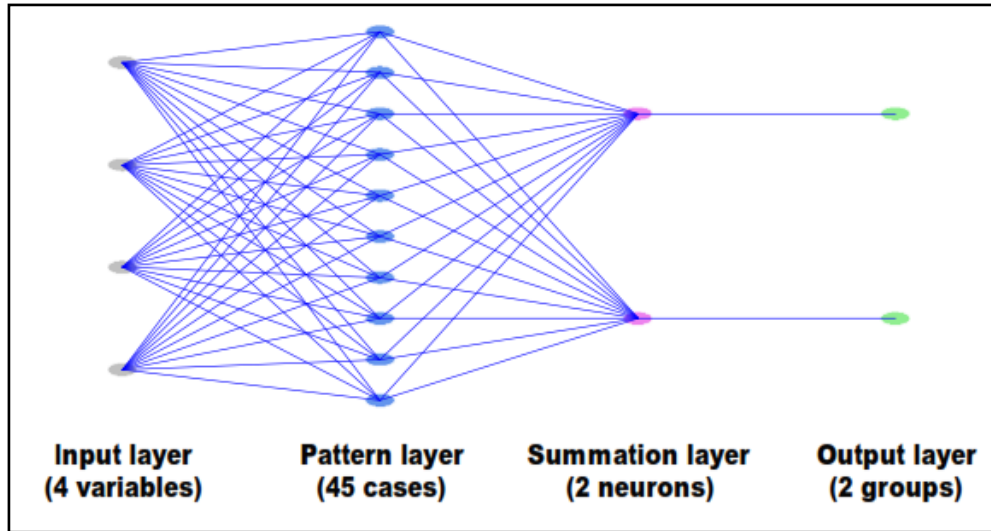
Figure 6. ANN Bayesian classifier 4-45-2-2 architecture for the treatment in the aquaponics system.

A constructed scatter plot of nitrates in the fish tanks and hydroponics units and ammonia in the fish tanks show relatively low values of all these parameters in the 60 Fish/T as compared to 80 Fish/T treatment (Figure 7).
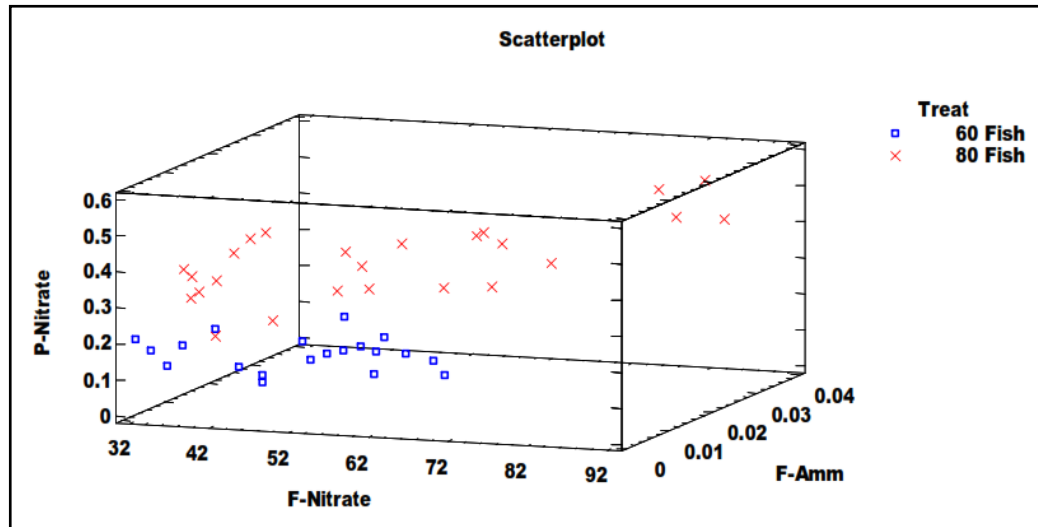
Figure 7. Scatter plot of nitrates and ammonia concentrations in the aquaponics system.

CONCLUSION

The theoretical concept in an aquaponics system is to convert the ammonia (NH_3) in fish waste into nitrite (NO_2-). Then nitrite (NO_2-) is transformed into nitrate (NO_3-) to be used in the plant bed (Somerville et al. 2014).

There are two major groups of nitrifying bacteria involved in the nitrification process: i) Ammonia Oxidizing Bacteria (AOB) that converts Ammonia (NO_3) to nitrate (NO_2-), commonly the genus Nitrosomonas and ii) Nitrite Oxidizing Bacteria (NOB) converts nitrite (NO_2-) to nitrate (NO_3-), commonly the genus Nitrobacter. Since the aquaponics system is totally reliant on the bacteria and the nitrogen cycle, the present study measures and analyzes these dimensions of nitrogen in both the aquaculture and the hydroponics units.

Main findings Since the values of dissolved oxygen were within the expected (4 - 8 mg L-1), nitrates also were in the expected range (<400 mg L-1), temperatures were 20.93±0.33 to 20.94 ±0.28 °C. The alkalinity target is 60-140 mg L-1, so it can be concluded that the water quality balance was within the conducive range for an aquaponics system.

The nitrate levels is expected to be 5 to 150 mg L-1 and in the current study, values obtained in both the aquaculture and hydroponics were ranging between 30 and 90 mg L-1 and between 0.15 and 0.55 mg L-1 respectively, it can be concluded that the system was optimized with the present levels of stocking, feeding and flow rate. The slightly high levels of nitrate in the aquaculture unit can be attributed to feed inputs. Although both treatments seemed to be efficient, there was initially higher levels of nitrates in the aquaculture unit but the concentration declined at a faster rate in the 80 Fish/T treatment (b=1.71) as compared to 60 Fish/T (b=1.09). This difference can be attributed to the differences in the amount of feed and feed utilization. Similarly in the hydroponics unit, there were slightly higher level of nitrates indicating the impact of external inputs to the fish tanks, assuming equal efficiency in the nitrification unit or biofilter.

Ammonia levels of below 0.01 mg L-1 can be considered as negligible in view of the time required for an aquaponic system to stabilize. In this study, ammonia was undetectable in the hydroponic unit and this observation has led to the belief that the nitrification system performed optimally in both treatments.

Significant differences in fish growth could be attributed to space and stocking density rather than the performance of the aquaponics system. Since 60 Fish/T grew at a faster rate than 80 Fish/T, stocking density has to be adjusted for the present prototype. The overall growth was considered adequate since monosex *O. niloticus* fry were raised to fingerlings of about 4 cm in 4-5 weeks. In practice, tilapia fingerling producers in Kenya take about the same time to raise fingerlings in hapas at relatively elevated temperatures of 24 °C as compared to 20.9 °C in this study.

The high nutrient (nitrate) in the 80 Fish/T (b=2.43) treatment is adequately reflected in significantly better plant growth as compared to 60 Fish/T (b=0.97). The preliminary results hence provide an indication of the potential to produce fish and crops using this system.

The study constructed an Artificial Neural Network Bayesian Classifier (ANN-B Classifier) to validate the impact of nitrates, ammonia and alkalinity as factors associated with the two treatments. This validation approach allows simulation of input factors to predict new observations. Even though the predictive ability of ANN-B Classifier is rare in biological sciences, it offers a more robust data grouping method than the conventional Discriminant Function Analysis (DFA) and Multi-Dimensional Scaling (MDS).

Main understandings-Based on the results in the study, it is concluded that:
i. The prototype aquaponics system developed in this study can be used to raise both fish and crops within the tropical setup and especially in water deficient East Africa.
ii. A single unit is presented in the report to show the basic design for small scale production when 2 to 5 units are connected in series or in parallel. Medium-scale production system involves connecting a series of the units in parallel or in series. The dynamics of the medium-scale system is kept at equilibrium by maintaining the measurements and specification of the single units.
iii. The nitrate nutrient cycle in the system is balanced and optimized for efficiency, assuming some critical water quality parameters are controlled.
iv. Both fish and horticultural crops had satisfactory growth performance in the prototype aquaponics system developed during this study.

v.   The biofilter system developed in the study is capable of efficient nitrification to provide required nitrates for the plant bed.

QUANTIFIED ANTICIPATED BENEFITS

This project has been instrumental in the following ways:

i.   One Ph.D. student has used the opportunity to collect preliminary data for his thesis hence contributing to knowledge on this un-explored opportunity for aquaculture in water deficient areas and land limiting urban/semi urban areas.

ii.   The Aquaponics Project has used feeds formulated and processed by a M.Sc. Student working on fish feeds for juvenile tilapia (*O. niloticus*) and hence complemented the testing of on-farm formulated feeds.

iii.   The demonstration unit was in a high visibility location and received attention from faculty, staff, students, and local area farmers. We expect that at least 200 individuals observed the workings of the unit. The fish and vegetables produced were consumed by students or sold to generate funds for student activities.

iv.   The unit was for farmers who have ponds and wish to use the nutrient enriched water to irrigate field and vegetable crops. We document the increased levels of nitrogen that can contribute to fertilizing plants and reducing the costs for chemical fertilizers for farmers.

ACKNOWLEDGMENTS

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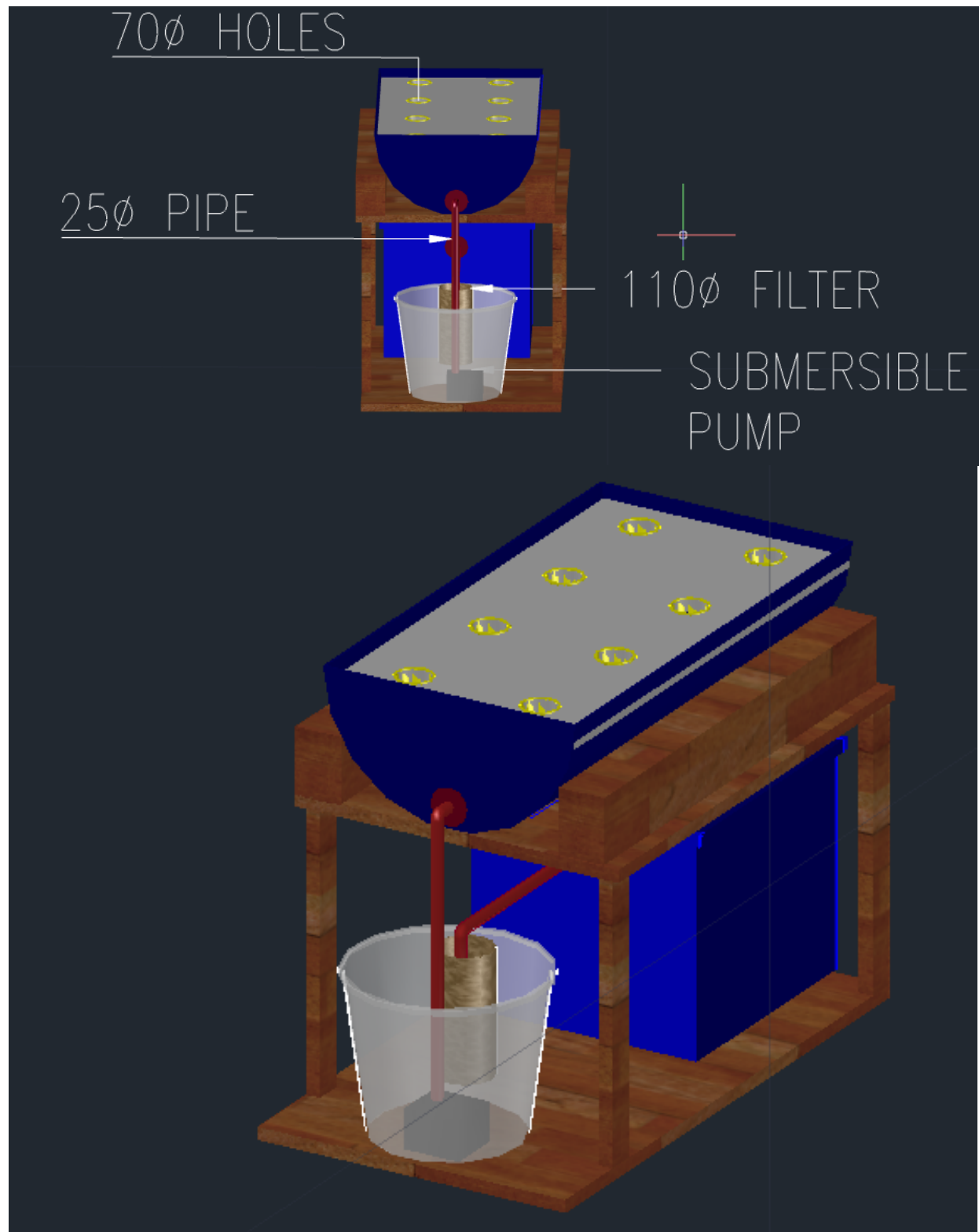
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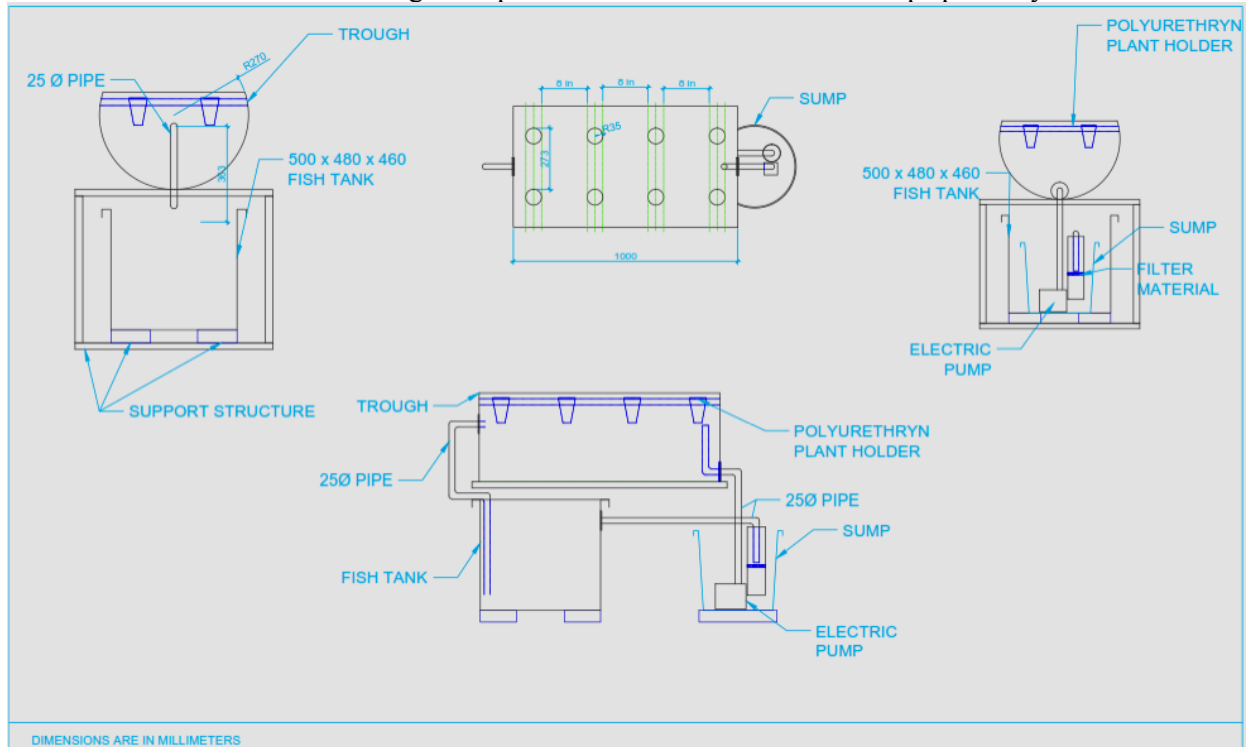
ADDITIONAL FIGURES

Prototype of Small-Scale Aquaponics Design and Specifications

70∅ HOLES

25∅ PIPE

110∅ FILTER

SUBMERSIBLE
PUMP
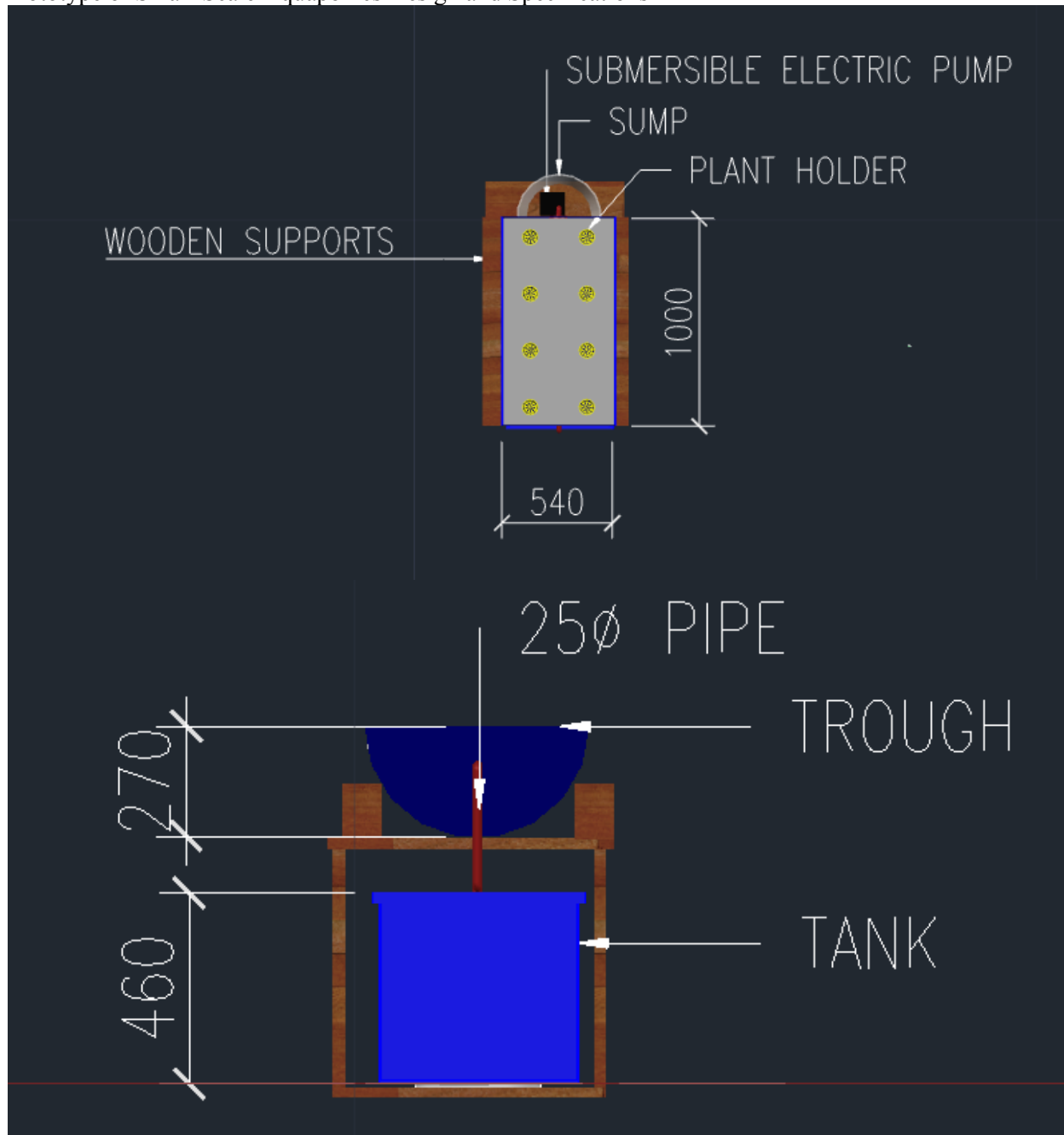
Cross Sectional Technical Drawing and Specifications of the Small-Scale Aquaponic System

DEVELOPMENT OF LOW-COST AQUAPONIC SYSTEMS FOR KENYA- PART II
DEVELOPMENT AND FIELD TRIAL OF MODERATE-SCALE LOW-COST AQUAPONICS SYSTEM FOR KENYA

Production System Design and Best Management Alternatives/Experiment/13BMA05AU

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ABSTRACT
A moderate-scale aquaponic system was designed and tested at the University of Eldoret (UoE) fish farm. The objective of designing this system was to demonstrate the concept and training but also offer an opportunity for extension and field trials. The moderate-scale aquaponic designed at the UoE had the capacity of about 200 kg of fish per circular tank and 120 kg fresh weight of vegetables from six floating raft plant beds. The system incorporated a vertical bio-filtration and nitrification unit and a sump operated by gravity flow. All the plant beds drained into a common underground sump through gravity. Complete circulation was achieved by using a primer pump to return purified water into the fish tanks through a gas exchange chamber.

Using trial data from the small-scale aquaponic system, the stocking density of fish and plants were optimized by proportion as well as the flow rate that was regulated by a venture valve to 20 L min-1 to the fish rearing tanks. Field trials were conducted with modified system using African catfish and a mixture of local vegetables, kales and spinach.

Both investment and production estimates were then used to prepare a partial enterprise budget for a single aquaponic system and feed input adjusted by an FCR or 1.5, 1.2 and 1.0 in order to determine the anticipated benefits of the system. Results show that the system can repay a loan within two 6 months growing cycles with a profit margin of 40% to 45% of the initial investment. The hydroponic unit for could be doubled or tripled without affecting the fish ponds due to the use of gravel bed instead of floating rafts.

INTRODUCTION
Many aquaponic systems are known to be efficient in utilization of nutrients (Richard et al. 2008; Wahyuningsih et al. 2015) as well as water conservation but also has its own challenges (Richard et al. 2011). Aquaponic systems are particularly useful in areas with water scarcity. When properly managed, aquaponic systems provide the advantages of both reducing water usage and effluent (Chanagun et al. 2015). Hu et al. (2015) stated that ammonia is firstly oxidized to nitrite by ammonia oxidizing bacteria and then converted to nitrate by nitrite oxidizing bacteria (mainly *Nitrobacter* spp. and *Nitrospira* spp.). Not enough bacteria in this aquaponic system possibly results in deteriorated water while too high bacteria could make fish prone to diseases.

According to Battina et al. (2016), aquaponics technology is applicable to a variety of situations including, commercial, community based urban food production, industrial scale production in rural areas, small scale farming in developing countries or as systems for education and decoration inside buildings. Trials using the University of Virgin Island (UVIA) Aquaponic system have shown that experimental results are usually not attained in field trials for plant yields (James et al. Undated Report).

OBJECTIVES
1. Design a moderate-scale aquaponic system for potential commercial application.
2. Construct a moderate-scale system to develop proof of concept and training.

METHODS

All the materials for design of the moderate-scale aquaponic system was purchased locally from the various hardware retail outlets and assembled at the University of Eldoret Hatchery area. The unit was then assembled within the existing greenhouse to address the issue of low temperatures for fish growth.

The following materials were necessary for assembling the system:
  i.   Two circular plastic tanks of capacity 10,000 L
 ii.   Concrete blocks for the plant units and pond liners
iii.   Styrofoam sheets
 iv.   Plastic drum (4) of capacity 100 L each to act as 2 vertical filtration units, a sump for feeding the plant beds and a sump for receiving water from the plant beds and subsequent pumping to a gas exchange chamber
  v.   Plastic drum of 200L capacity to act as a gas exchange chamber
 vi.   PVC Pipes of 2" for water reticulation and 4" drain pipe
vii.   Primer water pump of at least 6HP, 240V 50-60MHz frequency

The Design

The two circular plastic tanks were installed on a movable concrete base to receive water from the gas exchange chamber and each with an independent overflow into separate vertical filtration and nitrification chambers of 100L capacity each.

Both the vertical filtration units emptied into a common sump that fed the six plant beds through a reticulation system of pipes. Each plant bed was drained independently into a common underground sump from which the water was pumped back into the gas exchange chamber. Water from the gas exchange chamber was designed to flow by gravity. The design removed the necessity to have tow pumps and water flow through both the fish and plant units was by gravity (Figure 1 and 2).

RESULTS

The design specification and layout is shown in Figure1 while a cross sectional view of the moderate-scale aquaponic system is shown in Figure 2. The testing of the system showed a balance of water flow between the fish rearing tanks and the plant beds since pumping of water to the gas exchange chamber was balanced by the gravitational flow through the system.
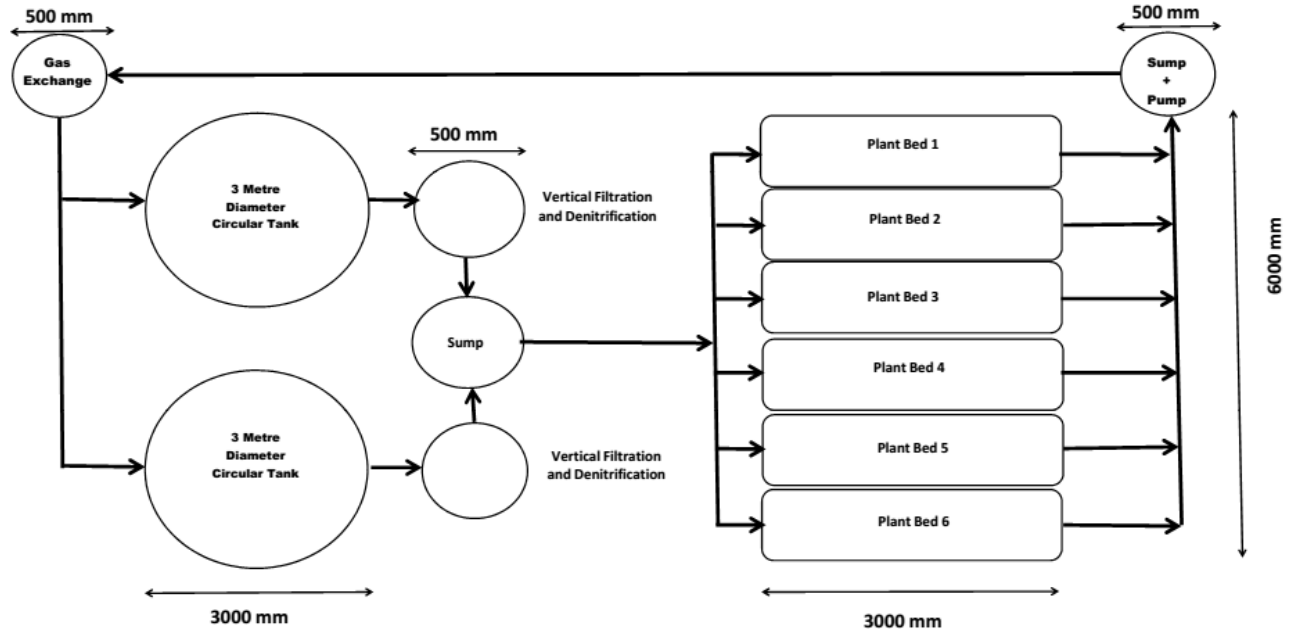
Figure 1. Technical Plan of the Medium-Scale Aquaponic System
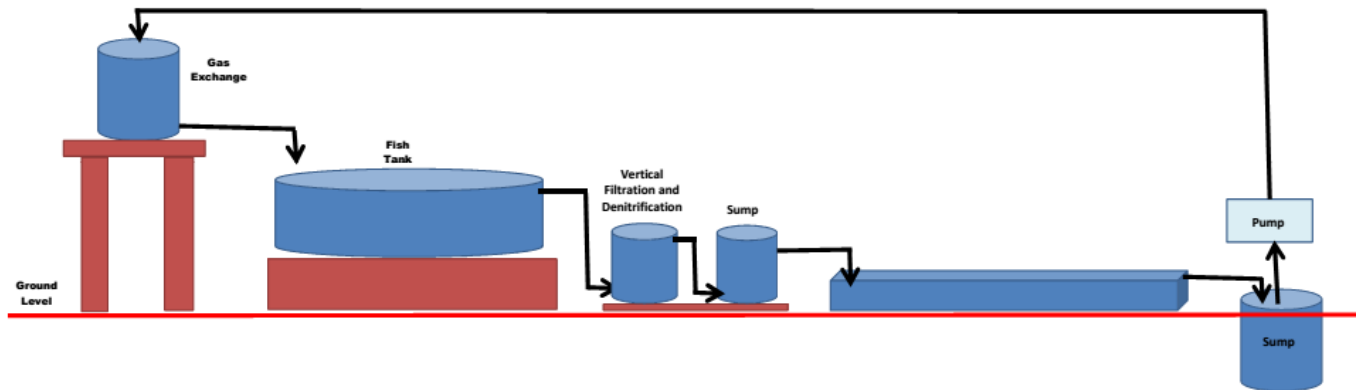
Figure 2. Cross Sectional View of the Medium-Scale Aquaponic System

Plate 1 shows the stages in developing the moderate-scale aquaponic system under when it was under full operation with both fish and plant units functional.

During the development and testing of the moderate-scale aquaponic system, there were five requests from farmers within Eldoret environs to help them develop an aquaponic system. Only one of the lady farmers who had functional ponds and she became a potential candidate for field trials.

Plate 1: i) Top Left-Construction of moderate scale aquaponic system at the University of Eldoret greenhouse, ii) Top Right – Completed moderate-scale aquaponics system, iii) Bottom Left-Nile tilapia in the fish rearing tanks, iv) Spinach in the floating raft plant beds.

Field Trials

Based on the experience from our small-scale floating plant bed, gravel bed and the moderate-scale aquaponic design, the project staff and students assembled at the firm of Robertina Chikamai at Kimumu area, about 2 km firm the University Campus to help her design a practical aquaponic system to integrate the two existing fish ponds with plant beds.

The farm had one large and one medium sized liner ponds of about 500 m2 and 200 m2. She had plans to incorporate poultry farming, strawberry farming and aquaponics. The farmer had initially attempted to install an aquaponic systems but she had challenges in kick-starting the system.

The farmer had opted for gravel bed aquaponic system and since she already had existing ponds, the only logical option was to re-design the system with a pump for the plant beds. We re-designed the system using the bell siphon technology to ensure the hydroponic component doesn't flood unnecessarily but wets the media on which the plants anchor. The crops adopted quickly to the system and had an improved growth in less than 10 days.

The main challenge remains as the cost of recirculating the water due to the cost of electricity. Consequently, the farmer has to periodically switch off the pump. Secondly, running such a pump continuously may damage it unless the pumps are redundant. In view of this challenge, we have contacted our sister department of Physics to assist her in designing a more practical solar powered pump based on existing solar panels in the Kenya market or improvising a wind powered pump for the system. Some of the main highlights of the activities involving aquaponics in the farm are highlighted in Plate 2-4 below:

Plate 2. Harvesting fish from the ponds

Plate 3. Josiah Ani inspecting of the germinating plants

Plate 4. Inspection of the germinating plants

QUANTIFIED ANTICIPATED BENEFITS

We have used the Aquaponic System of Robertina Chikamai to evaluate the potential benefits that are likely to accrue from both fish and plants for a moderate system.

The capital to advance this project was a loan of KES 500,000 ($4,950) provided from the family resources. This amount was used to set up ponds and install the hydroponic component around the ponds. The first pond has approximately a biomass of 1,800 kg of African catfish ready for sale. This translates to KES 540,000 ($ 5,347) at an average price of KES 300 kg-1.

The second pond has been stocked with 1,000 Nile tilapia fingerlings. The fingerlings were bought at a cost of KES 10,000 ($ 99). She has also incorporate poultry farming and strawberry farming in her 0.5-acre farm. The crops have adopted into the system and are doing well. Currently, she is growing a mixture of Traditional vegetables, Kales and spinach. Her vegetables on average give about KES 73,000 ($723) annually from one pond and the hydroponic system. In our opinion, the plant unit could be doubled or tripled for every aquaponic system by adding another row of plant growing beds.

From the trials, we have attempted to carry out a partial enterprise budget to illustrate the anticipated benefits from the aquaponic system based on three Food Conversion Ratios (1.5, 1.2 1nd 1.0) based on a single aquaponic system and based on African catfish production. Factoring the FCR is critical in environments such as Kenya where feed is still a major constraint in terms of availability, quality and quantity.

Table 1. Anticipated benefits of aquaponic system based on catfish, local vegetables, kales and spinach at the Robertina Fish Farm and FCR of 1.5

	UNITS	QTY	UNIT PRICE	KES	US $
Loan				500,000	4,950
Pond construction	ITEM	1	25,000	25,000	248
Catfish Fingerlings	PCS	1,000	10	10,000	99
Feeds (Assuming FCR of 1.5)	KG	2,700	100	270,000	2,673
Labour	MONTHS	6	10,000	60,000	594
Electricity	MONTHS	6	3,000	18,000	178
			Sub-total	383,000	3,792
Incidentals (12% of Total costs)	ITEM		**Incidentals**	45,960	455
			Total Costs	**428,960**	**4,247**
Potential Fish Harvest					-
Catfish	KG	1,800	300	540,000	5,347
Potential Vegetables Harvest					-
Local	KG	600	200	120,000	1,188
Kales	KG	600	100	60,000	594
Spinach	KG	600	100	60,000	594
			Total Income	**780,000**	**7,723**
			Net profit	**351,040**	**3,476**

Table 2. Anticipated benefits of aquaponic system based on catfish, local vegetables, kales and spinach at the Robertina Fish Farm and FCR of 1.2

	UNITS	QTY	UNIT PRICE	KES	US $
Loan				500,000	4,950
Pond construction	ITEM	1	25,000	25,000	248
Catfish Fingerlings	PCS	1,000	10	10,000	99
Feeds (Assuming FCR of 1.2)	KG	2,160	100	216,000	2,139
Labour	MONTHS	6	10,000	60,000	594
Electricity	MONTHS	6	3,000	18,000	178
			Sub-total	329,000	3,257
Incidentals (12% of Total costs)	ITEM		**Incidentals**	39,480	391
			Total Costs	**368,480**	**3,648**
Potential Fish Harvest					-
Catfish	KG	1,800	300	540,000	5,347
Potential Vegetables Harvest					-
Local	KG	600	200	120,000	1,188
Kales	KG	600	100	60,000	594
Spinach	KG	600	100	60,000	594
			Total Income	**780,000**	**7,723**

	UNITS	QTY	UNIT PRICE	KES	US $
			Net profit	411,520	4,074
Loan				500,000	4,950
Pond construction	ITEM	1	25,000	25,000	248
Catfish Fingerlings	PCS	1,000	10	10,000	99
Feeds (Assuming FCR of 1.0)	KG	1,800	100	180,000	1,782
Labour	MONTHS	6	10,000	60,000	594
Electricity	MONTHS	6	3,000	18,000	178
			Sub-total	293,000	2,901
Incidentals (12% of Total costs)	ITEM		Incidentals	35,160	348
			Total Costs	328,160	3,249
Potential Fish Harvest					-
Catfish	KG	1,800	300	540,000	5,347
Potential Vegetables Harvest					-
Local	KG	600	200	120,000	1,188
Lkales	KG	600	100	60,000	594
Spinach	KG	600	100	60,000	594
			Total Income	780,000	7,723
			Net profit	451,840	4,474

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DEVELOPMENT OF LOW-COST AQUAPONIC SYSTEMS FOR KENYA- PART III
ASSESSMENT OF THE IMPACT OF ECONOMIC STIMULUS PROGRAMME ON SUPPLY ENHANCEMENT, RURAL POVERTY ALLEVIATION AND FOOD SECURITY

Production System Design and Best Management Alternatives/Experiment/13BMA05AU

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ABSTRACT
This report covers the stakeholders' consultation at county level on the impact of Economic Stimulus Programme (ESP) implemented by the Government of Kenya on fish farming from 2007 to around 2012 when Kenya adopted a devolved Government System and aquaculture became a function of the County Governments. A number of counties selected for assessment included: a) Kisii; b) Vihiga; c) Kakamega; d) Bungoma; e) Nyeri and f) Meru Counties between 21st August and 6th September 2016. A total of 59 stakeholders were engaged on discussion on fish farming input availability and types such as feeds, seeds, pond liners, fishing gear, chemicals (hormones) and other piping/plumbing materials for construction of fish holding facilities. Further assessment was conducted on supply enhancement, rural poverty alleviation and food security. Diverse production systems were found to exist in Kisii, Vihiga and Kakamega while Bungoma had mainly of earthen ponds. In Kakamega, Nyeri and Meru, there was a mixture of earthen ponds and liner ponds due to the porosity of the soils. In addition, there are a number of large dams (up to 20 Ha) that have been variously stocked by the fisheries department to enhance production, income, protein availability and employment to the riparian communities. All these dams have management committees in place to regulate all the socio-economic activities related to water resource use and management.

There are over 6 large-scale fish feed producers in Kenya and numerous small-scale fish feed manufacturers. In addition, many farmers have resorted to on-farm feed manufacture to reduce to cost of feeds in their farms. There is a considerable amount of fish feeds imported into Kenya by Aller Aqua, Ranan Feeds and Skretting. The ESP, however, assisted in developing small-scale feed production units across all the 210 counties targeted by the program. Most of the small-scale feeds produced by farmers are sinking pellets as opposed to the preferred extruded and floating pellets from large-scale manufacturers. The feed availability was found to be adequate but the quality varies considerably between both small-scale and large scale manufacturers.

The ESP trained a number of local farmers in the production of monosex tilapia and over 30 hatcheries were registered by the Government to provide tilapia seeds to farmers. These hatcheries still exist but the demand for monosex fingerlings have declined considerable with the termination of subsidies from ESP.

The survey revealed that the current fish production from aquaculture has declined considerably due to the abrupt termination of the Government subsidies implemented during the ESP and Fish Farming and Enterprise Productivity Programme (FF&EPP). This abrupt termination was occasioned by the implementation of the new Kenyan Constitution in 2012 that devolved aquaculture function to Counties. The aquaculture sub-sector is characterized by weak marketing structures and hence low income since most of the fish are sold at the farm gate without much preservation, processing or value addition.

A few farmers in Kakamega and Meru specifically deep fry some of their fish produce for sale in their retail outlets. In Kisii County, the retail outlets is slightly well developed with ice boxes and motorcycles for collecting fish from farmers and processing facilities for production of fish sausages, samosas and minced fish products. The implementation of ESP is thought to be a major factor in enhanced availability of cultured fish and hence both food and nutrition security in many parts of rural Kenya.

To improve on fish marketing, the Government constructed four mini processing plants in Rongo, Kakamega, Nyeri and Meru with blast freezers, cold storage and ice plants. In addition, collection centers were created and each one of them equipped with chest freezers with a capacity of about 200 kg per day. So far, only the Nyeri plant is operational and uses a refrigerated truck to collect fish from the collection centers. The Nyeri plant was operationalized by a grant-in-aid of KES 2,400,000.00 (approximately US $ 240,000) from the County Government of Nyeri through the Kenya Agricultural-Sector Productivity Programme (KAPP). The farmed fish value chain seems to be complete but with weak linkages, support services, technological innovations, asset financing, credit lines and product development among other factors. All the counties visited had existing plans that currently offer subsidies to fish farmers in terms of fingerlings and feeds. There are also plans to construct hatcheries within the County Integrated Development Plans (CIDP) but many of these plans have not been implemented due to inadequate funding and budgetary constraints.

The most active and prominent farmer organization with a national scope is the Aquaculture Association of Kenya (AAK) which has been active in mobilizing fish farmers in capacity building and value addition. AAK has sub-branches in almost all the counties with high aquaculture potential and has registered growing membership. The AAK is currently undertaking activities in capacity building in value addition through a grant from the United Nations International Development Organization (UNIDO). Other programmes that have supported aquaculture in the past in Kenya include: a) Kenya-German-Israel Trilateral Project; b) FarmAfrica; c) Food and Agriculture Organization (FAO) African Sustainable Trust Fund (ASTF) targeting specifically Coordinating Unit (ASCU); and d) CRSP in Pond Dynamics e) Aller Aqua on training and feed formulation. A number of issues that require addressing include technology transfer, certification, financing mechanism of aquabusiness and policy matters.

Background Information
Prior to the year 2007, several initiatives on fish farming in Kenya had been executed by the Department of Fisheries, The main activities were geared towards using fish farming as a tool for poverty alleviation and food security, and were addressed through various project activities that included but not limited to: pond construction and management, stocking rates trials, feed trials, integration of fish farming with other agricultural activities, brood stock management, seed quality and evaluation of growth performance of Nile tilapia and African Catfish.

To enhance aquaculture production, the State Department trained fishers, implementing officers and stakeholders on fish farming practices; conducted a national aquaculture suitability appraisal and developed suitability maps for the 210 Constituencies; developed a fish breeding structure with a holding capacity of over 200,000 brood-stock; developed fish feed specifications for tilapia, catfish and trout and related supply chain; procured 54 Fish Feed Pelletizing machines and distributed them to the constituencies; procured 148 Motorcycles and recruited 286 Fisheries Extension Officers for extension service delivery in the constituencies; constructed (4) Fish Processing Plants in Tetu, Imenti South, Rongo and Lurambi constituencies; constructed a state of the art fish processing factory in Mitunguu, Meru County in collaboration with private sector investors; constructed 3 Recirculation Aquaculture Systems (RAS) in Kiambaa (Jambo Fish Farm & Samaki Tu Fish Farm) and Kisumu

Rural (Thinqubator Fish Farm) Constituencies; constructed over 69,998 fish ponds country-wide (46,824 fish ponds in 160 Constituencies country-wide by GoK, and some other 23,174 ponds under the multiplier effect by farmers & investors and stocked them with over 100 million fingerlings; increased the area under aquaculture from 722 Ha to 2,105.1 Ha; increased national aquaculture production from 4,220 MT to 23,501 MT; and created direct employment for over 100,000 fish farmers, short-term employment for over 100,000 youths and indirect employment for over 500,000 other Kenyans along the aquaculture value chain.
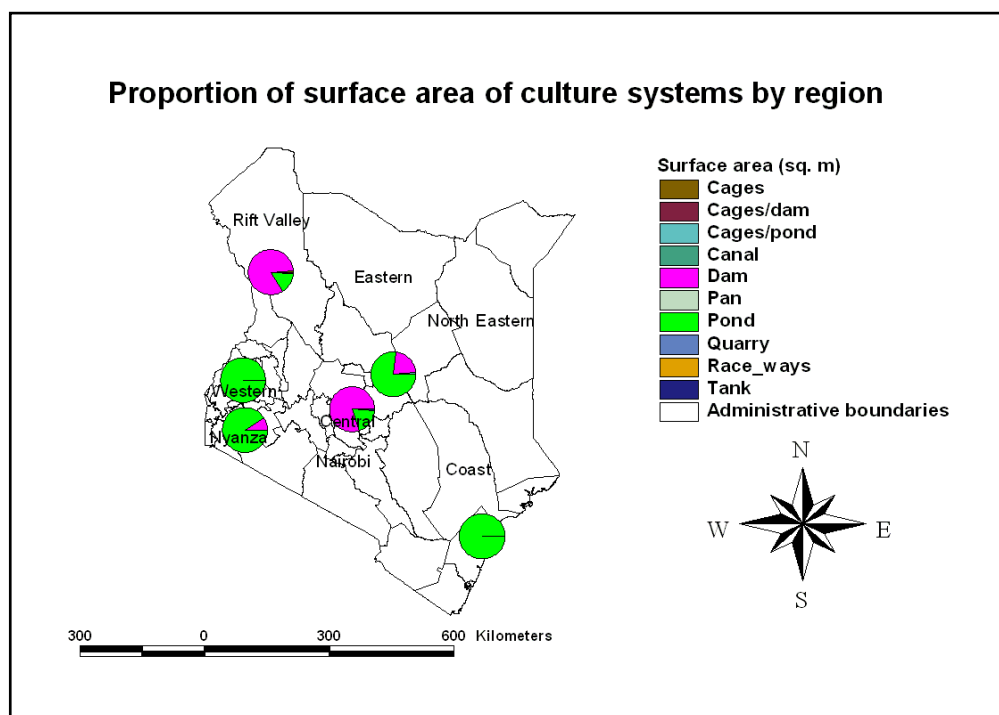

Figure 1. Map of Kenya showing the proportion of surface areas (m2) of aquaculture facilities by region; Coast, Eastern, Central, Rift Valley, Western and Nyanza (Source: Ngugi and Manyala, 2009).

The Initiation of the Fish Farming Economic Stimulus Programme started during the 2009/2010 financial year in Kenya, was envisaged to revolutionized fish farming practices in the country and has make Kenya a fish producing and fish eating nation. The project was implemented in high aquaculture potential areas of Western Kenya, Nyanza, parts of Rift Valley, Eastern, Central Kenya and Coast regions. These regions are endowed with suitable water resources that include springs, wetlands, rivers, water reservoirs and the temporary water bodies.

The State Department of Fisheries focused on promoting aquaculture development in the country to counter the declining production from capture fisheries. Aquaculture, being a food production subsector, was seen as an avenue and opportunity to contribute towards food security, generate income and create employment to rural communities, especially women and the young generation.

There has been an apparent progressive increase in farmed fish production based on the Fisheries Statistical Bulletins (GoK, 2006; 2008; 2010; 2012; 2014). Fish farming production during the year (2013) was estimated at 21,486, 828 kg (21,487 metric tons) with a farm gate value of KES 4,633,634,405 compared to 19,584,843 kg (19,585 metric tons) valued at KES 4,223,471,393 in 2011. Out of the total farmed fish production, Nile tilapia contributed 75% (16,115 metric tons), African catfish 18% (3,868 metric tons), Common carp 6% (1,289 metric tons) and Rainbow trout 1% (214 metric tons). This production was from 68,734 ponds with an area of 20,620,200 square meters

(2,062 hectares), 161 tanks measuring 23,085 square meters and 124 reservoirs with an area of 744,000 square meters throughout the country. Over the last ten years, fish production has increased from as low as 1,012 metric tons produced in year 2003 to the present production of 21,487 metric tons, figure 2.
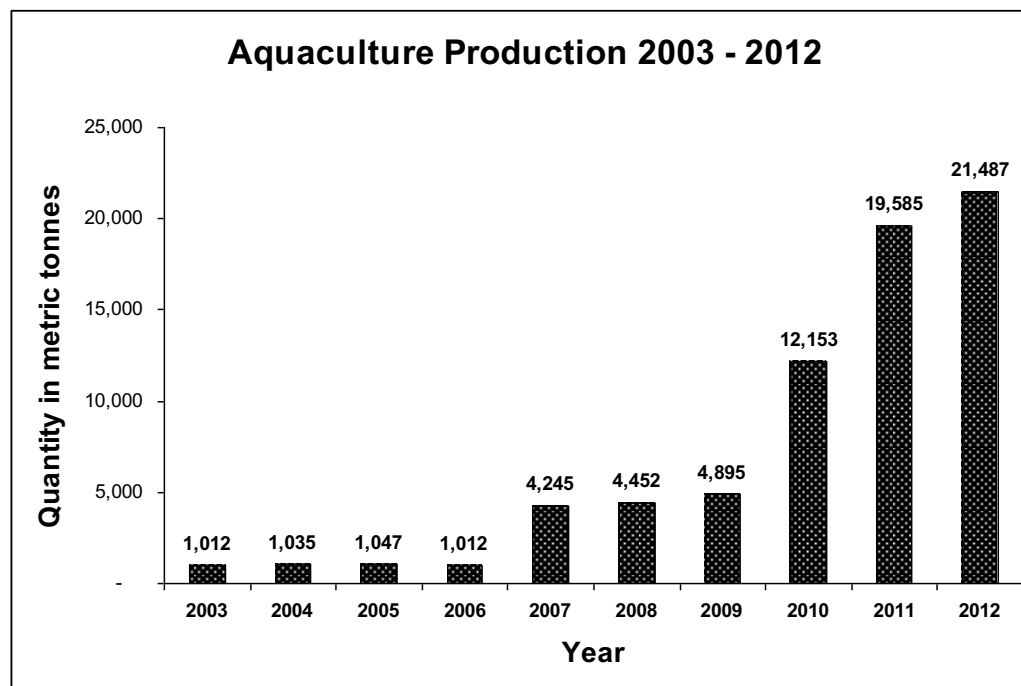
Figure 2. Aquaculture production for last ten years (2004-2012) showing the exponential increase in culture fish production in 2010 attributed to ESP

Over time, the following constraints have been identified to affect aquaculture activities in Kenya:
- i. Lack of readily available and affordable quality fish seed (fingerlings);
- ii. Lack of adequate good quality and affordable fish feeds;
- iii. Poor adoption of fish husbandry techniques by some farmers even after being trained on basic pond management;
- iv. Water scarcity due to other competing uses – industry, domestic and agriculture;
- v. Lack of and /or inadequate accurate market information for use by fish farmers;
- vi. Lack of good credit facilities and schemes for fish farmers;
- vii. Security and safety of fish in ponds posed by thieves and predators;
- viii. Poor book keeping and record management leading to inaccurate data from farmers along the aquaculture value chain e.g. input costs, management cost, quantities of fish harvested and value;
- ix. Sub optimal staffing levels especially extension personnel;
- x. Inadequate facilitation in terms of transport and timely funds towards carrying out of fisheries extension service provision.

Objective 4 of the study considered the impacts of the Kenya aquaculture stimulus project that aimed at constructing 200 farming ponds for 140 constituencies. The government effort expanded fingerling production, subsidized fingerling distribution, and endeavored to enhance technical assistance to producers. The present survey focused on the status of input supply for aquaculture, production and production trend, marketing, development plans farmer organization as a backstop for poverty

alleviation and food security in the rural economy. The report outlines past interventions in relation to ESP and their impacts in the development of aquaculture in Kenya in the context of capacity building.

OBJECTIVE

Assess the government funded Economic Stimulus Programme impacts on fish farming in terms of supply enhancement, rural poverty alleviation, and food security

MATERIALS AND METHODS

The assessment involved several steps that included:
1. Mobilization of the stakeholders through the Intergovernmental Secretariat (IGS) and the Council of Governors (CG) through a formal request to the State Department of Fisheries (SDF)
2. Identification of contact persons in each county to facilitate meetings and field visits.
3. Development of information collection tools:
   a. Key Informant Interviews (KII) checklist
   b. Structure questionnaire
4. Stakeholders engagements, consultations and field visits
5. Compilation of the assessment of the impact of ESP on inputs supply, poverty alleviation and food security among other socio-economic parameters.

RESULTS

The findings from the stakeholders' analysis could be summarized into the following sub-sections:

Input Supply- *Feeds Supply:*
In all the Counties visited, the Economic Stimulus Programme (ESP) and Fish Farming and Enterprise Productivity Programme (FF&EPP) were instrumental in providing farmers with fish feeds from 2009 to 2012. The main feeds suppliers identified by the stakeholders during the consultation were: a) Dominion Farms Ltd.; b) Jewlet Fish Farm; and c) Sigma Feeds. In Vihiga and Bungoma County, some fish farmers bought seeds from Bidii Fish Farmers in Luanda (Emuhaya).

The ESP and FF&EPP also provided the extension services for construction of earthen ponds to many fish farmers as well as technical advice. During this period, there was a considerable rise in fish production from aquaculture, apparently stimulated by the subsidies.

Plate 1. i) Top Left-Large scale feed producer from Bungoma (Eden Millers), ii) Top Right-Range of feed products offered by retail outlet Sweetex, iii) Bottom Left-Small-scale feed stockiest (Sweetex Animal Feeds), iv) Bottom Right-Imported fish feeds (Aller Aqua)

Seeds supply:
In all the Counties already visited, the Economic Stimulus Programme (ESP) and Fish Farming and Enterprise Productivity Programme (FF&EPP) were also instrumental in providing fingerlings to farmers from 2009 to 2012. The fingerling suppliers frequently mentioned by the stakeholders were; a) Dominion Farms; and b) Jewlet Fish Farm; c) Sagana National Aquaculture Research and Development Centre; and d) Lake Basin Development Authority (LBDA).

Plate 2. i)Top Left-Circular concrete nursery tanks for monosex tilapia fingerlings at Tigoi Fish Farm, ii) Top Right-Rectangular concrete nursery tanks for monosex tilapia fingerlings at Tigoi Fish Farm

During this period, a number of Private Sector (PS) operators were contracted by the Government to supply both fish feeds and fingerlings to farmers and all expenses were met by the programmes. A number of hatcheries were subsequently established by Private Sector (PS) operators to meet the high demand for fingerlings in the country in addition to the Government operated hatcheries.

The emphasis of ESP and FF&EPP were on monosex tilapia and this preference technically attributed to faster growth and better yields as compared to mixed sexes. All the Counties visited are still

providing fish farmers with monosex tilapia as a subsidy to fish farming from the same sources as the ESP/FF&EPP. The scale of subsidy to fish farming has gone down considerably and all supplies are purchased through the established procurement procedures at the county level.

All the counties visited have in place some budgetary allocation for the whole Ministry of Agriculture, Livestock and Fisheries and the financing is shared between all the directorates. The budgetary allocation for fish farming in all the counties seem to be inadequate to provide effective service delivery to fish farmers in terms of seeds and feeds.

Other inputs:
The construction costs were borne by the programme and a number of trained individuals were contracted to by the Government to construct earthen ponds for farmers. The basic ponds piping and fittings were also provided free of charge to the farmers.

With the advent of private hatcheries and operators, there arose further requirements to import hormones for sex reversal and hapa nets for nursery management of fingerlings. The demand for ethanol also increased considerably for monosex tilapia production. Since ethanol is a classified chemical, special authorization is required to purchase it under.

Production- *Production Systems:*
The ESP and FF&EPP facilitated the construction of earthen ponds and a limited number of liner ponds. Pond lining was used as a strategy to mitigate water leakages and seepages in ponds where soil types were not suitable for pond construction.

In Kisii, Vihiga, Kakamega and Bungoma, most of the culture facilities consist of earthen ponds because the soils are suitable for construction of such ponds. However, in Nyeri and Meru, a number of farmers use liner ponds as well as raised ponds due to the porous nature of the soils in these regions. In both cases, the cost of setting up these culture systems were borne by the ESP and FF&EPP.

Plate 3. i) Top Left – Pond culture in Bungoma County, ii)Top Right-Expansive pond culture system in Vihiga County, iii) Bottom Left- Pond system in Kakamega County, iv) Bottom Right-Aquaponic System at Tigoi Fish Farm (Vihiga County)

Trends in production:
Tremendous increase in production was attributed by all the stakeholders consulted on the input supply provided by the Government from 2008 to 2012. The production declined considerably thereafter due to two reasons: a) The new Kenya Constitution after 2012 General Elections provided for a two tier devolved government system with shared or devolved functions at each level; b) aquaculture became a devolved function under the County Government; and c) there was no exit strategy as the National Government could not continue to fund aquaculture through the ESP/FF&EPP.

The current state of fish farming indicate that: a) More than half of the ponds and facilities constructed under the ESP and FF&EPP have not been re-stocked after harvesting; b) There is limited input supply, especially of feeds to farmers either through subsidy or personal efforts; c) Extension services are limited; and d) production has generally declined in the last 4 years.

Marketing
The marketing structures for farmed fish is highly variable and at different levels of development among the counties. In Kisii County most of the fish is sold at the pond side (farm gate) but there are a couple of retail outlets developed by the ESP and FF&EPP. The retail outlets are equipped ice boxes and motorcycles to collect fish from farmers for processing, preparation and sale. The shops are equipped with facilities for preparing fish sausages, samosas and fish balls.

Plate 4. i) Left and Centre – Modern food processing equipment used for fish value addition in Kisii County, ii) Top Right-Value added fish products in Kisii County, iii) Bottom Right- Display unit for value added fish products in Kisii County

Poverty Alleviation
In Vihiga, the County Government invested in a retail outlet in each of the four sub-counties where the shops were renovated and equipped with chest freezers as retail outlets. So far, only one of them is operating at Emuhaya while the rest are closed due to inadequate supply of fish. Kakamega County has a mini-fish processing plant which is un-operational and hence the fish is sold at the farm gate or rarely transported to local markets for sale. One fish farmer is known to transport fish to Nairobi using public transport and one group has established a retail outlet at Navakholo with a capacity of

200 Kg at a time. Some farmers undertake processing by deep frying before selling the fish but all these are informal operations.

Plate 5: Shelter (house) constructed entirely from proceeds of fish farming and inset showing diversification and acquisition of high yielding dairy animals from proceed of fish farming by the same fish farmer.

In Bungoma County, there is no specific marketing structure or strategy and most of the fish is sold at farm gate. Some of the fish is transported to local markets and sold alongside the wild caught fish but faces stiff competition, especially from imports from Uganda through Malaba border.

Food Security

During the ESP/FF&EPP, the Government Constructed four mini fish processing plants in Nyeri, Meru, Kakamega and Rongo. These plants were equipped with blast freezers, cold storage facility and ice -making plants in order to address the issues of marketing. Only one plan in Nyeri is operational and is being managed by the Fish Farmers Co-operative Society though the plant is operated by staff from the County Directorate of Fisheries due to inadequate technical capacity by the Co-operative Society in fish processing and quality assurance. The Society has acquired a refrigerated truck for collecting the fish from designated fish collection centres. Additionally, the fish collection centres are equipped with deep freezers to keep the fish fresh before collection.

The Nyeri mini fish processing plant has been operationalized by a grant-in-aid of KES 2.4 million from the County Government. To guarantee adequate fish supply, the county has also invested in re-stocking of fish ponds of more that 130 farmers with 1,000 tilapia fingerlings and earmarked KES 2,200,000 for re-stocking in the 2016/2017 financial year.

Plans are underway to hand over the Meru and Kakamega minis fish processing plants to the Fish Farmers Co-operative Societies to manage. The marketing model being adopted by the Meru Fish Farmers Co-operative Society in running the mini-processing plant is shareholding by the fish farmers. The society intends to collect fish from Nyeri, Kirinyaga and Embu to meet its operational capacity as it awaits increased production from its own farmers.

Plate 6: Modern fish processing plant in Nyeri County for processing and marketing of farmed fish

Development Plans

Since the termination of ESP following the implementation of the 2010 Kenya Constitution, the function of fish farming and aquaculture is entirely devolved to the County Governments. In order to guarantee increased effort and investment in the aquaculture sub-sector, the County Governments are expected to streamline aquaculture activities in teir development plans as well as make budgetary provisions for promoting and supporting aquaculture activities. A sample review of the existing Aquaculture Development Plans for Kisii, Vihiga and Bungoma is briefly presented in the following section.

Kisii County

The County has earmarked the development of three fish multiplication centres for fingerlings production, training and a demonstration facility. One of these facilities is under construction and near completion, having been allocated funds for operationalization in the County Integrated Development Programme (CIDP) in 2016/2018 financial years while another two are earmarked for development in future. It is planned that each sub-county will eventually have at least one such centres in future. The county also plans to construct a fish cold storage facility as part of the municipal market.

Vihiga County

The County took over the Mitoko Fish Farm from the National Government and is developing it as a training centre a hatchery to provide fingerlings to its farmers. The county has been subsidizing fish farmers with both fingerlings and feeds as part of its regular extension service. It is proposed in the CIDP to implement a capacity building programme in fish farming throughout the county in the 2016/2018 financial years.

Bungoma County

The County has plans to develop a trout hatchery in Mount Elgon to supplement the tilapia and catfish farming activities in the county. The County also allocated resources in the El Nino fund to rehabilitate fish ponds and supply input to fish farmers under the agricultural sector interventions in the 2017/2018 financial year.

Farmer Organizations
Prominence of Fish Farmers Cooperative Society has been recorded in Kakamega, Nyeri and Meru and all of them have an objective in marketing. The marketing of farmed fish has been hampered in almost all the counties by lack of marketing infrastructure. Since mini processing plants were developed in Rongo, Kakamega, Meru and Nyeri, the production has not been adequate to run these plants except in Nyeri (at almost half capacity).

The biggest challenge that is currently being faced by the farmer organizations is how t increases production to a level where it becomes economically viable to embark on developing and investing on marketing infrastructure. At the moment, there are no fish farmer organizations that provide financial services or asset financing to its members.

The Aquaculture Association of Kenya (AAK) has been instrumental in capacity building and organizing fish farmers into networks for purposed of value addition interventions. AAK has had some funding from United Nations International Development Organization (UNIDO) to support its activities. AAK is currently operating as branches in most counties with high potential in fish farming.

Past and Present Interventions
There has been a number of interventions in fish farming in Kenya dating from 1950s from the American Peace Corps but the most recent in the last five years include: a) Government supported Economic Stimulus Programme (ESP) and Fish Farming and Enterprise Productivity Programme (FF&EPP); women and youth; c) FarmAfrica Capacity Building programme through the Agricultural Sector b) Food and Agriculture Organization (FAO) African Sustainable Trust Fund (ASTF) targeting specifically Coordinating Unit (ASCU); d) Aller Aqua training on feed formulation; and e) Kenya-German-Israel Trilateral Project on fish farming involved in tilapia fish value chain and capacity building as the main programmes

The Collaborative Research Support Program (CRSP) and AquaFish Innovation Lab has been operating in Kenya for a total of almost 25 years in research capacity building and field trials. The program has produced some of the custom extension information and materials presently being used in the aquaculture industry in Kenya. In addition, many of the beneficiaries of this programm are actively involved in aquaculture enterprises in Kenya.

Existing Farmed Fish Value Chains
The existing farmed fish value chains consist of the following input supplies: a) fingerlings (seeds); b) feeds and feed ingredients; c) various chemicals including hormones for sex reversal; d) fishing gears; e) pond liners and fittings and f) packaging materials for fingerlings; g) brood stock for hatchery operators

The services required in the aquaculture industry include: a) ponds construction; b) extension; c) capacity building and training d) networking and technology services. The transformation and logistics required in the value chain include: a) chilling and freezing; b) processing; c) transportation; and d) cooling facilities. Value addition is part and parcel of marketing, sales and consumptions. The development of products was found to be poor during the stakeholders consultation with most of the fish being marketed whole and fresh but without the necessary infrastructure.

DISCUSSION
In view of the current weak policy framework for aquaculture development in Kenya, there are a number of issues that can be addressed from both technical and policy perspectives. Some of these issues include financing mechanisms for aquabusiness, certification in aquabusiness and policy

reviews and amendments to address emerging issues such as cage culture in natural water bodies among others.

Aquaculture financing and development
It is clear from the existing information the development of aquaculture in Kenya has been slower than expected due to lack of inputs and financial partnerships. Since there are new prospects of financing aquaculture projects be micro-financial institutions and commercial banks such as Equity, this development should be streamlined into the Aquaculture Policy by the Ministry responsible for Fisheries.

However, there could be other major players in the financial sector that include the Treasury and Central Bank in Kenya that have statutory control over financial institutions in Kenya. The inclusion of these relevant institutions in drawing the policy would ensure that there are provisions of exemptions for inputs wherever required and whenever possible as applicable in many agricultural sectors in Kenya.

Developing private-public partnerships is an option that is currently gaining popularity in the development agenda in Kenya. Several options are available to foster this option but there are no guidelines on how this can be achieved.

There is need to involve and encourage nascent young and growing commercial aquaculture producers or community aquaculture development project in joint funding applications for research in collaboration with academic and research institutions such as University of Eldoret, Egerton University, Kisii University, Maseno University and KMFRI all of which have both human and infrastructure facilities for aquaculture and aquatic sciences. Some past and successful interventions require up-scaling such as USAID-KBDS Baitfish Cluster Development. This approach will guarantee not only positive research findings on key constraint to production and marketing but also for a constructive partnership between researchers and producers and improve needs driven capacity of research institutions.

Partner with large scale commercial fish farmers through production agreements in the form of out-growers such as practiced in the tea, sugarcane and some rice schemes in the country. This approach requires that contracted out-growers are provided with inputs at a cost and the cost is recovered at the time of delivery. The large scale farmer would need a business plan for financing this approach and this could be a possible source under long-term investment plans other than a simple business plan.

Some of the existing trust lands could be allocated to existing development agencies on request for the express purpose of aquaculture. This would require a policy framework and involvement of the Ministry of Lands (Commissioner for Land).

Some existing Government facilities that are essentially used as demonstration centres could be upgraded into commercial farm level by a group of entrepreneurs so that they run the farms on a commercial basis or on lease. There would be several conditions to fulfill such as developing a business plan and obtaining financial security for such an undertaking. This would guarantee that the centres are used for the intended purpose of demonstration but the emphasis shifted to large scale commercial production i.e they pay for themselves and eventually become economically sustainable. These facilities could be run on partnership with government agencies for research, extension and production.

Aquaculture certification
There is no clear certification process, procedure or implementation in aquaculture in Kenya. Even though the Government has developed a number of standards for fish feeds and fish quality through its national institution, the Kenya Bureau of Standards (KEBS), not even a single aquaculture enterprise has been certified yet. The structure for certification exist through the Kenya Accreditation Services (KAA) but it is hard to find any suitable Conformity Assessment Bodies (CAB) for aquaculture in the region.

Kenya Accreditation Service (KENAS) is the Sole National Accreditation Body (NAB) mandated to offer accreditation services in Kenya. It is established under the States Corporations Act, Cap 446; vide Legal Notice No. 55 of May 2009. KENAS gives formal attestation that Conformity Assessment Bodies (CABs) are competent to carry out specific conformity assessment activities. A CAB is a testing laboratory, calibration laboratory, certification body or an inspection body that provides inspection, testing, and certification services in all fields in the public and private sectors.

Aquaculture policy
Even though the draft National Fisheries Policy has a section on aquaculture, it is necessary to develop an aquaculture policy in parallel to a more general fisheries management policy. An aquaculture policy is specifically necessary because it will directly address issues of food security in line with the Strategy for Revitalization of Agriculture (SRA). Usually, the Ministry responsible for fisheries is responsible for developing such a policy but it is desirable that a very wide stakeholder's consultation is carried out during the policy development. The Aquaculture Policy will address a wide range of issues including the new development of cage culture in natural water bodies (sea ranching), certification and investment plans. This policy will not only address policy concerns but also provide a framework for stimulating rapid development in aquaculture by recognizing the critical input sector, technological sector, extension and marketing. The policy can possible be prepared in 3-5 years with both government and development partner funding.

Once the aquaculture policy is put in place, there would be need to harmonize various sections of legislation to avoid overlap, contradictions and conflicts. For example, export of aquarium fish is subject to live fish movement permit and aquarium fish dealers license under the current Fisheries Act while when it comes to certification for export, it is the veterinary department who is responsible.

The Public Health Act and the Environmental Management and Coordination Act (EMCA) are already in conflict when it comes to wetlands, standing pools of water and their utilization. While an envisaged aquaculture policy and act would encourage the development of standing waters (ponds and other facilities) for fish farming, the Public Health Act considers these as a health nuisance and hazards that should be drained and disinfected and EMCA prohibits the use, drainage or utilization of wetlands for either personal or commercial purposes.

Human resource (Extension)
Extension has been identified as one of the constraints in aquaculture development, it would be appropriate to consider strengthening this area by:
  i. Formation of target groups and farmer-to-farmer clusters with the ultimate goal of developing a critical mass of fish farmers who are able to move aquaculture to commercial level.
  ii. Organizing field days for farmers with demonstration centres for better technology transfer
  iii. Training clusters of fish farmers in aqua-business in line with the upgrading of demonstration centres into full scale production centres through various partnerships.

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